A METHODOLOGY FOR THE DESIGN OF QUALITY ASSURANCE FUNCTIONAL MODEL AND INFORMATION SYSTEM

by

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A Doctoral Thesis
Submitted in partial fulfilment of the requirements
for the award of
Doctor of Phylosophy
of Loughborough University

May 1997

Department of Manufacturing Engineering
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Dedication

To

My late father and my mother who have laid the foundation of my education and my wife for her support, my son Hossein and my daughter Hadith for the constant joy they bring.

CONTENTS

ACKNOWLEDGEMENTS

The author is very grateful to Ministry of Culture and Higher Education for its financial sponsorship and support.

The author wishes to express his sincere thanks to his supervisor Mr John E. Middle for his invaluable supervision, encouragement, suggestions and help throughout this research study. Thanks must also be extended to my director of research Dr. Allen J. Clegg, and those staff of department of manufacturing engineering who have been kind and helpful, especially David Walters, Clive Turner, and Trevor Downham.

The author would also like to take this opportunity to express his gratitude to the following:

- Dr David Johnson of Business School for his valuable suggestions.
- Dr Richard Buxton of Mathematical Science department for his help and his views on analysing the data.
- Those managers of business organisations which participated in this research.

The author wishes to thank all other research personnel who here and there helped him throughout this work especially Mr. M. Chateuka, and Mr. H.Khalf, and their friendship.

Finally, the author is very grateful to his wife and family who preserved and offered their warm encouragement and help over the past years.

GLOSSARY

ANOVA: *Analysis of variance*

BS5750: *British quality assurance standard*

CAD: *Computer aided design*

CAM: *Computer aided manufacturing*

CAQIS: *Computer aided quality information system*

CIM: *Computer integrated manufacturing*

CIQS: *Computer integrated quality system*

CNC: *Computer numerical control*

CNMA: *Communication network for Manufacturing applications*

COF: *Consequences of failure*

DFD: *Data flow diagram*

DOF: *Degree of failure*

DSDQAIS: *Decision system for design of quality assurance information system*

DSS: *Decision support system*

ER: *Entity relationship diagram*

ES: *Expert system*

EXPRESS: *Data definition language*

FMEA: *Failure mode and effect analysis*

FTA: *Fault tree analysis*

IDEF0: *ICAM Definition methodology*

IQS: *Integrated quality system*

ISO: *International standard organisation*

ISO9000: *Quality assurance standards*

JIT: *Just in time*

KBDS: *Knowledge based decision system*

KBS: *Knowledge based system*

MAP: *Manufacturing automation protocol*

MIS: *Management information system*

MRP: *Materials requirements planning*

OPS: *Order point system*

OR: *Operation research*

PCS: *Process capability study*

PM: *Preventive maintenance*

POF: *Probability of failure*

QA: *quality assurance*

QAIS: *Quality assurance information system*

QC: *Quality circle*

QFD: *Quality function deployment*

QIS: *Quality information system*

QS: *Quality system*

SADT: *Structural analysis and design technique*

SPC: *Statistical process control*

SQA: *Supplier quality assurance*

SQC: *Statistical quality control*

TOP: *Technical and office protocol*

TPM: *Total productive maintenance*

TQC: *Total quality control*

TQM: *Total quality management*

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SYNOPSIS

In spite of all advances in computer technologies, information processing, automation technologies, manufacturing processes, and the push for integration across all functional areas toward a totally integrated and automated manufacturing system, the suggestion is that quality assurance which covers all quality-based functions in the product-life cycle is often overlooked. In spite of the important role of quality information systems in achieving high quality processes little published research in this area is found in the literature.

Study of the available relevant literature and the collection of data from manufacturing industries confirm that different manufacturing situations require different quality assurance systems, and this is evident from the proliferation of differing QA systems found in industry. There are however some common features both universal /or within different classes of industries. Accordingly an ISO-9000 based generic structural model incorporating these common quality based functions and their associated information requirements has been developed.

This research further investigates and verifies those factors which may affect the design of a QAIS as a guide for designing Quality Assurance Information Systems for manufacturing business organisations.

Realising that knowledge-based systems can provide a support environment for designing QAIS, this research also considers and develops a KB Decision System for Designing Quality Information Systems (DSDQAIS). The DSDQAIS recommends the structure of a QAIS, in the form of an IDEF0 model, appropriate to specific company profiles input by the user. Since the available software applications and development tools which support the sub-systems run on a personal computer, the prototype of this system has also been developed and tested on PC. Recommendations for the further development of the system are given.

Chapter 1

Introduction

Increased competition in the world wide market place has forced companies to look for methods and tools to increase productivity, lower costs and hence lower selling prices with improved quality and value for the customer. This has resulted in further innovations in computer information technology, manufacturing processes, automation technologies and manufacturing organisation and management. The use of computer technologies such as computer aided design (CAD), computer aided process planning (CAPP), and computer aided manufacturing (CAM) to some extent have helped in attaining a significant competitive edge. Growing attention has also been paid to create methodologies and computer technologies which enable design of powerful information systems to integrate effectively different parts (islands) of the modern factory and its operations.

This thesis contains a contribution to one aspect of manufacturing information systems which has to some extent been neglected in the past i.e. quality assurance information systems.

This thesis addresses three major areas of research:

1-Design of a generic functional model for quality assurance information systems.

2-The establishment of a knowledge base (algorithm) of those business profile characteristics which may affect the design of a quality information system.

3-A decision system which can be applied as an aid in the design of an information system to support quality-based functions for specific manufacturing businesses.

In spite of all advances in the manufacturing area, and the push towards totally automated manufacturing systems, it is suggested that quality assurance is often overlooked. Nevertheless, companies are waking up to the truth that quality is a major competitive weapon and the assurance of quality, as a key business strategy, is fundamental to successful manufacturing operations. Thus it is becoming increasingly important to establish an effective and powerful quality assurance and control system, and the information system needed to support it . The relevant literature on quality assurance systems and in particular quality assurance information systems (QAIS) reviewed during this research is reported in chapter 2.

The research methodology adopted for the design and development of the business QAIS tool is based on a standard process for engineering design. This process, which involves a seven stage flow chart, is described in chapter 3.

Since quality activities in manufacturing systems span the entire product life cycle, the quality assurance system should be extended from production to additionally cover pre-production and post-production stages of manufacturing. Attainment of quality through all stages of manufacturing requires the performance of a variety of identifiable activities (quality functions). Quality-based functions are discussed in chapter 4.

To satisfy customer expectations and to achieve quality policy in an efficient manner, quality functions must be co-ordinated into a unified effort. To achieve this, an integration methodology and technology is needed which can glue all quality based functions together. In this respect the term Integrated Quality System (IQS) has been introduced in recent years. The integration of a quality system would result from integration of quality functions into one system (vertical integration), integration with other sub-systems of the manufacturing system (horizontal integration) and integration through the production cycle. The concept of integration and the necessity for integration among quality functions, and other business or manufacturing functions, and the structure of a quality assurance information system are presented and discussed in chapter 5.

Effective use of information is a key feature of integration. To design the right products for customers and improve the ability to predict and detect quality problems early in all stages of manufacturing, and to continuously improve, there is a strong need for an information system to support quality functions. A quality information system (QIS) is an organised method of collecting, analysing, and reporting information on all issues of quality to assist decision makers at all levels. Everyone in an organisation needs appropriate information, in the right form at the right time, in order to make timely and effective decisions. With regard to the concept of an integrated quality system, for any manufacturing environment a QIS should cover vertical, horizontal and process integration.

To represent a generic quality assurance information system in the form of a model, a modelling methodology can be used. Such a model will enable the analysis and understanding of the system and where necessary, its improvement or replacement. Various modelling methodologies have been developed, but diagrams or 'graph models' are most appropriate for functional models. Concise pictorial representations aid the system designer through easy visualisation, and they can be quickly understood by a user.

This research uses the IDEF0 graphical modelling technique which ensures that the context for any part of process model under analysis, in relation to the whole of the process model, is always known. Therefore a company can focus on part of a process model it is particularly interested in and develop further levels of detail without losing its context within the whole process. Modelling methodologies and the structural model of the quality assurance information system are described in chapter 6.

Different manufacturing situations will require different quality assurance systems. In order to understand the quality assurance requirements of different companies, and to investigate and verify those factors which can affect the design of a QAIS, an industrial survey was inevitable. Statistical analysis of the data and study of the results, confirmed commonality of some features between different classes of industries. Accordingly it has

been possible to develop an ISO-9000 based generic structural model incorporating all common quality based functions and information requirements. The model is a basis for designing quality assurance systems for various manufacturing industries. On the other hand there are distinctive features specific to different manufacturing environments and a quality assurance system must also provide for these characteristics. The results of the survey, and the effect of business profile factors, are represented as an algorithm. The design of quality assurance information systems is discussed in chapter 7.

Due to the number and diversity of factors that have to be considered, quality assurance systems design is a complex task. It was considered that by using a knowledge based expert system, the general and specific quality based features could be embodied in a set of modular blocks by application of the algorithm (a set of rules, frames or objects) stored in a repository. The Leonardo expert system shell was found to be easy and quick to use, both for development and consultation. This provided a powerful and flexible environment for the rapid development of a Decision System for Design of Quality Assurance Information System (DSDQAIS). The DSDQAIS recommends the structure of a QAIS, in the form of an IDEF0 model, appropriate to specific company profiles input by the user.

The role of knowledge based systems as an aid in the decision system for designing quality assurance information systems, and the development of DSDQAIS, is presented in chapter 8.

Chapter 9 presents a final discussion on the important issues of this thesis relative to the objective of the research, and the main findings and conclusions of the work.

For progressive enhancement of the subject of this thesis, recommendations for further works are discussed in chapter 10.

Chapter 2

Literature Survey

2.1-Introduction:

The aim of this chapter is to review the literature which is relevant to the application of integrated quality systems and quality assurance information systems (QAIS) within manufacturing industry and, in particular, the use of a decision system to support the design of QAIS for a manufacturing environment.

A general review of trends in quality assurance during the past decades is followed by a section identifying the characteristics of the current view of 'quality' and quality systems, and the quality system codes which are being used in the industrial sector.

A discussion of integration and especially the integration of quality-based functions within a quality system, and with other sub-systems of the manufacturing environment, is followed by discussion of the architecture of information systems which needs to be developed in order to integrate quality functions. In this regard a brief description and classification of tools and methodologies which are being used to develop information systems is presented.

The survey continues by reviewing the application of information technology to quality based subjects in particular quality assurance information systems.

The chapter ends with a short discussion of fundamental factors in the design of QAIS, and a review and discussion of the application of knowledge-based systems in 'quality' and the use of knowledge tools as an aid in the design of quality assurance information systems.

2.2-Quality:

A principal factor in the competitive performance of an organisation is the quality of its products and services. Quality has evolved to be an integral component of corporate strategies. What is quality? Definitions for quality, inspection, quality control, quality assurance, quality management and other related terms, can be found in many references on the management of quality [7,8,25,26,27]. An accepted definition of quality is meeting or surpassing customers expectations. All other issues in quality are concerned with fulfilling this objective.

2.2.1-Trends in product quality:

For manufacturing companies around the world, quality has become a cardinal priority and the assurance of quality, as a key business strategy, is fundamental to successful manufacturing operations. Feigenbaum [26] has identified three reasons for this belief :

- Customers have increased their quality requirements sharply;
- As a result of the increased demand for high quality products, company practices have to be updated;
- Quality costs have become unacceptably high.

Juran[7] has suggested that this situation has evolved through a number of changing business conditions including competition, changing customer base, changing product mix, product complexity, and higher levels of customer expectation.

Due to this quality based competition, over the years, several major changes and trends in quality management practices in the manufacturing environment have emerged [64]:

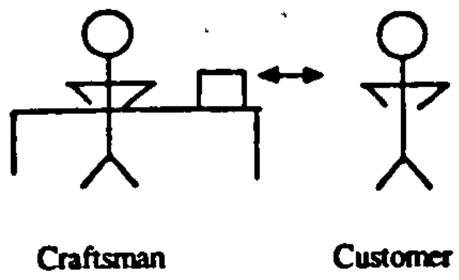
- A shift from an inspection-oriented to a defect prevention approach [8, 87];
- A shift from a manufacturing-focused to a organisation-focused approach;
- A shift to up-stream design and process decisions;
- A shift to downstream marketing feedback on customer perceptions of quality;
- Finding that it is always cheaper to do the job right first time;
- Finding that quality and productivity are often correlated [39].

Advances in communication and transportation have opened the world to international business. World-class quality is essential for those who wish to compete in both the domestic and international marketplace. Companies are recognising that product quality and lengthened warranties are characteristics that sell products. Customers are flocking to companies whose products excel[87].

2.2.2-Today's view of quality:

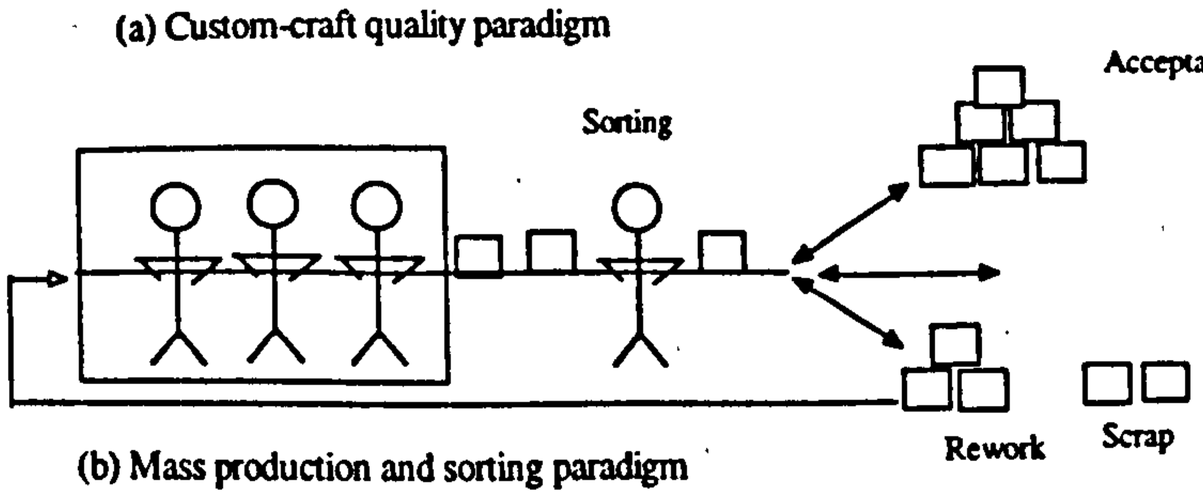
Manufacturing industry today is characterised by a number of business pressures affecting all sectors of the industry. The intensity of global competition in manufacturing has led to a situation where companies must achieve excellence in terms of price, quality, and delivery. In addition to these three criteria, the life cycles of products being manufactured must be shortened as customers demand ever more customised items. These pressures lead to the need for production resources and manufacturing systems to be more flexible, more effective and efficient [61]. Kolarick [63], explains today's situation as the Techno-craft paradigm era. He suggests that the Techno-craft paradigm is a new frontier in quality and customers get exactly what they want. The Techno-craft paradigm seeks to emulate the Custom-craft paradigm in performance, but reduces the cost and the delivery time. He believes a high level of flexibility in product and process design is necessary to make this paradigm feasible, and integrated manufacturing systems are rapidly making the Techno-craft paradigm a reality (Fig. 2.1).

Quality management is now moving beyond defect prevention into quality creation. It can become an integrated process creating profit, improving productivity, and providing greater market share for the company smart enough to use quality management systems in the proper way [87].



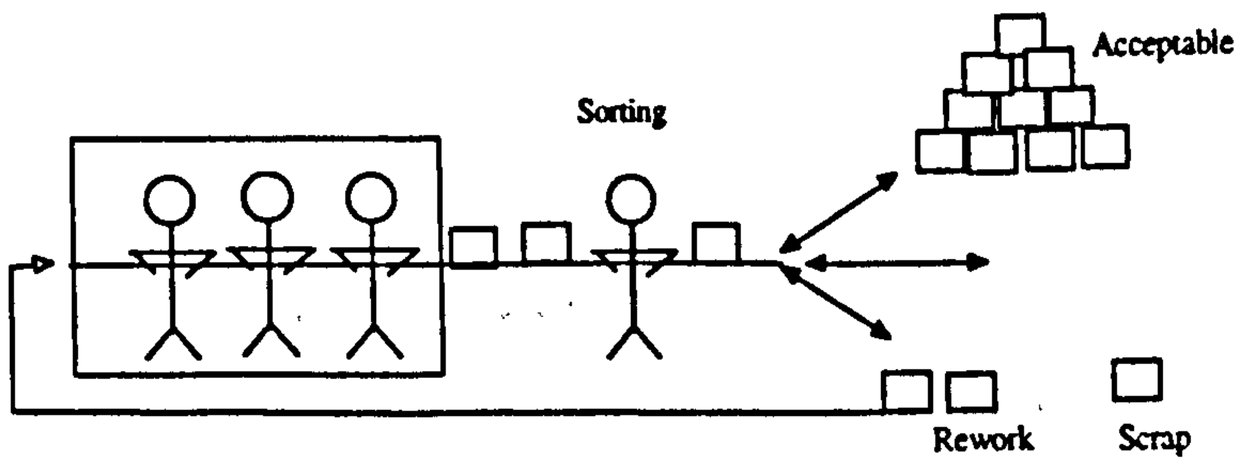
(a) Custom-craft quality paradigm

Each product unit is designed and built exactly the way our customer wants it



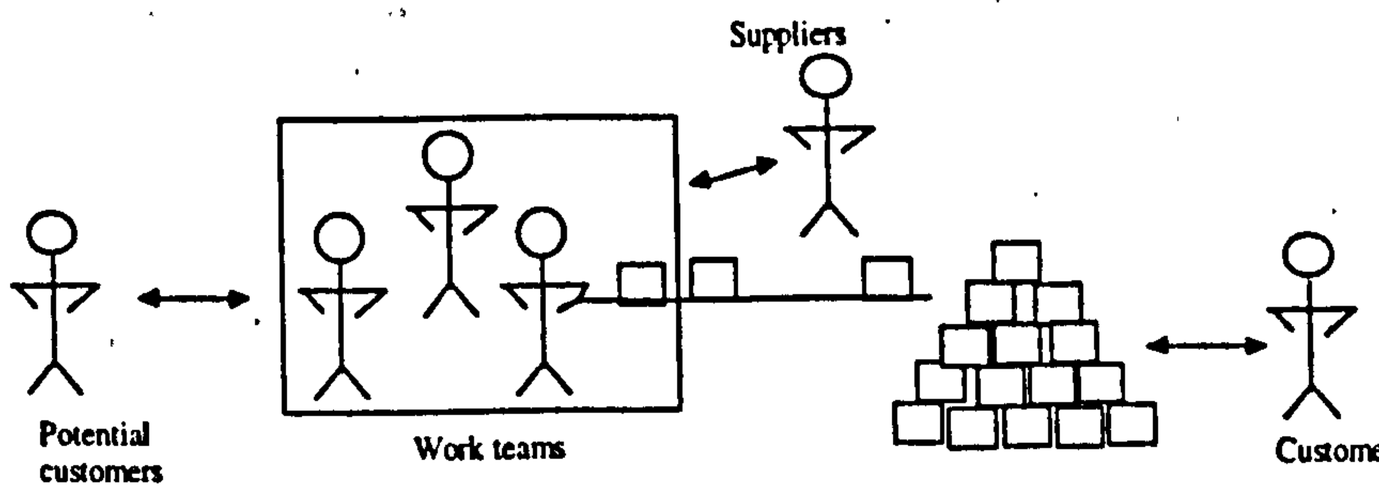
(b) Mass production and sorting paradigm

Products are designed and built, then customers are generated.



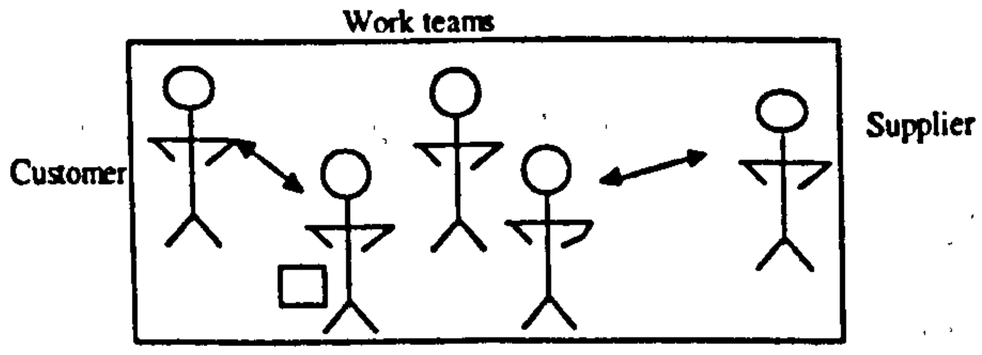
(c) Statistical quality control paradigm

Products are designed and built, statistical process control and statistical sampling are used, then customers are generated.



(d) Total quality management paradigm

Potential customers tell us what to design and build. Using proactive and reactive quality strategies and tools we deliver a product the customers want.



(e) Techno-craft quality paradigm

Each unit is designed and built exactly the way our customer wants it built.

Figure 2.1: The trends on process-based quality thinking (Kolarick [63])

2.2.3-Quality systems:

A world wide trend towards stricter customer expectations with regard to quality is a growing realisation that continual incremental improvements in product and service quality are necessary. To achieve and sustain good economic performance requires an efficient organisational structure, procedures, processes and resources within a company for implementing quality management and to pursue continuous improvement on a long-term basis. A quality system, in the broadest sense, constitutes a culture of people who work as a unit to produce products that satisfy customer requirements [63]. It would be more correct to use the term quality sub-system, because the characteristics concerned are the elements of the whole organisation system that relate to the quality mission [88]. The total involvement of all staff in a quality system together with suppliers, distributors and even customers, in bringing about quality, has become the more recent understanding of another term, quality assurance system.

2.2.4-Quality system standards:

As already said an efficient organisation and appropriate procedures within a company are required in order to fulfil the needs of customers. It is necessary to demonstrate that not only is the product, service or material to specification, but also that the manufacturing operations are under control at all times. Moreover, major purchasers demand proof of a company's ability to consistently produce quality products or provide quality services. This has led to the development of quality system standards. Quality system standards are concerned with the way in which a company is organised and operates, and are dependent on its processes and the products provided [11].

It is well-known that there are three basic levels of standardisation: company, national and international [8] each level having its particular uses. It must not be forgotten that international standards are influenced by many more factors than are national standards and company standards. It is argued that recognised national and international product standards which reflect the requirement of world markets, and not just the particular conditions of the domestic market, can help reduce the multiplicity of procurement

specifications and increase product quality. Consistent compliance with these standards can be ensured through the use of quality assurance systems [38].

There are several forms that quality systems (QS) can take, from those with little-documentation that exist in many smaller plants, through to relatively sophisticated in-house systems. In addition to plant-tailored QS, there are several important published national and international standards [8,12] such as ASQC-Q90, ISO 9000, ANSI Z-1.15, CSA Z299 , DEF 05-21 to 05-29, AQAP-1 to AQAP-9, EN29000.

The five standards in the series - ISO 9000, ISO 9001, ISO 9002, ISO 9003, and ISO 9004 - have been adopted as national standards in more than 60 countries, including all the developed nations [41]. The ISO language is generic; it is intended to be applicable to a wide range of products and services. The first manual, the ISO9000 standard in four parts, describes the quality concept and serves as a guide to which quality models to use. The remaining standards - ISO 9001, 9002 and 9003, are distinct quality assurance models written for specific types of suppliers. The last manual in the series, 9004, sets guidelines for implementing and auditing the actual quality process [42].

It is stated that quality standards themselves must be of the highest possible quality and must be capable of accommodating future changes [40]. Standards such as ISO9000 are generally perceived to be good and comprehensive quality system codes, but they are inflexible. They do not take into account the extreme variability of industry. The value of such codes is, however, that they can be presented as a standard which may be used for constructive comparison and reference [12].

All of these standards reflect what should be, the criterion against which operating results are compared. Therefore, it is necessary, but sometimes difficult, to define and develop unambiguous, precise standards that accurately reflect what is required. Often the only feasible way to do this is through consensus experts. Also it is difficult to keep standards up-to-date and unaffected by physical or operational change [59].

In building a quality system, It is unlikely that any one enterprise would find all elements equally pertinent or necessary [59]. It also has to be stressed that the quality system is dynamic and must be adjusted as process and product quality improves. If the process is capable of producing defect-free product, process control may be minimised [87].

2.2.5-Integrated quality system:

Organisations produce products intended to satisfy users' needs or requirements. Such requirements are often incorporated in specifications. However, these may not in themselves guarantee that a customer's needs will be consistently met.

A good quality system is no more than good management and should cover all aspects of the company's activities and operations [8]. It is increasingly acknowledged that in order to achieve the best quality, business areas such as design, planning and manufacture can no longer work separately and need to follow concurrent engineering principles and rules. Similarly, the term 'concurrent quality assurance' has been discussed [10].

Quality activities in a manufacturing system should span the entire product life cycle and go through the stages of design, manufacturing, distribution, utilisation to disposal after use [9]. These activities should be integrated into an overall manufacturing system [28]. Dessouky et al [65] defines an 'integrated quality system as a co-ordinated set of resources and processes to ensure that the system as a whole achieves its quality objectives'. They consider the relationships of quality-based parameters through the stages of pre-production, production and after production and have proposed a methodology for integrated quality systems. The basis of this methodology is modelling of the transformation which takes place at every stage. Thacker [29] defines the goal of integration as 'the information required by each activity on a timely basis, in the format required'. An information system which supports the quality functions must provide this integration in the manufacturing environment.

Furthermore, it must be stressed that integration is a never-ending process because the enterprise is in a permanent process of change and hence an integrated quality system should be dynamic to cope with such change.

2.2.6-Quality and information systems:

In recognition of the fact that quality is influenced by activities and decisions in all phases of the design and manufacturing cycle, there must be an overall organisational responsibility for quality.

A key ingredient to quality in a product is information [89]. Workers involved in a production line need to know where they stand with regard to quality at every step along the way. Similarly quality policy, methodologies and performance measures need to be disseminated throughout the business. Hence there is a strong need for an information system to support quality functions [2, 24, 197].

The information systems currently used for quality control are largely restricted to manufacturing and confined to such applications as vendor quality rating or shop floor scrap monitoring [4]. A lesson learned through manufacturing competitions is that producing defect free products does not necessarily guarantee customer satisfaction. First the customers and their requirements have to be identified and then the right products to satisfy their needs provided, defect free. On this basis, many researchers have suggested that the quality information system should be extended from the production stage to cover the pre-production and post-production stages as well [2, 3, 4].

According to the philosophy behind TQM, to be successful any company or organisation needs to have defined polices and objectives together with the necessary operational system to achieve these aims in the provision of their product or service. This shows the necessity for involvement and commitment of management. The author suggests that the implementation process for quality information systems would thus involve four areas; management support system, pre-production, production and post-production.

Quality information can be generated in one and utilised by other functional areas. A functional area can be marketing, sales, design, production, purchasing etc. The amount of data associated with all areas, and from which quality information is obtained, is enormous. Some researchers [2, 3, 4, 5] have discussed functions and related data for the QIS in each individual area, but as far as the author is aware, no general function model and information model have yet been introduced.

From the review of the literature on quality information systems, it appears to be possible to develop a general functional model of a QIS which also shows the information which is transferred among quality-based functions.

2.2.7-Organisational position of QAIS:

Based on the understanding that quality is a relatively new competition area, and accepting that the span of responsibility of quality includes all areas of manufacturing and all phases of the product life cycle, the necessity for an information system to support and communicate with all quality functions is clear [2,28].

The literature on quality management rarely considers quality information systems as a specific dimension of quality management frameworks. Giffi et al [102] highlight the fact that information plays a critical role in shaping quality improvement strategy, but do not recognise the quality information system dimension. Some authors assume the quality information system to be part of a management information system. Damachi [43] believes that a computer based quality information system can be created as an integral component of the corporate management information system (MIS).

A significant exception is the model proposed by Binshan Lin [90]. He believes that rapid development of computer integrated manufacturing necessitates the development of coherent systems for supporting quality control activities in a CIM environment. The important aspect of this system is the role of information management in quality control systems. In this paper an architecture for quality control information systems is presented.

Another exception is constituted by Juran and Gryna [7], and Bersbach [91]. They define a quality information system as an organised method for collecting, storing, analysing and reporting information on quality to assist decision makers at all levels.

Juran et al [7] believe that an MIS attempts to provide all the information needs of management through one integrated system. When an organisation implements an MIS, the system will impact on the quality information system. Such impact makes it imperative that those who design QAIS work closely with those who are responsible for the MIS.

Chang [2] following a CIM approach, proposes a general design of a total quality information system. He says that the management information systems and decision support systems (DSS) that support the management and operations in a manufacturing system, and the QAIS, can be considered as individual parts in a CIM environment.

2.2.8-Information Technology and QAIS

It has become a well accepted fact that information technology can significantly improve the efficiency of QAIS and the implementation of quality concepts, leading to conditions that can be met only with the use of information technology [69]. One of the main advantages through information technology is the ability of some machines or process to incorporate on-line quality control automatically. It allows immediate signalling of defectiveness and avoids the repetition of defectiveness before production is stopped. It also makes it possible to collect data to be processed subsequently off-line, removing the need for time consuming and error prone data entry by the operator.

In the literature, there are several applications of modern information technology in the field of quality assurance. Most of these applications have implemented computer-based quality information systems at some level [96,97,100]. Some of those applications represent integrated information systems for quality assurance at specific organisations [96,97,98,99]. However, most of these systems are limited to after-the-fact quality

inspections, statistical process control, calibration, capability studies, quality costs, reliability, vendor quality monitoring, and localised solutions in fixing past crises [101]. As a result, various quality information sub-systems are often not consistent in a single manufacturing organisation. These sub-systems form "islands of automation" to solve specific quality problems.

These quality information "islands" can be transformed into an integrated computer based system to take full advantage of the unique capabilities of computer and management technologies. The computer provides the means of accomplishing quality information tasks with unprecedented scope, accuracy and efficiency [3]. Chen [68] addresses some of the integration problems associated with quality information islands and computer integrated quality assurance.

Papers which present general integrated information systems for quality assurance are often just guidelines for developing such a system, or a framework for the implementation. Chelickna Sylla [66] investigated the issue of information planning for a quality assurance system and introduces an information centre for planning and controlling the quality of products and processes in a factory . The role of this centre is to tie together quality related functions from design through to after sales to optimise overall factory performance.

Jian et al [67] have introduced a computer-integrated quality system (CIQS) as one of the sub-systems in CIM which, they believe, ties together such quality activities as quality planning, inspection, test and monitoring, quality evaluation and quality control, and quality information management to ensure optimum product quality. They claim that a preliminary design of the CIQS has been completed but no evidence of this is presented.
A significant exception is the model proposed by He et al [71]. They have introduced a software system framework for a computer aided quality information system (CAQIS) and a brief explanation of a functional model of CAQIS.

Alexandru and Branici [69] have presented an architecture for a computerised quality system in two levels of a distributed system, the first level with a main relational database and the second with real-time distributed databases. No explanation of this is provided. Sarkis and Reinmann [28] have indicated the importance of architectural approaches for QIS and presented some brief examples of information systems architectures for a quality information system.

Gang Wu et al[72] introduce the hierarchical structure of a computer integrated quality management system which goal is to integrate various quality activities and quality knowledge. It consists of three layers; function integration, quality data integration and quality equipment integration.

2.3-The need for system modelling and integration tools:

Young [61] points out that the successful integration of manufacturing systems needs careful investigation, through analysis and the application of appropriate modelling and integration tools. The need for appropriate modelling tools is also emphasised in Parunak's paper on factory reference models [60].

2.4-Modelling methodologies and information system:

A modelling methodology refers to a class of similar methods, where a method is an organised, single purpose discipline or practice.

Various methods have been developed to assist in the modelling of different aspects of information systems which support manufacturing environments. The methods have been classified into four groups:

2.4.1-Functional modelling methods: The description of a system's functions through the process of function decomposition is provided by functional modelling. A functional model depicts how a certain activity is performed in multi-staged functional levels. The

structural analysis and design technique (SADT) [44] and IDEF0 [45] modelling tools are two widely used functional modelling tools.

- **SADT**

The structural analysis and design technique, SADT, was originally developed by softTech Inc. and has been used in a variety of systems problems. The method classifies schematically the relationship between entities (objects or data) and functions (activities performed by people, machines and computers) [76]. It views the system as a series of diagrams from a top general abstract description, with each subsequent layer representing the decomposition of the preceding layer into greater levels of detail. Each layer is partitioned into three to six main functions each of which is father to the functions in the next lower layer (Figure 2.2).

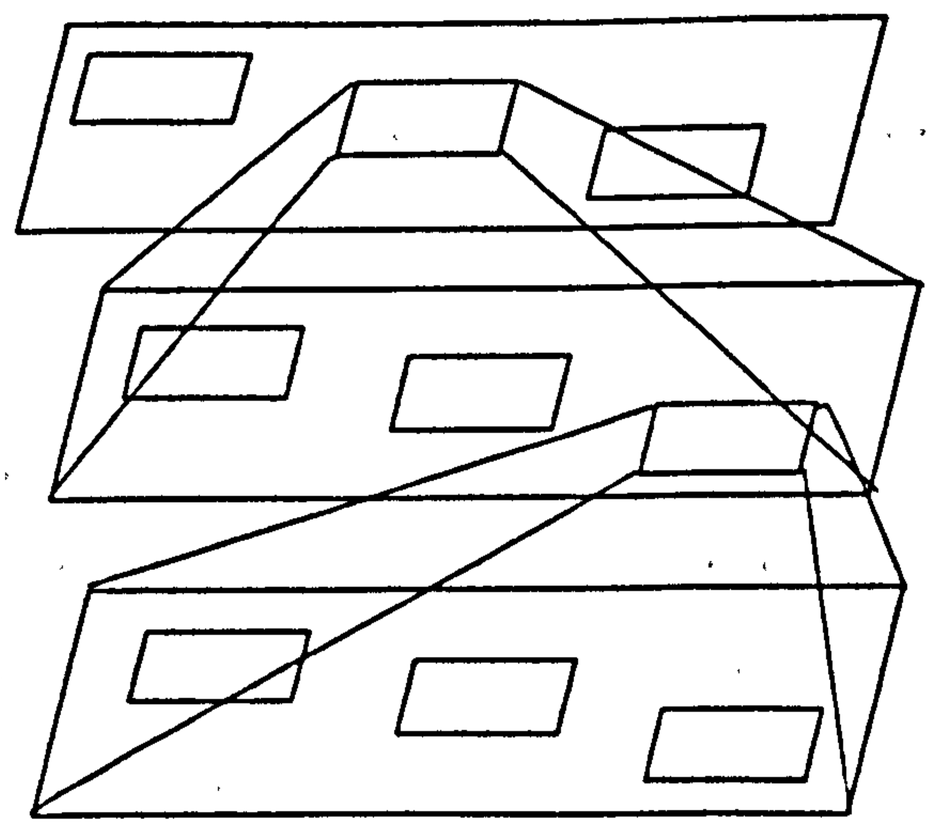


Figure 2.2: SADT diagram

- **IDEF0**

The Integrated Computer Aided Manufacture, ICAM, project carried out by the US Air Force in the early 1970s gave birth to the ICAM Definition, IDEF, modelling language. This methodology is derived from SADT but has been more specifically tailored for conceptual design of manufacturing systems. A total IDEF model views the manufacturing system as consisting of three integrated structures: functions, information and dynamics. These are modelled individually using clearly defined disciplines: IDEF0,

IDEF1 and IDEF2 respectively. The reader can see an explanation of IDEF0 in Appendix I.

2.4.2-Data/information modelling methods: A data model allows the description of the information structure relevant to a system in an implementation-independent format. Data modelling methods have generally been derived as aids to database design.

Information modelling is related to the identification, representation and composition of data, information and knowledge that describe real objects. There are basically two differences between data and information modelling. Data modelling is targeted to generate a data model that is computer processable, the information model is not, but could be computer processed. An information model must be made explicitly and formally documented, therefore data modelling techniques can be used to develop information models [46]. Entity relationship diagram (ER), Data Flow Diagram (DFD) [57, 48], IDEF1, IDEF1X [77], NIAM [49, 54]and Express [54]all follow this methodology.

- **Entity Relationship**

An Entity Relationship diagram provides a view of the data entities and their associated relationships. The information entities can be represented in a real world manner. An important characteristic of this method is its simplicity, and the mapping of ER diagrams into a relational database design is simple and relatively straightforward[78].

- **Data Flow Diagram**

The Data Flow Diagram [79] approach was initiated at Improved Systems Technologies [80]. DFDs provide a view of the data flows inside a system. This is a popular method in software engineering design. It is generally used to schematically determine the information contained within a system. It can be decomposed hierarchically but does not clearly show the process flow in a manufacturing system (Fig. 2.3).

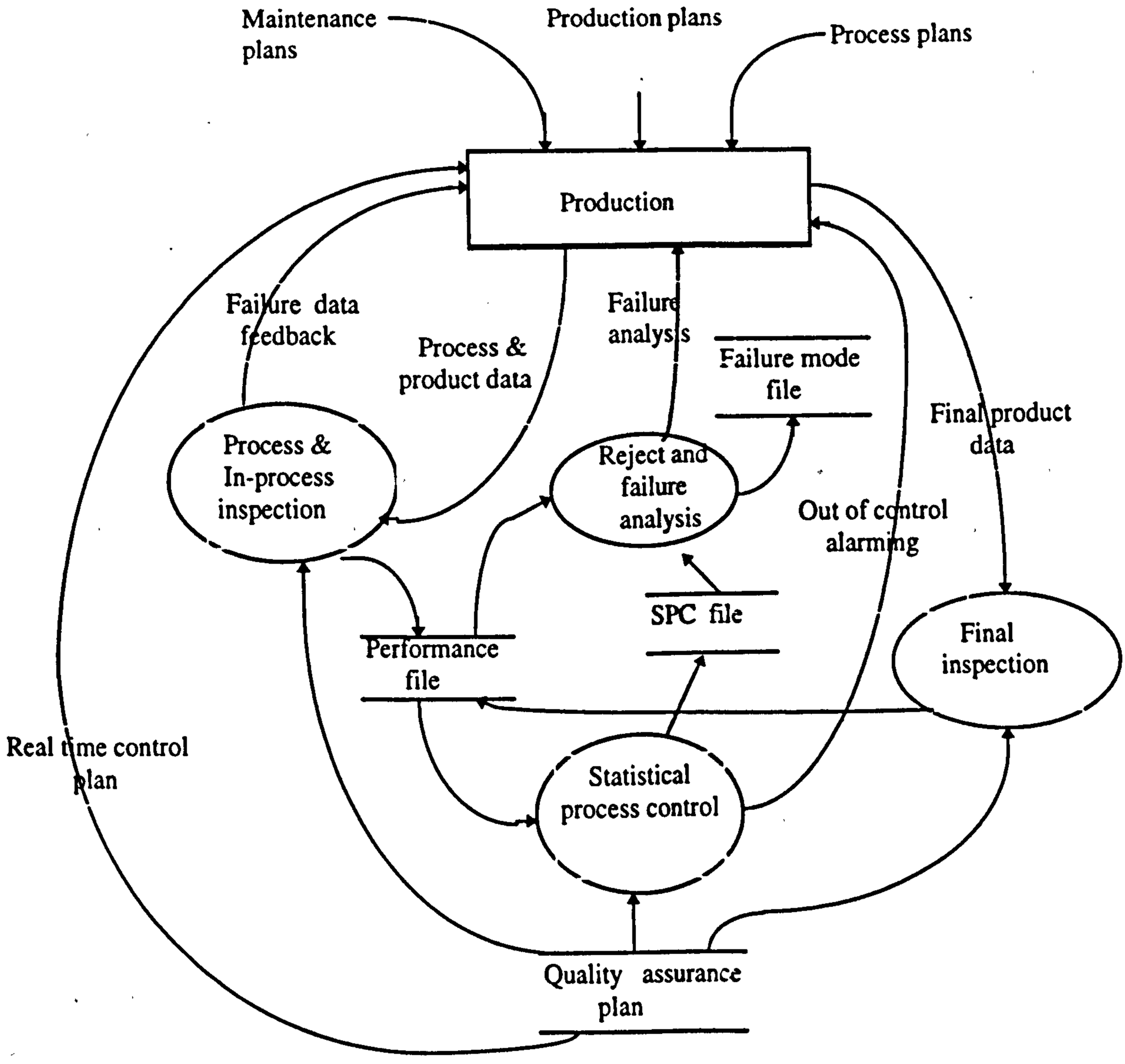


Figure 2.3: Schematic of DFD diagram

- **IDEF1/IDEF1X**

The IDEF1 and IDEF1X [77] methods are similar to ER conceptually, but their graphical representation is different. IDEF1 and IDEF1X are more complicated semantically, thus making them more difficult to use than Entity-Relationship. Nevertheless the IDEF methodology is more integrated within itself than other methodologies.

- **NIAM**

The Nijessen's Information Analysis Modelling (NIAM) methodology is one of the most popular data modelling methods used in engineering. It allows the user to model constraints in addition to showing objects and their relationship [81, 82]. It is simple to learn and use, and can be mapped into a relational database design.

- **EXPRESS**

The STandard for Exchange of Product model data (STEP) has defined a data definition language know as EXPRESS. It allows the development of an information model specification in lexical language. EXPRESS models the constraints which are to be imposed upon the things which are modelled and the operations in which things modelled will participate [83]. EXPRESS-G, which was created in 1990 graphically displays the models written in EXPRESS language [54].

2.4.3-Dynamic behaviour modelling methods: These modelling techniques are concerned with the dynamic behaviour of systems [50]. Behaviour modelling describes the dynamics of a system, operation execution and performance through time [53]. IDEF2 [84]and Petri Nets [51] are examples of this kind of methodology.

- **IDEF2**

IDEF2 [84] modelling aims at describing the time-varying behaviour of a system; the resources used to produce a product; the paths an entity can take and the resources needed along the path; status of resources; and controls on activities [76]. Banerjee [76] states that the IDEF2 process is particularly time consuming and may not be cost effective in real life applications unless a suitable software tool is produced.

- **Petri Nets**

Petri Nets are models for the representation and analysis of systems which exhibit concurrency, parallelism, synchronisation, non-determinism, and resource sharing features [74]. Petri Nets include such features as a graphical tool, is similar to flow charts

and networks and can be used as an aid to visual communication. Petri Nets can be used as a mathematical tool to set up mathematical equations governing the behaviour of a system [51].

2.4.4-Composite modelling methods: The characteristics of these modelling methods is to show real world objects as completely and realistically as possible. The integration and use of different modelling dimensions in these methods enable them to construct models which are a reflection of reality. Object-oriented modelling may be seen as a hybrid methodology tool.

- **Object-Oriented Modelling Methodologies**

The object-oriented approach makes the basic assumption that the world is made of an organised collection of objects [52]. This approach has its foundations in set theory. Each set is called a class and elements of a class are the objects. All objects of a class share the same properties defining their structure and behaviour. M*-OBJECT methodology has been developed as an object-oriented methodology which consists of an object model, a dynamic model, and a functional model [75].

Various studies are reported in the literature which compare the capabilities of different modelling methodologies [53, 92, 55, 56]. To date, as far as the author is aware, no one methodology includes capabilities for modelling the functional, information, dynamic and decision-making aspects of systems. As a result, independent and separate use of a number of methods will be required if the formal modelling of systems is required on a comprehensive basis.

2.5-Modelling tools and quality:

A system is defined as a set of integrated components, functions and processes with relationships between them. Systems modelling techniques have evolved because of the need to represent the functions and processes that occur within the growing number of increasingly complex manufacturing and other types of system that are being designed.

This is primarily in order to facilitate the study of existing systems (as-is) and to aid the design of new complex systems (to-be).

Quality systems and related topics, particularly the quality information system as a sub-system of manufacturing organisation is sufficiently complicated to absorb the attention of researchers and authors. Stephen [6], by using the IDEF0 modelling system, has presented a method of performing independent assessments of quality systems. Ranky [70] in his paper 'Total quality information system design model within a CIM architecture' has used data flow diagrams (DFD) and IDEF0 for system definition. He suggests that they can be used as a framework to build the dynamic models necessary to simulate a system's operational performance.

Chang [5] in considering Quality Function Deployment has used data flow diagrams (DFD) to illustrate a general view of the pre-production stage of a quality information system.

Heredia et al [73] have used the IDEF0 methodology to show a structured framework for an integrated quality system.

2.6-Functional model of QIS:

Manufacturing integration has been the focus of extensive research and development over the last two decades. Different forms of integration can be defined [15], in general three levels of integration have been introduced [29]:

- Integration which concerns the interconnection of different parts of the manufacturing system by means of computer networks and communication protocols;
- Integration which concerns the interconnection of applications and information-based systems requiring the use of exchange protocols and application program interfaces.

- Integration which concerns full enterprise and business co-ordination. This needs a good assessment of enterprise operations, rules, and structures in terms of functions, information systems, resources, applications and organisation unit.

The functional model of a system will identify the functions and functional relationships of activities or processes. Such a model reflects how system functions interrelate and operate just as the blueprint of a product reflects how the different pieces of a product fit together. An optimal implementation of the functional component of the QAIS model would show roughly the physical process it serves. Thus a functional architecture that can be shown as a hierarchical relationship will help modelling of the physical architecture.

There are a number of techniques that are used for identifying the functional architecture of a system. One tool which has proven effective for modelling the functional relationships of an organisational process and addressing the enterprise integration concerns is the IDEF modelling tool. Tannock et al [23] have suggested a number of reasons for utilising IDEF0 as a functional design and documentation tool from a quality systems perspective. By using an IDEF0 model they have presented an integrated quality system for a manufacturing factory and suggest that the proposed model incorporates the ideas of automation and integration in quality data collection, analysis and management.

2.7-Knowledge based system approach to quality:

During the past few years an increasing amount of literature has focused on the application of knowledge-based systems, in particular expert systems, in industrial situations. The two major industrial applications of expert systems have been to provide sufficient knowledge for operatives and staff to perform tasks to a given set of rules, and to assist managers, engineers and experts to reach and make correct decisions in an effective and efficient way. These normally fall into three board areas: diagnostic, process control and provision of advice [18].

Reports on the use of knowledge-based system in the field of quality include: Bailey [19] for controlling product quality in the chemical industry: Hubbell [20] who considers the possibility of using an expert system in statistical process control; Gipe [16] who proposes the use of three levels of expert systems in the cost-based analysis of quality based data; Ballad [21] who postulates on the prospects for expert systems in quality management, using the example of quality costing. Chen [15] has suggested that an expert system can be used to train people to understand the ISO9000 quality system standard. Franz and Foster [13] describe a decision support and expert system for a management application. This provides assistance in designing TQM programs to enhance the quality and productivity of an organisation. It recommends the appropriate technology to implement, e.g. JIT, based on the assessment and selection of characteristics representative of the current status of quality within the organisation. Deslanders and Pierreval [14] present an expert advisory system for quality control, which provides expertise in the selection of quality methods among twenty five chosen methods available in the knowledge-base. Edgell and Kochhar [17] describe a knowledge-based approach to the design of BS5750 (ISO9000) systems. They suggest that it may be used for auditing existing quality systems and procedures in an organisation to highlight the problems which must be addressed and actions required. Birman [34] suggests that using an in-process expert system can help in solving some of the problems encountered when applying SPC to small batch production.

Based on the above, and the review of current directions in expert systems for quality assurance, it seems that the works published to date are related to specific areas such as SPC applications and diagnosis systems. To the author's knowledge, a system based on the overall quality-based functions which will provide assistance in selecting appropriate quality functions and designing the quality assurance information system, does not yet exist.

There remains a need for the use of expert systems and artificial intelligence to place knowledge of 'quality' into computer systems. This way of building a corporate memory

using past experience, can help prevent future problems in new system designs and rapidly resolve problems on current designs.

2.8-Manufacturing technology and quality:

High technology relates to quality in several ways. One is the use of high-technology equipment in the conduct of quality functions for inspection, test, non-destructive testing, analysis, and the use of proven computer-based standards. Another is through application of high technology in design, manufacturing, service, and systems with new or advanced processes, materials, machines and equipment, parts, and computer systems [87].
The availability of microprocessors on equipment has enabled more precise controls to be installed on many processes. This provides for feedback of error signals to correct or stabilise processing variables, resulting in more consistent processing.

Improved processes and more uniform performance through the application of robotics also changes the role of the quality function. The general move to Just-in-Time production and the use of computer numerical control (CNC) machining centres has led to a contraction in batch sizes in many industries. Small-batch production should lay emphasis on the 'right first time' approach to quality control [32].

The techniques of quality control have been developed over a number of decades [31], during which the technology of manufacturing was essentially static in terms of control and strategy. Advances within the past decade have led to substantial changes in the manufacturing environment. Recent trends in manufacturing, such as use of group technology, cellular and flexible manufacturing, and market-driven production have led to smaller lot sizes. Automation including the use of robots, automated inspection devices and automated processes has revolutionised some industries. Changes in the extent, type, and breadth of application of automation call into question some of the basic assumptions of classical quality control. Changes in the mode of manufacturing, such as JIT and the emphasis on smaller lot sizes [31], and short production runs [30] raise further questions as to the validity of classical quality control in the modern manufacturing environment

[31,35]. Alternative approaches based on use of control charts for the machining process, rather than for the machined components have been presented [36,37].

Kegg [33] indicates that statistical quality control (SQC) techniques are not fully applicable to batch production, However he believes that quality improvement can be reached through the reduction in set-up errors achieved by flexible automation.

The application of new technology in the design, analysis, manufacture, and quality control of products affects the quality system used. A careful evaluation of these conditions is necessary to provide the right quality activities, statistical process control, inspection, testing, etc. to end up with a system providing low-cost, high quality products that satisfy the market place. Most importantly the dynamic nature of the manufacturing enterprise means that its systems, including its quality systems, must similarly respond and change with the enterprise.

