THE ROLE OF THE ENGINEERING INFORMATION SYSTEM IN COMPUTER INTEGRATED MANUFACTURING

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Richmond, 1990

I declare that this dissertation is my own, unaided work. It is being submitted for the Degree of Master of Science in Engineering in the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.

P.B. Kalil

Paul B. Kalil

15th day of May 1990

ABSTRACT

This dissertation shows that the engineering information system (EIS) is the primary integration mechanism in computer integrated manufacturing. The EIS has been defined by creating a functional as well as an information model. These models are the initial steps in the process of implementing an EIS by means of a database management system. The modelling of the EIS is defined within a work breakdown structure for CIM acquisition which is applicable to any CIM project. The impact of the scope of CIM and the changes this requires are also defined. It is also shown that for an enterprise involved in the manufacture of complex systems it is more beneficial to introduce CIM in those areas outside the area of factory automation. The complexity of the EIS information model is such that it has not been possible to construct it manually. Automated tools should be used to create the EIS information model.

To my wife, Christel and our children, Matthew
and Jennifer, for our joint futures.

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1 INTRODUCTION

1.1 The Problem Statement

Computer Integrated Manufacturing(CIM) in the manufacture of complex systems has three aspects, namely, the strategic issues, the acquisition of a computer integrated manufacturing system and operation and support of computer integrated manufacturing systems. In the acquisition of systems the major application areas can be defined by computer aided engineering(CAE), computer aided design(CAD), computer aided manufacture(CAM) and engineering information systems(EIS). Of these the engineering information system is potentially the most difficult yet most rewarding area to define, create and implement.

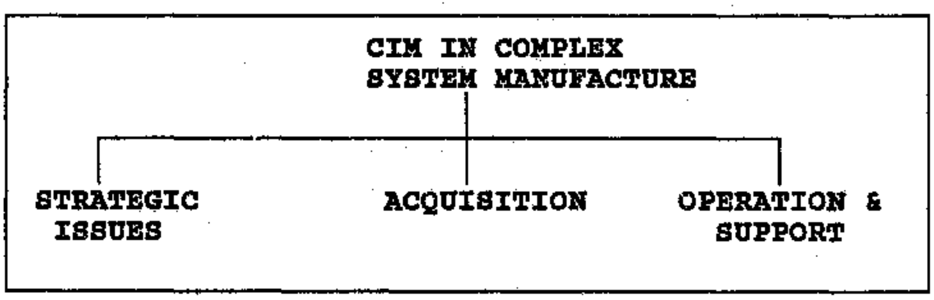

Figure 1.1 The Scope of a CIM Project

1.2 The Sub-Problems

a) Computer integrated manufacturing in the manufacture of complex systems.

b) Acquisition of computer integrated manufacturing systems.

c) The engineering information system in computer integrated manufacturing.

d) Defining the engineering information system.

e) Creating the engineering information system.

1.3 The Hypotheses

a) The major computer integrated manufacturing benefits in the manufacture of complex systems are achieved in the pre-production stages of the product life cycle. (Project management, system engineering, concept design, detail design and production planning.)

b) Acquisition of the computer integrated manufacturing system occurs within the strategic framework of the corporation and must be addressed holistically to ensure that the ultimate benefits of computer integrated manufacturing are achieved.

c) The engineering information system is the means through which true integration of applications, people and systems is achieved.

1.4 The Delimitations

a) The study will not cover industries other than those involved in the manufacture of large, complex systems such as aircraft, ships or other similar systems.

b) The study will not address the need for strategic management, a pre-requisite for computer integrated manufacturing, or the operational and support issues in computer integrated manufacturing except where these must be addressed as part of the acquisition process.

c) The study will not attempt to define specific hardware or software for use in a computer integrated manufacturing system. The detailed needs within application areas vary from industry to industry and between companies within the same industry.

d) The study will only address the areas of CAE, CAD and CAM in-so-far as these areas interact with the EIS.

1.5 Assumptions

a) The need for computer integrated manufacturing to increase productivity in manufacturing is accepted.

b) The social impact of computer integrated manufacturing is not an issue for complex system manufacturers.

c) The author's experience and research are relevant and applicable to a broad spectrum of manufacturers.

d) No specific staff or funding limitations exist, implying an ideal environment. In real life the implementation of computer integrated manufacturing systems is governed by the funding available as well as the capability of the staff assigned to the task.

1.6 The Importance of the Study

By describing the introduction of computer integrated manufacturing into organizations manufacturing complex systems, a comparison can be made with the theoretical proposals as described in the literature as well as other experiences in different industries. A practical and detailed generic breakdown of what to do and how to do it can assist both managers and implementors to estimate the scope and magnitude of the work for their own organization to successfully implement computer integrated manufacturing.

In addition, the definition of a generic model for an engineering information system can be used as the basis for development of company specific systems, easing the integration of the application islands available from vendors of computer integrated manufacturing systems. The financial/organizational impact of introducing/not introducing computer integrated manufacturing can be estimated for similar organizations. The role and requirements for a system integration function can be established.

2 A REVIEW OF THE RELATED LITERATURE

2.1 A Computer Integrated Manufacturing Overview

The term Computer Integrated Manufacturing (CIM) was first coined by Joseph Harrington in his book with the same title, published in 1975.[1] Harringtons' perception of CIM was the linking of areas of manufacturing that used computers by computers. This would enable better communication of information and commands, more rapid and thorough consideration of alternatives and the making of better decisions. With the advances made in computer technology since that time the ideal of an automated "Factory of the Future" has come closer to being a reality.

Much work is being done in this field and one of the first issues to be addressed is the definition of CIM. As can be seen from the following quotations no uniformly accepted definition exists and it is doubtful that there ever will be one.

"The tools, organization and interconnecting relationships that enable a manufacturing enterprise to gain the benefits and market advantage necessary for it to thrive and prosper." [2]

"The use of computer and information/ communication technologies to effectively integrate all of the ;

- engineering/design functions
- manufacturing planning functions

- equipment/process technologies
- manufacturing control processes
- management functions

necessary to convert

- raw materials
- labor
- energy
- information

into a high quality, profitable product, within a reasonable amount of time."[3]

A clear unambiguous definition of CIM is called for if confusion and misunderstanding are to be avoided. Attempts have been made to provide a single, global definition of CIM but as yet none of these appear to have gained any measure of broad acceptance. The detailed definition of CIM is a function of the industry under discussion and even of the individual enterprise within an industry.

In the USA a number of public projects related to CIM have been completed or are in progress.[4] Among these are the following ;

a) Integrated Computer Aided Manufacturing (ICAM) intended to improve the state of the art of manufacturing automation.
b) Computer Aided Manufacturing - International (CAM-I) directed at advanced factory management.

c) Manufacturing Automation Protocol (MAP) aimed at setting up standards for local area networking in manufacturing.
d) Initial Graphics Exchange Specification (IGES) for data exchange between CAD systems.
e) Advanced Manufacturing Research Facility (AMRF) for integrating advanced manufacturing systems.

In Europe the ESPRIT project is aimed at applied research and standards setting for aspects of CIM perceived to be critical to the EEC countries. A great deal of work is also being carried out in Japan and in the Eastern Bloc countries.

2.2 The Scope of Computer Integrated Manufacturing

The scope of CIM is not fixed, no clean boundary existing between CIM and non-CIM enterprise functions. Some definitions of CIM see it solely in terms of shop floor automation, others see it only in areas directly involved with products while others include all enterprise functions in their view of CIM. No one view is "correct" and in reality the scope of CIM is a function of the industry and the culture of any particular enterprise.

It is proposed that three views of CIM exist, the user view, the technology view and the enterprise view.[5] The user view is characterized by the demand for information, while the technology view considers the supply of information which is made possible by the use of new technologies. The enterprise view considers the other views, but also addresses the integration and consistency required by the enterprise as a whole.

In parallel to the three views of CIM is a proposal that three drivers of CIM exist, namely technology, economics and social pressures.[6] The technology driver is the consequence of the advances and reduction in costs of computer related technologies. The economic driver is the result of the globalization of markets calling for large increases in manufacturing productivity so as to remain competitive. The social pressure results from the tendency, specifically in first world industrialized nations, to the post-industrial society. More employment is being created in service industries and fewer people wish to work in an industrial or factory environment.

The need for a uniform, easily understood, definition of CIM within a particular enterprise or organization is crucial to the successful introduction of CIM. Such a definition needs to be communicated in an easily understood, clear and rigorous manner, so as to avoid any confusion or misunderstandings. Various modelling systems exist, some providing for functional modelling, others for data modelling. All have constituencies in terms of where they find the most favour.[7] As an example the Yourdon-De Marco system is widely used in the data processing industry.

The systems all have different strong points but also weaknesses such as ambiguity, lack of integration and lack of clarity. Realizing these drawbacks, the US Air Force contracted for the development of a technique to be used in the representation of the functional and information structures of aerospace manufacturers.[8] In addition a means for the simulation of such enterprises using a computer-based stochastic simulation system was developed. The system, known as the IDEF system (ICAM DEFinition), is being widely used and has been successfully transplanted into non-aerospace manufacturing environments.

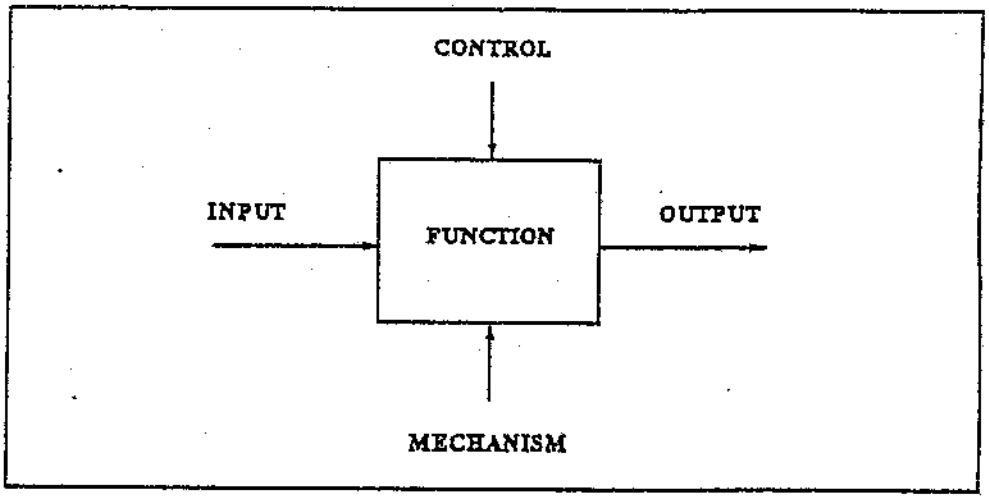

Figure 2.1 The IDEF0 function block

The IDEF system provides the tools to graphically represent the functional structure of an organization (IDEF0) (Figure 2.1), to establish the information/data relationships between functions (IDEF1) (Figure 2.2) and then to simulate the dynamic functioning of the organization (IDEF2). [9] Such techniques assist in the establishment of a uniform, unambiguous, rigorous and clear definition of CIM for a particular enterprise, a pre-requisite for successful CIM development and implementation.

The plethora of CIM definitions as well as various proposed scopes has made for difficulty and confusion in the communication of the concepts of CIM. The proposed three views of CIM, user, technology and enterprise, are complimented by three drivers of CIM viz. technology, economics and social pressures. With all these available alternatives the need for a clear, uniform definition of CIM for a particular enterprise is apparent. The IDEF methodology provides a means for establishing a clear, rigorous definition of CIM that is easily understood for any system or organization.

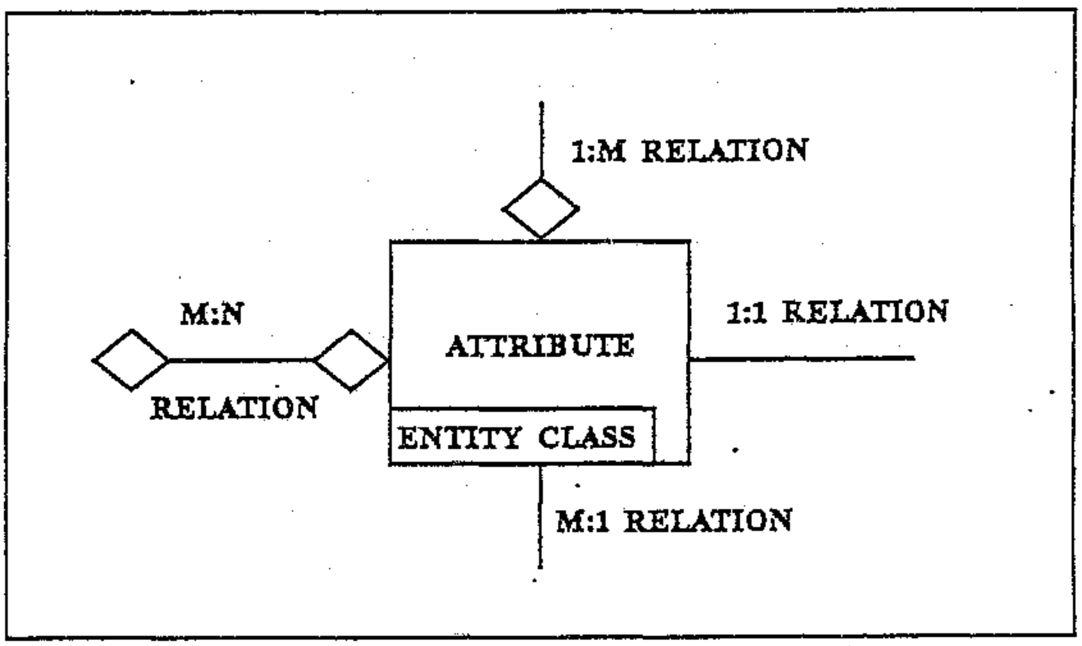

Figure 2.2 The IDEF1 entity block

2.3 Initiating Computer Integrated Manufacturing

Most people find themselves in the initiation stage of a CIM Programme without having explicitly intended so. If all of the critical factors are not addressed in the initiation stage, it can be expected that numerous difficulties will be experienced during later stages of the CIM Programmes. Although it is agreed by the authors of a number of articles that certain conditions are necessary for the initiation of a CIM programme, no clarity or unanimity exist as to what they are.

Top management understanding and comprehension is often stated as being a critical factor for initiating any activity such as CIM. It is proposed that this is a fallacy that is used by many people as a reason for not doing anything.[10] Generally top management decisions are made based on faith in an individual manager and not necessarily from a true understanding of all the issues involved.

In another article the author contends that middle managers are the best suited to act as agents of change.[11] He bases this contention on the fact that they are close enough to the technology to understand the specific demands that it makes. Furthermore, with years left in their careers, many would want to be associated with successful innovative activities. Middle managers are also felt to form the communication backbone of the company and are proposed as ideal mediators between "young" professionals and "old" top management.

In contrast to this, in another article, it is proposed that the middle manager will be "squeezed out" in the restructuring that will occur as a consequence of CIM.[12] Fewer levels of management will be required and enterprises will become leaner and more competitive.

At the stage of CIM initiation it is proposed that certain critical factors should be addressed. Of these, the support of top management is often stated as being essential. In another proposal it was felt that middle managers are best suited as CIM initiators. In contradiction to this it was stated that the ranks of middle management would be reduced by the organizational changes brought about by CIM. Other factors such as early policy statements and user involvement were also discussed.

2.4 Justifying Computer Integrated Manufacturing

Justification for any large capital expenditure is a difficult task and it is made more so when the success of that expenditure depends on changing the way an enterprise functions. The need for productivity gains in the "real" wealth producing sectors of the economy, the extractive and manufacturing sectors, cannot be denied.[13] However, is this need for the productivity gains brought by CIM a sufficient justification for implementing CIM ?

The major need for using some or other justification technique is the necessity of deciding between alternative projects or routes. Without a detailed financial analysis the risk exists that one may obtain an inadequate return on the capital invested. One might also invest in a project that does not represent the best possible application or one could avoid investing when it would be better to do so.

Three approaches to CIM justification are evident from the literature.[14][15][16] The first is the familiar cost/benefit approach, the second the "Strategic Framework" approach and the third is faith or no justification at all.

Productivity improvement is the primary CIM objective and to be able to improve productivity one has to be able to measure it. Productivity measurement allows one to monitor historical productivity performance and its impact on profits. Furthermore one can evaluate the feasibility of business plans in terms of the changes in productivity levels required.[17]

Profits = Productivity + Price Recovery

Productivity = Capacity Utilization + Efficiency

Figure 2.3 The profit - productivity relationship

To improve the cost effectiveness of manufacturing, one must increase productivity. The relative contribution to productivity increases by labor, capital and technology in USA manufacturing industries has been shown to be smallest for labour, then capital and largest for technology. It is apparent that the wise application of technology can provide large improvements in productivity.

Predictions as to the potential benefits of CIM are all generally positive. The results of one of the surveys carried out by Ingersoll Engineers are as follows:[18] (Table 2.1)

Table 2.1 CIM Benefits

BENEFIT	AMOUNT
Reduction in Engineering Design Costs	15-30%
Reduction in Overall Lead Time	30-60%
Increased Product Quality	2-5 times
Increased Capabilities of Engineers	3-35times
Increased Productivity of Production	40-70%
Increased Productivity of Capital Equipment	2-3 times
Reduction of work in progress	30-60%
Reduction of Personnel Costs	5-20%

These figures in Table 2.1 would seem to indicate that, although significant cost savings can be made, the major CIM benefits are primarily intangibles such as quality, engineer capabilities and overall productivity.

The standard cost/benefits analysis addresses three factors, namely technical, operational and economic feasibility. Historically the major emphasis has been on economic justification with little or no difficulty in the technical and operational areas. CIM justification is very different since the major critical areas of success are people, will they work it? (i.e. Operational), and technology, will it work? (i.e. Technical), prior to even considering economic justification.

It is felt that the usual capital budgeting assumptions preclude the evaluation of CIM projects by standard means as shown by the following table.(19)

Table 2.2 The impact of CIM on capital budgeting

CRITERIA	STANDARD SYSTEMS	CIM SYSTEMS
Application Areas & Benefits	Narrow	Broad
Capabilities of Equipment	Known	Developing
Costs and Benefits	Quantifiable	Harder to quantify
Best person to suggest & evaluate	Manager Concerned	CIM Project Team
Appraisal of Requests	Case by Case	Part of CIM Plan

The process of cost justification usually consists of the following activities:

- a forecast of differential cash outflows is made
- a forecast of differential cash inflows is made
- the net cash flow by year is established
- the net cash flow is discounted by the cost of capital so as to determine the Net Present Value or Internal Rate of Return (Discount rate at which the net value of inflows exactly equals the value of outflows)

The common pitfalls in using this technique to evaluate CIM investments are:

- evaluating capital expenditure proposals versus

business building strategic investments
- overlooking indirect cost reduction
- using excessive discount rates
- underestimating the residual values of CIM equipment
- relying on a single conclusion when a range of likely outcomes would be more appropriate.

Justification of CIM investments is felt to be difficult, given the scope and nature of CIM requirements. The need for justification is apparent when looking at the costs of CIM. Few, if any, organizations can automate overnight and hence the major function of justification is to distinguish between alternatives.

Three approaches to CIM justification are apparent, the cost/benefits approach, the strategic framework approach and "faith" or no justification at all. Since one of the primary goals of CIM is productivity improvement the need to measure productivity is apparent. The recorded benefits of CIM are impressive but do not represent all of the automation failures that have occurred. It is also felt that the standard capital budgeting techniques are not suitable for evaluating CIM investments and the pitfalls in using these techniques are highlighted.

2.5 Planning for Computer Integrated Manufacturing

The major task facing any enterprise that has decided to embark on a CIM programme is that of CIM planning. To plan successfully requires preparation in terms of organization, procedures and methods. The primary goal of CIM planning calls for the use of formal, structured planning techniques that are both easy to understand and rigorous.

The planning that occurs in most corporations is planning related to cash flow, profitability and product mix. Most manufacturing planning is justified in terms of cost/benefits and the tendency is to appease top management by justifying improvements on the basis of rapid short-term returns.[20] It is proposed that better results could be achieved by having a total integration framework over a long term planning horizon. Projects could be justified within this framework, allowing for the approval of projects which in isolation are not feasible but are important to future projects.

Very little system planning is done at manufacturing facility level.[21] The most common approach used is the blind adoption of the latest technology with the assumption that the potential benefits will be obtained. If the systems approach is adopted within a planning framework then successful integration of manufacturing functions requires that one knows and understands them. The importance of a common definition of CIM cannot be overemphasized in this process.

The major requirement specified by most authors when discussing CIM planning is the need for strategic planning. The CIM strategy should support the Manufacturing Strategy which in turn should support the Corporate Business Strategy. It is felt that strategic planning time horizons are a function of the particular industry and hence it is not the time scale over which planning is done but the nature of the planning that makes it strategic.

Various routes to achieving a focused manufacturing enterprise are proposed in the literature. One proposal is that the example of the Japanese should be followed. By merging long and short term planning, avoiding false dichotomies such as cost versus quality and integrating specialized objectives into a consistent and coherent programme they achieve focus.[22] Job definitions should be broadened such that long term goals take priority over parochial specialization.

Another, more specific, proposal is that there are ten steps to CIM, namely ; [23]

1. Prime the corporate culture for change
2. Clearly define expectations
3. Establish a project team
4. Identify CIM champions
5. Carry out detailed environmental analysis
6. Identify the technologies that a particular strategy requires
7. Formalize operating policies
8. Establish working partnerships with suppliers and vendors
9. Follow a sound, proven implementation policy
10. Track and report progress

As obvious as these steps may seem very few organizations appear to take all of them when embarking on CIM or CIM related projects.

Various environments within which technology planning occurs are felt to exist. Different techniques and philosophies are called for in the different environments. The particular environment in any particular organization must be identified prior to carrying out any planning.[24] The following diagram shows the various environments with respect to each other and to "diffusion" (a measure of deployment) and "Infusion" (a measure of impact).

↑ System Diffusion (Deployment)	FEDERATION (Critical Success Factors)	COMPLEX (Eclectic)
	TRADITIONAL (Stages of Growth)	BACKBONE (Business System Planning)
	System Infusion (Impact) →	

(*Eclectic - choosing, accepting freely from various sources.)

Figure 2.4 Technology Planning Environments

Although many authors state the requirement for strategic management it is not always clear as to what is meant by the term. It is proposed that there are four stages to strategic management. Few people are explicit in defining which stage CIM requires. Generally stages cannot be skipped and it is felt that the majority of businesses never leave the early stages of strategic management.[25]

The tools of project management such as Gantt charts, networks and resource scheduling are felt to be inadequate for CIM planning.[26] Project management can only be applied once it has been decided what to do, how tc do it and when to do it. Computer based simulation techniques are proposed as providing the necessary capabilities for CIM systems.

Table 2.3 The four stages of strategic management

Stage	Value System
1. Financial planning	Meet the budget
2. Forecast based planning	Predict the future
3. Externally orientated planning	Think strategically
4. Strategic Management	Create the future

As mentioned previously the inadequacy of existing techniques prompted the US Air Force to fund the development of a system for CIM planning. The system is known as IDEF (ICAM Definition) and was developed by a group of aerospace manufacturers specifically for aerospace manufacturing.[27][28][29]

The technique is used by means of an author/reader cycle (Fig.2.5) providing for continuous peer review of all work to ensure quality and reduce errors. The reader corrects syntax, clarifies terminology, checks consistency and assures completeness.

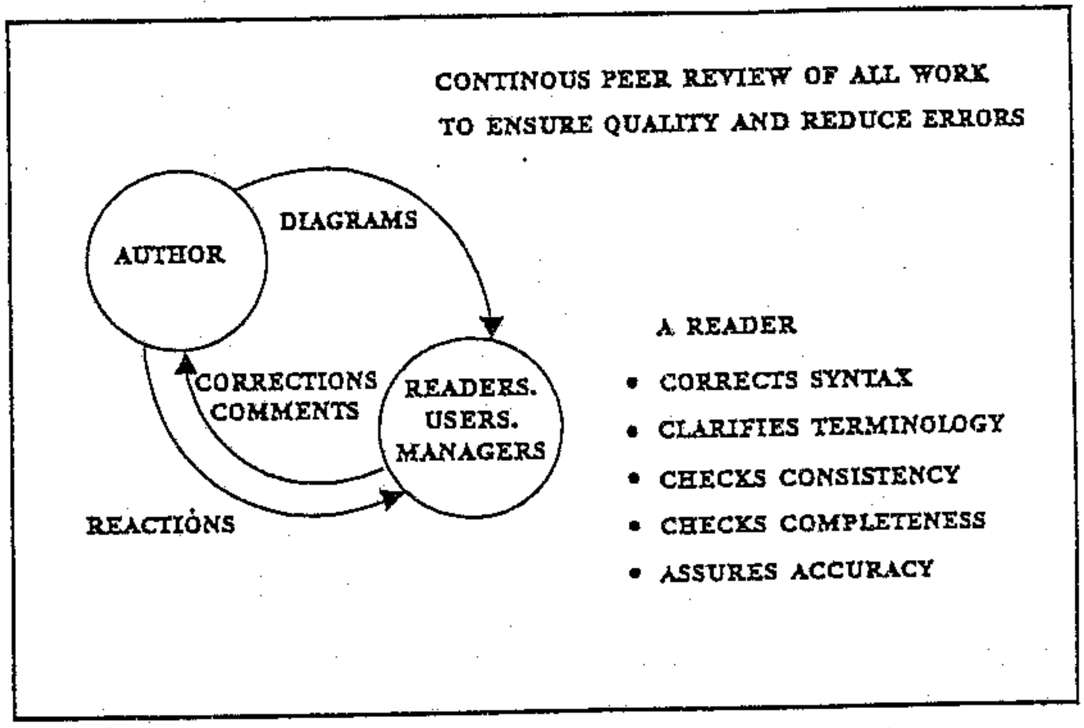

Figure 2.5 The IDEF author/reader cycle

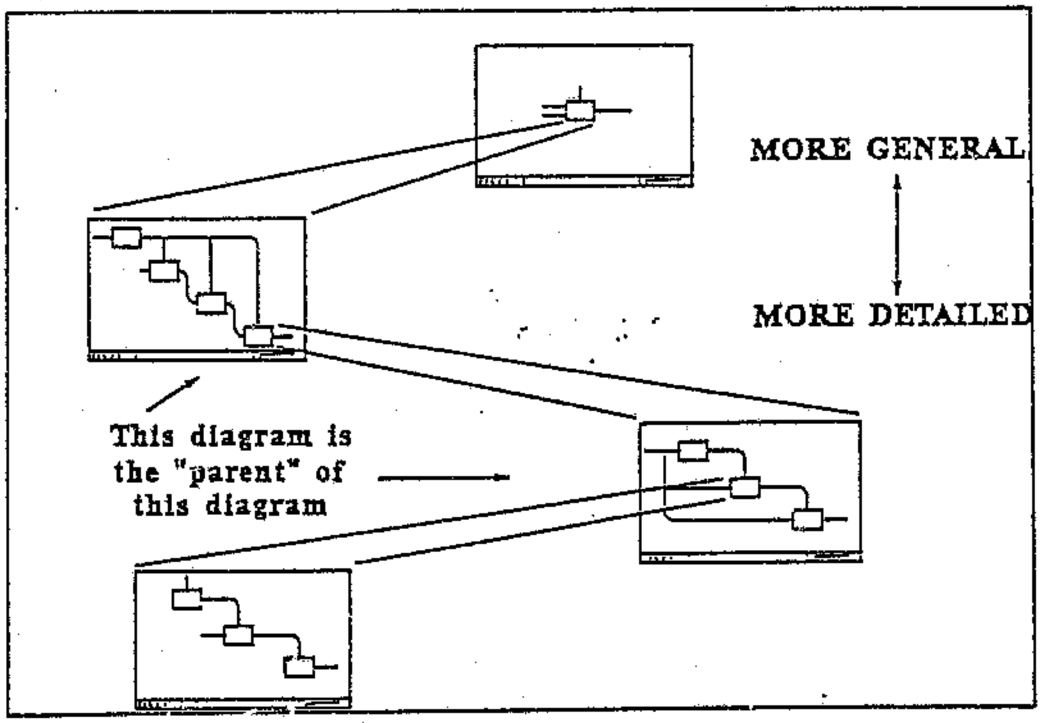

Figure 2.6 The IDEF0 hierarchy of diagrams

The IDEF0 diagrams are arranged hierarchically with successive levels of decomposition providing greater levels of detail. (Fig.2.6) IDEF1 builds on the functional model and deals with information and data modelling of the system. IDEF2 is a computer based stochastic simulation package which uses the functional and information models as inputs to the modelling and simulation of systems or organizations. This allows for extensive "what-if" type analysis and hence the impact of possible system changes can be predicted much more accurately. The graphical nature of the systems assists the ease of understanding as well as the creation of a common definition of CIM and manufacturing in general. The technique has been successfully transplanted and used in non-aerospace environments, providing both simplicity and rigor in communicating how an organization or system functions.

A model of a future system does not tell one how to create that system. Other techniques must be used to establish the short and long term projects required to do so. It is proposed that work sessions with operations line managers must be the forum in which major projects are identified and prioritised.[30] To improve the productivity of such sessions the author proposes that the Nominal Group Technique be used. This consists of asking three basic questions:

What do we do right?
What areas can be improved?
How can the improvement be achieved?

Once projects have been identified within an overall CIM programme the ranking of the individual projects must be done. A technique proposed is that of opportunity matrices. Individual technologies or projects are rated according to their potential impact on the criteria used to measure a particular organizations' success. Only at this stage, after projects have been identified and prioritised, can the techniques of project management be used.

CIM planning is a major task and certain tools and techniques are needed to carry it out. Most planning done is of the short term cost/benefits type and very little "systems" planning is ever done at the manufacturing facilities level. The CIM planning should support the manufacturing and business strategies of an organization. To achieve focus in manufacturing it is proposed that certain Japanese practices could be adopted. One of the issues affecting planning is the environment in which it takes place and four generic planning environments were defined. Strategic management was felt to consist of four phases with most businesses never leaving the earlier phases. Once system planning has been done using techniques such as IDEF, projects can be identified and the techniques of project management can be applied.

2.6 The Organizational Impact of Computer Integrated Manufacturing

The potential of CIM will be achieved by people, not technology. If the human aspects of CIM are ignored there can be little chance of a successful CIM programme. The major impact of CIM will be in the way people work, calling for higher levels of skill as well as multiple skills. The role of middle management will also change from that of supervisory/control type functions to a training role.[31] The impact on top management will be significant with organizations having to move more people with manufacturing backgrounds into senior positions since they understand the requirements of CIM more readily.

The massive changes wrought in moving to CIM will call for retraining of virtually the entire work force. Once the transition has occurred, continuous training will be required to keep up with the rapid technological innovation taking place. Projections made of the training required indicate that each worker/manager will spend four to six hours a week in training by 1990. The training to be given will be defined, guided and controlled by middle management. The training will be so specific to any one plant that only the local managers will be in the position to monitor training quality and content. The cost of this training during the transition to CIM is estimated to be five to ten percent of the total capital cost of the transition.

Projections made in various studies of employment in the USA indicate that, as a percentage of the total work force, employment in manufacturing dropped from thirty percent in 1947 to 21.7% in 1978 and is projected to be between two and five percent in the Year 2000.[32] Reduction in the work force will come mainly at the expense of unskilled workers and hence also first line supervisors. Shortages of skilled workers and engineers will only be avoided if suitable education and training is carried out.[33] Present industrial and academic programmes are felt to be inadequate in fulfilling the CIM training requirements.

It is proposed that joint industry/ academic programmes could be a solution to this training problem.[34] Industry could provide equipment and expertise while the faculties do mass training of industrial staff and manufacturing engineering students.

People are the key to CIM and throughout the restructuring brought by CIM the "people " issues must be continuously addressed. The changes needed and caused by CIM will mean a vast amount of training and retraining. Employment in manufacturing is projected to fall, yet there will be shortages of skilled people. Joint industry/academic programmes are proposed to provide all of the training required in the transition to CIM.

2.7 Conclusions from the Literature Review

a) A clear definition of CIM must be established for any specific CIM programme.

b) The scope of CIM is a function of the industry type and culture of any enterprise.

c) In initiating a CIM programme it is crucial to define reasonable expectations and to cover all of the CIM critical functions.

d) Justification of CIM projects is crucial for establishing priorities and so distinguishing between alternative projects.

e) CIM planning calls for formal, structured planning techniques that are both easy to understand and rigorous.

f) The human aspects of CIM must continuously be addressed in a CIM programme if it is to succeed.

3 COMPUTER INTEGRATED MANUFACTURING FOR COMPLEX SYSTEM MANUFACTURE

3.1 A Complex System

A complex product system is typically made up of tens of thousands of components arranged in sub-systems within the product system. The product system in turn generally forms a small part of the overall user system. The number of systems built is also often low, ranging from three or four (ships) to hundreds (aircraft) and thousands (armoured vehicles).

The life cycle cost profile of a complex system is typically divided as follows :

10-12% in Research and Development
28-30% in Production
60-70% in Operation and Support

The number of systems produced per life cycle phase varies from zero for systems such as ships to something like the following for aircraft and other vehicles :

Experimental Development Models	1-2 systems
Engineering Development Models	2-6 systems
Pre-Production Models	4-10 systems

A complex system is most often built to order and is subject to strict specifications. The number of people involved per phase is typically as follows :

Research and Development	- hundreds

Production	- thousands
Operation and Support	- thousands

In the research and development and production phases many trade-offs are necessary to achieve the desired performance. Co-ordination and integration costs are high and component records produced in this phase often have to be kept for 30 to 50 years after delivery. In the operation and support phase field use records have to be kept to provide logistics feedback to the design function.

3.2 Complex System Manufacture

An enterprise involved in complex system manufacture (CSM) can be defined both in terms of the products as well as the functions it carries out. Typically within such an enterprise marketing, development, production and product support are the core functions while the supporting functions of finance, personnel and information services as well as the management processes must exist. Typically CSM is divided into several life cycle phases as follows :

Concept Phase
Validation Phase
Full Scale Development Phase
Industrialization Phase
Production Phase
Deployment Phase
Operation Phase
Phase-Out Phase

The primary output of the conceptual phase is a functional baseline, typically in the form of a specification. From the validation phase an allocated baseline consisting of specifications and related documents is created. The production baseline is the corresponding result of the full scale development phase and is, in essence, the 'build-to' requirement.

3.3 Computer Integrated Manufacturing for Complex System Manufacture

The primary requirement in complex system manufacture is for integration and co-ordination, not automation. The integration called for is that of people and processes, not hardware and machines. The output from the CSM process is primarily information, information based on copious amounts of data that are ideally stored and accessed by means of computer. With the volume of the data being so large and the nature of the data being so diverse the essential problem in designing a CIM system for CSM is the ownership and control of the data.

The other feature of CSM that changes the CIM design approach is the large need for highly skilled resources in all phases of the life cycle. The use of computers and related technologies to leverage this scarce, highly skilled resource pool is more easily justified than the replacement of a less expensive production type resources with extremely expensive automated systems such as robots and automatic guided vehicles.

The greater impact of earlier life cycle decisions implies that one of the major objectives of any system should be to improve the decision making in the earlier life cycle stages. This is achieved by providing better, more up to date information, timeously. A major requirement of any system handling the information flow, especially when 'fast-tracking' is that the system be responsive yet rigorous in managing change.

The areas defined in Figure 3.1 below are not all equally important and the focus for a CSM enterprise should be on those functions falling under the following broad categories ;

Computer Aided Engineering (CAE)
Computer Aided Design (CAD)
Computer Aided Manufacture (CAM)
Engineering Information Systems (EIS)

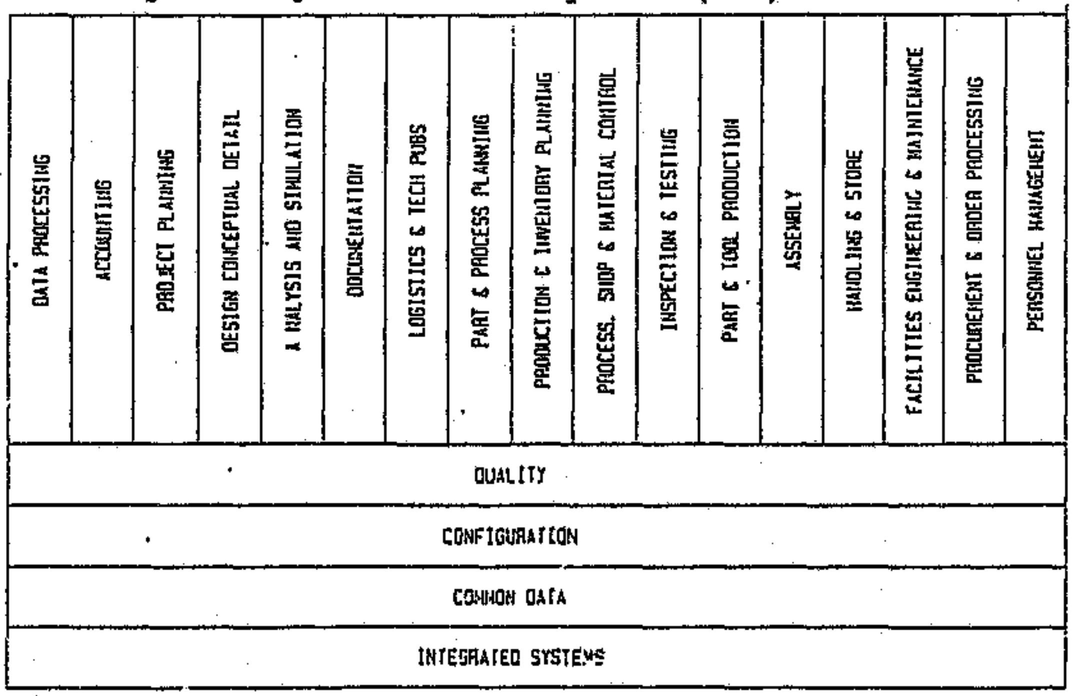

Figure 3.1 A CIM System for CSM

4 COMPUTER INTEGRATED MANUFACTURING ACQUISITION

4.1 Acquisition Strategy

The risks that exist for an acquisition project of this nature can be grouped as follows :

Financial risk incurred in purchasing hardware and software that is or becomes inappropriate.

Technology risk that arises as a result of technological change, both obsolescence and teething problems.

Time scales are risks associated with the lead times in procuring hardware, training users and the project milestones.

Operational risks are a result of poorly defined user requirements, changing user requirements, inappropriate systems and inadequate training.

Resistance to change, when the users themselves are threatened by and feel negative towards the implementation of the system. This situation could occur due to insufficient education and lack of training. However, management commitment to the effective use of the system and training of their staff can prevent this situation occurring.

To address these risks and to minimize their effect the following steps have to be taken.

4.1.1 Strategic structure

A CIM strategy in support of the Business Strategy must be developed. This will ensure that the system acquired will fulfill the real business requirements of the company. A top management steering committee should guide the development and implementation of the CIM strategy.

4.1.2 Project management

The acquisition of the computer facilities must be run on a project basis. This will provide the tools, reporting and control structure needed for success.

4.1.3 System engineering

The use of system engineering tools and techniques addresses the problem holistically such that successful system development can occur.

4.2 Design Strategy

4.2.1 Alternatives

Four primary information systems acquisition strategies exist. The first is the Ad Hoc design, or no strategy at all. New systems and technologies are introduced in reaction to some external pressure such as client demand or user crisis. Inevitably this approach results disjointed, [illegible]ly designed systems which ultimately consume a great deal of money an produce very poor returns. Many manufacturing systems have evolved in this manner as corporate MIS functions have reacted to pressure from manufacturing to provide something other than accounting systems.

The second strategy could be described as the function or organization driven design. The focus of this approach is linked very closely to the organizational structure of a company. Each function attempts to create the perfect system for themselves without consideration for the broader company requirements. What results is aptly described by the term "Islands of Automation". For example, the design function acquires a CAD system without the necessary CAM capabilities required by the manufacturing group.The sum of the local optimum solutions throughout the organization generally is far from an optimum solution for the company as a whole.

Technology driven design is the third alternative design strategy, taking two distinct forms. One of these involves the single minded pursuit of the fastest/ latest/ biggest available systems regardless of the real requirements. Again this is far from cost effective and management disillusion soon sets in as diminishing returns are received for ever higher expenditure. The other form of technology strategy is characterized by a policy of only purchasing a single brand of technology. This often occurs in an environment where the corporate MIS function has been pushed into supporting functions other than the classical business systems. An advantage to this approach is that the hardware is typically more easily supported and fewer difficulties are experienced when attempting to link systems.

The danger in this single source approach is the wide spread notion that if two applications exist on the same hardware platform they must be integrated. This almost never true and physical integration does not imply any degree of logical integration. With the advent of open systems and international standards in almost every area of hardware and software technology, the benefits of single sourced solutions are rapidly being obviated. In essence, hardware has become a commodity and should not be the primary driver of any systems acquisition project.

Data driven design is the fourth strategy alternative. It entails the establishment of a logical data structure for an enterprise or some sub part of the enterprise. Defined in terms of independant data standards, it is employed to write specifications for software procurement or development.

The logical data model is derived from a top down function or activity model of the enterprise. Using bottom up techniques such as data normalization the information requirements identified in the activity modelling process are consolidated to form a logical data model.

This data model is then used to evaluate software packages for compatibility with the data standards/requirements. It can also be used to specify requirements for software development projects where no suitable software packages exist.

Data statistics such as volume, usage and timing are derivable from the combination of the activity and data models. These statistic play an important role in quantifying the requirements for hardware such as processing power, storage device sizes and communication requirements. It is almost a prerequisite to successful distributed systems design to establish such data measurements.

4.2.2 The Design Objective

The design objective adopted is the creation of a high performance computing environment which supports a single system view of:

- individual information
- project information
- divisional information
- corporate information
- computing resources.