2.9-Business profiles and quality management:

Much has been written about how quality should be managed in an organisation. The quality literature contains many case studies of successful companies and descriptions of quality concepts. To-date, however; there has been no systematic attempt to organise and synthesise the various descriptions offered.

The quality and quality management literature describes how some business profiles may affect the practise of quality management. Studies suggest that a high rate of change of product/process design may adversely affect the practise and effectiveness of quality management [85]. Armine et al [95] suggest that as the size of the firm is increased; the logistics of meeting overall product quality goals can become extremely complicated as more people, more equipment, more plant sites, and more products are introduced.

A low proportion of product/service purchased outside, a high level of batch content in a process, and a high level of product complexity may affect quality management adversely

in all areas since these conditions create a more-complex product/process environment [85, 86, 95].

Company size may positively influence quality management since larger companies tend to devote more resources and money to organised quality programs than smaller ones.

2.10-Research Focus:

Based on a study of a variety of manufacturing industries, discussed in chapter 7 and the available literature on quality assurance systems, it is clear that many of these different manufacturing situations require different quality assurance systems [94]. It is possible to develop an ISO-9000 based generic structural model incorporating all common quality based functions and information requirements. This generic model can become a base for designing quality assurance systems for various manufacturing industries. The author recognises that a knowledge-based expert system, linked to this generic functional model of a quality assurance information system, will provide a decision system to assist the design of quality assurance systems, with appropriate information flows, to suit the requirements of various business profiles [93]. It is suggested that the IDEF0 modelling tool is capable of representing complex functions and their inter-relationships graphically and show them as a combination of functions. It ensures that the context for any part of a process model under analysis in relation to the whole of the process model is always known. Therefore it is possible to focus on any part of a process model in which there is particular interest and develop further levels of detail without losing its context within the whole process.

Chapter 3

Outline of research methodology

3.1-Introduction:

In spite of advances in computer technologies, information processing, automation technologies and manufacturing processes, and the push for integration across all functional areas towards a totally automated manufacturing system, the suggestion is that quality assurance is usually neglected [103]. The author recognises that in the context of company-wide quality [26] and ISO9000 [104], to satisfy or surpass customers' requirements can be achieved by designing quality into every aspect of an organisation in the form of an integrated quality assurance system [93].

In order to achieve the above objective, there is a strong need for an information system to integrate and support all quality functions. It is clear that the first step for establishing an information system is to know the destination of the information, that is who requires the information, where and in what form. Then it is necessary to determine the appropriate source, where, who, what and how the information is obtained. The answers to these questions may be easily represented by building a model which uses symbols for destinations, sources, and information.

It is also clear that different manufacturing situations require different quality assurance systems. It is necessary to identify and understand how major differences in the manufacturing environment will have an important influence on choosing quality functions to suit a particular environment. However, literature review has revealed no significant directly relevant published research. The author recognises that through reviewing the literature on manufacturing quality assurance in general one can reach

some conclusions on which manufacturing criteria may affect the design of quality assurance information systems. However, it was considered to be insufficient to rely only on literature, and it was decided that the knowledge of human experts, those who have successfully implemented quality functions in their companies, should be collected, by questionnaire technique, and analysed.

Due to the number and diversity of the factors involved, by embodying the results as rules in a knowledge base, an expert systems approach can be utilised to consider all of them and to recommend appropriate elements for specific cases. Such an expert system will help disseminate expertise and best practice in the design of quality systems and quality information systems when incorporated into a decision support system.

3.2-Methodology:

The overall methodology adopted for this research has been:

1-Acquisition of knowledge, through literature research and questionnaire methodology, of quality functions and information needs of manufacturing;

2-Building a generic model of those essential quality-based functions, and associated information flows that take place within a manufacturing environment;

3-Preparing an algorithm for the design of QAIS by reviewing, assembling and analysing the available knowledge of quality assurance systems and its application in various manufacturing environments, and finally;

4- Designing and building a knowledge-based decision-support tool to serve in the selection of appropriate quality functions and information needs to suit specific company profiles.

The process adopted for design and development of a tool is based on the standard process for engineering design. The process involves a seven stage flow chart which has been schematically represented as Y-shaped and shown in Fig. 3.1 [105].

Stage 1A: Confrontation: This project is described as the development of an algorithm and expert system tool for the selection of a structural model of manufacturing quality information systems. The area of application would be in the quality assurance management sector. Some companies have an abundance of expertise in areas such as quality systems design. On the other hand, there are many companies in which such expertise is limited or non-existed. An expert system capturing available knowledge and best practice, and supporting a quality assurance system design model is potentially a valuable decision support tool.

Stage 1B: Source of information: The only reliable sources of information are published literature on manufacturing quality assurance systems, expert industrial practitioners and academic researchers working in the quality domain.

Stage 2A: Formulation of problem: Due to the number and diversity of factors that have to be considered, quality assurance information system design is a complex task. It is not sufficient to evaluate each of the factors individually, since many of them are interrelated. Also, whereas in the past markets had been characterised by similarity and stability, the characteristics of today's markets are their differences and high rate of change necessitating flexibility in manufacturing processes and systems. Using an expert system as a design tool which consider all factors and can recommend the structural model of a quality information system to match strategic and operational need is well justified.

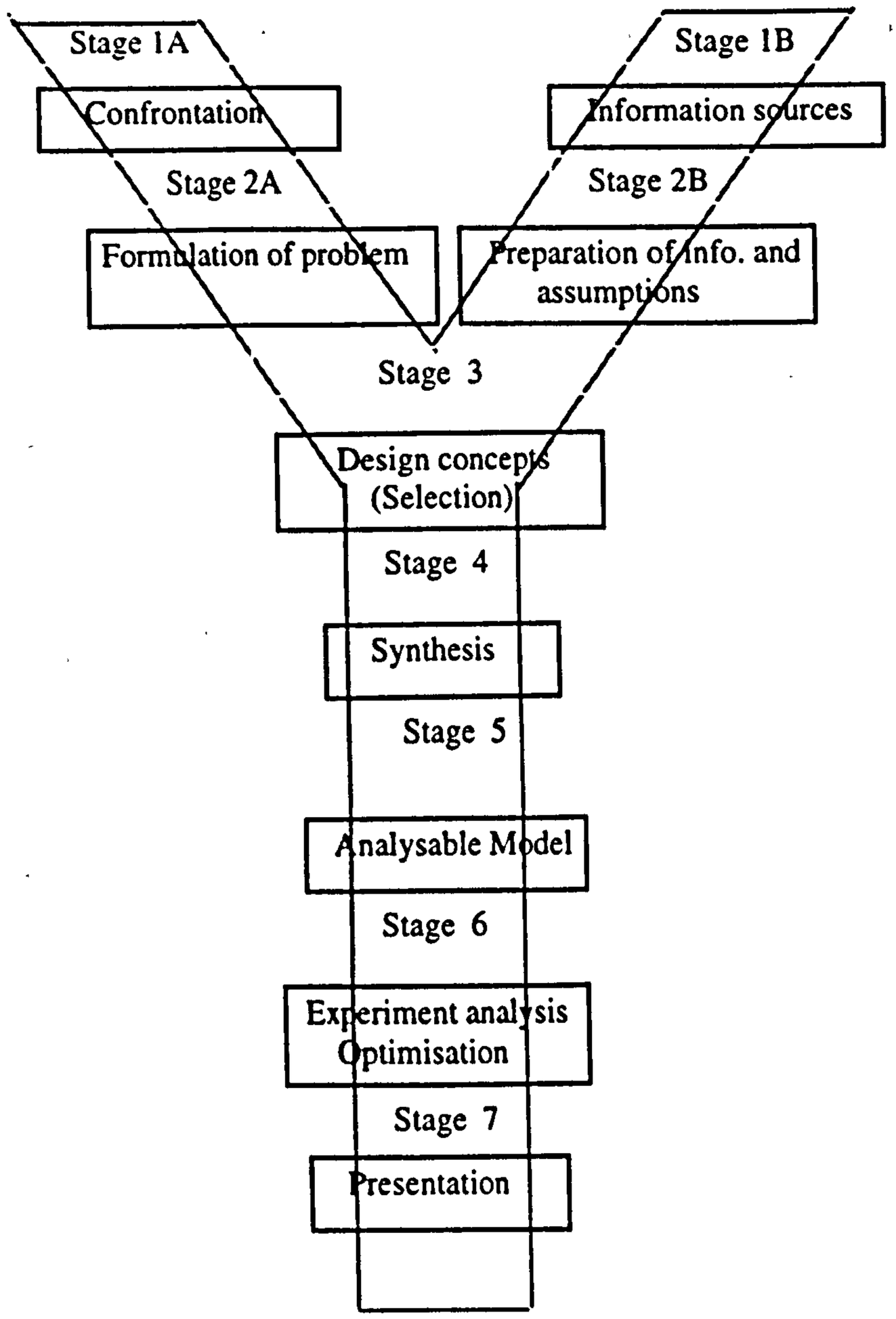


Figure. 3.1: The seven stages flow chart of design methodology

Stage 2B: Preparation of information and assumptions: It was estimated that the time required for knowledge acquisition would be very long because, in many instances, human experts are not very efficient in explaining the way in which they arrive at conclusions and make decisions. Therefore a well-structured questionnaire was used to

elicit knowledge. Allowing a process of data analysis to be applied to much of the information received.

At this stage, first a generic functional model of quality assurance information system was prepared. Next, according to that model, the questionnaire considering the different manufacturing profiles and quality functions was developed and sent to selected various manufacturing organisations.
Assumptions made have been discussed in chapters 5 and 7.

Stage 3: Design, Concepts (Selection): Keeping the foregoing stages in mind and considering the problem, two alternative design concepts were conceived as discussed in chapter 6.

- Designing a graphical algorithm model
- Designing a mathematical model

Stage 4: Synthesis: In a mathematical model, the objects and their attributes are represented by mathematical variables. The operations and actions are described by mathematical functions which define the interrelationships between variables.

Analytical approaches using sophisticated mathematical techniques require precise definitions, otherwise they cannot adequately represent the object. For developing an expert system tool the interrelationships between variables are shown in the form of rules. These rules can in turn be incorporated in the graphical algorithm model itself.

Stage 5: Analysable model: The collected data regarding quality assurance systems can be analysed in three ways:

1) For the quality functions found in each business profile;

2) The business profiles which utilise specific quality functions;

3) Correlation among company profiles and among quality functions.

It is thus possible to put together all the results in an algorithm. The algorithm will recommend elements of a QAIS appropriate to specific company profiles, determined by the user.

Stage 6: Experiment, analysis, optimisation: The best way for doing analysis and experimental validation on the algorithm is to test the algorithm in situations in which it will be used. The questionnaire in particular provided data of good practice in various manufacturing environments and the algorithm could be tested by using that data.

Since the design process is not a one-way, single-pass effort, it is often necessary to use feedback and iterations to optimise the design. Any optimisation of the algorithm was to be done in this stage.

stage 7: Presentation: An expert decision support system and a graphical tool are to be demonstrated. To enable transformation of expert system output to graphical mode, a transformation tool was developed by the author to enable the automatic creation of graphical models. On directly entering the profiles of a business by a user, the system recommends the functional model of QAIS in a graphical form.

An overview of research methodology has been shown in Figure 3.2.

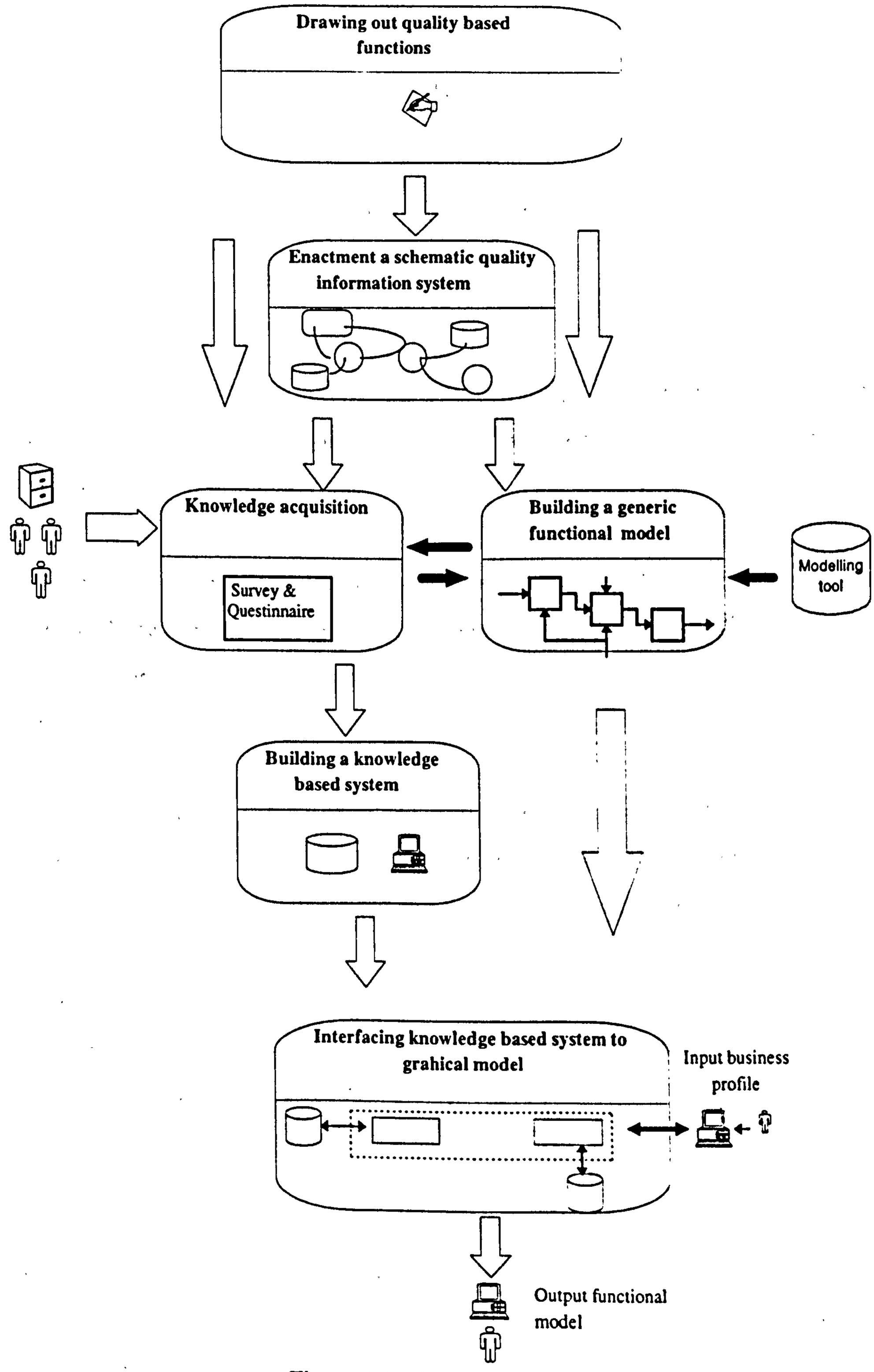


Figure. 3.2 : Overview of research methodology

Chapter 4

Quality functions

4.1-Background:

Quality has evolved to be a major competitive weapon, and the assurance of quality, as a key business strategy, is fundamental to successful manufacturing operation. This quality-based competition has resulted in several major changes in quality management:

1-Total Quality Control (TQC) concepts are being adopted throughout manufacturing. It begins with the specification and design of product or service and ends only when the product or service has been placed in the hands of the customer, who is, and remains, satisfied.

2-Quality has become the responsibility of the entire organisation and not just manufacturing. In this case Total Quality Management (TQM) is a way of managing to improve the effectiveness, flexibility and competitiveness of the business as a whole [25].

3-The assurance of quality has become increasingly important as technologies and societies demands have become more complex. The total involvement of all staff in an organisation together with suppliers, distributors, and even customers, in bringing about quality and satisfaction has become the recent understanding of quality assurance [27].

4-More than ever, public and private sector clients demand documented evidence of an organisation's commitment to quality. In this way, quality standards, and particularly

ISO9000, have emerged which play a strategically important role to guarantee that the supplier conforms to fundamental product quality assurance requirements [88].

5-The emphasis on quality of physical products in manufacturing industries has changed, and now includes application of quality concepts to all products, all functional activities, and all industries. It now lies in the design, planning, and control of all activities related to quality attainment, the goal of satisfying the customer. In other words, attainment of quality requires the performance of a wide variety of identifiable activities, quality tasks or quality functions.

Quality functions are the entire collection of activities through which the business achieves fitness for use [8]. It is evident that some these quality functions are performed within manufacturing companies and the others are done elsewhere.

4.2-Quality functions

It is possible in any organisation to identify quality functions. The achievement of fitness for use or meeting all of a customer's requirements involves the performance of a number of separate activities in a logical progression [8].

To achieve this, the quality-based activities needed, are divided among many sections in the organisation. To satisfy customer expectations and to achieve quality policy in an efficient and effective manner, these functions must be co-ordinated into unified effort.

4.2.1-Quality assurance in marketing:

A manufacturing organisation must define its place in the market and the goals it wants to pursue. For this reason, it must know the market potential, developments, technical and commercial trends, product innovations, future supplies of resources, and its competitive status[106].

The objective of an effective quality system should be to satisfy customer needs and expectations, whether the customer is the ultimate consumer, user or second party. As with all functions in an organisation, activities within the marketing function can benefit from the application of quality concepts.

One essential contribution of total quality programs today is the establishment of customer-oriented quality disciplines throughout the whole organisation, especially in the marketing section [26]. On this basis, the successful and superior performing companies are those that continually watch the market and pursue changes to meet the demands of the market.

In order to develop optimised company strategies to be competitive, a company also has to know its main competitors. Their status and strategies will affect the company in setting its own offensive and/or defensive strategies [2]. In this regard, the benchmark technique may be used to judge quality of products in comparison to those of competitors.

Identifying the product features, specific customer requirements and the level of quality that will persuade customers to purchase a product are other quality-based functions that should be considered, for example through the marketing input to the Quality Function Deployment (QFD) methodology.

4.2.2 Quality assurance in sales:

Although the way in which customers' orders and requests are placed and then are satisfied may be quite different, they have some quality assurance functions in common. As soon as orders or enquiries are received by sales, details will be discussed with relevant sections in order to agree on specifications and acceptable delivery date. The tender and after that the contract which will be prepared for the customer should be adequately defined and must satisfy the requested requirements. Any differences between the contract and tender should be resolved, and the supplier

must be sure that it is capable of meeting the tender and contract requirements. The contract review function as required by ISO9000 may be the means by which this is achieved.

4.2.3-Quality assurance in product design and development:

During the product development phase, the overall design will be developed and validated. This will involve not only the preparation of drawings and detailed specifications of product, but also the application of various techniques to ensure the design is optimised.

The best production/operation methods cannot compensate for poor or inadequate design, and design activity is fundamental to the creation of product quality. According to research, around 40 percent of fitness-for-use problems of complex mechanical and electronic products arise from errors during product design and development. This statistic for process industries in which product development is responsible for both creating the design of the product and developing the manufacturing process, is around 50 percent [7].

Quality, reliability, safety and durability cannot be inspected into a product. These must be designed in before manufacture by the effective and accurate translation of customer requirements and desires as indicated by market research, into practical designs and specifications for materials, product and processes.

Because of the complexity involved, it is useful to document and analyse the design logic for modern products. Such an approach has a variety of names such as systems engineering, functional analysis, and Quality Function Deployment (QFD) [110].

QFD is a powerful technique for converting the consumers' demands into quality characteristics and engineering solutions, and developing a design quality for the

finished product by systematically developing the relationships between the demands, characteristics and solutions [111].

- **Design review:** Design and development normally follow a chronological sequence of conceptual design, preliminary or embodiment design and detailed design. The design review process, as required by ISO9000, serves as a proactive tool which can help designers to improve product design [63]. At the conclusion of each phase of the design development cycle, a formal, documented, systematic and critical review of the design should be conducted. Tools such as Fault Tree Analysis (FTA) and Failure Mode and Effect Analysis (FMEA) may be employed in the design review process. As appropriate to the design phase, the following elements should be considered:
  - The feasibility of the design with respect to function, form and fit;
  - The producibility of the design with respect to production-process capabilities;
  - Verify that the design will indeed satisfy customer requirements.

- **Failures reporting and corrective action system:** With the help of historical records of previous failures maintained by sales, and the reliability laboratory and other sections in the manufacturing area, critical failure points are highlighted in a FMEA. The FMEA is utilised for study, action and removal of the potential causes of failures before releasing designs and drawings. It is also used in the recommendation of corrective actions for inclusion in later desired engineering changes [5] and for improving detection methods of remaining potential faults.

- **Prototype of design:** Design validation may be undertaken independently or in support of design reviews by building and testing prototypes as a pre-production test. Prototype test results aid the subsequent quality assurance planning. They indicate the characteristics that may need more attention, and help establish cause-and-effect relationships between process and product. The effects of significant factors at different quality levels or values can also be studied.

- **Reliability, safety in design:** In addition to customer needs, the designer needs to give due consideration to the requirements relating to safety, environmental, ergonomic and other necessary regulations. Today. there is an increasing amount of international legislation which places certain constraints on designs, which must be taken into account prior to the production of products and services for sale [8].

  Potential critical failures must be identified. The failures that might occur in a product or its components, and the effects that such failure might have in its operation must be predicted, and the steps which should be taken to prevent determined.

- **Quality documents:** Quality assurance in design hinges considerably on the quality of the associated design documentation. There are, for instance, the design principles and procedures, codes and standards. Design documents should be reviewed with regard to :

  -Accuracy, adequacy, and clarity.

  -Design activities and decisions must be traceable in case of future failures and defects.

  -Customer and producer must have clear information concerning quality characteristics.

  -Process planning, production planning and production require final product descriptions and drawings.

- **Test instruction:** Although inspection and test are widely considered to be non-value-adding activities, in some manufacturing enterprises and for some products, it is essential to conduct tests of some of the details of material in process, and finished product. Since much time and money is often invested in this appraisal work, the test functions must be properly developed and instructed, and strategically applied.

- **Quality characteristics:** As products become more complex, with many factors affecting performance, it becomes difficult to know (1) what factors do affect

performance and (2) what nominal values to set for each factor [7]. One of the purposes of development testing is to investigate these matters. Taguchi [192] has developed a method for determining the optimum values of product and process parameters which will minimise variation while keeping the mean value a target.

Quality characteristics as the attribute or measurable factors are unequal in their effect on fitness for use and clearly, the more important characteristics should receive the greater attention. For product quality characteristics, this may involve such classification as: critical characteristics, major characteristics, minor characteristics and incidental characteristics [26]. Such classification of characteristics enables the quality effort to be directed to the matters of greatest importance, thereby assuring required quality and continuous production at minimum quality cost.

4.2.4-Quality assurance in process planning and development

Process planning analyses existing processes and/or designs the new processes required to produce the designed product, and determines the processing sequence needed to produce the end product.

The increased complexity of products and processes and, for example, the lack of buffer inventory to replace defective products under just-in-time production systems make it necessary to place the emphasis on defect prevention and to perform an evaluation of process design. Various evaluations should be done to ensure that processes satisfy the end product design specification, including [7]:

- Clarity of all requirements
- Availability of processes to meet tolerances
- Ability to meet special requirements
- Relative importance of product characteristics
- Special skills required of manufacturing personnel
- Availability of measurement processes and equipment
- Ease of access for measurement and test

4.2.5-Quality planning and standards:

Quality goals and standards are developed along with process planning, so the establishment and specification of quality standards can help to assure that the planned processes will produce the product with quality of conformance.

The concept of TQM involves everyone in an organisation in satisfying their customer needs and continuously improving their part of a process. Therefore, individual sections need to take the lead and become responsible for matters pertaining to quality improvement. In this case the following activities are likely to be facilitated and/or co-ordinated by the quality assurance department:

- Developing quality plans according to quality policy determined by management
- Developing a quality system which will satisfy the quality plan
- Developing a quality manual and procedures
- Defect/failure analysis
- Quality cost analysis
- Quality training

4.2.6-Quality assurance in purchasing:

Very few organisations are self-contained to the extent that their products are all generated at one location from basic materials. Some types of materials, components and sub-assemblies are usually purchased from outside organisations and therefore contribute to the safety, reliability, and quality of the products. In this case. the quality of purchased items becomes increasingly important, especially given today's emphasis on applying a JIT (Just-in-Time) manufacturing strategy. In this context if a portion of the purchased product is defective, production would be disrupted. This is due to absence of back up inventory.

Although the value of purchased items varies from one industry to another, on average it would be approximately 60 percent of turnover [7].

In view of the fact that the overall objective of any purchaser is to obtain the correct materials with consistent high quality at the right time and minimum price, it is essential to set out a purchasing system (Fig. 4.1) in a written manual which specifies the responsibility, the means of selecting suppliers and the documentation to be used.

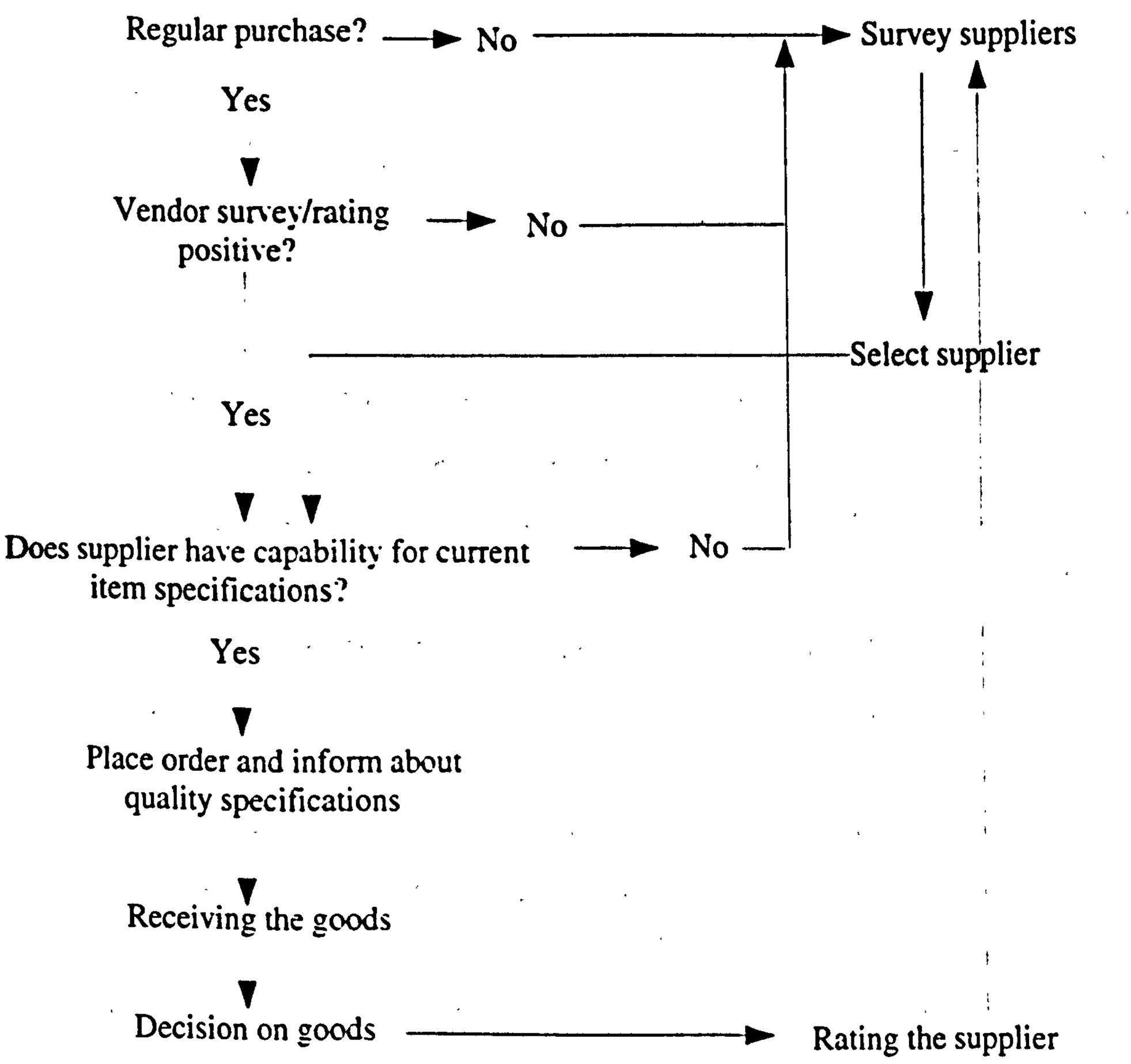


Figure. 4.1: A broad view of a purchasing process

- **Supplier Selection:** Before anything else, the buyer must transmit to the supplier a full understanding of the specification and use of the product and

must also obtain information to be sure that the supplier has the capability to provide a product that meets all customer's requisites, including delivery schedules, etc., at agreed cost.

Having defined the requirements, it is necessary to decide the number of suppliers. Both multiple source of supply and single source of supply have their advantages but the trend now is to work with a small number of suppliers and to achieve good supplier/customer relationships or partnerships.

There is a variety of methods for assessing a supplier's capability. These are ISO9000 certification, on-site assessment of supplier's capability, evaluation of product samples, past history with similar supplies, test results of similar supplies, and published experiences of other users.

- **Supplier rating:** The objective of a supplier rating system is to ensure that suppliers are, at least, maintaining the required standards of quality and service. Supplier rating is used to select a supplier. Six factors can be used to measure the performance of a supplier: price stability, price level, delivery promise, delivery performance, quality, and accuracy [107]. In single source relationships, business performance might also be important.

- **Supplier surveillance:** Surveillance is a continuous monitoring of the status, procedures and methods of the supplier. In fact it is an auditing of the supplier's quality assurance system which is done by the purchaser in relation to the stated references. This is to ensure that specified requirements for quality continue to be met. Surveillance can take several forms such as inspection of product, inspection of process and others. A certified supplier is typically one who is found, after extensive investigation, to be capable of consistently supplying quality material. There is usually no need to perform

routine inspection/testing on each lot received. Supplier certification can take several forms but it relates to supplier-purchaser contract management.

- **Verification of receiving materials:** Procedures should be enforced in the goods-receiving area to ensure that the right quantity of the right materials has been supplied. So any goods received should be accompanied by the supplier's advice note, which should include supplier's details, purchase order number, details of goods delivered, and details of packages.

- **Incoming materials inspection:** Incoming material control activities place strong emphasis upon control of material at its source, but receiving inspection is recognised as very important. Evaluation of supplier product can be achieved by using one of the following methods:
  - The purchaser relies on the suppliers quality assurance system;
  - inspection/testing by the supplier;
  - Submission of specified inspection/test data or process control records with shipment, and possibly a certificate of conformance;
  - Lot acceptance inspection/testing by sampling or 100% inspection by the purchaser;
  - Implementation of a formal quality assurance system as specified by the purchaser;
  - Without inspection or "ship to line" with inspection on the line.

To "stream line", the incoming inspection, statistical acceptance sampling is used as widely as possible in place of 100 percent, spot checks or no inspection [26]. There are measurable risks associated with sampling, but it is well recognised that inspection itself is a far from perfect activity.

- **Non-conforming materials:** With any incoming material or product there may arise instances of non-conformance. The supplier should be notified by

the purchaser with precise descriptions of symptoms or defects. Decisions on received non-conforming material depend on agreements between supplier and customer and should be mentioned in the purchase contract. Such decisions and actions range from return to supplier for rectification or replacement, concession to use as received, to rectification by the purchaser. Control, documentation and the information flow relating to non-conforming suppliers is a critical aspect of the SQA system.

- **Purchase contract management:** Today's circumstances have led to a revolution in the relationship between buyers and suppliers. The key word is partnership, working closely together for mutual benefit of both parties. Each side's success is dependent upon the other's. In this case the supplier can be required to operate a quality system that meets the requirements of ISO 9000, and/or satisfy the purchasers own SQA system requirements such as Ford Q101 [113].

4.2.7-Quality assurance in production

As mentioned before, quality cannot be inspected into a product, first, it must be designed in, after which the manufacturing function is responsible for producing products in accordance with the design requirements.

To prevent non-conforming products being made, manufacturing must be carried out under controlled conditions in the specified manner and sequence. Quality assurance assumes an enlarged and different role under the TQC setting in the production stage:

- **Process capability studies:** Every operator, machine or process has inherent variability and the extent of this variation is referred to as its process capability. Consequently, processes should be verified as being capable of producing product in accordance with specifications. So, there is need to:

* Consider the process capability of work methods in order to ascertain whether a task can be accomplished satisfactorily;

* Establish the process capability of existing plant

* Monitor process capability on a regular basis to detect and eliminate potential causes of non-conformance and variation and to identify plant maintenance requirements.

* Use such information in the design and process planning procedures.

- **Preventive maintenance program:** Experience has shown that an interaction exists between quality of the products and quality of production equipment [108, 198]. So equipment needs to be adequately identified, maintained, stored in appropriate conditions and be well protected between use, and verified or recalibrated at appropriate intervals to ensure its optimal capability and precision. A programme of preventive maintenance (PM) is an important quality assurance technique because it enables a regularly scheduled examination of processing facilities before they break down or reach a critical state. This ensures continuing process capability, with special attention being given to equipment characteristics that contribute to key product quality characteristics, and simultaneously increases productivity. Total productive maintenance (TPM) is an extension of the concept [109].

- **Training:** One of the essential ingredients of broad-scope quality assurance is an extensive amount of training. The quality assurance system can be successful in assuring customer satisfaction at proper profit only if it is operated by knowledgeable, capable people who want to make it work. In other words, everyone should understand and recognise that achieving and maintaining a reputation for product quality is vital to the success and growth of an organisation and to every individual within it. So appropriate training should be provided to all levels of personnel within the organisation performing activities affecting quality. With regard to commitment and

involvement of all personnel to achieve quality objectives, the following training items based on a manpower plan should be provided in the organisation:

- Overall training in quality system subjects and awareness;
- Management and technical personnel training;
- New operator quality familiarisation;
- Inspector and tester training;
- Field personnel training;
- Rotational training for flexible skills;
- Training effectiveness measurement;
- Personnel quality participation;
- Skill analysis and provision of job training

- **Process and in-process verification:** Inspection and test typically include measurement of an output and comparison to specified requirements to determine conformity. Inspections are generally performed at important points in the production process for the purposes of process control. The locations and frequency of the inspection stations will depend on the importance of the characteristics, nature of production process and ease of verification at the related stage of production. Verifications may include the following checks:

  * Set-up (first-off) inspection
  * Patrol inspection
  * Fixed sampling inspection
  * Fixed continuous inspection (100%)

- **Statistical process control (SPC):** Once a process has been defined, SPC can be used to ensure the output conforms to requirements. Statistical process control (SPC) is a means by which an operator (or controller) can determine

whether a process is producing, and/or is likely to continue producing, conforming output. In fact, it is a preventive approach to manufacturing process control. SPC also enables a business to reduce the variations in the output from a process. The key questions asked when using SPC methods are [25]:

i) is the process capable of doing the job correctly?

ii) is the process actually producing confirming output?

iii) can the process be improved to reduce variability?

- **Final inspection:** To augment inspections and tests made during processing, it is customary in some situations to perform a final verification and test of completed items prior to delivery of goods from one processing department to another or prior to shipping completed products to storage or to customers. Two forms of final verification are available:

  * 100% inspections or tests may be used to ensure that finished product conforms to the specified requirements.

  * Inspection of samples selected as representative of completed lots of products may be used to ensure conformance to specified requirements.

  Final inspection and test, and possibly issue of a certificate of conformance may be a contractual requirement imposed by the customer, and carried out according to strict procedures. In these circumstances, unlike much of inspection actually, this is a value-adding activity. Indeed without this inspection the product has no value.

- **Non-conforming product:** Methods for preventing processing. completion or delivery of non-conforming product are essential to the control and improvement of product quality. It is important that suspected non-conforming product be immediately identified and segregated and then should be assigned appropriately for reworking, scrapping or resubmission under concessionary procedures.

Reject analysis will be done on results of in-process verification. final inspection and statistical process control to identify the defects and their causes so that the appropriate corrective improvement actions are initiated.

- **Measuring and test equipment:** Any measuring equipment will at some time during its operating life have been or have to be adjusted to the required accuracy within known limits. It should not be assumed that just because a device was once correct it will remain so for ever.

It is clear, any measurement work is valueless unless its results are known to be valid and sufficiently accurate for intended purpose. So for equipment in regular use, either installed in connection with some processes or in use in a factory or laboratory, checking at regular time intervals provides a good assurance that measurements taken with it will be satisfactory. The intervals at which calibration is desirable will vary with the nature of the device, the conditions under which it is used and the seriousness of the consequences if it produces incorrect results [8].

Essential to implementing equipment calibration is to have a documented system such as ISO 10012 quality assurance requirements for measuring equipment [114] which is capable of providing and demonstrating that the necessary control is exercised over all equipment.

4.2.8-Quality assurance in post-production

In order to ensure that a business is successful, customer loyalty must be retained so that repeat orders do not pass to a competitor. To do this, as has been mentioned before, it is necessary to provide a quality product at the right price. But this is probably not enough if a company wishes to attain world-class standards and remain in the competitive market, since it is also necessary to deliver product on time and service the customer after delivery.

The need to provide this post-production service depends on the type of business and all of the activities of this sub-system may not pertain to a given company.

Quality assurance functions will cover two sections: pre-use phase and use phase.
Pre-use quality-based actions shall be:

- **packaging process and stocks area :** Research has shown that more customer complaints are caused by store activities, especially in packaging the product, than were caused by the original manufacturing [106]. Packaging needs a sequence of quality based functions similar to those used to achieve a quality product itself. These activities include design and the purchasing, manufacturing and testing of packaging materials [176].

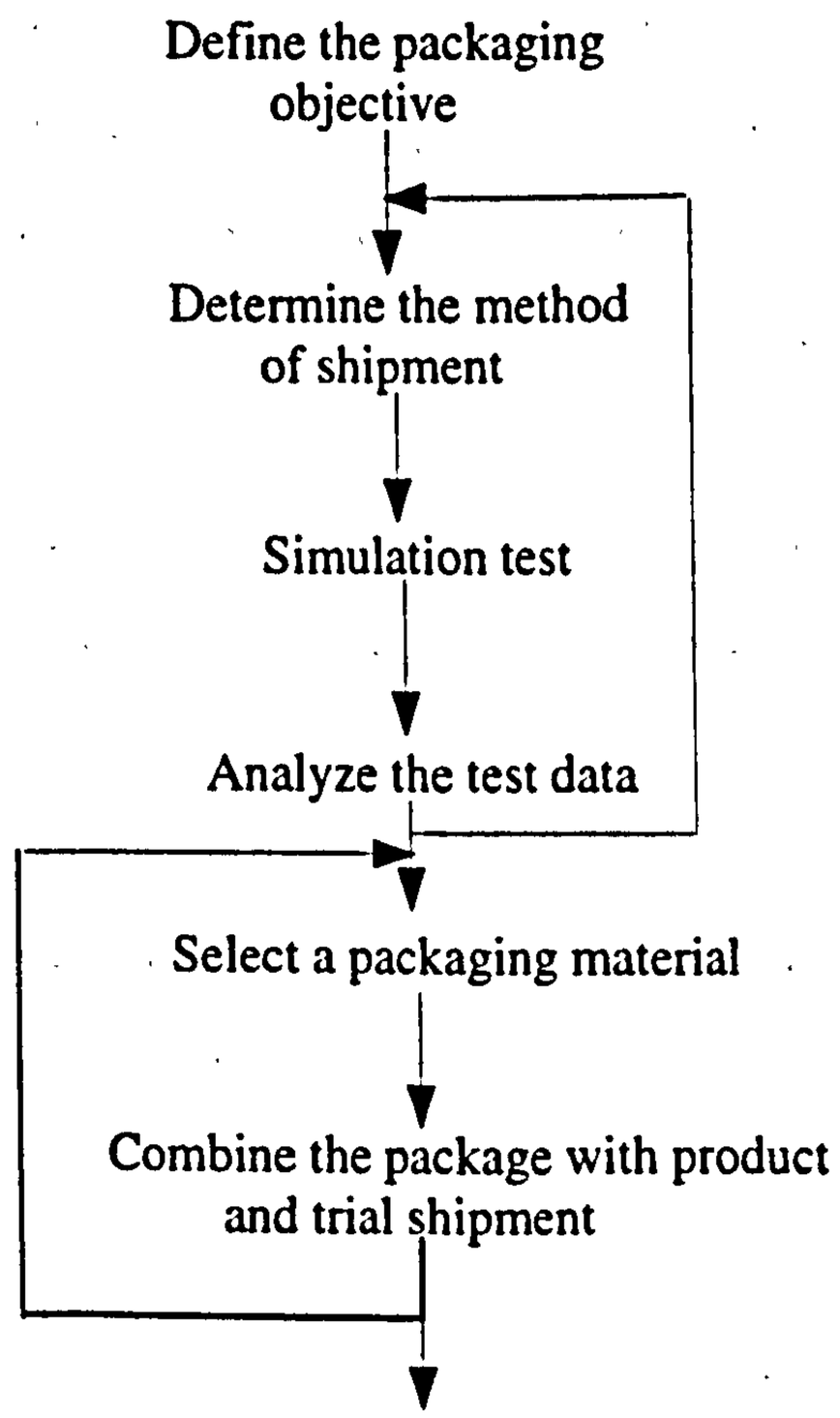


Figure 4.2: A schematic of handling program

- **Handling methods:** The method of handling materials and goods needs to be considered carefully in order to prevent damage occurring. So the handling of materials requires a proper program and documented system. Fiedler [112] has

recommended a seven-step program for protecting product during handling as shown in Fig. 4.2.

- **Delivery:** To some extent, the way in which deliveries are made to customers will be governed by the type of orders received, but the way in which delivery is specified on an order can vary such as direct, phased, on-time and back-order. In any case, provision for protection of the quality of product, specifically those products with limited shelf-life, or requiring special protection must be done during all phases of delivery. A delivery audit plan should be developed and carried out in order to determine whether the delivery system is defect free.

- **Installation:** Before the packaged product is put into use, it undergoes additional processing during installation and check out. The installation and check out may be done by specialists or by the user, in any case, instructions for installing and commissioning must be available and include provisions which preclude improper installation or factors degrading the quality, safety of performance.

The use phase or after-sales is as important as delivering the product itself. An effective after-sales programme guarantee to sustain customer satisfaction with both the product and its supplier.

- **Warranty:** When the product is made available to the customer, it is valuable to guarantee the quality of the product to the customer. Two kinds of general warranty and special warranty either "full" or "limited" are applied.

A full warranty is not limited in time and means that the manufacturer will fix or replace any defective product free of any charge during the agreed product life.

- **Complaints' procedure:**. Collecting, analysing, and responding to customer complaints about a product are essential in order to minimise customer

dissatisfaction, and to contribute to continuous improvement activity. On the other hand, the process of handling customer claims and complaints has emerged as an important tool of competition in achieving sales.

As the size of company and the number of complaints increase, the need for a systematic approach to handle the complaints, as shown in Fig. 4.3, also increases.

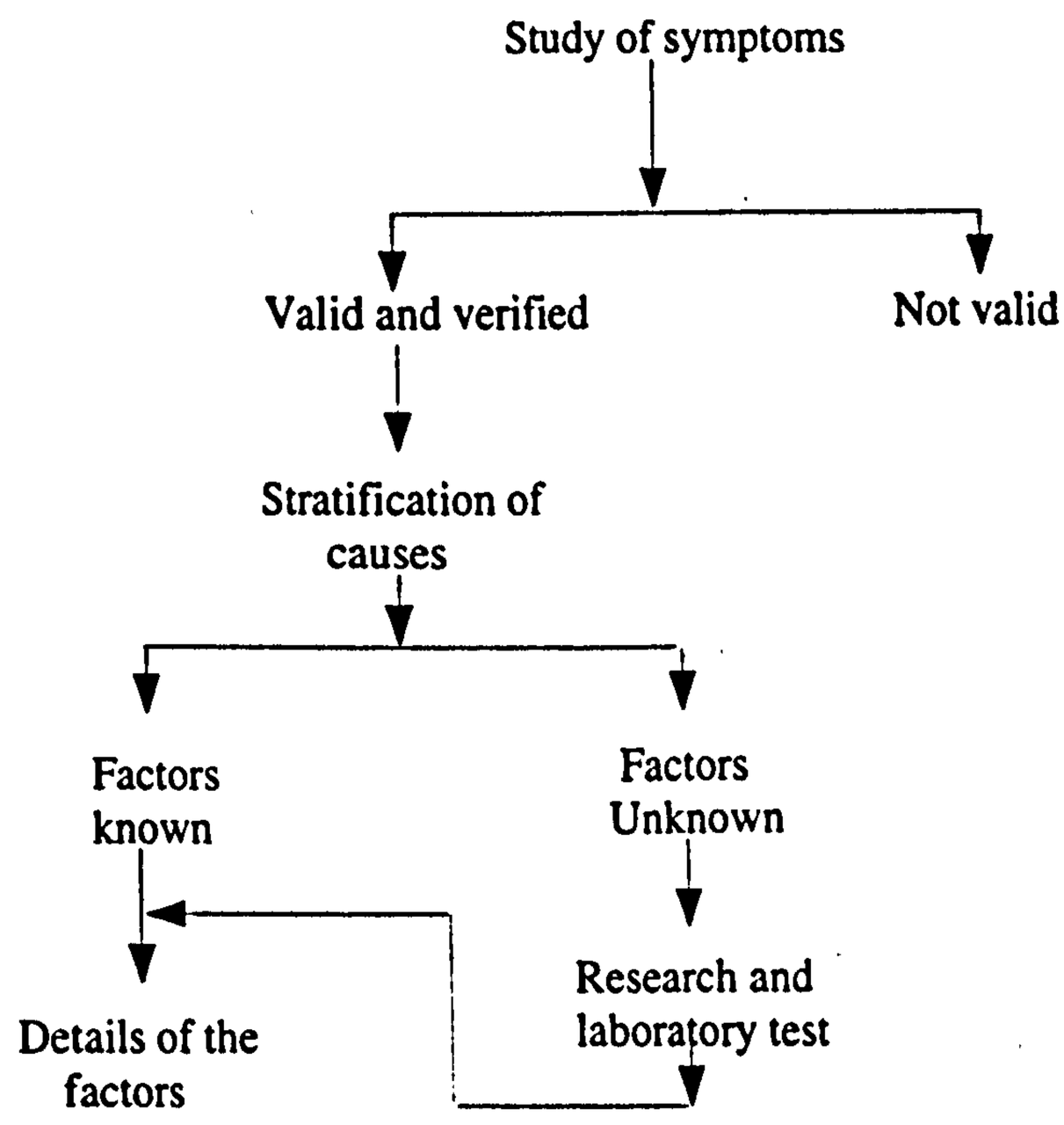


Figure 4.3: A scheme of organised approach to quality problem solving

Each quality complaint poses different problems requiring different programs of action:

-Satisfying the complainant

-Identifying the serious complaints

-In-depth analysis to discover the basic causes of the complaints

-Feed back the results of analysis to other parts of the organisation

The accumulated data of field complaint analysis can be useful as a basis for ongoing improvement of process variation in many process oriented ways.

- **Failure Analysis:** Failure analysis can be applied at any stage of product life, so it is suitable that this analysis be used in the post-production phase to analyse the complaints and returned products. It is a means of going back into design or process to make changes that will improve quality. In this case various techniques and methods have been introduced such as FMEA, Fault Tree Analysis (FTA), Cause and effect diagram, etc.

Fault Tree Analysis is an important reliability/safety design technique which starts from consideration of system failure effects. The analysis proceeds by determining how these can be caused by individual or combined lower level failures or events.

- **Reliability testing:** To be fully effective, it is recommended that failed returned products are sent to the reliability laboratories for testing and failure analysis. The resulting analysis often serves to diagnose the basic cause for abnormal operation so that corrective action can be taken on the particular unit under test. The analysis of product failure, and assembly errors can be used to point out where corrective action should be taken or where further study should be made.

- **Customer audit:** Measuring and improving customer satisfaction with the product or service is an important consideration for any organisation that wishes to remain in business. Customer satisfaction, which is the ultimate validation of design and conformance to design however, is most difficult to measure accurately. Numerous factors can effect customer loyalty, and it is necessary to take account of all of them to provide a practical measurement system. This study can be done in two ways:

-personal interviews

-sending a questionnaire with the product or mailing the questionnaire at some time thereafter.

Among the important attributes which can be measured are the following[26]:

-Quality of product operation
-Quality of product functional design
-Quality of shipment
-Quality of product installation
-Maintainability
-Serviceability
-Quality of service

It is not sufficient to rely on unsolicited feedback, which will generally be complaints. It is generally accepted that only 1 out of 10 dissatisfied customers will complain. Therefore solicited feedback (audit) should be deployed to sample the whole source of information and to ensure that any positive feedback is also obtained.

4.3-Company-wide quality:

To achieve the right product with reasonable price at the right time, all areas in a organisation and everyone that directly and indirectly affect the product should work together as an effective system. Failure in one part of the system creates problems elsewhere, leading to a cycle of more failure and more problems. In other words, if every section in the organisation is satisfying their own impending customers' needs (Fig. 4.4) then there is a much greater chance that the final product will meet the ultimate customer expectations.