To reach this goal we shall adopt the three schema architecture as a basis for the global system design. The main elements of this approach are:

Information Architecture :
What the user sees;

Control Architecture :
"Meanings" or relationships that transform facts into information;

Computer Systems Architecture :
Where data/facts are physically stored;

The three schemas that correspond to these architectures are:

- External Schema
- Conceptual Schema
- Internal Schema

These schemas can best be described by the following diagram: (Figure 4.1)

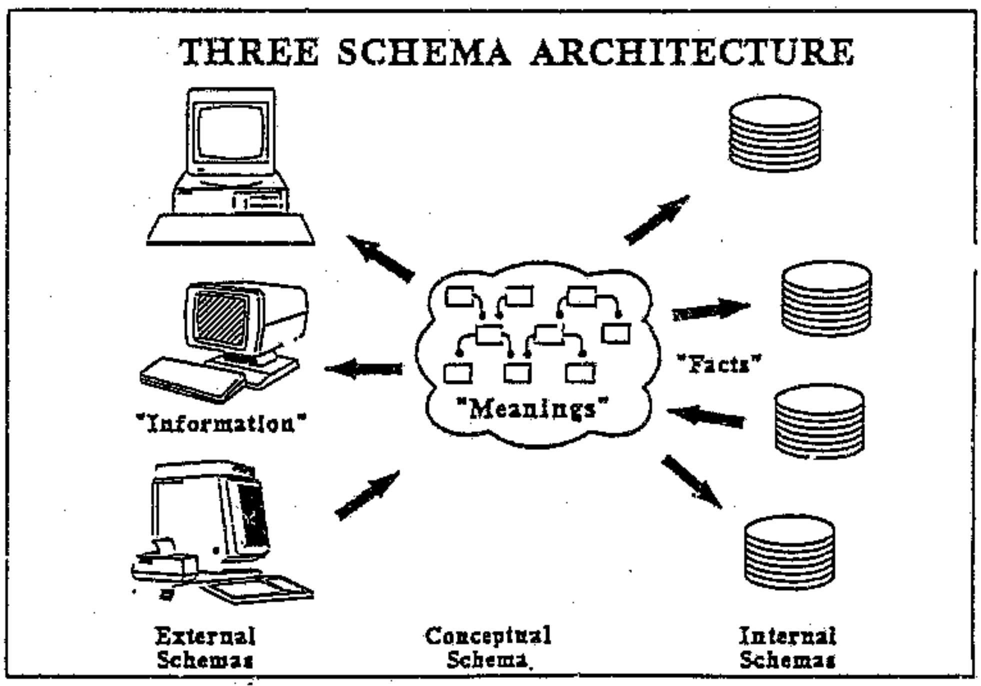

Figure 4.1 The three schema architecture

On line data access technology such as the high speed networks planned for in the system design allow the three schema architecture to   ılfilled. The capability exists for any authorized user to define an information requirement (external schema) that can subsequently be routed through the conceptual schema to data located an any computer file (internal schema). As long as developers of internal schemas ensure that there is a route back to the conceptual schema, and the creators of external schemas do the same, complete data transparency exists.

The conceptual schema is the key to the success of the system. It is up to the controlling group to develop and maintain the conceptual schema and to ensure that the standards and procedures necessary to maintain it as an active control are developed. The conceptual schema provides the data standards necessary to run a data driven enterprise.

Incorporated into the project plan are three major activities that lead towards defining and setting up the conceptual schema. a)Functional system design (IDEF0) leads to b)data modelling (IDEF 1) which in turn results in c)database design.

The results of these three activities are, a)user information requirements, b)control structures needed to control the source, destination and status of all data and to transform it into usable information and c)the physical location and storage of various data.

These outputs will then clearly define the three schema architecture which will allow the development or acquisition of applications to satisfy the user requirements. The high speed networks planned in the design will allow the three schema architecture to be implemented. Each department/cell can store the data they generate within their own cell, and it can be made available to other users via the network and the conceptual schema. The conceptual schema can therefore provide a platform on which to build a configuration management and change control system.

4.2.3 Evaluation of Alternatives

A cost effectiveness model for computer systems has been established. The details of this model as well as the definitions of the terms used can be found in Appendix B. Using this model as a basis, a user value system can be established for every application area. The value system should not be used to attempt to design a system but only to differentiate between alternatives once these have been established.

A short-list of alternative hardware configurations and application packages is established by the project team. These alternatives must meet prerequisites that are established by the project team and management. The prerequisites are typically similar to the following ;

> Use of industry standards where applicable;
> Stability and growth of all vendors;
> Local vendor support and maintenance;
> System openness allowing for integration;

The short list of hardware/software will then be evaluated by the users by means of the value system and they will then decide as to which alternative to procure. If no suitable system is available for procurement, a user system requirement document must be compiled and a system development project initiated.

4.3 The Work Breakdown Structure for Computer Integrated Manufacturing Acquisition

When attempting to address a CIM project it is essential to define the work required very carefully since the scope of any such project is so large. Typically a five year plan should be established, yet it is extremely difficult to get management commitment in terms of funding for such a long period of time.

A further problem arises when it is realised that a CIM project team of thirty or more people with various skills is required for a project such as the one depicted in Figure 4.2. The difficulties associated with getting and keeping the type of skills required for a CIM project are by no means minor. The ideal project member has both engineering and computer qualifications as well as at least five years of experience in engineering computer applications.

Obviously every project would be different but all would follow the work breakdown structure (WBS) in Figure 4.2 to some extent. The project management leg of the WBS is self explanatory but the other elements require some explanation.

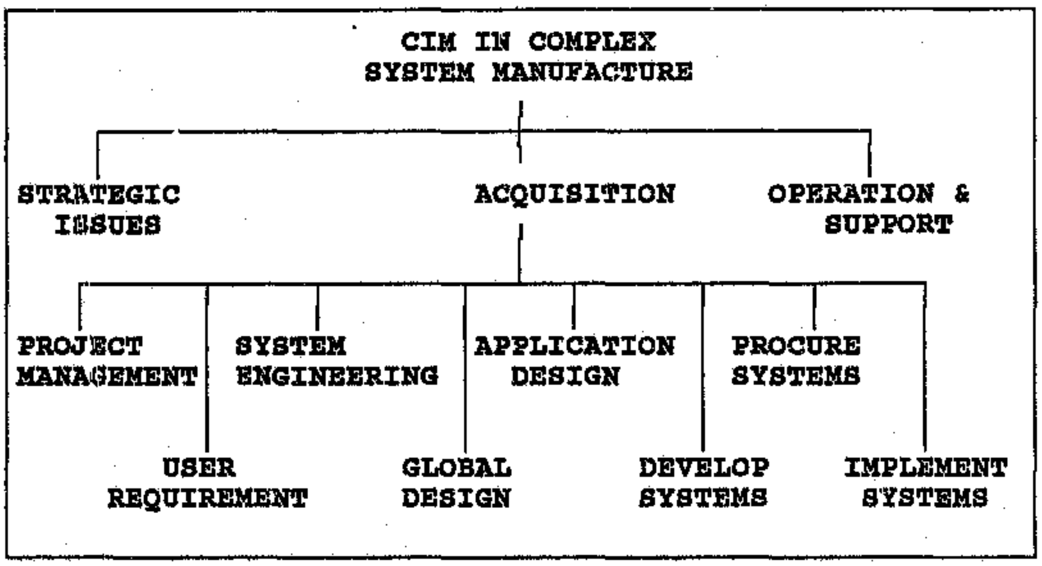

Figure 4.2 The work breakdown structure for CSM CIM acquisition

When such a project is initiated it is very rare to find a complete definition of either the project scope or the user requirements. A great deal of the initial work involves setting boundaries for the project as well as facilitating communication with and between the users to assist them in defining their requirements of any system.

While the scope is being defined by means of the project management and user requirements elements the system engineering and CIMS design elements can be initiated. The system engineering activities involve;

a) system definition
b) configuration definition and management

c) technical performance achievement
d) operational feasibility elements

System definition entails an analysis of the requirements, a functional analysis and allocation for the system, trade studies between alternatives and finally, the synthesis of a system solution.

Under the configuration element the specification of the system as well as general configuration management of the definition is carried out.

Risk analysis and management, technical performance measurement and performance verification comprise the performance achievement element.

To establish the operational feasibility of the system, integration of engineering specialties as well as system effectiveness and life cycle cost modelling is performed. In addition the logistic support and produceability analyses are also carried out under this element.

The CIMS design element covers the functional modelling, data modelling and database design as well as computer systems design, the establishment of policies and procedures, infrastructure and education and training. The application design element is one of the elements that would be tailored to suit a particular project. In this model it is broken down into the areas of computer aided engineering (CAE), computer aided design (CAD), computer aided manufacture (CAM) and the engineering information system (EIS).

The CIMS development element would also be tailored depending on the software purchased or developed and the customization required of purchased software. The procurement element is also highly modifiable depending on the specific site and covers all those functions related to software and hardware procurement.

The final element, that of implementation, is crucial to the success of a CIM system. If inadequate preparation of facilities and staff has taken place the CIM system will immediately be seen in a bad light. The effect of this could be so bad that it ultimately leads to the failure of the system or portions thereof.

4.4 Technology Issues in Computer Integrated Manufacturing

4.4.1 Engineering workstations

Each user will have access to a stand alone engineering workstation and software that suits his specific application. Each user will have his own hardware and software available on local disk. System performance will therefore not be affected by the number of users on the system at any time. The 32-bit processing power of each workstation will ensure a consistently fast response time. The high resolution graphics and wide range of application software available will ensure that every user's needs are satisfied.

4.4.2 High speed networks

A diagram illustrating the logical communications via high speed networks appears in Figure 4.3. All engineering workstations, minicomputers and mainframes will be networked, thus allowing transparent information access across all departments.

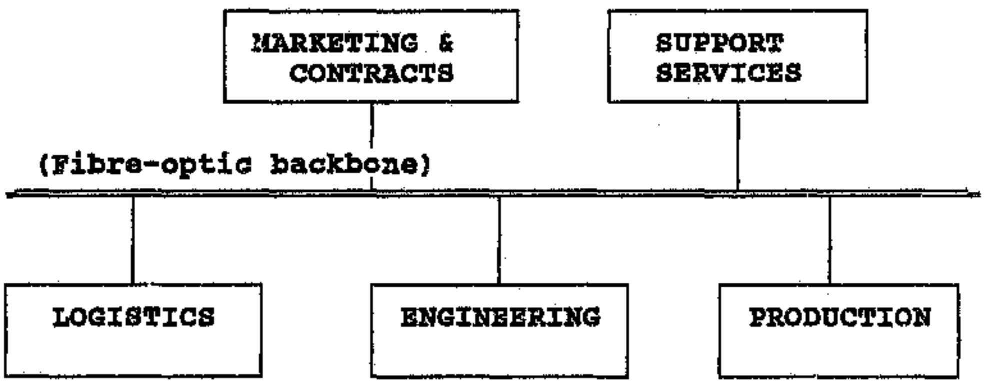

Figure 4.3 An inter-building network

The connection solution most suited to the topology of the site and the nature of the applications is the IEEE 802.3 standard, commonly known as Ethernet. The use of fibre optic media is proposed in order to enhance security and also to eliminate susceptibility to lightning. Within each building, a multi-port repeater will be used to split the single fibre optic input to six copper outputs. (Thin Ethernet cabling). The network is expected to operate at ten megabits per second.

This will provide for ease of communication between the major groups involved. The network design includes a fair amount of expansion possibilities. Each multi-port repeater can be exchanged for a fibre optic hub, which will provide a network in each building equal to the size of the entire currently proposed network.

Within these buildings there are teams of technical specialists using the same applications and sharing most of their data in a cellular fashion. These cells will be linked via the token ring network system. The cells within each building have various amounts of computing needs. Typically a cell may range from one engineering work station and a dot matrix printer to thirty engineering workstations, microcomputers, printers, plotters, laser printers etc. However, the logical system and network design remain exactly the same regardless of the size of the cell.

Communication requirements of a typical cell :

- Communications between [illegible] workstations and PC's within the cell.
- Communications between the cell and other cells in the building.
- Communications between the cell and other cells in other buildings.

Figure 4.4 shows the logical system and network design within a typical building. Computing cells are connected to the multi-port repeater via thin Ethernet cabling and an file server. The cells therefore communicate to any other cell or device in the network via the multi-port repeater.

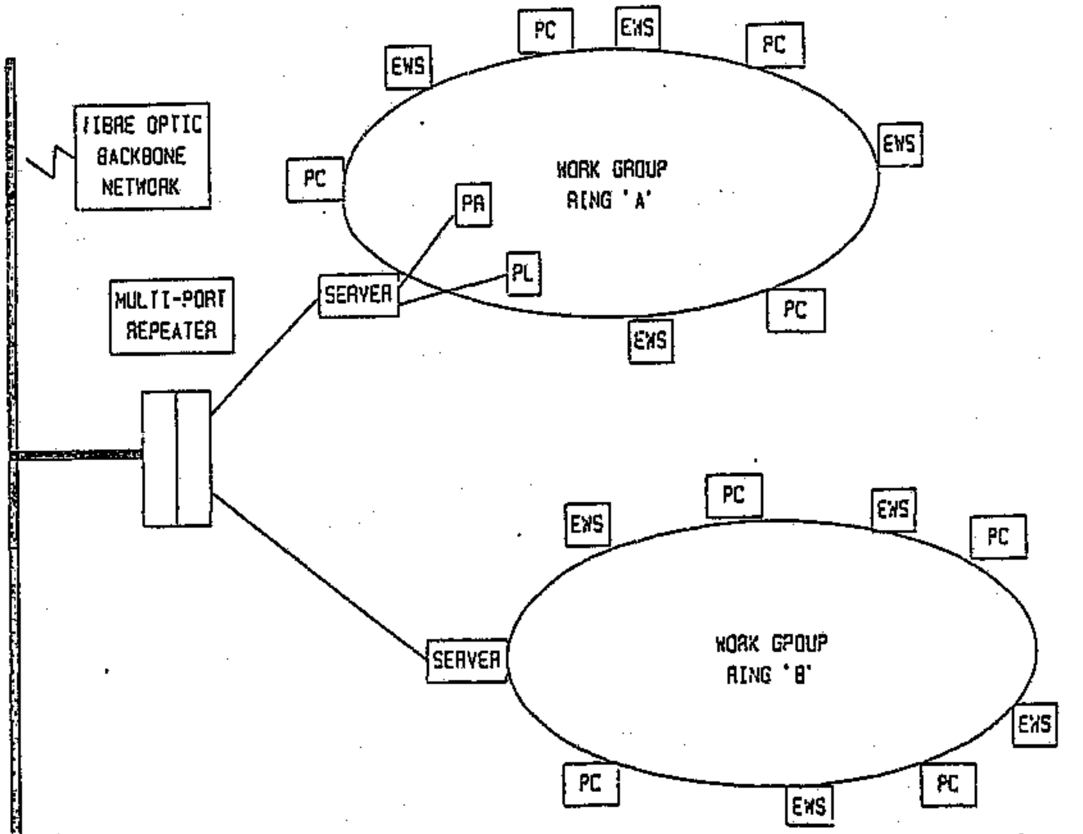

Figure 4.4 An intra-building network

Communication within each cell is achieved by use of a token ring network. This extremely fast network allows the common data within the cell to be transparent to all users. Each ring network or cell includes an file server. The file server's functions are :

- Provide a gateway between the Ethernet network and the token ring network.
- Physical storage of the cell's common data.
- Numerical Processing in the case of computational intensive applications.
- Allows connection of multiple peripherals.

In some cases a super mini computer/mainframe is also connected to the multi-port repeater for numerical processing. The mini computers and mainframes are connected to the Ethernet network using TCP/IP protocols. (Industry Standard). The workstations can access these mini/mainframe computers via the file servers and the Ethernet network.

At the system level all peripherals and other network resources such as numerical processing are available to authorized users. Furthermore, although the system is distributed, it is logically one single file system or data base. This facilitates the configuration management function as well as providing access for all to a single product data base.

4.4.3 Numerical processors

Super minicomputers with large amounts of processing power will also be linked to the network. These computers are to be used to run computational intensive tasks. Thus, a user wanting to perform a large finite element modelling task can download the task from his workstation to the numerical processor. His workstation is then released to perform other functions while the computational intensive task executes in the background. These super minicomputers are to be used solely to run applications normally resident on the engineering workstations. In other words, the super minicomputers are intended to increase the processing power of the department's workstations.

4.4.4 Departmental minicomputers

Mini computers that run applications not resident on the CIM workstations will also be linked to the network. These "independent" minicomputers will not increase the processing power of the department's workstations but will be able to pass data to and from the workstations. An example of this type of application is the electronics design and simulation mini computer.

4.4.5 Application specific software

A list of suitable software has to be compiled following the study of the user requirements. Information on the relevant packages should then be made available to the users in order for them to decide on alternati.es. Eventually a range of software can be made available to the users that satisfies their needs and can be supported by the system administrators. See Appendix C for a typical list of applications.

4.4.6 Peripherals

Peripherals such as printers, plotters, digitisers, tape readers/punches etc., will be provided to the users. These peripherals will have a network ID, and can therefore be accessed by all users. Expensive peripherals can also be shared between departments.

4.4.7 Integration with existing systems.

Information transfer between existing systems and the proposed new system is made possible via the network.

The network design allows communication to occur according to accepted industry standards such as TCP/IP, Ethernet IEEE 802.3 etc.

4.5 Organizational Requirements

4.5.1 Acquisition

The acquisition of the CIM system should be tackled as a project with a dedicated project team of the necessary seniority, experience and training being established. The composition and size of the project team can naturally vary with the varying demands of the different project phases.

A project steering committee should be formed with representatives of senior management from each division. This will aid the project team to operate successfully, as the nature of the project requires access and communication across divisional boundaries.

4.5.2 Operation and support

The correct operating environment for workstations and minicomputers is vital to ensure maximum system availability. A central group of specialists will be required to oversee the operation and support of the entire system as well as any system level applications or functions such as configuration management. This group would typically consist of the following :

1) System Manager and secretarial service
2) A system administration group
3) System software specialists
4) System hardware specialists

5) Project system administrators
6) Networks and communications staff
7) Applications specialists
8) Development project teams and project managers
9) Data Base Administrators
10) A maintenance workshop and staff

In addition to this central group, in every major functional area (department or division) there will be a system administrator for the local systems as well as operators to support the users with system tasks such as backups, plots and the like. Generally, the application specialists will be located in the areas where they are most needed.

4.6 Advantages of the Proposed System

The advantages of the proposed solution are :

4.6.1 Flexibility

In a broad CIM environment such as a complex system manufacturer it is difficult to accurately determine the user requirements. The elegance of a distributed computing environment such as the one proposed in this document lies in the ability to easily alter the system as user requirements change. Workstations can be moved between departments and buildings with minimal effort, and can be reconnected to the network in another physical location.

Incremental expansion costs are also kept to a minimum, as any expansion is simply a matter of acquiring extra workstations and connecting them to the network infrastructure which will already be present. This is in contrast to mainframe based systems where large, expensive incremental steps, (ie. another CPU), are required.

As the workstations are stand alone units, frequent technological updating of the equipment is possible and can be performed on a modular basis without affecting the rest of the system.

4.6.2 Availability of the system

The dedicated 32-bit CPU in each workstation ensures a fast, predictable response time. The user is therefore not affected by the number of users on the system at any time. In the event of the network temporarily not being available for maintenance or other reasons, each user can still proceed with his own specific computing functions. In essence, the event of total system failure can never occur.

Maintenance of the workstations is very simple. The faulty workstation is removed and replaced by a workstation in working order from a maintenance pool. When the faulty workstation has been repaired, it is simply swopped back again.

4.6.3 Industry standards

The system design is such that it adheres to a wide range of industry standards. This will facilitate the connectivity of future hardware and integration of future software. It also allows the users to choose software from a long list of available application software from various vendors.

4.6.4 Security

Another major advantage of a distributed computing system is security. From a strategic point of view, there is no one building or computer that houses all the companies computing resources and data. If any building were to be damaged by lightning or destroyed by any other means, the system could still function without being seriously affected by the loss of resources in that building. Backup tapes of the destroyed section of the system can be loaded onto workstations in other buildings and the affected departments could proceed with their functions.

4.6.5 Productivity

The primary objective of the system to be designed is the improvement of productivity in the design and production of complex systems. To achieve this objective a number of different approaches to the system design are possible, all with advantages and disadvantages.
These major categories of computing are:

- Centralized computing (Mainframe based)
- Departmental computing (Mini computer based)
- Distributed or End User computing (Networked work stations)

The effect that these computing environments would have on productivity played a major role in the design process.

In an engineering computing environment productivity has two major elements, individual productivity and work group productivity. Individual productivity calls for predictable high performance, a customized environment and solution specific applications. Work group productivity on the other hand calls for a single file system, communications across products from various vendors, group productivity tools and applications integration.

To provide a comprehensive solution, both individual and group productivity must be addressed without conflict or compromise. Unless both the individual and the work group are addressed simultaneously then gains made in either area are negated. Alternative system architectures can be characterized as in Figure 4.5

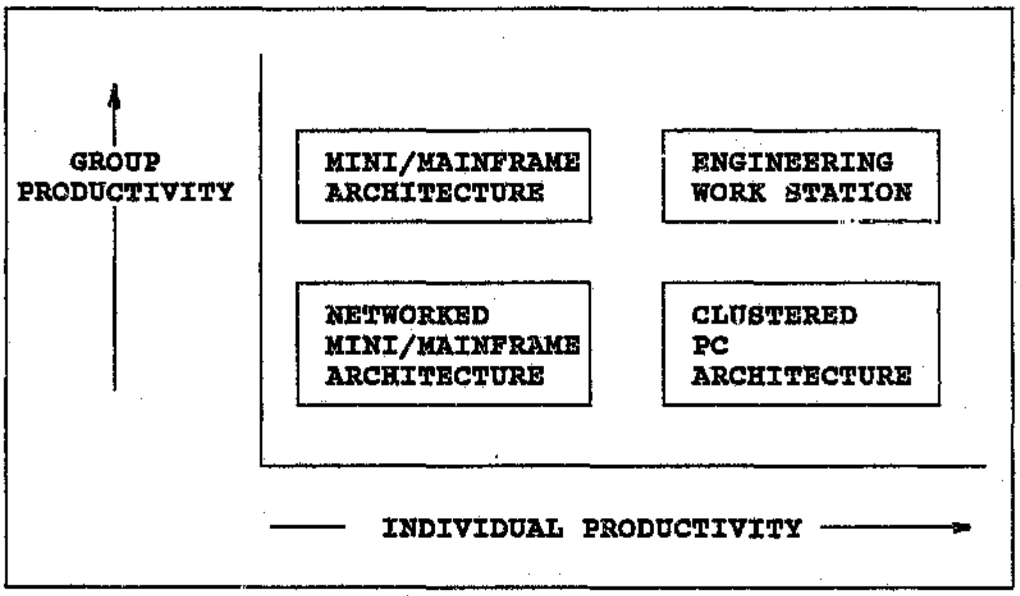

Figure 4.5 The effect of computer architecture on productivity

The matrix demonstrates the effect of various computer system architectures on individual and group productivity :

The mini/mainframe architecture performs well on group productivity because the file systems are designed on a single system which permits excellent group sharing. However, they are low on the individual axis because of the individuals need for a predictable high performance environment. This is the largest drawback of these time shared systems.

Clustered PC's and workstation architecture have the exact opposite effect on productivity. The individual enjoys the benefit of dedicated processor performance, while the group sharing needs are compromised due to the layered nature of their communication technology and its inherent drawbacks. These are added cost, administrative overhead, increased response time, security, etc.

The networked mini/mainframe architecture suffers the worst of both worlds. The access complexity and the administrative expense of multiple file systems are needed to do justice to the group's needs, while the variable performance characteristics of shared processor performance do not meet the needs of the individual.

The engineering workstation system performs excellently on both axes. Stand alone workstations allow individual productivity gains, while the transparent file/data access provided by high speed networks and a single file system boost group productivity. The following attributes make the engineering workstation system outstanding for engineering computing :

- dedicated 32-bit power
- high resolution graphics
- high speed networking
- transparent communications across products from different vendors
- flexible system configuration
- incremental growth paths
- support of industry standards

Based on the preceding discussion, one can see that a major benefit of the proposed system is increased productivity in the design and manufacturing computing areas.

4.6.6 Applications

A wide variety of software is available on the proposed systems so allowing for solution specific applications. In addition, the nature of the system allows for the integration of applications, thus minimizing the need for conversion programs and data duplication. One of the system requirements which is simplified by the proposed design is that of configuration management. This is due to the fact that the proposed system supports a single logical view of all data on the system.

5 THE ENGINEERING INFORMATION SYSTEM IN COMPUTER INTEGRATED MANUFACTURING

5.1 Defining the Engineering Information System

The primary distinction between the engineering information system (EIS) and the other systems within an organization is the nature of the information within the system. The EIS is concerned primarily with data which defines a product in terms of its form, how it is made and how it is supported. Product information is not of a financial or time nature although the costs and schedule for the establishment of the information must always be known.

The initial definition of the product is in terms of the need that it has to fulfill and even at this early stage the EIS can be implemented to support the process of needs definition and interpretation. Ultimately this user requirement is transformed through the system engineering and design processes into a development baseline.

It is in these definition phases that the EIS plays a major role, culminating in a product definition that can be produced and deployed to satisfy that initial customer requirement. During the production phase the EIS plays a supportive role in defining and managing changes as well as recording the "as built" configuration of the product. In the deployment phase the EIS role is reduced but still monitors field performance data and incorporates any changes made in response to this information.

The processes that create and use this data are broadly defined by the following areas of activity ; (See Figure 5.2 - Integrated Manufacture of Products and Services)

5.1.1 Marketing

Definition

Those activities directed at satisfying needs and wants through exchange processes.

The sub functions of marketing relate to defining and interpreting market requirements through the execution of client relations, market research, marketing planning and execution and contract management. One result of these activities is the creation of a requirements baseline which in turn forms the starting point of the development process.

5.1.2 Development

Definition

The design, definition and qualification of, a product, the processes necessary to produce the product and the items and procedures necessary to support the product.

The development process consists of four primary sub functions, namely system engineering, product development, production development and product support development. In the first stages of the development process, system engineering, as defined here, takes place;

The application of scientific and engineering efforts to;

(1) transform an operational need into a description of a system configuration which best satisfies the operational need according to the measures of effectiveness;

(2) integrate related technical parameters and assure compatibility of all physical, functional and technical program interfaces in a manner which optimises the total system definition and design;

(3) integrate the efforts of all engineering disciplines and specialties into the total engineering effort.

These activities are followed by the engineering development process which entails the design, definition and qualification of a product. Once a product is defined the process then moves on to developing the production of the product, resulting in the design, definition and qualification of the processes and equipment required to produce a product.

The third of the development activities is that of product support development. This involves the design, definition and qualification of the equipment, documentation and procedures required to support a product in use in the field.

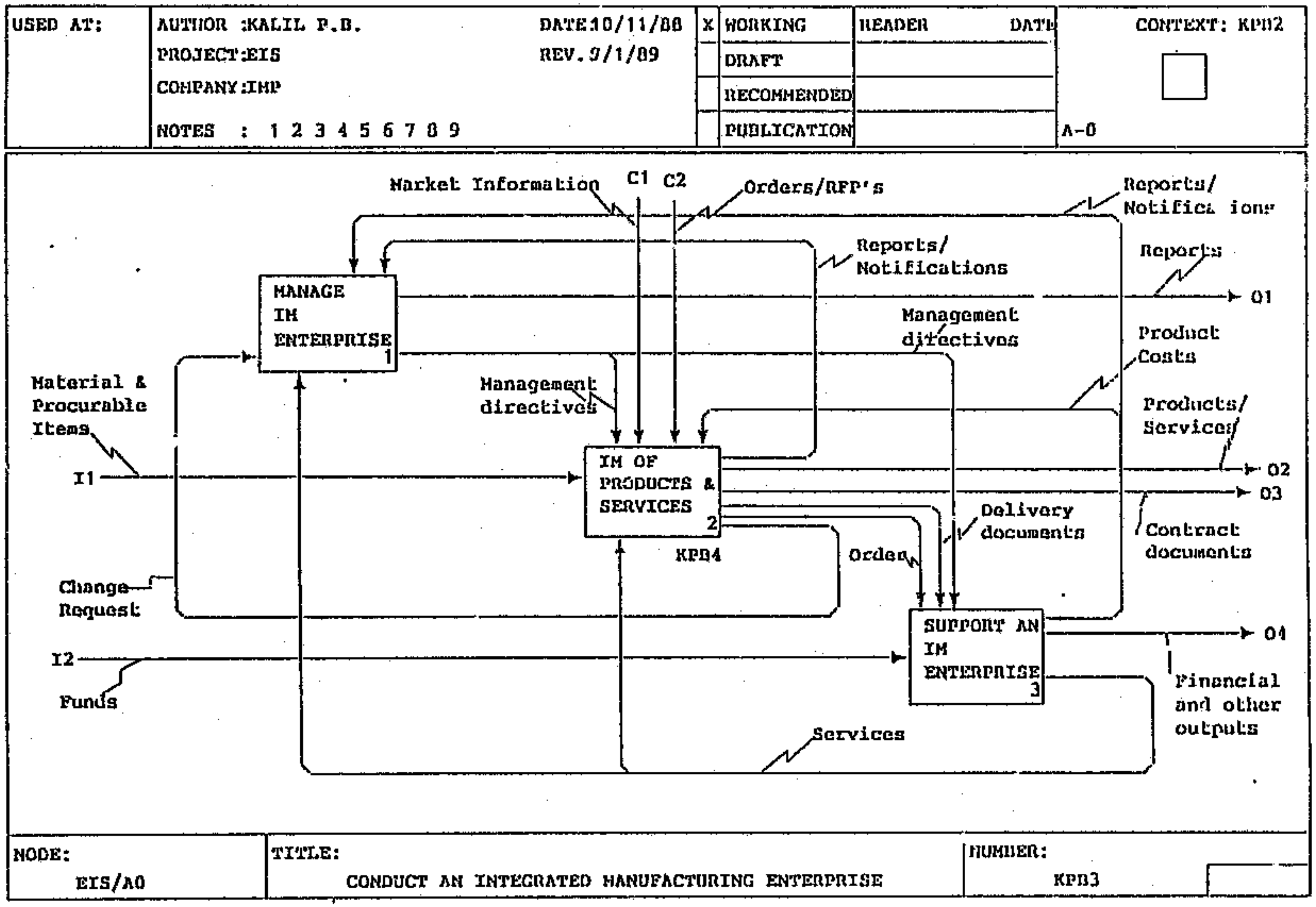

Figure 5.1 Conduct an integrated manufacturing enterprise

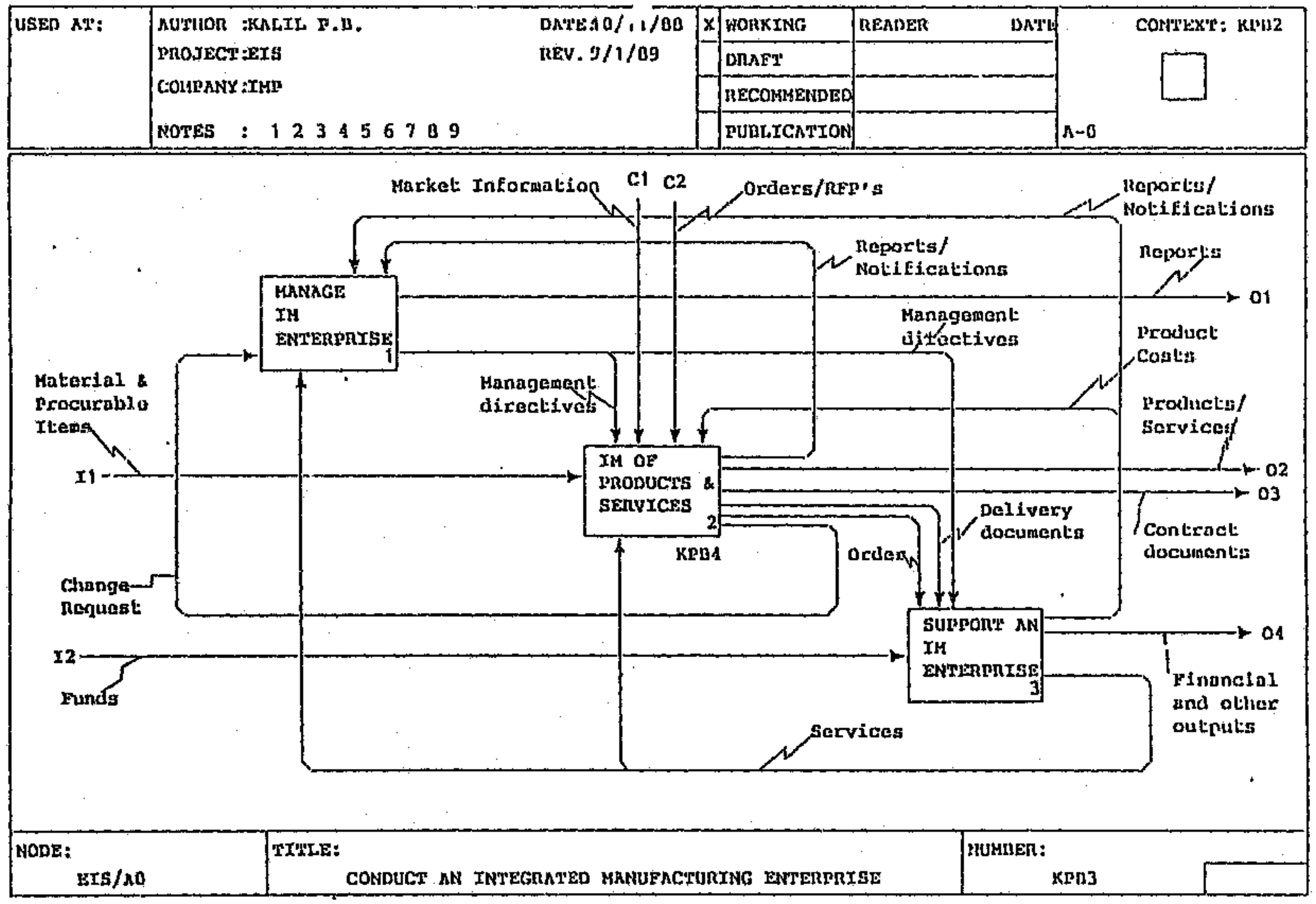

Figure 5.1 Conduct an integrated manufacturing enterprise

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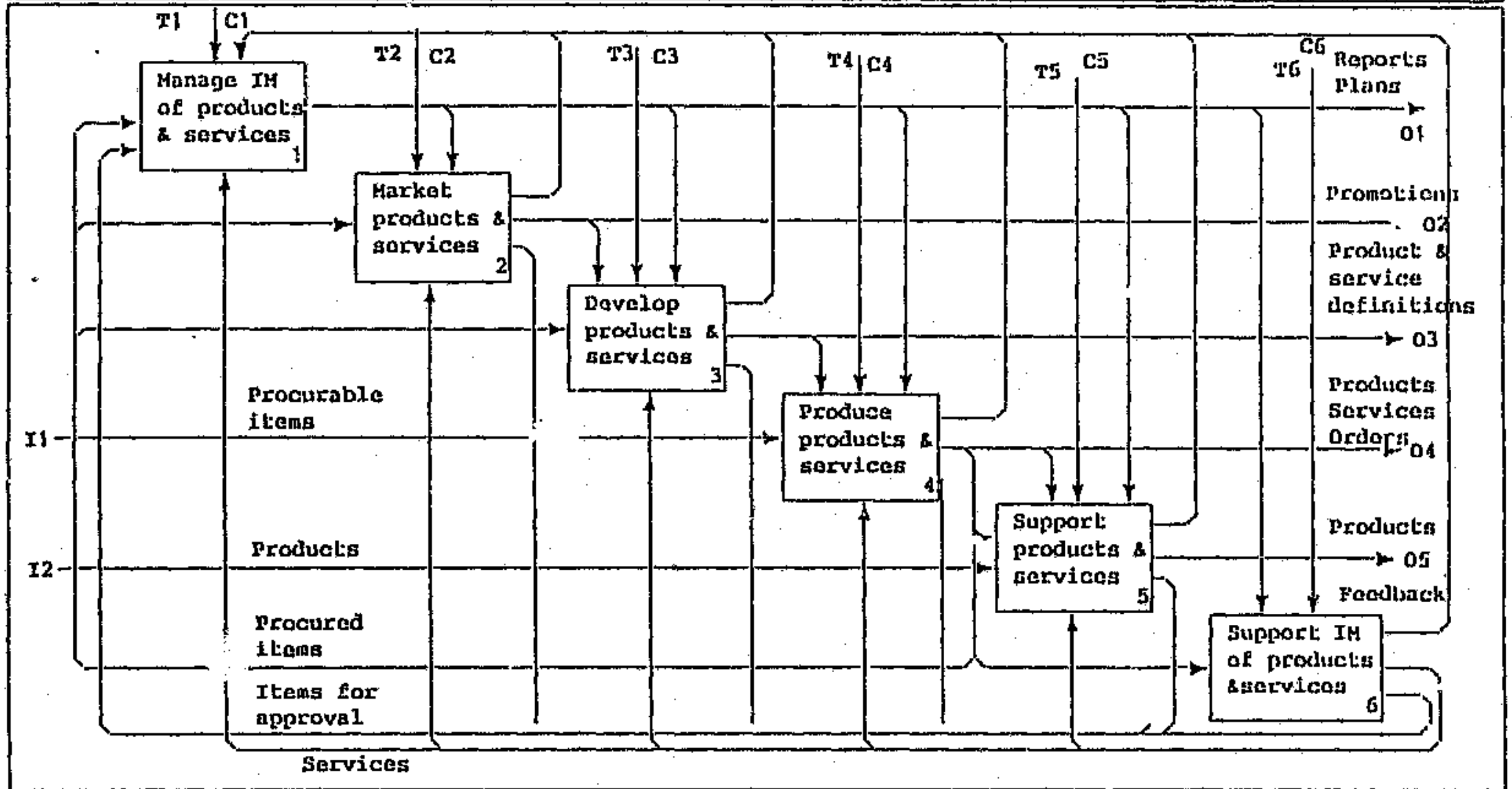

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Figure 5.2 Integrated manufacture of products and services

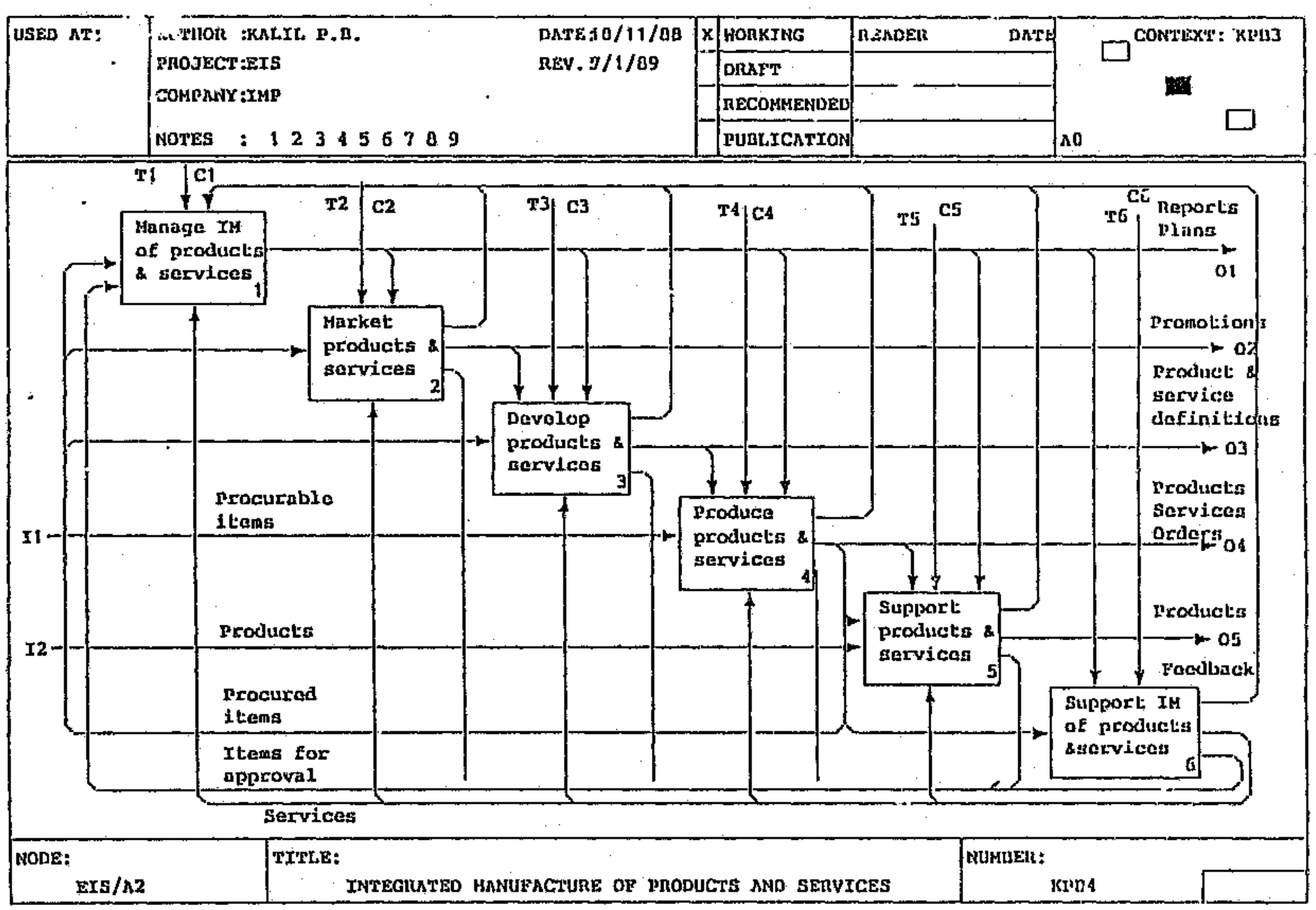


Figure 5.2 Integrated manufacture of products and services

5.1.3 Production

Definition
The processes and procedures designed to transform a set of input elements into a specified output element.

The sub functions of production are production planning, production control, production demonstration and testing, production method development, fabrication, assembly, installation and testing.

5.1.4 Product support

Definition
A disciplined, unified and iterative approach to the management of and technical activities to :

(1) Integrate support considerations into system and equipment design.
(2) Develop support requirements that are related consistently to readiness objectives, to design and to each other.
(3) Acquire the required support.
(4) Provide the required support during all product life cycle phases at minimum cost.

Major sub functions of the product support process are, logistic support analysis, SE/ILS management, SE/ILS engineering, maintenance, support equipment design, supply support development, transportation, personnel and training, creation of technical publications and preservation, packaging, packing and marking of the product.

Two areas which are often not explicitly addressed but form an integral part of all of these processes are quality assurance and configuration management.

5.1.5 Quality assurance
(See Figure 5.3 Assure quality of products and services)

Definition
To ensure the suitability of a product in terms of ef ectiveness, life cycle cost, fitness for use and customer satisfaction.

The quality assurance process has four primary foci, the quality of the concept, definition, conformance and performance of the product. Most quality assurance activity is directed toward assuring the quality of the conformance of a product to the specifications. Quality of concept is generally addressed by means of market research and product trials, leading into the quality of definition activities such as design reviews, modelling and analysis. Quality of performance is involved with the collection, analysis and reporting of field failures, leading to improvements to existing and future products.

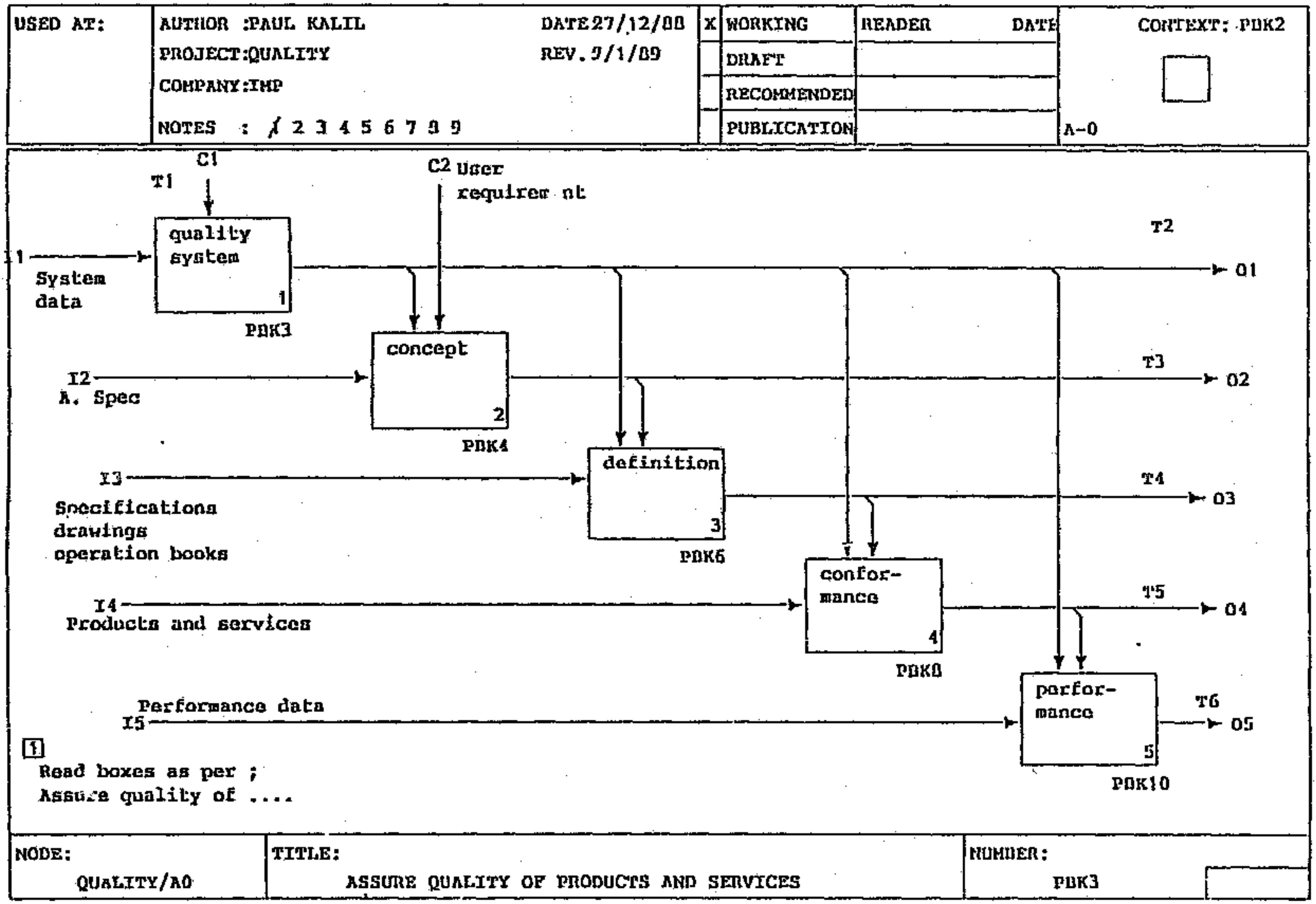


Figure 5.3 Assure quality of products and services

5.1.6 Configuration management

(See Figure 5.4 Manage configuration of products and services)

Definition

A discipline applying technical and management principles to:

(1) Identify and document functional and physical characteristics of hardware and software.

(2) Control changes to these characteristics

(3) Report change processing and implementation status

Three of the four configuration management sub functions are ongoing activities while the fourth, configuration audits, is carried out randomly. The three continuous activities are configuration identification, configuration control and configuration status accounting

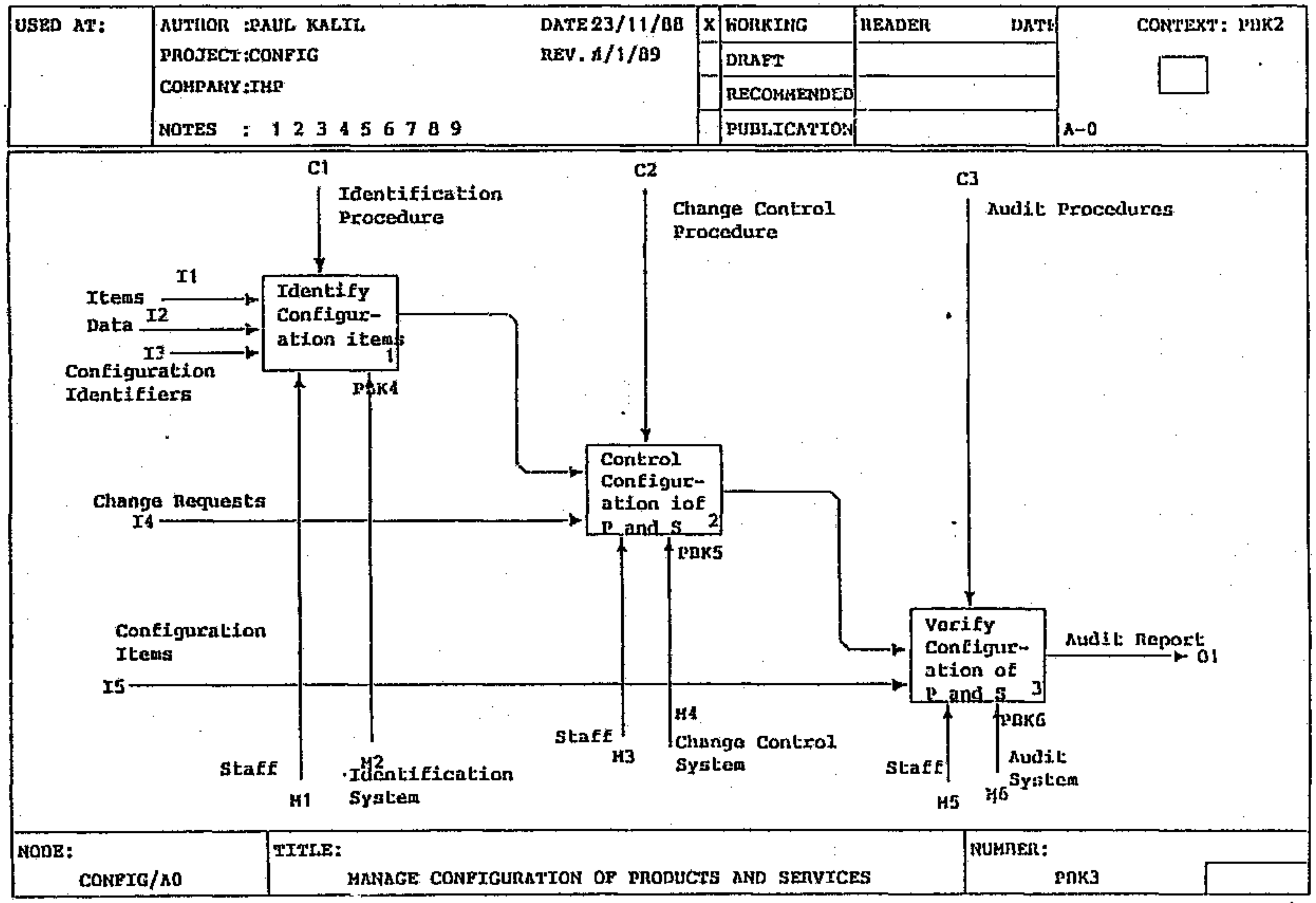


Figure 5.4 Manage configuration of products and services

5.2 The Role of the Engineering Information System in Computer Integrated Manufacturing

The primary objective of the EIS is the integration of development activities by enhancing the coordination of these activities. This can be achieved by integration of the information flow within and between the development activities. Other forms of integration such as control integration and material flow integration can be used but in the area of development activities the most effective is the integration of information flow.

The EIS is required to integrate the activities of large design teams, improve the management of engineering data, provide fast, accurate communication and increase development productivity.
To do this the EIS eliminates the duplication of development data but also increases the availability of development data to those who need it. In addition, the data is secured by the EIS with only authorized staff having access to the data.

The EIS, apart from being a repository for many different applications' data, has to also provide the tools and utilities to carry out the following functions. These are preferably automated and essentially transparent to the user of the system.

File and Data control
Process control
Configuration Management
Notifications

Archiving
Maintenance of relationships
File conversion and communication
Control of non-electronic data

The benefits to any enterprise with an EIS are numerous with some of the major benefits being a reduction in development times, an improvement in product quality, reduction in costs and greater control over processes, designs and changes.

5.3 Creating the Engineering Information System

5.3.1 Architecture

Any information system requires the definition of an architecture or design philosophy for the successful creation of the system. The three schema architecture is accepted as the most flexible and successful approach to adopt and it is the one proposed for the definition and creation of an EIS.

5.3.2 Models

The use of models in information systems development has become widespread but not every modelling technique provides the desired rigor.

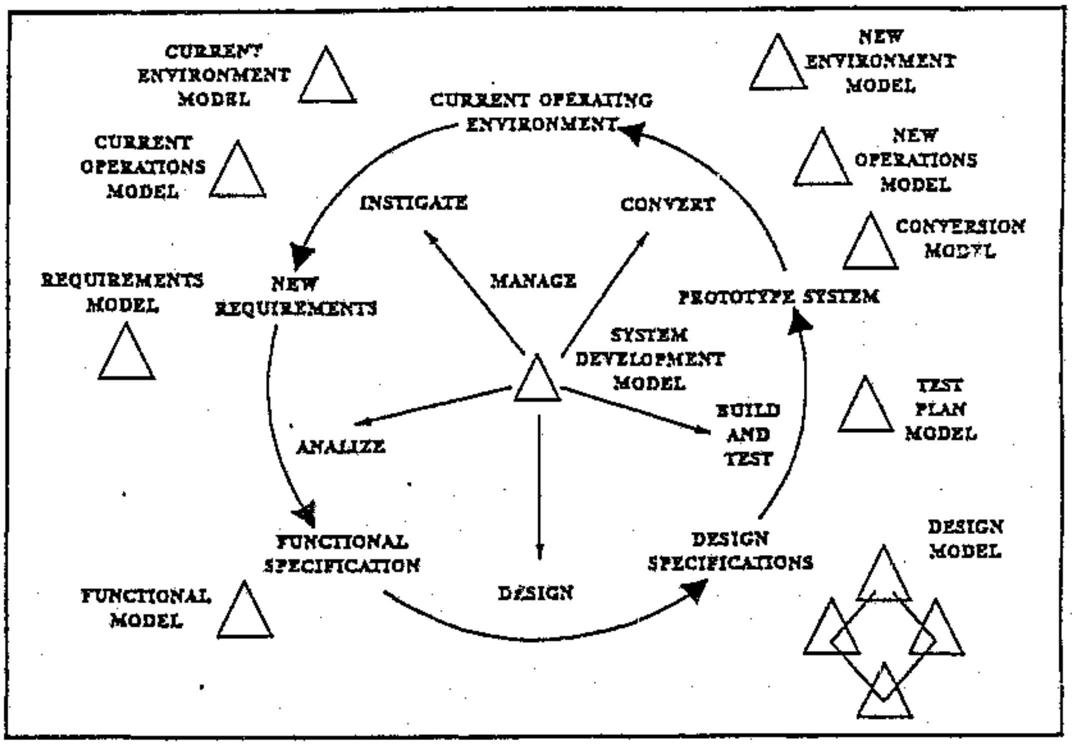


Figure 5.5 Models in the information systems life cycle

Any choice of a model or models to use should be made considering the environment of the system and its end objectives. Not all modelling methods will provide the desired solutions. Diagramming techniques are important and, if selected carefully, can have a tremendous impact on the development of an information system. They assist in establishing a clear, rigorous yet easily understood definition of a system and so improve the quality and accessibility of a design. In some advanced systems the design can be decomposed to the point where automatic generation of software can take place.

The approach used in this system is the creation of a functional model of an engineering information system based on the IDEF0 model discussed in Chapter 2 and Appendix D in the dissertation. This allows for the definition and decomposition of the functions and information flows of a typical EIS for an integrated manufacturing enterprise.

From the functional model an information model known as IDEF1 is derived. This model is based on the entity - relationship-attribute data model. The entity-relationship-attribute model is a starting point of the software system life-cycle.

In Table 5.1, the stages in any EIS definition are presented. In this model it can be seen that various data models are used at different stages in the life cycle. The corporate entity model defines the high level scope of the entire enterprise and does not contain vast amounts of detail. The business entity model presents a more detailed, thorough representation of a particular aspect of the enterprise activities such as the EIS or the financial information systems.

At the functional or application level the data models represent the logical data requirements of an application such as CAD or MRP. At this point the models lose their system independence since the physical data models represent the hardware and software specific implementations of the functional data models.

In the further life cycle phases no new models are created but the functional and physical models are used and maintained right through to the point of disposal, assisting in the migration to a new system.

5.3.3 Technologies

In addition to the functional and information models there are other requirements for the successful creation of an EIS in the areas of computing, communications and databases.

The advent of the personal computer and engineering work stations has seen a dramatic change in the price performance factors of computing. The mini and mainframe computers no longer stand as central repositories of data and processing capability and in engineering environments the shift to distributed end user computing is progressing faster than just about anywhere else.

With both the processing power and storage capacity they require on their desks as well as high resolution graphics, the engineer today is very much more involved in the information technology than before. The implication however, of the distributed end user systems, is that networks have had to improve significantly to provide both the performance and the low cost linkage between many disparate systems, from PC to mainframe. The use of fibre optic technology is becoming widespread and the network management role is becoming all the more important.

The EIS places some unique pressures on a database management system (DBMS) as result of both the volume and the nature of the transactions that take place in an engineering environment. Some of the requirements the EIS places on a DBMS are ;

Size

A typical integrated manufacturing enterprise with fully electronic systems would require approximately twelve billion words of data on line and about nineteen billion words of data available within ten minutes.

Speed

For on line database applications studies have shown that sub-second response should be maintained if the operator/user productivity levels are to be kept high. This however can obviously only apply to simple transactions and not to complex non-key searches or calculations.

Heterogeneity

The EIS environment is such that multiple types of hardware and even of DBMS's must be expected to exist and any integrative system must cope with this heterogeneity and the communications load that this implies.

Security

Security of the data in the EIS has many aspects but the major issues are the integrity of the data, controlled access to the data by authorised applications and the recovery of the data in cases where system failures do occur.

Distributed

Any advanced manufacturing environment today has many computer sites and computers disseminated throughout its facilities. To integrate such an environment calls for distributed databases to support the distributed or end user computing.

Text and Graphics
The EIS should ultimately have the capability to manage and display not only textual information but also graphical information. This will entail a level of capability not found in today's "commercial" databases.

The benefits of using a DBMS for an EIS are numerous but the primary ones are ;

The DBMS simplifies and standardizes access to data by both applications and users. This has large time and cost benefits when creating new applications as well as cross training staff.

If a suitable DBMS is selected easier hardware migration can take place without major disruption of applications and data access.

Data independence is achieved when one is no longer held hostage by a particular application because of the amount of data one has stored in a proprietary file system or DBMS used by that application.

By defining a data model and controlling it the accuracy of development data can be significantly improved. Along with the improvement in accuracy one can reduce data redundancy, so improving the integrity of development data.

The major DBMS structures that exist today are the hierarchical, the network and the relational databases.

The object oriented database is receiving a lot of attention in specialised areas but the relational database structure appears to have developed to the point where it can replace all others. Virtually all existing engineering databases are based on a relational DBMS and tainly all new systems will have a relational DBMS as their core.

5.4 An Engineering Information System Model

5.4.1 The functional model

The diagrams in Figures 5.1 through 5.4 represent the top levels of three distinct models. The primary model is that of a complex system manufacturer (CSM), as modelled by the author, focussing specifically on the areas of concern within an engineering information system. The other models are complimentary and represent the quality and configuration management systems within the CSM. The complete models can be found in Appendices E, F and G re spectively.

Method

The models were created by means of work sessions conducted by the author with the various elements of the company. The first levels of the model were derived from sessions held with the senior management of the company who were trained in the use of the technique. Once the higher levels were completed in draft form the various functional areas of the company were involved, in turn, in work sessions varying in length from as little as four hours to as long as five days.

Each first time work session was initiated with a discussion of the purpose and future of the work that was to be done. This placed both the technique and its results in perspective for the people in the work session. Figure 5.6 was often used to represent this graphically. Once the initial IDEF0 models were established the IDEF author/ reader cycle was established and used to minimise the time spent in joint sessions where these were not required for any other reason.

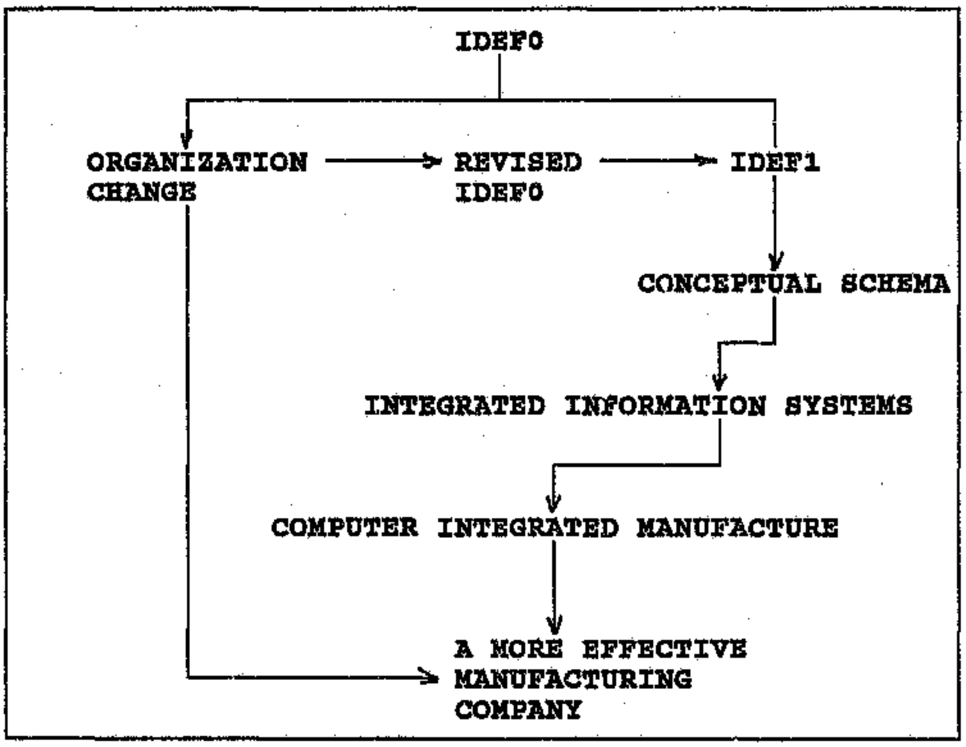


Figure 5.6 The IDEF modelling context

Once an acceptable functional model had been established for an area it was then used as a basis for both discussions on the organizational structure of that area as well as the information and information system requirements of the area. Those processes that were identified as being both necessary and suitable to computerise were then identified.

5.4.2 The information model
Creation of the information model commences with the decomposition of the information classes, identified in the functional model, into entities. Entities being defined as the people, places, events and things that are of interest in any particular enterprise. The next step in this process is to identify the attributes which comprise the entities and then, from these attributes, identify the primary key (unique identifier) of any entity. (See Appendix D)

The last step in this process is the establishment of the business rules and relationships amongst the entities, resulting in the identification of alternate keys, foreign keys and referential constraints. The means by which this process is driven is the activity of data normalisation.

Table 5.1 Information system life cycle phases

PHASE	CONFIGURATION BASELINE PRODUCED	SYSTEM REVIEWS	DOCUMENTATION PRODUCED	INFORMATION/DATA MODEL
(1) PLANNING PHASE	CONCEPTUAL BASELINE		USER REQUEST TOR WBS SOW	CORPORATE ENTITY MODEL
(2) CONCEPTUAL PHASE	OPERATIONAL BASELINE	SYSTEM REQUIREMENTS REVIEW	FEASIBILITY STUDY USER REQUIREMENTS SPECIFICATION	BUSINESS ENTITY MODEL
(3) DESIGN PHASE				
(3A) PRELIMINARY DESIGN SUB-PHASE	FUNCTIONAL BASELINE	PRELIMINARY DESIGN REVIEW	SYSTEM SPECIFICATION SOFTWARE REQUIREMENT SPECIFICATION PRELIM. INTERFACE CONTROL DOCUMENTS FUNCTIONAL DESIGN PRELIMINARY TEST PLAN	FUNCTIONAL DATA MODEL

Table 5.1 (Continued)

PHASE	CONFIGURATION BASELINE PRODUCED	SYSTEM REVIEWS	DOCUMENTATION PRODUCED	INFORMATION/DATA MODEL
(3B) DETAIL DESIGN SUB-PHASE	DEVELOPMENT (ALLOCATED) BASELINE	SYSTEM DESIGN REVIEW CRITICAL DESIGN REVIEW	DETAILED DESIGN DOCUMENT INTERFACE CONTROL DOCUMENT UPDATED FUNCTIONAL DESIGN TEST PLAN	PHYSICAL DATA MODEL
(4) DEVELOPMENT PHASE	PRODUCT BASELINE	PRE-TEST DESIGN REVIEW POST-TEST DESIGN REVIEW	MODULE DEVELOPMENT FOLDERS TEST PROCEDURES TEST REPORTS OPERATING INSTRUCT.	PHYSICAL DATA MODEL
(5) IMPLEMENTATION PHASE				
(5A) INSTALLATION SUB-PHASE	INSTALLATION BASELINE	PRE-PRODUCTION DESIGN REVIEW	DESIGN DOCUMENTS (AS BUILT)	NONE
(5B) IMPLEMENTATION SUB-PHASE		SYSTEM ACCEPTANCE REVIEW	VERSION DESCRIPTION DOCUMENTS	
(6) MAINTENANCE PHASE				
(7) DISPOSAL PHASE				

Data normalisation is a process carried out to ensure that each piece of real world information appears only once in the entity model. This eliminates redundancy in the model, the applications built on the model and, ultimately, in the functions using the system. Normalisation is a means of non-loss decomposition and is carried out in stages, each corresponding to a level of normalisation known as a normal form.

There are six normal forms of interest to real world applications and each normal form exists within the context of the preceding normal form. For istance, to satisfy X normal form an entity must be in X-1 normal form and meet some additional constraint. Each normal form has a definition as presented on the following pages.

ZERO NORMAL FORM (0NF)

Every entity must have a set of attributes and/or relationships that uniquely identify an occurrence of it.

Table 5.2 Zero normal form

EMPLOYEE

EMPNO	EMPNAME	DEPTNO	DEPTNAME	MNGR	MNGRNAME	PROJNO	PROJNAME	STARTDATE	BILLRATE
1234	COOPER	10	SALES	7788	JONES	10	SCOPE	10/9/88	100
						20	ANALYSIS	20/9/88	100
						30	TEST	20/10/88	150
7788	JONES	20	SUPPORT	7000	SMITH	10	SCOPE	10/9/88	200
						40	HANDOVER	30/10/88	150
7800	COOPER	10	SALES	7050	PHILLIPS	20	ANALYSIS	20/9/88	200
						30	TEST	20/10/88	150

FIRST NORMAL FORM (1NF)

Every attribute must have a single value for any occurrence o it's entity at any one point in time.

Table 5.3 First normal form stage

EMPLOYEE

EMPNO	EMPNAME	DEPTNO	DEPTNAME	MNGR	MNGRNAME
1234	COOPER	10	SALES	7788	JONES
7788	JONES	20	MARKETING	7000	SMITH
7800	COOPER	10	SALES	7050	PHILLIPS

ASSIGNMENT

EMPNO	PROJNO	PROJNAME	STARTDATE	BILLRATE
1234	10	SCOPE	10/9/88	100
	30	TEST	20/9/88	100
	40	HANDOVER	20/10/88	150
7788	10	SCOPE	10/9/88	200
	20	ANALYSIS	15/9/88	250
	40	HANDOVER	20/10/88	200
7800	20	ANALYSIS	15/9/88	150

SECOND NORMAL FORM (2NF)

Every attribute must depend on the entire identifier of it's entity for it's value.

Table 5.4 Second normal form stage

EMPLOYEE

EMPNO	EMPNAME	DEPTNO	DEPTNAME	MNGR	MNGRNAME
1234	COOPER	10	SALES	7788	JONES
7788	JONES	20	MARKETING	7000	SMITH
7800	COOPER	10	SALES	7050	PHILLIPS

ASSIGNMENT

EMPNO	PROJNO	STARTDATE	BILLRATE
1234	10	10/9/88	100
	30	20/9/88	100
	40	20/10/88	150
7788	10	10/9/88	200
	20	15/9/88	250
	40	20/10/88	200
7800	20	15/9/88	150

PROJECT

PROJNO	PROJNAME
10	SCOPE
20	ANALYSIS
30	TEST
40	HANDOVER

Third Normal Form (3NF)

Every attribute must not depend on anything except the unique identifier of it's entity for a value.

Table 5.5 Third normal form stage

EMPLOYEE

EMPNO	EMPNAME	MNGR	MNGRNAME
1234	COOPER	7788	JONES
7788	JONES	7000	SMITH
7800	COOPER	7050	PHILLIPS

DEPARTMENT

DEPTNO	DEPTNAME
100	MARKETING
200	SALES
300	PRODUCTION
400	LOGISTICS

ASSIGNMENT

EMPNO	PROJNO	STARTDATE	BILLRATE
1234	10	10/9/88	100
	30	20/9/88	100
	40	20/10/88	150
7788	10	10/9/88	200
	20	15/9/88	250
	40	20/10/88	200
7800	20	15/9/88	150

PROJECT

PROJNO	PROJNAME
10	SCOPE
20	ANALYSIS
30	TEST
40	HANDOVER

Boyce-Codd Normal Form (BCNF)

Every determinant must be a candidate key.

See Figure 5.8 for an example of the entity relationship diagram.

Table 5.6 Boyce-Codd normal form stage

EMPLOYEE

EMPNO	EMPNAME	MNGR
1234	COOPER	7788
7788	JONES	7000
7800	COOPER	7050

DEPARTMENT

DEPTNO	DEPTNAME
100	MARKETING
200	SALES
300	PRODUCTION
400	LOGISTICS

ASSIGNMENT

EMPNO	PROJNO	STARTDATE	BILLRATE
1234	10	10/9/88	100
	30	20/9/88	100
	40	20/10/88	150
7788	10	10/9/88	200
	20	15/9/88	250
	40	20/10/88	200
7800	20	15/9/88	150

PROJECT

PROJNO	PROJNAME
10	SCOPE
20	ANALYSIS
30	TEST
40	HANDOVER

Fourth Normal Form (4NF)

The entity must not contain independent multi-valued mappings.

Fifth Normal Form (5NF)

An entity must obey no symmetric constraints other than between candidate keys.

Generally, where existing relational database technology is being used it is very unusual to need to progress beyond the Boyce-Codd normal form.

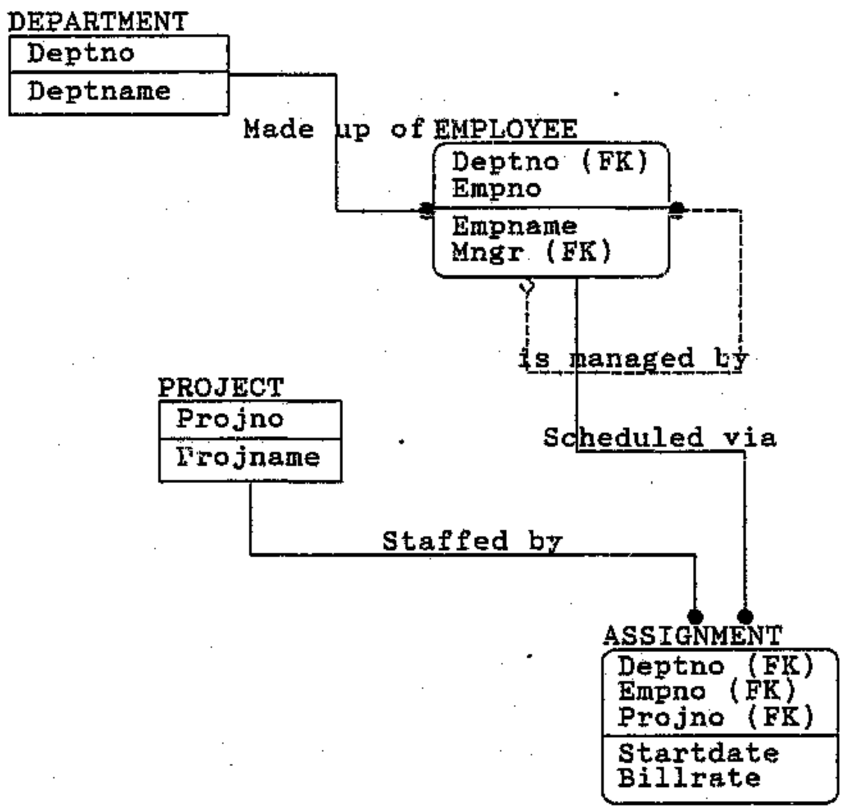


Figure 5.7 The resulting BCNF entity-relationship diagram

As can be seen from Figure 5.7, the entity-relationship diagram can grow rapidly to the point where creation and maintenance of the model become extremely difficult without the use of automated tools of some sort. In any enterprise level model sixty to seventy entities can be identified fairly quickly. As the process of normalization is carried out this number grows rapidly. By working at a lower level, corresponding to the application level, a more focussed, controllable model can be derived. As is reflected in Table 5.1, this is the general progression of any information systems project adopting these techniques.

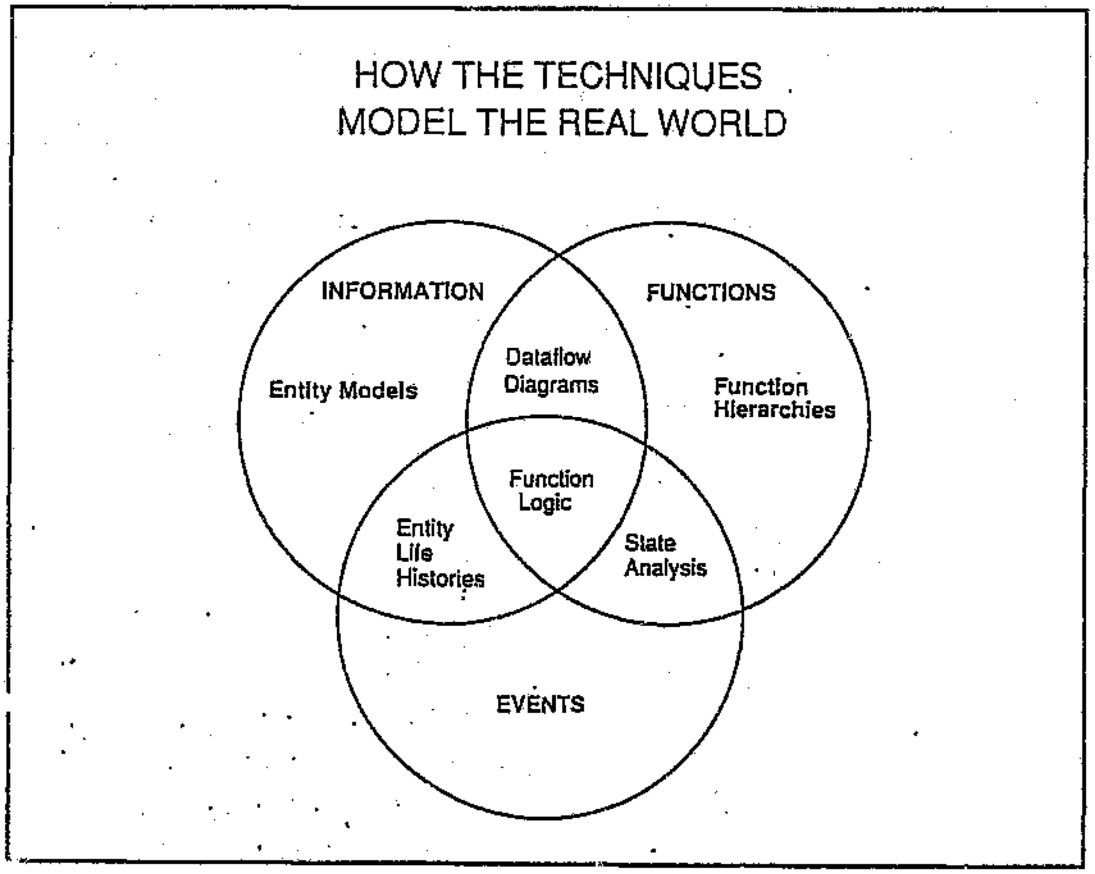


Figure 5.8 Modelling the real world

No one technique is used in isolation and it is the combination of techniques as represented in Figure 5.8 that imparts the true strength of the proposed approach. Other techniques such as dataflow diagrams, state analyses, entity life histories and action diagrams all combine to fill out the modelling and analysis of a system. All of which leads to fundamental, rigorous and ultimately cost effective integration of systems, resulting in truly computer integrated manufacturing.

6 SUMMARY AND CONCLUSIONS

6.1 Summary

A complex system is defined by many things but is generally a system which comprises many components while the number of individual units built is low. The complex system has a distinct life cycle with different, clearly defined phases. Often prototypes of the system are built in the development phases to minimise the risks involved. The number of people involved also varies from phase to phase with typically several hundred being involved in development phases and several thousand in production and operational phases.

To create and support a complex system an organisation typically has four core functions, namely marketing, development, production and support. An organisation that produces complex products and has these four functions can be defined as a complex system manufacturer.

Computer integrated manufacturing for complex system manufacture is shaped by the requirements of CSM which are primarily the need for coordination and integration of information. This is especially true in the formative phases of the complex system life cycle. In these phases the staff involved are primarily highly skilled, scarce resources and the decisions made with regard to the product have the greatest impact on product cost and effectiveness.

It is therefore apparent that a great need exists for timeous, accurate information in these early life cycle phases. The distinction between data and information is important to define here as the provision of information is predicated on the availability of data. A datum can be seen as being a fact and a meaning. A fact without context or meaning is not a datum. Information exists when a datum exists and there is a need for that datum. This indicates the transient nature of information since it is only while a need for it exists that a datum is information.

The fluid nature of the operating environment in the development phases of a complex system also imposes the need for any systems used in these phases to be able to cope with continuous change. The computer related systems of primary importance in these phases are, computer aided engineering (CAE), computer aided design (CAD), computer aided manufacturing (CAM) and the engineering information system (EIS).

When acquiring a CIM system there are many risks that are faced before a successful system is established. Although these risks will vary from project to project and are often not directly controllable it is possible to minimise them by adopting certain techniques and approaches in the acquisition project.

The CIM acquisition must firstly form part of the CIM strategy developed for and supporting the company's business strategy. It must also be addressed as a project and the tools and techniques of project management applied. Further to these steps it is essential to make use of system engineering practices to ensure that an holistic approach to the acquisition is adopted.

The information systems within CIM must be developed according to an architecture which results in flexible yet cost effective systems. Such an architecture is the three schema architecture as specified by the ANSI-SPARC Committee. The three schema architecture provides for the treatment of data as an asset whereby the user applications are buffered from the physical computer systems by means of a central control or logical schema.

In the work breakdown structure established for CIM there are three major elements which result in the creation of a conceptual schema. These are the elements of functional modelling (IDEF0), information modelling (IDEF1) and database design.

Other elements of the work breakdown structure deal with project management and user requirements definition, common to any project. The system engineering and CIMS design elements deal with the architecture related activities while the other elements are related to the design, development, procurement and implementation of hardware and software systems.

A further parameter in the CIM equation is that of technology. A CIM project's success is often predicated on the success of a certain technology or combination of technologies. Some of the major areas of concern are end user computing, communications and distributed heterogeneous applications. The crux of the problem is the integration of personal computers, mainframes, minicomputers and peripherals at both the physical and logical levels.

Staffing of such an acquisition project is difficult and the correct mix of engineering and computer staff must be found for any specific project. In the operation and support of a CIM system a unique mix of system staff and application specialists must be established. This group must be continuously focussed on the global purpose of the systems they are working on to prevent the fragmentation of the systems into isolated islands of automation.

The advantages of adopting such a structured approach as described here can be seen in the results obtained by such systems. The systems are highly flexible and available yet adhere to industry standards while providing high levels of security. The net result is that a tremendous gain in productivity is achieved in those areas which have traditionally not seemed amenable to any improvement efforts.

As the core of any CIM system it is necessary to focus on the engineering information system. It is defined to be a system that contains data related to the marketing, development, production and support functions as well as quality and configuration management data. The engineering information system is also seen as an adjunct to the areas of computer aided engineering, computer aided design and computer aided manufacture.

Creating the EIS under the three schema architecture ensures that a flexible and effective system can be created at low cost. This is particularly so since this approach allows for phased implementation of applications without any penalty. Modelling of the EIS is crucial to this creation process. The choice of models and diagramming techniques is important since not all techniques can provide the solutions desired.

The IDEF0 technique for functional modelling is used to establish the EIS functional model while the IDEF1 or entity-relationship-attribute model is used for information modelling. The IDEF1 model is the most appropriate point to initiate the software system development life cycle.

The software development life cycle is characterised by three phases, an analysis phase, a logical phase and a physical phase. The IDEF diagrams are prerequisites for the analysis phase.

The EIS is bound by technology limitations in three areas, viz. computing, communications and database management systems. The computing field has been revolutionised by personal computers and the advent of end user computing. Each user controls his own processing and storage as well as having access to other computing, storage and output resources.

A prerequisite for true end user computing is communication, communication of such a nature that it becomes essentially transparent to a user where any data or application is physically located. Access to remote devices and data should be as if they were present on the users own disk.

Unique pressures are placed on a database management system by the EIS. The nature of the EIS data and transactions are such that they are not comparable to the usual database applications. The EIS database has to be both large and fast yet also provide high levels of security in a distributed, heterogeneous environment. The database management system should also be able to deal with both textual and graphical information. The benefits of using a DBMS for creating the EIS are that the access to data is simplified, hardware migration is more easily undertaken and data integrity is much improved.

A functional model of the EIS has been created with two supplementary models, those of quality assurance and configuration management. The model is placed in context by indicating how it is used prior to embarking on a modelling session. The EIS is placed in context by modelling the enterprise top down and hence indicating the interaction between the EIS and the other systems in the enterprise.

The functional model, once established to sufficient detail, forms the basis for the definition of the information requirements within the enterprise. The information entities (arrows in the IDEF0 diagrams) are easily identified to create the IDEF1 diagrams.
The EIS is entity rich and although it is possible to establish a single entity-relation-attribute model it quickly becomes so complex and difficult to read that it is essentially useless. It is far better to establish many smaller entity-relation-attribute

diagrams, each appropriate to a specific user view or application. The combination of the many smaller models creates a mosaic of views, ultimately defining the entire global EIS entity-relation-attribute model.

To do this manually is possible but extremely laborious and probably highly inaccurate. It is essential to use an appropriate tool which maintains all the links and references within the model automatically. This ensures both the integrity and completeness of the model so created.

Which tool to use is dictated by the specific project selection of a database management system. In some instances it is possible to generate the database automatically from the model by defining the data dictionary for the database management system.

The final step in the creation of the EIS is the definition of the applications which supply and use the data within the EIS. This process is much simplified by the existence of the database prior to the application development or procurement.

6.2 Conclusions

a) A complex system manufacturer should first adopt CIM in the areas of the enterprise prior to the shop floor.

b) CIM acquisition should be handled as a distinct project and system engineering principles applied in the acquisition process.

c) The IDEF modelling technique should be used to define CIM system.

d) The information systems implemented as part of the CIM system should comply with the three schema architecture.

e) The engineering information system should be defined to function as an integrator of the related areas of CAE, CAD and CAM.

f) The engineering information system should be implemented by means of a database management system.

g) The engineering information system information model should be a composite of all the smaller user and application information models.

h) The information models should be created and managed by means of automated tools, preferably linked to a database management system.