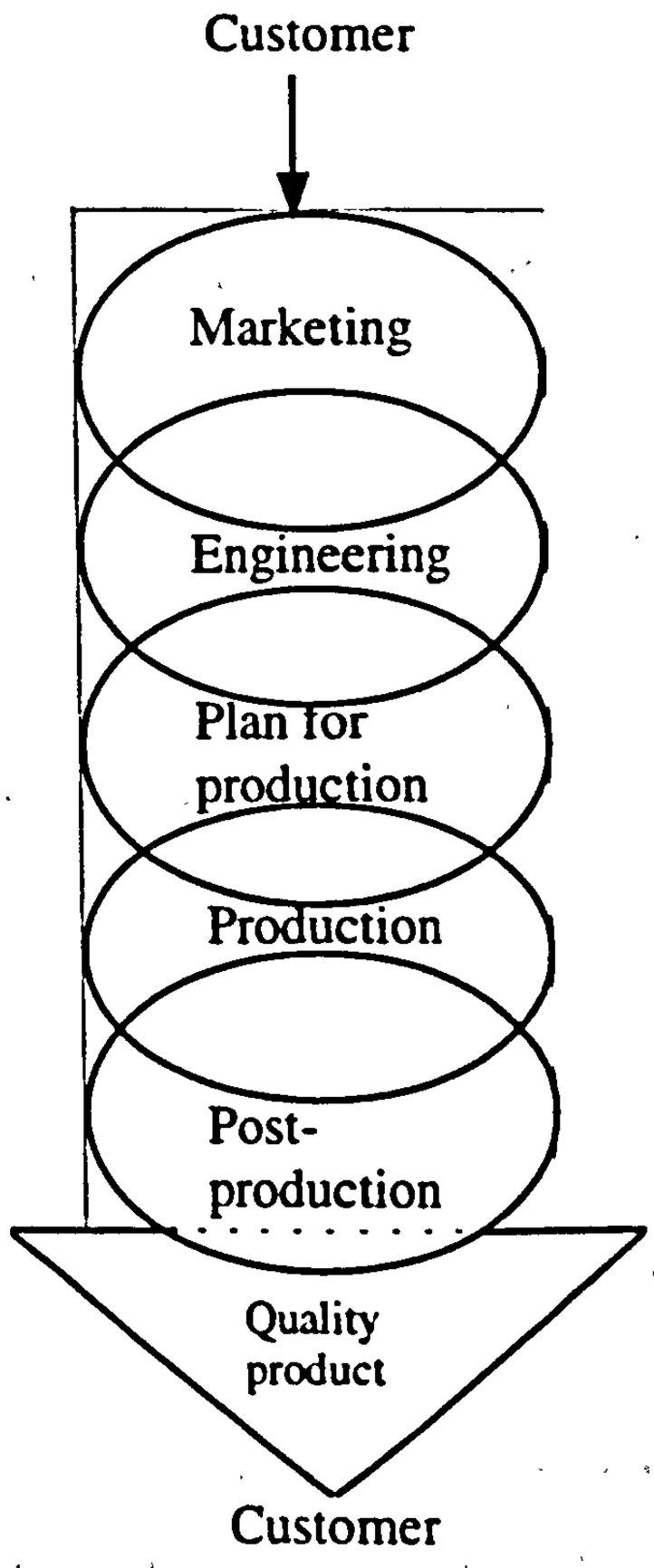


Figure 4.4: Schematic of satisfying customer requirements

4.4-Summary:

Quality has become the responsibility of the entire organisation. Quality-based functions are the entire collection of activities among many sections in the organisation through which the business achieves meeting customer expectations. Those quality-based functions which take place within different sections of any manufacturing environment were drawn out and discussed.

Chapter 5

Integrated quality assurance information system

5.1-Introduction:

As mentioned in the last chapter, an important fundamental in modern industry and in today's quality assurance is that quality is everybody's business. The responsibility for quality is spread throughout the entire organisation, and areas have to work together as an effective system.

In contrast to the above principles, the traditional quality control function is typically a separate department set up to detect problems through methods such as inspection and appraisal. This is inefficient and costly for companies operating in today's highly competitive world markets. As a result there is a trend among forward looking companies to distribute quality responsibilities, yet to integrate all quality functions with each other and into the manufacturing process, and ultimately throughout the entire organisation, thereby achieving better results at less cost. Integrated Quality Systems(IQS) have been developed in recent years and are attracting the attention of those companies who actively seek comprehensive solutions to improve their competitiveness.

5.2-Integrated quality system-The concept:

The three words making up Integrated Quality System(IQS) define its meaning; a system which integrates all quality functions. Quality functions were described and explained in the previous chapter. The quality actions must be brought together in proper relationship through the quality system to provide the single major function of getting a quality product to market. Before any discussion about IQS, it is better to have a clear understanding of what is meant by "integration".

Integration is the key concept in the new approaches to manufacturing. However, as Below[116] believes, no universally accepted definition of the meaning of "integration" exists today. Various definitions of "integration" have been presented. Most dictionaries define "integrate" as to make a whole, to unify the parts of something. Most dictionaries of computing terms define "integration" as the facility of computer hardware or software systems to work in conjunction with previously incompatible systems. Several authors, however, considered integration as more than mere physical compatibility of equipment and components[185, 186].

Thacker[118] defines integration as 'the information required by each activity available on a timely basis, accurately, in the format required, and without asking.' Petrie[184] implicitly assumes a broader concept of integration for the enterprise and suggests that enterprise integration(EI) is the task of improving the performance of large complex processes by managing the interactions among the participants'. He emphasises that the most important feature of EI is the focus on improving the co-ordination among interacting organisations, individuals and systems.

All in all, the term "integrated" refers to the fact that all the elements of a system must work together for the system to function as a whole and an integrated system is representative of how an organisation is structured whereby each function is related to other functions either directly or indirectly forming a total system[120].

In considering quality assurance as a system within an organisation which itself has other sub-systems, and referring to the definitions of integration, it is clear that the concepts of integration can be applied to this area.

Several researchers have discussed this issue. Steel[117] suggested that an integrated quality system is a systems management of quality related responsibilities which extends from the identification of customer needs through integration of quality related functions at all levels. He believes that the integrated quality system is the system management

process of doing what companies have wanted to do, but have previously been unable to do, to improve their quality.

Jian[67] believes that while integration of the engineering design and manufacture of products is a major task in today's manufacturing environment, quality control and quality assurance play a unique and important role in the manufacturing enterprise and should not be considered as an individual part but should be integrated with other systems.

Dessouky [65], by considering improvement along four principal dimensions or axes of statistical quality control, total quality control, human resource management, and quality management, defines IQS as a co-ordinated set of resources and processes to ensure that the system as whole achieves its quality objectives, along with other objectives such as productivity and profitability. This systems approach spans the entire product life cycle and includes all levels of the manufacturing system with emphasis on long-term quality planning, and quality based human resource development.

In simple terms , the objective of IQS is to integrate all phases from initial identification to final realisation of requirements and customer expectations in order to achieve maximum effectiveness and full customer quality satisfaction.

5.3-Dimensions of integration in quality systems:

Manufacturing and business integration has been the focus of extensive research and development over the two last decades. Goranson [119] believes that the dimensions of integration, up to user or supplier requirements, are different. He suggests three dimensions of: inter-company integration, intra-company integration and value chain integration' for enterprise integration (EI). Figure 5.1 illustrates the types of integration which can be realised in manufacturing enterprises [123]. The primary goal of EI is to achieve functional integration in an organisation. Integration of the enterprise begins with

a conceptual understanding that discrete, functional elements can work more efficiently and economically together than apart [118].

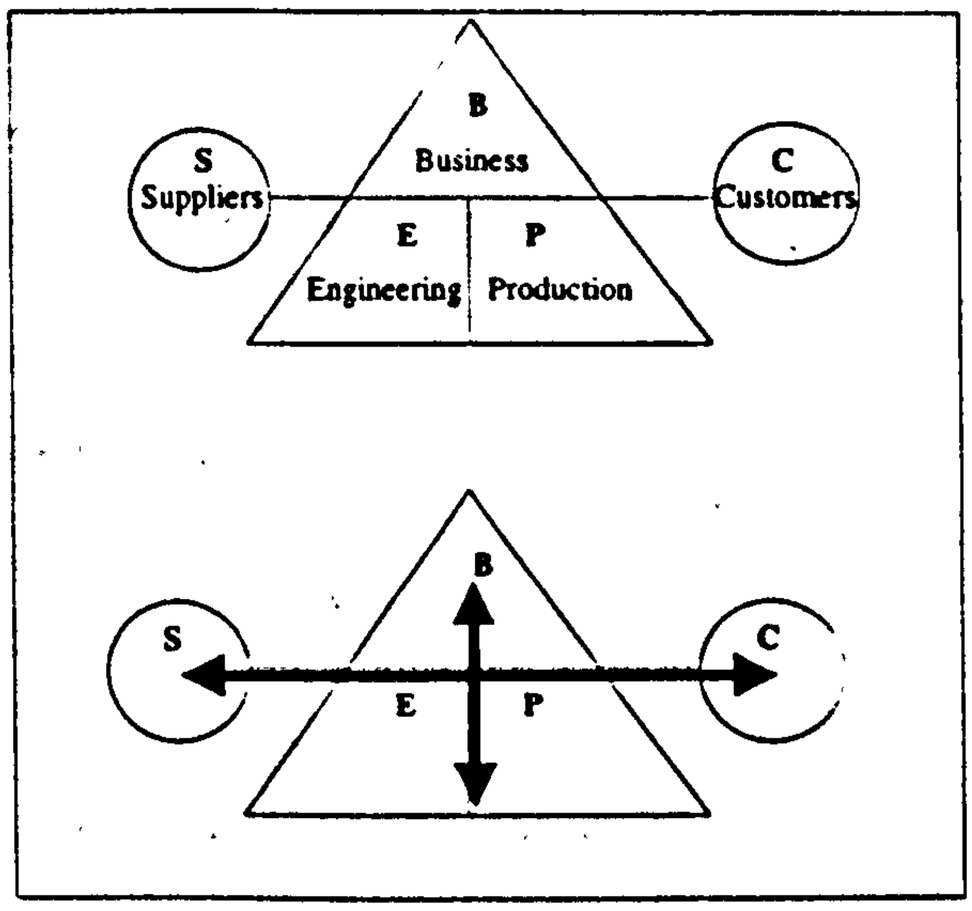


Figure 5.1: Types of integration in manufacturing enterprise

By considering high quality as a major objective and responsibility of the entire organisation, and not just manufacturing alone, the quality system plays a unique and important role. In an integrated business, to prevent isolation of the quality system module and to reach the objective behind IQS, it must be integrated to other functional areas and, at the same time, all quality functions within the quality system have to be integrated with each other: vertical integration and functional integration. Although various authors have explained these two dimensions in different terms, the meaning behind all of them are almost the same. Kolarik [63] suggests that these two dimensions are intra-system integration and inter-system integration. Tannock [23] suggests 'process integration' as the third dimension of integration and Goranson [119] introduces 'value chain integration' which provides integration among partners and users in a dynamically configured value chain and it is often termed electronic commerce. Figure 5.2 schematically shows the integrated quality system.

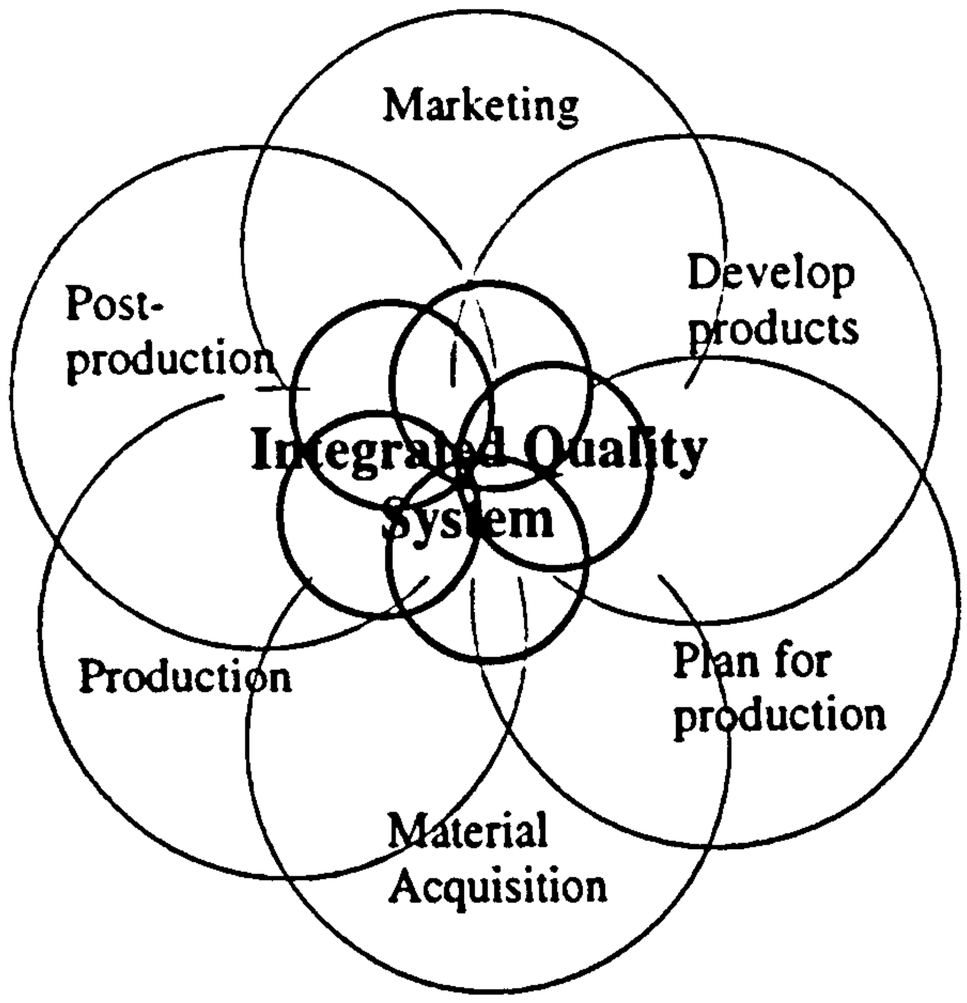


Figure 5.2: Schematic of integrated quality system

5.3.1-Vertical integration: Depending on the size, type and nature of business, a quality system itself will include sub-systems and functions. The quality system must be internally integrated and focused on addressing customer needs and expectations. All quality-based activities from the marketing phase, where customer needs and competitors' strategies are studied, through pre-production design and planning, and quality control during operations, to the post-production service and follow-up activities, where feedback is collected to determine the level of customer satisfaction, have to work in an integrated environment. Information and data on quality performance may be passed upward from, for example, lower level inspection to quality management. On the other hand, quality plans will pass downwards from quality management to inspection and horizontally between functions.

5.3.2-Functional integration: A quality system cannot operate alone. The quality system must be integrated with other functional areas. A functional area can be, for example, marketing, design, manufacturing engineering, production, or purchasing. It is entirely possible to see an organisation with a good documented quality system structure fail due to lack of attention or success in integrating the quality system with other systems in the organisation.

5.3.3-Process integration: This dimension introduced by Tannock [23] involves the following aspects: Planning of inspection and monitoring activities; Process control using quality data of manufacturing cycles at various stages. Inspections are normally performed at the key points in the production sequence for the purposes of process control. The locations and frequency of inspection points are included in an inspection plan. It is commonly agreed [8,26] that process control without inspection and monitoring plans is worthless.

If attitudes are positive and the control system is adequate, interactive and flexible, then the process managers can gradually improve their processes and begin to consider not only correction, but also improvement [88].

5.4-Levels of integration:

By taking into account the dimensions of integration, integration can be achieved at the three levels: the physical system level; the applications level; and the functional level [115, 29, 119]. Patankar [115] believes that enterprise integration (EI) mainly refers to integration of high level functional elements in an organisation, while CIM systems are generally restricted to integration at the physical and application levels.

Wu et al [72] have suggested a function hierarchical structure of a quality management system in a CIM environment. This comprises three sub-systems:

-the quality decision sub-system, whose purpose is to control product quality towards the user requirements;

-the quality information sub-system, which feeds the quality decision sub-system with significant information;

-the physical sub-system, which performes the quality inspection activities using human and technical resources.

Further more they suggest that these sub-systems can be integrated at three levels of:

-quality function integration;

-quality data integration;

-quality equipment integration.

5.5-Integrated quality information system:

There are some guidelines for attaining integration. Below [116] believes that there is usually some commonality between sub-systems, and integration is a result or an effect of that commonality. However, the ability to discern commonality and to choose correct commonality is critical to the success of the integration effort.

Identification of the appropriate common factors is difficult. An appropriate common factor will be one which is a necessary condition for the success of all functions or activities involved. The challenge before industry today is to discover which aspects of the enterprise should be common and which should not [116].

As discussed before, in order to design and supply the right products to customers, an IQS is an essential requirement of a manufacturing organisation. Information is a common requirement among all parts of a business including the quality-based functions. IQS can therefore be achieved through this commonality of information. In the integrated organisation, the quality information system exchanges information with other functions. In spite of the large amount of data that must be handled and translated by the quality information system, there are only a few classes of data which are generated specifically by quality functions. This quality information may be generated in one and utilised by other functional areas.

5.6-Structure of quality information systems:

A quality information system is an organised method of collecting. storing and analysing data, and reporting the resulting information on quality to assist decision-makers at all levels [7]. Consequently, an integrated quality information system should cover the quality-based functions of pre-production, production, post-production stages and the management support system [93]. Fig. 5.3 represents the hierarchical subsections of QIS.

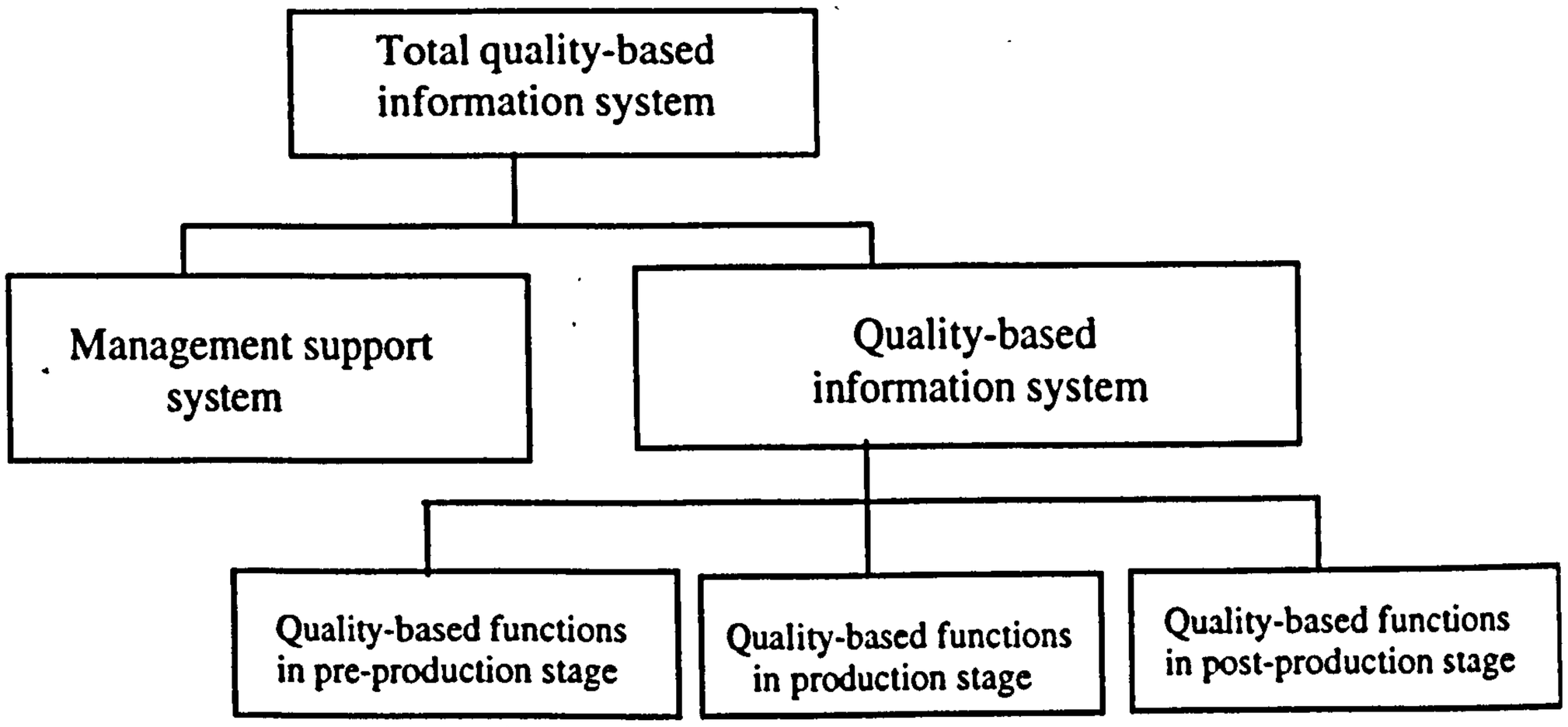


Figure 5.3: The business quality based information sub-systems

The QIS collects, distributes, co-ordinates and analyses information and data throughout the above sub-sections.

5.6.1-Key management interactions: The responsibility of management in respect of the quality assurance information system encompasses all activities of the overall management function.

- Consistent with other policies, the quality policy and quality objective should be defined and documented.
- The necessary measures should be taken at all levels of the organisation to ensure that the quality policy is implemented.
- Total quality cost should be calculated
- A quality system should be developed, established and implemented, in order to effectively accomplish the stated policies and objectives.

Figure 5.4 represents the interfaces of a management support system and QAIS with other functions in a manufacturing organisation[93].

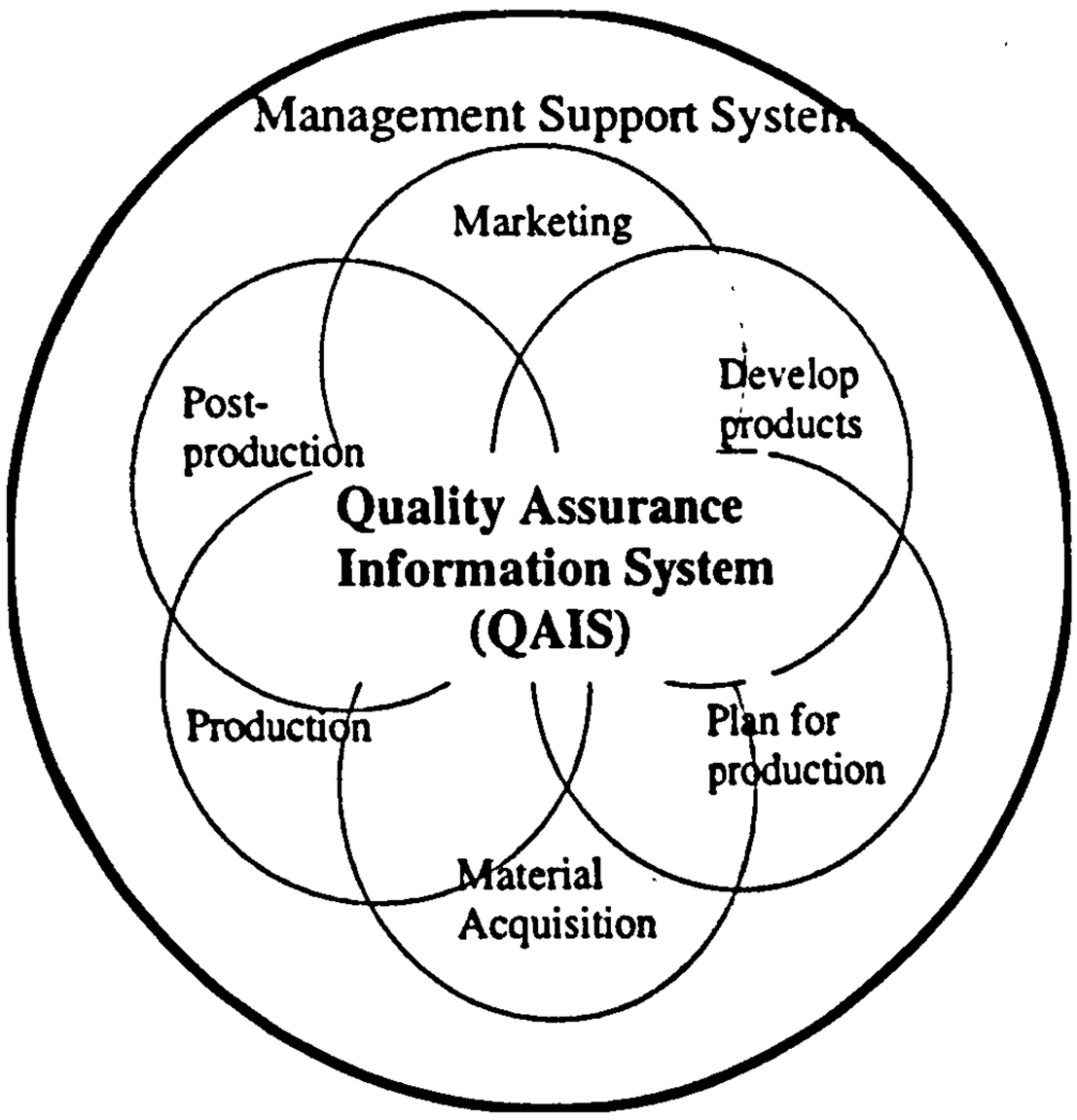


Figure 5.4: The interfaces of the management support system and QAIS with other functions

5.6.2-Information system in pre-production: The information system to support QA in the pre-production phase should ensure that the product that is designed meets customer requirements and can be produced defect free and reliable [4]. This step shall include the following matters:

- A company has to know about its customers and its main competitors. Through market research, a company must establish requirements that will satisfy customers and then set out its own strategies.
- A process of translating the customer requirements in terms of product functions, systems and other descriptions must be followed.
- Before submission of a tender, or acceptance of a contract or order, each must be reviewed in respect of the customer requirements and the capability of achieving them.
- Design, and design documents, must be reviewed before release to production.
- Verification of the design through prototype testing should be carried out.

- Safety and environmental compatibility of the product must be assured.
- Quality characteristics that are crucial to the safe and proper functioning of the product must be identified.
- Failure mode and effect analysis should be undertaken.
- To assure that the planned processes will produce the desired product and, in accordance with quality policy and quality objectives, quality plans, quality standards, and inspection procedures should be developed.
- A non-conforming disposition instruction for both incoming materials and produced products to prevent the customer from receiving non-conforming products must be implemented.
- Sub-contractors or suppliers must be evaluated and selected on the basis of their ability to meet contract or order requirements.
- Supplier quality assurance methods and periodic evaluation of sub-contractors quality must be agreed.
- To prevent use of defective purchased materials or parts, incoming inspection and verification may be used to assure that only quality and correct parts will be sent to the production line and/or stores.
- Procedures for review of non-conforming material, and for decisions on return, screening, scrapping, or acceptance must be established.
- Quality records of sub-contractors and suppliers should be established and maintained.

Figure 5.5 shows a perspective of QAIS in pre-production stage.

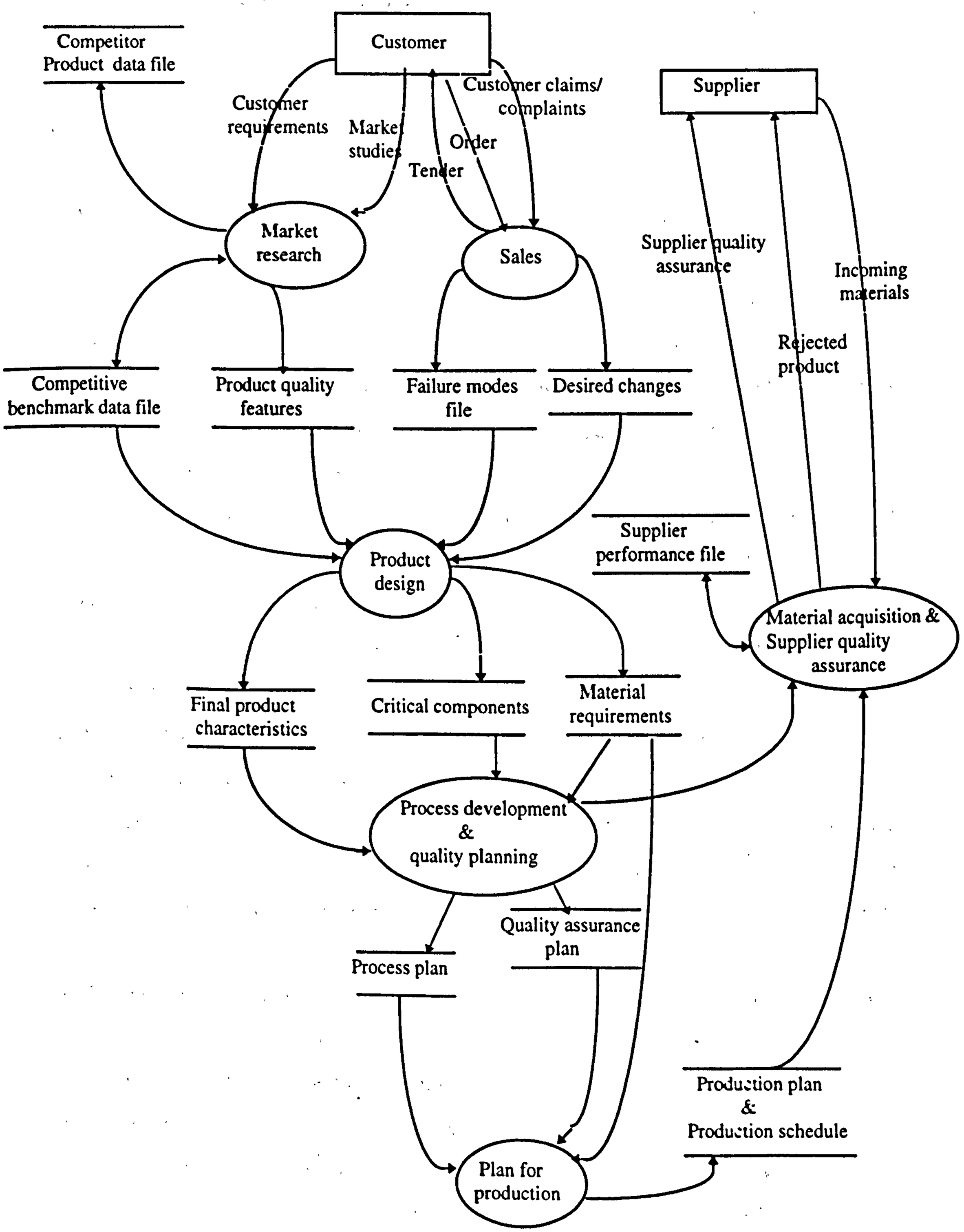


Figure 5.5: A perspective of QAIS during pre-production stage

5.6.3-Information system in production: The information system to support QA in the production phase should consider the following matters:

- Processes should be verified as being capable of producing product in accordance with specifications.
- Verification, typically by inspections or tests, should be considered at appropriate points in the process to verify conformity. Location and frequency depend on the importance of the characteristics and ease of verification during processing.
- Process performance should be checked by analysing historical or current data, in order to detect special causes of out of control conditions in a process and for avoiding recurrence of the problem. Such analysis can also be used to identify trends in process performance and to initiate preventive control measures.
- To augment inspections and tests made during processing, the final inspection should be carried out in accordance with the quality plan to complete the evidence of conformance of the finished product to specified requirements.
- Suspected non-conforming items or lots must be immediately identified, removed and reported.
- Non-conforming product should be reviewed, segregated, identified and repaired, accepted or scrapped. Repaired products must be re-inspected again.
- Reject analysis should be done on results of in-process inspection, final inspection and statistical process control to identify the defects, their causes and significance of their potential impact on safety, performance, customer satisfaction and product costs so that the appropriate corrective actions and steps are initiated to eliminate them.
- To provide confidence in decisions or actions based on measurement data, documented procedures should be established and maintained to control, calibrate and maintain inspection, measuring and test equipment.
- To ensure continued process capability, all equipment should be proved for accuracy prior to use. A program of preventive maintenance should be introduced, for all equipment, specifically for those equipment characteristics that contribute to product quality.

- The results of process and product audits should be carefully analysed to identify specific areas which call for investigation of design, processing, control methods or procedures.

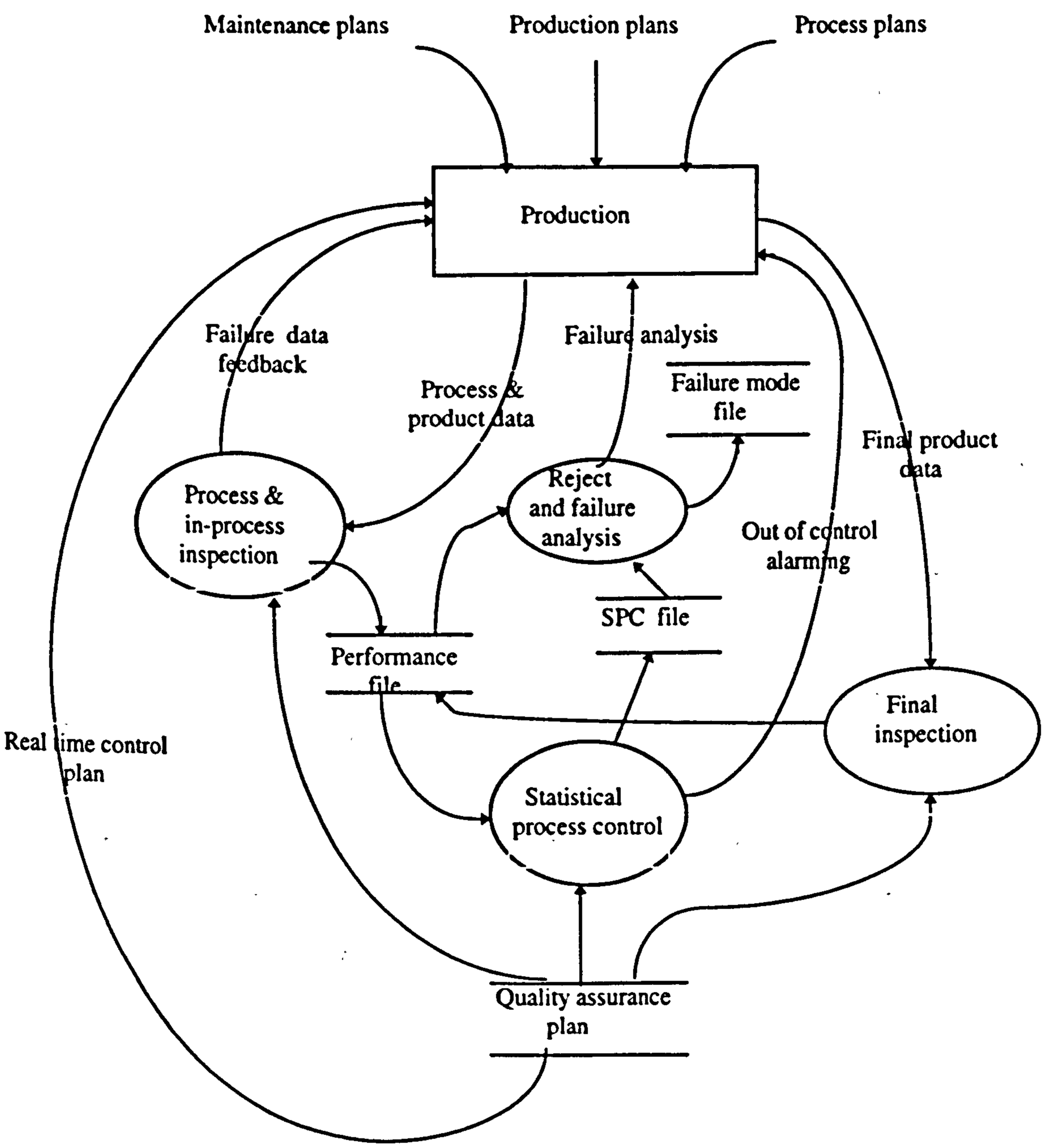


Figure 5.6: A schematic of QAIS during production stage

5.6.4-Information system in post-production:

Research has shown that more customers complaints are caused by store activities, particularly in packaging the product than were caused by original manufacturing [4]. The most critical aspect of the quality of packaging is acquisition of effective packaging materials, packaging design and the packaging process.

The information system to support QA in the post-production phase should cover the following matters:

- Documented procedures for handling, storing and packaging should be established and maintained.
- To ensure conformance to specified requirements, the packing and packaging must be controlled.
- In order to detect deterioration, the condition of product in stock should be assessed at appropriate intervals.
- Procedures should be established, documented and maintained to ensure that defective or deteriorated products are not shipped.
- All necessary technical data and instructions including installation instructions must be delivered to customers in appropriate format.
- Handling and transport introduce many fully predictable perils to the products. The condition of handling processes must be audited at appropriate times.
- There should be a program for satisfying customer complaints.
- Failed products should be sent to the reliability laboratories for testing and failure analysis.
- To apply corrective action in design, processing and/or use of the product, reports of field failures, returned products and user dissatisfaction should be monitored, recorded and analysed in-depth. Along with unsolicited data of field failures, customers should be periodically audited as necessary.
- Identified failure causes should be subject to new failure mode and effect analysis.

The following figure (Fig. 5.7) is an outlook of QAIS in post-production stage.

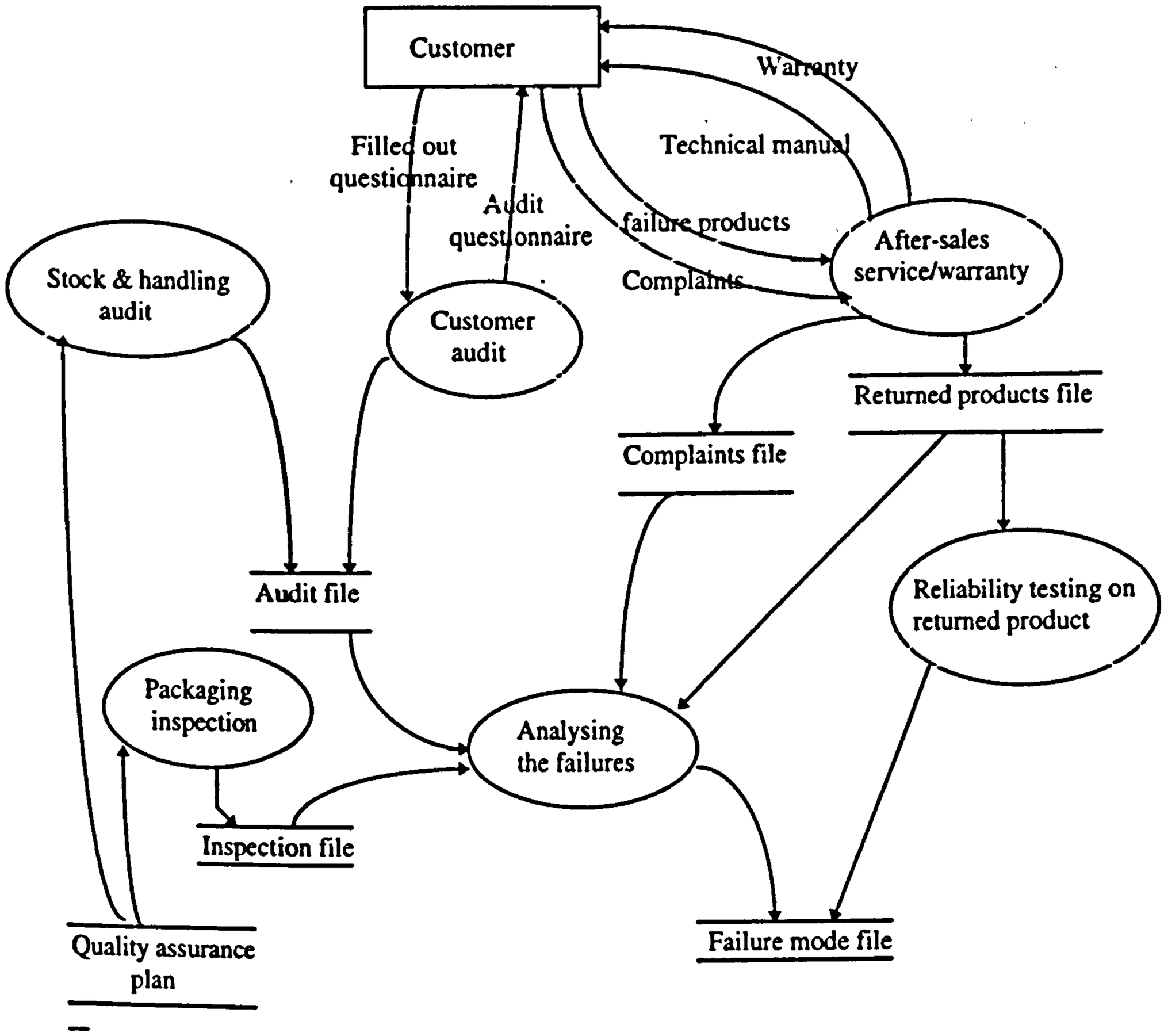


Figure 5.7: An outlook of QAIS during post-production stage

5.7-Physical integration: To achieve the advantages of integration, physical integration is certainly necessary for all dimensions of integration. Much work has been done on the methodology and implementation of physical integration in the manufacturing area [121, 122], and has resulted in OSI-based developments such as manufacturing automation protocol (MAP), technical and office protocol (TOP), and communication network for manufacturing applications (CNMA)[119]. Tannock has discussed the development and implementation of integration in the IQS environment [23]. This step is out of the scope of this work.

5.8-Summary:

The concept of integrated quality systems has been introduced in recent years. This integration of a quality system would result from integration of quality functions, integration with other sub-systems on the manufacturing system and integration throughout the production cycle. The structure of a quality assurance information system, and a macro-structure which shows in detail the interfaces between manufacturing functions, QAIS and management support system were presented.

Chapter 6

Functional model of an integrated quality assurance information system

6.1-General background:

It is often considered that information is the life blood of organisations [135], and information systems as co-ordinators of information, are increasingly playing a basic role towards the integration within and between manufacturing functions. The reason behind this tendency, as Chandra [124] believes, can be summarised as:

- To provide optimal quality and quantity of information to different parts of an organisation so as to do their job effectively and efficiently.
- To provide the right information to the right person at right time and at lowest cost.
- To improve the data gathering, processing and to eliminate redundancy in records and promote data sharing.
- To establish effective channels for providing free flow of information to raise the level of knowledge inside the organisation.

An integrated information system is viewed as possessing specific qualities that distinguish it from other information systems. Specifically, an information system is said to be integrated when it has the ability to share common data and is capable of responding well to physical changes [128].

As discussed before, there is also a strong need for an information system to support the quality function. Integrating these systems and integrating information are the challenges

ahead of many manufacturing organisations as they continue to improve their competitiveness.

6.2-Information system design:

In today's complex and highly cost conscious manufacturing environment, there is no room for error in the design of manufacturing systems. Hence resources must be invested beforehand in developing the optimum design for the system's particular application.

On the other hand, standard methods of representing relationships between activities and flows of data are important to ensure common understanding of systems. Systems modelling techniques have evolved to facilitate the design and implementation of manufacturing systems by representing the operations and activities that occur within the growing number of increasingly complex manufacturing and other types of systems.

6.3-Methods of modelling:

Professionals in various disciplines feel the need to describe and develop a system according to prescribed rules before being able to understand. analyse, improve or replace the system. Systems are composed of interfaced or interdependent parts that work together to perform useful functions. System components can be any combination of things, including people, information, software, processes, equipment, products, or raw materials. A system model describes what a system does, what controls it, what things it works on, what means it uses to perform its functions, and what it produces [131], In fact as Zeigler [142] defines a model is a 'microscope', or 'conceptual tool' with which a complex system can be observed from a particular point of view.

The classification of models is a complex subject. Various types of models have been suggested such as linear or mathematical, graphical and physical [106] , deterministic, stochastic, static, and dynamic [136].

- In a mathematical model, the objects of a system and their attributes are represented by mathematical variables. The operations and actions are described by mathematical

functions which define the interrelationships between the variables. Operational Research (OR) methods include linear programming, dynamic programming, queuing theory, inventory models , network analysis and numeric simulation and provide various tools for the construction of manufacturing models [106].

Analytical approaches using sophisticated mathematical techniques require precise definitions. Manufacturing systems are complex and are much more difficult to define [125].

A written description of an information system would be a linear model, with the words of the description following one another in the sentence structure. This type of model has been used many times, but in view of the complexity of manufacturing, it becomes wordy and confusing.

- Graphic models are important tools for representing the behaviour of manufacturing systems. The manufacturing operation may be visualised by either icons or symbols. There are various ways of symbolising a manufacturing operation such as Petri nets and flow process charts.
  In comparison to two dimensional models, while three dimensional models are most instructive, because of problems such as the need for large amounts of memory for running the software application, they are not operationally applicable [126].

- Manufacturing operations are often modelled by pilot operations. With these methods an attempt is made to build a physical image of a factory, or a component of it, in a simplified manner. This may become a time consuming and expensive endeavour. Also, the extrapolation of the behaviour of the model to that of the real system may lead to unrealistic results. Physical models are being replaced by mathematical or graphical models, but to some extent are still used in facility layout planning.

6.4-Information systems modelling:

Since an information system is a complex system, several tools and modelling methodologies have been developed to facilitate their design and implementation for an object system, such as IDEF, ER, NIAM, OODA, DFD, SADT, ISAC, BSP, BIAIT, MILLE, YADAV , etc. [45, 49, 54,57, 76, 77, 79, 137]. Most of these methodologies, however, take only a partial view of an object system. This shows that a single model will not suffice for this purpose and one needs to look at an object system from at least three different but related viewpoints in order to get a complete understanding of the object system [45, 127]. These three viewpoints give rise to three different models. These models are:

1-Functional model: A function model helps us to understand the activities and their inter-relationships within an object system.

2-Information model: An information model helps in understanding the structure of information to be required by the object system.

3-Dynamic model: A dynamic model shows the behaviour of functions and information interactions over time.

The communication model is a recent development in information technology (IT) and provides another viewpoint of an object system, when the design of IT systems are considered [140]. In this case the OSI-ISO basic reference model has been developed for open systems interconnection for example harmonising communications between computers [29].

In the modelling of manufacturing systems and other systems within them, static models are used for system definition and are thus a framework around which to build the dynamic models which are used to simulate the system's operational performance [70].

Conceptually, functional structured analysis is a means of decomposing a system into easily understood, related elements and representing that decomposition in the form of diagrams and texts [187].

6.5-Functional model of a QAIS:

Discussions about the necessity of QAIS for manufacturing business can be found in the literature [2, 3, 70]. On the other hand, literature relating to the implementation of information systems for quality systems and associated methodologies for establishing a QAIS in manufacturing environment is sparse and much work remains to be done in this area.

A functional area of a manufacturing system may contain information that can be utilised in the QAIS and, mutually, the statistical data, data analysis and other information of the QAIS may be utilised in any other functional area. The essential step for every communication of information such as required for a QAIS, referring to dimensions of integration, is to determine the answers to such questions as:

- What kind of information is essential and in what form should it be presented to be immediately usable as a basis for decision and action? Information may be embodied in words, numerals, report or geometric forms.
- What are the sources of the information? Which function is the sender of information?
- To where and when should information be sent? To be useful, the information must be visible and accessible when required to those who are to use it, either a function, a person, a machine or a computer.

The input/output analysis has been used to translate the voice of the customer into appropriate functions for each stage in a product's development and production cycle and, finally, for finding all quality-based information of business (Fig. 6.1).
It is clear that the information generated by a function may act upon other functions in any of the following forms:

- as a control, which is used to activate/ regulate the other functions.
- as an input, which is required by other functions.
- as a data resource, which is used as a mechanism to support the other functions.

A practical way to design and build an information system is first to develop a functional model which reflects the system's functions and the integration of them within the overall enterprise. It is believed that by designing the functional model of a quality assurance information system the aforementioned questions will be answered.

Diagrams or 'graph models' are most appropriate for functional modelling because a concise pictorial representation can be quickly understood. They are also useful for assisting the designer. A graphical model with which we are familiar is a road map. It represents a piece of the earth's surface, with cities and roads displayed for reference. It has many merits: it is printed on a reduced scale, so that we may scan an entire area at one glance. It omits a host of details which are not relevant to the map reader's needs. Most important of all, it shows, at one glance, the relative location between several cities and towns. The eye can see, and the mind can comprehend, these multiple simultaneous relationships.

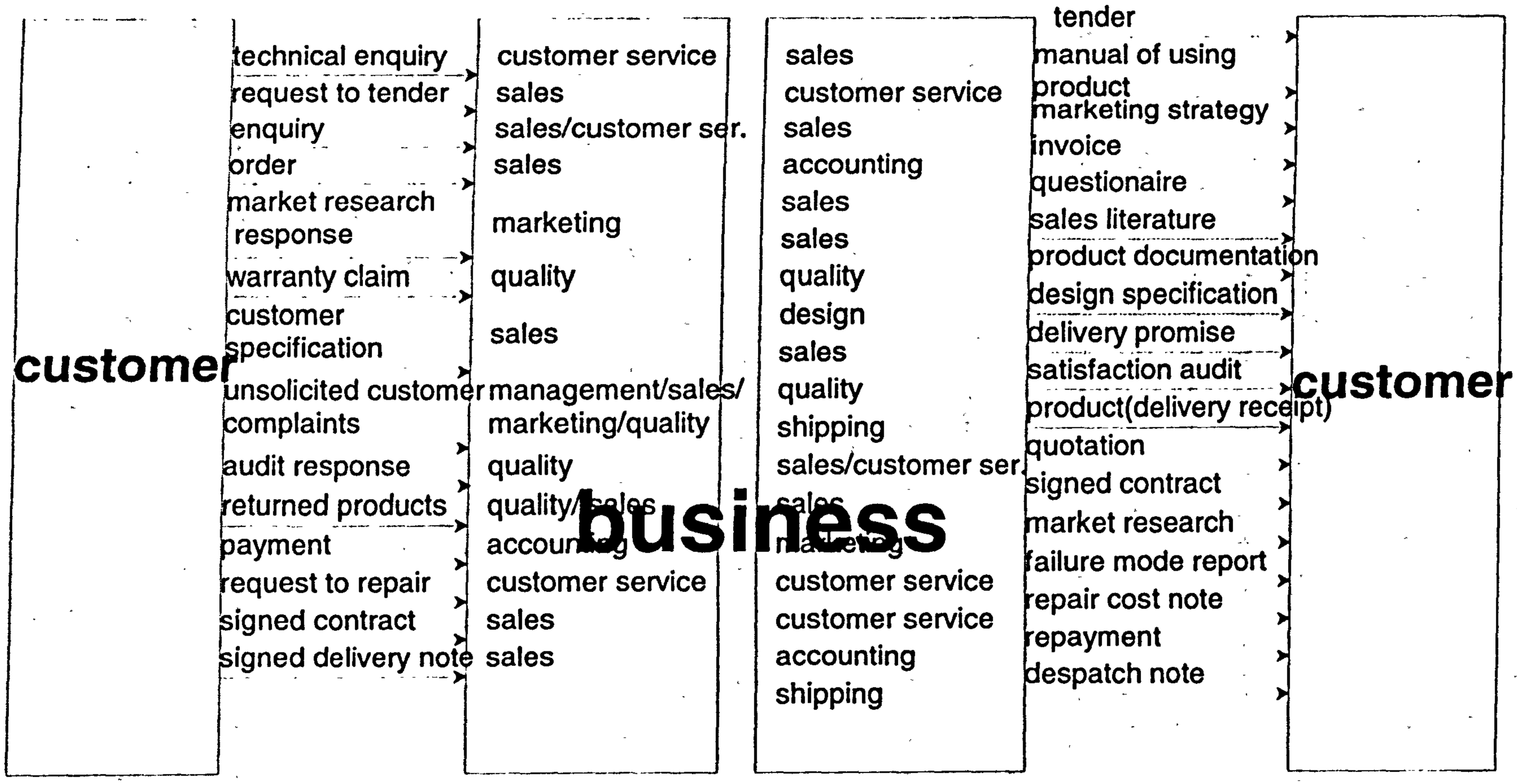


Figure 6.1: Input-output based quality function information flow

6.6-Model construction:

The method of construction of models is another feature of some debate. Systems analysts use various approaches when dealing with complex information systems [134]:

- Considering an ad-hoc approach without paying attention to other problems for integrating systems.
- Using a database approach with emphasis on the development of a common database in which linkages are established in the database to relate associated data.
- Using an Object-oriented approach, in which data are grouped into objects or manageable chunks [139] which occur naturally. The interfaces between the objects is the only way in which data within an object can be accessed.
- Considering a top-down approach which begins with general concepts (the coarse-grain model) and gradually fill in the details.
- Beginning with the detailed, fine grained model and collecting details together into larger units. This is 'bottom-up' modelling.

In recent years, efforts have been made to apply an object-oriented approach. However, most work is still at a relatively early stage and more research work is required before an object-oriented approach can be widely used for the analysis and design of manufacturing systems [138].

The hierarchical decomposition approach is the technique principally advocated for the representation, analysis and design of information systems and, more generally, any complicated system [141].

It is clear that developing an information systems environment for a quality assurance system for the whole of a manufacturing enterprise is a creative problem which requires one to start at the fundamental conceptual level, then to identify what functions and information will be required to support the object level.

6.7-IDEF0 modelling methodology:

The generally desirable criteria for an ideal modelling tool for the manufacturing environment as suggested by Chadha [137] are:

- be able to express different levels of abstraction
- be able to decompose from a high level
- easy to learn, use and understand
- able to incorporate manufacturing and information constraints
- be able to describe the resources needed
- be able to describe sequences of events and processes, and their interactions and relationships.

What was needed in this research was a modelling "language" with the following characteristics [131]:

a) Generic (for analysis of systems and subject areas of varying purpose, scope and complexity);
b) Rigorous and precise (for production of correct, usable models)
c) Concise (to facilitate understanding, communication, consensus and validation);
d) Conceptual (for representation of functional requirements independent of physical or organisational implementation);
e) Flexible (to support several phases of the life cycle of a project)

Among various modelling tools, IDEF0 modelling methodology is a well-tested tool [131] specifically developed for use in the functional modelling of complex and interrelated systems. It is a comprehensive graphical tool which provides a mechanism for decomposing a function into a number of smaller sub-functions and verifying that the inputs and outputs of the function match those of its sub-functions. Here a function is to transform the inputs into the outputs, under the influence of a control, using the mechanism provided (Fig. 6.2) which covers the various ways in which information from one function may act upon other functions -as described in section 6.5. Using IDEF0 as a modelling technique also ensures that the context for any part of a process model under

analysis in relation to the whole of the process model is always known. Therefore it is possible to focus on any part of a process model in which there is particular interest and develop further levels of detail without losing its context within the whole process. This allows many individuals to work on different aspects of the total system and yet be consistent in terms of final system integration.

Another feature of IDEF0 is that it can be generated by a variety of computer graphic tools [182, 183]; numerous commercial products specifically support development and analysis of IDEF0 diagrams and models.

The above features of IDEF0 are very important in modelling contemporary manufacturing industry, where substantial efforts are being focused on total system integration. Without a language which is understood by all system analysts working on different parts of a company model, and without a model which is supported by software application, communication would be more likely to be subject to failure, making successful design and implementation of a total integrated system much more difficult to achieve [130]. An overview of the IDEF0 model is presented in Appendix I.

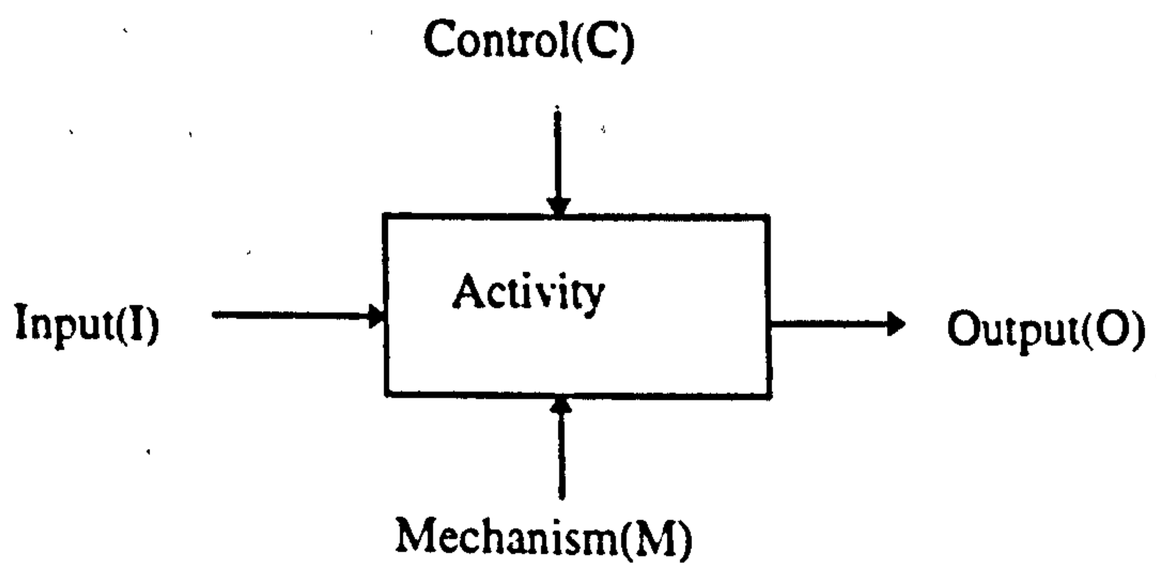


Figure 6.2: The IDEF0 methodology

IDEF modelling is not limited to the functional aspects of systems. There are other versions that have been developed [128]:

- IDEF1 (Information model methodology): IDEF1 was designed as a method for organisations to analyse and clearly state their information resource management

needs and requirements. Rather than a database design method, IDEF1 is an analysis method used to identify: Information collected, stored, and managed by the enterprise; rules governing the management of information; logical relationships within the enterprise reflected in the information; problems resulting from the lack of good information management.

- IDEF1X (Data modelling): IDEF1X is a method for designing relational databases with a syntax designed to support the semantic constructs necessary in developing a conceptual schema. These models can be used by the programmers who take the blueprint for the logical database design and implement that design.

- IDEF2 (Dynamic model methodology): IDEF2 is a methodology which has been designed to allow one to describe the time varying behaviour of manufacturing systems. The IDEF2 model aids in determining and quantifying system design alternatives and problems early before development of the systems [84].

- IDEF3 (Process description capture): The IDEF3 Process Description Capture Method provides a mechanism for collecting and documenting processes. The resulting IDEF3 descriptions provide a structured knowledge base for constructing analytical and design models.

- IDEF4 (Object-oriented design): IDEF4 stresses the object-oriented design process over the graphical syntax, using the graphical syntax and diagrams as aids to focus and communicate important design issues. IDEF4 divides the object-oriented design activity into discrete, manageable chunks. Each subjectivity is supported by a graphical syntax that highlights the design decisions that must be made and their impact on other perspectives of the design.

- IDEF5 (Ontology description capture): The IDEF5 method provides a theoretically and empirically well-grounded method specifically designed to assist in creating, modifying, and maintaining ontologies.

6.8-A generic IDEF0 model of a quality assurance information system:

In this research a generic model has been constructed which comprises those functions or essential activities which influence quality and which must necessarily take place within any manufacturing process. This functional structure is a graphical static model which makes all the functions work together to produce the desired end result. In the same way that a facility layout and flow chart indicate how materials flow in the manufacturing area, the functional model indicates how quality information flows within the manufacturing system [129]. The quality information and information flow requirements of any specific manufacturing industry will be found within the generic model.

A generic IDEF0 model introduces no specific mechanisms for its functions, and is equally valid for all possible profiles of a manufacturing business. It is suggested that the use of generic IDEF0 modelling can help to capture a clear picture of complex aspects of a manufacturing organisation and can lead to very precise thinking about what specific people and departments are suppose to be doing [132], in this case in relation to quality. For a generic model the level of analysis must contain functions which are at a level of detail that is applicable to all companies.

Chapter 4 has drawn out those essential quality-based functions which need to take place within a manufacturing environment. As the level of hierarchy of system becomes lower, functions are more dependent upon many factors such as: the size of industry, manufacturing strategy, production systems, production technology, manufacturing production management and the nature and requirements of the desired end product.

Figure 6.3 shows the node index of the generic IDEF0 model of a total quality assurance information system. The model comprises activity diagrams in the format illustrated in

figures 6.4 and 6.5. These are the second and the third tiers of the IDEF0 model diagrams, in which the third layer includes: pre-production; production; and post-production nodes in the decomposition of A2 node -quality assurance manufacturing system- of the second tier. The complete IDEF0 model is included as Appendix II.

A0-Total quality-based information system
A1-Management support system
A2-Manufacturing quality-based information system
A21-Pre-production quality-based functions
A22-Production quality-based functions
A23-Post-production quality-based functions
A211-Marketing
A212-Develop product
A213-Plan for production
A214-Material acquisition

A221-Production control
A222-Convert material to products
A223-Quality control
A224-Maintenance

A231-Packaging
A232-Warehousing
A233-Shipping
A234-Post-sales

A2111-Enquiry processing
A2112-Tendering
A2113-Sales and contracts
A21131-Order processing
A21132-Contract preparing
A21133-Contract control
A2121-Develop design

A21211-Develop conceptual design
A21212-Develop preliminary design
A21213-Prototype development
A21214-Reliability control
A21215-Develop detailed design
A21216-Reviewing the design
A2122-Production engineering
A2123-Quality planning & standards

A21221-Process planning
A21222-Reviewing the process plan
A21223-Tool & fixture design
A21224-Plant layout & material handling
A21225-Industrial engineering

A21231-Product quality planning
A21232-Process quality planning
A21233-Quality planning

A212161-Product design verification
A212162-Failure mode and effect analysis

A2131-Master production scheduling
A2132-Materials requirements planning
A2133-Capacity requirements planning
A2134-Production scheduling

A2141-Purchasing
A21411-Suppliers recording & selection
A21412-Purchase processing
A21413-Supplier surveillance
A2142-Receiving
A21421-Receiving materials verification
A21422-Incoming materials inspection
A21423-Non-conformity control
A2143-Inventory management
A21431-Inventory control
A21432-Materials stores

A2231-In-process inspection
A2232-Statistical process control
A2233-Final inspection
A2234-Non-conformity control
A22341-Cause and effect analysis
A22342-Non-conforming disposition

A2341-Service/warranty
A2342-Sales/field return
A2343-Reliability lab. study

Figure 6.3: Node index for generic IDEF0 model

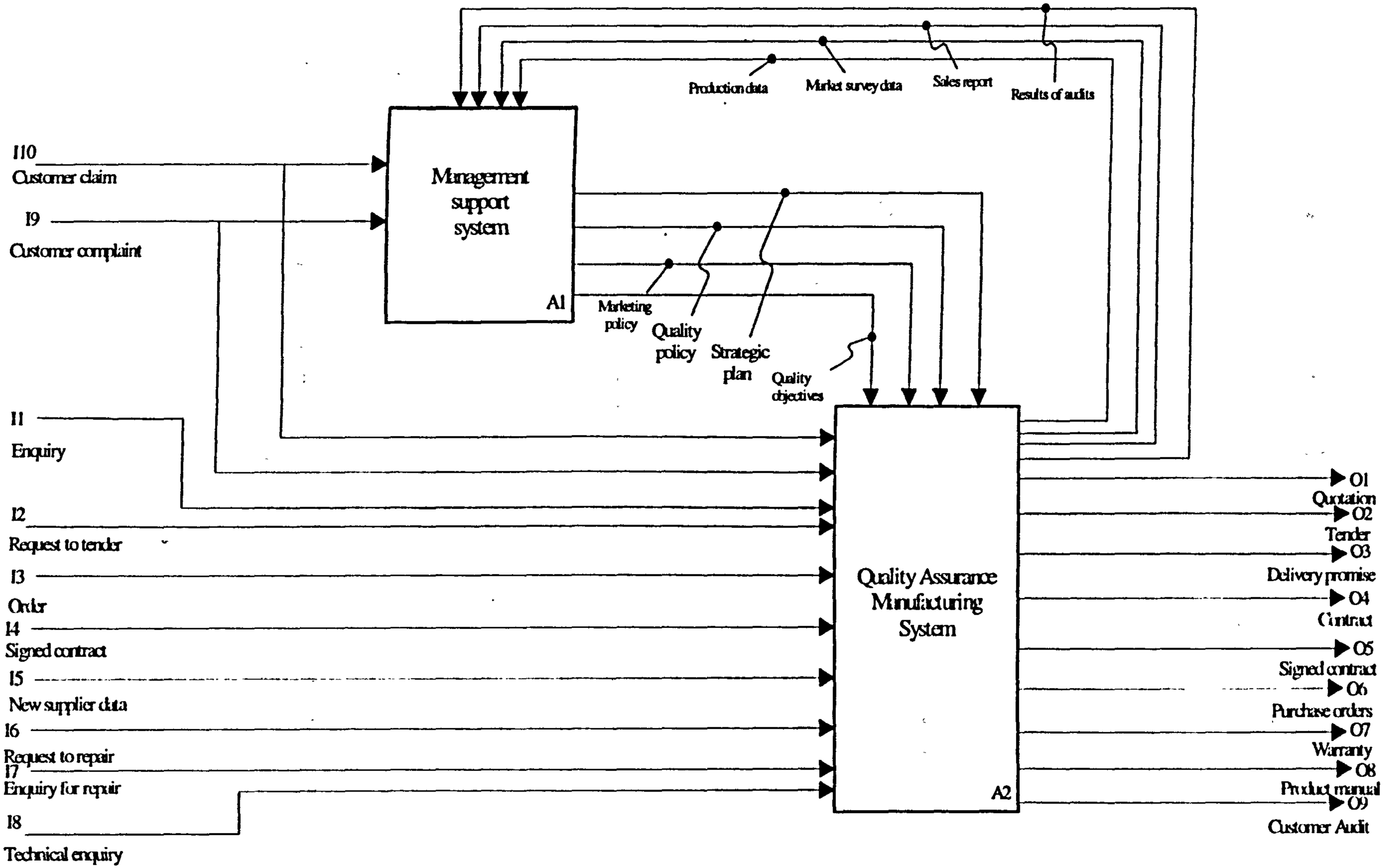


Figure 6.4: Total quality-based information system

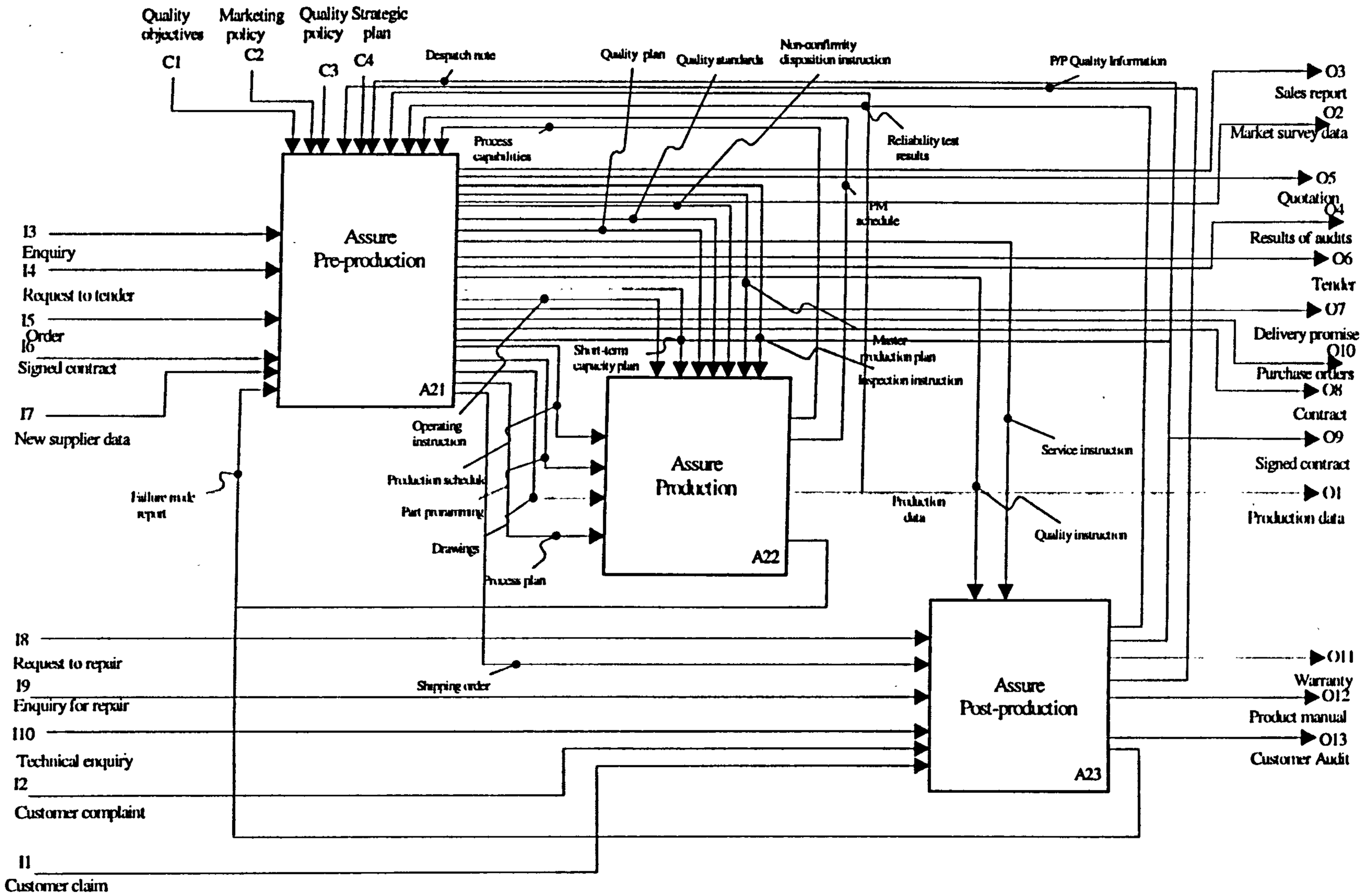


Figure 6.5: Manufacturing quality-based information system

6.8-Summary:

Accepting that information is a key feature of integration, a generic model which shows the basic elements of establishing a quality assurance information system, the source and destination of information and the integration of them within an overall enterprise, was proposed. IDEF0 methodology was used to graphically show this generic model.

Chapter 7

The effect of business profile on design of quality assurance systems

7.1-Introduction:

All industries have features which are unique to that particular industry, and largely common across individual companies within a type of industry, in terms of market, manufacturing processes, raw materials, type of person employed, geographical spread and so on as well as in terms of the actual product supplied.

On the other hand, actual manufacturing activities are in fact highly diversified. The author has identified more than 1100 separate manufacturing industries with their products classified into about 33 major groups. Table 7.1 shows the main types of manufacturing industry groups.

Understanding the context of manufacturing and studying all types of manufacturing systems will help us to appreciate the needs of that environment, specifically for this work in regard to designing a support system such as a quality assurance system.

7.2-Manufacturing classification:

There have been many attempts to classify manufacturing systems and, with regard to production processes, layout planning, production management systems, manufacturing strategies, a number of classifications have been introduced. Ingham [154] developed a broad classification of company types based on their observed sales, products manufactured and the market environment. New [161] introduced a list of factors as the

Table 7.1: Main manufacturing industry groups

• Coal and peat. • Crude petroleum and natural gas. • Quarrying. • Precious and semi-precious stones. • Minerals. • Food and tobacco. • Beverages. • Leathers, furs and their products, footwear. • Textiles. • Wearing apparel and made-up textile goods, umbrellas. • Wood and cork products. • Furniture. • Cellulose, paper and board products. • Printing and publishing. • Rubber products. • Plastics products. • Chemicals and oil refining.	• Non-metallic mineral products. • Basic metal industries. • Metal industry. • Electrical, electronic, data processing and nucleonic equipment. • Precision equipment, measuring, testing, optical, photographic, medical and surgical equipment. • Transport equipment • Hydraulic and pneumatic, steam machines, heating and air conditioning equipment • Agriculture, horticulture, food and drink equipment. • Chemical, rubber and plastics plant and equipment. • Textile, clothing, leather industry and shoemaking equipment.	• Pulp and paper industry equipment. • Mining , oil and gas extraction equipment • Heavy industry and metal working plant and machinery. • Metal and woodworking machines, machine tools and accessories. • General mechanical engineering. • Watches, jewellery, toys and musical instruments.

Source: Kompass the Authority on British Industry, 1994.

basis for company classification by numerical taxonomy, with some factors being functions of other factors. Barber [160] proposed a basis for classification of companies according to production-control complexity. Schmitt [155] has reviewed the classifications based on operational characteristics and has developed a framework which defines and relates many types of production processes.

McCarthy [156] has reviewed and analysed some of these classifications. He believes that all manufacturing classification methods come under five general headings: operational characteristics, operational objectives, operational flow structures, detailed sub-classification and combination schemes.

By and large, the basis for classifying manufacturing industries by similar operating characteristics refers to the movement, logistics and control of the physical resources and materials required for production [156]. There are two basic categories of industrial plant, namely continuous process and discrete parts manufacturing.

Continuous process industries involve the continuous production of product. It is based on the criterion that process industries change the physical and chemical character of a material [126]. A continuous process will theoretically run for 24 hours per day, but whilst this is often the objective, it is rarely achieved [162].

Discrete parts industries involve the production of individual items, or production consists of a number of operations identifiable as accruing at separate points in space and time and follow one of four common patterns of operation. There are sequential, combinative, disjunctive and location patterns [126]. This kind of industry, in regard to volume of production, is further subdivided into three broad categories - mass production, batch production and jobbing shop production [162].

Wild [157] further developed a flow line classification scheme for mass production systems. From this scheme, two distinct types of flow line can be identified, the transfer

line which utilises automatic material transfer between machines which are themselves automatic and the assembly line which is principally engaged in product assembly.

With regard to the nature of the process technology, production volumes, facility utilisation, level of capital investment, and nature of production, batch production can be further subdivided into conventional job shops, stand-alone NC production, manufacturing cells and the flexible manufacturing systems (Fig. 7.1).

Another way of classifying production activities is according to marketing strategy. The manufacturing operation is key to competitive advantage, and its strength and weakness will to a very large extent be constrained by how the company may exploit or develop its market position. On the other hand, to attain a viable market position may often require fundamental changes to the manufacturing operation. There is therefore a proactive interrelationship between marketing strategy and manufacturing strategy. However, the manufacturing strategy exists to support the company's chosen marketing strategy, and not vice versa.

Table 7.2: Changing of manufacturing emphasis

	1960s	1990s
Philosophy	Production led	Market led
Techniques	Simple	Complex
Product range	Narrow	Wide
Tooling	Dedicated	Flexible
Fixed costs	Low	High
Labour costs	High	Low
Product life cycle	Long	Short
Competition	National	Global
Customers	Stable	Demanding

Source: Industrial Technology(March 1991)

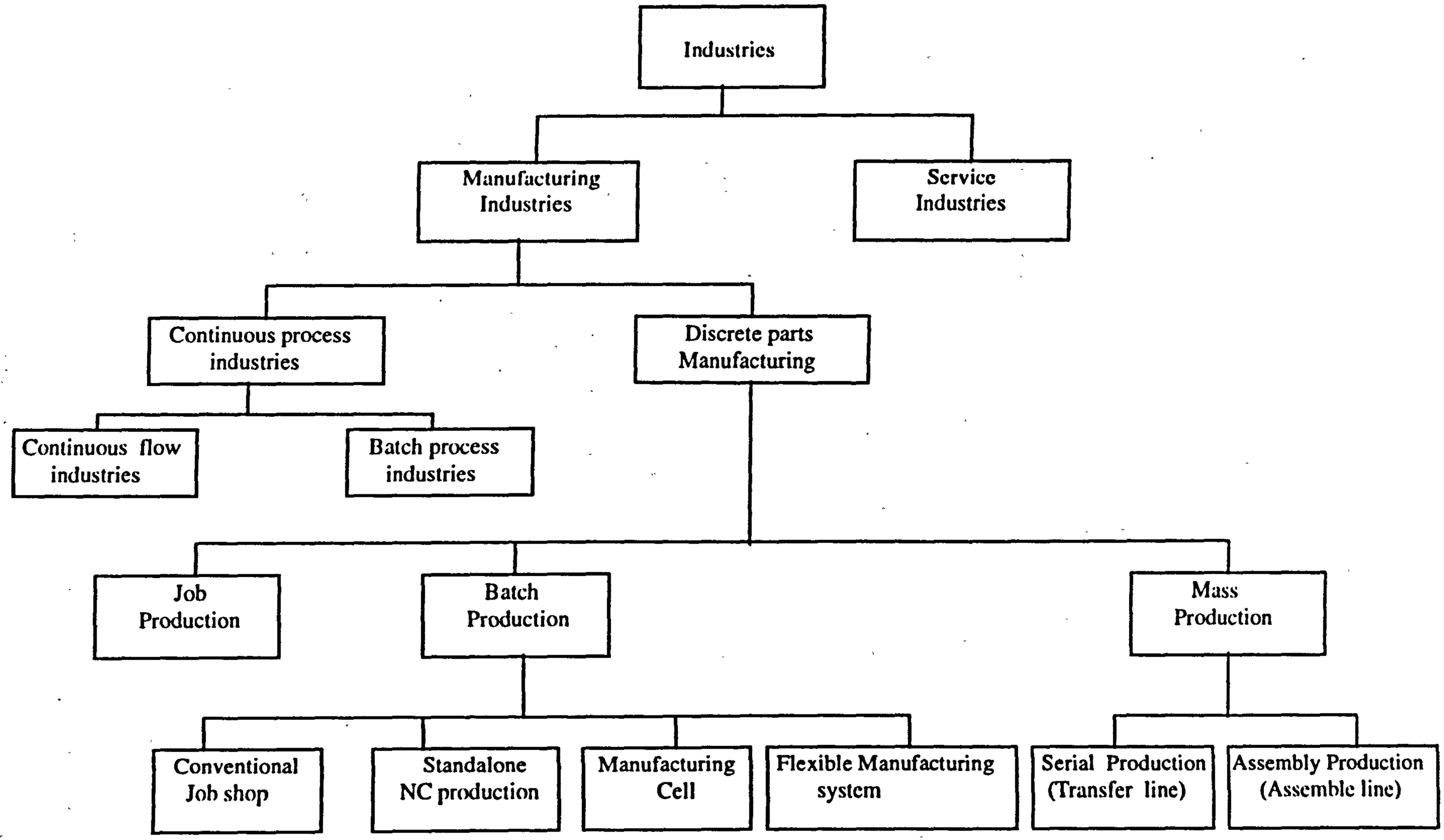


Figure 7.1 : Classification of manufacturing industries in regard to production nature

Hill [159] has suggested, whereas past markets had been characterised by similarity and stability, the characteristics of current markets are their difference and high rate of change, Table 7.2 shows the fundamental shifts in manufacturing emphasis during the past three decades.

In regard to manufacturing strategy, Wild [158] has defined four basic types of strategy namely: from stock, to stock, to customer; from source, to stock, to customer; from stock, direct to customer; from source, direct to customer. The first two types are also classified to as make-to-stock and the last two as make-to-order manufacturing systems [130]. Scott [163], expanded that classification to four categories and the author has added a fifth category as shown in Table 7.3. As a company moves from level one to five the overall lead-times will reduce.

Table 7.3: Alternative manufacturing strategy (Hill [159])

• Design-to-order (Company designs and manufactures a product to meet special needs of a customer)
• Engineer-to-order (Changes to standard products are offered to customers and only made to order)
• Make-to-order (Concerns manufacturing a standard product/or customer designed product only on receipt of a customer order or against an agreed schedule or call-off.)
• Assemble-to-order (Components and subassemblies have been made to stock. On receipt of an order the required parts are drawn from work-in-progress/component inventory and assembled to order).
• Make-to-stock (Finished goods are made ahead of demand in line with sales forecasts. Customer's orders are met from inventory)

The other classification for manufacturing industries is in regard to the production management system. The primary objective of the production management system is the balancing of supply and demand for component parts and materials, to ensure that the correct parts or materials for manufacture or assembly are available in correct quantities, at the right time and in the right place.

Within a production management strategy two basic scheduling systems have been defined:

1-Push system: parts are completed as scheduled and sent to the next workstation-whether or not that station is ready for it. Usage and production rates, subject to numerous sources and causes of variability, are different. Idle inventory often characterises push scheduling. MRP is considered to be the classical example of a push system.

2-Pull system: a pull or JIT system, on the other hand, looks at the manufacturing process from the other end. Parts are drawn from or sent by the supplier as needed. If the customer has problems, then the supplier must respond to those problems. If the supplier has problems, then the customer is forced to stop work, so the sources and causes of variability become visible and must be controlled. A characteristic of pull scheduling systems is that inventory is alive, and not kept in pallets or stores. Toyota called this particular technique Kanban, and for a time Kanban was synonymous with Just-in-Time.

According to manufacturing strategy, production led or market led, different material planning methods have been introduced and implemented of which the most well known are:

- Order-point system (OPS) : Stock replenishment is triggered by stock falling below a re-order point, which is calculated based upon the expected demand over the replenishment lead time.

- MRP (materials requirements planning): Computer based time phased order-point system which recognises that demand for component parts is dependent on the demand for components or products of which they are consistent parts.
- Kanban system (JIT): The Kanban system is associated with JIT manufacture and is the application of order point replenishment techniques to the short-lead time supply chain.

None of the above classifications specifically and directly make reference to or reflect the factors which can affect the quality of product(s) and service. Caplen [146] in considering the differences among processes has classified four kinds of industries: discrete production; continuous production; assembly production; and services. They need different quality control techniques.

7.3-Quality assurance systems in various manufacturing environments:

Although there may be common features, different manufacturing situations will require quality assurance systems which in some respects are significantly different from the approaches used in other industries. By reviewing literature on manufacturing quality assurance systems [143, 144, 146, 164], it became clear that the quality functions that operate within a specific quality assurance system naturally depend on different factors such as:

- **The products which are produced:** The degree of confidence required of a quality assurance system will not be the same for all products [144]. There is scope for defining quality systems at different levels according to product. The more important or critical the product's characteristics, the greater the attention it should receive in such matter as: extent of quality planning; precision of process; tooling and instruments; etc. For example, a very high degree of confidence is required in the design, manufacture and inspection of a pressure vessel, or a piping system used for carrying hazardous fluid.

- **Design novelty and maturity:** The extent to which the total design is known and proven, either by performance testing or field experience. In the case of new products, prototypes are normally built to generate data on performance and reliability aspects of the product at the earliest possible stage. The number or amount of prototypes made and extent of testing undertaken depends largely on the costs involved [148].

- **Product and process complexity:** These factors deal with [8]:
  - The difficulty of designing the product;
  - The availability of proven production or operation processes;
  - The need for development of new processes;
  - The number and variety of processes required;
  - The impact of process on the performance of product;

- **Product safety:** The selection of an appropriate quality system for a given item (or project) is determined by both the consequences of failure and the probability of failure which in turn comprises the probability of a fault being present and the probability of the fault being detected. Therefore. it is necessary to quantify both these features as accurately as possible.

$$DOF = COF \times POF$$

where, DOF- is the degree of failure,

COF- is the consequences of failure,

and POF-is the probability of failure.

- **Production management:** The push system and pull system are production management systems in general use. A manufacturer using the pull system will not succeed without a first-class quality system in place. In just-in-time (JIT) manufacturing, parts should arrive at the process precisely at the moment they are needed, and they must be fit for use. In the ideal JIT system there are no extra parts to cover for defective parts, and defectives occurring anywhere in the manufacturing

'chain' will result in line stoppages. Quality parts must be procured and manufactured at each stage of production. Any quality problems arising must be permanently solved in an environment of continuous improvement. A quality assurance system is critical to the success of a just-in-time manufacturing system and must reflect these special demands.

- **Method of production:** The principal manufacturing function is to take inputs and convert them into products. To do this, a business usually has a choice to make between different methods of production. Taking into account the nature of the products and the required rate of production, different methods of production such as continuous process; mass production; batch production and one-off production may be applied to meet the requirements. The timing of the inspection and monitoring procedure in relation to the production process is an important consideration in quality control and much research has been done to this aspect [194, 195, 196]. For instance in a high volume production process such as a continuous process in which materials will be transferred automatically from one part of process to the next and the process runs for twenty- fours a day, on line or real-time monitoring might be required. On the other hand in another process first and last checks may be all that is necessary.

- **Size of company:** Company size may influence quality management since larger companies tend to need to devote more resources to organised quality programs than smaller ones [147]. Moreover, since the relative soundness of the internal quality assurance system has a decisive impact on the overall quality performance of the company organisation, the more a company grows, the more special quality functions must be designed and integrated with the existing organisation [27].

- **Manufacturing strategy:** Depending on which of the five levels of manufacturing strategy shown in Table 7.3 applies, the design of an appropriate total quality assurance system for a product will be different. Special products, which in a design-

to-order based strategy are designed and manufactured, need a quality assurance system which covers all parts of the pre-production section of the model described in chapter 6. On the other hand, manufacture of standard products for which the design have been proven, or where manufacture is of customer designed product, should require no emphasis in the design aspects of the QA system. Hence ISO9002 [104], which covers this situation makes no provision for QA of the design process.

- **Quality policy:** In considering manufacturing strategy and other factors, the supplier may follow a different quality policy such as: producing error-free products for general sales; satisfying specific customer requirements; delighting the customer. The overall quality intentions and direction of an organisation are normally expressed by top management.

- **Economics:** Quality-related costs are those which arise from a wide range of activities in the design, implementation, operation and maintenance of an organisation's quality assurance system, the cost of organisational resources committed to the process of continuous quality appraisal and improvement, plus those costs incurred owing to failures of the systems, products and services. These costs can be classified as: prevention costs; appraisal costs; failure costs [8].

Quality assurance systems may range from simple inspection to systems exceeding the requirements of the ISO9000 or other similar standards hence, quality-related costs of all quality assurance systems are not the same. Knowledge about quality-related costs enable business decisions about quality assurance systems to be made.

Among the above-mentioned factors which may have an affect on quality functions, the business profile quality-based factors chosen for this study are summarised and listed in Table 7.4. Both the quality cost and quality policy, as mentioned before, are important factors that can affect choice of quality functions, but since they are not business profiles, they are not considered here.

Table 7.4: Business profile factors

Business profile factor	Classification of each factor
Primary activity	Service, manufacturing
Process	Discrete parts manufacturing, continuous process, batch process
Size	Small, medium, large
Product nature	Mechanical, electrical and electronic, chemical, biological, other
Manufacturing strategy	Design-to-order, engineer-to-order, make-to-order, assemble-to-order, make-to stock
Product complexity	Complex, semi-complex, non-complex
Plant layout	Multi-product flow line in single location, multi-product in different sections, single-product flow line in single location, one basic product in different sections, GT or cellular layout.
Production method	Mass production, batch production, one-off production
Material and production management	Order-point system (OPS), MRP, JIT

7.4-The data collection instrument:

In order to understand the quality assurance requirements of different companies, the available literature on quality assurance systems has been reviewed. The author has found no research concerned with the relationship between the above factors and propounded quality functions. It was therefore necessary to conduct an industrial survey.

A questionnaire was designed and sent to more than 500 UK companies. The main objective of the study was to gather data about approaches to quality assurance systems used by different types of business and to investigate those factors, both generic and business type or company specific, which can affect the design of a quality assurance information system. The complete questionnaire is in Appendix III.

The manufacturing business organisations selected for study were obtained from the Financial Analysis Made Easy (FAME) database [191], which is available on CD-ROM, and Kompass [145]. FAME and Kompass provide profiles, financial details and address of more than 12000 UK business organisations. Kompass provides the details of quality-assessed companies.

The various manufacturing businesses of either small, medium or large size were selected from the FAME and Kompass lists primarily based on the following criteria:

- Manufacturing business organisations, either in the public domain or in the private sector, which have been assessed and awarded some kind of required quality certificate, particularly ISO9001 and ISO9002.
- Manufacturing businesses which export some of their products.
- Manufacturing businesses with a high rate of return on investment, or turnover, and good business performance history.

Companies matching these criteria were considered likely to have sound quality assurance systems.

A total of 143 (28.6%) companies of different sizes and various processes completed the questionnaire. Table 7.5 summarises the companies according to the size and process and Table 7.6 shows the companies according to manufacturing strategy and method of production.

Table 7.5: Statistics of companies that completed the questionnaire

Process / Size	Discrete parts process	Continuous process	Batch process	Total
Small	26	4	2	32
Medium	63	16	5	84
Large	15	9	3	27
Total	104	29	10	143

Table 7.6: Statistics of companies according to their Manufacturing strategy and method of production

	Mass	Batch	One-off	Mass & batch	Batch & one-off
Design-to-order	1	31	9	3	8
Engin.-to-order	1	8	2		2
Make-to-order	4	44	1		2
Assem.-to-order	3	6	1		
Make-to-stock	9	7		1	

The data collection instrument consisted of two parts. In the first part managers were asked for data that could be used to classify their business or company. The main items were the business type classification previously discussed; nature of their product; complexity of their products; size of their company; manufacturing strategy; production management strategy; production process (method). This part of the questionnaire provided the data to specify the profile of their business.

The second part of the questionnaire asked for ratings on presumed quality functions which were based on the generic quality assurance information system discussed in

Chapter 6. The rating is based on the importance of the function to the respondents' business and the extent to which it suits the specific requirements of their business profiles and manufacturing strategies. Respondents were also asked to identify any functions which had not been included in the questionnaire

Results from the responses were analysed using the Statistical Package for Social Science (SPSS) [149] as discussed in the following section.

7.5-Data analysis:

The first stage of data analysis should always be a detailed examination of the data. This will determine whether the problem we are solving is simple or complex or whether for example we should do analysis of variance or non-parametric tests on the data.

To understand this, the distribution of data values should be distinguished to make sure that there is nothing unusual. One of the techniques for data distribution is to create a graphical representation of the data. A histogram provides information about the distribution of observed values and a boxplot displays summary statistics for that distribution.

There is a large number of statistical tests available to determine whether a difference between two or more groups is significant. In deciding which is the most appropriate statistical test to use in the analysis of the data, it is necessary to bear in mind the following considerations:

- Categorical data: If the data are of a categorical or nominal nature, where the values refer to the number of cases that fall within particular categories, it is only possible to use what is referred to as a non-parametric test.
- Ordinal and interval data: If the data are of a non-categorical nature, then it is necessary to decide whether it is more appropriate to use a parametric or non-parametric test.

- Related or unrelated comparison groups: The kind of test which can be used also depends on whether the values to be compared come from different cases, or from the same or similar ones.

The tests generally used given these criteria [181] are listed in Table 7.7.

Parametric versus non-parametric tests: One of the issues in data analysis is the question of when parametric rather than non-parametric tests should be used. Some writers have suggested that it is only appropriate to use parametric tests when the data fulfils the following two conditions [151]:

1. The populations we are sampling can be approximated closely to a Normal distribution.
2. These populations all have the same variance.

Table 7.7: The general test which are applied to different criterias (Bryman [181])

Nature of criterion variable	Type of test	Number of comparison groups or samples				
		Unrelated data			Related data	
		1	2	3+		3+
Categorical: nominal or frequency	Non-parametric	Binomial Chi-square	Chi-square	Chi-square	McNemar	Cochran Q
Non-categorical: ordinal or ranked	Non-parametric	Kolmogrov-Smirnov	Kolmogrov-Smirnov Median Mann-whitney	Median Kruskal-wallis	Sign Wilcoxson	Friedman
Non-categorical: interval or ratio	parametric Variances	t	t F	One-way ANOVA Cochran C Harteley's F Barlett-Box F	t t	Multivariate ANOVA

Considering Table 7.7, since all the data on quality functions are unrelated ranked data and the comparisons have to be done on three or more groups, the following tests (Table 7.8) are appropriate.

Table 7.8: Tests considered appropriate for analysing the data

Type of test	Test
Non-parametric	Median , Kruskal-wallis
Parametric	One-way ANOVA , Cochran C Harteley's F, Barlett-Box F

Here we have to decide whether the observed differences among more than two sample means can be attributed to chance or whether there are real differences among the populations sampled. The method normally used to test the null hypothesis that several population means are equal is called analysis of variance (ANOVA). This technique examines the variability of the data within each group as well as the variability between the group means. Before carrying out ANOVA, an analysis was done on the quality functions to find if there is any correlation between them. It was found that there are some low positive correlation between quality functions for which it might be better to apply multi-variate analysis on the quality function's data. However, since the gathered data was insufficient, doing multi-variate analysis was not possible.

Two kinds of analysis of variance may be applied: One-way and two-way ANOVA. The one-way ANOVA is needed when one variable is used to classify cases into the different groups and the two-way ANOVA is used when two or more variables are used to form the groups. The two conditions mentioned above are critical to the ANOVA procedures as a parametric test and require to be fulfilled by the data.

One way to roughly check normality is to construct histograms for each group. Histograms reveal skewness and bimodality [151]. To test the null hypothesis that the groups come from populations with the same variance, normally the Levene test which is less dependent on the assumption of normality than most tests [152] is used.

To recognise which quality function relates to which profile factor or factors and to identify if there is any interaction between profile factors on each quality function, the analysis was conducted on the data, from both parts of the questionnaires, in four stages. First, a histogram was produced for all data on each quality function to check that the data came from a normal population. An initial inspection of graphical plots of distribution showed a heavy skew in some of them which suggest that the conditions are violated. However, a power transformation of these raw data was enough to make them approximately normally distributed. Since the order of the observations is not changed by the transformation, any conclusion about differences in the transformed data are true for the original data [151].

In stage two, a Levene test of homogeneity-of-variance, of quality functions for each profile factor, was done to find if the observed significance level is small. Results showed that almost all quality functions with a normal distribution did not have a small significance level.

In the third stage, as each quality function is classified into different groups by business profile factor, one-way analysis of variance was needed to analyse the variability between groups and within groups. Since the size of each group could be different, one-way ANOVA with unequal sample size method was used.

In stage four, to find if there is any interaction between profile factors on each quality function, two-way analysis of variance was used.

As an example of how this methodology was carried out, the quality function "market-studies" is analysed. Prior to conducting the statistical analysis, cases with missing data were eliminated from the data set reducing the sample size from n = 143 to 134. The table 7.9 shows the data set.

Table 7.9: The whole data set of market-studies function

No.	Function	No.	Function	No.	Function	No.	Function	No.	Function
1	3.00	31	5.00	61	7.00	91	2.00	121	3.00
2	10.00	32	.00	62	6.00	92	5.00	122	.
3	4.00	33	5.00	63	7.00	93	9.00	123	2.00
4	7.00	34	6.00	64	6.00	94	2.00	124	5.00
5	7.00	35	6.00	65	6.00	95	10.00	125	1.00
6	6.00	36	5.00	66	5.00	96	7.00	126	6.00
7	6.00	37	.00	67	10.00	97	9.00	127	5.00
8	8.00	38	8.00	68	8.00	98	5.00	128	2.00
9	4.00	39	5.00	69	9.00	99	6.00	129	6.00
10	8.00	40	4.00	70	8.00	100	8.00	130	6.00
11	4.00	41	5.00	71	8.00	101	9.00	131	6.00
12	9.00	42	9.00	72	3.00	102	9.00	132	7.00
13	6.00	43	7.00	73	10.00	103	5.00	133	10.00
14	4.00	44	4.00	74	10.00	104	9.00	134	8.00
15	8.00	45	1.00	75	4.00	105	4.00	135	4.00
16	8.00	46	8.00	76	7.00	106	7.00	136	2.00
17	6.00	47	4.00	77	10.00	107	.	137	3.00
18	8.00	48	8.00	78	5.00	108	.	138	4.00
19	9.00	49	6.00	79	6.00	109	5.00	139	2.00
20	8.00	50	.	80	.00	110	3.00	140	9.00
21	4.00	51	3.00	81	.00	111	9.00	141	6.00
22	.	52	.	82	8.00	112	2.00	142	9.00
23	6.00	53	5.00	83	8.00	113	.	143	7.00
24	4.00	54	6.00	84	8.00	114	.00		
25	7.00	55	5.00	85	7.00	115	8.00		
26	.	56	5.00	86	5.00	116	3.00		
27	.	57	4.00	87	9.00	117	9.00		
28	.00	58	7.00	88	7.00	118	5.00		
29	10.00	59	6.00	89	10.00	119	3.00		
30	5.00	60	7.00	90	4.00	120	1.00		

Histogram: One way to check the assumption of normality, at a glance, is to use a histogram. Figure 7.2 is the histogram of the data. This shows approximate normality. Although a histogram provides a rough basis for checking normality, it is often desirable to test the data by other tests which show better any unusual situation. The normal probability plot is normally used.

Tests of normality: Since the normal distribution is very important to statistical inference, the assumption that data comes from a normal distribution has to be tested. One way to do this is with a *normal probability plot.* Figure 7.3 is a normal probability plot of the sample of points for the market studies data. As can be seen the points fall more or less on a straight line, so it can be concluded that the distribution of data has roughly the shape of a normal distribution.