APPENDIX A

A WORK BREAKDOWN STRUCTURE FOR CIM ACQUISITION

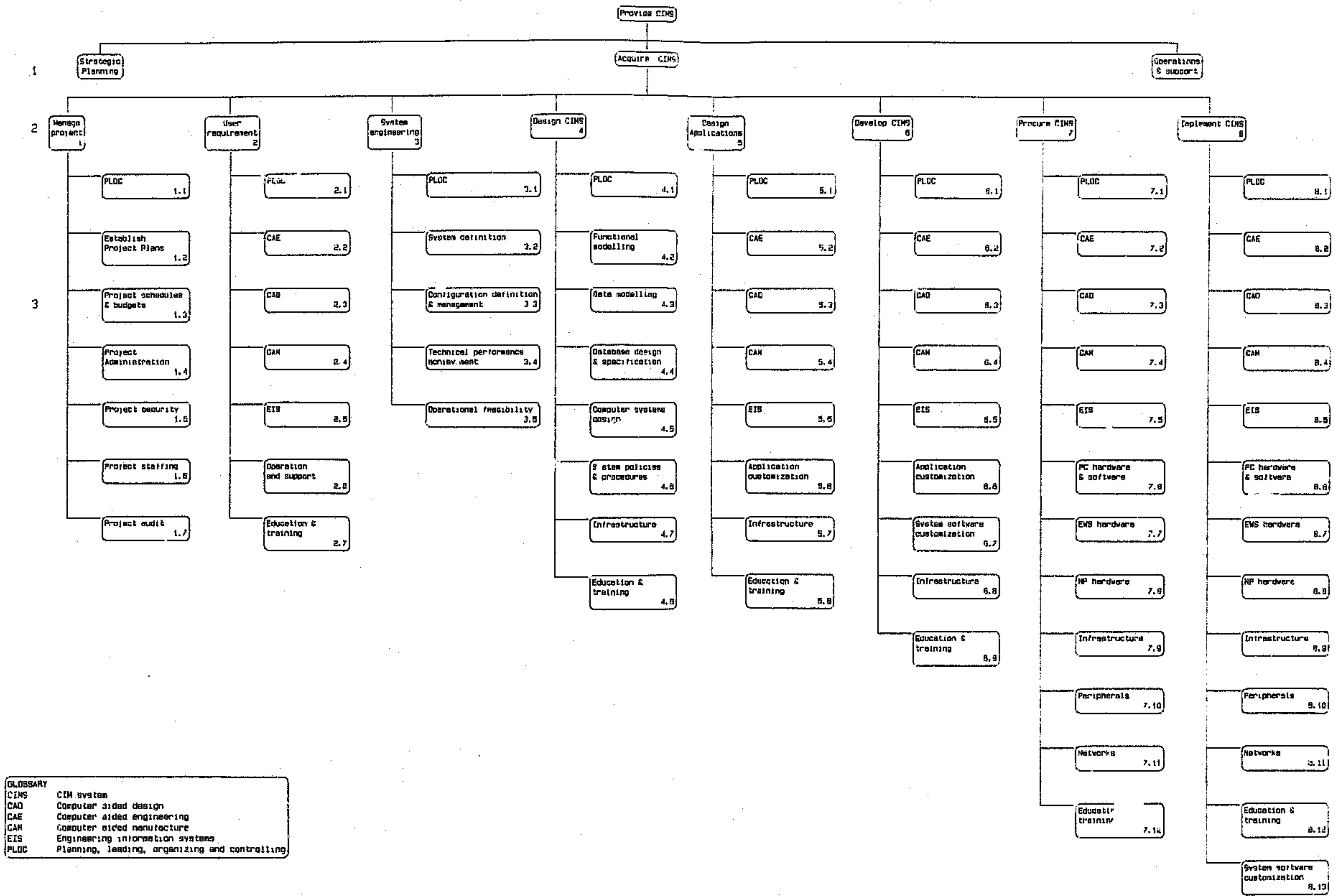
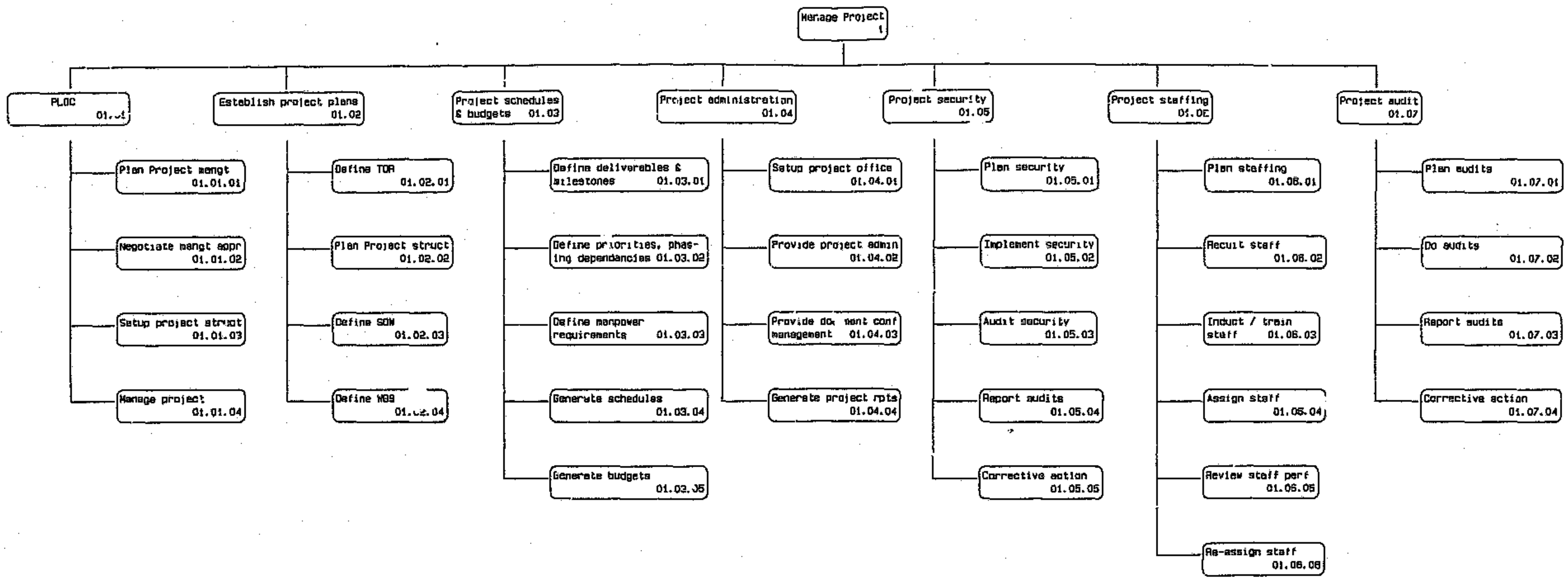
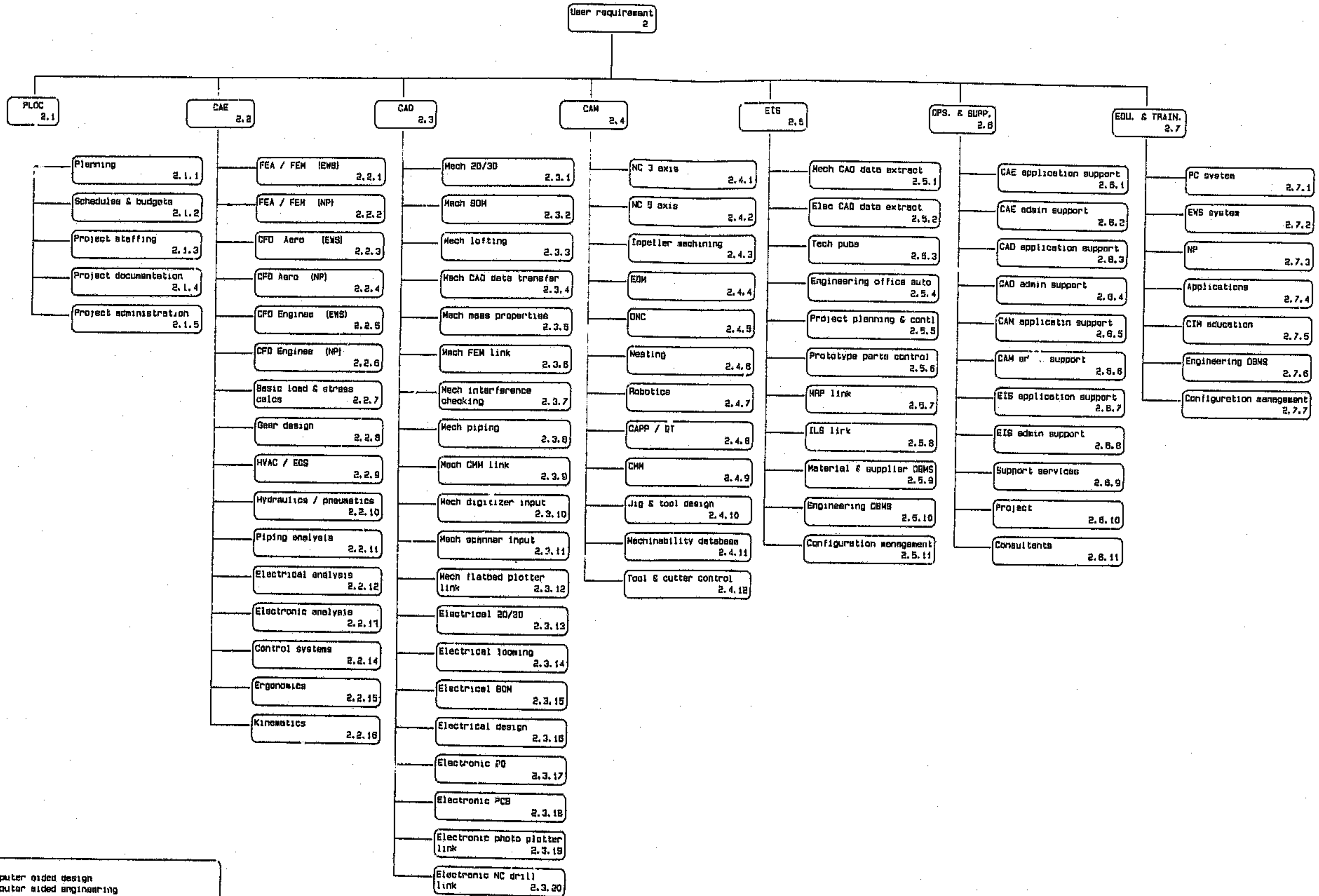


FIGURE A1 CIM acquisition



GLOSSARY	
PLOC	Planning, leading, organizing and controlling

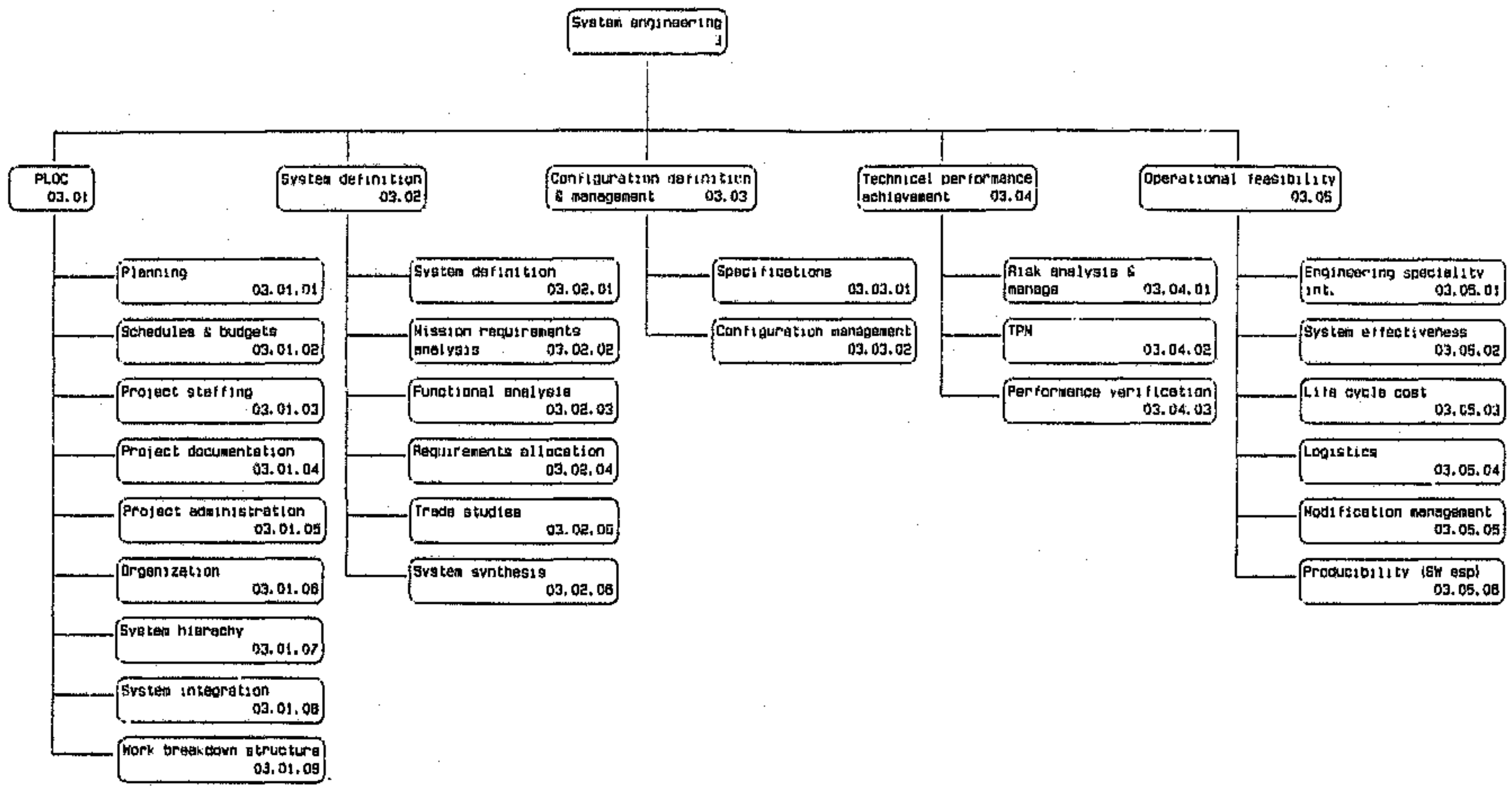
Figure A2 Project management



GLOSSARY

CAD	Computer aided design
CAE	Computer aided engineering
CAM	Computer aided manufacture
EIS	Engineering information systems
PLOC	Planning, leading, organizing and controlling

Figure A3 User requirement



GLOSSARY	
TPM	Technical performance measurement
PLOC	Planning, leading, organizing and controlling

Figure A4 System engineering

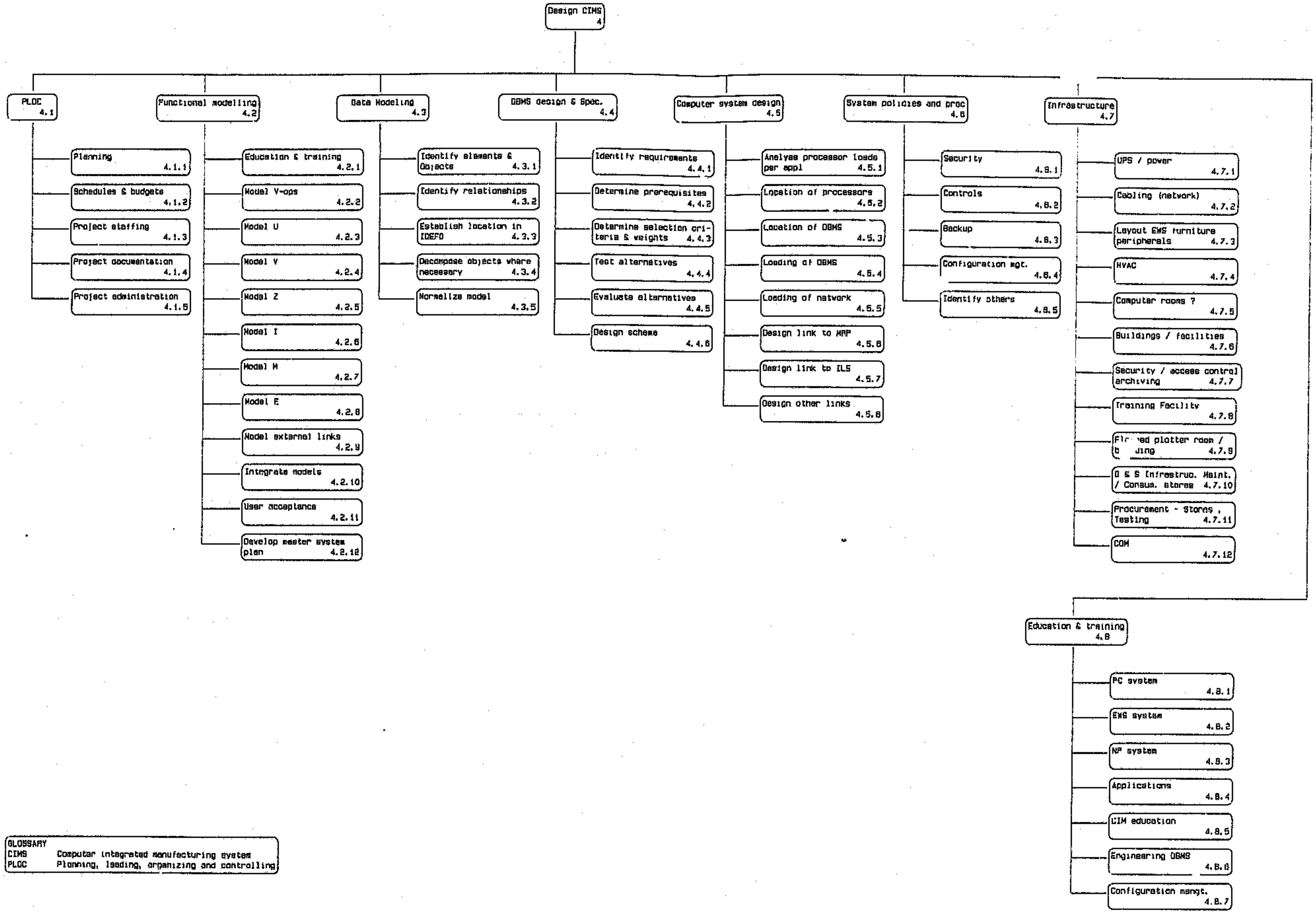
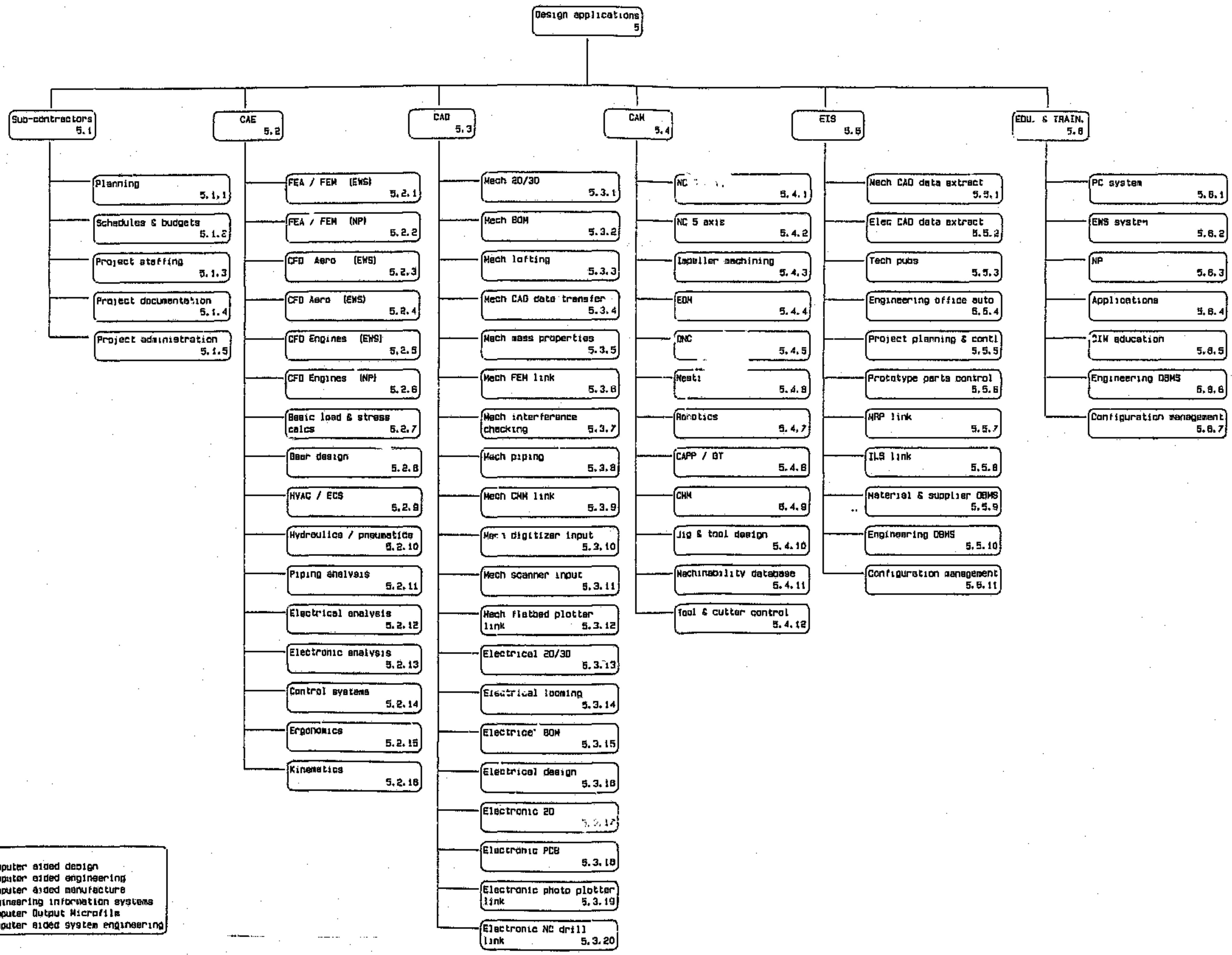


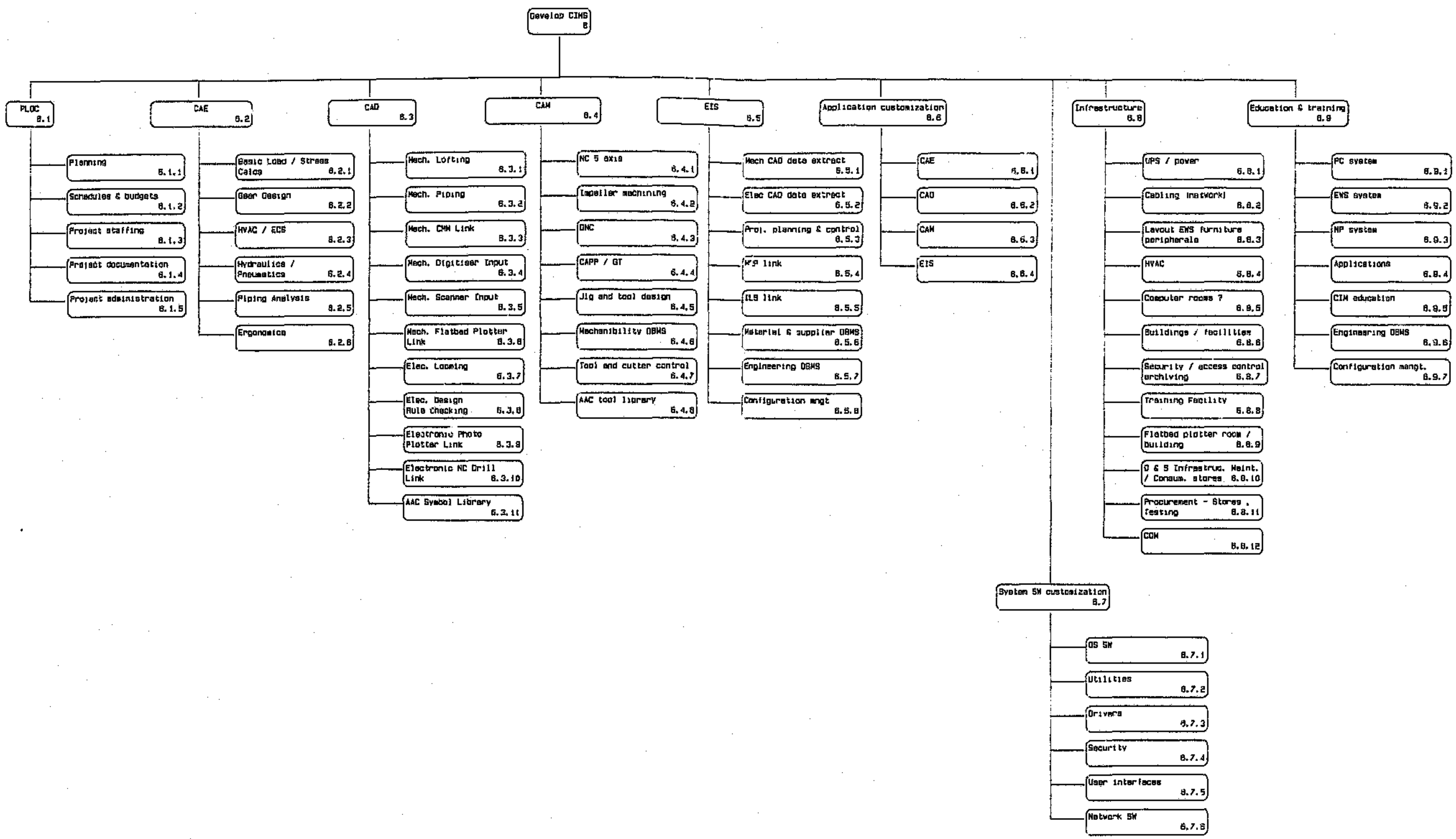
Figure A5 Design CIM system



GLOSSARY

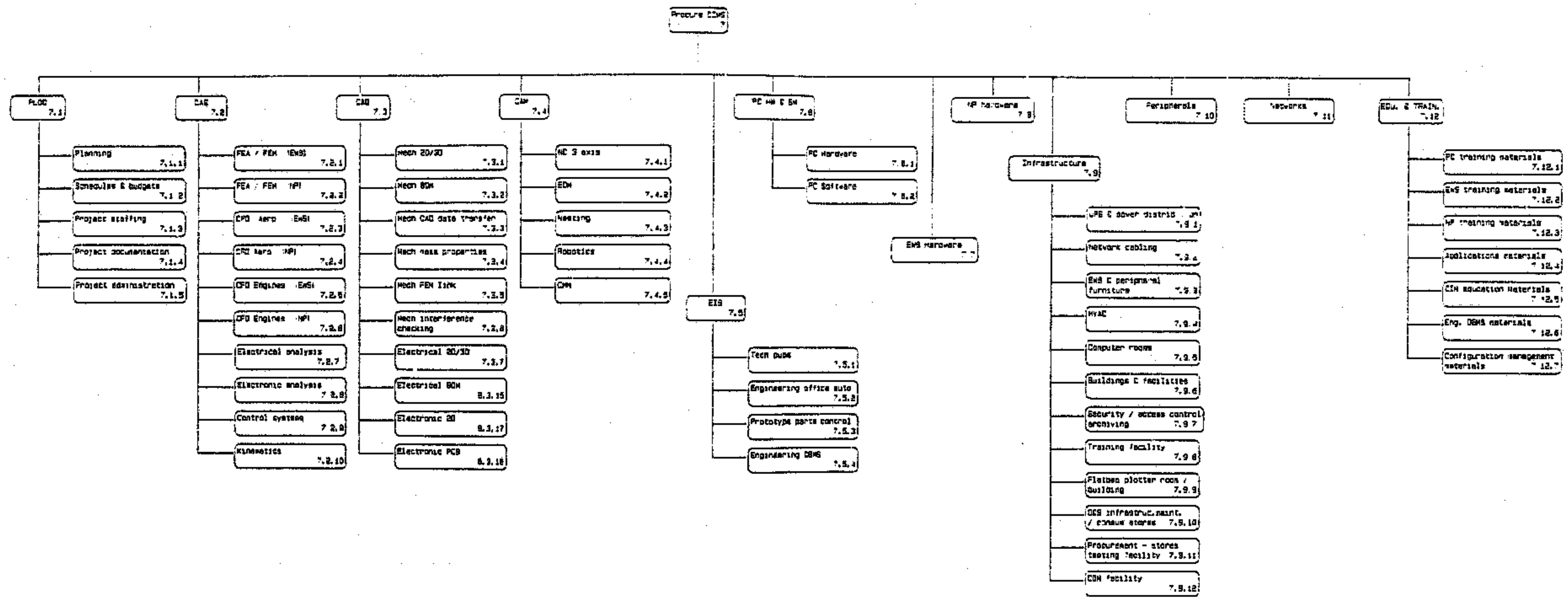
CAD	Computer aided design
CAE	Computer aided engineering
CAM	Computer aided manufacture
EIS	Engineering information systems
COM	Computer Output Microfilm
CASE	Computer aided system engineering

Figure A6 Design applications



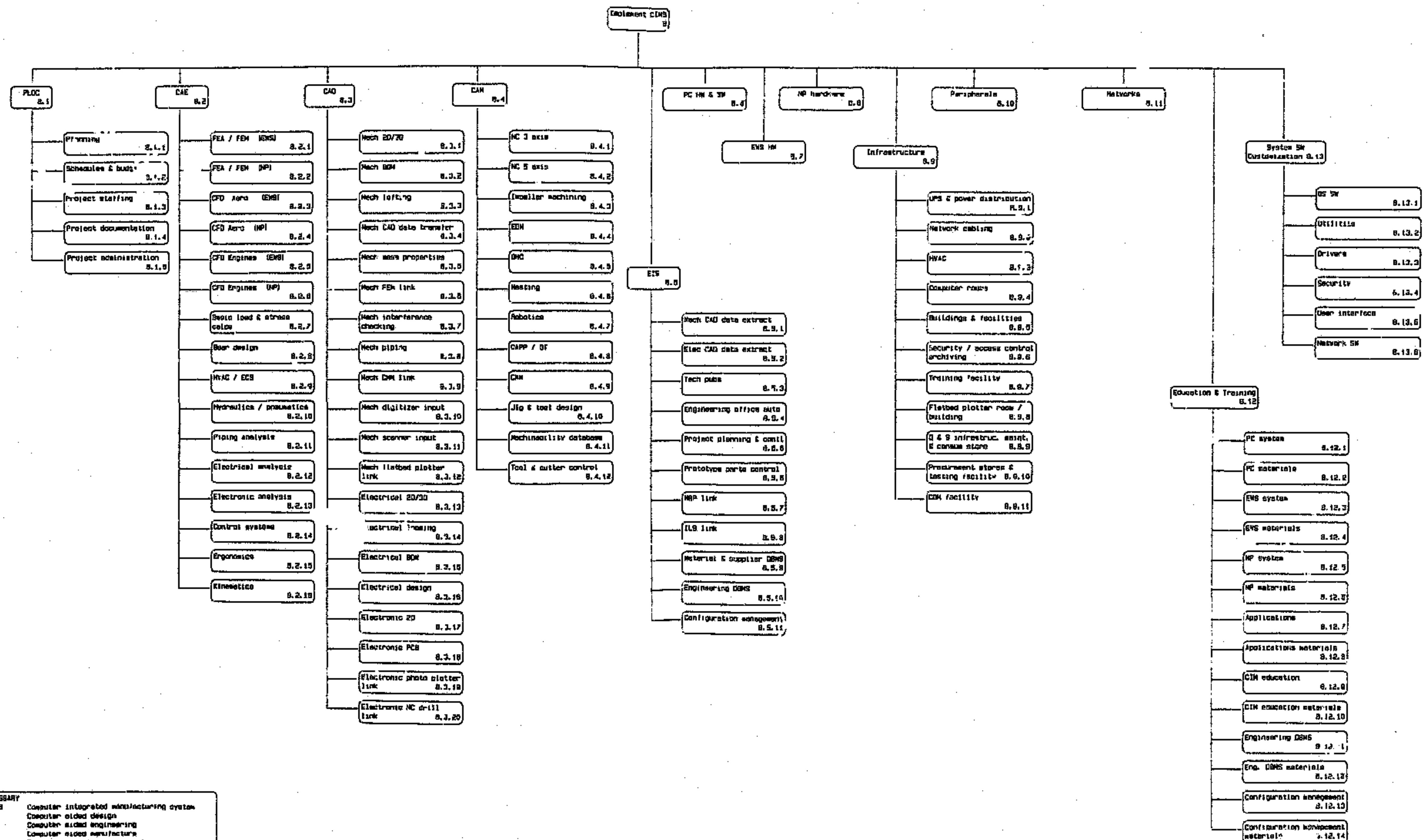
GLOSSARY	
CIMS	Computer integrated manufacturing system
CAD	Computer aided design
CAE	Computer aided engineering
CAM	Computer aided manufacture
EIS	Engineering information systems
PLOC	Planning, leading, organizing and controlling
COM	Computer output microfilm

Figure A7 Develop CIM system



GLOSSARY:	
CIMS	Computer integrated manufacturing system
CAD	Computer aided design
CAE	Computer aided engineering
CAM	Computer aided manufacture
EIS	Engineering information systems
PLOC	Planning, leading, organizing and controlling

Figure A8 Procure CIM system



GLOSSARY	
CIMS	Computer integrated manufacturing system
CAD	Computer aided design
CAE	Computer aided engineering
CAM	Computer aided manufacture
EIS	Engineering information systems
PLOC	Planning, leading, organizing and controlling

Figure A9 Implement CIM system

APPENDIX B

A COMPUTER SYSTEM COST EFFECTIVENESS MODEL

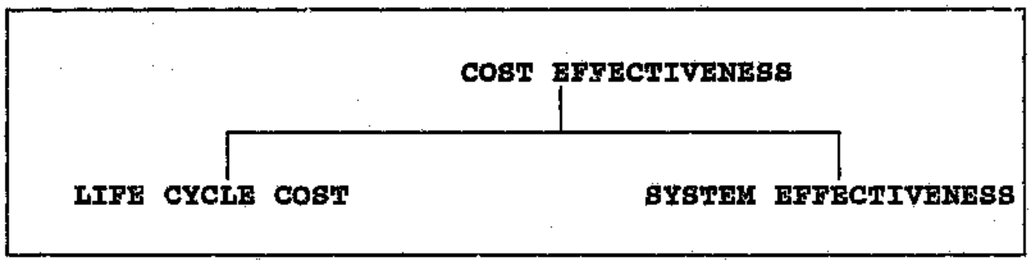


Figure B1 Cost effectiveness

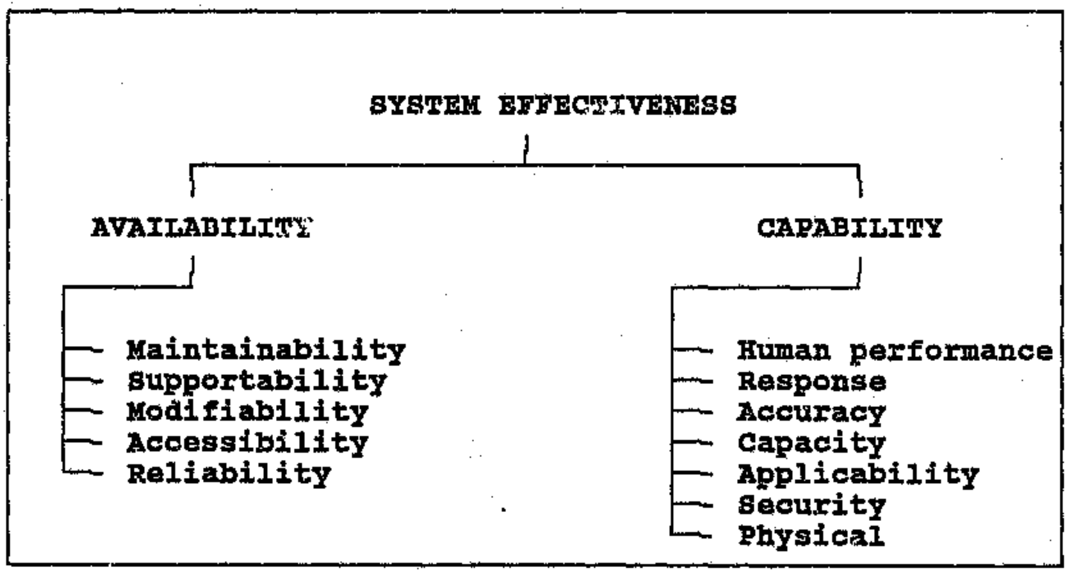


Figure B2 System effectiveness

DEFINITIONS

1. SYSTEM EFFECTIVENESS

A measure of the extent to which a system may achieve a set of specific mission requirements.

1.1 AVAILABILITY

An expression of the probability that the system is operating satisfactorily at any time, when used under stated conditions.

1.1.1 MAINTAINABILITY

The extent to which a system facilitates the correction of deficiencies.

1.1.1.1 MAINTENANCE

Activities carried out to pre-empt failures and hence to keep high availability.

1.1.1.2 REPAIR

Activities carried out to restore a system to its original condition after a failure has occurred.

1.1.1.3 SKILLS & MANPOWER

The number of men and the levels of their skills necessary to achieve the desired level of availability.

1.1.1.4 EFFORT TO TROUBLESHOOT

The effort required to establish the cause of a failure once it has occurred.

1.1.1.5 ALLOWABLE DOWNTIME

The maximum amount of time that a system may be non-operational once a failure has occurred

1.1.2 SUPPORTABILITY

A measure of the extent to which a system facilitates backup and logistical activities.

1.1.2.1 HARDWARE
The level of internal and external capability necessary to ensure the desired level of hardware availability.
1.1.2.2 APPLICATIONS
The level of internal and external capability necessary to ensure the desired level of software availability.

1.1.3 MODIFIABILITY
A measure of a systems ability to incorporate changes once the
desired c[illegible]nge has been decided upon.

1.1.3.1 FLEXIBILITY
A measure of a systems ability to perform different missions to the desired level of performance.
1.1.3.2 EXPANDABILITY
The measure of the extent to which a system facilitates the enhancement of it's capabilities.
1.1.3.3 PORTABILITY
A measure of the ease with which applications can be carried out on other systems.

1.1.4 ACCESSABILITY
A measure of the probability that a user will find an access point to the system available at a particular time.

1.1.4.1 NUMBER OF POINTS
The number of access devices required to obtain the desired availability.
1.1.4.2 PLACEMENT OF POINTS

The positioning of the access devices relative to the potential users.

1.1.5 RELIABILITY
The probability that a system will perform satisfactorily for at least a given period of time when used under stated conditions.

1.1.5.1 HARDWARE
The performance levels required of the hardware of a system to ensure the overall system availability.
1.1.5.2 SOFTWARE
The performance levels required of the software of a system to ensure the overall system availability.
1.1.5.3 DATA
The performance levels required of the data of a system to ensure the overall system availability.
1.1.5.4 SECURITY
The performance levels required of the security of a system to ensure the overall system availability.

1.2 CAPABILITY
A measure of the system's ability to achieve the mission objectives, given the system condition during the mission.

1.2.1 HUMAN PERFORMANCE
A measure of the quality and quantity of work or effort of the human element of a system.

1.2.1.1 ERGONOMICS
The environmental factors effecting the physical performance of the human element of the system.
1.2.1.2 INTERACTION

The interaction between the human and the other elements of the system.

1.2.1.3 SKILLS

The levels of knowledge and training required of the human element of the system to attain the desired performance.

1.2.2 RESPONSE

The period between the initiation of an activity or function and the satisfactory execution of that activity or function.

1.2.2.1 PROCESSING

The processing speed of the system or subsystem central processing unit.

1.2.2.2 PERIPHERALS

The speed at which system peripherals such as disc drives perform.

1.2.2.3 NETWORKS

The speed at which instructions and information are carried through the system.

1.2.3 ACCURACY

A measure of a systems capability to provide outputs sufficiently precise to satisfy their intended use.

1.2.3.1 FLOATING POINT

The precision level required of numerical values used by applications to achieve the necessary level of accuracy.

1.2.3.2 ALGORITHMS

The applications and hardware algorithms must provide sufficiently close approximations to satisfy the overall accuracy requirements.

1.2.3.3 RESOLUTION

The level of hardware and software driver resolutions must be such that sufficiently accurate results are produced.

1.2.4 CAPACITY

A measure of a systems capability to accommodate the volume of activities desired by the user.

1.2.4.1 STORAGE

A sufficiently large amount of primary and secondary storage as required by data and applications.

1.2.4.2 TRAFFIC

The system must provide the necessary capacity to handle all the data and information transfers.

1.2.4.3 PROCESSING

The system must provide sufficient processing capacity to accommodate the volume of work at any one time.

1.2.5 APPLICABILITY

A measure of the extent to which a system satisfies the applications desired by the user.

1.2.5.1 WHAT

The system must provide the user with the tools and the data to do what he wants to do.

1.2.5.2 HOW

The system must provide capabilities that allow the user to work in the manner which desires.

1.2.5.3 WHEN

The system must provide the user with the capabilities and the information when he wants them.

1.2.6 SECURITY

A measure of the extent to which a system satisfies the security requirements of the user.

1.2.6.1 PHYSICAL

The control over access to the physical components of the system.

1.2.6.2 DATA

The control over access and changing of data.

1.2.6.3 SOURCE

The control over the origin of components of the system.

1.2.7 PHYSICAL

The physical limits, constraints and requirements the user places on a system.

1.2.7.1 ENVIRONMENT

The sensitivity of the system or components of the system to the operational environment of the system.

1.2.7.2 VOLUME

The volume occupied by the system or components of the system.

1.2.7.3 MASS

The mass of the system or components of the system.

1.2.7.4 LAYOUT

The arrangement of the physical components of the system.