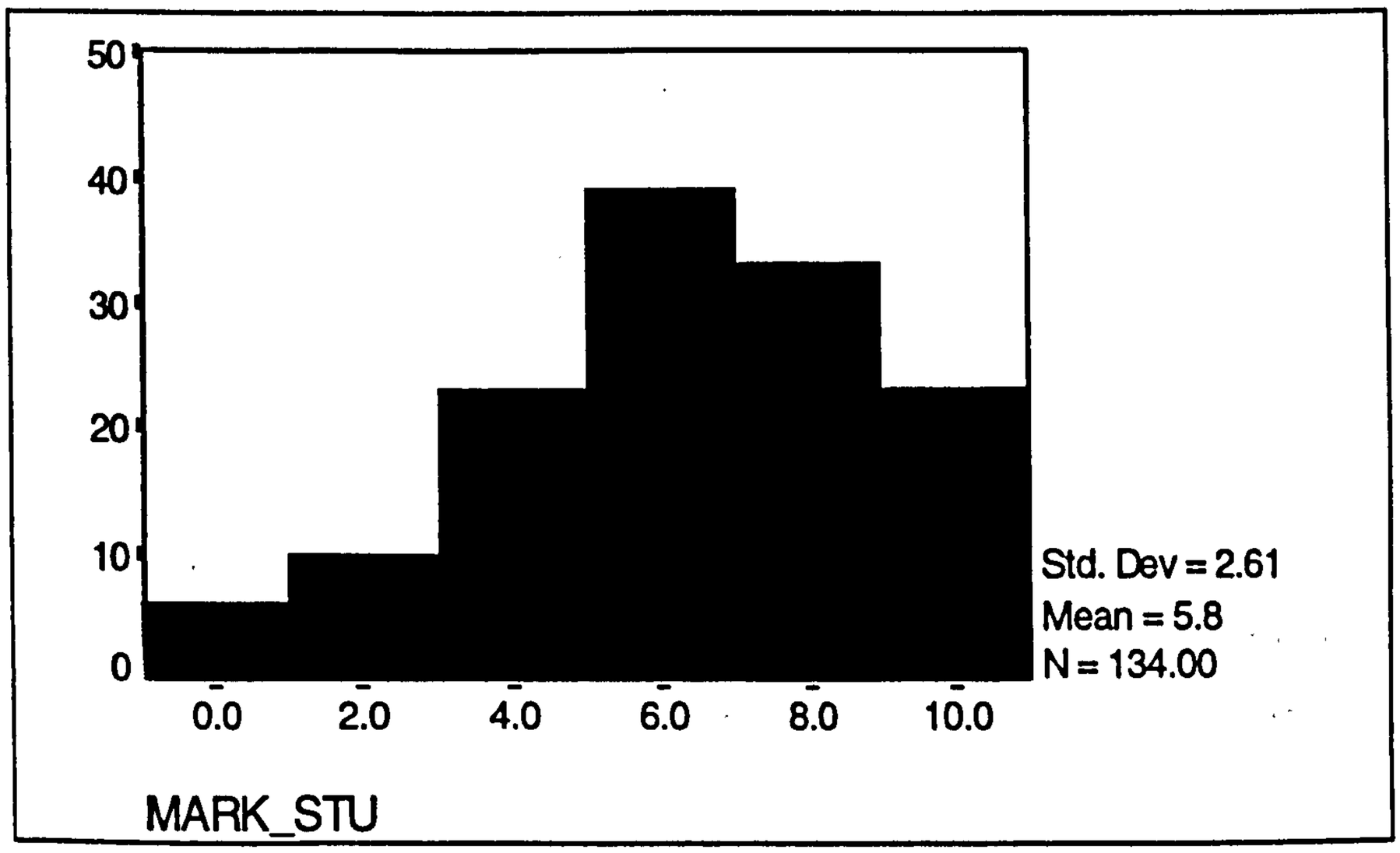


Figure 7.2: The histogram of market-studies data

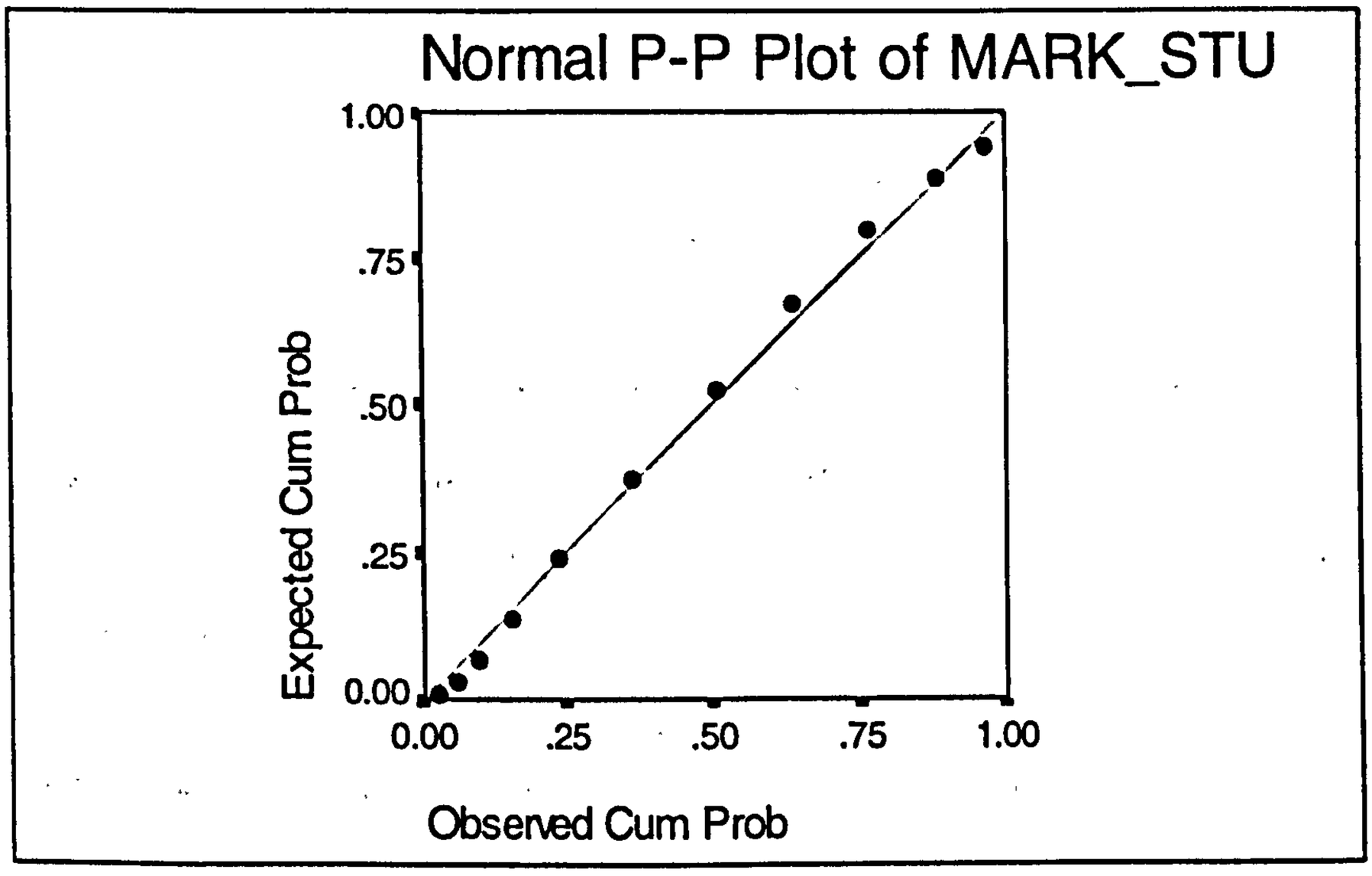


Figure 7.3: Normal p-p plot of market-studies data

Equality of variance: An analysis of variance assumes homogeneity of variances, that is, all the groups have the same variance. Numerous tests such as Hartley's test; Cochan's test; and Bartlett's test [151] are available for evaluating the assumption of homogeneity of variances. However, as said previously, among the various tests, the Levene test is less dependent on the assumption of normality and is thus particularly useful with analysis of variance[152]. This test can be run on the SPSS software package [149, 152] along with ANOVA.

The Levene test itself is simply a one way analysis of variance on the absolute values of the deviations from the group means. Table 7.10 shows the results of Levene test on the market-studies data. Since the observed significance level is not zero or approximately zero, the null hypothesis that all group variances are equal can be accepted.

Table 7.10: The results of Levene test on market-studies data

Levene Test for Homogeneity of Variances			
Statistic	df1	df2	2-tail Sig.
0.9966	4	66	0.416

Analysis of variance: In analysis of variance, the observed variability in the data is divided into two parts: variability of the observations within a group and the variability among the group means.

To analyse the market-study function, one-way ANOVA is done on its data with regard to manufacturing strategies to test the null hypothesis that the market-study function is necessary and equally important for each of the five manufacturing strategies. The results are shown in Table 7.11.

To do a one-way analysis of variance considering the five manufacturing strategies of: design-to-order, engineer-to-order, make-to order, assemble-to-order, and make-to-stock as five different groups, there is need to first calculate between-groups variability and within-groups variability and then divide one by the other to determine the F ratio. Comparing the calculated F value to the F distribution ($F_{\alpha,v1,v2}$), if the observed sample means vary more than is expected ($F > F_{\alpha,v1,v2}$), is evidence to reject the null hypothesis.

Table 7.11: The results of ANOVA on market-studies and manufacturing strategies

One-way analysis of variance					
Source	D.F.	Sum of Squares	Mean squares	F Ratio	F Prob.
Between Groups	4	193.7429	48.4357	10.3270	0.0000
Within Groups	66	309.5529	4.6902		
Total	70	503.2956			

The observed significance level (F prob.), from Table 7.11, is very small, so the population means of the five groups (manufacturing strategies) are probably not all equal, it means the hypothesis that the market-study function is equally important and necessary for the five manufacturing strategies can be rejected.

As can be seen, ANOVA does not say which pairs of groups appear to have different means. It may have rejected the null hypothesis because only two means are unequal. There is a need to use special tests called multiple comparison procedures to determine which means are significantly different from each other.

Several multiple comparison procedures are available such as [151]:

- Fisher's least significant difference
- Duncan's new multiple range test
- The student-newman-keuls' procedure
- Turkey's honestly significant difference
- Scheff's method

for which it is assumed that all treatment group sizes are equal. For the unequal group sizes of the present data, it is necessary to use a modification of these procedures.

In this case the group sizes are equal and Fisher's least significant difference procedure [153] has been used. According to this procedure, the difference between two means is significant if:

$$\text{MEAN (J)} - \text{MEAN (I)} >= t_{\alpha/2,N-\kappa} * \text{SQRT } (SM_E * (1/N(I) + 1/N(J)))$$

where α- is the type I error's probability (significant level set by experimenter);

N-is the sum of data belonging to all groups;

k- is the number of treatment groups;

t- is the t test;

SM_E- is the error mean square;

N(I)- is the size of group I;

and N(J)- is the size of group J.

Considering the results of the multiple comparison procedure in Table 7.12, it can be distinguished that the mean of Group 5 is significantly different from the other groups especially groups 1,2, and 3. It means that those companies which have chosen a make-to-stock strategy as a response to markets certainly need to do market studies to be successful in the market. This is perhaps the intuitive judgement and shows the suitability of the procedures adopted.

The means belonging to groups 3 and 4 are also different to those of groups 1 and 2, so it is better that those companies which are assemble-to-order or make-to-order implement market studies for their business.

Table 7.12: The results of Least Significant Difference on different groups of data for market studies.

Multiple Range Tests: LSD test with significance level .05

G G G G G

r r r r r

p p p p p

2 1 3 4 5

Mean	STRATEGY		
3.0000	Grp 2		Grp2: Engineer -to order
3.5000	Grp 1		Grp1: Design -to-order
4.1351	Grp 3		Grp3: Make-to-stock
5.2000	Grp 4		Grp4: Assemble-to-order
8.0714	Grp 5	* * * *	Grp5: Make-to-stock

(*) Indicates significant differences

The results of analysis of variance on market-study functions with regard to business profile factors are shown in Table 7.13. Except manufacturing strategy and production method factors, the factors do not show any significant difference between the groups' means. This means that, with the exception of manufacturing strategy and production method, these factors may not play any role in the decision whether on not to apply market studies.

Table 7.13: The results of one-way ANOVA on market-studies considering all business profile factors

Analysis of Variance						
Variable: Market-study						
By variable	Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Process	Between-G	2	11.4298	5.7149	0.8359	0.4358
Size	Between-G	2	0.6086	0.3043	0.0440	0.9570
Nature	Between-G	3	26.6553	8.8844	1.2973	02821
Complexity	Between-G	2	4.6862	2.3431	0.3402	0.7123
Strategy	Between-G	4	193.7429	48.4357	10.3270	0.0000
Layout	Between-G	3	30.7781	10.2594	1.5301	0.2100
Product-met	Between-G	2	74.4606	32.2303	5.5611	0.0050
Automation	Between-G	2	8.1000	4.0500	0.6614	0.5289
MPM	Between-G	2	7.2819	3.6469	0.5066	0.6041

In spite of all the results of one-way ANOVA on the market-study function, one question still remains which must be answered. Is there any particular combination of profile factors which can affect the decision on implementing market studies? The statistical technique used to evaluate this question is an extension of one-way ANOVA called

simple-factorial ANOVA. The same assumptions as for one-way ANOVA are needed for correct application.

The only interaction that was found to be rather significant was the interaction between production method and production management (Table 7.14). Therefore, it must be appreciated that in considering effects on quality functions it is necessary to consider both variables STRATEGY and MPM together, and not to consider their possible effect individually.

Table 7.14: Two-way interactions between profile factors applying two-way ANOVA

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
2-Way Interactions STRATEGY /SIZE	35.409	6	5.902	1.249	0.295
2-Way Interactions STRATEGY /MPM	32.275	4	8.819	1.870	0.134
2-Way Interactions STRATEGY /COMPLEX	18.796	6	3.133	0.659	0.683
2-Way Interactions MET_PRO /PROCESS	10.152	2	5.076	0.743	0.478
2-Way Interactions MET_PRO /COMPLEX	19.504	3	6.501	0.976	0.407
2-Way Interactions MET_PRO / MPM	34.135	4	8.534	1.244	0.299

In the same way, the analysis has been done on the other marketing quality functions, Table 7.15 summarises the results of the analysis. These quality functions being part of the pre-production quality functions.

7.6-Summary of findings

Considering both data of manufacturing strategy and method of production together, summarised in Table 7.6, it can be concluded that those companies which have chosen make-to-stock as a manufacturing strategy logically don't produce products in batches of size one and vice versa.

Table 7.15: Summary of the results of analysis on four marketing quality functions data

Manufacturing profile characteristics	Market studies	Competitor studies	QFD	Product specification studies
Manuf. Process method	No	No	No	No
Company size	No	Yes *	Yes	No
Product nature	No	No	No	Yes
Product complexity	No	No	No	No
Manufacturing strategy	Yes *	Yes *	Yes	Yes
Process layout	No	No	No	No
Method of production	Yes	No	No	No
Production management	No *	No	No	No

* Indicates interaction between profiles

The above conclusion may be expanded that along with effects of business profiles on selecting quality functions, conversely, it can be suggested that there are some points which generally affect configuration of business profiles. One of the important points is the criteria which define each profile factor, so all the profile factors for a specific business have to be congenial with each other. The idea behind just-in-time manufacturing is not congenial with a make-to-stock strategy, so it can be concluded that there is no company with a JIT manufacturing policy which directly serves customers from stock.

Taking into account the above points, statistical analysis was done on other quality functions. The summary of results is shown in Table 7.16 and the complete analysis is provided in Appendix IV. It should be mentioned that none of the profile factors affects the quality planning function. In other words and considering the data, it can be said that the quality planning is an essential function in any quality assurance system.

Table 7.16: the summary of the data analysis on all quality functions

Quality function	Profile factors which are effective in selecting QF
Marketing	Size, product's nature, M-strategy, production method
Sales	Process method, P-complexity, M-strategy
Design	Process, nature, P-complexity, M-strategy, production method
Process planning	M-strategy
Quality planning	***
Material acquisition	Size, M-strategy, production management
Production	Complexity, nature ,production method, production management
Post-production	Process, nature, complexity, M-strategy, production manag.

*** Representing no profile factors

The whole set of results may be summarised in an algorithmic form, such as has been done in Figure 7.4 for marketing quality functions. The algorithm is used in the formulation of the knowledge base of a Knowledge-based Decision System (KBDS) for the design of company-wide quality assurance information systems to suit the specific requirements of various business profiles and manufacturing strategies. The complete algorithm is shown in Appendix V.

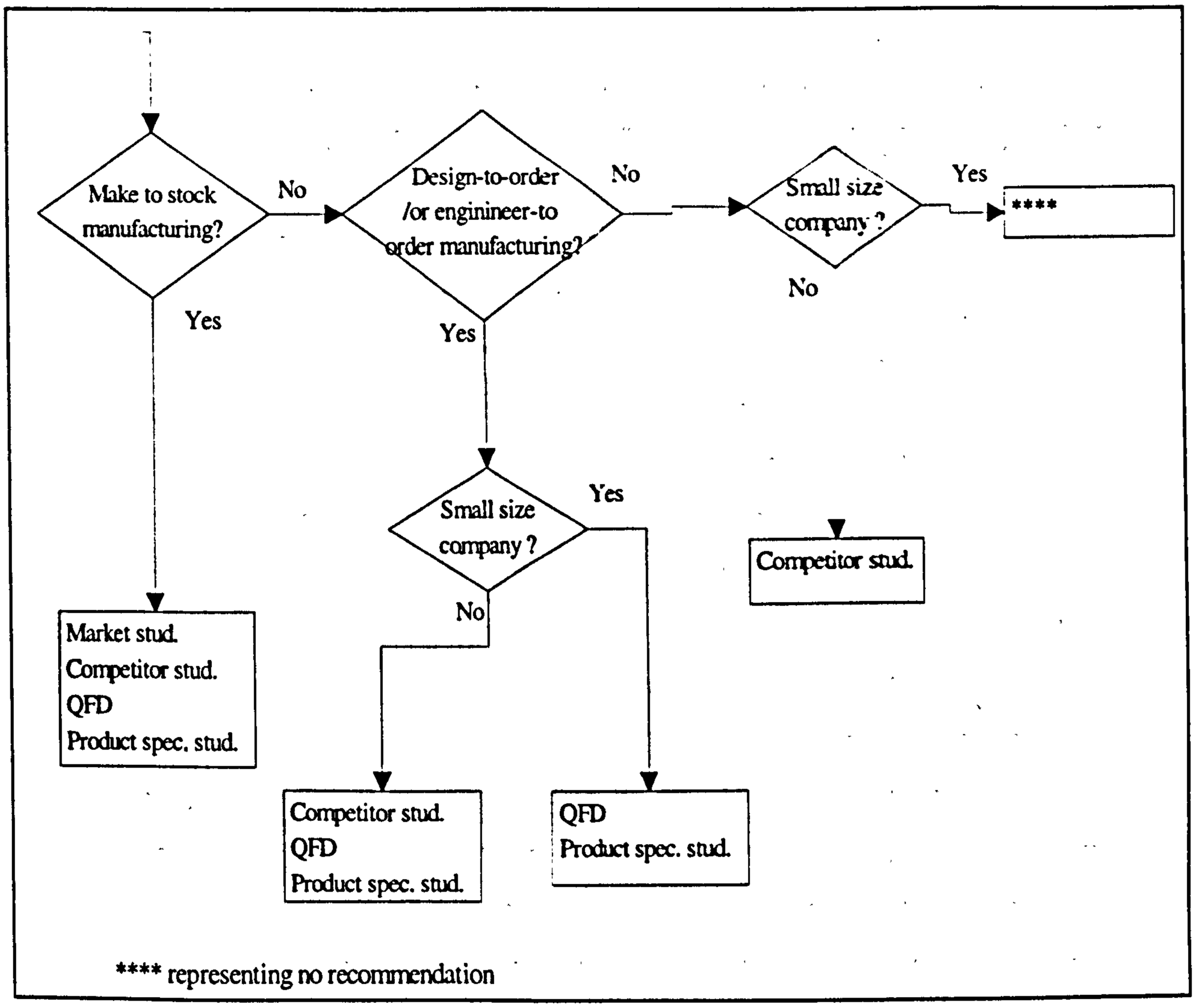


Figure 7.4: The results of analysing the data of four quality functions in an algorithm form

7.7-Validation of results (algorithm):

To make sure that the algorithm is valid and reliable, the results have to be evaluated. To do this, the algorithm was tested by applying the questionnaire respondents' business profiles to check if there is any difference between quality functions which the algorithm recommends, and the quality functions actually operated by each specific business.

The algorithm has been evaluated by the marketing quality function data of thirty manufacturing factories. Results are shown in Table 7.17. As it can be seen, one hundred and two of the one hundred and twenty recommended quality functions' cells verify the algorithm, and twenty four out of thirty sets of data are justified by the results of the algorithm.

Table 7.17: The results of the algorithm compared with the gathered data

Number	Size	Strategy	Mark-st	Com-st	QFD	Pro-s-s	Validation
1	L	5	10 *	9 *	10 *	7 *	OK
2	L	5	7 *	7 *	9 *	8 *	OK
3	M	1	4 *	7 *	9 *	9 *	OK
4	M	3	4 *	7 *	5 *	5 *	OK
5	L	1	4 *	8 *	9 *	9 *	OK
6	M	5	8 *	7 *	8 *	8 *	OK
7	L	5	9 *	8 *	8 *	8 *	OK
8	L	1	4 *	9 *	9 *	8 *	OK
9	S	1	4 *	2 *	7 *	7 *	OK
10	S	4	7	5 *	3 *	4 *	
11	M	3	0 *	7 *	5 *	5 *	OK
12	L	3	0 *	9 *	5 *	3 *	OK
13	M	1	5 *	9 *	7 *	7 *	OK
14	M	3	6	8 *	6	4 *	
15	M	1	0 *	7 *	8 *	8 *	OK
16	M	4	5 *	3	6	8	
17	S	3	5 *	5 *	0 *	4 *	OK
18	M	3	4 *	8 *	.	.	OK
19	S	3	5 *	4 *	.	.	OK
20	M	1	4 *	7 *	7 *	9 *	OK
21	M	1	1 *	7 *	8 *	8 *	OK
22	M	3	4 *	8 *	5 *	5 *	OK
23	S	3	5 *	1 *	4 *	5 *	OK
24	M	5	6 *	7 *	10 *	7 *	OK

Table 7.17: The results of the algorithm compared with the gathered data(continued)

Number	Size	Strategy	Mark-st	Com-st	QFD	Pro-s-s	Validation
25	M	3	9	7 *	.	.	
26	M	3	5 *	7 *	5 *	5 *	OK
27	L	3	4 *	7 *	.	5 *	OK
28	M	3	10	5	.	8	
29	L	1	4 *	9 *	10 *	8 *	OK
30	M	3	5 *	5	.	.	

where: * = representing those QF cells which verify the algorithm

. = indicating no response; and 0-10 are the ranking numbers for QF

S = Small ; M= Medium ; L= Large

1= Design-to-order; 2= Engineer-to-order; 3= Make-to-order; 4= Assemble-to-order; 5= Make-to-stock

7.8-Summary:

By examination of details of publicly held corporations, it has been possible to compile a list of industry types. It is clear that many of these different manufacturing situations require different quality assurance systems. In order to understand the quality assurance requirements of different companies, and to investigate and verify those profile characteristics which can affect the design of a QAIS, the available literature on quality assurance systems was reviewed and an industrial survey was done.

The results of the study have shown that there is some commonality of features between different classes of companies and, on the other hand, there are distinctive features specific to different manufacturing environments. Finally, the main results of the study were represented in the form of an algorithm.

Chapter 8

A knowledge-based system as a design aid for quality assurance information system

8.1-Introduction:

Manufacturing industry has witnessed significant development in recent years and one key to success is proper selection and effective use of manufacturing systems. At the same time, the design problems related to modern manufacturing systems have become more complex. Designers and users of advanced manufacturing systems have attempted to develop new tools to cope with these complexities.

Computerised knowledge-based systems have typically been used to solve problems that are either too complex for mathematical formulation or too difficult to solve using optimisation. Some of the difficulties encountered when using optimisation techniques may be offset by combining them with knowledge-based systems.

A knowledge-based system stores, manipulates and retrieves data in the form of knowledge about specific areas of interest called domains, attempting to emulate human inferencing or reasoning.

While the basic task of knowledge-based systems is solving complex problems, there are other benefits including cost reduction; increased output; improved quality; consistency of employee output; reduced downtime; captured scarce expertise; flexibility in providing services; easier operation of equipment; increased reliability; faster response; ability to work with incomplete and uncertain information; improved training [167].

Knowledge-based systems represent a class of modern tools that have been applied to improve, for example, the design and management functions in modern manufacturing systems. In this work it is applied to the design of quality assurance information systems.

8.2-The complexity of quality assurance system design:

Due to the number and diversity of factors that have to be considered, the process of designing a quality assurance system is a complex task. From the research that has been conducted it is noted that it is not sufficient to evaluate each of a business profile's factors individually, since many of them are interrelated. Using a knowledge-based system the general and specific quality based features can be embodied in a set of modular chunks. A knowledge-based decision system having appropriate decision criteria and rules to recommend modules of a quality assurance system appropriate to specific company profiles will therefore be a very valuable tool for executives and managers of manufacturing businesses.

8.3-Importance of designing the correct quality assurance system:

The objective of an effective quality assurance system should be to assist a company to satisfy customer needs and expectation, while at the same time serving to help protect the company's interests, ultimately 'bottom line' profit.

Customer demands and expectations , however, tend to be changeable and manufacturing companies have to be flexible so that they can respond to these changes and continuously satisfy customer demands. Therefore the quality assurance system as a sub-system of the manufacturing system must also be designed to cope with these issues of change.

8.4-Knowledge-based decision systems:

Knowledge-based systems that are capable of replacing the human decision-maker by producing a required decision, or sequence of decisions might be termed knowledge-based decision systems [165]. Obviously the most important element of any knowledge-

based system is the knowledge itself. Knowledge consists of established facts or experiential opinion relating to what has been discovered, inferred, learned, perceived and understood in respect of a specific subject.

8.4.1-Knowledge elicitation:

The development of knowledge-based systems involves a process of acquiring, analysing and interpreting the domain-specific knowledge to be represented in the system. It may be obtained from a variety of sources including documented rules and procedures, published texts, the content of existing databases or the undocumented knowledge in the minds of human experts.

Collecting knowledge from experts can be a slow process because, in many instances, human experts are not very efficient in explaining the way in which they arrive at conclusions and make decisions. Historically, this has been the most time-consuming, tedious and expensive job in the developments of K.B systems. Traditionally highly skilled knowledge engineers have undertaken this task.

The methods of eliciting knowledge can be categorised into two broad groups, top-down and bottom-up. Zahedi [170] has classified all the knowledge acquisition methods as shown in Figure 8.1.

In the application of knowledge-based systems to the design of quality assurance systems, since direct access to experts was limited, the use of a questionnaire had the potential to ease the burden of knowledge elicitation from manufacturing companies. A questionnaire, as explained in chapter 7, was prepared and sent to practitioner experts in each of the companies selected as described in chapter 7. The questionnaire provided focused questions to elicit expert perceptions on the importance of various quality functions and the associated information requirements within specific business types and their manufacturing systems. This expert knowledge was supplemented with knowledge

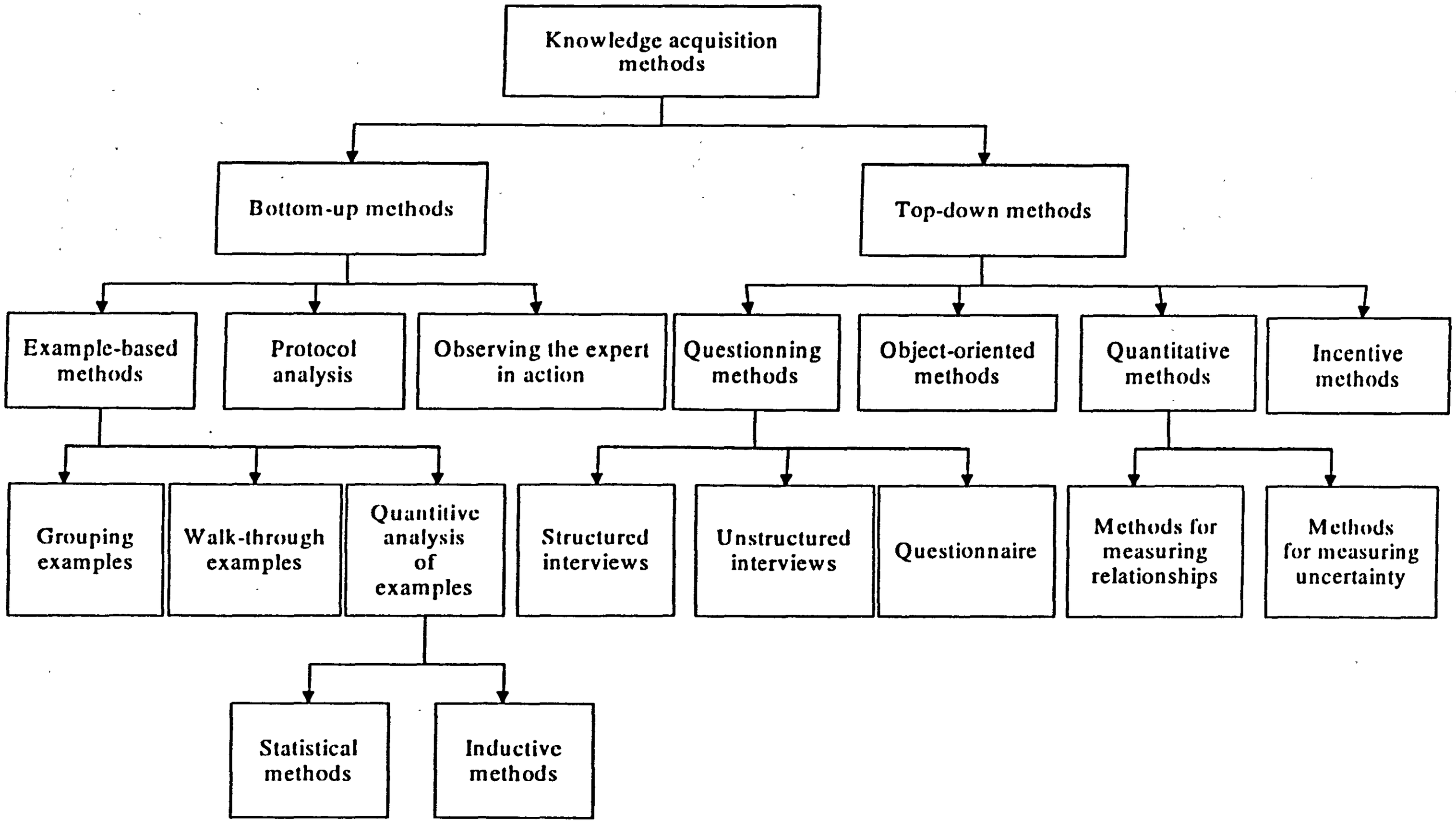


Figure 8.1: Categories of knowledge acquisition methods (Zahadi [170])

obtained from the published literature, this tending to represent the academic view of quality assurance system design.

8.4.2-Knowledge representation:

After collecting the information needed for designing the knowledge-based system, the next phase is proper knowledge representation.

Knowledge representation means that knowledge is formalised in a symbolic form, that is, by a symbolic expression that can be interpreted. In Artificial Intelligence (AI), we are interested in knowledge representation formalisms that can be manipulated by computer programs. Knowledge representation can be either declarative or procedural. Declarative knowledge representation includes logic, semantic networks, frames and scripts, while procedural knowledge representation includes procedures and production rules [120].

8.4.3-Comparison of different representation:

Knowledge representation is the heart of knowledge engineering [188]. The notion that knowledge representation schemes play an important role in building intelligent systems is widely accepted by both researchers and practitioners of AI [189]. In spite of this, as Niwa [190] says, there is no ultimate scheme for all purposes, because every scheme has its limitations and its strengths and there is no one formalism that is better than the others *per se*. One must keep in mind that each representation depends on the problem domain and the task that is to be performed.

Table 8.1 shows a comparison among different knowledge representation formalisms which shows that, by and large, the rule-based paradigms satisfy most of the criteria and have an overall acceptable performance [188], hence the vast majority of the earlier knowledge-based reasoning systems were based on the representation of knowledge in the form of production rules. Many knowledge-based systems built today use this approach [165].

Criteria	predicate logic	rules	semantic networks	frames
Declarative knowledge	3	1	3	3
Procedural knowledge	1	3	1	3
Granularity	4	4	4	1
Reasoning strategies	4	4	4	4
Easy of use by expert	2	3	2	1
Modularity	4	4	1	2
Maintenance	3	3	3	2
Processing efficiency	1	3	3	4
Volume of knowledge base	2	3	3	1
Volume of inference engine	2	3	3	1

Table 8.1: Comparison among different knowledge representation (created from Bingi [189], Niwa [190])

The main advantage of rule-based representation is that rules are relatively easy to construct[166]. In this programming paradigm, rules are used to represent heuristics or "rules of thumb". which specify a set of actions to be performed for a given situation. A rule is composed of an *if* (condition) portion and *then* (action) portion. The *if* portion of a rule is a series of patterns which specify the facts which cause the rule to be applicable. The *then* portion of a rule is a set of actions to be executed when the rule is applicable. If patterns of data are found which match the conditional elements of the rule, the 'action' part of the rule may be executed.

8.4.4-Expert system environment:

A computer program that employs knowledge and inferencing to solve problems is generally termed a knowledge-based system. When knowledge and inferencing procedures are modelled after human experts, such a knowledge-based system is called an expert system.

An expert system has a built-in dialogue from experts in the field. The task of eliciting and modelling the problem-solving knowledge and building a computer system is called

knowledge engineering. Figure 8.2 shows the main concepts associated with expert systems[172].

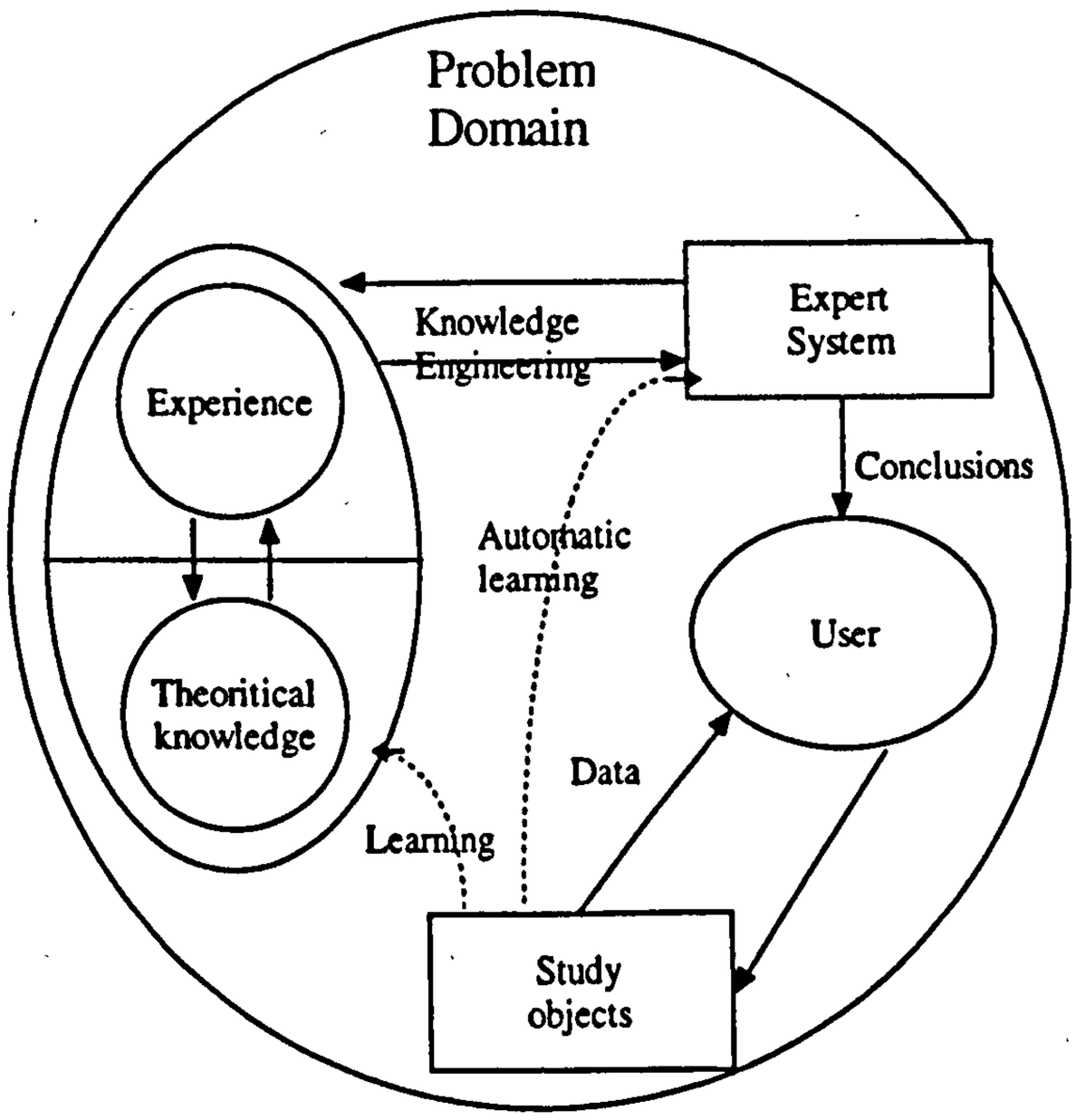


Figure 8.2: The main concepts of an expert system (klein [172])

8.5-Expert systems as a management tool:

Expert systems are suitable for all tasks that require experience in order to perform them proficiently. Gaining experience is a time-consuming, and often a very expensive process. Expert systems provide people with the opportunity of gaining experience at a fast rate with far less cost.

From management's perspective expert systems provide a potentially powerful tool that can quickly and efficiently upgrade the performance of employees

8.6-Expert systems as an extension of quality circles:

A study by Stylianou [167] has showed that the major reasons for using an expert system are to capture critical expertise and distribute that knowledge throughout an organisation.

Quality circles (QC) have been used in Japan for several decades. In group working, staff are invited to share their knowledge and expertise to solve common problems in an efficient and unique way. It can be reasonably argued that applying expert systems in business and industry is an extension of the Quality Circle methodology. The widespread use of PCs throughout industry provide an ideal network for disseminating quality-based knowledge via expert systems.

8.7-Tools for building expert systems:

There are three categories of tools for implementing expert systems on computers. These are general programming languages, special programming languages and expert systems shells.

General programming languages include algorithmic languages such as C, functional programming languages such as LISP and logic programming language such as PROLOG.

Special production systems programming languages are tools which more closely provide the programming needs of production systems. Examples of this class of language are OPS5 and ROSIE.

The vast majority of the early expert systems were built using a traditional AI language such as LISP. After a while it became evident that development of custom expert system applications is expensive, and also gives rise to a variety of problems, particularly that the entire expert systems needed to be built from scratch for each application. The way to overcome this was to separate out the knowledge from that part of programme which drives the expert system. This strategy resulted in a new category of knowledge engineering tool, the expert system shell.

Expert systems shells are highly specialised tools for building expert systems in special domains. Shells provide a means for experts to easily develop expert systems for their

area of expertise. In short, a shell is an empty expert system (without the domain-specific knowledge) and is a tool for building expert systems.

Expert system shells provide the basic component needed to construct an expert system [171], and:

- Allow developers to rapidly prototype a solution to a problem;
- Impose prior structure thus enabling developers to concentrate on substantive content rather than form;
- Help to reduce the levels of skill required by developers by effectively supplying some of the required expertise.

Moving from general languages to shells implies sacrificing generality and flexibility in the choice of solutions, but development time is shortened and the programming skill needed is less specialised [174].

Expert system shells are now used widely in the construction of expert systems.

8.8-Architecture of an expert system shell:

The shell is made up of a number of components (Figure 8.3):

1-Knowledge base: The repository of facts and rules that represent the domain-specific knowledge.

2-The inference engine: The driver of the system in the sense of making inferences from the knowledge base.

3-The working memory: A data area for storing intermediate results generated by problem-solving.

4-Development tools: Designed for use by knowledge engineers, these are tools for building and testing the knowledge base.

5-User interface: Allows end-users to run the expert system and interact with it. This enables the user to ask questions of the system, about how, for instance, the system came to a particular conclusion.

6-Knowledge acquisition facility: These are the facilities designed primarily to enable a domain expert to impart his expertise to the system directly [169].

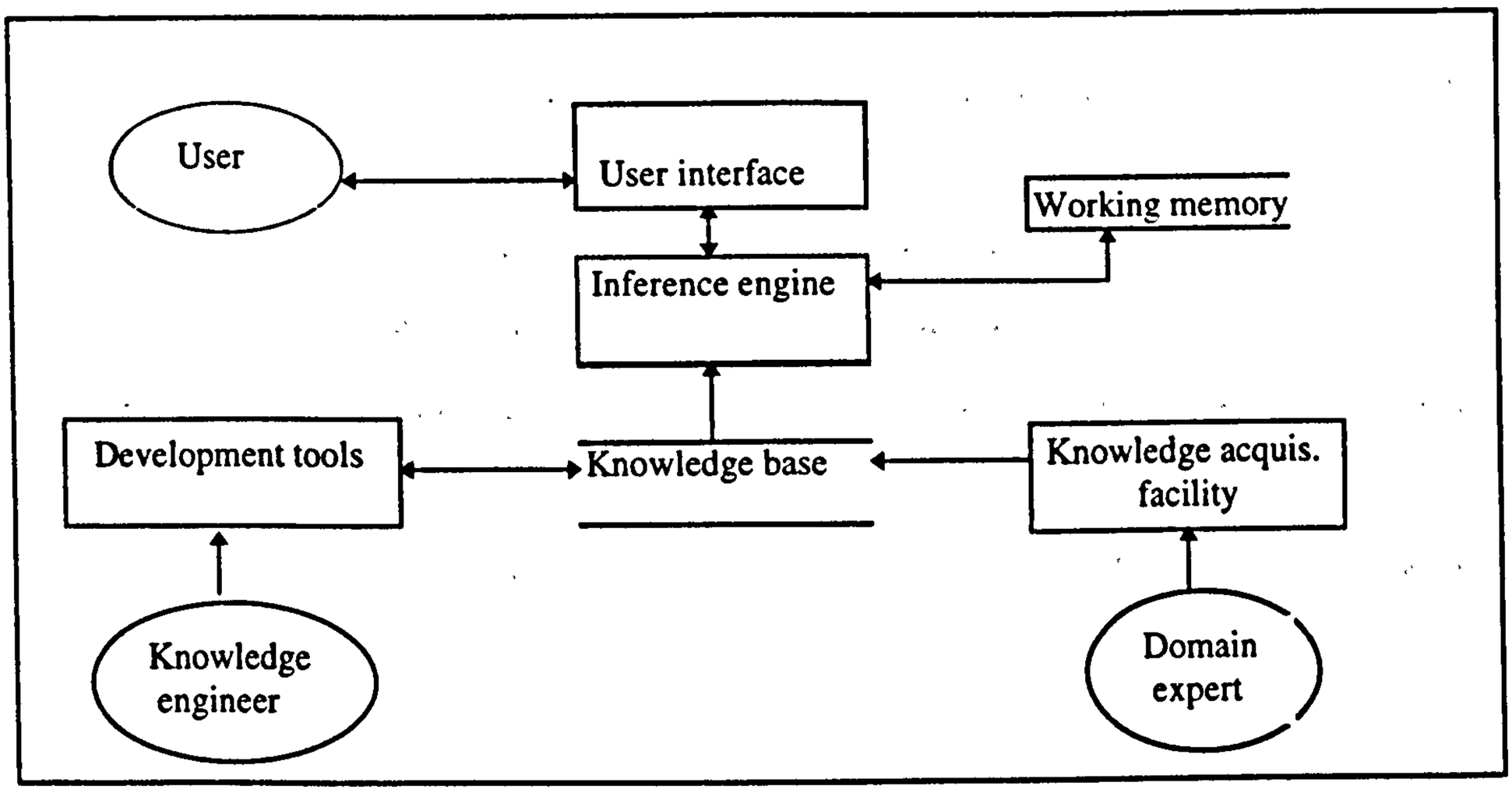


Figure 8.3: The architecture of expert system shell

8.8.1-Choosing the appropriate shell:

The selection of a specific Expert system (ES) shell for a particular application is an important decision. If the wrong shell is selected it could result in an inefficient or ineffective system or even in project failure. In general, the difficulties encountered during the process of evaluating and selecting ES shells are not unlike those for other software packages [168]. The availability on the market of a large number of rapidly evolving ES shells and the lack of industry standards or benchmarks, along with lack of user experience with this technology, make the comparison and selection of an appropriate shell a difficult task.

In the past few years the software market has witnessed the introduction of a number of commercial expert system shells. The advent of low-cost, PC-based expert system shells allows many more organisations to participate in this new technology. But what should one look for when selecting one of these software packages? Do some shell characteristics appear more useful for developing expert systems for a particular domain than others?

In the selection of the right tools, three major aspects should be considered [167, 171]:

- Problem domain requirements versus expert system tool capabilities;
- Inter-operability of the expert system development tools with other development tools, as well as inter-operability of completed expert systems with other automated systems; and
- Specific selection criteria used in selecting expert system building tools for specific projects.

8.8.2-Leonardo expert system shell:

As a result of an evaluation the Leonardo expert system shell was found to be easy and quick to use, for development, consultation and running, and it provides frames for storing and manipulating class details, making knowledge representation and maintenance simple. The other major factors influencing the choice of Leonardo were:

1. Its default consultation environment: this is quite attractive with plenty of scope for quickly building menus and input fields and for incorporating help text. explanations, and both brief and extended recommendations.
2. It does not require high level computer hardware and it is installed and run on a PC.
3. It has a free form rule editor which allows easy editing.
4. Leonardo can work with three types of external files- sequential, direct access and bytestream. It is able to open and read a file or write to the file.
5. It is able to run a completed application out of the development system environment: The Leonardo expert system has a separate program for running finished applications which contains none of the development, editing or knowledge base maintenance tools of the development system, so the application can be run automatically.

8.9-A Knowledge Decision System for Designing QAIS:

On the assumption that the functions of the problem processing system are (a) to retrieve information from the knowledge system, and (b) to use this information to generate useful

results using predefined models, a knowledge-based decision system (KDS) can be applied to improve the design of management functions in advanced manufacturing systems including quality assurance information systems as a sub-system of advanced manufacturing systems. The DSDQAIS presented here is a knowledge-based decision system which designs and outputs the structural model for a specific manufacturing company.

8.9.1-Host Environment of DSDQAIS:

The host environment includes the computer hardware and operating system in which the system can be run.

DSDQAIS has been designed to run on the minimum configuration of 486-based PC, Microsoft Windows 3.1 and a version of DOS 3.X.

The environment itself is built from an aggregate of the following tools:

(A) Dos-based Leonardo runtime system;

(B) Design/IDEF model development system;

(C) Winbatch dialogue development;

(D) Two specially developed tools which have been written in the C programming language.

8.9.2-Structure of DSDQAIS:

The system can be conceptualised as consisting of a dialogue sub-system, a knowledge based system, a transformation tool and graphic model sub-system(Fig. 8.4) that will work together. The structure is rather similar to the framework for DSS mentioned by Sparque and Carlson [173]. DSDQAIS requires the user to indicate or input the profile specification of a specific company, then the system presents a suitable structural model of quality functions and inter-related information for that company.

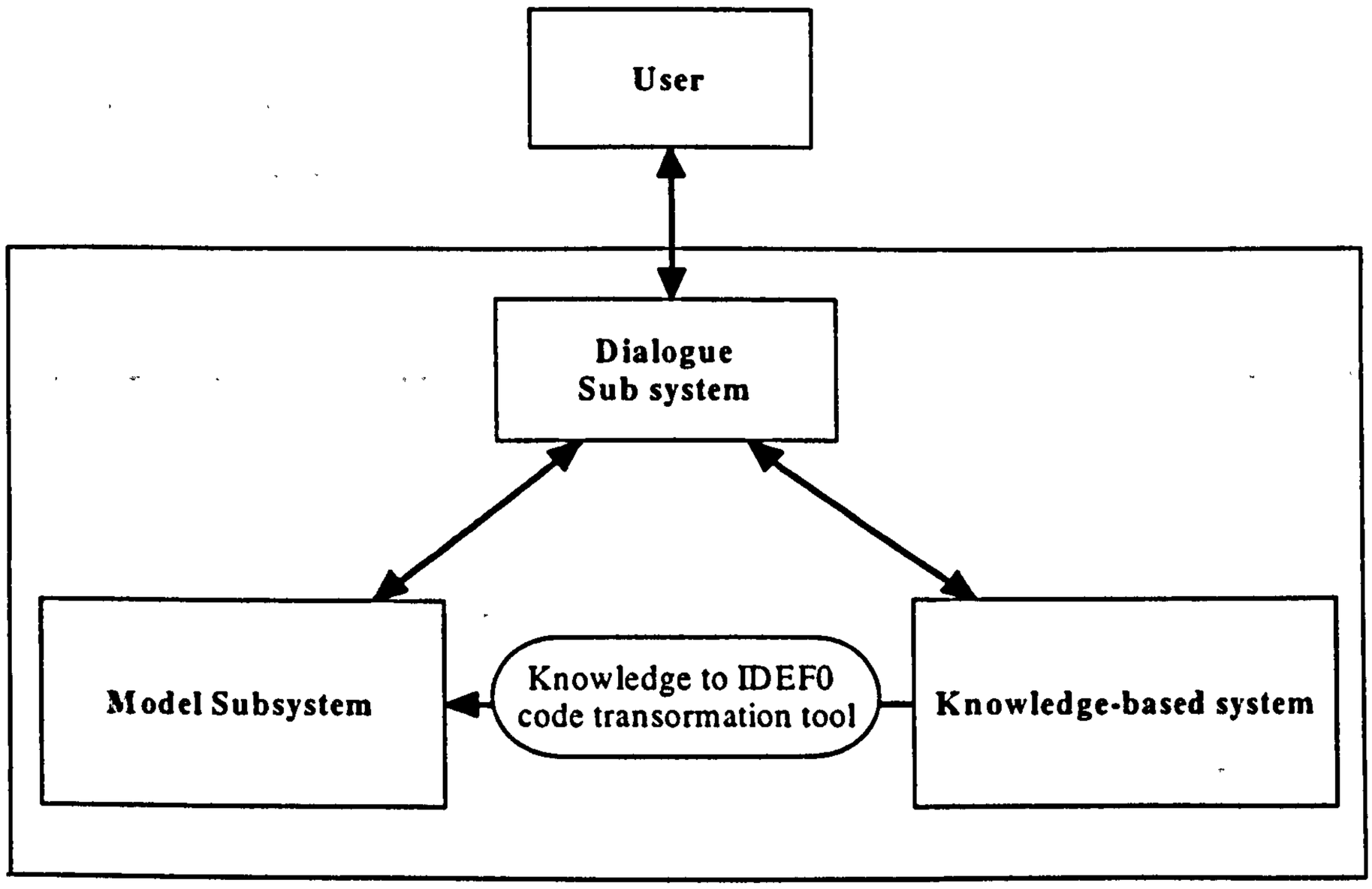


Figure 8.4: The structure of DSDQAIS

- **Dialogue sub-system:** Much of the power, flexibility, and usability characteristics of an application are derived from capabilities in the user system interface. Sparque [174] identifies the user, terminal, and software system as the components of the interface sub-system. The dialogue system is mainly a menu driven interface for users interacting with the system. It presents users with appropriate questions ,information and choices.

- **Knowledge-based system:** It consists of three modules, namely the knowledge-based module, inference module and the acquisition module. As discussed in Chapter 5, in the design of a structural model for QAIS a number of design rules have to be considered. In this section, the design rules are coded as production rules and are incorporated as a decision system. The expert system presents users with appropriate questions and choices through the dialogue sub-system for each of the manufacturing sub-systems of pre-production, production and post-production.

The version of Leonardo ES shell available for this research has limited knowledge based capacity, therefore the knowledge base was divided into three modules, one for each manufacturing subsystem. Figure 8.5 shows the specifications of each of the knowledge based modules(KBM).

	Pre-production KBM	Production KBM	Post-production KBM
Rules	215	61	31
Frames	14	12	9
RuleSets	2	2	2
Procedures	157	40	11

Figure 8.5: The specification of knowledge based modules

The reader can find more explanation about Leonardo Object Frame and RuleSet in Appendix VI.

- **Combining tool:** The output of each of the three knowledge-based sub-systems represents part of the whole QAIS. To present all of the information and activities together, it was necessary to create a combining tool. This operates by combining all of the output model information for pre-production, production and post-production to create a new file containing the data for the whole QAIS.