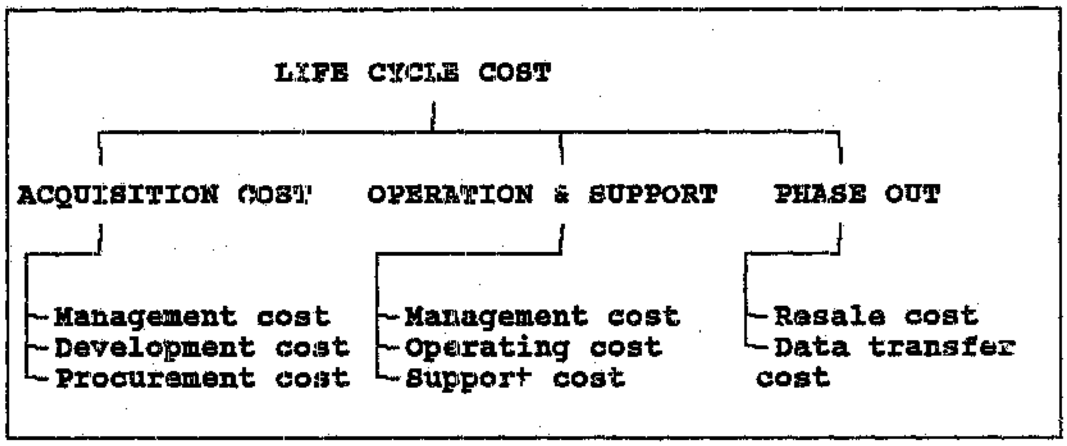


Figure B3 Life cycle cost

2. LIFE CYCLE COST
The total cost of a system through all stages of the system life.

2.1 ACQUISITION
The costs of a system in the acquisition phase of its life.

2.1.1 MANAGEMENT
The acquisition phase management costs.

2.1.1.1 EDUCATION AND TRAINING
The costs of providing education and training for staff.
2.1.1.2 PROJECT MANAGEMENT
The cost of managing the acquisition project.

2.1.2 DEVELOPMENT
The cost of research and development during the acquisition phase of the system life cycle.

2.1.2.1 DESIGN
The cost of designing a system to fulfill the user requirement.

2.1.2.2 EVALUATION
The cost of development test and evaluation of potential solutions to the requirement.

2.1.3 PROCUREMENT
The cost of obtaining all of the components of a system and of implementing these components as a system.

2.1.3.1 MATERIAL
The cost of the physical components of a system including software.

2.1.3.2 FACILITIES
The cost of the facilities necessary for the implementation of the system.

2.1.3.3 FINANCE
The cost of money used in acquiring the system components.

2. OPERATION AND SUPPORT
The cost of the system during the operation and support stage of the system life.

2.1 MANAGEMENT
The management costs of this phase.

2.1.1 EDUCATION AND TRAINING
The cost of education and training during this phase.

2.1.2 MANPOWER
The manpower costs of managing the system.

2.2 SYSTEM SUPPORT

The cost of providing the support necessary to ensure the system mission is satisfactorily carried out.

2.2.1 MAINTENANCE

The cost of maintaining the system to ensure that the desired system availability is achieved.

2.2.2 EXTERNAL SUPPORT

The cost of the external support including manpower required to ensure system performance.

2.2.3 INTERNAL SUPPORT

The cost of the internal support including manpower required to ensure system performance.

2.3 OPERATION

The operating costs of the system

2.3.1 ENERGY

The cost of energy consumed in accomplishing the system mission.

2.3.2 CONSUMABLES

The cost of items consumed in accompli hing the system mission.

2.3.3 DEPRECIATION

The cost as a result of the depreciation of the system components.

2.3.4 INSURANCE

The cost of insuring the system adequately.

3. PHASE OUT

The cost of changing to another system and moving away from the existing system.

3.1 RESALE

The resale value of the system or components of the system.

3.1.1 DEPRECIATION RATE

The book value of the system as a result of the rate of depreciation.

3.2 INFORMATION TRANSFER

The cost of transferring information from the old system to the new system.

APPENDIX C

SCHEDULE OF APPLICATIONS

This list is typical of those functions identified for a complex system manufacturer outside of the business and production scheduling and control systems

	APPLICATION	PRIORITY
1.	CAD MECHANICAL (2D)	
	3-D DESIGN	
	SURFACES(SCULPTURED)	
	SOLIDS (B-REP & CSG)	
	FEM/FEA LINK	
	NC - 3-AXIS	
	NC - 5-AXIS	
	PIPING	
	DATA EXTRACTION	
	MASS PROPERTIES	
	LOFTING	
	CAD DATA TRANSFER	
	BOM	
	INTERFERENCE CHECKING	
	CMM LINK/PROGRAMMING	
	NESTING	
	ELEC. DISCHARGE MACHINING	
2.	KINEMATICS	
	ROBOTICS	
	ERGONOMICS	
3.	CAD - ELECTRICAL	
	DATA EXTRACT	
	LOOMING	
	BOM	
4.	CAD - ELECTRONIC	
5.	FEA ON NUM. PROC.	
	PRE AND POST PROC.	
6.	FLOW MODELLING:	
	AERODYNAMICS TYPE	
	ENGINES TYPE	
	INCOMPRESSIBLE	
7.	THERMODYNAMICS	
8.	MATERIALS & SUPPLIER	
	DATABASE	
9.	CAPP/GROUP TECHNOLOGY	
10.	CMM LINK	
11.	JIG AND TOOL DESIGN	

12.	PROJECT PLAN & CONTROL	
13.	INVENTORY CONTROL	
14	MRP LINK	
15.	ILS LINK	
16.	CONFIGURATION MANAGEMENT	
17.	PHOTOPLOTTER LINK	
18.	PCB NC DRILLING M/C LINK	
19.	DIGITIZER INPUT	
20.	SCANNER INPUT	
21.	FLATBED PLOTTER LINK	
22.	GEAR DESIGN	
23.	COMBUSTION SIMULATION	
24.	CONTROL SYSTEM DESIGN	
25.	MACHINABILITY DATABASE	
26.	TOOLS & CUTTER INVENTORY SYS	
27.	DNC COMMS	
28.	HVAC / ECS	
29.	HYDRAULIC SYSTEM DESIGN	
30.	PNEUMATIC SYSTEM DESIGN	
31.	ELEC. DESIGN RULE CHECKING	
32.	BASIC LOAD / STRESS CALCS.	

APPENDIX D

CREATING IDEF DIAGRAMS

Figure D1 Define the basic activities

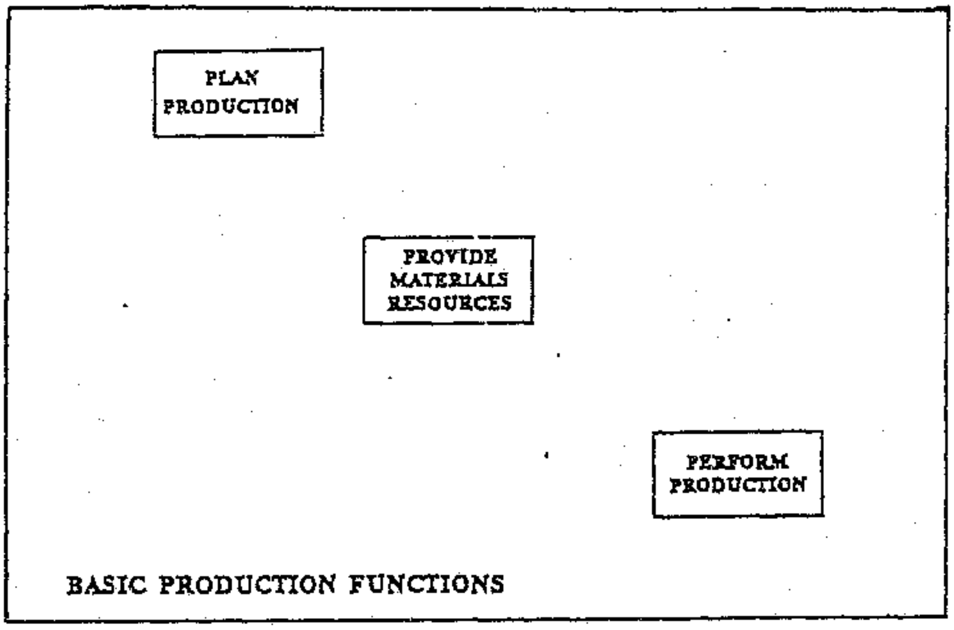


Figure D2 Establish the inputs and outputs of the activi'ies

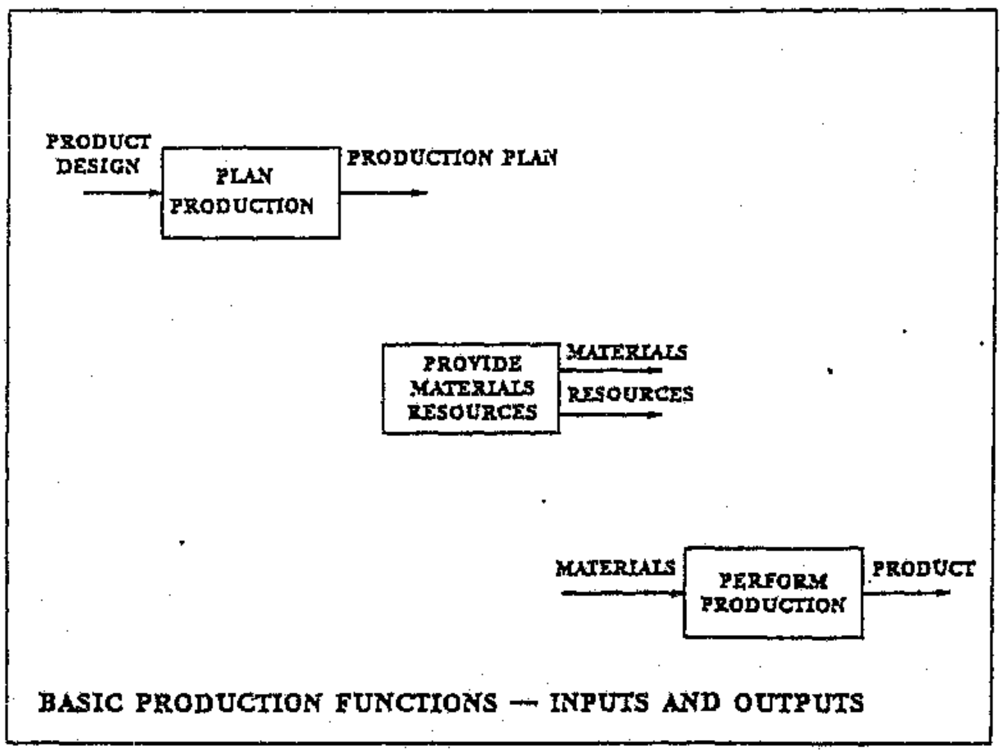


Figure D3 Identify the controls on the functions

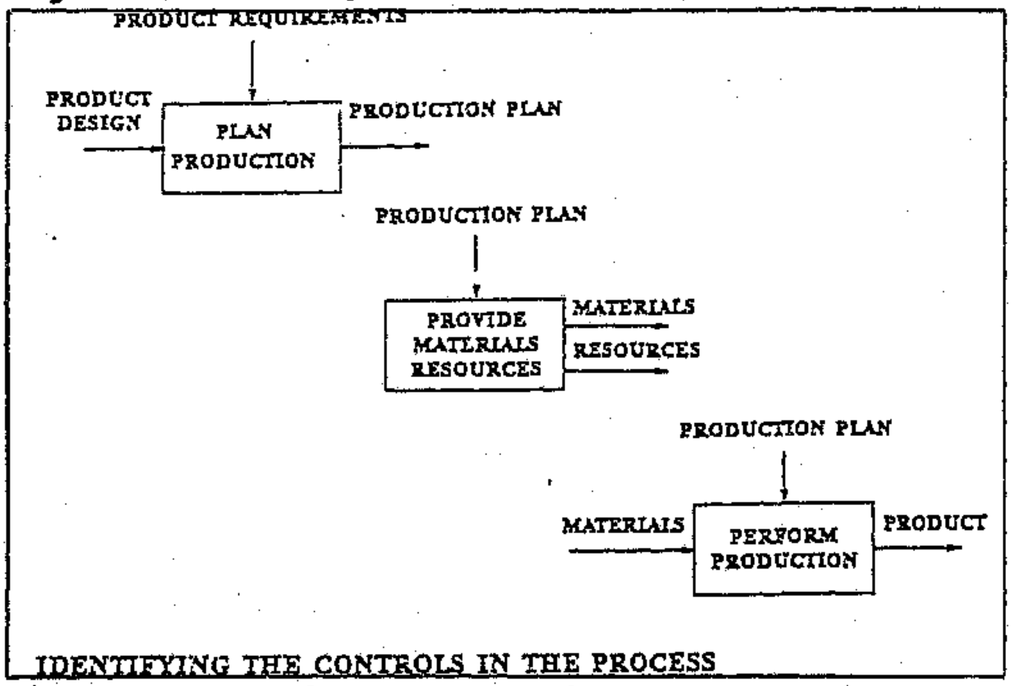


Figure D4 Identify the mechanisms that perform the activities

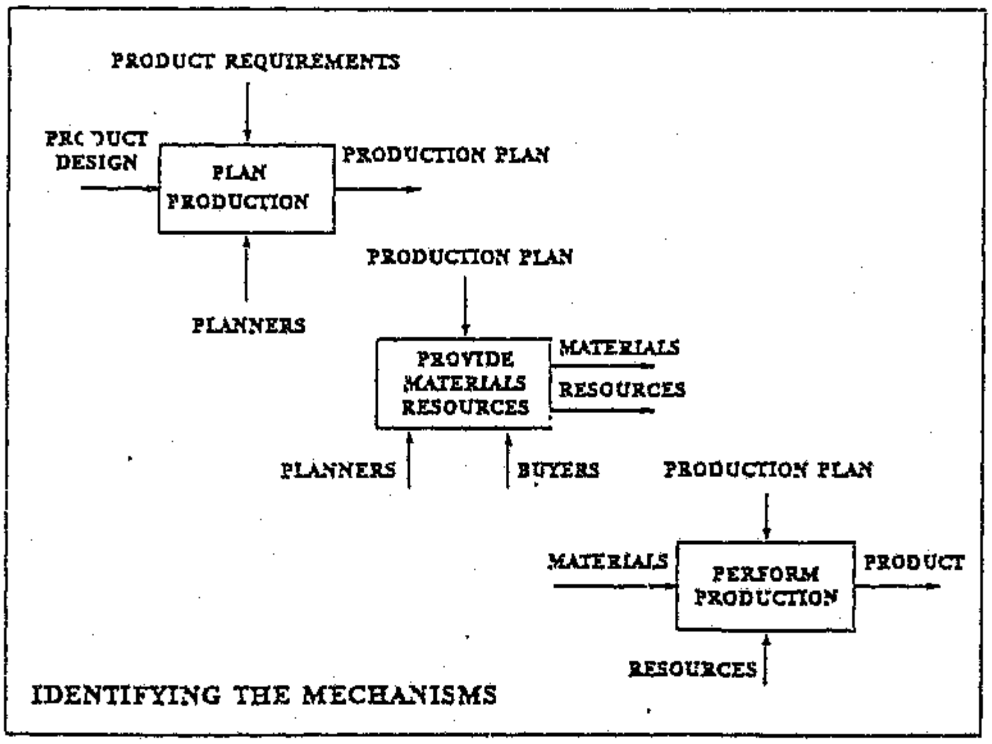


Figure D5 Identify the entity classes

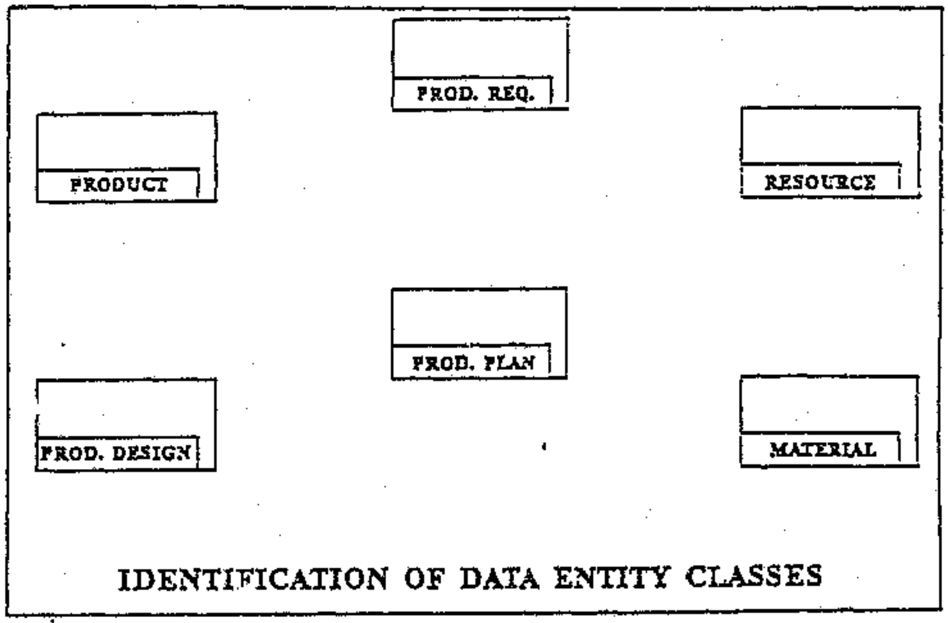


Figure D6 Establish the relationships between the central entity class and all others

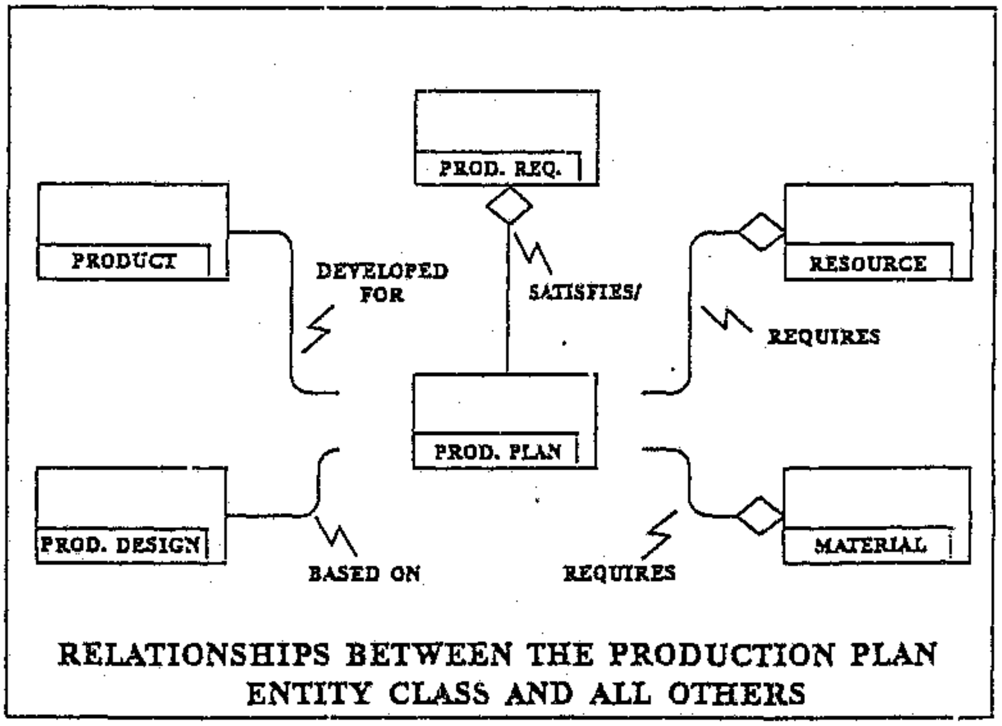


Figure D7 Establish relationship of all other entity classes to the central entity class

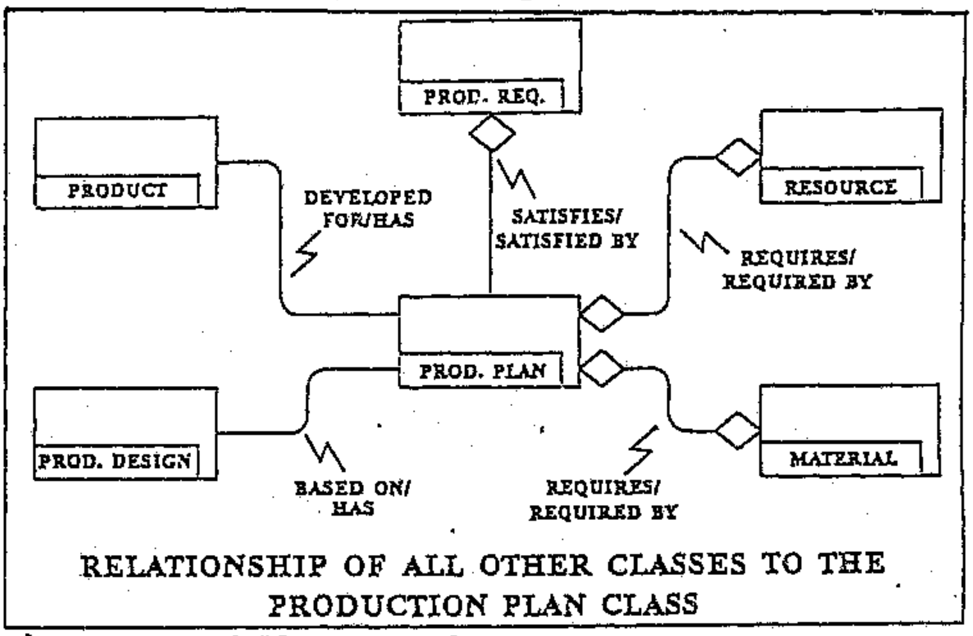
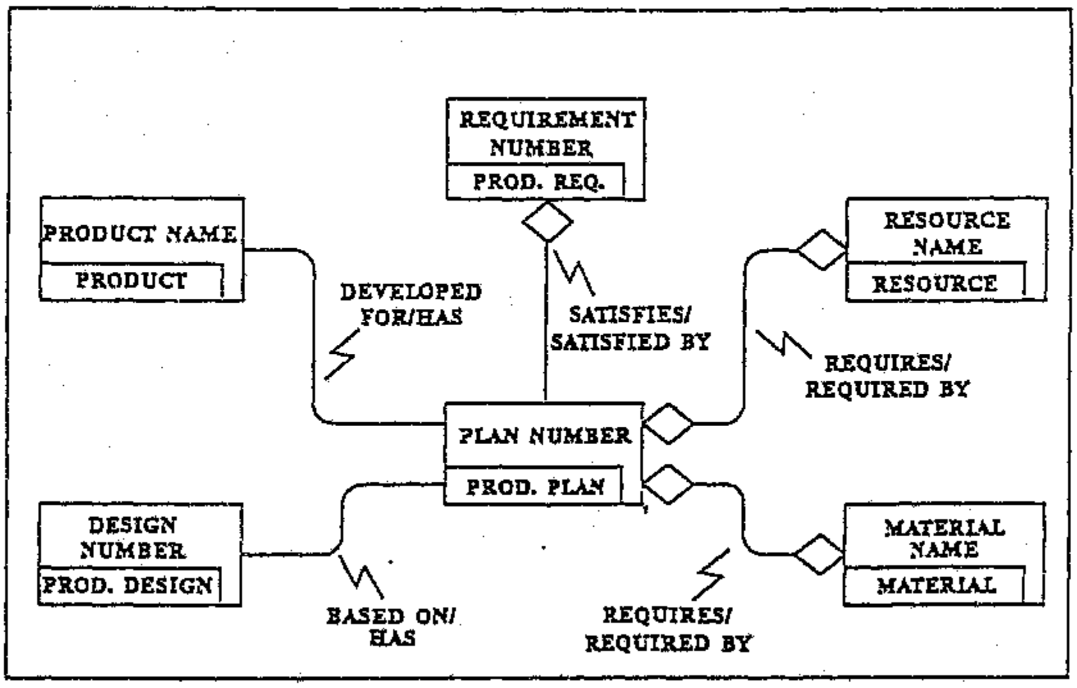


Figure D8 A full IDEF1 diagram



APPENDIX E

A FUNCTIONAL MODEL OF INTEGRATED MANUFACTURING

USED AT:	AUTHOR :KALIL P.B. DATE 23/12/88	X	WORKING	READER DATE	CONTEXT:
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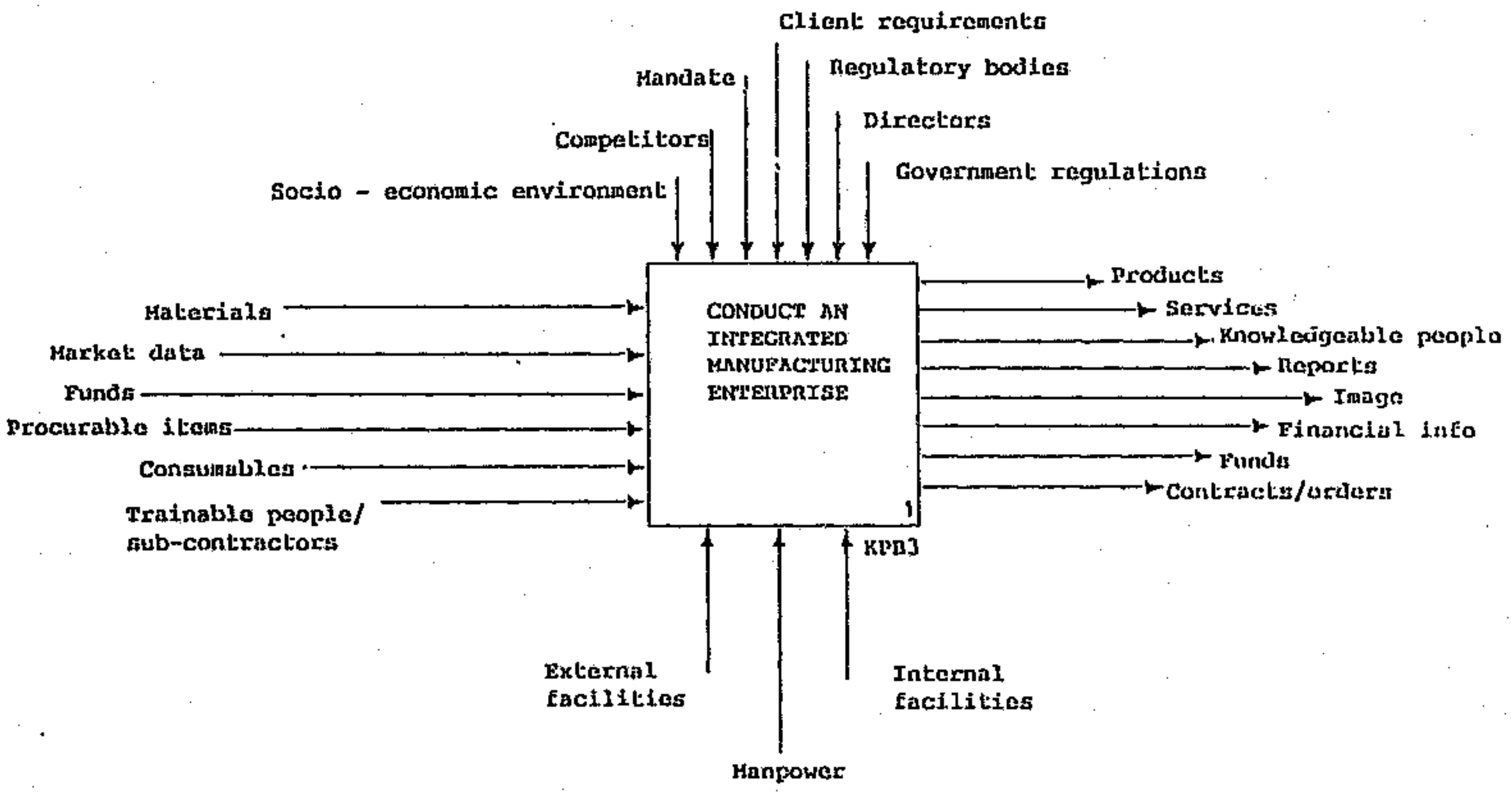
	COMPANY:IMP		RECOMMENDED		
	NOTES : 1 2 3 4 5 6 7 8 9		PUBLICATION		



NODE:	TITLE:	NUMBER:
EIS/A-0	ENTERPRISE TOP	KPB2

Figure E1 A-0 Enterprise Top

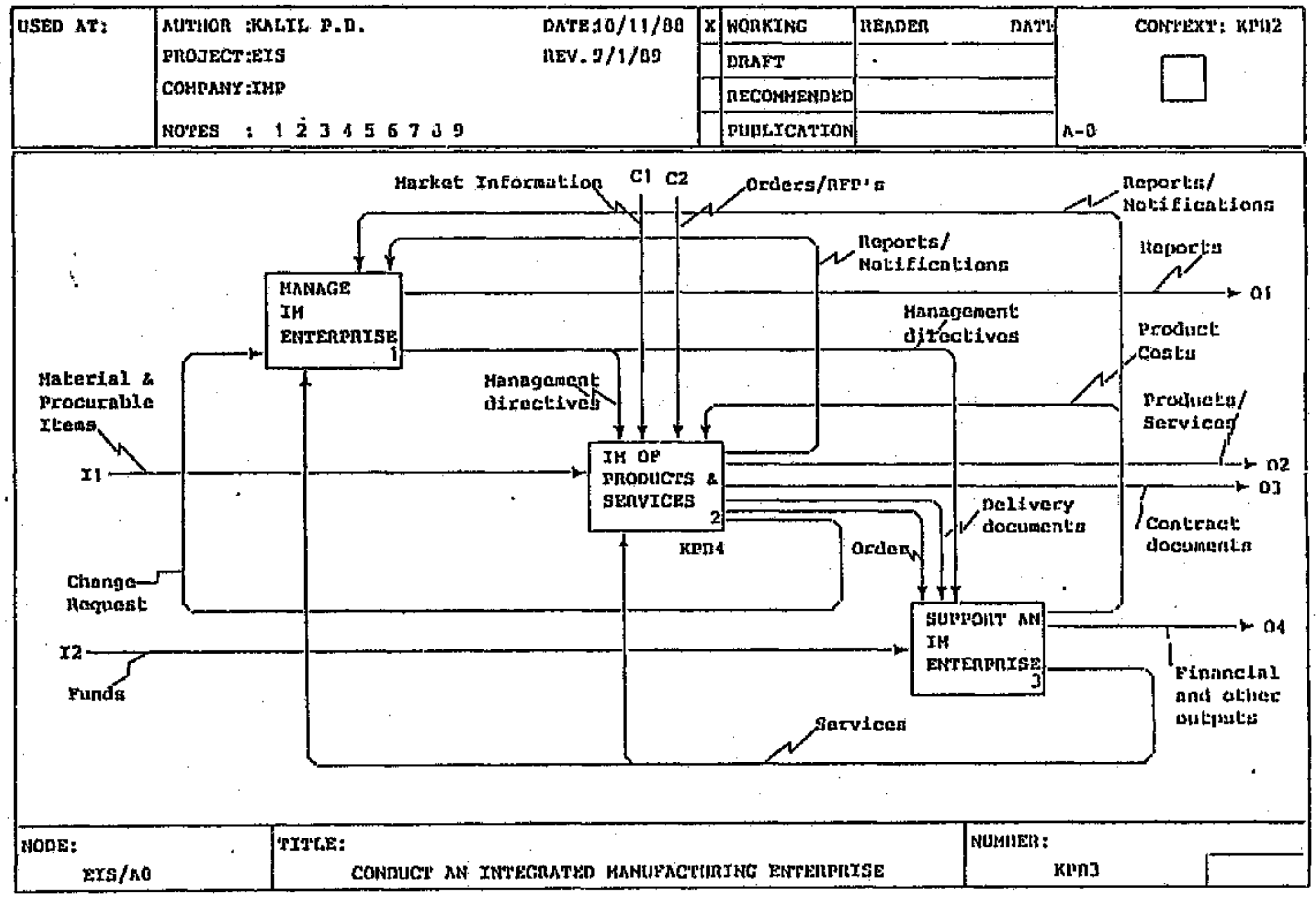


Figure E2 A0 Conduct an integrated manufacturing enterprise

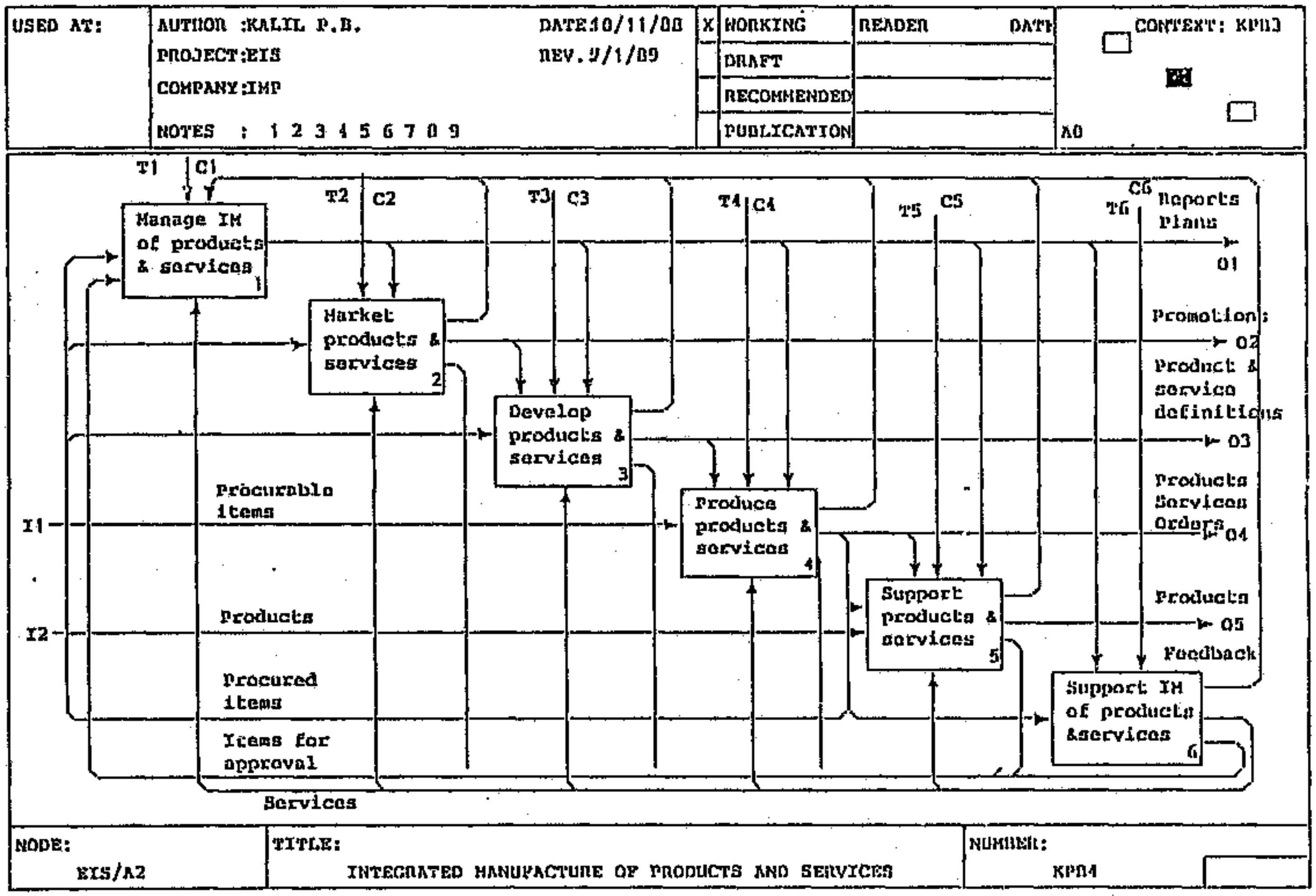


Figure E3 A2 Integrated manufacture of products and services

Entities identified as notes on Figure E3

T1 : Business plan, Sales plan, Orders, Financial authorization, Policies and directives, Progress reports.

T2 : User requirements, Technology, Product life cycle, Pricing policy, ROI, Budgets.

T3 : Plans, Schedules, Directives, CP's, CAR's, WA's, Resource availability.

T4 : Product definition, Schedules, Quality requirements, Requests, Requisitions, MPS, MRI.

T5 : Planned spares levels, Planned product levels, Spares usage, Delivery history, Usage profiles.

T6 : Service requests, Management directives, Financial authorizations

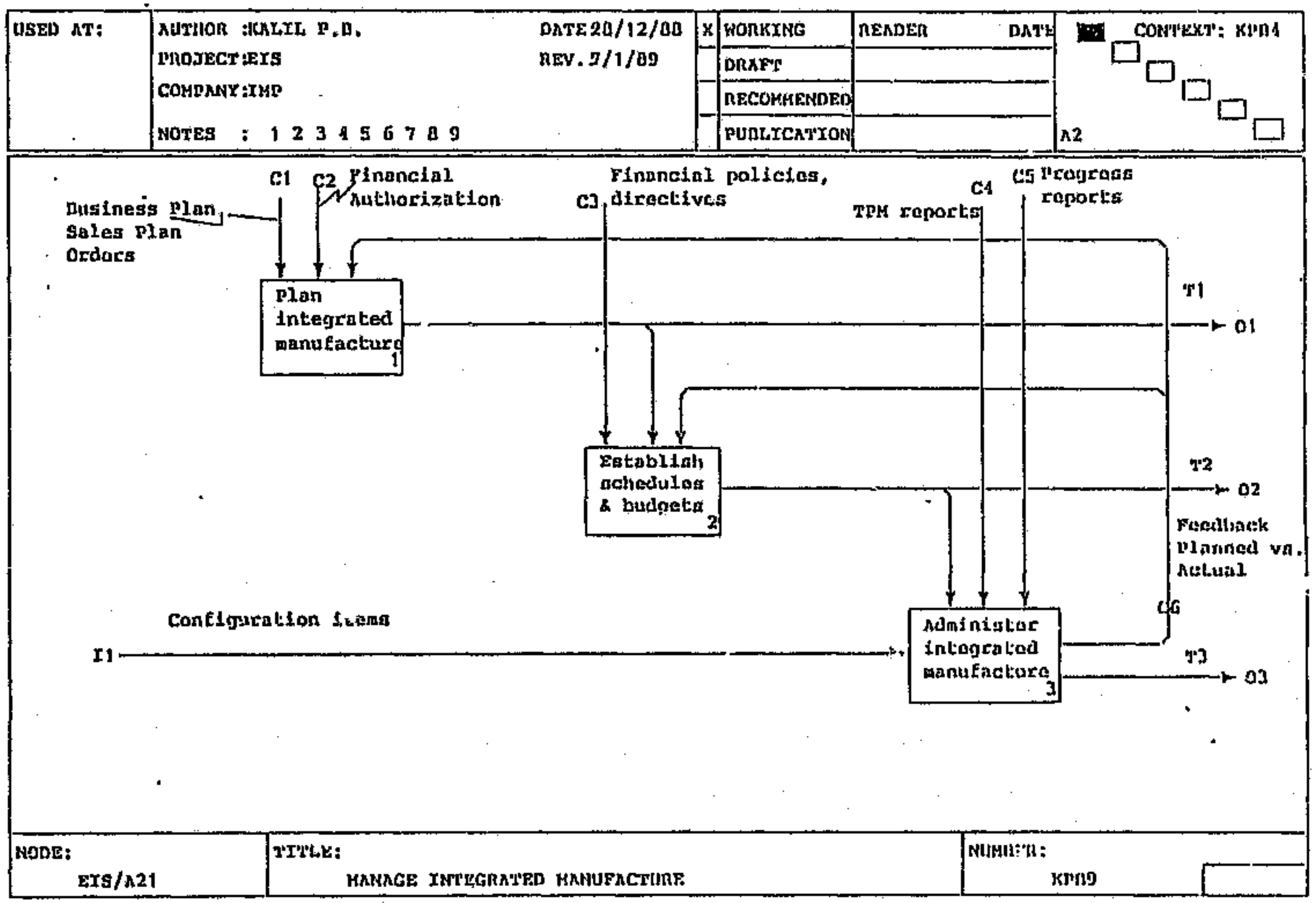


Figure E4 A21 Manage integrated manufacture

Entities identified as notes on Figure E4

T1 : Master production schedule, Production plans, Resource plans, Material requirements plans, Capacity requirement plans, Project plans, Reports.

T2 : Schedules, Budgets, Work authorizations.

T3 : Manufacturing directives, Product definitions, Service definitions, MRI's, Production information, Concession/deviation/CP information, Requisitions, Status reports.

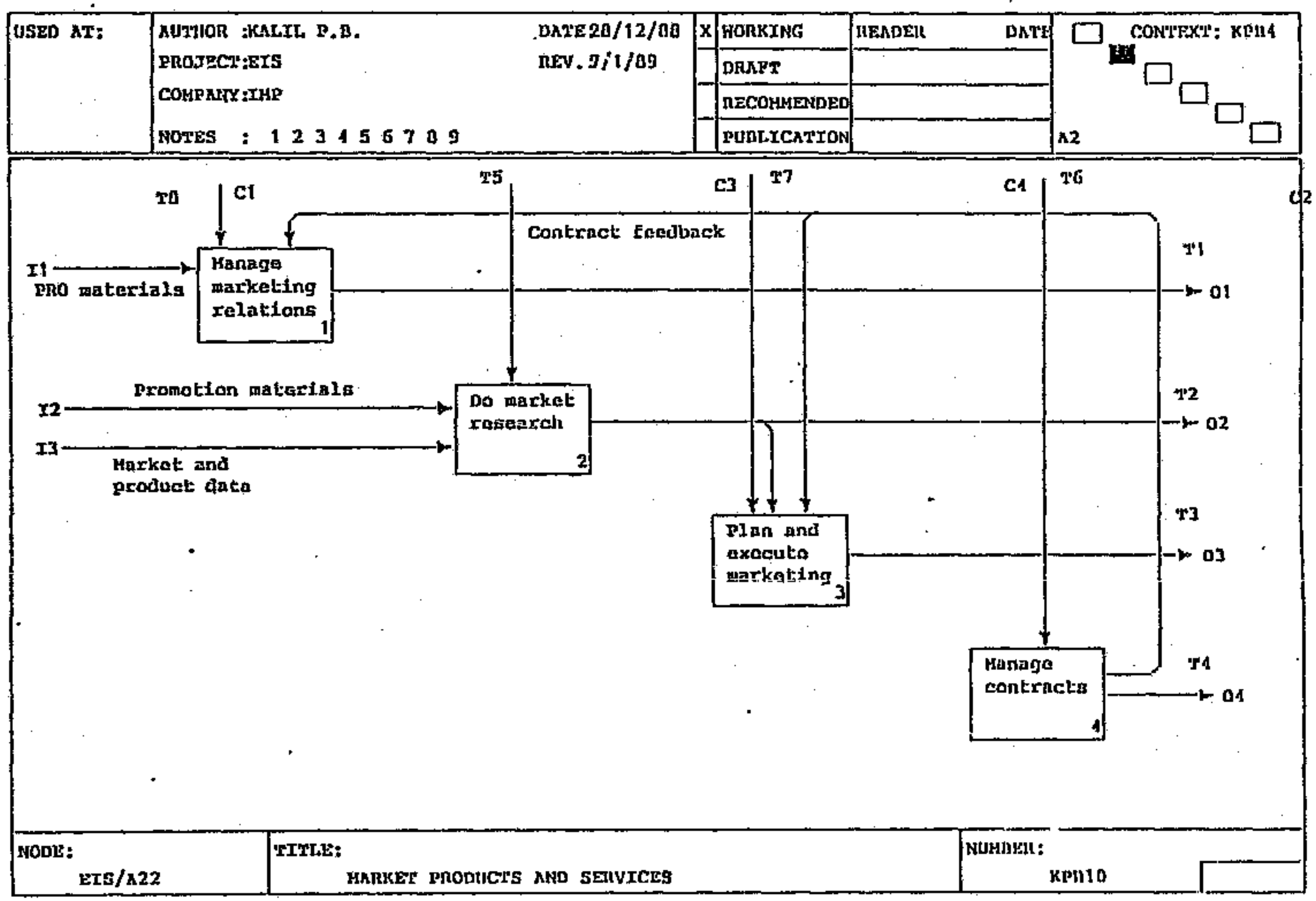


Figure E5 A22 Market products and services

Entities identified as notes on Figure E5

T1 : Fund requirements, Marketing strategy, Reports, Promotions, Business agreements, Company loading.
T2 : Technology objectives, Capacity requirements, Product strategies, Adverising, Demonstrations, Shows, Media.
T3 : Marketing plans, actions
T4 : Project objectives,
T5 : User requirements, Existing technology, Product life cycle, Competitors, Pricing policy, Turnover targets, ROI, Budgets, Market needs, Promotion policy.
T6 : Orders, RFP's, Contract feedback, Product performance feedback.

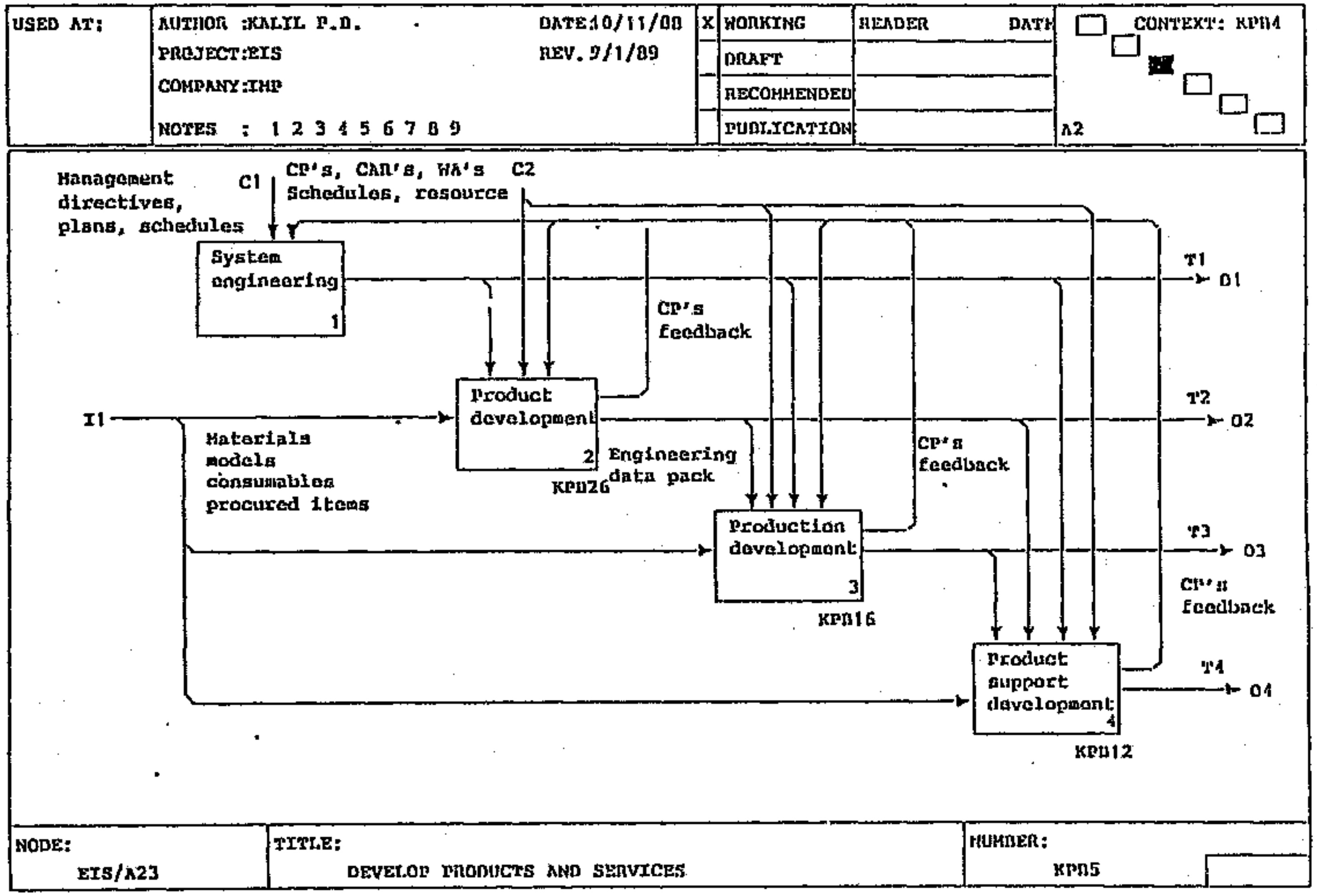


Figure E6 A23 Develop products and services

Entities identified as notes on Figure E6

T1 : B,C,D,E Specifications

T2 : Product definition

T3 : Production definition

T4 : Product support definition

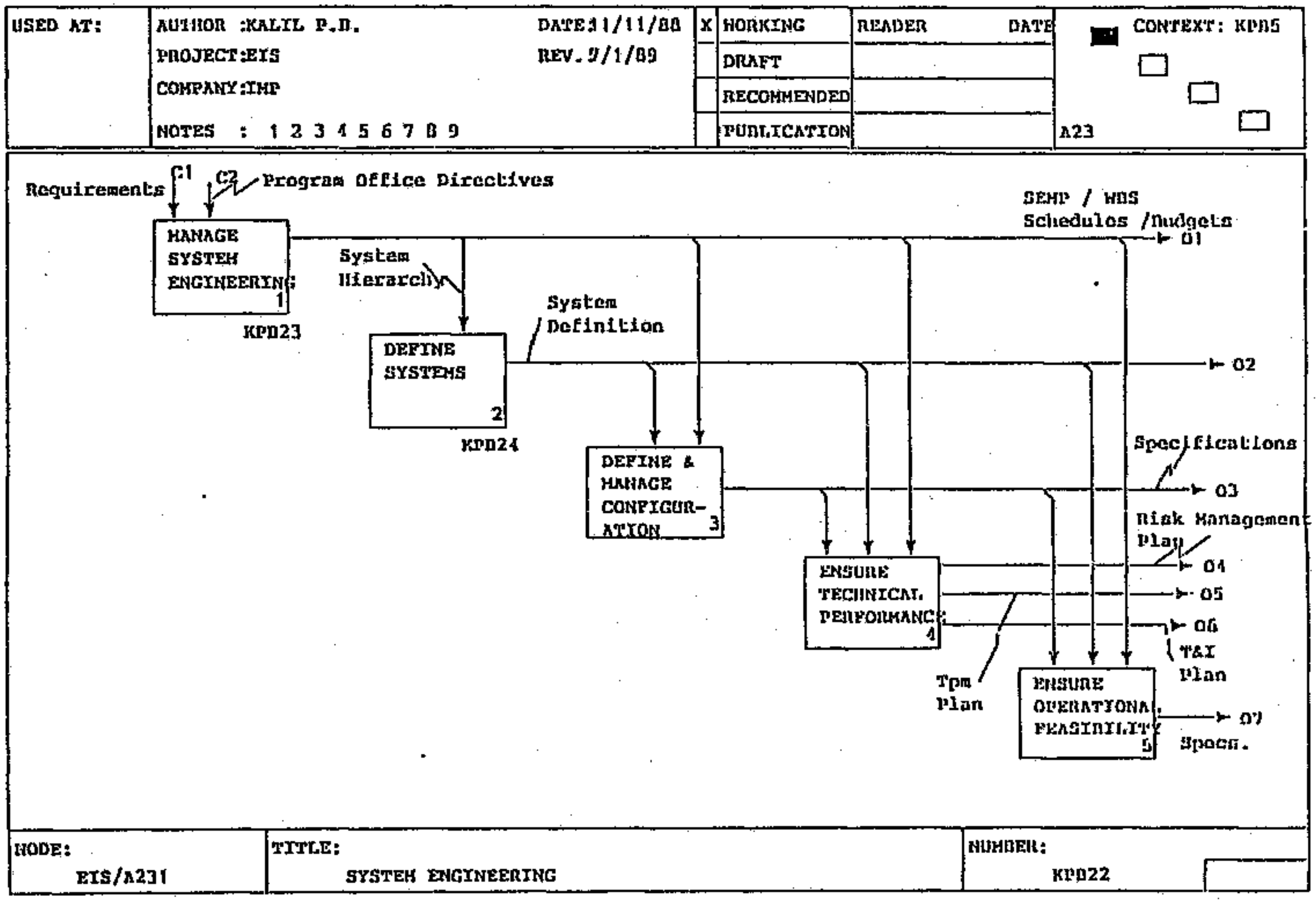


Figure E7 A231 System engineering

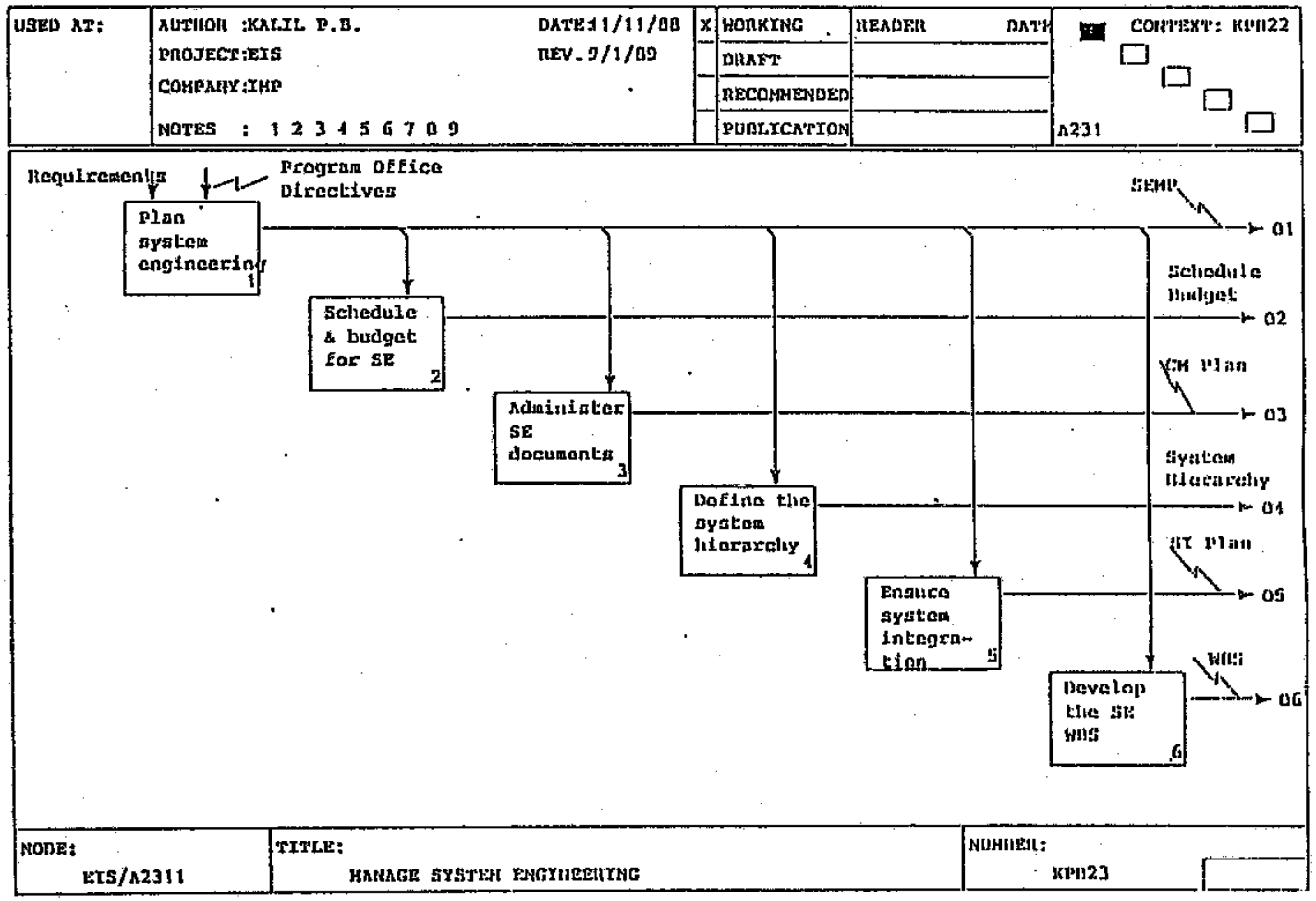


Figure E8 A2311 Manage system engineering

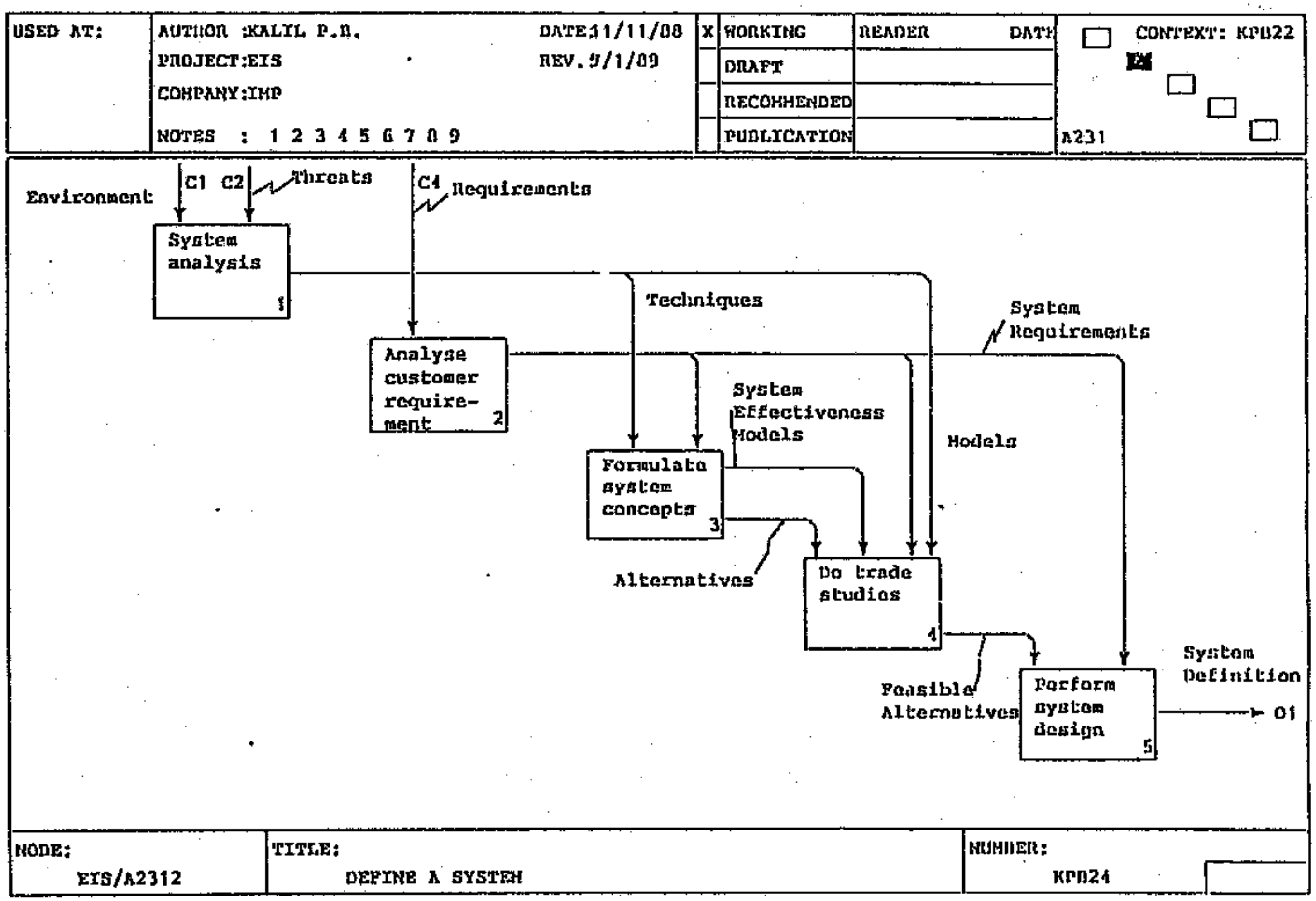


Figure E9 A2312 Define a system

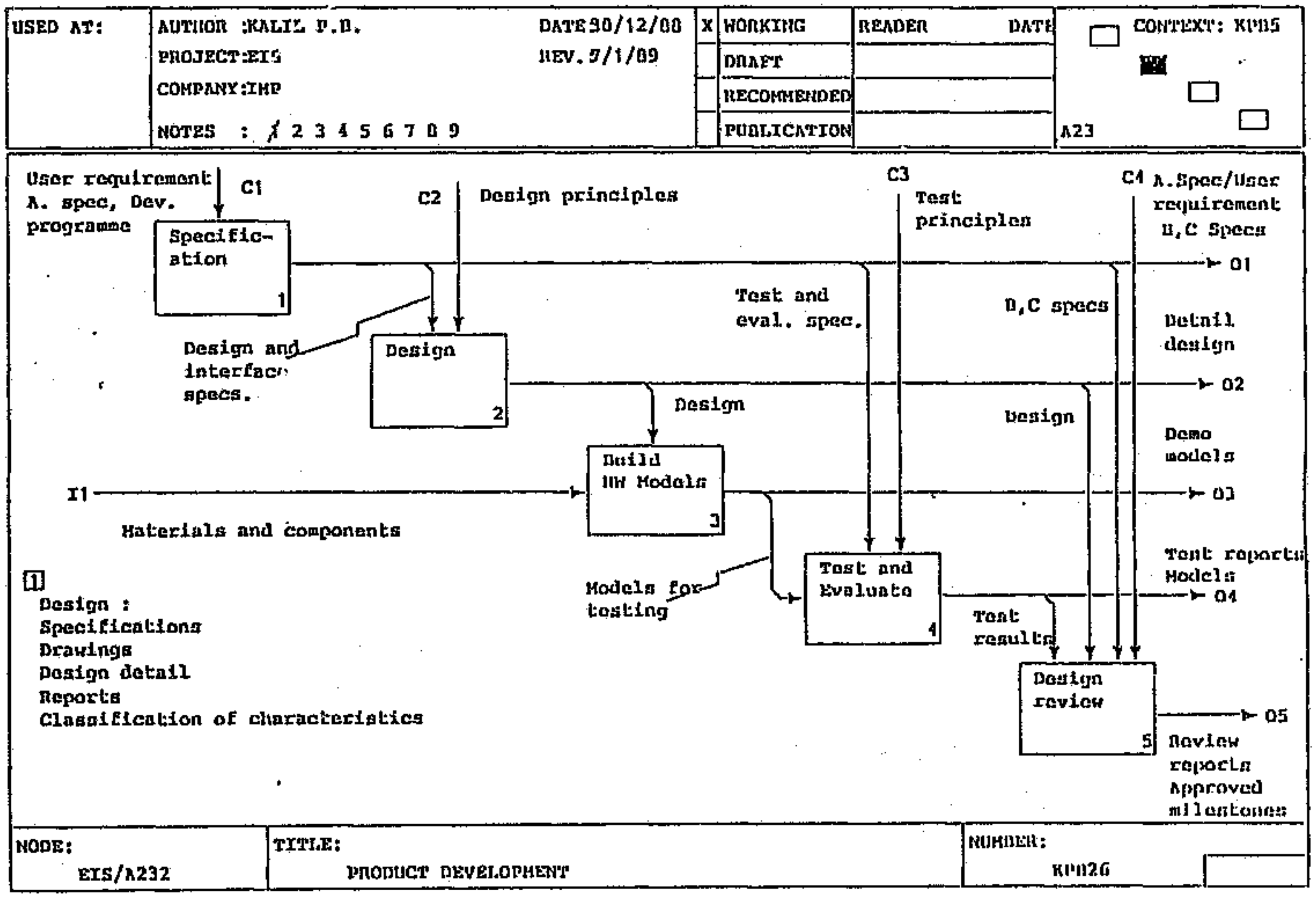
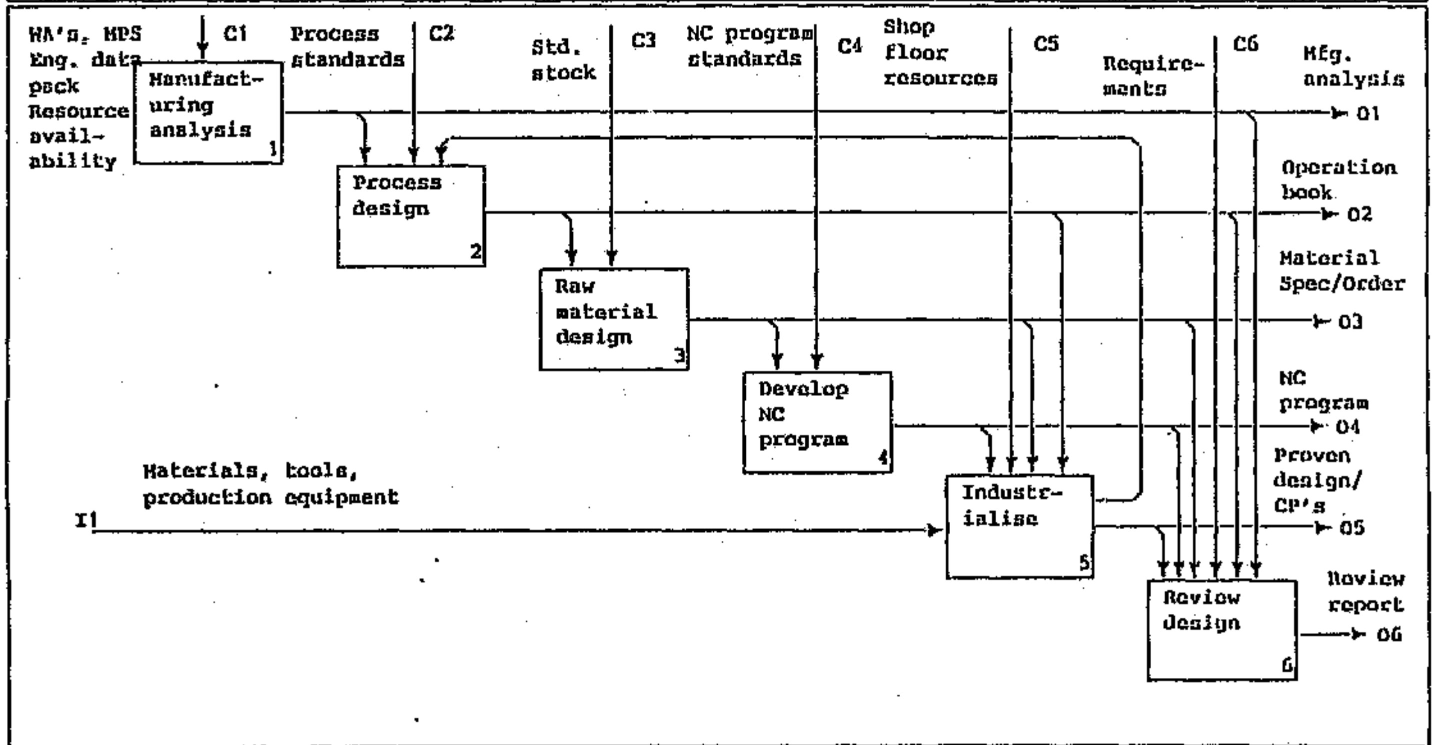


Figure E10 A232 Product development

USED AT:	AUTHOR :KALIL P.B. DATE 23/11/88 PROJECT:EIS REV. 9/1/89 COMPANY:IMP NOTES : 1 2 3 4 5 6 7 8 9	X WORKING DRAFT RECOMMENDED PUBLICATION	READER DATE	CONTEXT: KPB5 A23



NODE: EIS/A233	TITLE: PRODUCTION DEVELOPMENT	NUMBER: KPB16

Figure E11 A233 Production development

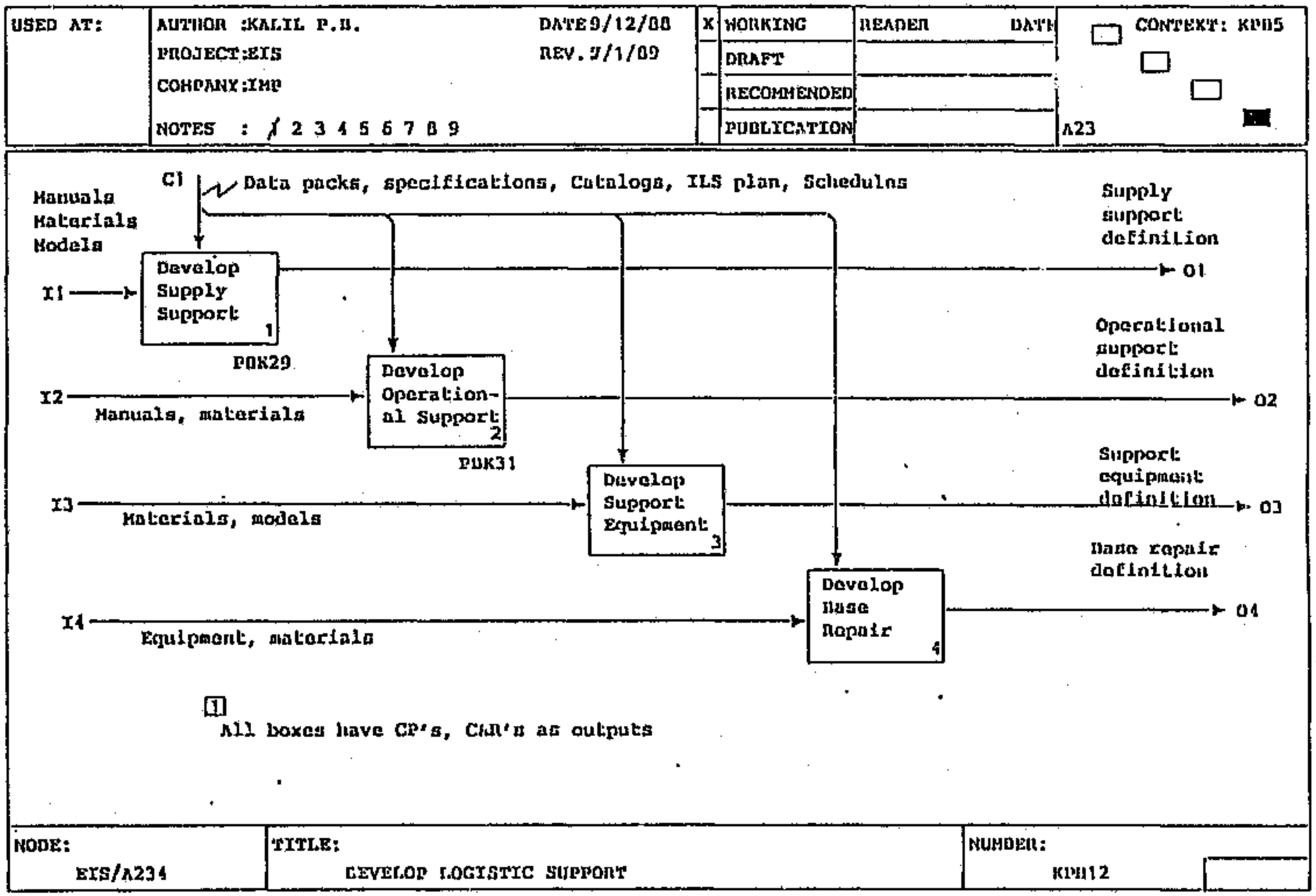


Figure E12 A234 Develop logistic support

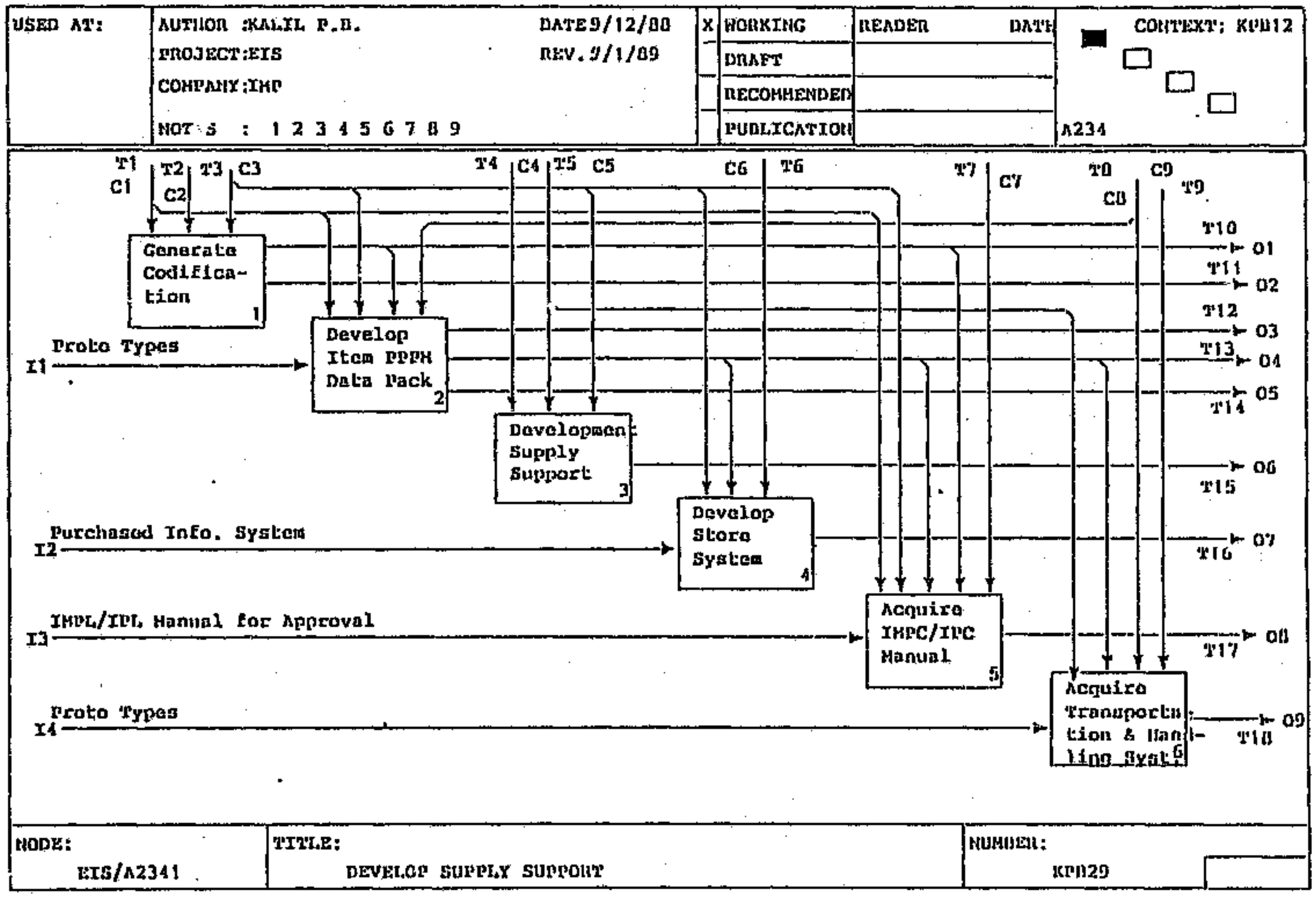


Figure E13 A2341 Develop supply support

Entities identified as notes on Figure E13

T1 : PME and Support equipment data packs
T2 : Specifications and catalogs (lists)
T3 : Reliability and maintainability breakdown
T4 : ILS Plan
T5 : Development MPS, Progress feedback (order, return)
T6 : Client store systems
T7 : Approved IPC development specification
T8 : Specifications
T9 : Expected usage profile
T10 : Codification documents
T11 : II Cards
T12 : PPPM process master
T13 : PPPM data pack
T14 : Product/item PPPM manual
T15 : RBO, Development supply support MPS
T16 : Facility specifications, Information system
T17 : IMPC/IPC specifications
T18 : Specifications, data packs, Client supplied items

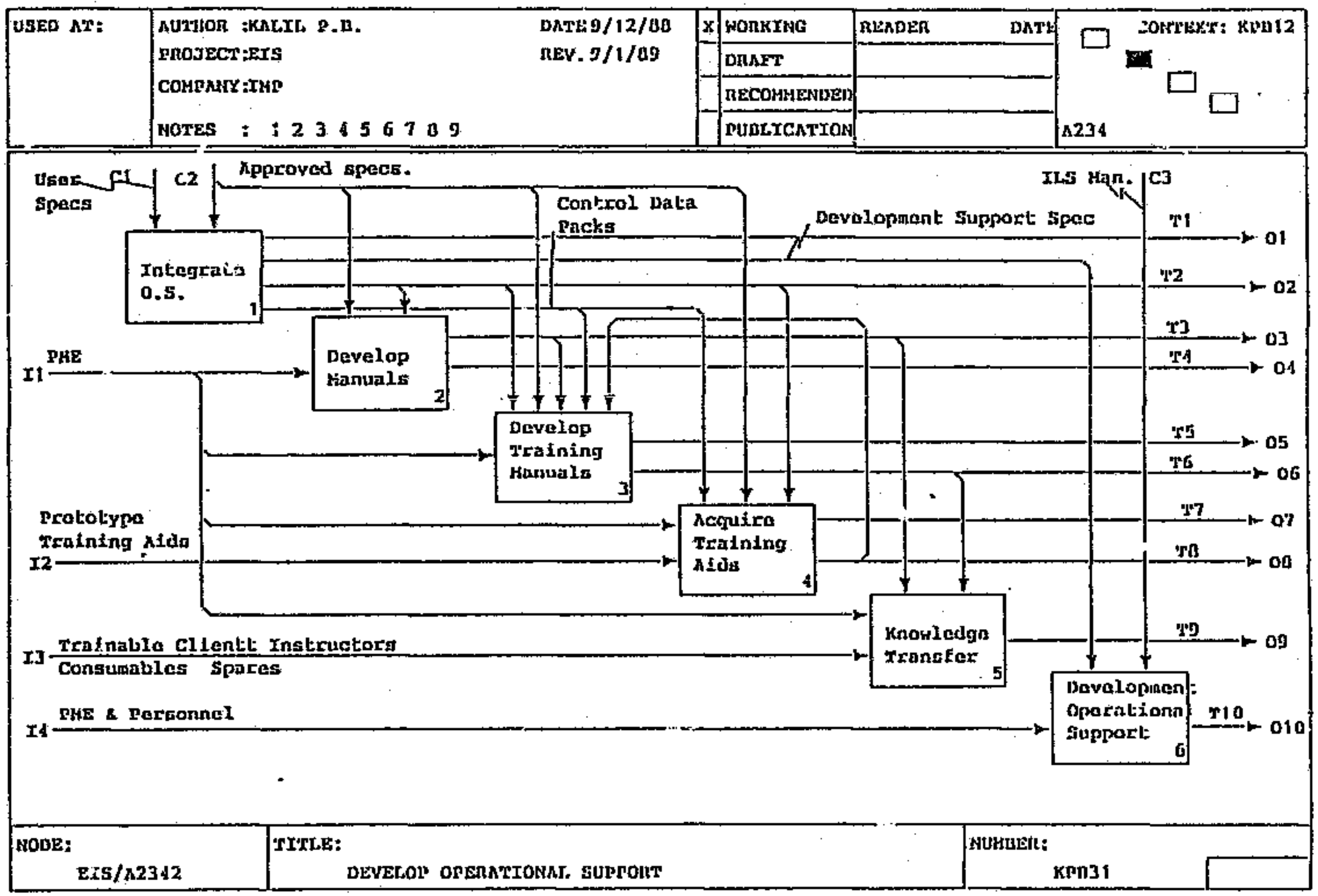


Figure E14 Develop operational support

Entities identified as notes on Figure E14

T1 : Development specifications, Training concepts, T&E plan

T2 : Curriculum (Objective Pyramid)

T3 : Manuals, Data packs

T4 : Manual manufacturing and acceptance specifications

T5 : Training manual specifications, PME

T6 : Training manual data packs

T7 : Training aid specifications, PME

T8 : Training aid data packs

T9 : MPS, Client instructors, PME, Feedback to FRACAS, Consumables/spares/equipment BOM

T10 : Trials manuals, trained personnel

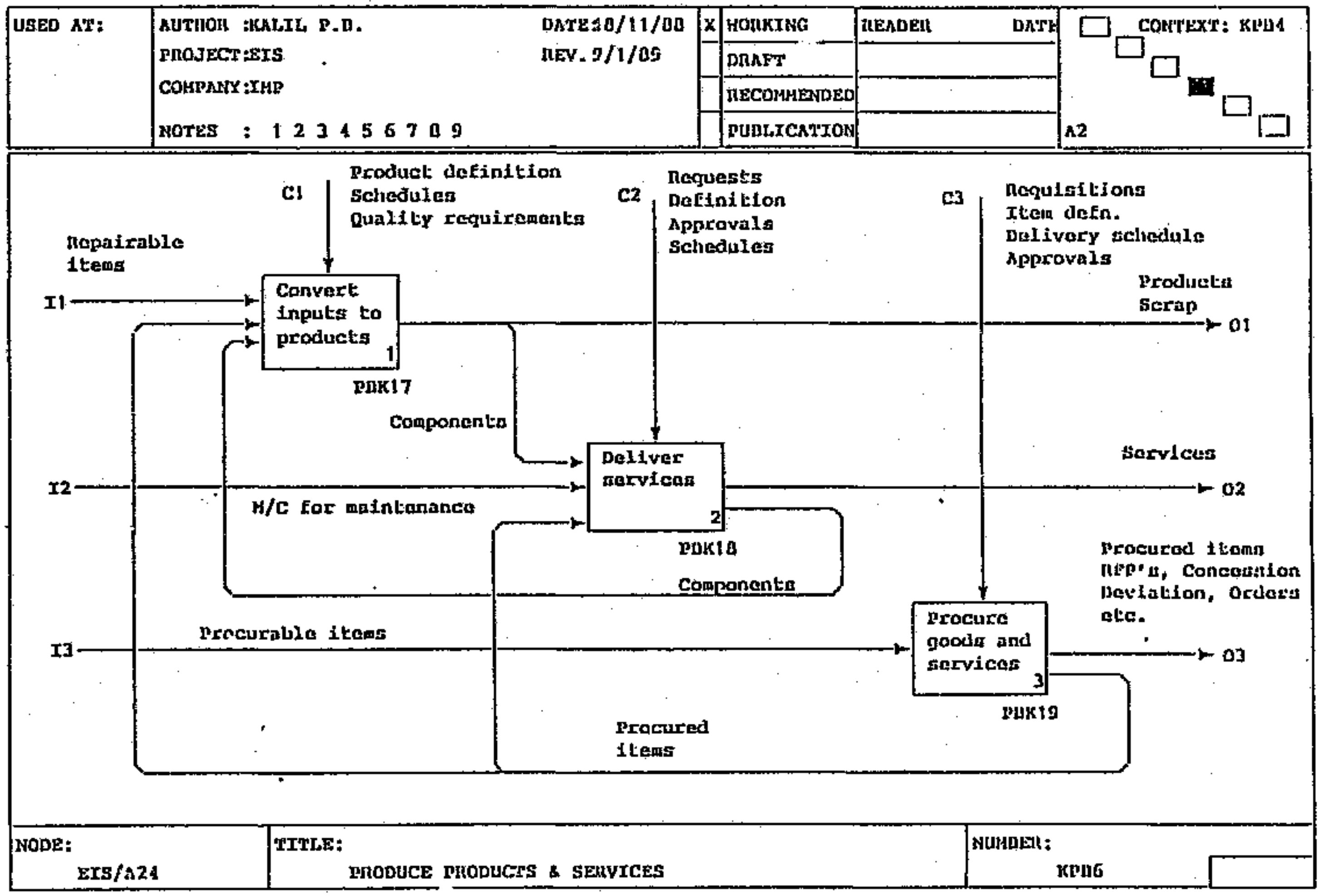


Figure E15 A24 Produce products and services

Entities identified as notes on Figure E15

Reports : Scrap, Progress
Budgets : Production plan, Development, Technology,
Departmental operational, Capital
Orders/Requests : Capital equipment, Fixed assets not capitalised, Sub-contracts, Refurbished products, Development/technology projects
Production Information : Standard times, Set-up times, Machine use, Progress, Percentage scrap, Lead times
Services : Measuring, Supply of ; tools, fixtures, gauges, Consultation
Measurement Reports : Calibration, Qualification, Final inspection, In progress
Engineering data pack ; Engineering drawings, BOm, Specifications for special processes, Classification of characteristics
Change Proposals
Concessions (difference from spec. has occurred)
Deviations (difference from spec. will occur)
Production equipment : Tools, gauges, fixtures
Product specification :
Assembly operation books : Assembly instructions, Gauge numbers, Assembly sketches, Packaging instructions
Build History book : Concessions, deviations, Final inspection results
NC Data pack : APT and program listing, Progress sheet, CP's