- **Transformation tool sub-system:** This tool was developed by the author to enable the automatic transformation of the output of the knowledge based system to a symbolic language(IDL) that can be used to represent an IDEF0 model form. It operates by directly mapping the stored entities of the KBES output into entities of the IDL language via reference to a model and is stored in a repository file. The reader should refer to Appendix VII for the reference model program which has been written in the IDL language and Appendix VIII for details of the transformation tool program listings.

- **Graphic model sub-system:** By importing IDL descriptions into this sub-system the structure and inter-related information requirements of the QAIS for the specified manufacturing company can be shown as an IDEF0 model. The establishment of the IDEF0 model of the QAIS not only offers formal structuring of activities and information, but also supports the design, build and change information system associated with them. Subsequently, the user can generate a full information report on the model.

The methodology which has been used to design and develop the DSDQAIS includes the steps shown in Fig. 8.6.

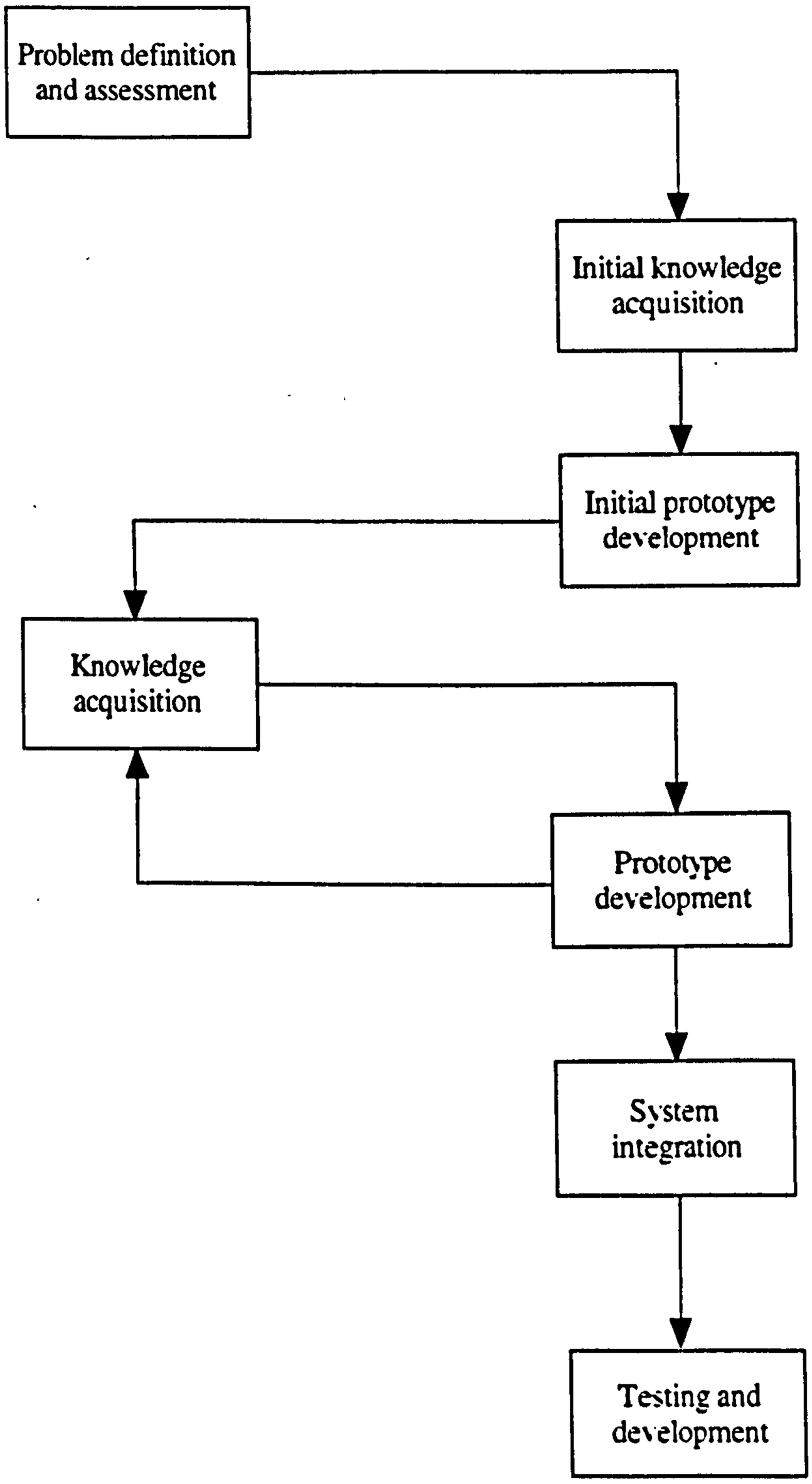


Figure 8.6: The methodology of designing and developing DSDQAIS

8.9.3-Design approach in DSDQAIS:

The design approach of the knowledge-based decision system for the design of QAIS is outlined in the following steps:

Step 1. Collect data from the user;

Step 2. (a)Generate knowledge according to an available algorithm;

(b)Put the knowledge in opened files;

(c)Combine the data and transfer to a file;

Step 3. (a) Transform the knowledge to a symbolic language(IDEF0 model code);

(b)put the coded knowledge in opened file;

step 4. Use the coded knowledge to generate an IDEF0 model;

step 5. User can generate a complete listing of all information in the form of a report.

Figure 8.7 schematically shows the above steps.

An example of how the DSDQAIS system works is shown in Fig. 8.8. Readers can find more information about this example in Appendix IX.

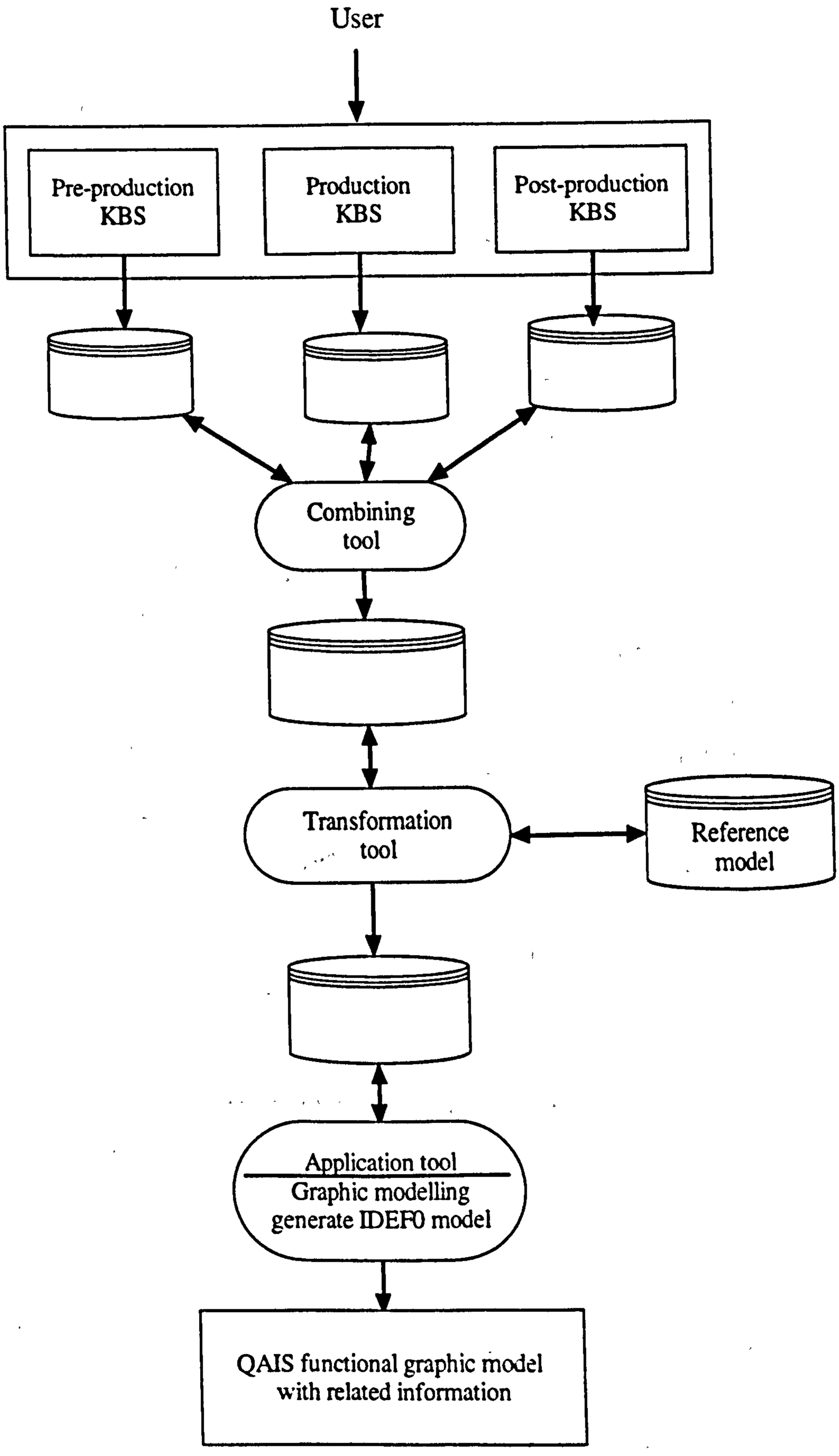


Figure 8.7: Schematic environment of decision system for designing QAIS

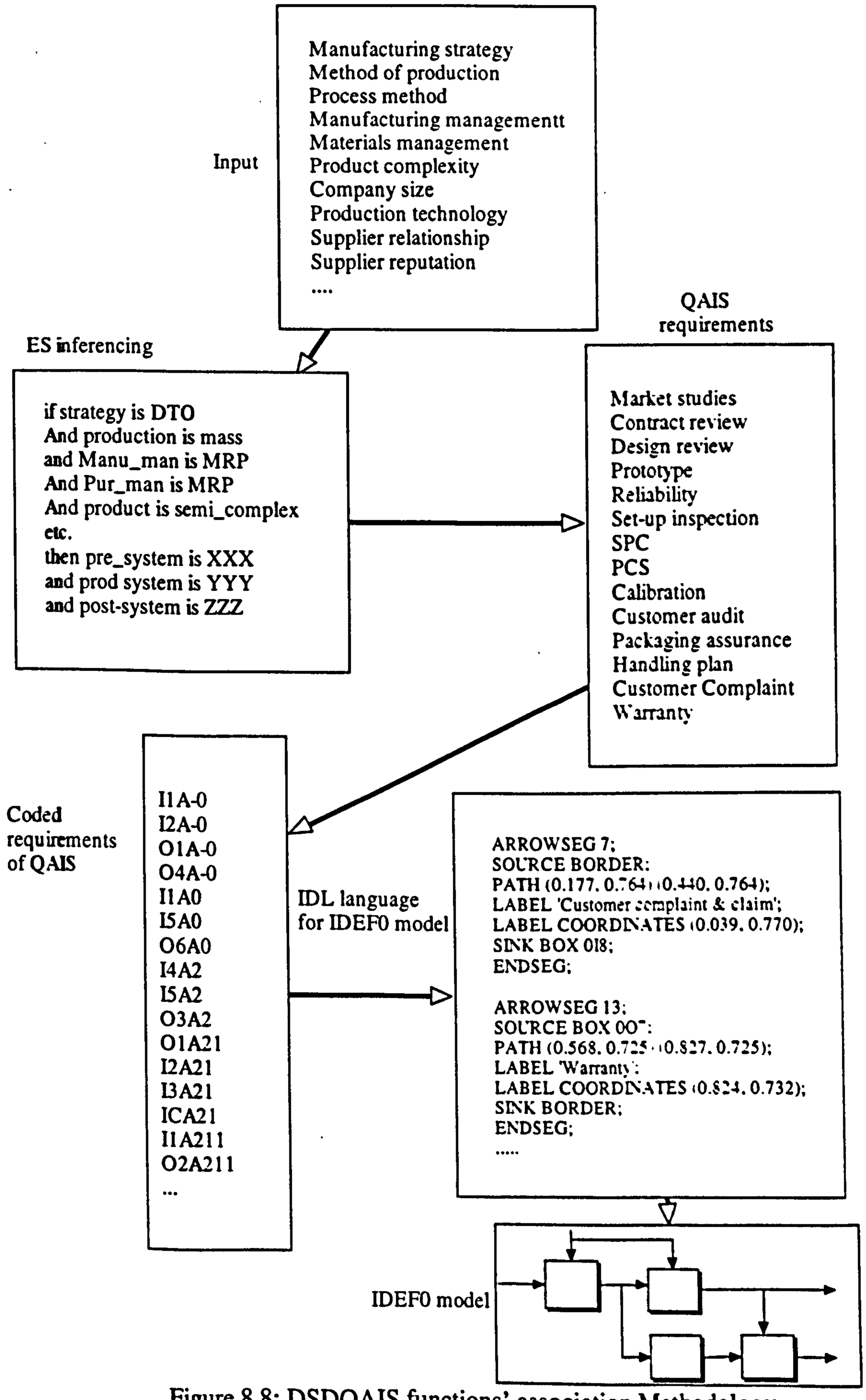


Figure 8.8: DSDQAIS functions' association Methodology

8.10-Summary:

The functions of a knowledge-based system(KBS), as a problem processing system, are to retrieve information from the knowledge system and to use this information to generate useful results. On this assumption, the issue of a knowledge-based decision system as an aid for designing quality assurance information system(DSDQAIS) was investigated and a prototype of this system was developed.

Chapter 9

Discussions and Conclusions

The aim of this chapter is to consider the conclusions which can be drawn from the research work reported in this thesis and to outline the major results of the survey conducted.

9.1-Introduction:

The main objectives of this research have been the acquisition of quality-based knowledge, creation of a generic model of quality functions and associated information, preparation of an algorithm and development of a decision system capable of recommending a quality assurance information system for specific manufacturing organisations.

To achieve these objectives, a comprehensive study on production systems, manufacturing strategies, production management systems, quality management systems, business profiles, expert systems and modelling tools has been undertaken. In the following section, the main findings of the research will be discussed.

9.2-Main research results:

I-The importance of the quality assurance function, has evolved from inspection to quality control engineering. The emphasis in quality assurance of physical products in manufacturing industries has changed to the application of quality concepts to all products, all functional activities, and all industries. It now lies in the design, planning, and control of all activities related to quality attainment. In other words, attainment of quality requires the performance of a wide variety of identifiable activities, quality tasks or quality functions and appropriate flow of information between them. This research has drawn out those essential generic functions which need to take place within any manufacturing environment. Those functions specific to particular manufacturing

environments have also been identified. Input/Output analysis has been used to translate the voice of the customer into appropriate functions for each stage in a product's development and production cycle.

II-The importance of integrating quality functions and inter-related information has been discussed in the literature [3, 65, 69, 117, 178, 179]. An integrated quality information system should cover the quality-based functions of pre-production, production, post production and the management support system. It is therefore helpful to have a structure which covers these facets of manufacturing and shows the interfaces among them. A macro-structure which shows graphically the relations between manufacturing functions, quality assurance information system and management support system has been created. This schematic model gives a perspective of the position of a QAIS in relation to other business functions.

III-Accepting that there is a strong need for an information system to integrate and support quality functions, this work has proposed a generic model of business functions that have an impact on quality, and their structure within an integrated quality assurance information system for any manufacturing environment. This generic model shows the basic elements of establishing a quality assurance information system, the information, the source of information, destination of information and the integration of them within an overall enterprise.

IV-Review of the literature on manufacturing quality assurance systems showed there to be no classification which specifically and directly makes reference or applies to factors which can affect the quality of product or service. However, it became clear that the quality functions that operate within a specific quality assurance system may depend on different factors. This research has shown some factors such as process and product complexity, product's nature, business manufacturing strategy, business production method and business production management to have significant affect on the design of quality assurance system.

V-Even though quality management is studied widely, little attention has been paid to comparisons between ideal quality management, as described in the academic literature, and actual quality management practice. The quality literature, by and large, supports the proposition that ideal quality management should not be affected by contextual and/or business profile variables. For example, Juran et al [176] state that ideal quality management is universal and suggest that the expectations regarding quality management should be the same regardless of the context and profiles. Similarly, Langevin [5] indicates that expectations regarding quality management should be the same in service and manufacturing organisations. Generally speaking, the view that expectations regarding ideal quality management should be context-free is reflected in much of the quality literature [1, 26, 177]. This research identified a gap between actual and ideal quality assurance systems practice. It has been shown, from a large sample of successful and competitive businesses that actual quality management is in fact influenced by an organisation's business profile.

VI-According to the quality literature, it is strongly advocated to put into place a quality-related training and education programme for all organisation members to stimulate a culture throughout the organisation that continually views quality as a primary goal [7, 8, 63]. The survey conducted in this research confirms the importance of awareness training.

VII-The widespread use of PCs throughout business and industry, along with the application of knowledge based expert systems, provide an ideal network for disseminating knowledge throughout an organisation. Use of an expert system in the design of quality assurance information systems helps to release managers and specialists from the routine issues of the task, allowing them to concentrate on the more complex problems and issues. Such an expert tool will also help non-technical specialists to reach and make correct decisions in an effective and efficient manner. This research has investigated and developed the issue of a knowledge-based decision system for designing quality information system (DSDQAIS).

Chapter 10

Further Recommendations

10.1-Introduction:

The author believes that this research has shed new light on the importance of an organisation's profile to the practice of quality management, and specially for the quality assurance information system. Also, the use of a knowledge-based approach to the design of a quality assurance information system has been demonstrated. However, additional research and empirical work in this area is needed. For progressive enhancement of the design of a structural model of QAIS as described in this thesis, the author recommends further investigation, work and development in the following key areas:

10.2- Some recommendations:

(A)-Developing a mathematical model for QAIS:

It is clear that to establish a quality assurance information system it is necessary to select and define quality functions and the interrelated information which transfers among them. This work has established an algorithm, and based on this, has developed a DSD system. The author believes that through further research and using mathematical methods such as general linear models (GLM) or operational research models (OR), it should be possible to develop a mathematical model for quantitative evaluation and selection of quality functions and their related information which will assure satisfaction of the desired product (or process) quality requirements. The variables of such a model could be various organisations' profiles.

Such a model could be incorporated as a subsystem of a decision-support system for the design of a QAIS allowing the DSD system a continuous interaction with the end-user.

(B)-Using Fuzzy logic expert system for designing QAIS:

The data that the expert system acquires as it attempts to recommend a solution for a problem often comes from error-prone humans. Therefore, it cannot be expected to be 100% precise. Even if the recommendation is related with precision, it may not be a binary response. On the other hand, it is important that an expert system be able to accept and properly interpret imprecise information provided by the system user. An organised method for dealing with this uncertainty and imprecise data is called 'fuzzy logic' [180]. An expert system which incorporates fuzzy logic and/or fuzzy set theory into the reasoning process and/or knowledge representation scheme may be used to design QAIS. The theoretical basis behind fuzzy techniques will allow us to deal with uncertainty in a manner that is well supported.

(C)-Developing a DSDQAIS for specific manufacturing industry(expansion of the DSDQAIS knowledge base):

This work has presented a generic framework of a structural model for QAIS and includes the commonalities between companies irrespective of the industrial sector to which they belong. The DSS then identifies company specific requirements. As the level becomes lower, quality functions are more and more dependent upon the products being manufactured and the technology and system employed. This can be used as a starting point from which to derive generic models for specific industries. The development of a DSDQAIS for various kind of industry such as electrical, chemical, mechanical, low volume, high volume and even of further depth in the hierarchy such as the metal-cutting industry or the automotive industry can be imagined. Such models would be expected to have a greater degree of common elements which simplifies the task of assigning special requirements.

(D)-Developing the generic information and data model of a quality assurance information system:

This work has presented the structural model of QAIS. The author believes that one of the next steps for enhancing the present work is to develop a generic information model and data models of the QAIS using known graphical modelling tools such as IDEF1, and IDEF1X , ER, NIAM, OMT, Shlaer-Mellor or EXPRESS-G [54]. By developing these generic models the structure and semantics of information within the quality assurance system will be established. An information model represents the structure of information needed to support the functions of the system or environment. It also provides descriptions of the information necessary for an organisation to manage and accomplish its objective. Once the information requirements are known, data models may serve to support the management of data as a resource, the integration of information systems and the building of computer databases. After finishing with information modelling, the next step would be dynamic modelling possibly using IDEF2 or Petri nets.

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APPENDICES

Appendix I

Overview of IDEF0 methodology

IDEF0 modelling review

IDEF0 is a modelling tool specifically developed for use in the functional modelling of complex and interrelated systems. Originally, IDEF0 was derived from another graphical model known under the acronym SADT (structural analysis and design technique) by the US Air Force to describe the organisation structure of complex manufacturing systems[9] and initially tested in several large aerospace manufacturers. Later the model was redeveloped and tested against non-aerospace firms.

IDEF0 views a complex system as a combination of functions, whether implemented by using machines, people or other means. Here a function is to transform the inputs into the outputs, under the influence of a control, using the mechanism provided (Figure A1.1). IDEF0 is applied using top down hierarchical decomposition. At the top of the hierarchy is the overall purpose of the model(A-0 layer), the global activity that is the subject of the model. The overall activity is decomposable into components that, when taken together, comprise the global activity. The second tier of the model is the A0 layer and, similarly, the decomposition of the second and subsequent tiers continues until there is sufficient detail to serve the purpose of the model builder(figure A1.2 includes A-0, A0, A1 layers).

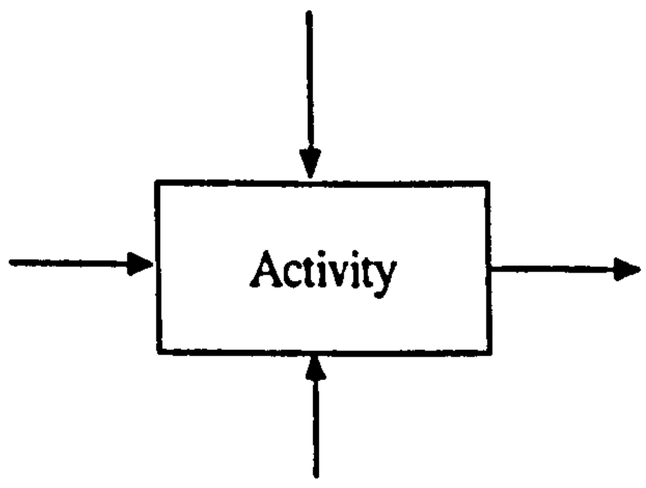


Figure A1.1: The IDEF0 methodology

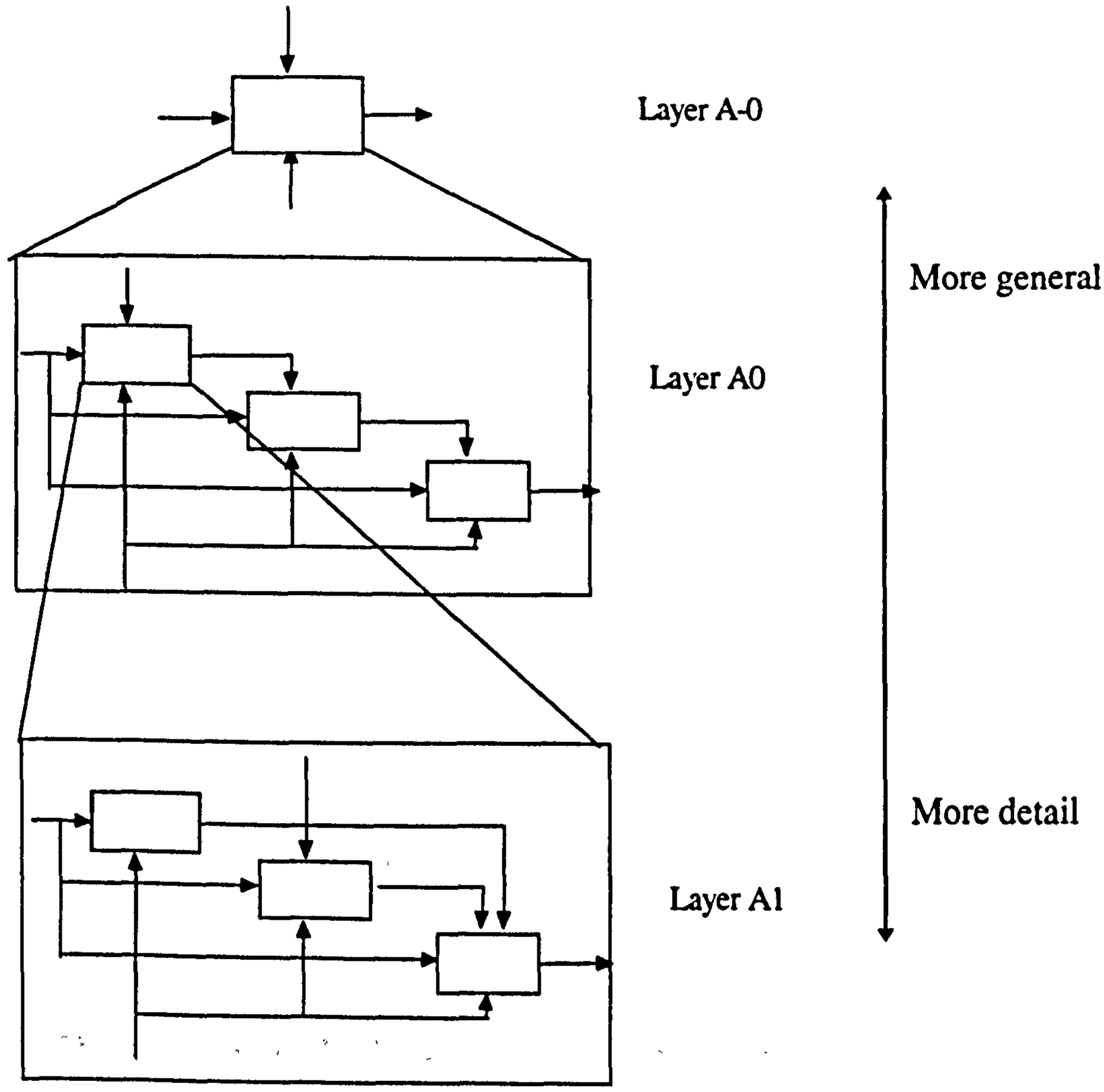
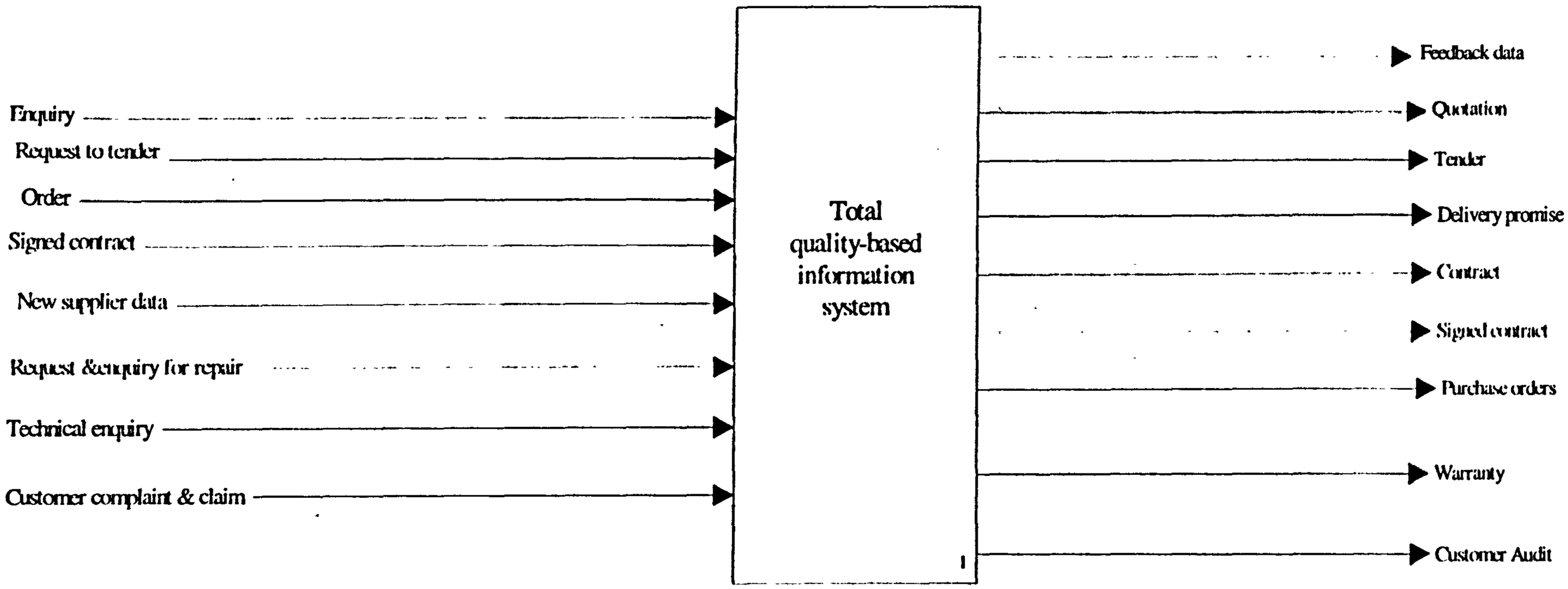


Figure A1.2: IDEF0 hierarchical decomposition

Appendix II

The IDEF0 model of Quality Assurance Information System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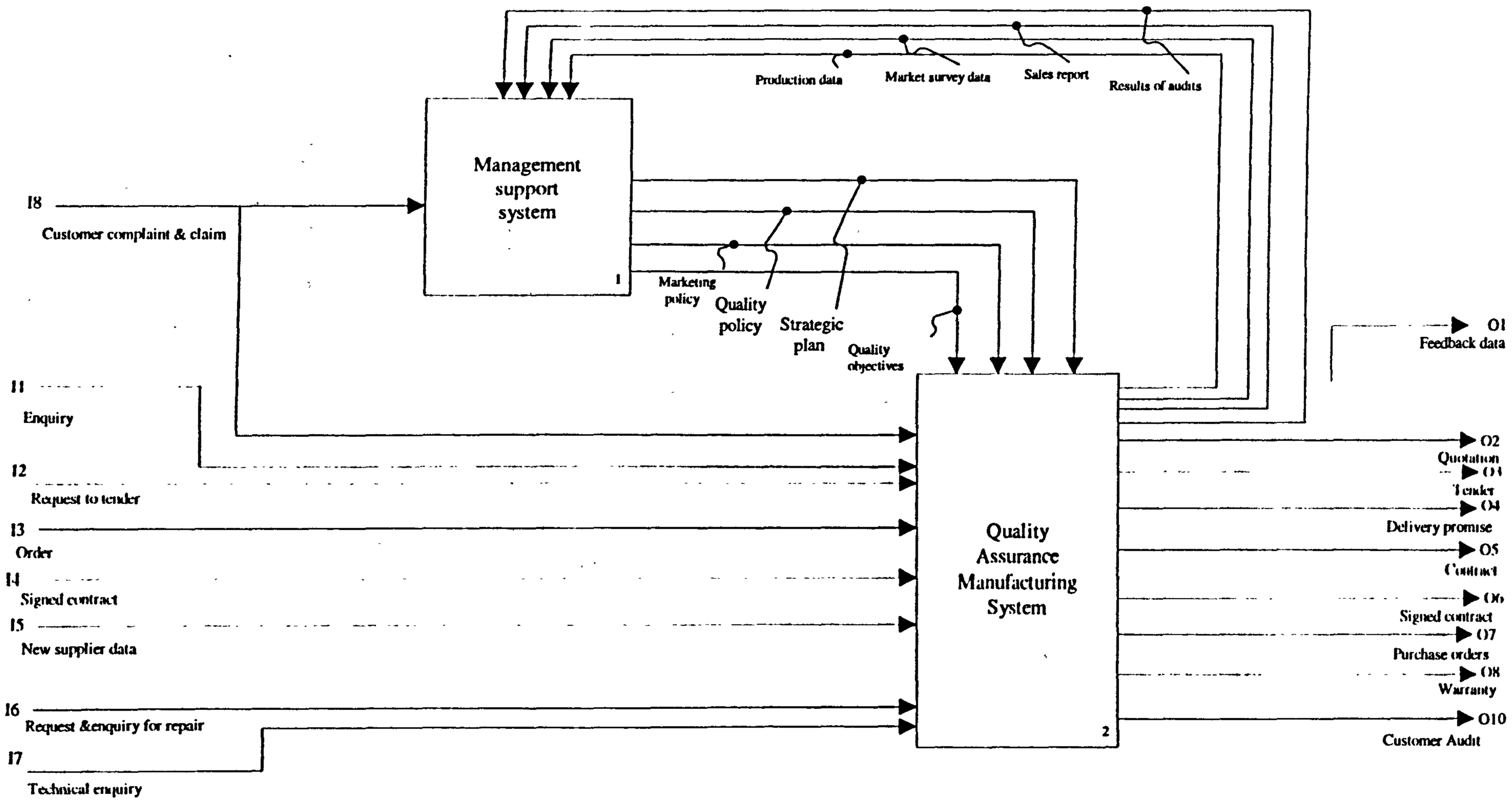
Request to tender
Order
Signed contract
New supplier data
Request &enquiry for repair
Technical enquiry
Customer complaint & claim
Total quality-based information system
Feedback data
Quotation
Tender
Delivery promise
Contract
Signed contract
Purchase orders
Warranty
Customer Audit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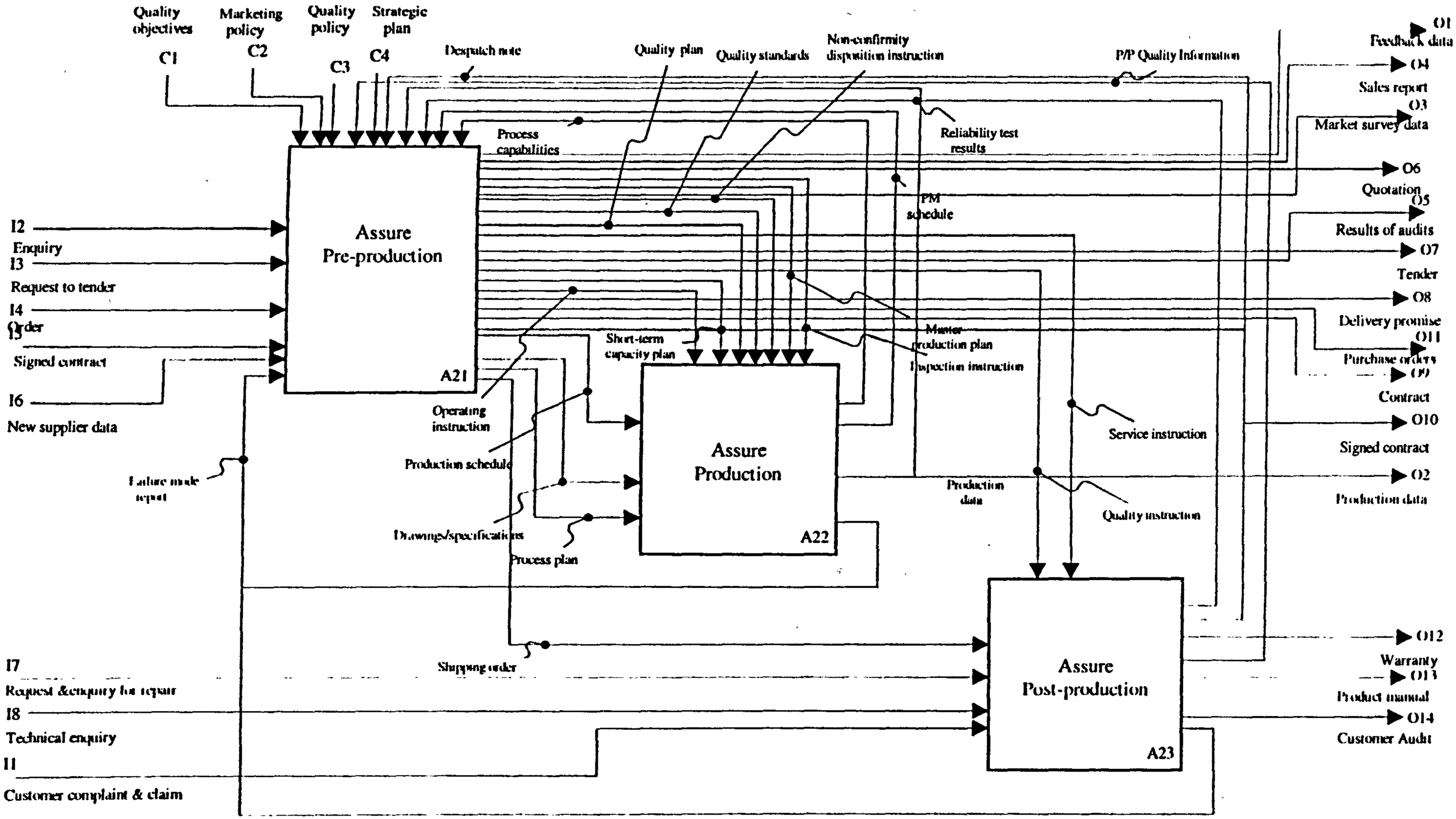
Market survey data
Sales report
Results of audits
Management support system
1
I8
Customer complaint & claim
Marketing policy
Quality policy
Strategic plan
Quality objectives
O1
Feedback data
I1
Enquiry
I2
Request to tender
I3
Order
I4
Signed contract
I5
New supplier data
I6
Request &enquiry for repair
I7
Technical enquiry
Quality Assurance Manufacturing System
2
O2
Quotation
O3
Tender
O4
Delivery promise
O5
Contract
O6
Signed contract
O7
Purchase orders
O8
Warranty
O10
Customer Audit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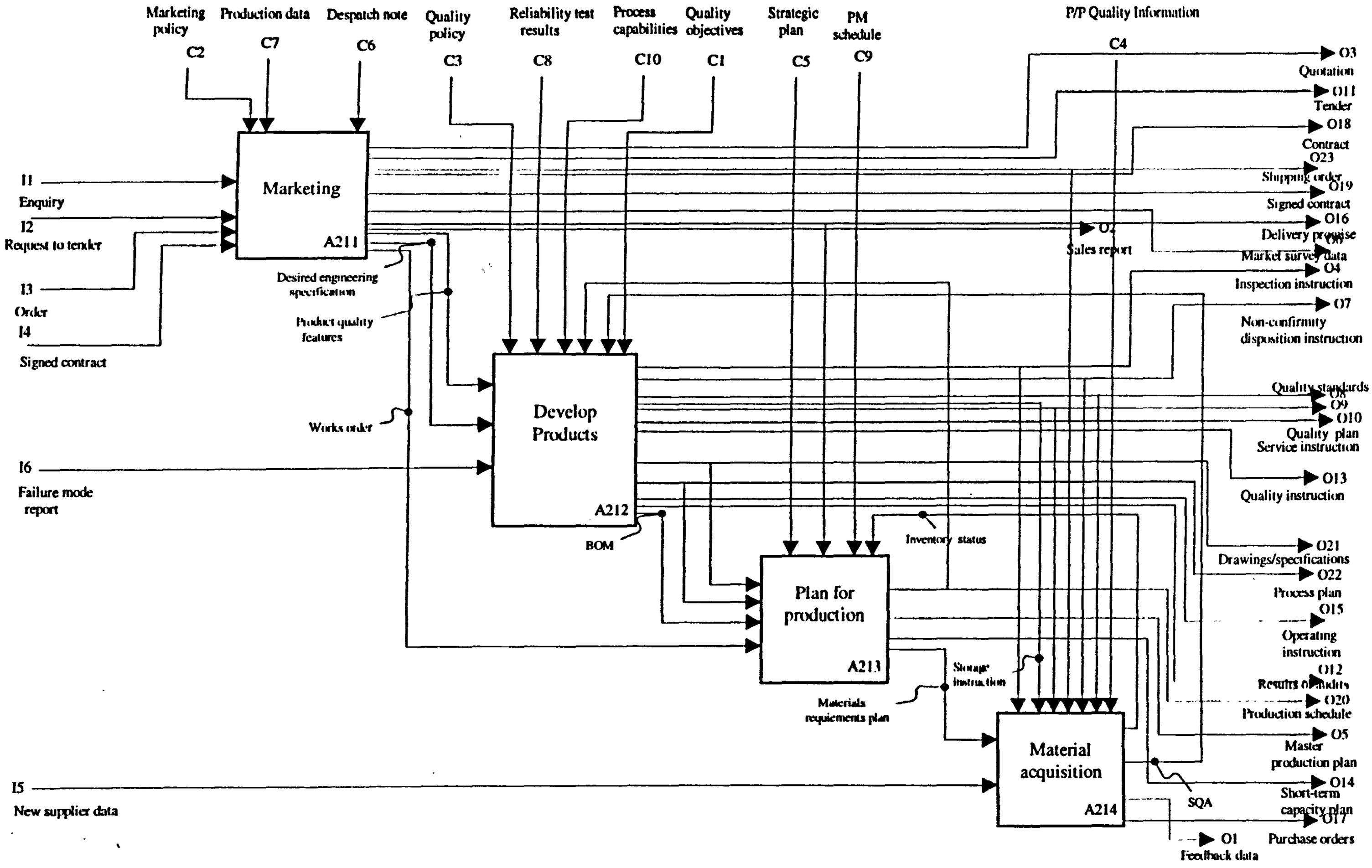
Marketing policy
C2
Quality policy
C3
Strategic plan
C4
Despatch note
Quality plan
Quality standards
Non-confirmity disposition instruction
P/P Quality Information
O1
Feedback data
O4
Sales report
O3
Market survey data
Process capabilities
Reliability test results
O6
Quotation
PM schedule
O5
Results of audits
I2
Enquiry
I3
Request to tender
I4
Order
I5
Signed contract
I6
New supplier data
Assure Pre-production
A21
O7
Tender
O8
Delivery promise
O11
Purchase orders
O9
Contract
O10
Signed contract
Short-term capacity plan
Master production plan
Inspection instruction
Operating instruction
Production schedule
Failure mode report
Service instruction
Assure Production
A22
Production data
O2
Production data
Quality instruction
Drawings/specifications
Process plan
Shipping order
O12
Warranty
O13
Product manual
O14
Customer Audit
I7
Request &enquiry for repair
I8
Technical enquiry
I1
Customer complaint & claim
Assure Post-production
A23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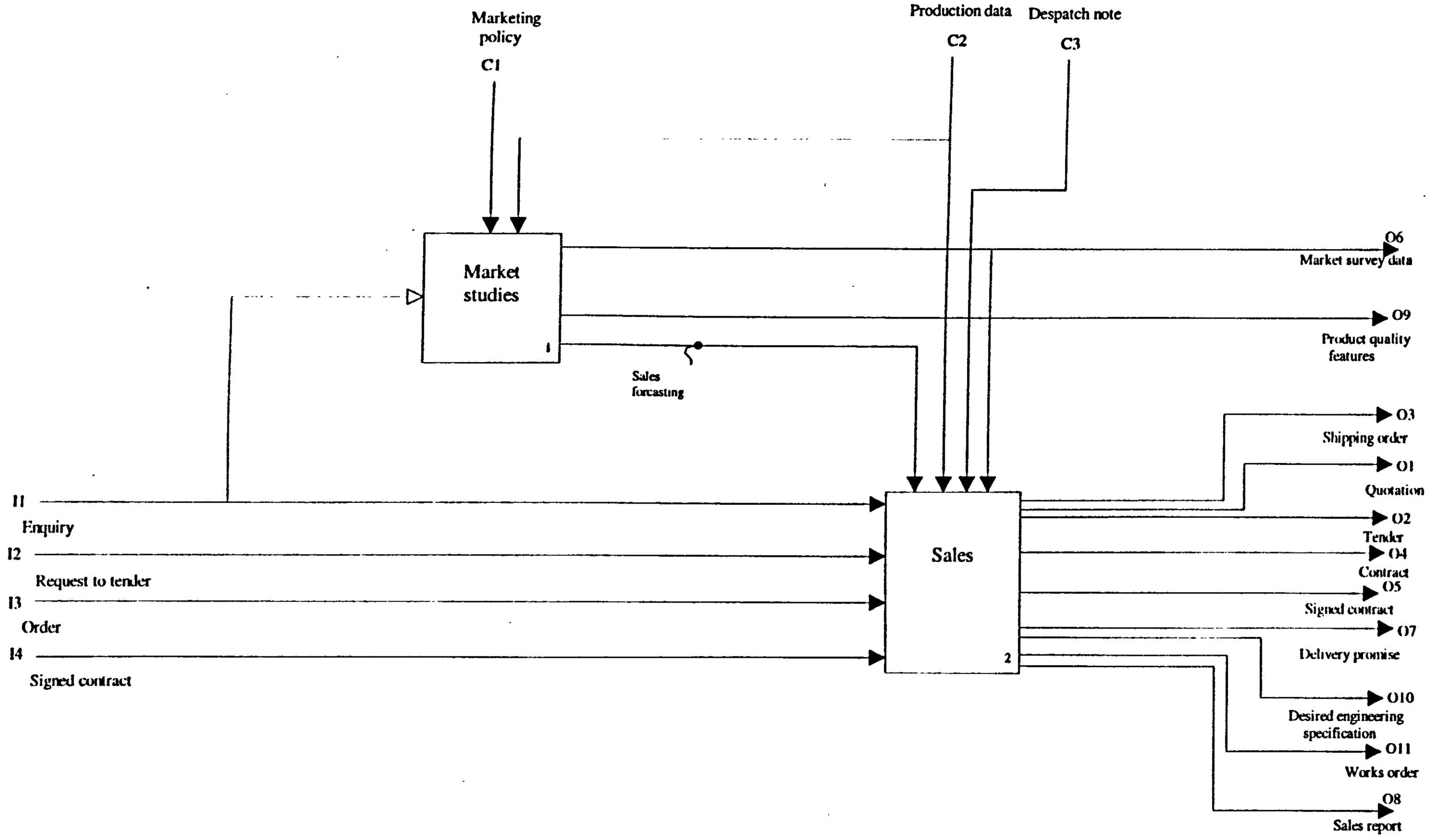
Production data
C7
Despatch note
C6
Quality policy
C3
Reliability test results
C8
Process capabilities
C10
Quality objectives
C1
Strategic plan
C5
PM schedule
C9
P/P Quality Information
C4
Marketing
A211
Develop Products
A212
Plan for production
A213
Material acquisition
A214
I1 Enquiry
I2 Request to tender
I3 Order
I4 Signed contract
I6 Failure mode report
I5 New supplier data
Desired engineering specification
Product quality features
Works order
BOM
Inventory status
Storage instruction
Materials requirements plan
SQA
O3 Quotation
O11 Tender
O18 Contract
O23 Shipping order
O19 Signed contract
O16 Delivery promise
O2 Sales report
O6 Market survey data
O4 Inspection instruction
O7 Non-confirmity disposition instruction
O8 Quality standards
O9
O10 Quality plan
Service instruction
O13 Quality instruction
O21 Drawings/specifications
O22 Process plan
O15 Operating instruction
O12 Results of audits
O20 Production schedule
O5 Master production plan
O14 Short-term capacity plan
O17 Purchase orders
O1 Feedback data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C2
Despatch note
C3
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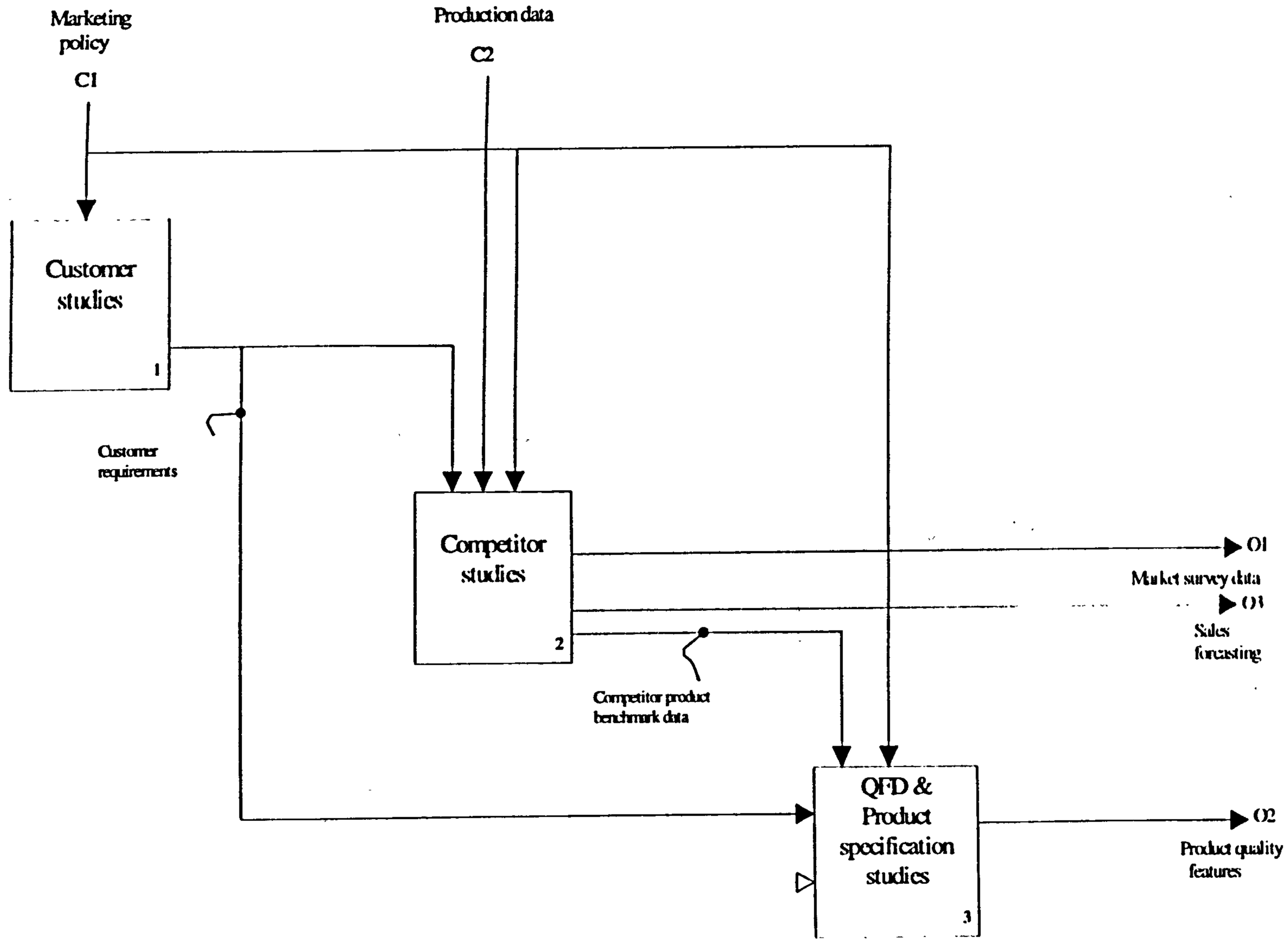
1
Sales forcasting
O6
Market survey data
O9
Product quality features
O3
Shipping order
O1
Quotation
O2
Tender
O4
Contract
O5
Signed contract
O7
Delivery promise
O10
Desired engineering specification
O11
Works order
O8
Sales report
I1
Enquiry
I2
Request to tender
I3
Order
I4
Signed contract
Sales
2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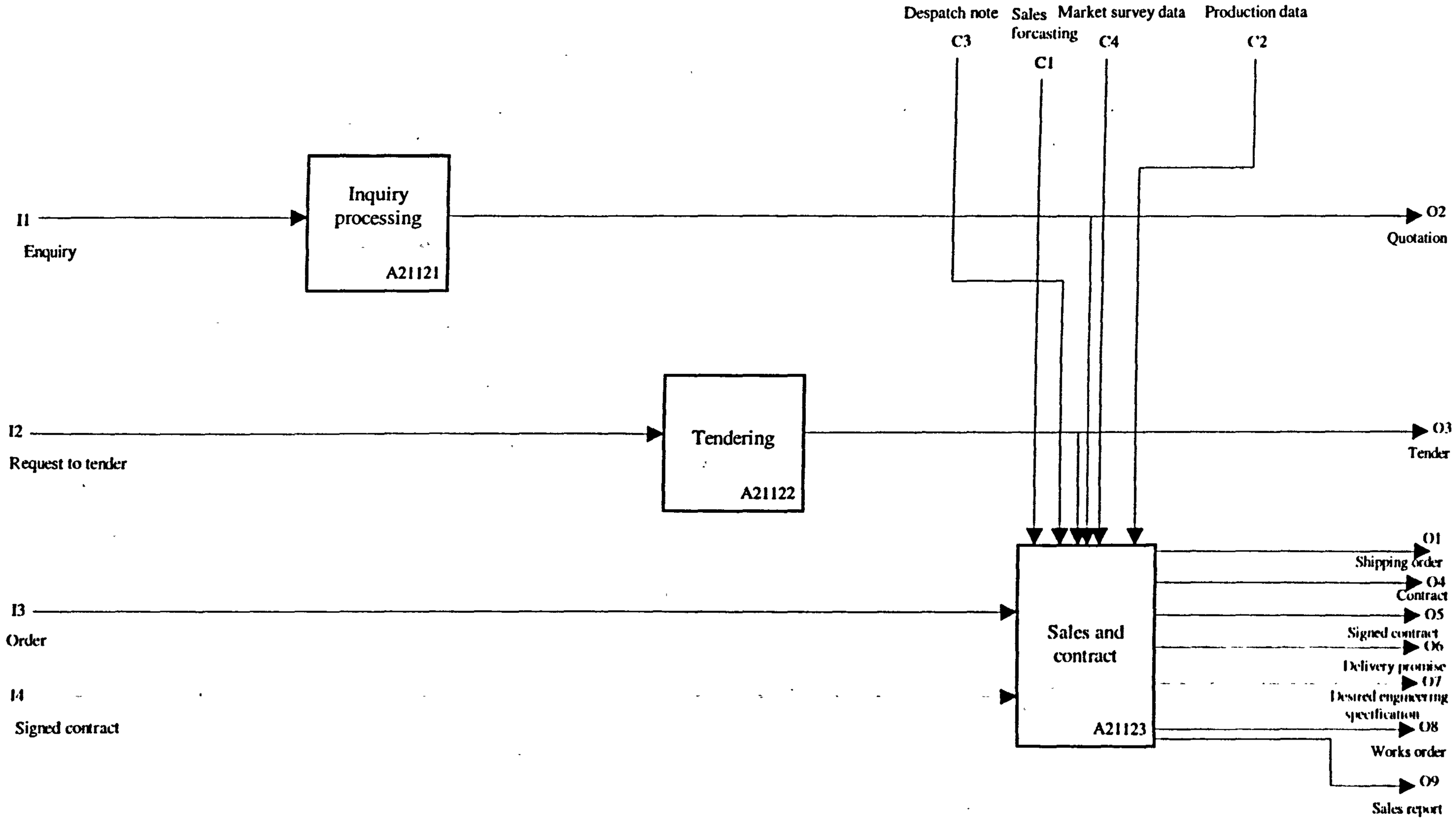
Competitor product benchmark data
QFD & Product specification studies
3
O2
Product quality features
Inquiry