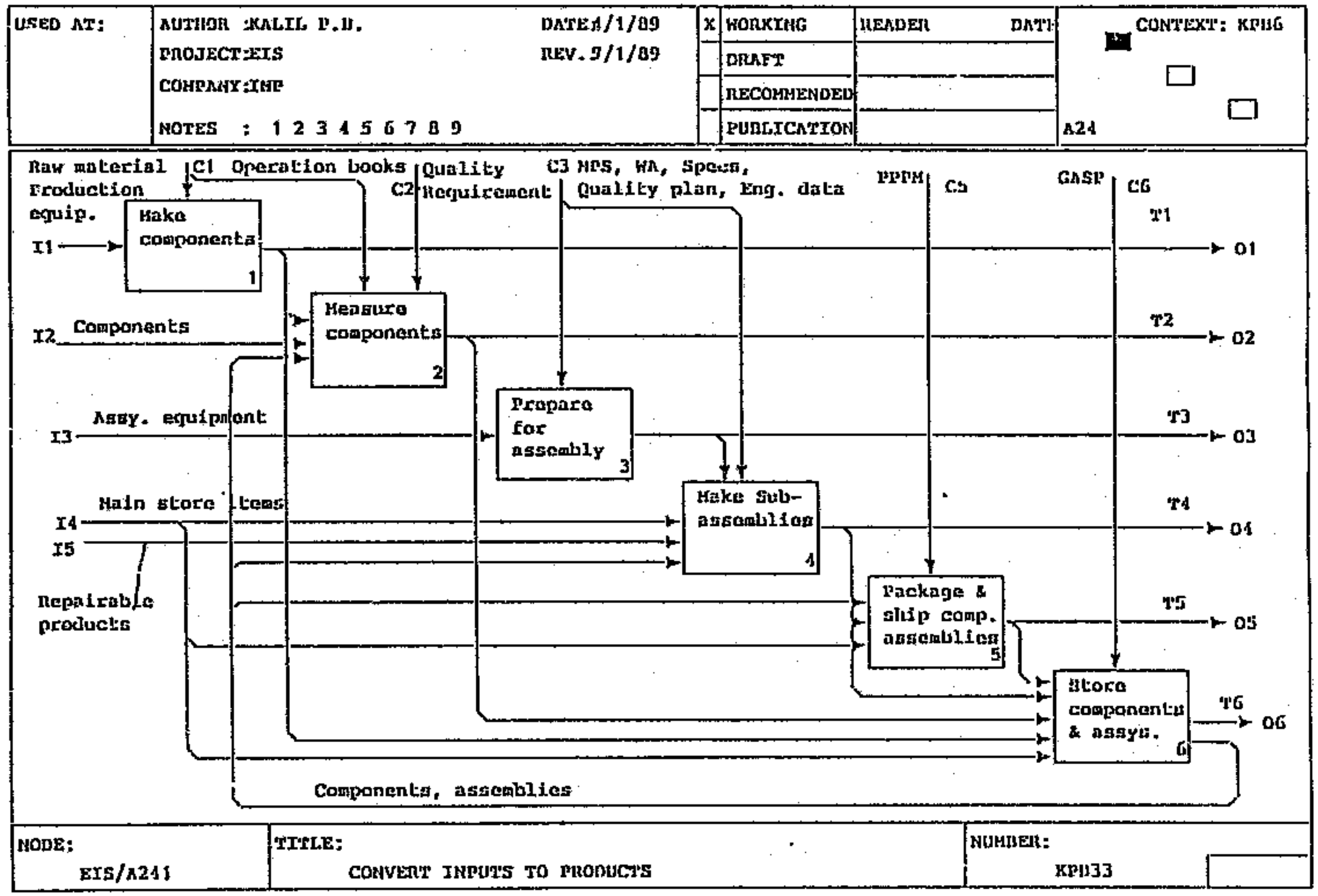


Figure E16 Convert inputs to products

Entities identified as notes on Figure E16

T1 : Components, Scrap, Scrap reports, Requests

T2 : Components, Measurement reports, Statistical data

T3 : Requisitions, Gauge requirements, Assembly equipment requisitions

T4 : Build history, Assemblies, Concession/deviation applications

T5 : Packaged, preserved, packed and marked products, Delivery notes, Shipping instructions

T6 : Stock records

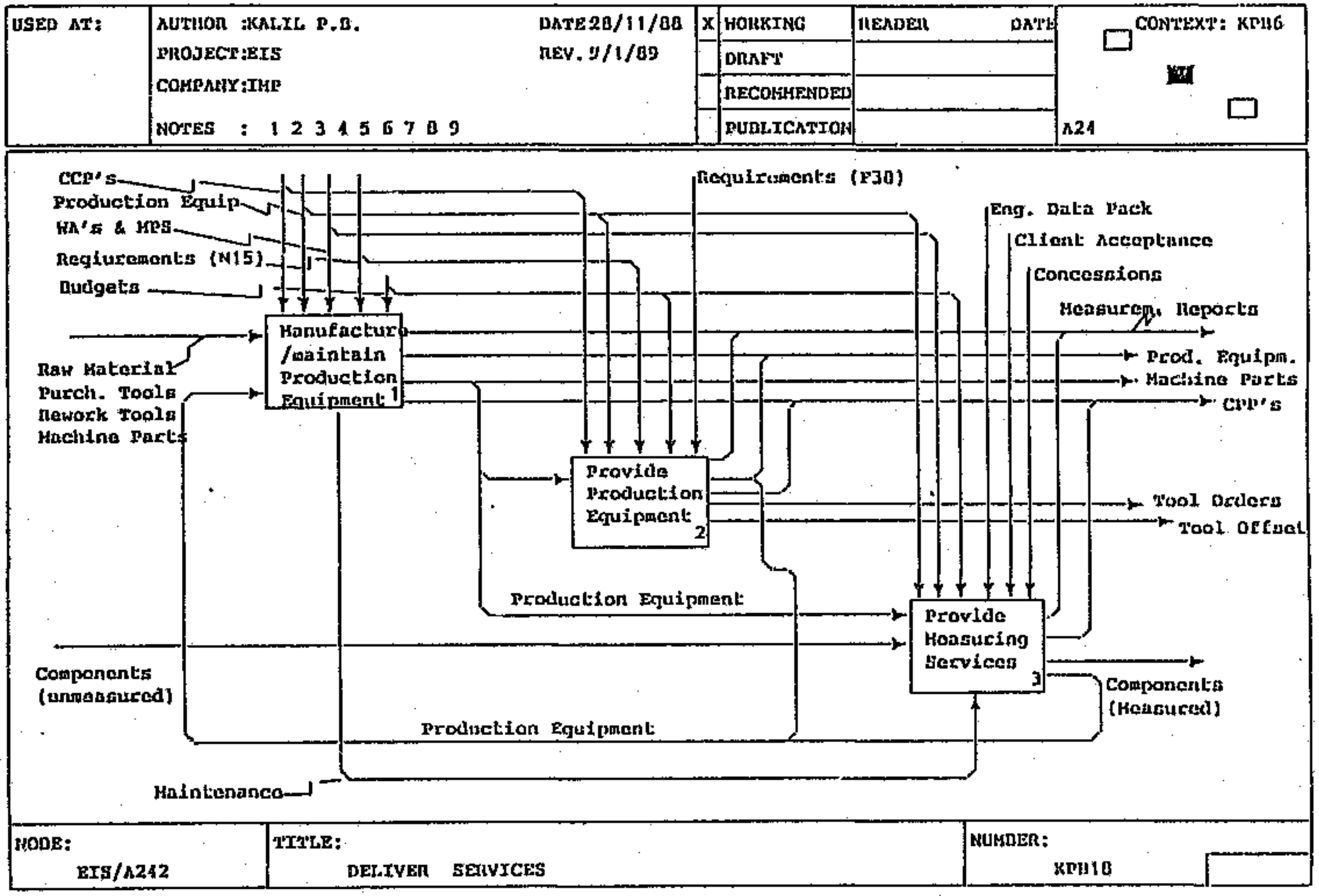


Figure E17 A242 Deliver Services

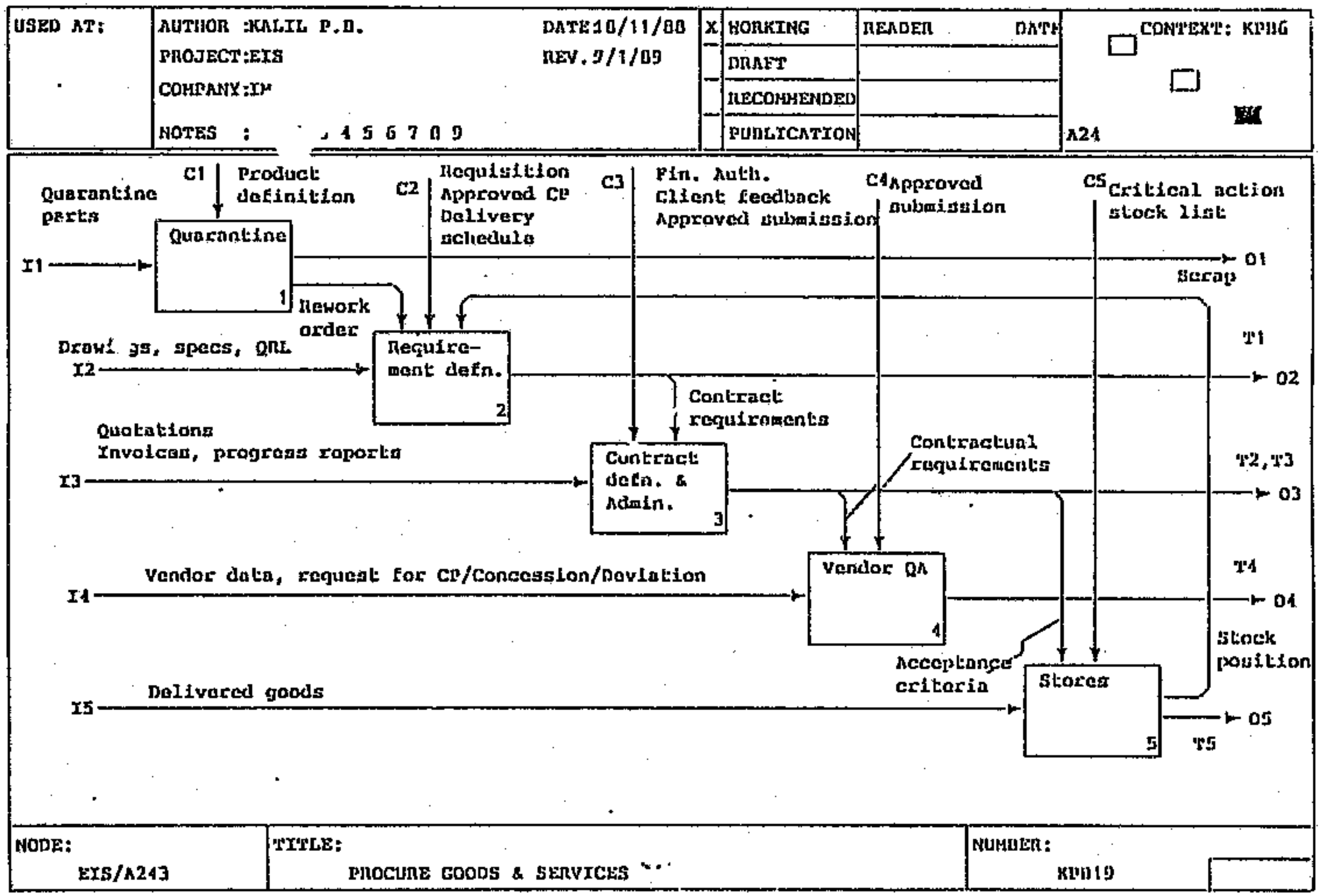


Figure E18 A243 Procure goods and services

Entities identified as notes on Figure E18

Requirements definition : Clarify requirements, Request drawings and specs, Establish quality requirements, Prepare RFP.

Contract Definition : Proposal negotiation, Quote evaluation, Pre-contract negotiation, Prepare submission, Place order

Contract administration

Vendor quality assurance : Product acceptance, Vendor survey and selection, Vendor audits, Services, CP/Concession/Deviation requests and evaluations

T1 : Request for drawings and specifications
T2 : Contract, Order
T3 : Submission, Feedback to client, Approved invoices
T4 : Acceptance certificates, Preferred vendors list, Application for CP/Conc/Dev.
T5 : Production stock, Updated stock records, Goods received voucher

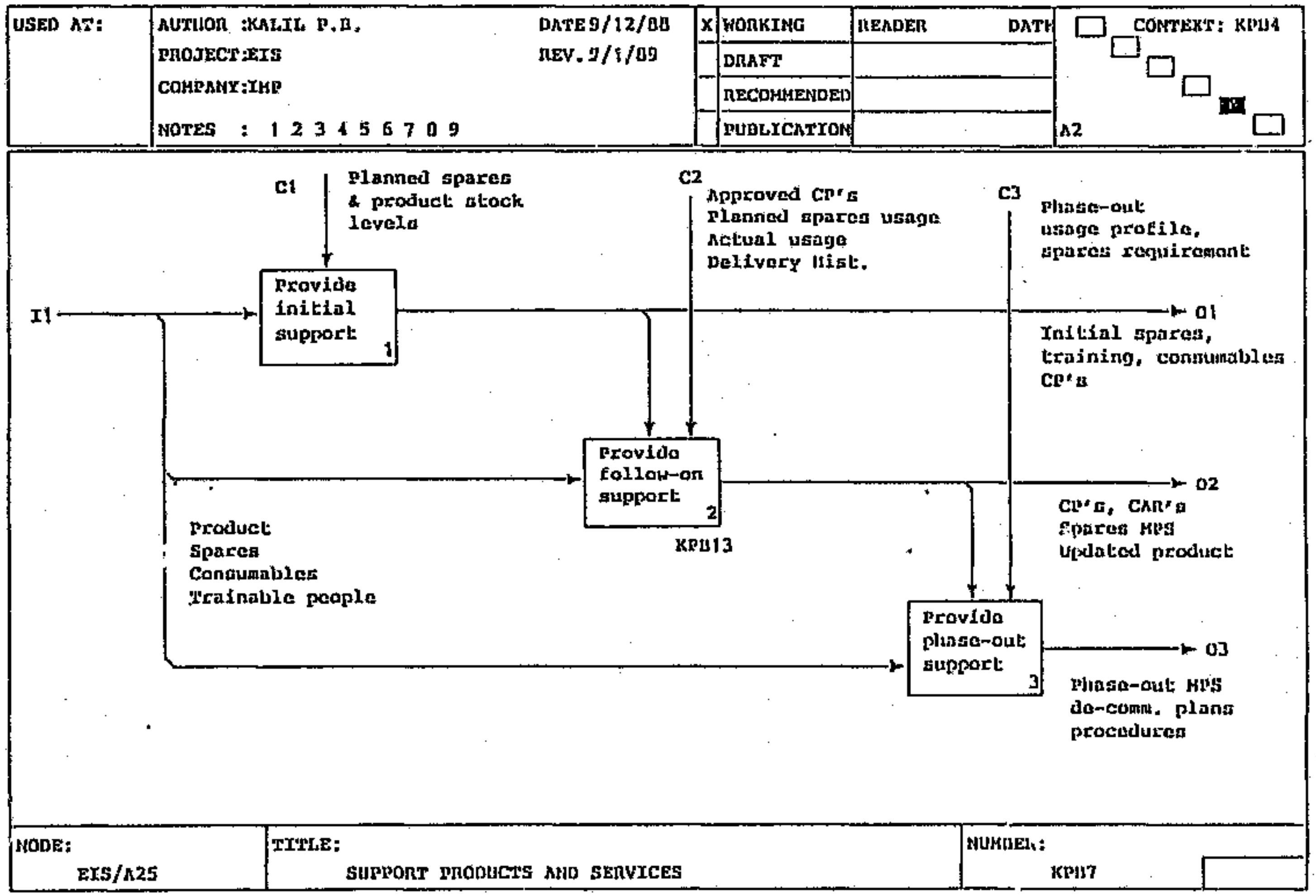


Figure E19 A25 Support products and services

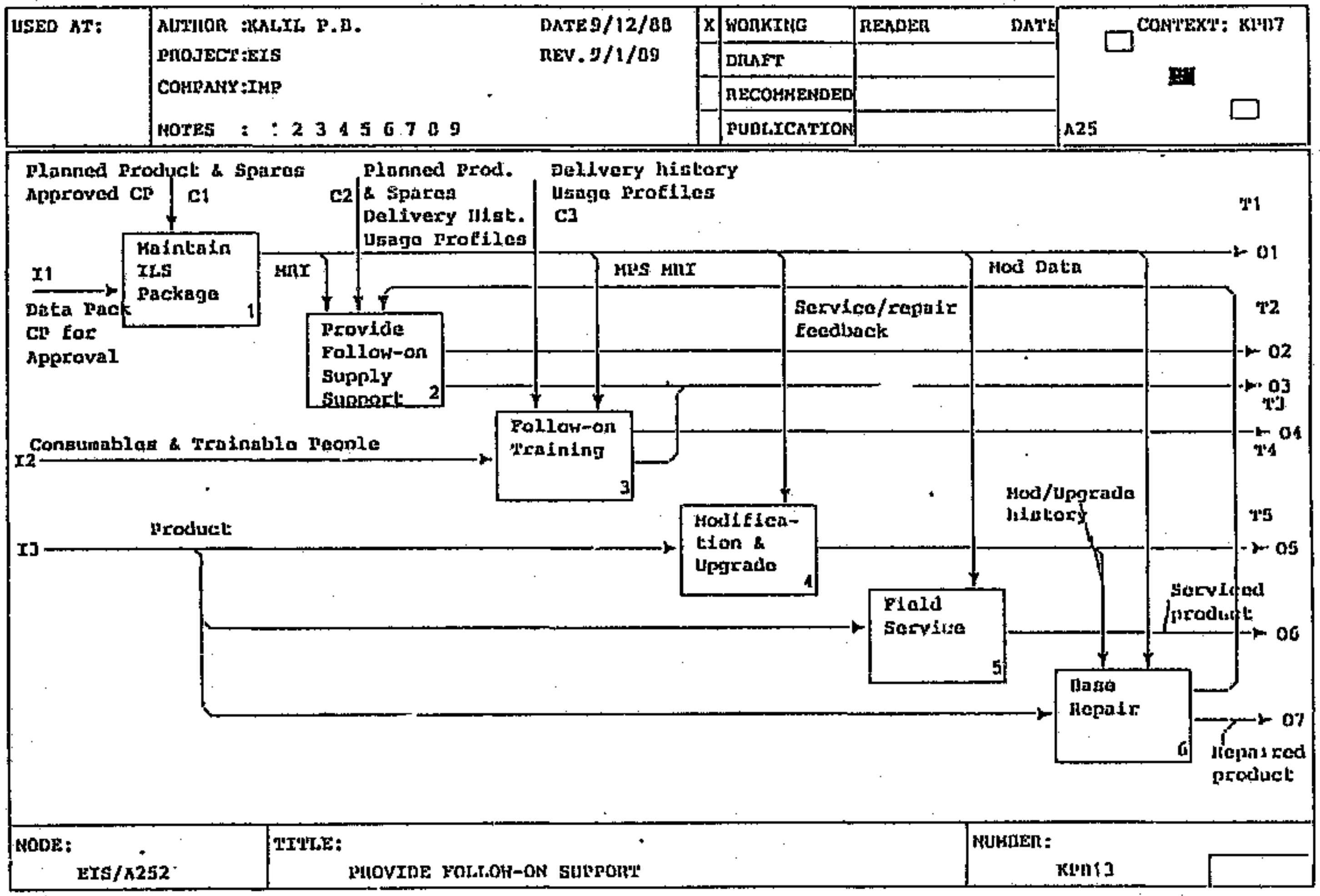


Figure E20 A252 Provide follow-on support

Entities identified as notes on Figure E20

T1 : Approved change proposal, Updated data packs

T2 : Activated spares MPS, Follow-on supply support plan

T3 : Exceptional usage report, Training report

T4 : Activated training MPS, Training plan, Trained people

T5 : Updated/modified product

APPENDIX F

A FUNCTIONAL MODEL OF A QUALITY SYSTEM

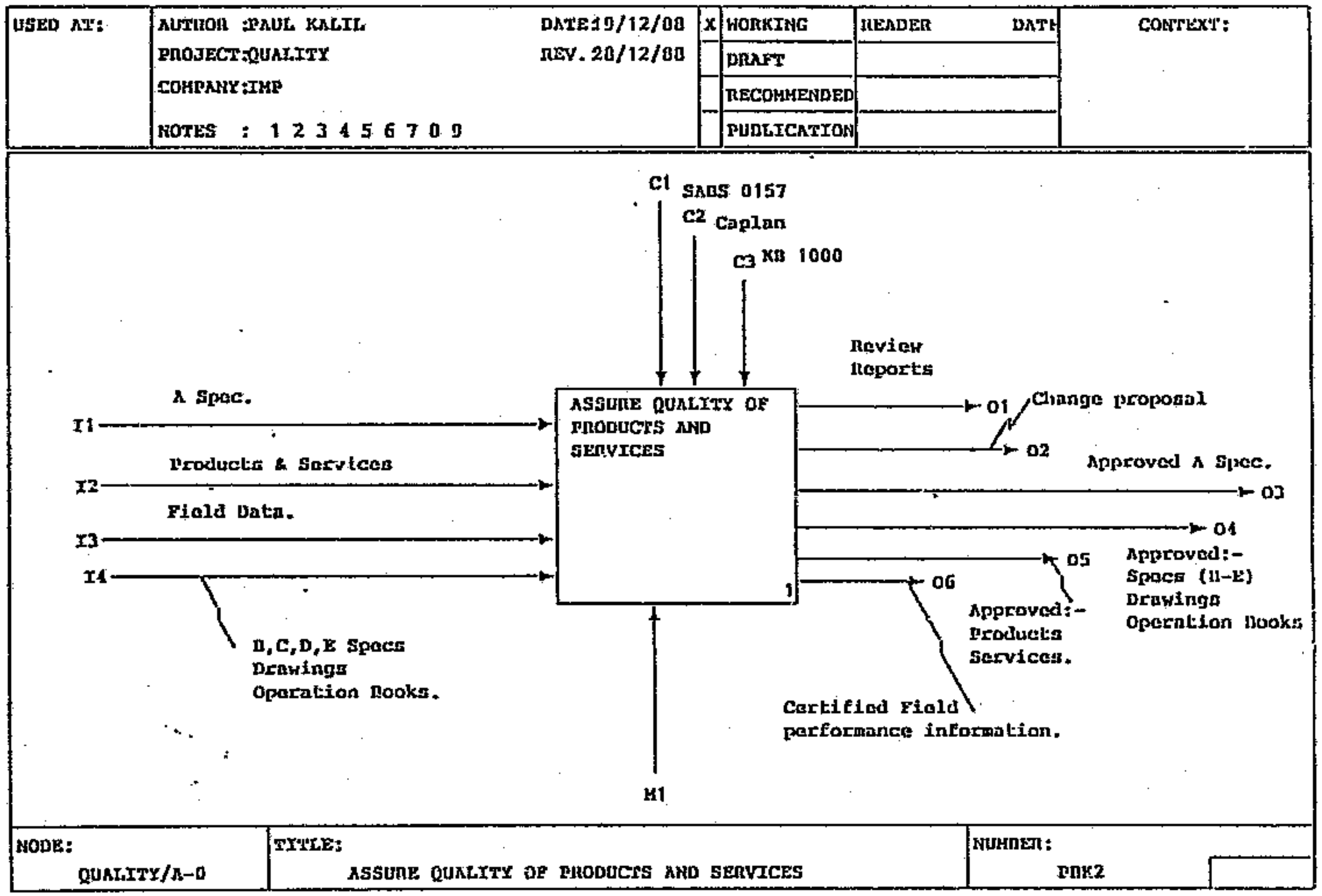


Figure F1 A-0 Quality Map

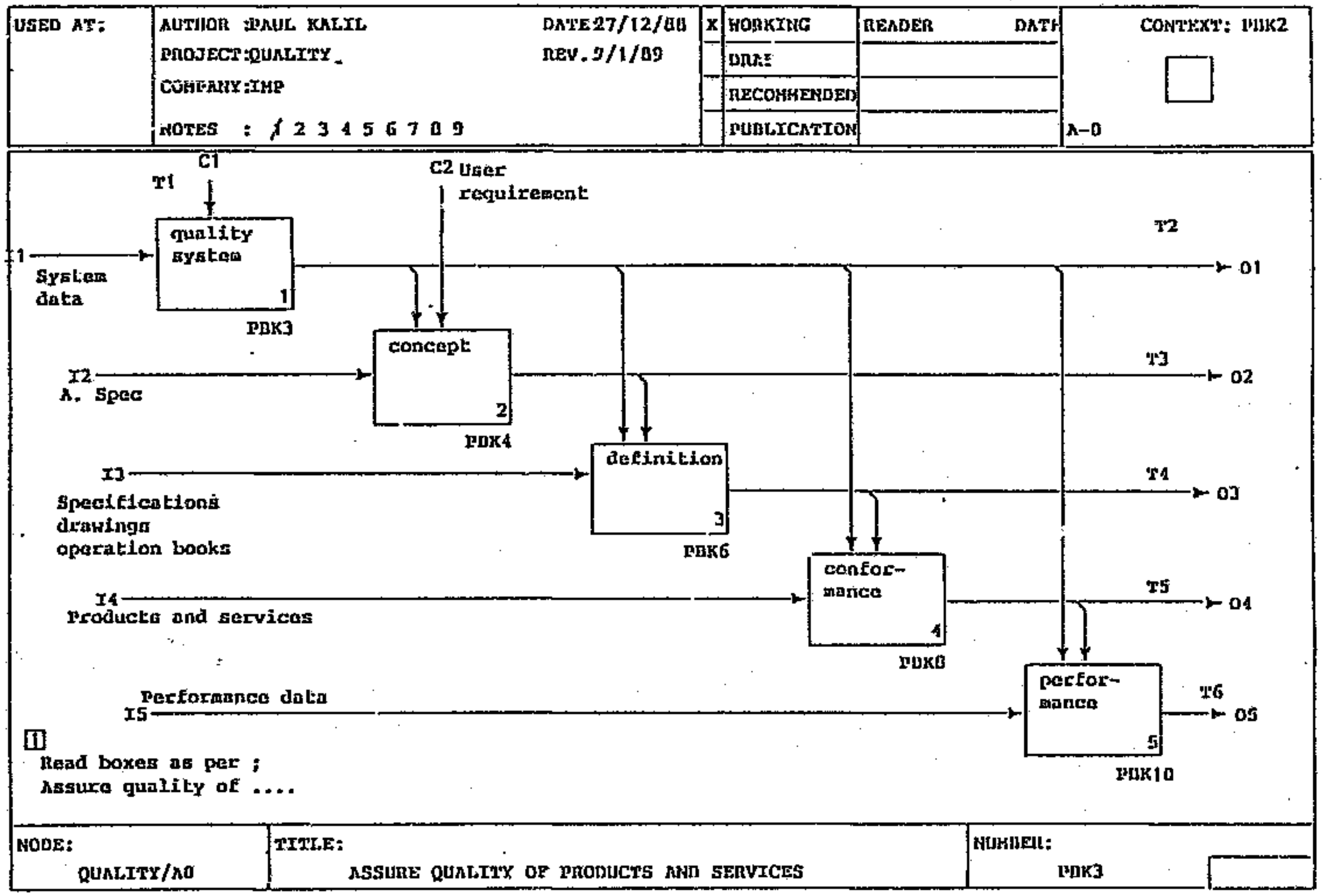
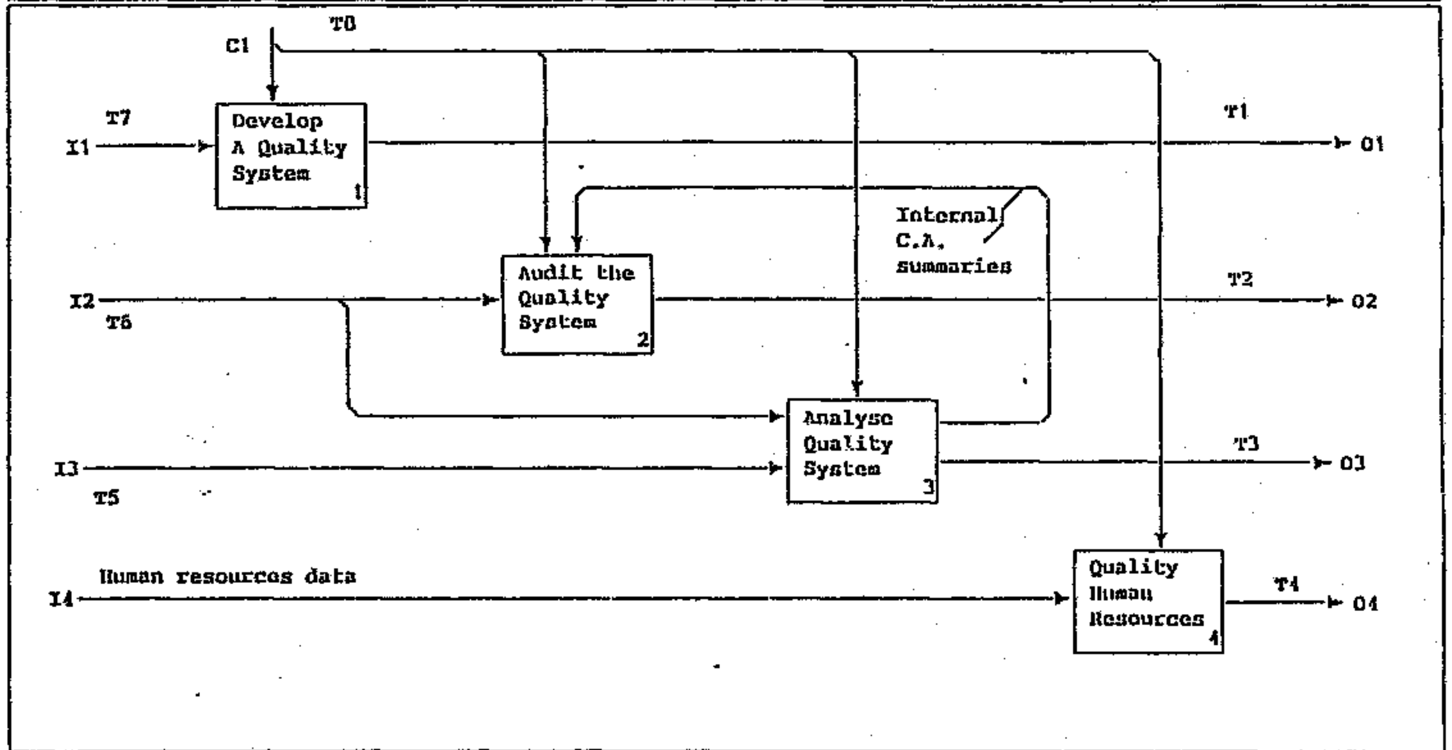


Figure F2 A0 Assure quality of products and services

Entities identified as notes on Figure F2

T1 : SABS 0157, SABS 0159, Contractual requirements, Policies and procedures
T2 : Reports, Certificates, Definitions, Needs, CP's, CAR's, Recommendations.
T3 : Review reports, Change proposals, Rejected specifications, Accepted specifications
T4 : Review reports, Drawings, Operation books, Approved B,C,D,E Specifications
T5 : Conformance review reports, Rejected products and services, Approved products and services, Change proposals
T6 : Change proposals, Performance review reports, Certified field performance information

USED AT:	AUTHOR :PAUL KALIL DATE27/12/88	X	WORKING	READER DATE	CONTEXT: PBK3
	PROJECT:QUALITY REV. 7/1/89		DRAFT		
	COMPANY:IMP		RECOMMENDED		
	NOTES : 1 2 3 4 5 6 7 8 9		PUBLICATION		A0



NODE:	TITLE:	NUMBER:
QUALITY/A1	ASSURE QUALITY OF QUALITY SYSTEM	PBK5

Figure F3 A1 Assure quality of quality system

Entities identified as notes on Figure F3

T1 : Corporate quality policies and procedures, System definitions, Needs analysis, Planning

T2 : Internal audit report summaries, CAR's, CP's, Q.P.E. Review reports, Q.S. review reports, Recommendations

T3 : Cp's, Recommendations, Status reports, Evaluation reports

T4 : Human resource certification and qualification requirements, Human resource capability and availability reports, Human resource training needs, H.R. performance reports

T5 : CAR records, Build history, Scrap and defect reports, Concession and deviation reports, Inspection reports, Vendor performance reports

T6 : Internal audit reports, Internal surveillance reports, Vendor survey reports

T7 : Audit reports, Quality cost reports

T8 : SABS standards, Policies, Contractual requirements

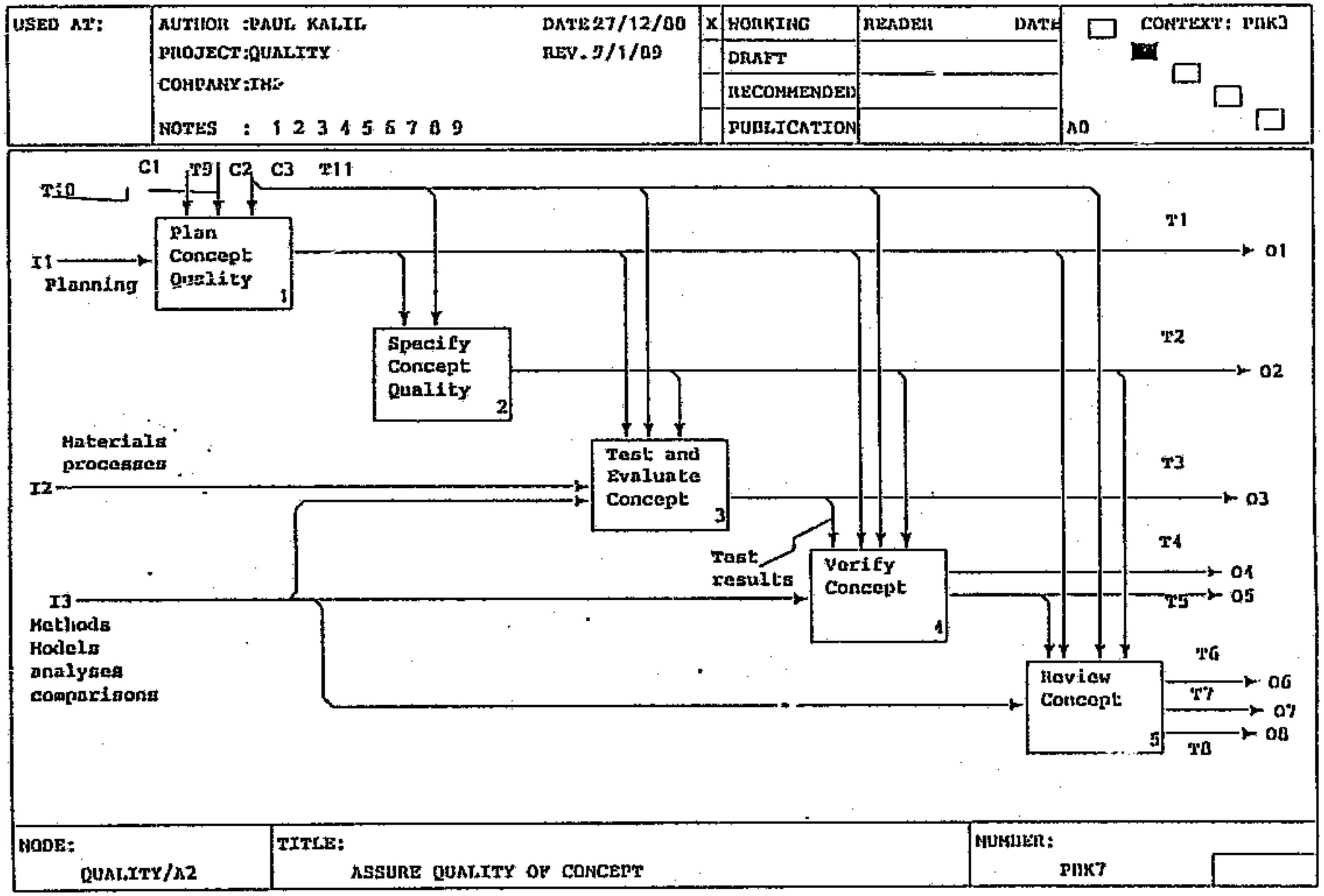


Figure F4 A2 Assure quality of concept

Entities identified as notes on Figure F4

T1 : WA planning, Quality Programme plan, Quality plans, Project plans, SEMP

T2 : Quality assurance provisions, Test specifications, Test instructions

T3 : Test reports, Surveillance reports

T4 : Unaccepted test results, olans, methods, Accepted test results, plans, methods

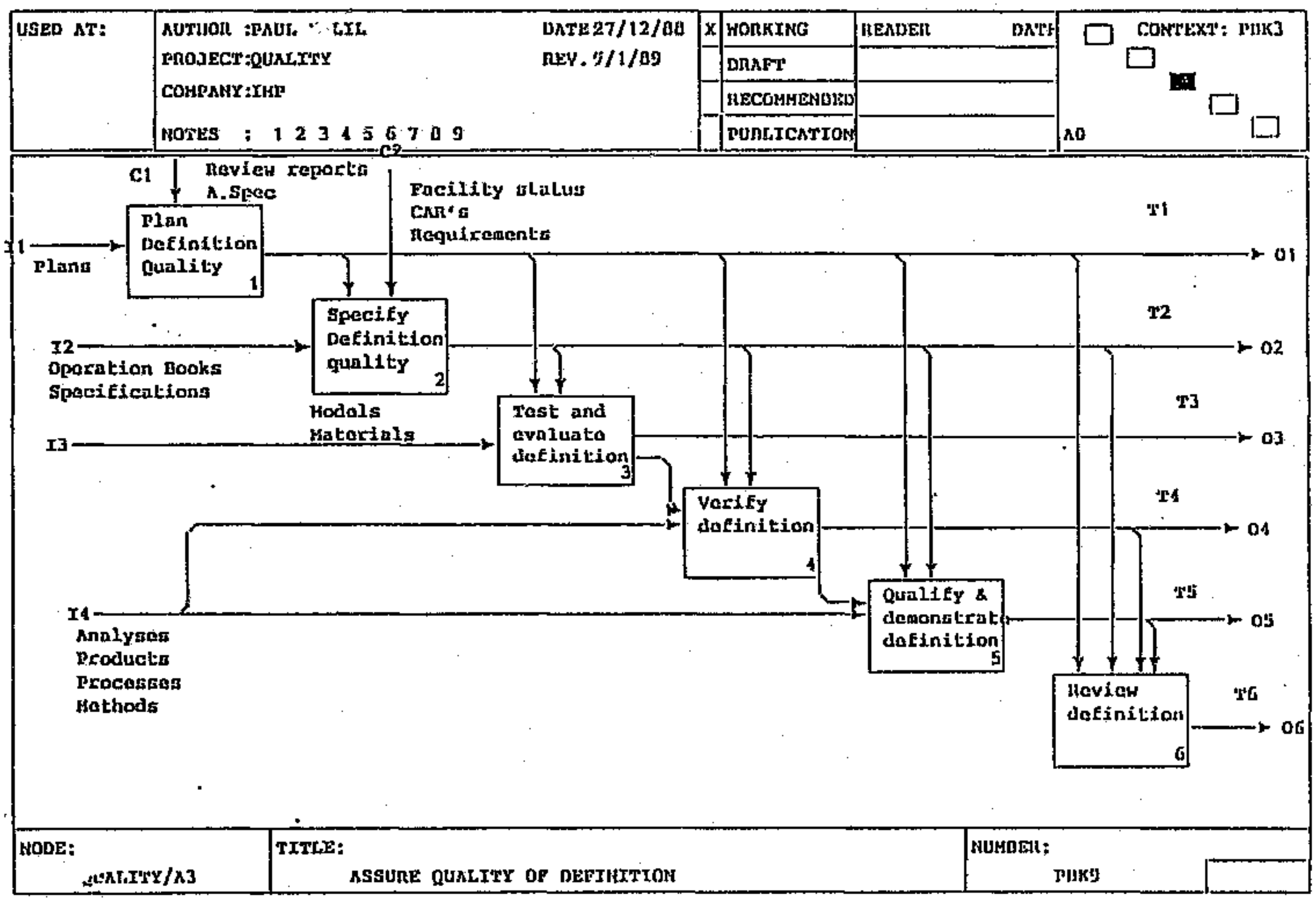


Figure F5 A3 Assure quality of definition

Entities identified as notes on Figure F5

T1 : Work authorizations, Quality programme plan, Quality plans, Operation books, Quality element plans, Vendor quality plans, "In process" inspection and gauging plans, Production quality plans, Assembly quality plans, Quality data acquisition plans, Quality data analysis and management reporting plans

T2 : Operation books, Quality assurance provisions, Acceptance norms, Test specifications and instructions, Inspection methods and procedures, IMT equipment specifications, IMT equipment calibration specifications and procedures, "In process" quality control requirements, SPC's, Quality requirements list, Approved vendor list

T3 : Test results and reports, Documented evidence, Build history

T4 : Verified : Vendor selection, Measurement systems, Process designs, Plans, Specifications, Tests, Methods, Processes, Models, Analyses

T5 : Qualification reports for ; Gauges, Processes, Products, Methods, and Build history

T6 : Change proposals, Corrective action requests, Review reports, "Released" definitions

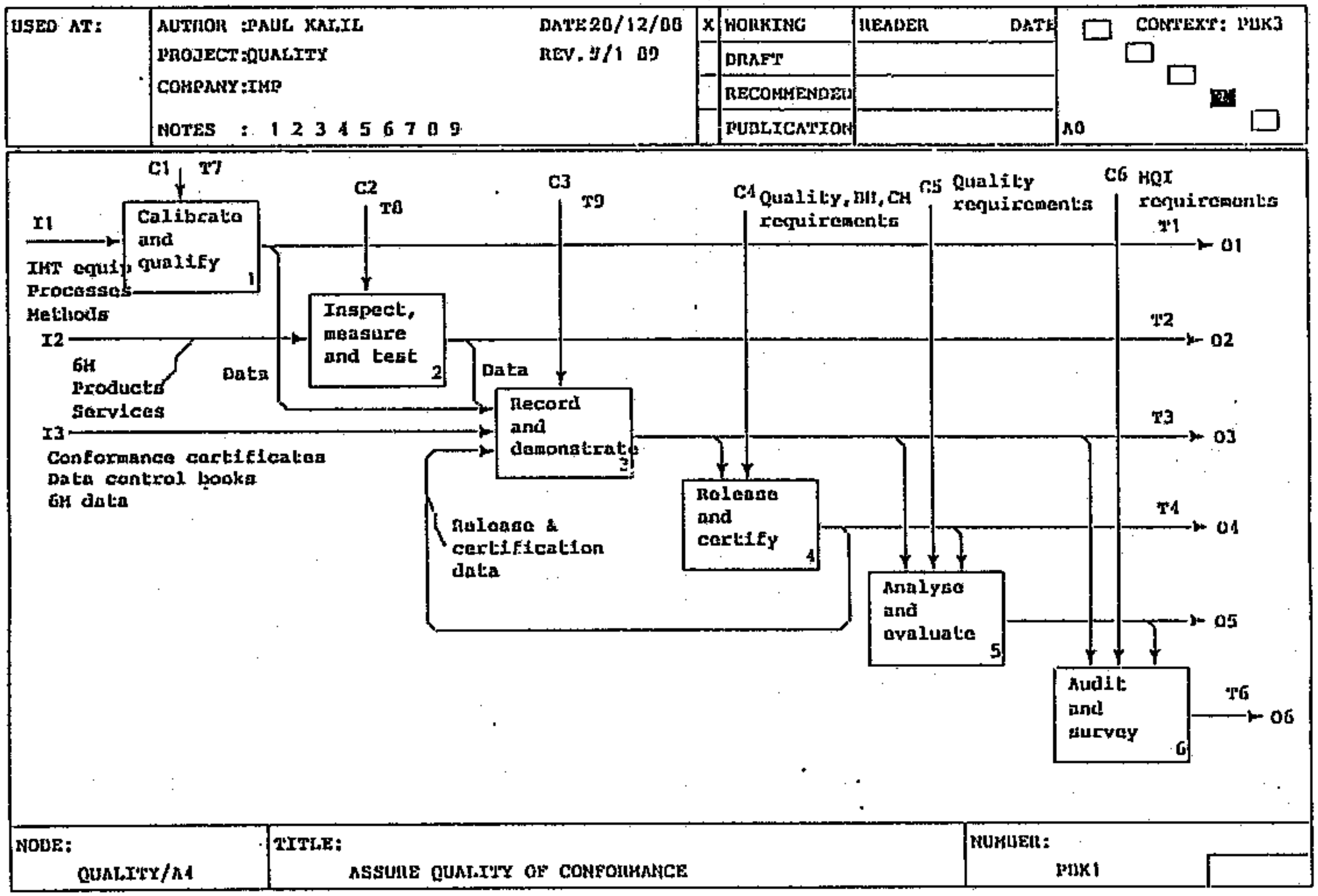


Figure F6 A4 Assure quality of conformance

Entities identified as notes on Figure F6

T1 : Recalibrated IMT equipment, Requalified processes and methods

T2 : REPORTS ; Laboratory, Test, Inspection, Scrap and Defect, Quarantined/accepted/rejected materials, Products, Services, Reject notes

T3 : Build history

T4 : Certificates, Release notes

T5 : STATUS REPORTS ; Concession/Deviation, CAR, CP, 6M, Yield performance, Quality costs, Vendor performance, Process, Quarantine

T6 : CP's, CAR's, Audit reports, Survey reports, AAE Status reports

T7 : Quality requirements, Quality standards, Design definition, SABS 0159

T8 : Concessions, Deviations, Procedures, Quality requirements, SABS 0157

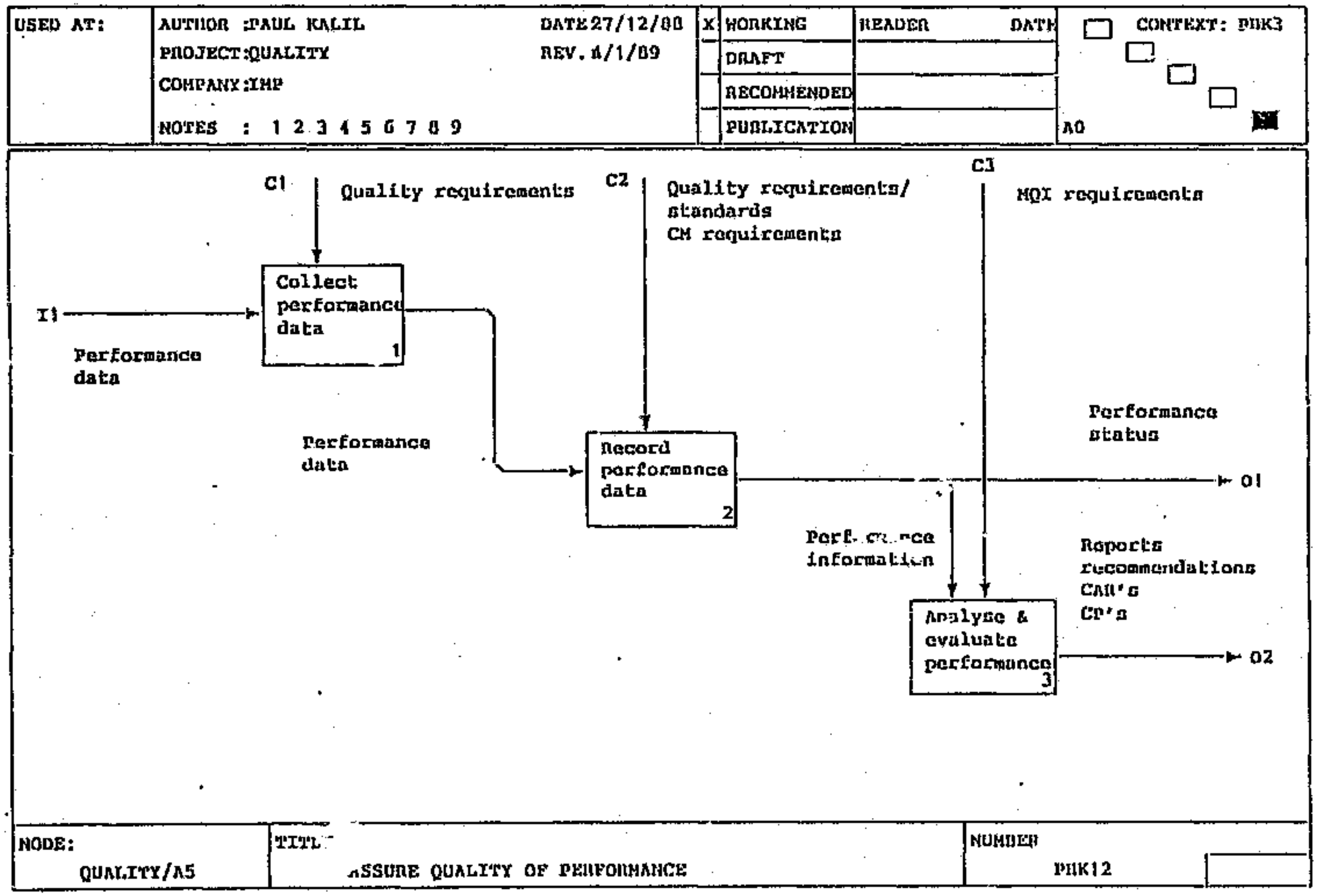


Figure F7 A5 Assure quality of performance

APPENDIX G

A FUNCTIONAL MODEL OF A CONFIGURATION MANAGEMENT SYSTEM

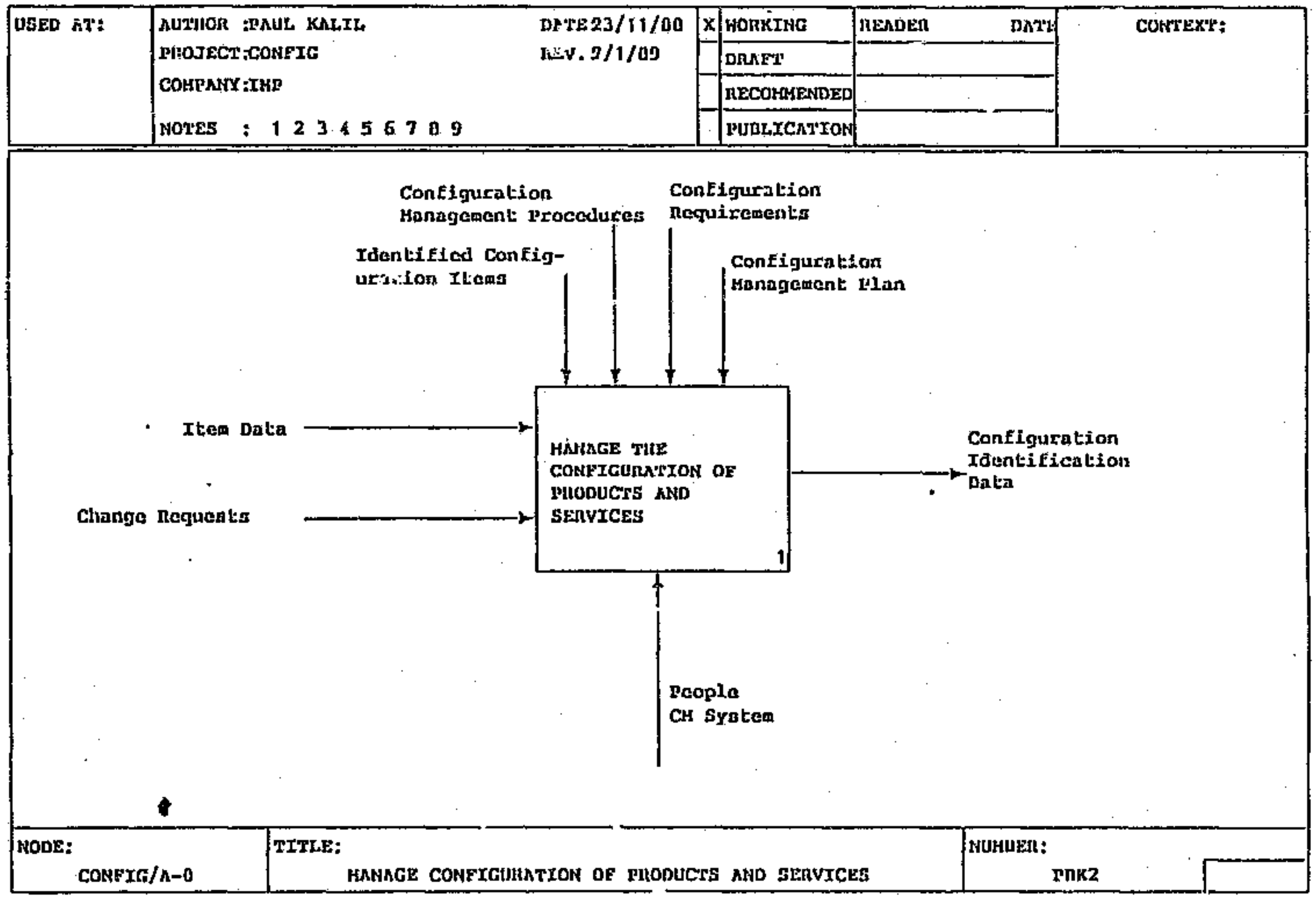


Figure G1 A-0 Configuration Management Top

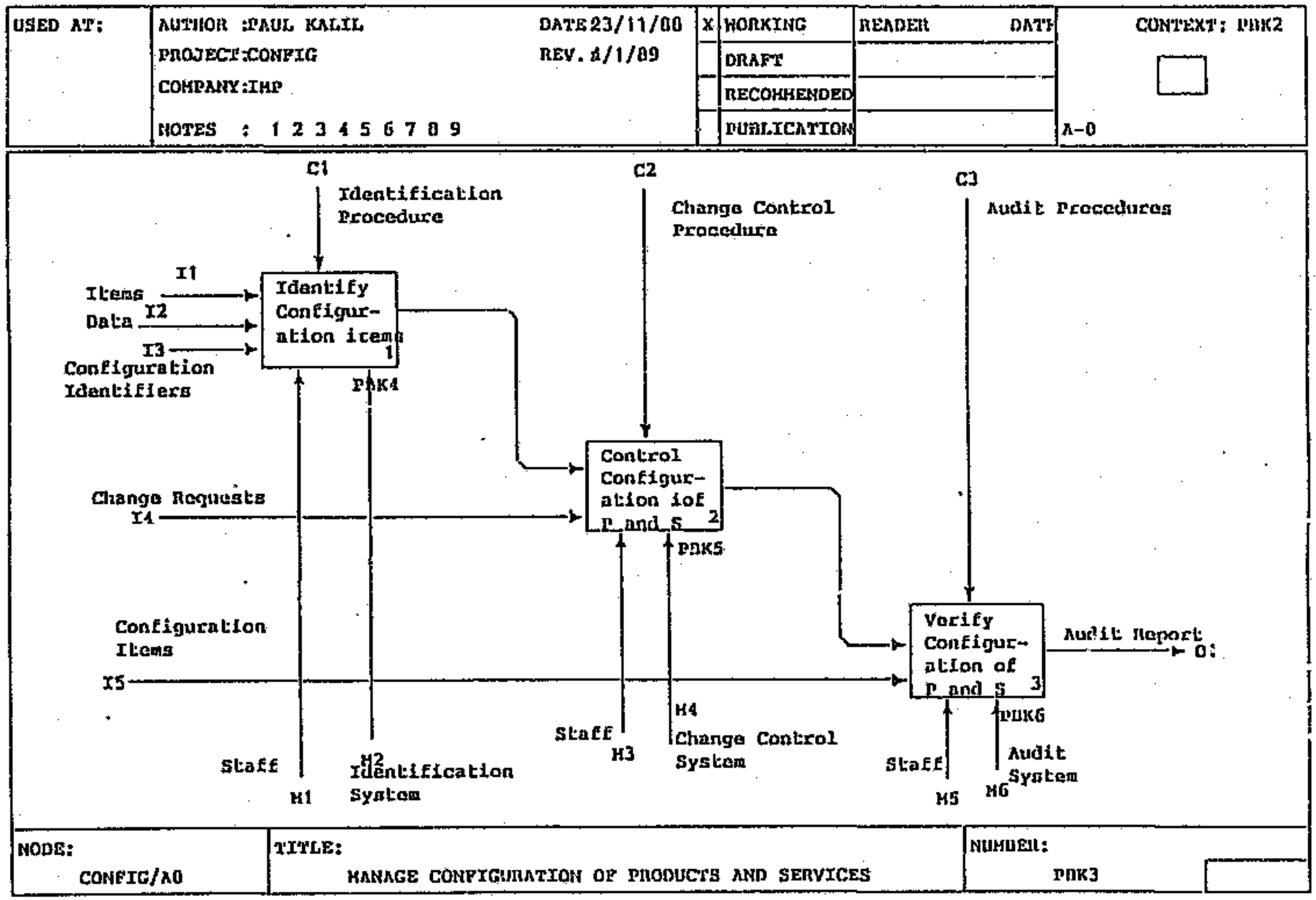


Figure G2 A0 Manage Configuration of Products and Services

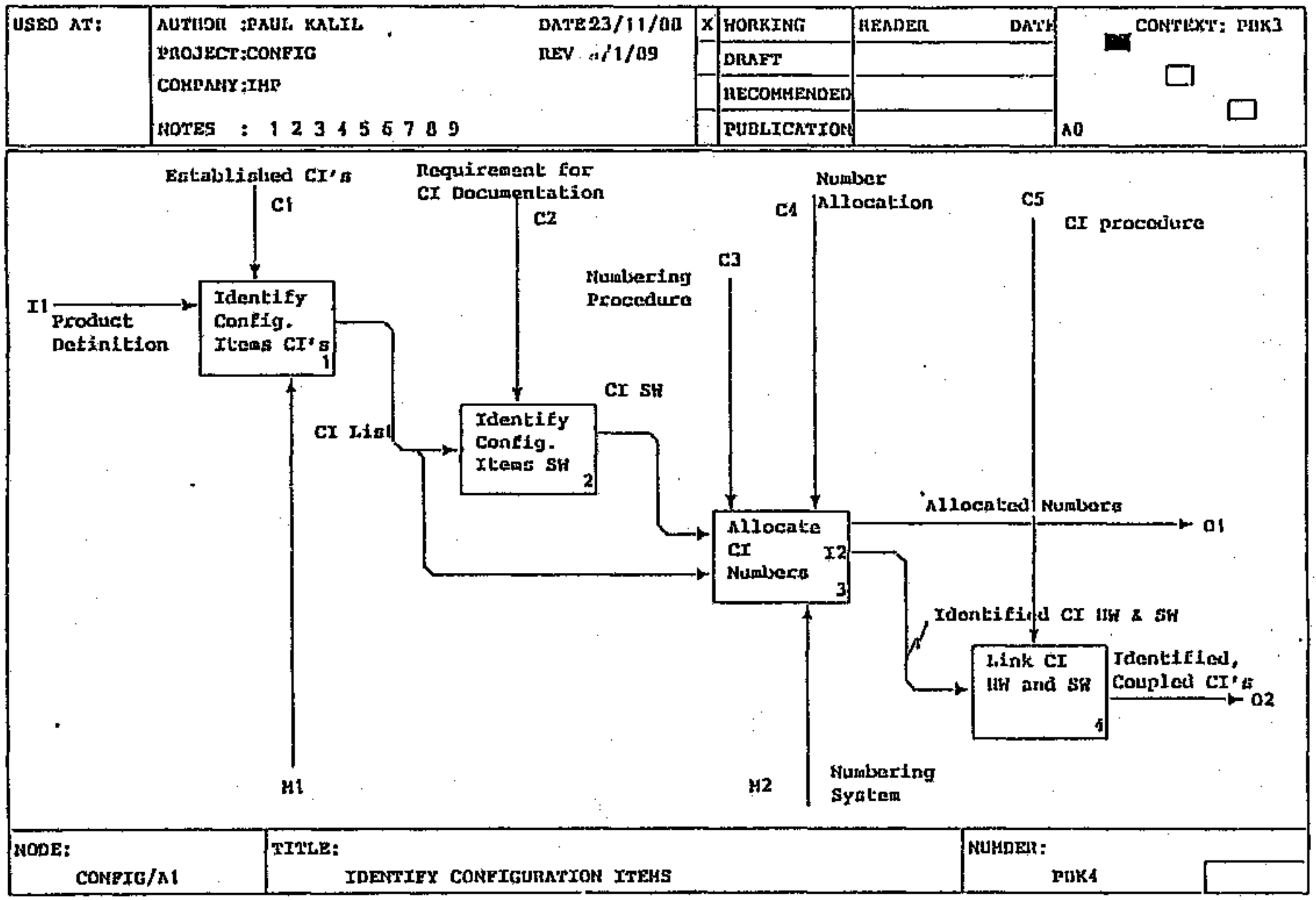


Figure G3 A1 Identify configuration items

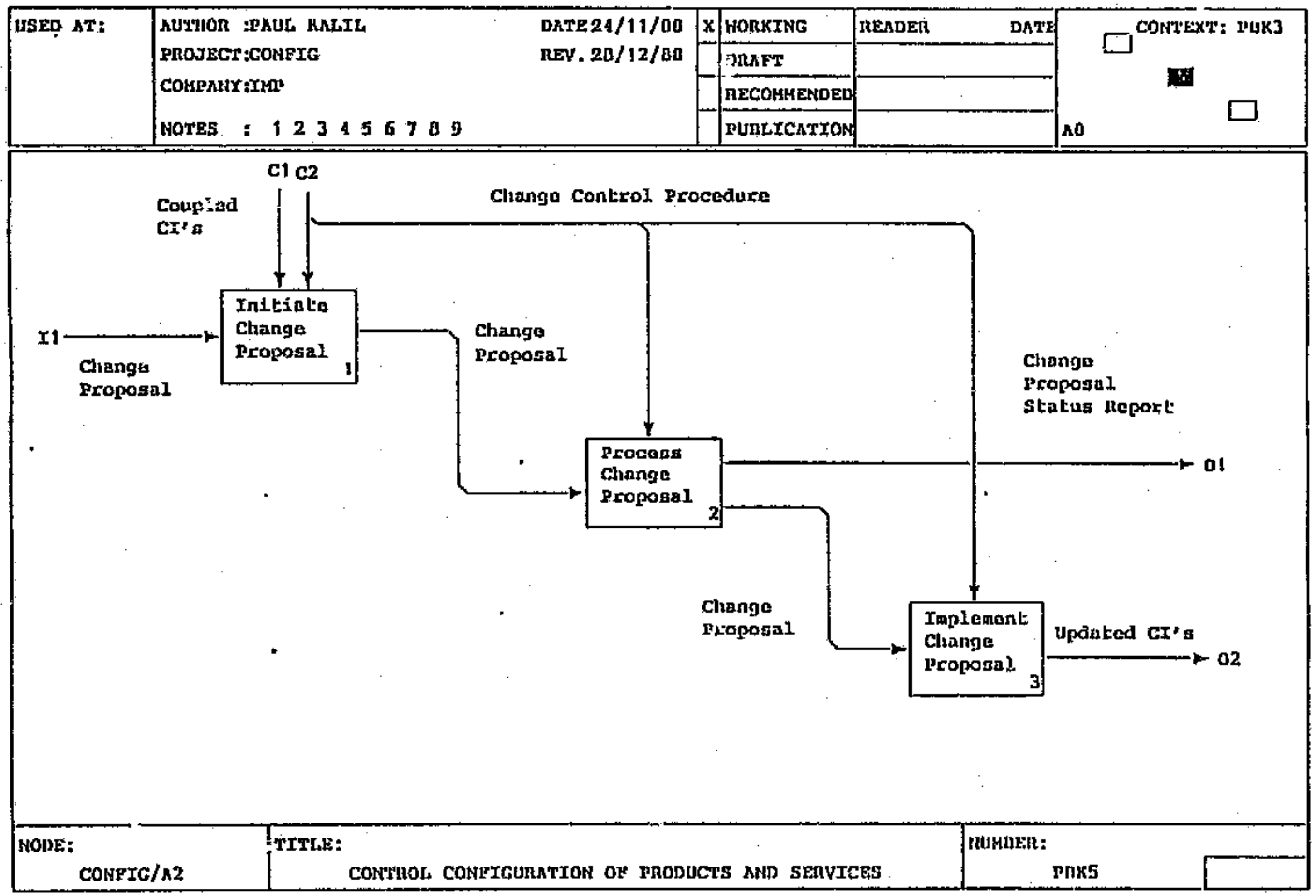


Figure G4 A2 Control configuration of products and services

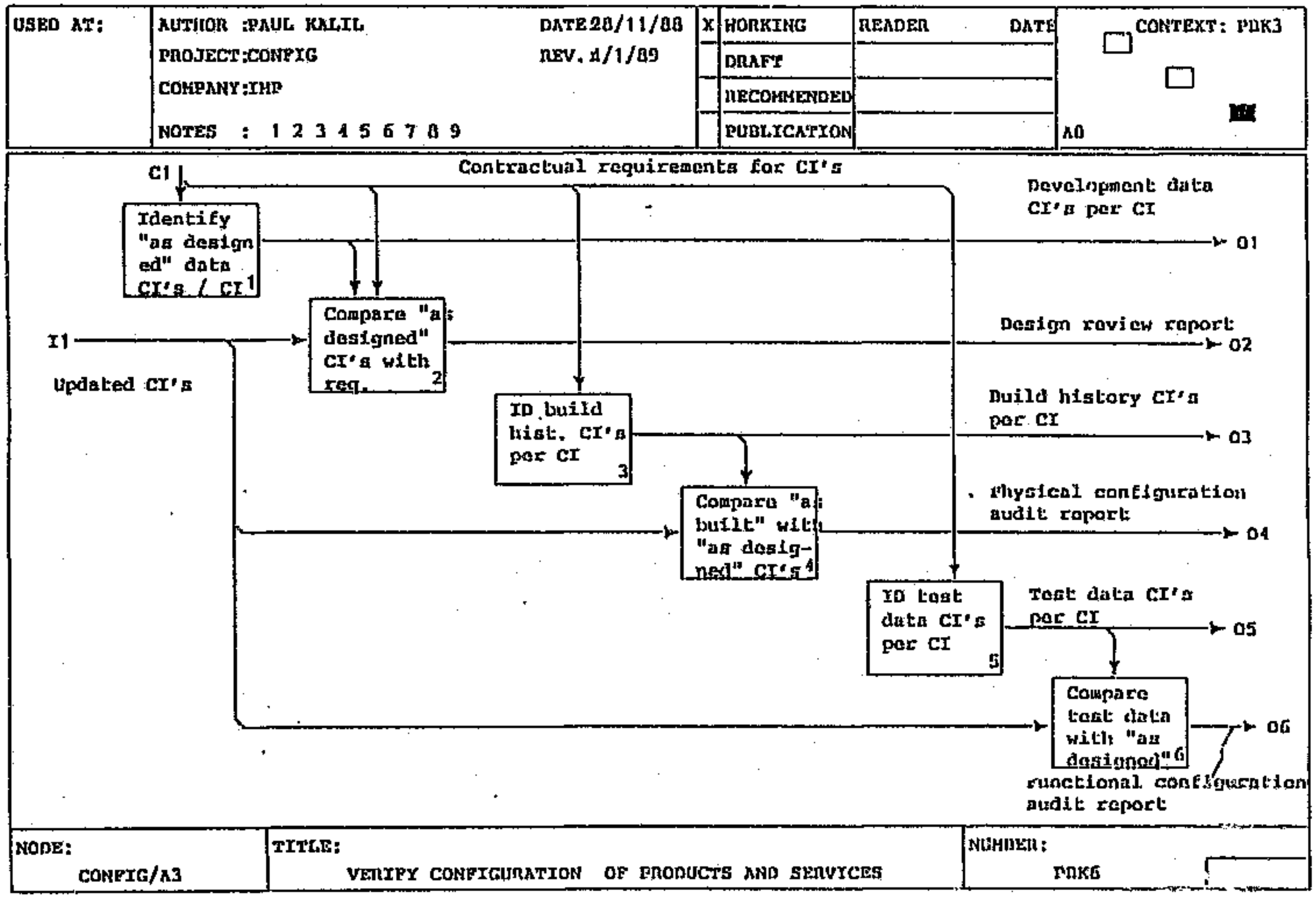


Figure G5 A3 Verify configuration of products and services

REFERENCES

1. Harrington, J. **Computer Integrated Manufacturing**, New York, R.E.Krieger Publishing, 1979.

2. Arnold, J.C. and Johansson, H.J. Establishing a framework for the analysis and justification of computer integrated manufacturing, **Proceedings of Synergy '84 Conference** , 1984, p.29.

3. Mize, J.H. et al, Formation and working of a corporate wide CIM committee at Garrett Corporation, **Industrial Engineer**, 1985, p.77.

4. Appleton, D.S. The state of CIM, **Datamation**, December 1984, pp.66-70.

5. Ibid, pp. 66-70.

6. Merchant, M.E. The factory of the future, **Industrial Management**, Sept.-Oct. 1985, pp. 2-3.

7. Pittenger, J.L. and Hatch, D. Computer integrated manufacturing - where to begin, **Proceedings of International Computers in Engineering Conference**, 1984, pp. 474-475.

8. Mackulack, G.T. Planning techniques for computer integrated manufacturing, **National Productivity Review**, 1984, Vol:3, No:3, pp.324-333.

9. Le Clair, S.R. IDEF the method, architecture the means to improved manufacturing productivity, **CASA-SME**, 1982, pp. 1-14.

10. Settles. S. and Mize, J. Managing change from the middle, **Inuustrial Engineer**, Sept. 1985, pp.14

11. Ibid, pp.14-16.

12. Arnold, op cit, p.31.

13. Merchant, op cit, p.1.

14. Arnold, op cit, p.32.

15. Lipchin, L. CAD/CAM program as a strategic tool for manufacturing business planning, **Computer Integrated Manufacturing Group, Arthur D. Little, Inc**, pp. 1094-1112

16. Murphy, A.D. Developing a CIM strategy and plan, **Proceedings of the 6th Annual Conference on Design Engineering**, 1983, p.26.

17. Van Loggerenberg, B.J. and Cucchiaro, S.J. Productivity measurement and the bottom line, **National Productivity Review**, pp.87-90.

18. Ingersoll Engineers, **Integrated Manufacture**, New York, Springer-Verlag, pp.42-43.

19. Murphy, Op cit, p.26.

20. Mackulack, Op cit, p. 316.

21. Ibid, p.317.

22. Wheelwright, S.C. Japan - where operations really are strategic, **Harvard Business Review**, July-August 1981, pp.67-74.

23. Dicasali, R.L. Developing your CIM strategy, **Manufacturing Systems**, Mar. 1985, pp.42-43.

24. Sullivan, C.H. Systems planning in the information age, **Sloan Management Review**, Winter 1985, p.6.

25. Gluck, F. et al, The four phases of strategic management, **The Journal of Business Strategy**, 1983, pp. 11.

26. Mackulack, op. cit.,p.318.

27. Ibid, pp.322-329.

28. Le Clair, op. cit., pp.1-14.

29. Pittenger, op. cit., pp.474-476.

30. Mackulack, op.cit., pp.329-333.

31. Hagedorn, H.J. Adopting factory automation, **American Machinist**, Dec. 1985, pp.88-90.

32. Slautterback, W.H. The manufacturing environment in the year 2000, **Proceedings Autofact III**, November 1986, pp.21-23.

33. Challis, H. How does AMT affect the worker, **Production Engineer**, Feb. 1986, p.22.

34. Jain, A.K. Education for factory automation, **Manufacturing Systems**, Sept. 1985, pp.50-51.

BIBLIOGRAPHY

1. American Machinist Special Report, **The AM Award - Joseph Harrington Jr**, American Machinist, December 1984, pp.90-99.

2. American Machinist Special Report 756, **Sensors: the eyes and ears of CIM**, American Machinist, July 1983, pp. 109-124.

3. American Machinist Special Report 772, **The Interface Challenge**, American Machinist, January 1985, pp. 95-102.

4. American Machinist Special Report 775, **Integrated QA: closing the CIM loop**, American Machinist, April 1985, pp. 137-160.

5. CASA-SME Blue Book Series, **Fifth generation management**, 1986.

6. CASA-SME, CIM Series, Vol. 1, No. 2. **Achieving Integrated Automation Through Computer Networks**, 1981.

7. CASA-SME, CIM Series, Vol. 1, No. 3. **Preparing for the factory of the future**, 1981.

8. CASA-SME, CIM Series, Vol. 1, No. 4. **The CIM Database**, 1981.

9. CASA-SME, CIM Series, Vol. 2, No. 1. **Computer Integrated Manufacturing**, 1981.

10. Allaine, Y. and Firsirotu, M. **How to Implement Radical Strategies in Large Organizations**, Sloan Management Review, Spring 1985, pp.19-34.

11. Appleton, D.S. **DACOM Products for Information Asset Management**, California, D. Appelton Company Inc. brochure.

12. Appleton, D.S. **Business Rules: The missing link**, Datamation, October 1987, pp. 145-150.

13. Appleton, D.S. **Interorganizational CIM**, CIM Review, Summer 1987, pp. 54-57.

14. Appleton, D.S. **Interorganizational CIM**, CIM Review, Winter 1987, pp. 66-68.

15. Appleton, D.S. **Measure Twice: Cut Once**, Datamation Magazine, August 1982, pp. 128-136

16. Appleton, D.S. **The modern data dictionary**, Datamation, March 1987, pp. 66-68.

17. Appleton, D. S. **The State of CIM**, Datamation, December 1984, pp.66-70.

18. Appleton, D.S. **The Technology of Data Integration**, Datamation, November 1, 1985, pp. 104-116.

19. Bancilhon, F. and Korth, H.F. **A Model of CAD Transactions**, Proceedings of Conference on Very Large Data Bases, 1985, pp.25-33.

20. Banks, R.L. and Wheelwright, S.C. **Operations vs. strategy: trading tomorrow for today**, Harvard Business Review, May-June 1979, pp. 112-120.

21. Baselmans, R. **Evolution Of Configuration Management**, ACM Sigsoft Software Engineering Notes, vol. 10, no. 5, Oct. 1985, pp. 20-29.

22. Benayoune, M. and Preece, P.E. **Methodology for the Design of Databases for Engineering Applications**, Computer-aided design, vol. 18, no.5, June 1986, pp.258-262.

23. Britton, H.O. and Hammer W.E. **Designers, Users and Managers Share Responsibility for Ensuring CIM System Integrity**, Industrial Engineer, May 1984, pp. 36-48.

24. Chen P.P. **The entity-relationship model - Toward a unified view of data**, ACM Transactions on Database Systems, Vol. 1, No. 1, March 1976, pp. 9-36.

25. Crawford, G.W. **CAD\CAM: Justification, Implementation and Evaluation**, Westinghouse Productivity and Quality Center, Pittsburgh, Pennsylvania, pp.88-90.

26. Dunlap, G.C. **CAM - Geometric Systems Integration**, AIAA Phoenix Section - Computer Graphics Symposium, 1982, pp. 34-36.

27. Emond, J.C. and Marechal G. **Experience in Building ARCADE, a Computer Aided Design system based on a relational DBMS**, IEEE Transactions, 1983, pp. 13-22

28. Feightner, C.L. **The Changing Role of the Design Engineer**, Computer Graphics World, March 1985, pp. 33-104.

29. Fenves, S.J. and Rasdorf, W.J. **Treatment of Engineering Design Constraints in a Relational Database**, Engineering with Computers, 1985, pp. 27-37.

30. Fong, J.T. **Integration of Analysis and Databases for Engineering Decision Making**, Computers in Mechanical Engineering, July 1986, pp. 42-55.

31. Fulton, R.E. **A Framework for Innovation**, Computers in Mechanical Engineering, March 1987, pp. 26-40.

32. Garvin, D.A. **Quality on the line**, Harvard Business Review, September-October 1983, pp. 65-75.

33. Gloudeman, J.F. and Brown, R.R. **Managing Engineering Analysis Data**, Computers in Mechanical Engineering, March 1987, pp. 42-44.

34. Gondert, S. J. **Understanding the Impact of Computer-integrated Manufacturing**, Manufacturing Engineering, September 1984, pp.41-42.

35. Harrington, J. **Computer Integrated Manufacturing**, New York, R.E. Krieger Publishing Company, 1979.

36. Hayes, R.H. **Why Japanese factories work**, Harvard Business Review, July-August 1981, pp. 56-66.

37. Hess, G.J. **1982 Industry Lead Award Winner - Revisited in 1986**, Rockford, Illinois: The Ingersoll Milling Machine Company , 1986, pp. 1-13.

38. Hess, G.J. **Computer Integrated Manufacturing - How to get started**, Rockford, Illinois: Ingersoll Milling Machine Company, pp. 54-68.

39. Jarvis, J.H. **Strategic Planning vs Design Specification of Computer Integrated Manufacturing Projects**, MHI Advanced Technologies Exposition Business Control Forum, March, 1984, pp.1-9.

40. Jelinek, M. and Goldhar, J.D. **The Strategic Implications of the Factory of the Future**, Sloan Management Review, Summer 1984, pp.29-37.

41. Miller, J.G. **Fit production systems to the task**, Harvard Business Review, January-February 1981, pp.145-154.

42. Mintzberg, H. **The Structuring of Organizations**, Englewood Cliffs, Prentice-Hall, 1979.

43. Kaclala, J. **Software links CAD and CAM**, Machine Design, July 10, 1986, pp.85-88.

44. Kemper, A. **CAM Databases: Requirements and Survey**, Internal Report No. 17/85, Faculty of Informatics, Karlsruhe University, 1985.

45. Keys, D.E. **Limitations of cost accounting in an automated factory**, CIME, July 1987, pp. 26-29.

46. Lapen, R.J. and Jeffrey, R.J. **A proven approach to CIM systems design and planning**, CIM Review, Summer 1986, pp. 36-48.

47. LeClair, S.R. and Hill T.W. **Functional Planning Approach Maps Out Connections between People and Systems**, Industrial Engineering, April 1984, pp. 26-37.

48. Lee, S.E. and Mosier, C.T. **The Development of a Computer Integrated Manufacturing System : A Modular Approach**, Proceedings of International Industrial Engineering Conference, 1984, pp. 49-56.

49. Lipchin, L. **CAD\CAM Program as a Strategic Tool for Manufacturing Business Planning**, Massachusetts: Computer Integrated Manufacturing Group, Arthur D. Little, Inc, pp. 1094-1112.

50. Marks, P. **Database Implementation for the Next Generation of CIM Systems**, CIM Review, Fall 1987, pp. 42-47.

51. Mechler, E.C. **Implementing Technology Change - A Systems Approach**, International congress on Technology and Technology Exchange, October 8-10, 1984, Pittsburgh, Pennsylvania, USA.

52. Melkanoff, M.A. **The CIMS Database: Goals, Problems, Case Studies and Proposed Approaches Outlined**, Industrial Engineer, November 1984, pp. 78-93.

53. Miller, S.M. **How Robots and other automation change the nature of the work force**, American Machinist, May 1985, pp. 128-131.

54. Nickodemus, G.H. and Yanus, I.D. **A Computer Integrated Engineering System for Design and Life Cycle Management**, Naval Engineers Journal, May 1986, pp. 115-121.

55. Owens, D.A. **"The Factory with a Future" An Overview of One Automated Factory**, Quality Progress, June 1984, pp. 18-20.

56. Pitts, C. **Making the plans come together**, Management, December 1984, pp.41-42.

57. Putnam, A.O. **A Redesign for Engineering**, Harvard Business Review, May-June 1985, pp.139-144.

58. Sadowski, R.P. Ed. **Computer Integrated Manufacturing Systems Series**, Industrial Engineer, January 1984 - December 1985.

59. Skinner, W. **The Focused Factory**, Harvard Business Review, May-June 1974, pp.113-121.

60. Smuts, J.C. **Holism and Evolution**, London, MacMillan and Co, 1925.

61. Rasdorf, W.J. **Extending DBMS's for Engineering Applications**, Computers in Mechanical Engineering, March 1987, pp. 62-69.

62. Richards, A.W. **Multiple Inheritance in CAD Data Models**, 3rd Int. Workshop on Software Specification and Design, IEEE, 1986, pp.1-5.

63. Ross, D.T. and Schoman, K.E. **Structured analysis for requirements definition**, IEEE Transactions on Software Engineering, Vol.SE-3, No. 1, January 1977, pp. 6-15.

64. Ross, D.T. **Applications and extensions of SADT**, IEEE Computer, April 1985, pp. 25-34.

65. Ross, D.T. **Structured analysis (SA): A language for cor⁻unicating ideas**, IEEE Transactions on Software Engineering, Vol.SE-3, No. 1, January 1977, pp. 16-34.

66. Rouse, N.E. **Developing Network Standards**, Machine Design, December 1985, pp. 69-73.

67. Salvendy, G. **Human aspects in integrated manufacturing systems**, International Journal of Production Research, Vol. 24, No. 4, 1986, pp. 749-762.

68. Shapiro, R.D. **Get leverage from logistics**, Harvard Business Review, May-June 1984, pp. 119-126.

69. Shapiro, S. **Getting the Most out of Today's Technology**, Computer Design, July 1986, pp.77-95.

70. hunk, D. et al. **Making the most of IDEF modeling - The triple diagonal concept**, CIM Review, Fall 1986, pp. 12-37.

71. Slautterback, W.H. **The Manufacturing Environment in the Year 2000**, Proceedings Autofact III, November 1986 pp. 21-1 - 21-9.

72. Snodgrass, N.B. **Templates for an Integrated Common Database**, D. Appelton Company Incorporated, pp.1-39.

73. Spur, G. and Specht, D. **Computer Integrated Manufacturing in Future Factories**, Robotics and Computer-Integrated Manufacturing, Vol. 3, No. 2, 1987, pp. 147-155.

74. Srihari, K. and Greene, T.J. **Computer-Aided Process Planning - A CAD\CAM Interface**, CIM Review, Summer 1988, pp.47-54.

75. Staley, S.M. and Anderson, D.C. **Functional Specification for CAD Databases**, Computer-aided Design, vol. 18, no.3, April 1986, pp. 133-137.

76. Sterling, M. **Linking Manufacturing to Design**, Manufacturing Engineering, October 1984, pp.67-69.

77. Su, S.Y.W. **Modeling Integrated Manufacturing Data with SAM**, IEEE Computer, January 1986, pp. 34-49.

78. Taraman, S. **Assembling a Database for Manufacturing**, Computers in Mechanical Engineering, January 1986, pp. 36-42.

79. Taylor, W.A. **Managing Information in the Automated Factory**, Machine Design, April 1985, pp.77-81.

80. Thyr, R.W. **A User-Driven Methodology for the Design of CAD/CAM and Engineering Databases**, Autofact III Conference Proceedings, November 1986, pp. 11-10 - 11-23.

81. Weisberg, D.E. **Technology Trends in CAD/CAM**, IEEE Industry Applications Society, Annual Meeting, 1985, pp. 129-133.

82. Wheelwright, S.C. and Hayes, R.H. **Competing through manufacturing**, Harvard Business Review, January-February 1985, pp. 99-109.

83. Wheelwright .C. **Japan - where operations really are strategic**, Harvard Business Review, July-August 1981, pp. 67-74.

84. Yates, J.E. **Systems Engineering - A Methodology for Implementing Change**, International Congress on Technology and Technology Exchange, October 8-10, 1984, Pittsburgh, Pennsylvania USA.

85. Young, R.E. and Mayer, R. **The Information Dilemma: To Conceptualize Manufacturing as an Information Process**, Industrial Engineering, September 1984, pp. 28-34.