Despatch note
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Sales forcasting
C1
Market survey data
C4
Production data
C2
I1
Enquiry
Inquiry processing
A21121
O2
Quotation
I2
Request to tender
Tendering
A21122
O3
Tender
I3
Order
I4
Signed contract
Sales and contract
A21123
O1
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Contract
O5
Signed contract
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Delivery promise
O7
Desired engineering specification
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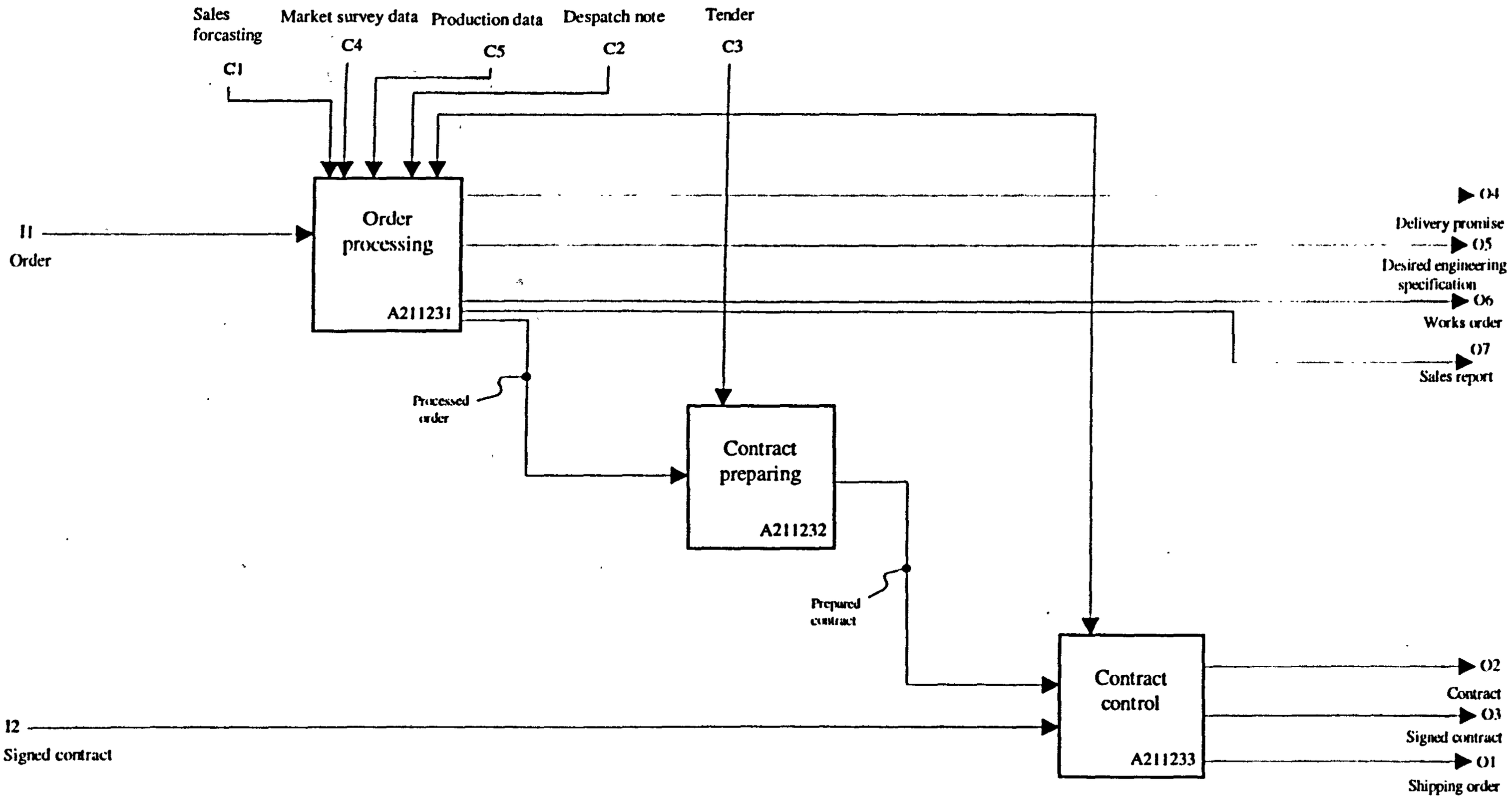
Works order
O9
Sales report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Tender
C3
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O5
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Works order
O7
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Contract control
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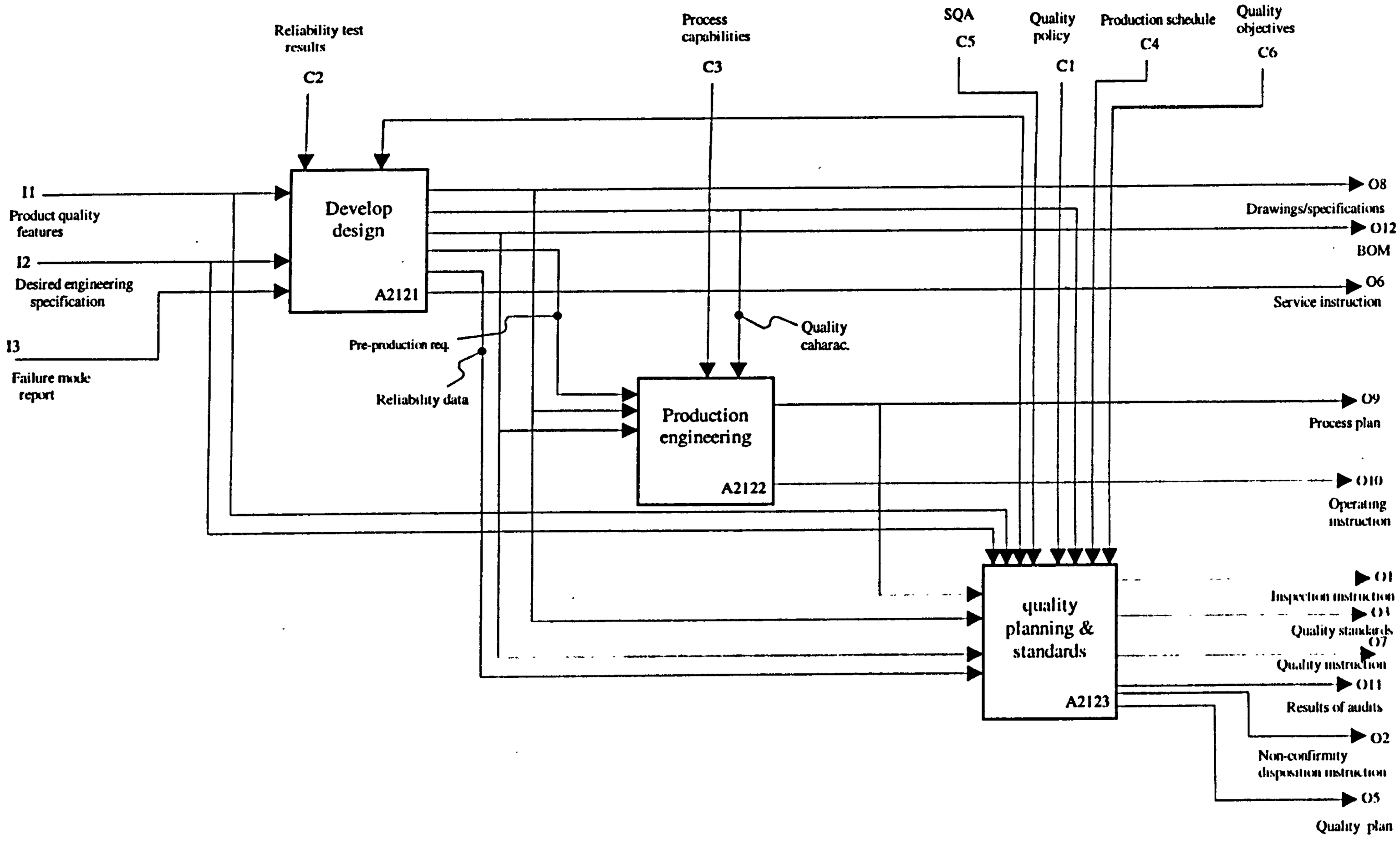
O2
Contract
O3
Signed contract
O1
Shipping order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Production schedule
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Quality objectives
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quality planning & standards
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BOM
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Process plan
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Results of audits
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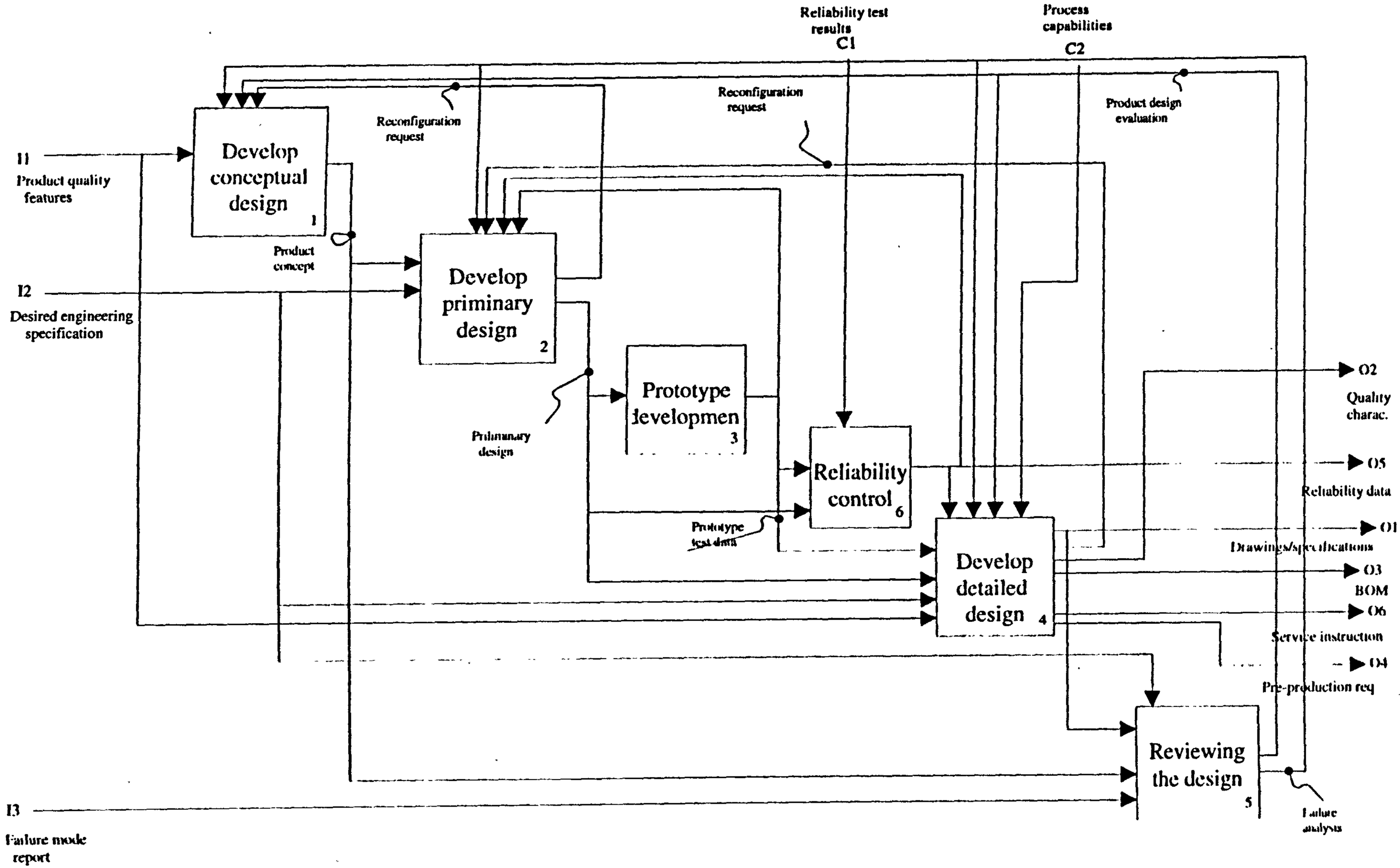
O5
Quality plan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Priminary design
Reliability control
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Prototype test data
Develop detailed design
4
Reviewing the design
5
Failure analysis
I3
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BOM
O6
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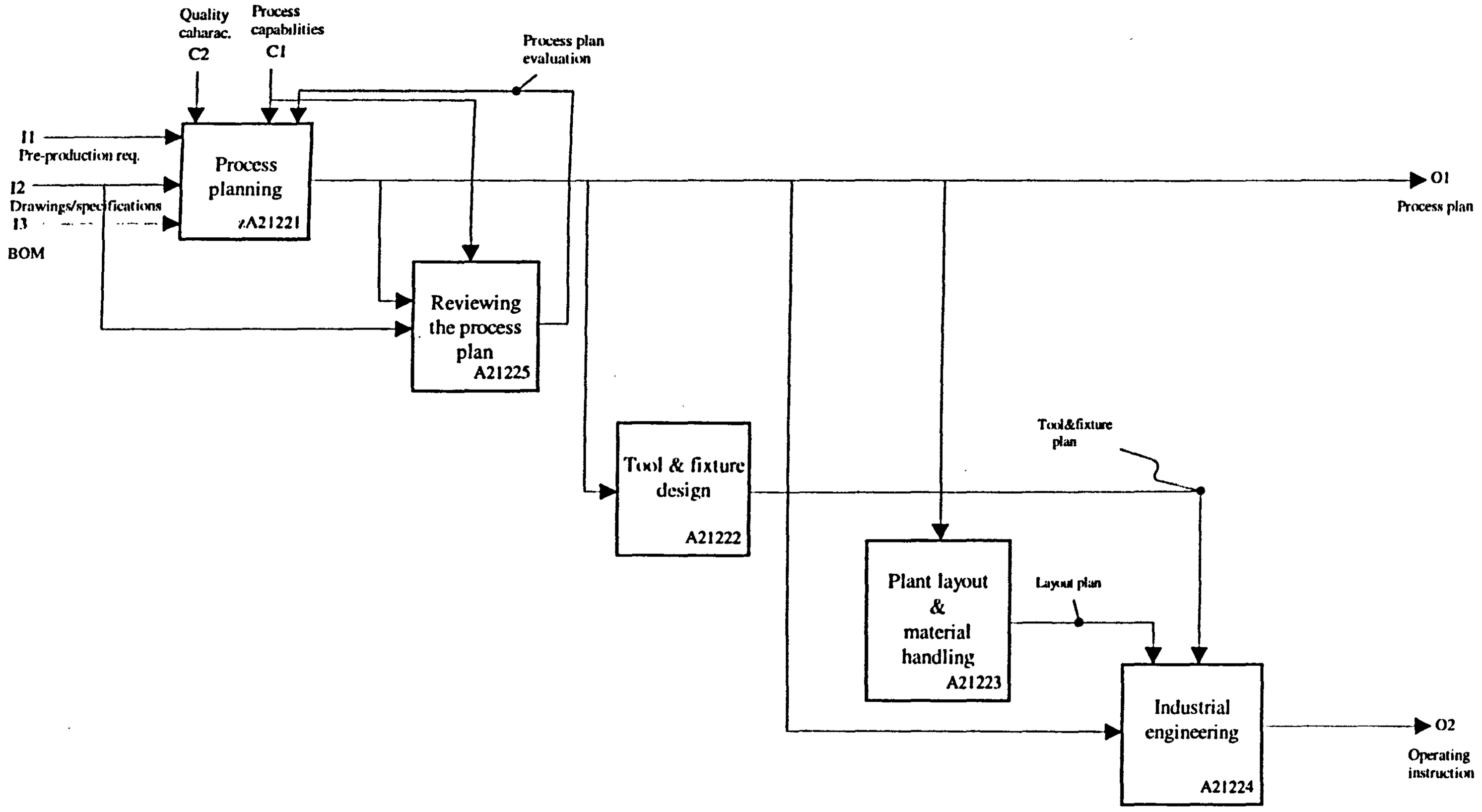
Pre-production req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Pre-production req.
I2
Drawings/specifications
I3
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Layout plan
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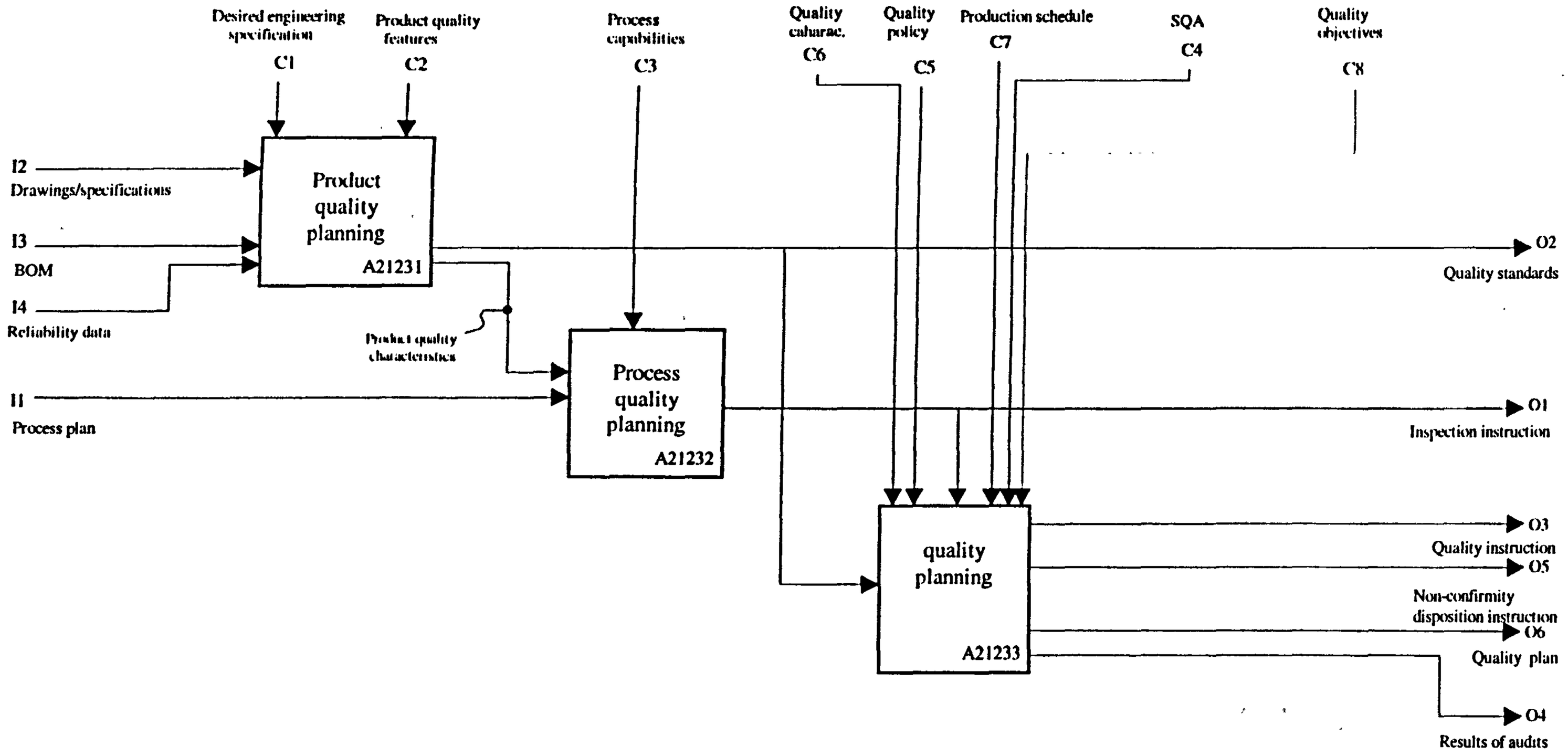
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Process capabilities
C3
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C6
Quality policy
C5
Production schedule
C7
SQA
C4
Quality objectives
C8
I2
Drawings/specifications
I3
BOM
I4
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Product quality planning
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Process plan
Process quality planning
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quality planning
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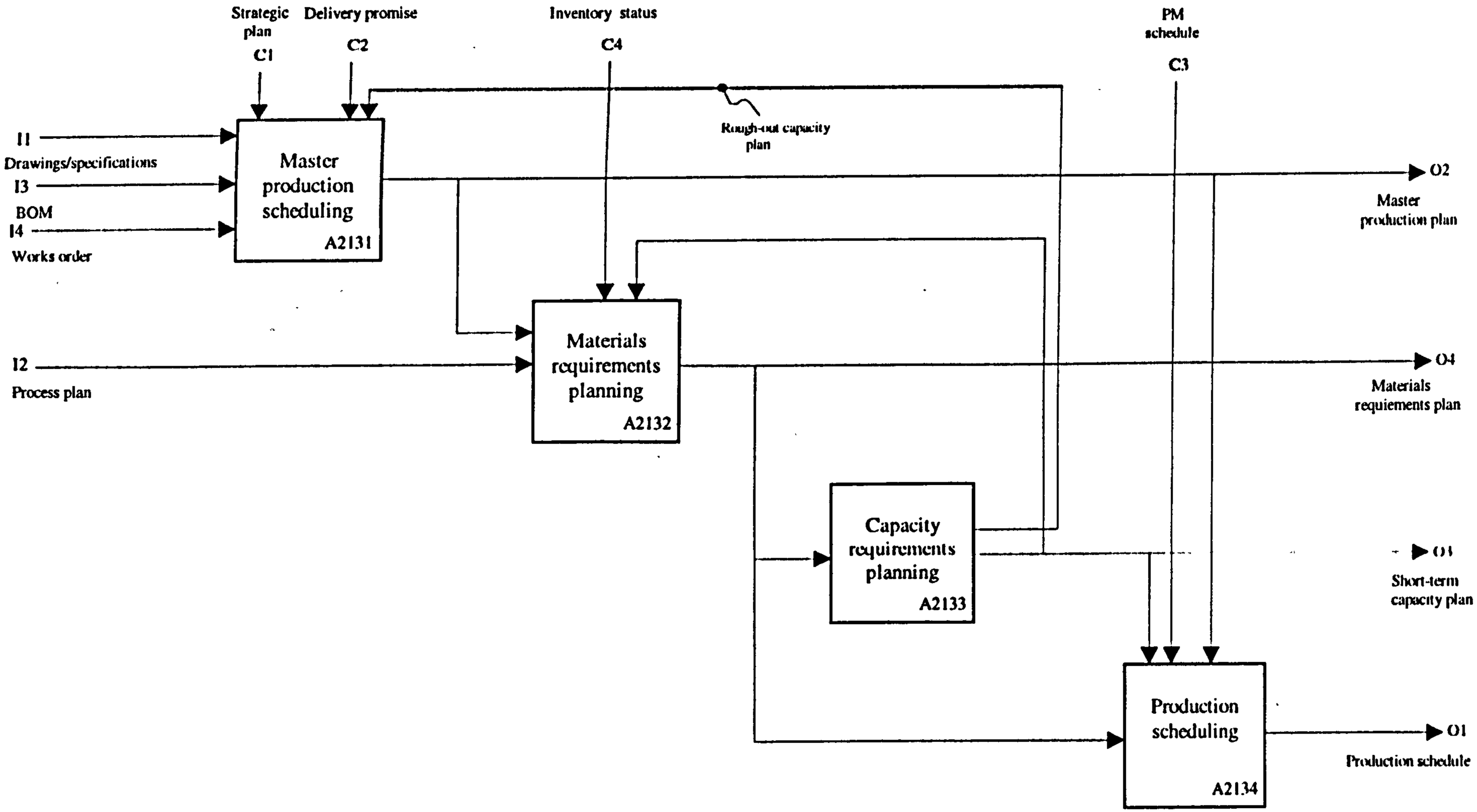
O4
Results of audits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C4
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Rough-cut capacity plan
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BOM
I4
Works order
Master production scheduling
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Master production plan
I2
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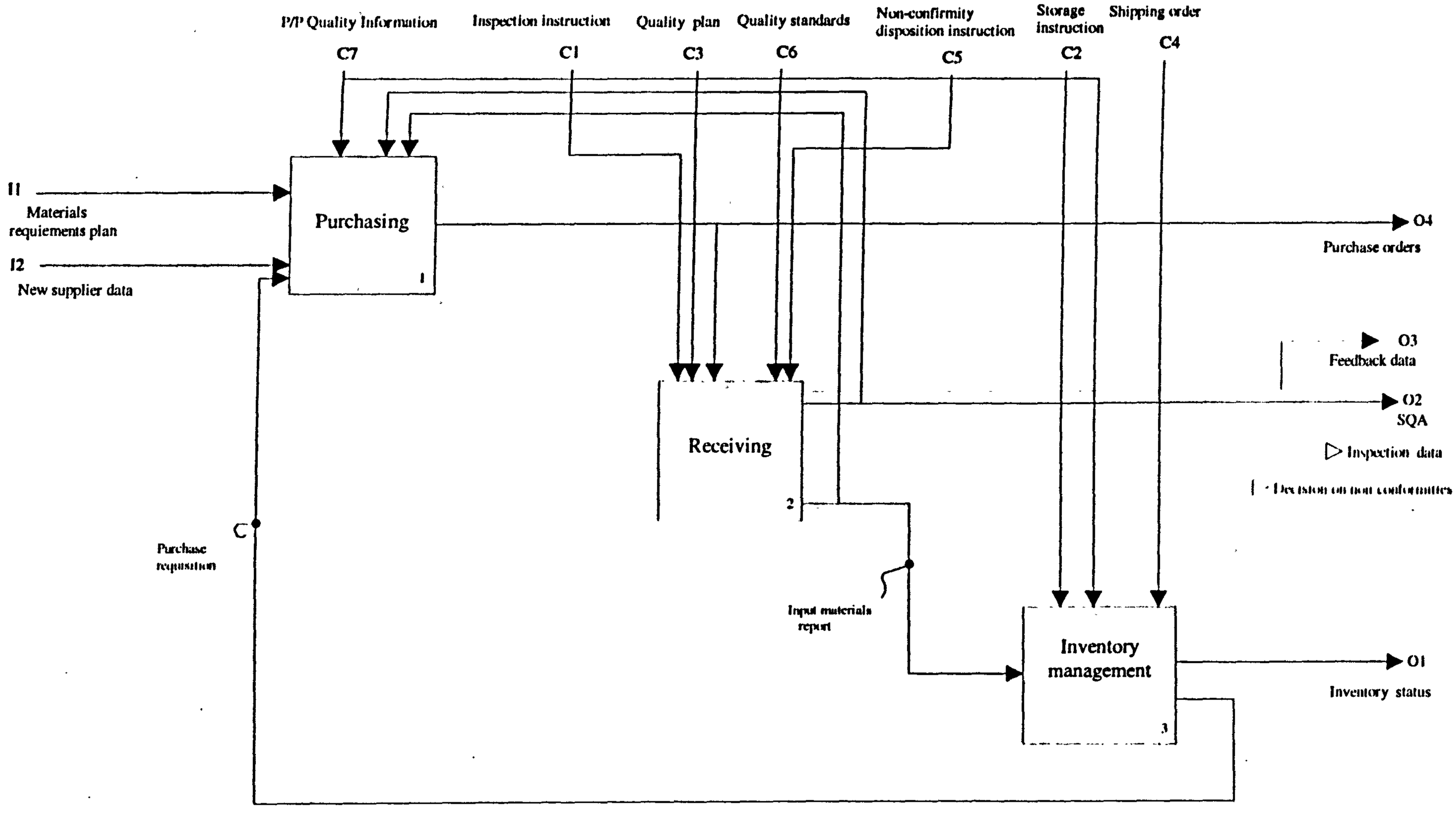
Production schedule


P/P Quality Information
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Quality plan
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Quality standards
C6
Non-confirmity disposition instruction
C5
Storage instruction
C2
Shipping order
C4
I1
Materials requiements plan
I2
New supplier data
Purchasing
1
O4
Purchase orders
O3
Feedback data
O2
SQA
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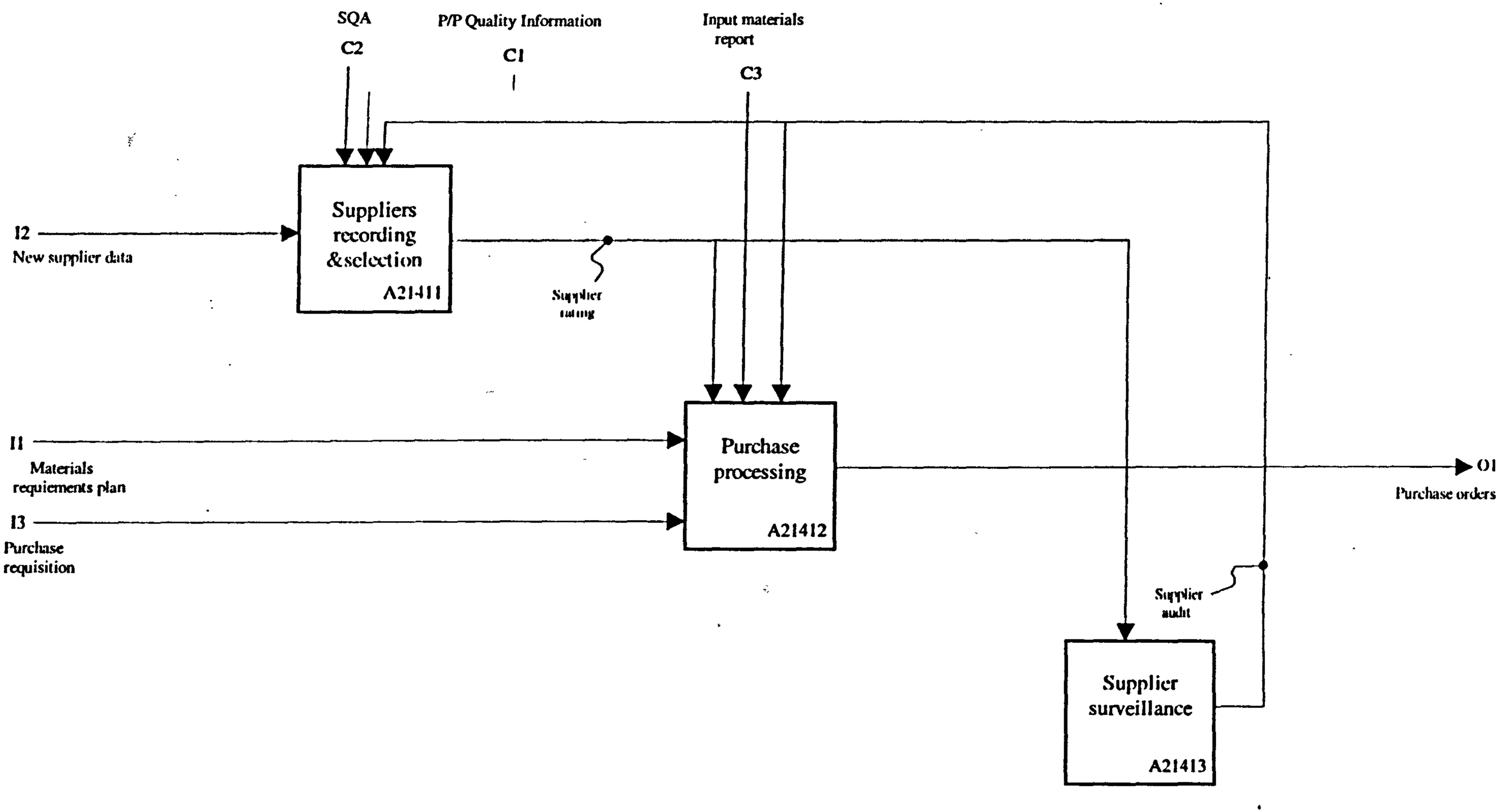
Receiving
2
C
Purchase requisition
Input materials report
Inventory management
3
O1
Inventory status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P/P Quality Information
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C3
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Supplier rating
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Supplier surveillance
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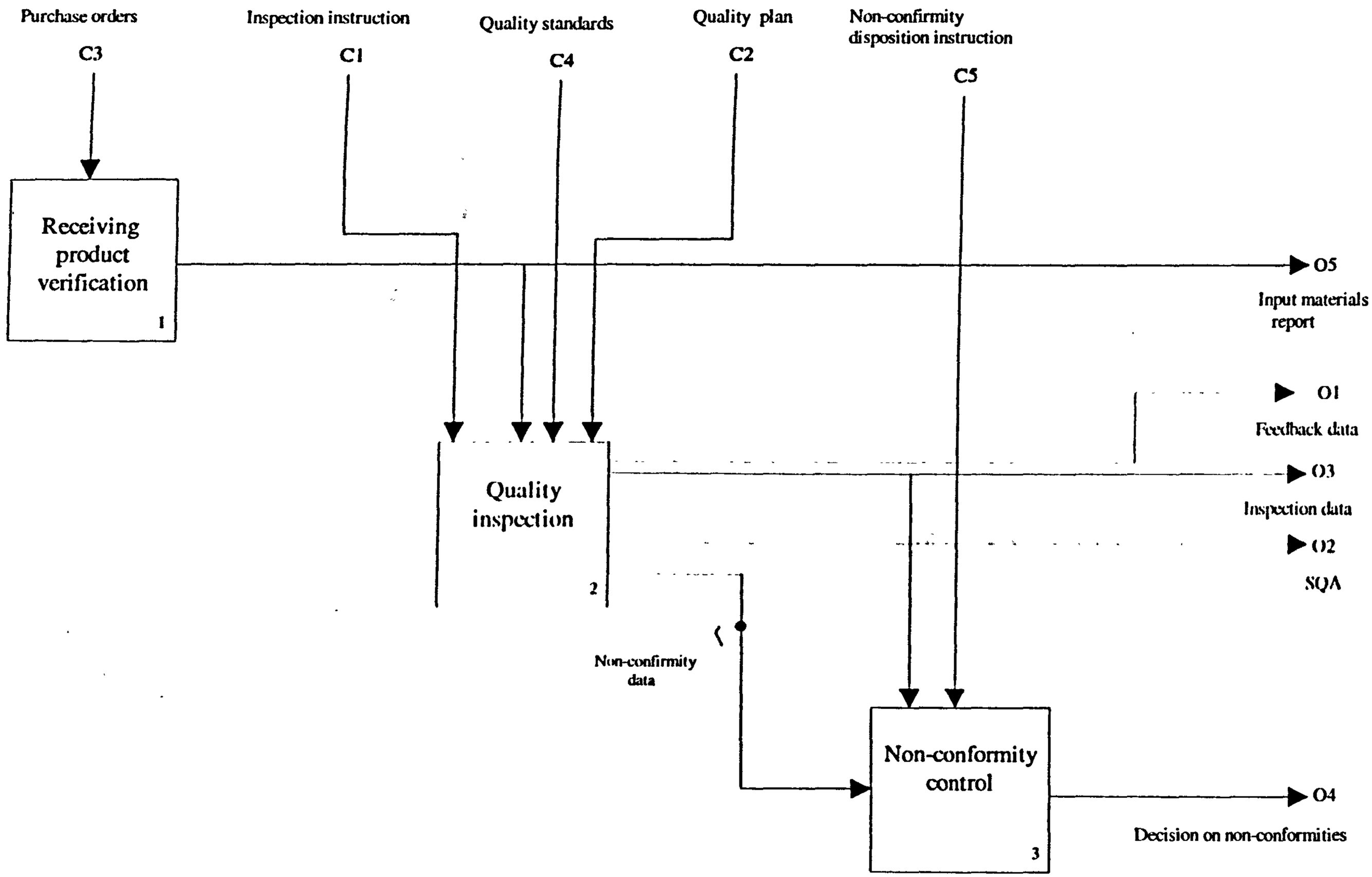
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Inspection instruction
C1
Quality standards
C4
Quality plan
C2
Non-confirmity disposition instruction
C5
Receiving product verification
1
O5
Input materials report
O1
Feedback data
Quality inspection
2
O3
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SQA
Non-confirmity data
Non-conformity control
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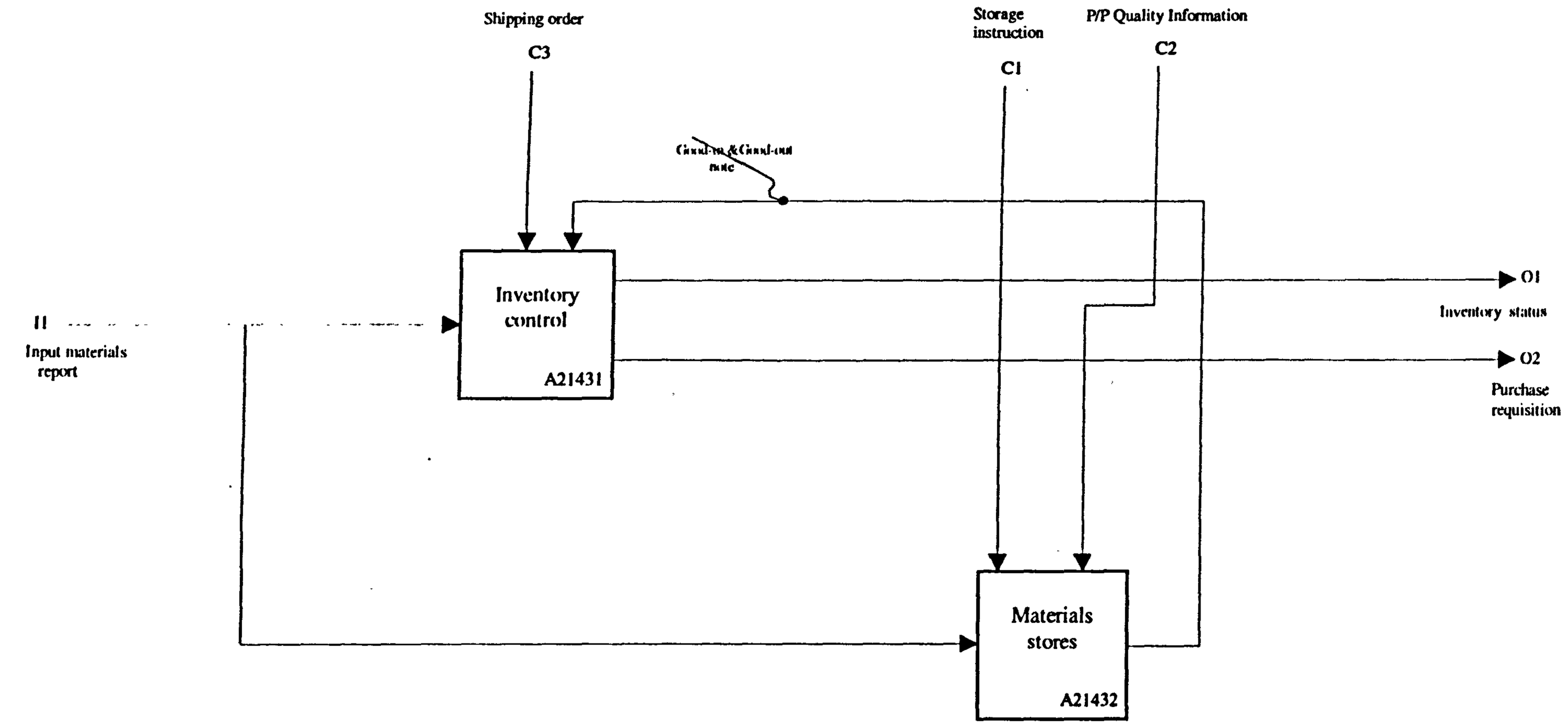
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Storage instruction
C1
P/P Quality Information
C2
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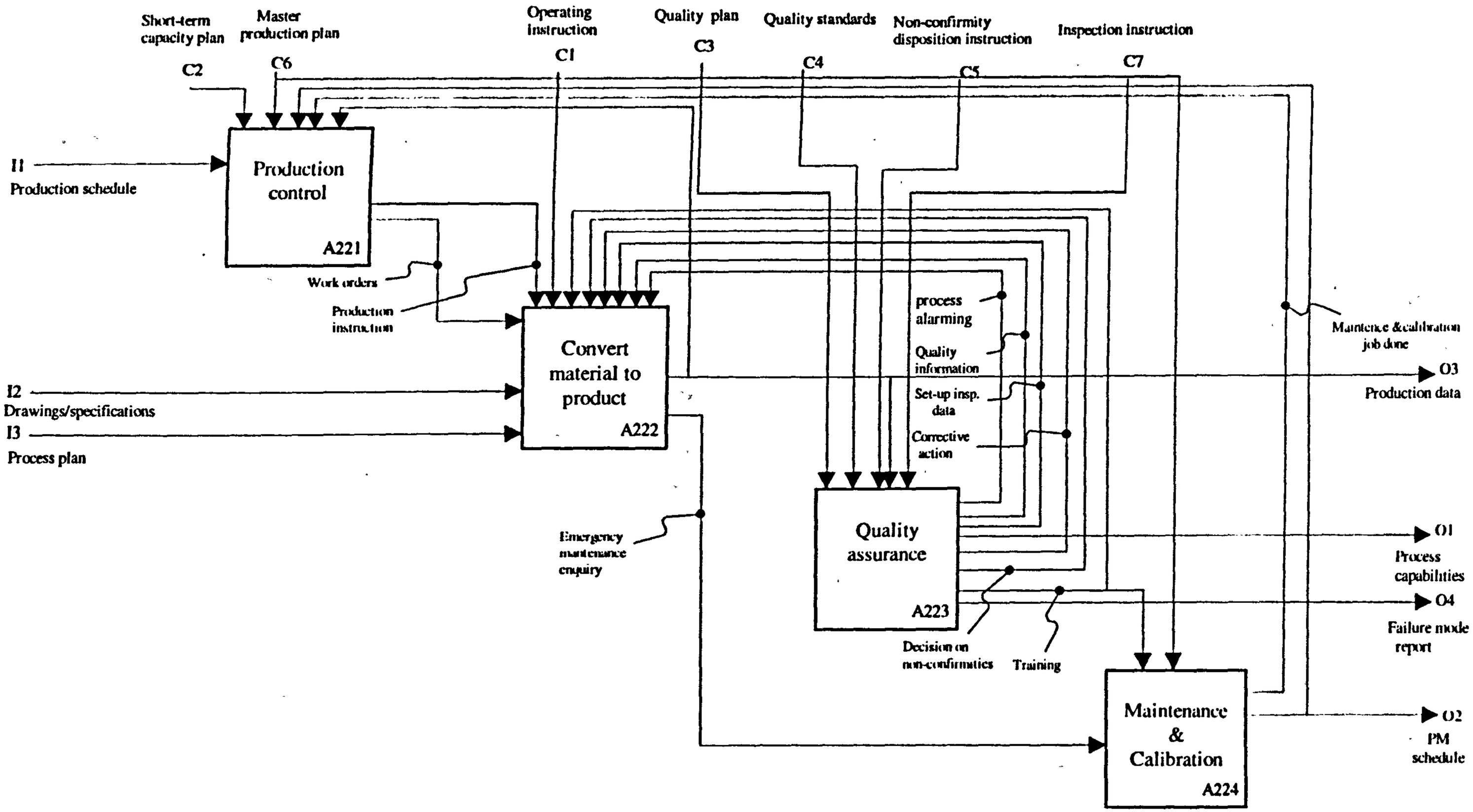
O1
Inventory status
O2
Purchase requisition
Materials stores
A21432


Short-term capacity plan
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Master production plan
C6
Operating instruction
C1
Quality plan
C3
Quality standards
C4
Non-confirmity disposition instruction
C5
Inspection instruction
C7
I1
Production schedule
Production control
A221
Work orders
Production instruction
Convert material to product
A222
I2
Drawings/specifications
I3
Process plan
process alarming
Quality information
Set-up insp. data
Corrective action
Maintence &calibration job done
O3
Production data
Emergency maintenance enquiry
Quality assurance
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Decision on non-confirmaties
Training
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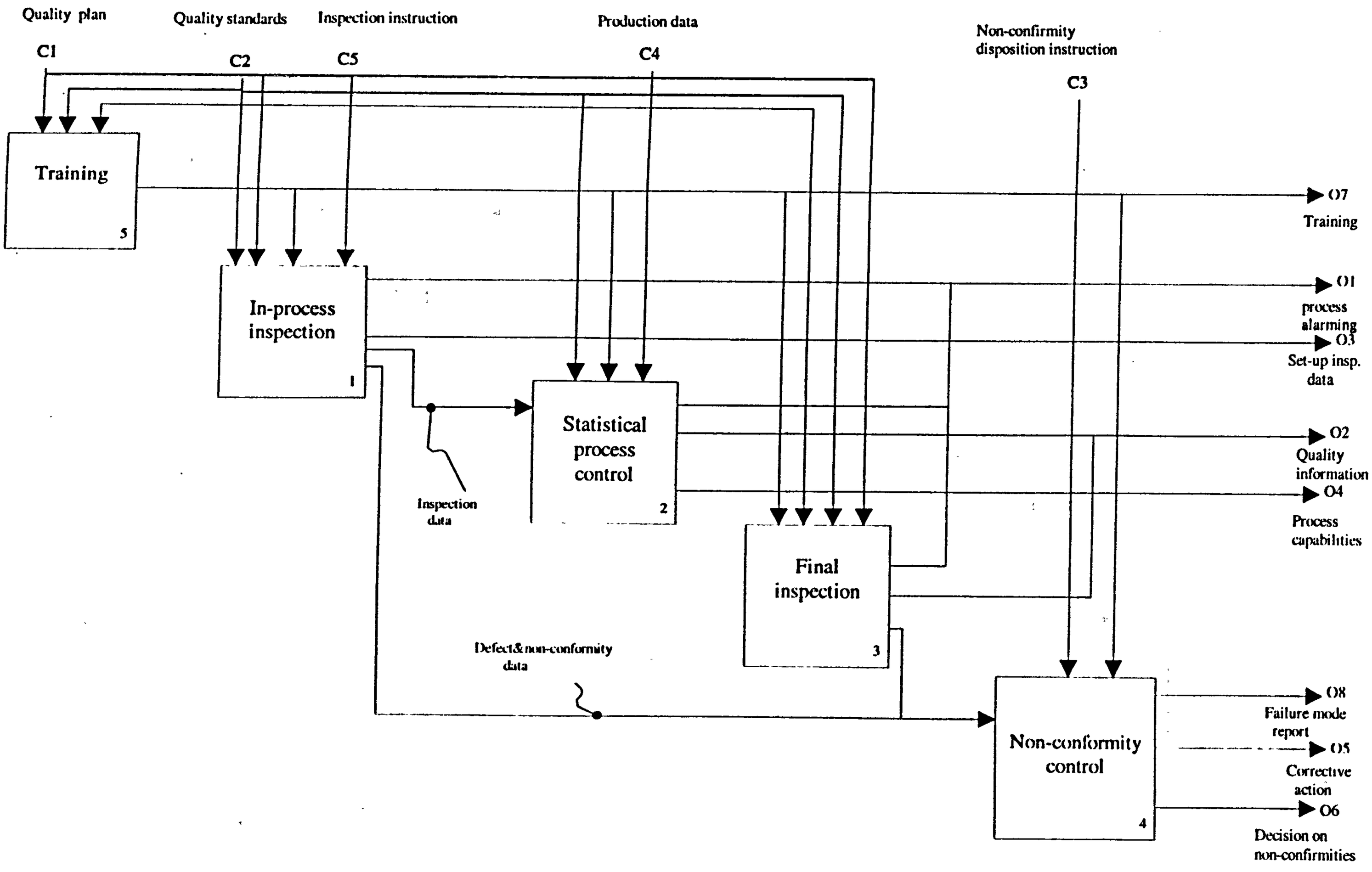
Process capabilities
O4
Failure mode report
Maintenance & Calibration
A224
O2
PM schedule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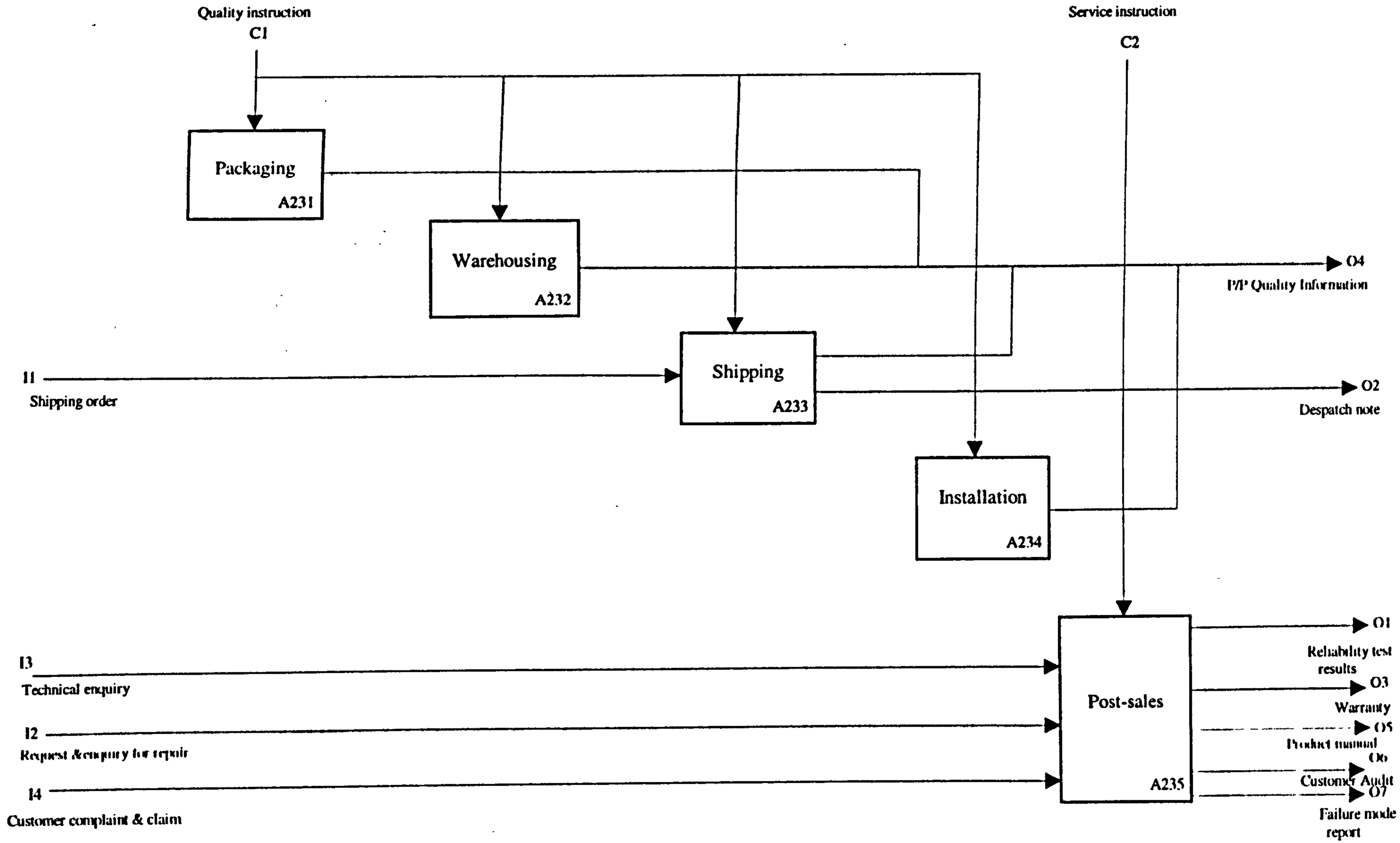
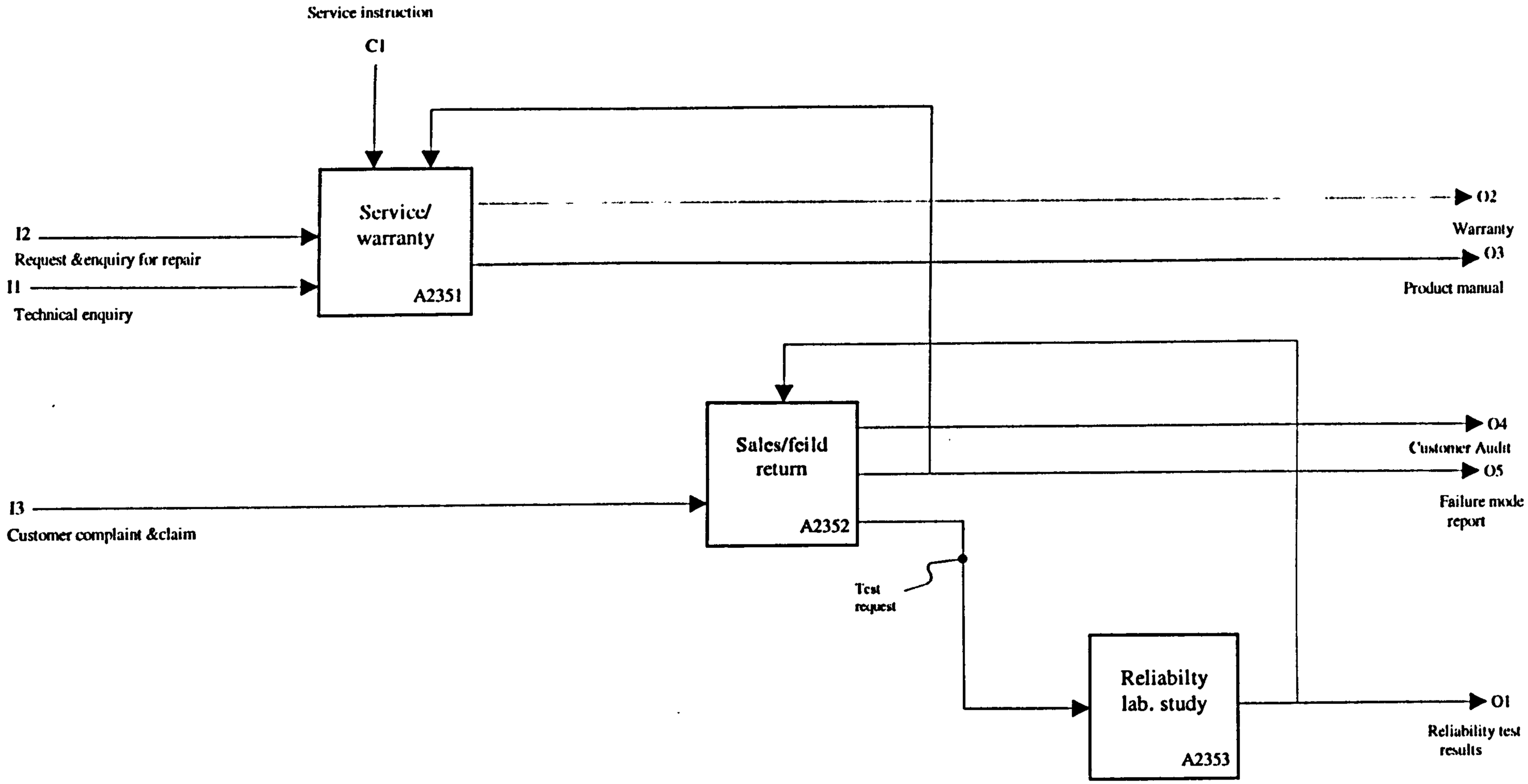
Quality standards
C2
Inspection instruction
C5
Production data
C4
Non-confirmity disposition instruction
C3
Training
5
In-process inspection
1
Statistical process control
2
Final inspection
3
Non-conformity control
4
Inspection data
Defect&non-conformity data
O7
Training
O1
process alarming
O3
Set-up insp. data
O2
Quality information
O4
Process capabilities
O8
Failure mode report
O5
Corrective action
O6
Decision on non-confirmities


Quality instruction
C1
Service instruction
C2
Packaging
A231
Warehousing
A232
Shipping
A233
Installation
A234
Post-sales
A235
I1
Shipping order
I3
Technical enquiry
I2
Request &enquiry for repair
I4
Customer complaint & claim
O4
P/P Quality Information
O2
Despatch note
O1
Reliability test results
O3
Warranty
O5
Product manual
O6
Customer Audit
O7
Failure mode report


Service instruction
C1
Service/
warranty
A2351
I2
Request &enquiry for repair
I1
Technical enquiry
O2
Warranty
O3
Product manual
Sales/feild
return
A2352
I3
Customer complaint &claim
O4
Customer Audit
O5
Failure mode
report
Test
request
Reliabilty
lab. study
A2353
O1
Reliability test
results

Appendix III

Questionnaire

University of Technology

Department of Manufacturing Engineering

Loughborough Leicestershire LE11 3TU

This questionnaire is part of a research project investigating modelling and design of information systems for quality assurance, which is being conducted by a research student at the department of Manufacturing Engineering. The purpose of this questionnaire is to gather data about the approaches to business quality assurance systems used by different types of business.

NAME:

NAME OF COMPANY/INSTITUTION:

ADDRESS:

TELEPHONE:

PLEASE COMPLETE AND RETURN AS SOON AS POSSIBLE.

Thank you very much for spending time to complete this questionnaire, your contribution will be of invaluable help to my research! . (Every detail of information will be highly appreciated and held in confidence).

You may return the completed questionnaire in the enclosed addressed envelop. If you require further information or clarification, please contact A.Nookabadi at:

Tel: 01509- 228253

Fax: 01509- 267725

Email: enas1@hpc.lut.ac.uk

Part I- Profile of the organisation:

1-Which of the following best describes the nature of your primary activity? [please tick one]

- Service industry [ ]
- Manufacturing industry [ ]
- Other (please describe)---------- [ ]

2-If your answer to the above question is manufacturing industry, which of the following categories best describes your industrial processes?

- Continuous process industry [ ]
- Discrete parts manufacture [ ]
- Other(please describe)---------- [ ]

3-If your answer to the question 2 is "continuous process industry" which of the following categories best describes your processes?

- Conversion process [ ]

(Conversion of basic raw materials into refined materials directly usable or suitable for subsequent fabrication into finshed products).

- Fabrication process [ ]

(Variety of mechanical processes are used to fabricate finished products).

- Mix [ ]
- Other(please describe)----------[ ]

4- With regard to volume of production, turnover ,capital investment and number of employees, which of the following division categories is size of your organisation?

- Small [ ]
- Medium [ ]
- Large [ ]
- Other ---------- [ ]

5-What is(are) the nature of the product(products) being manufactured?

- Mechanical [ ]
- Electrical [ ]
- Chemical [ ]
- Biological [ ]
- Other(please describe) ---------- [ ]

6-With regard to manufacturing strategy, which of the following alternatives are you using?

• Design-to-order (Your company designs and manufactures a product to meet special needs of a customer)	
• Engineer-to-order (Changes to standard products are offered to customers and only made to order)	
• Make-to-order (Concerns manufacturing a standard product/or customer designed product only on receipt of a customer order or against an agreed schedule or call-off.	
• Assemble-to-order (Components and subassemblies have been made to stock. On receipt of an order the required parts are drawn from work-in-progress/component inventory and assembled to order.	
• Make-to-stock (Finished goods are made ahead of demand in line with sales forecasts. Customer's orders are met from inventory)	
• Other ----------	

7-With due attention to, the nature of product, the cost of product unit, the number of components in the product and the criticality of product, do you think your product(products) is(are):

- Complex ? [ ]
- Semi-complex? [ ]
- Non-complex? [ ]
- Other---------- [ ]

8-Which of the following situations best describes your company?[please tick one.]

- A multi-product plant(a number of different product flow lines in a single location) [ ]
- A multiple product plant (a number of different manufacturing sections in the plant, involving specialised technologies). [ ]
- A plant with one basic product flow line at a single location. [ ]
- One basic product(a number of different manufacturing sections in the plant) [ ]
- Other(please describe)---------- [ ]

9-Which of the following production systems best describes your company?

- Mass production [ ]
- Batch production [ ]
- One-off production [ ]
- Other (please describe)---------- [ ]

10- If your answer to question 8 is "Batch production" , which of the following classic processes best describes the process of your industry?

- Conventional job shop [ ]
- Standalone NC production [ ]
- Manufacturing cell [ ]
- Flexible manufacturing system [ ]

- Other (please describe) ---------- [ ]

11-If your answer to question 8 is "mass production" , which of the following classification best describes your production technology?

- Fully automation [ ]
- semi-automation [ ]
- Predominantly manual [ ]
- Other (please describe)---------- [ ]

12-In terms of materials planning methods which of the following systems is employed in your company?

- Order-point system (OPS) [ ]

  Stock replenishment is triggered by stock falling below a re-order point, which is calculated based upon the expexted demand over the replenishment lead time.

- MRP [ ]

  Computer based time phased order-point system which recognizes that demand for component parts is dependent on the demand for components or products of which they are consistent parts.

- Kanban system(JIT) [ ]

  The Kanban system is associated with JIT manufacture and is the application of order-point replenishment techniques to the short-lead time supply chain.

- Other (please describe)---------- [ ]

Part II-Information on quality assurance system

According to modern understanding of quality, customers expect high quality reliable products, delivered on time and with short lead time after the order is placed. They also expect good pre- and post-sales service.

1-Consistent with the above definition of quality, what do you think is the appropriate quality policy of your kind of industry?

- Producing defect-free products. [ ]
- Satisfying customer requirements. [ ]
- Delighting the customers. [ ]
- Other(please describe)---------- [ ]

2-In conformity with the quality policy, which of the following functions are you implementing /or would consider appropriate to apply? Rate on a scale of 1 to 10 (10 highest) the importance of the selected functions to achieving customer satisfaction. [please tick as many as boxes you consider appropriate to apply]

2.1-Marketing:

	✓	Rating
• Customer studies.		
• Competitor studies(competitive product evaluation).		
• Quality function deployment.		
• Product specification studies.		
• Other ---------- •		

2.2-Sales:

	✓	Rating
• Reviewing the tender (before submission to customer).		
• Reviewing the contract(before submission to customer).		
• Other ---------- •		

2.3-Design and development:

	✓	Rating
• Reviewing the conceptual design(in regard to customer requirements).		
• Functional verification of the design through prototype test.		
• Reliability, environmental ,ergonomic and safety assessment.		
• Design review.		
• Identifying the potential critical failures(by Failure mode and effect analysis).		
• Reviewing the design documents before release.		
• Developing test instruction.		
• Classifying quality characteristics (specifically identifying critical ones).		
• Other ---------- ----------		

2.4-Process planning:

	✓	Rating
• Evaluation of process design(in regard to process capability).		
• Other ---------- ----------		

2.5-Quality planning & standards:

	✓	Rating
• Developing quality plans, quality standards and inspection procedures.		
• Developing procedures and instruction for dealing with non-conforming materials and products.		
• Other ----------		

2.6-Material acquisition:

	✓	Rating
• Supplier or sub-contractor selection.		
• Supplier or sub-contractor rating.		
• Supplier or sub-contractor surveillance.		
• Verification of receiving materials .		
• Incoming materials inspection.		
• Control of non-conforming materials.		
• Other ----------		

2.7-Production:

	✓	Rating
• In-process inspection.		
• Statistical process control.		
• Final inspection.		
• Control of non-conforming product.		
• Process capability studies.		
• Out of control situation alarming.		
• Measuring and test equipment inspection and calibration.		
• Implementing preventive maintenance program.		
• Training		
• Other ----------		

2.8-Post-production:

	✓	Rating
• Control on packaging of products.		
• Audit of the condition of product in stock.		
• Documented handling methods.		
• Delivery audit.		
• Providing installation procedures (with due attention to factors regarding quality, safety and performance).		
• Product warranty service.		
• Complaints' procedure.		
• Failure mode and effect analysis.		
• Reliability testing.		
• Customer audit.		
• Other ----------		

3-If in production section(2.7), you have chosen in-process inspection, which of the following types of in-process inspection do you think are applicable?

- Set-up(first-off) inspection. [ ]
- Patrol inspection. [ ]
- Fixed sampling inspection. [ ]
- Fixed continuous inspection(100%). [ ]
- Other ---------- [ ]

4- If in production section(2.7), you have chosen the statistical process control, which of the following types of statistical process control do you think are applicable?

- Variables control($\overline{X}$,R charts, cusum charts,...) [ ]
- Attributes control(p, np charts,...). [ ]
- Defect fraction control(C, U charts,...). [ ]
- Other---------- [ ]

5- If in production section(2.7), you have chosen the final inspection , which of the following types of inspection do you think are appropriate?

- Sampling inspection. [ ]
- 100% inspection. [ ]
- Other ---------- [ ]

6-For non-conforming item, which of the following do you think appropriate for your company?

- Cause and effect analysis on non-conforming products. [ ]
- Decision on accepting , repairing or rejecting the non-conforming items. [ ]
- Other ---------- [ ]

7-For choosing and/or implementing any of the above quality functions, which of the following factors influence your decision?/What is the importance rate of each?(on a scale 1-10, 10 highest)

	✓	Rating
• harm or damage resulting from failure		
• Probability of errors being committed		
• Quality costs		
• Other ----------		
• ----------		

8-Do you agree that an appropriate audit programme should be planned and carried out to determine the effectiveness of the quality system?

- Yes [ ]
- No [ ]

9-If your answer to above question is "Yes", Which of the following authorities do you consider responsible for quality system audit?

- Managemen [ ]
- Quality manager [ ]
- Quality planning & standards [ ]
- Other---------- [ ]

10-Which of the following do you consider appropriate for organisational control?

- Centralised. [ ]
- Decentralised. [ ]
- Mixed [ ]
- Other ------- [ ]

11-Would you please state any other function which in your opinion is relevant to quality assurance for your kind of industry?

12-If you would like to receive details of the results of this research, which will be available in approximately 6 months, please tick this box.

[ ]

Appendix IV

Analysis of data

Analysis of data:

Taking into account business profile characteristics. statistical analysis was done on quality functions. The summary of the whole set of results is shown in table A4.1. The analysis records one-way ANOVA on final inspection function in figures A4.1 to A4.9, two-way ANOVA on profile factors and final inspection in figures A4.10 to A4.23. The raw data and complete analysis records for all quality functions have been provided in the attached diskette.

Table A4.1: The summary of whole results

	Quality Function	Manuf. process	Company Size	Product Nature	Product Complexity	Manufac. Strategy	Process Layout	Production Method	Automation	Manufac. Management
1	Market-stud.					**	*	**		
2	Competitor study		**			**				
3	QFD	*	**		*	**	*			
4	Product speci. study			**		**				
5	Tender-revi.	**			**	**				
6	Contract-rev.				**	**	*			
7	Conceptual design revi.			**	**	**		**		
8	Prototype				**	**				
9	Reliability				**	**				
10	Design-revi.					**				
11	FMEA	**				**				
12	Design-doc.	**		**	**	**				*
13	Test-instru.				**	**				
14	Quality-char.					**				
15	Process-eval.		*			**				
16	Quality-plan			*						
17	Non-conf. plan	*							*	
18	Supplier-sel.		*		*		*			**
19	Supplier-rat.									**
20	Supplier-sur.		**			**			**	**

* Variability between groups are slightly different (which is not so important).
** Variability between groups are significantly different.

Table A4.1: The summary of whole results(continued)

	Quality Function	Manuf. process	Company Size	Product Nature	Product Complexity	Manufac. Strategy	Process Layout	Production Method	Automation	Manufac. Management
21	Materials Verification						*			
22	Input insp.									**
23	Non-conf. Control									
24	Process ins.								**	
25	SPC			**	**					
26	Final insp.				**			**		**
27	Non-conf. control				*					
28	Process cap. study	**		**		**				**
29	Alarming							**	**	
30	Calibration			*	**					
31	Preventive manitenance							**	**	
32	Training									
33	Packaging			**	**					
34	Stock audit				**	**				**
35	Handling			**	**					
36	Delivery aud			**	**					**
37	Installation				**					
38	Warranty	*		**	**					
39	FMEA	**		**	**					
40	Reliab. test	**		**	**	**				**
41	Customer audit									

* Variability between groups are slightly different (which is not so important).
** Variability between groups are significantly different.

Variable FINAL INSPECTION
By Variable PROCESS

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	24.2139	12.1070	1.9552	.1454
Within Groups	139	860.7227	6.1922		
Total	141	884.9366			

Levene Test for Homogeneity of Variances

Statistic	df1	df2	2-tail Sig.
1.1212	2	139	.329

Variable FINAL INSPECTION
By Variable PROCESS

Multiple Range Tests: LSD test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 1.7596 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 2.80

- No two groups are significantly different at the .050 level

Grp 1 discrete part process
Grp 2 continuous process
Grp 3 Batch continuous process

Fig. A4.1: Analysis records of final inspection and process methods

Variable FINAL INSPECTION
By Variable SIZE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	10.5431	5.2715	.8380	.4347
Within Groups	139	874.3936	6.2906		
Total	141	884.9366			

Levene Test for Homogeneity of Variances

Statistic	df1	df2	2-tail Sig.
.9544	2	139	.388

Variable FINAL INSPECTION
By Variable SIZE

Multiple Range Tests: LSD test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 1.7735 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 2.80

- No two groups are significantly different at the .050 level

Grp 1 small size
Grp 2 Medium size
Grp 3 Large size

Fig. A4.2: Analysis records of final inspection and company size

Variable FINAL INSPECTION
By Variable NATURE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	20.7426	6.9142	1.0493	.3760
Within Groups	74	487.6292	6.5896		
Total	77	508.3718			

Levene Test for Homogeneity of Variances

Statistic	df1	df2	2-tail Sig.
1.3794	3	74	.256

Variable FINAL INSPECTION
By Variable NATURE

Multiple Range Tests: LSD test with significance level .05

The difference between two means is significant if
MEAN(J)-MEAN(I) >= 1.8152 * RANGE * SQRT(1/N(I) + 1/N(J))
with the following value(s) for RANGE: 2.82

- No two groups are significantly different at the .050 level

Grp 1 Mechanical
Grp 2 Electrical
Grp 3 Chemical
Grp 4 Biological

Fig. A4.3: Analysis records of final inspection and product nature

```
   Variable  FINAL INSPECTION
By Variable  COMPLEX

                        Analysis of Variance

                                Sum of        Mean          F          F
Source            D.F.        Squares      Squares       Ratio      Prob.

Between Groups       2       206.8947     103.4474     21.2069     .0000
Within Groups      139       678.0419       4.8780
Total              141       884.9366

Levene Test for Homogeneity of Variances

    Statistic      df1        df2          2-tail Sig.
      1.5471         2        139             .216


   Variable  FINAL INSPECTION
By Variable  COMPLEX

Multiple Range Tests:  LSD test with significance level .05

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 1.5617 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE: 2.80

   (*) Indicates significant differences which are shown in the
lower triangle

                                 G G G
                                 r r r
                                 p p p

                                 3 2 1
Mean        COMPLEX

3.9310      Grp 3                        Grp 1  complex  product
6.0506      Grp 2        *               Grp 2  semi-complex =
7.5588      Grp 1        * *              Grp 3  non-complex  =
```

Fig. A4.4: Analysis records of final inspection and product complexity

```
   Variable  FINAL INSPECTION
By Variable  STRATEGY

                    Analysis of Variance

                    Sum of      Mean        F          F
Source      D.F.    Squares     Squares     Ratio      Prob.

Between Groups       4         11.5429     2.8857     .4913     .7421
Within Groups       66        387.6402     5.8733
Total               70        399.1831

Levene Test for Homogeneity of Variances

   Statistic      df1      df2          2-tail Sig.
      .5491         4       66             .700


   Variable  FINAL
By Variable  STRATEGY

Multiple Range Tests:  LSD test with significance level .05

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 1.7137 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE: 2.82

- No two groups are significantly different at the  .050 level

          Grp 1 Design-to-order
          Grp 2 Engineer-to-order
          Grp 3 Make-to-order
          Grp 4 Assemble-to-order
          Grp 5 Make-to-stock
```

Fig. A4.5: Analysis records of final inspection and manufacturing strategy

```
    Variable  FINAL INSPECTION
By Variable  LAYOUT

                    Analysis of Variance

                    Sum of      Mean          F          F
Source      D.F.    Squares     Squares       Ratio      Prob.

Between Groups      3         4.1950    1.3983        .2159  .8852
Within Groups     130       841.8946    6.4761
Total             133       846.0896

Levene Test for Homogeneity of Variances

    Statistic      df1       df2          2-tail Sig.
      1.3820         3       130             .251


    Variable  FINAL INSPECTION
By Variable  LAYOUT

Multiple Range Tests:  LSD test with significance level .05

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 1.7995 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE: 2.80

- No two groups are significantly different at the  .050 level

  Grp 1 Single-location multi-product plant
  Grp 2 Multi-section multi-product plant
  Grp 3 Single-location single-product plant
  Grp 4 Multi-location single-product plant
```

Fig. A4.6: Analysis records of final inspection and process layout

```
   Variable  FINAL INSPECTION
By Variable  MET_PRO

                    Analysis of Variance

                                Sum of       Mean         F          F
Source                D.F.      Squares      Squares      Ratio      Prob.

Between Groups           2      43.8300      21.9150     3.6447     .0290
Within Groups          121     727.5571       6.0129
Total                  123     771.3871


Levene Test for Homogeneity of Variances

    Statistic      df1        df2          2-tail Sig.
      1.6663         2        121             .193


   Variable  FINAL INSPECTION
By Variable  MET_PRO

Multiple Range Tests:  LSD test with significance level .05

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 1.7339 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE: 2.80

   (*) Indicates significant differences which are shown in the
lower triangle

                                G G G
                                r r r
                                p p p

                                2 1 3
    Mean        MET_PRO

    5.6421      Grp 2                    Grp 1 mass production
    5.7647      Grp 1                    Grp 2 batch = = = =
    7.6667      Grp 3        * *         Grp 3 one-off = = =
```

Fig. A4.7: Analysis records of final inspection and production methods

```
   Variable  FINAL INSPECTION
By Variable  AUTOMAT

                                    Analysis of Variance

                    Sum of        Mean          F          F
Source    D.F.      Squares       Squares       Ratio      Prob.

Between Groups       2           12.2054       6.1027      1.9069  .1774
Within Groups       18           57.6042       3.2002
Total               20           69.8095

Levene Test for Homogeneity of Variances

  Statistic      df1      df2          2-tail Sig.
    1.9138         2       18              .176


   Variable  FINAL INSPECTION
By Variable  AUTOMAT

Multiple Range Tests:  LSD test with significance level .05

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 1.2650 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE: 2.97

- No two groups are significantly different at the  .050 level

          Grp 1 Full-automation technology
          Grp 2 Semi-automation technology
          Grp 3 Predominantly manual
```

Fig. A4.8: Analysis records of final inspection and automation levels

```
   Variable  FINAL INSPECTION
By Variable  MPM

                                Analysis of Variance

                    Sum of       Mean          F          F
      Source  D.F.  Squares     Squares     Ratio     Prob.

Between Groups     2    76.7652   38.3826    6.5081  .0022
Within Groups    103   607.4612    5.8977
Total            105   684.2264

Levene Test for Homogeneity of Variances

    Statistic     df1     df2        2-tail Sig.
       .7631       2     103            .469


      Variable  FINAL INSPECTION
   By Variable  MPM

Multiple Range Tests:  LSD test with significance level .05

The difference between two means is significant if
  MEAN(J)-MEAN(I)  >= 1.7172 * RANGE * SQRT(1/N(I) + 1/N(J))
  with the following value(s) for RANGE: 2.80

   (*) Indicates significant differences which are shown in the
lower triangle

                              G G G
                              r r r
                              p p p

                              3 2 1
    Mean        MPM

    4.2500      Grp 3                          Grp 1 OPS
    6.1875      Grp 2         *                Grp 2 MRP
    6.7241      Grp 1         *                Grp 3 JIT
```

Fig. A4.9: Analysis records of final inspection and materials and production managements

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by PROCESS
SIZE

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	34.815	4	8.704	1.396	.239
PROCESS	34.195	2	17.097	2.742	.068
SIZE	1.128	2	.564	.090	.914
2-Way Interactions	24.546	4	6.136	.984	.419
PROCESS SIZE	24.546	4	6.136	.984	.419
Explained	55.632	8	6.954	1.115	.357
Residual	829.305	133	6.235		
Total	884.937	141	6.276		

143 cases were processed.
1 cases (.7 pct) were missing.

Fig. A4.10: The results of Two-way ANOVA on process method , company size and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by PROCESS
LAYOUT

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	52.710	5	10.542	1.674	.146
PROCESS	34.833	2	17.417	2.766	.067
LAYOUT	27.669	3	9.223	1.465	.228
2-Way Interactions	47.972	5	9.594	1.524	.187
PROCESS LAYOUT	47.972	5	9.594	1.524	.187
Explained	71.569	10	7.157	1.137	.341
Residual	774.521	123	6.297		
Total	846.090	133	6.362		

143 cases were processed.
9 cases (6.3 pct) were missing.

Fig. A4.11: The results of Two-way ANOVA on process method , plant layout and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by PROCESS
MET_PRO

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	51.977	4	12.994	2.125	.082
PROCESS	8.275	2	4.138	.676	.510
MET_PRO	22.472	2	11.236	1.837	.164
2-Way Interactions	1.326	2	.663	.108	.897
PROCESS MET_PRO	1.326	2	.663	.108	.897
Explained	55.775	6	9.296	1.520	.178
Residual	715.612	117	6.116		
Total	771.387	123	6.271		

143 cases were processed.
19 cases (13.3 pct) were missing.

Fig. A4.12: The results of Two-way ANOVA on process method , production method and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by PROCESS
MPM

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	85.837	4	21.459	3.753	.007
PROCESS	27.198	2	13.599	2.379	.098
MPM	52.488	2	26.244	4.590	.012
2-Way Interactions	34.997	3	11.666	2.040	.113
PROCESS MPM	34.997	3	11.666	2.040	.113
Explained	123.917	7	17.702	3.096	.005
Residual	560.309	98	5.717		
Total	684.226	105	6.516		

143 cases were processed.
37 cases (25.9 pct) were missing.

Fig. A4.13: The results of Two-way ANOVA on Process method , materials and production management and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by SIZE
COMPLEX

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	102.605	4	25.651	5.148	.001
SIZE	2.427	2	1.213	.244	.784
COMPLEX	96.836	2	48.418	9.718	.000
2-Way Interactions	9.685	4	2.421	.486	.746
SIZE COMPLEX	9.685	4	2.421	.486	.746
Explained	222.260	8	27.782	5.576	.000
Residual	662.677	133	4.983		
Total	884.937	141	6.276		

143 cases were processed.
1 cases (.7 pct) were missing.

Fig. A4.14: The results of Two-way ANOVA on company size , product complexity and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by SIZE
STRATEGY

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	19.427	6	3.238	.575	.749
SIZE	6.742	2	3.371	.598	.553
STRATEGY	9.260	4	2.315	.411	.800
2-Way Interactions	48.754	6	8.126	1.443	.214
SIZE STRATEGY	48.754	6	8.126	1.443	.214
Explained	72.469	12	6.039	1.072	.400
Residual	326.714	58	5.633		
Total	399.183	70	5.703		

143 cases were processed.
72 cases (50.3 pct) were missing.

Fig. A4.15: The results of Two-way ANOVA on company size , manufacturing strategy and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by SIZE
LAYOUT

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	20.977	5	4.195	.630	.677
SIZE	14.197	2	7.098	1.067	.347
LAYOUT	10.897	3	3.632	.546	.652
2-Way Interactions	11.906	5	2.381	.358	.876
SIZE LAYOUT	11.906	5	2.381	.358	.876
Explained	27.443	10	2.744	.412	.939
Residual	818.647	123	6.656		
Total	846.090	133	6.362		

143 cases were processed.
9 cases (6.3 pct) were missing.

Fig. A4.16: The results of Two-way ANOVA on company size , plant layout and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by SIZE
MPM

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	77.447	4	19.362	3.137	.018
SIZE	6.636	2	3.318	.538	.586
MPM	68.462	2	34.231	5.546	.005
2-Way Interactions	2.739	4	.685	.111	.978
SIZE MPM	2.739	4	.685	.111	.978
Explained	85.532	8	10.691	1.732	.100
Residual	598.695	97	6.172		
Total	684.226	105	6.516		

143 cases were processed.
37 cases (25.9 pct) were missing.

Fig. A4.17: The results of Two-way ANOVA on company size , materials and production management and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by COMPLEX
STRATEGY

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	47.311	6	7.885	1.711	.135
COMPLEX	31.536	2	15.768	3.422	.039
STRATEGY	7.514	4	1.879	.408	.802
2-Way Interactions	37.137	6	6.190	1.343	.253
COMPLEX STRATEGY	37.137	6	6.190	1.343	.253
Explained	131.956	12	10.996	2.387	.014
Residual	267.227	58	4.607		
Total	399.183	70	5.703		

143 cases were processed.
72 cases (50.3 pct) were missing.

Fig. A4.18: The results of Two-way ANOVA on product complexity, manufacturing strategy and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by COMPLEX
MET_PRO

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	100.053	4	25.013	4.851	.001
COMPLEX	59.759	2	29.880	5.795	.004
MET_PRO	10.170	2	5.085	.986	.376
2-Way Interactions	11.809	3	3.936	.763	.517
COMPLEX MET_PRO	11.809	3	3.936	.763	.517
Explained	173.246	7	24.749	4.800	.000
Residual	598.141	116	5.156		
Total	771.387	123	6.271		

143 cases were processed.
19 cases (13.3 pct) were missing.

Fig. A4.19: The results of Two-way ANOVA on product complexity, production method and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by COMPLEX
MPM

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	126.820	4	31.705	8.807	.000
COMPLEX	121.474	2	60.737	16.872	.000
MPM	60.160	2	30.080	8.356	.000
2-Way Interactions	41.576	4	10.394	2.887	.026
COMPLEX MPM	41.576	4	10.394	2.887	.026
Explained	335.032	8	41.879	11.633	.00
Residual	349.194	97	3.600		
Total	684.226	105	6.516		

143 cases were processed.
37 cases (25.9 pct) were missing.

Fig. A4.20: The results of Two-way ANOVA on product complexity, materials and production management and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by STRATEGY
MPM

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	54.380	6	9.063	1.440	.223
STRATEGY	5.225	4	1.306	.208	.933
MPM	35.290	2	17.645	2.803	.072
2-Way Interactions	3.373	4	.843	.134	.969
STRATEGY MPM	3.373	4	.843	.134	.969
Explained	73.712	10	7.371	1.171	.337
Residual	258.057	41	6.294		
Total	331.769	51	6.505		

143 cases were processed.
91 cases (63.6 pct) were missing.

Fig. A4.21: The results of Two-way ANOVA on manufacturing strategy, materials and production management and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by LAYOUT
MPM

UNIQUE sums of squares
All effects entered simultaneously

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	75.802	5	15.160	2.532	.034
LAYOUT	20.840	3	6.947	1.160	.329
MPM	64.426	2	32.213	5.380	.006
2-Way Interactions	34.808	5	6.962	1.163	.334
LAYOUT MPM	34.808	5	6.962	1.163	.334
Explained	121.921	10	12.192	2.036	.038
Residual	550.895	92	5.988		
Total	672.816	102	6.596		

143 cases were processed.
40 cases (28.0 pct) were missing.

Fig. A4.22: The results of Two-way ANOVA on plant layout, materials and production management and final inspection

* * * A N A L Y S I S O F V A R I A N C E * * *

FINAL
by MET_PRO
MPM

UNIQUE sums of squares
All effects entered simultaneously

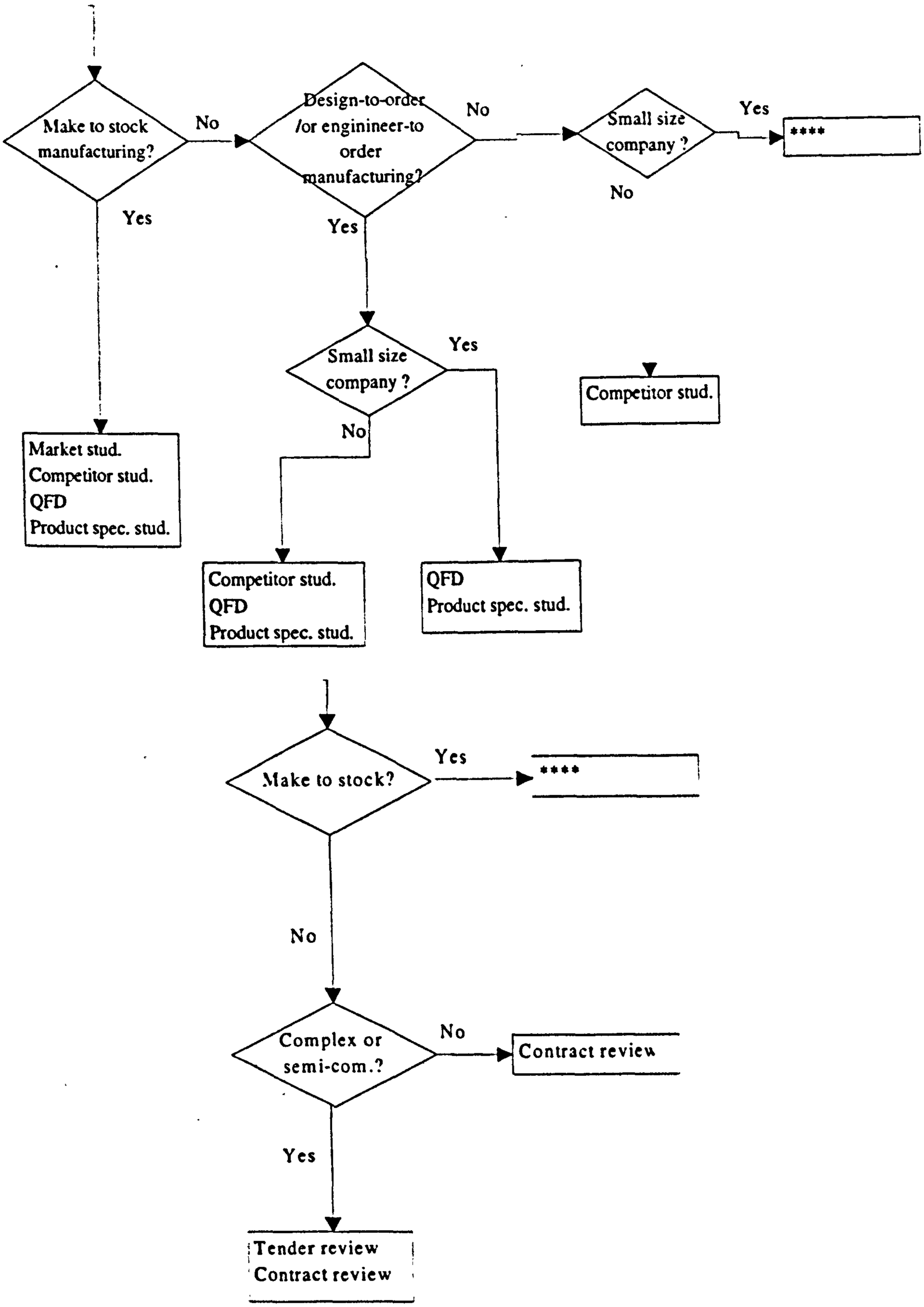
Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	81.856	4	20.464	3.536	.010
MET_PRO	30.118	2	15.059	2.602	.080
MPM	38.600	2	19.300	3.335	.040
2-Way Interactions	9.858	4	2.465	.426	.790
MET_PRO MPM	9.858	4	2.465	.426	.790
Explained	113.064	8	14.133	2.442	.020
Residual	486.119	84	5.787		
Total	599.183	92	6.513		

143 cases were processed.
50 cases (35.0 pct) were missing.

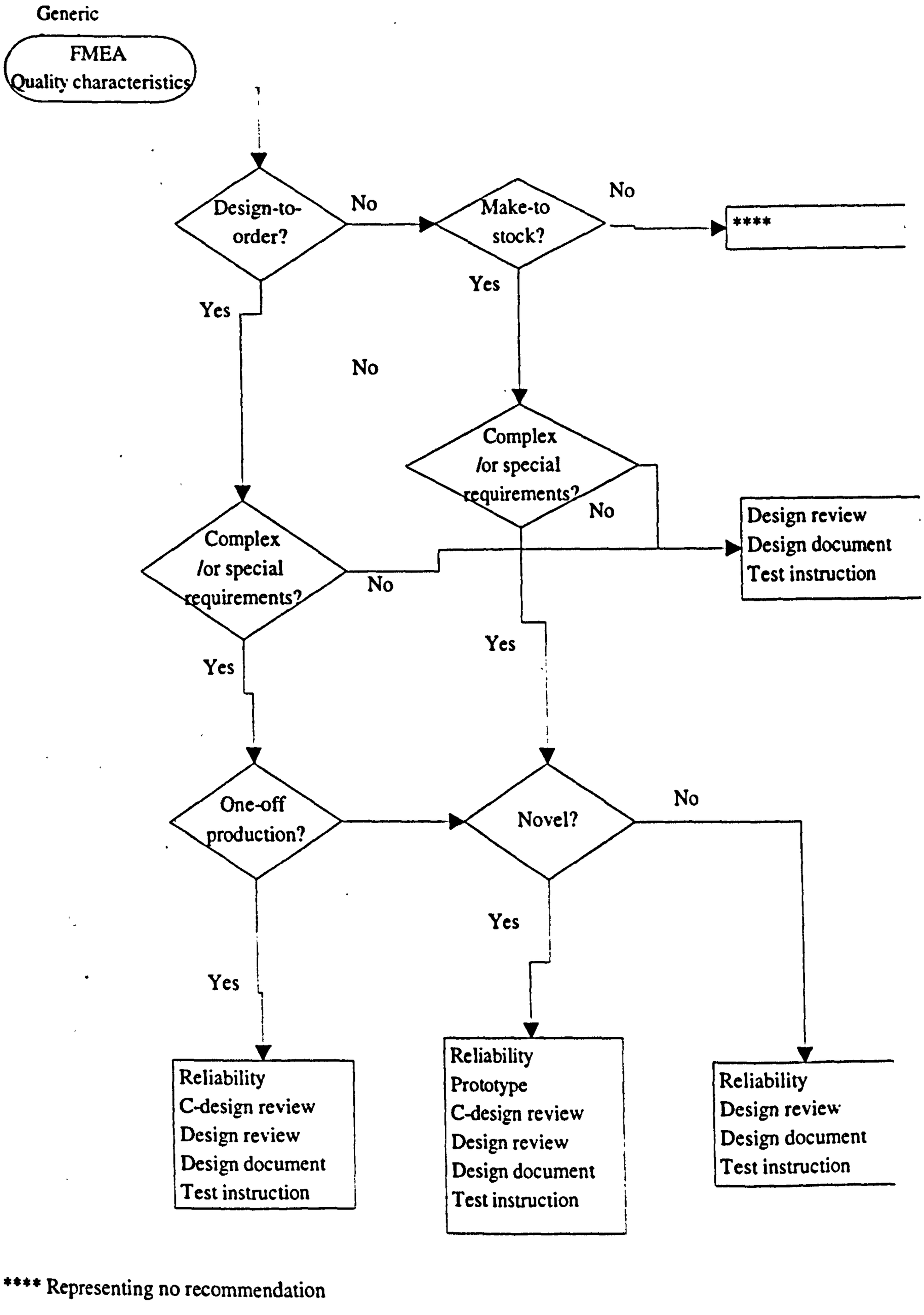
Fig. A4.23: The results of Two-way ANOVA on production method, materials and production management and final inspection

Appendix V

Algorithm



**** Representing no recommendation



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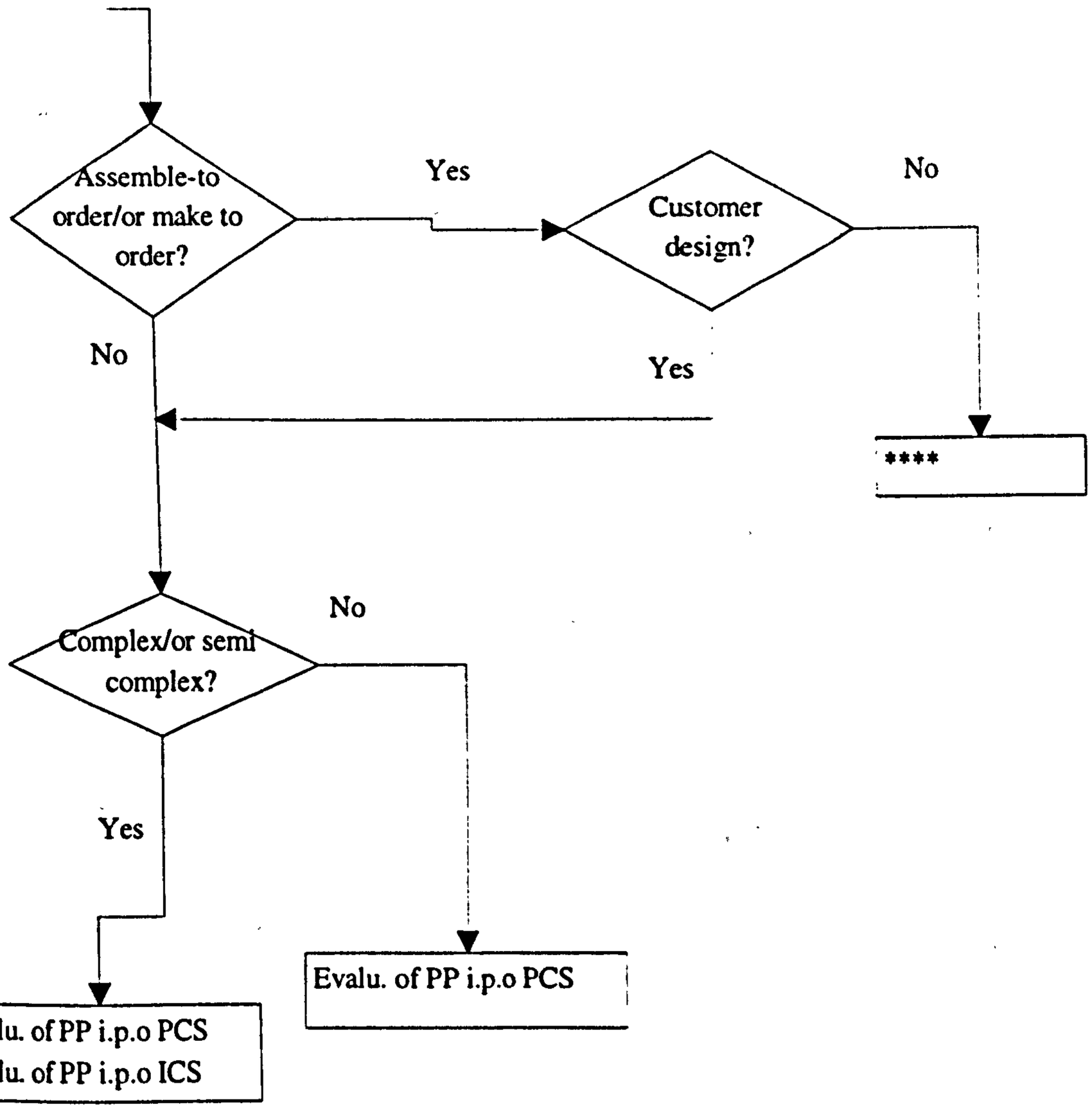

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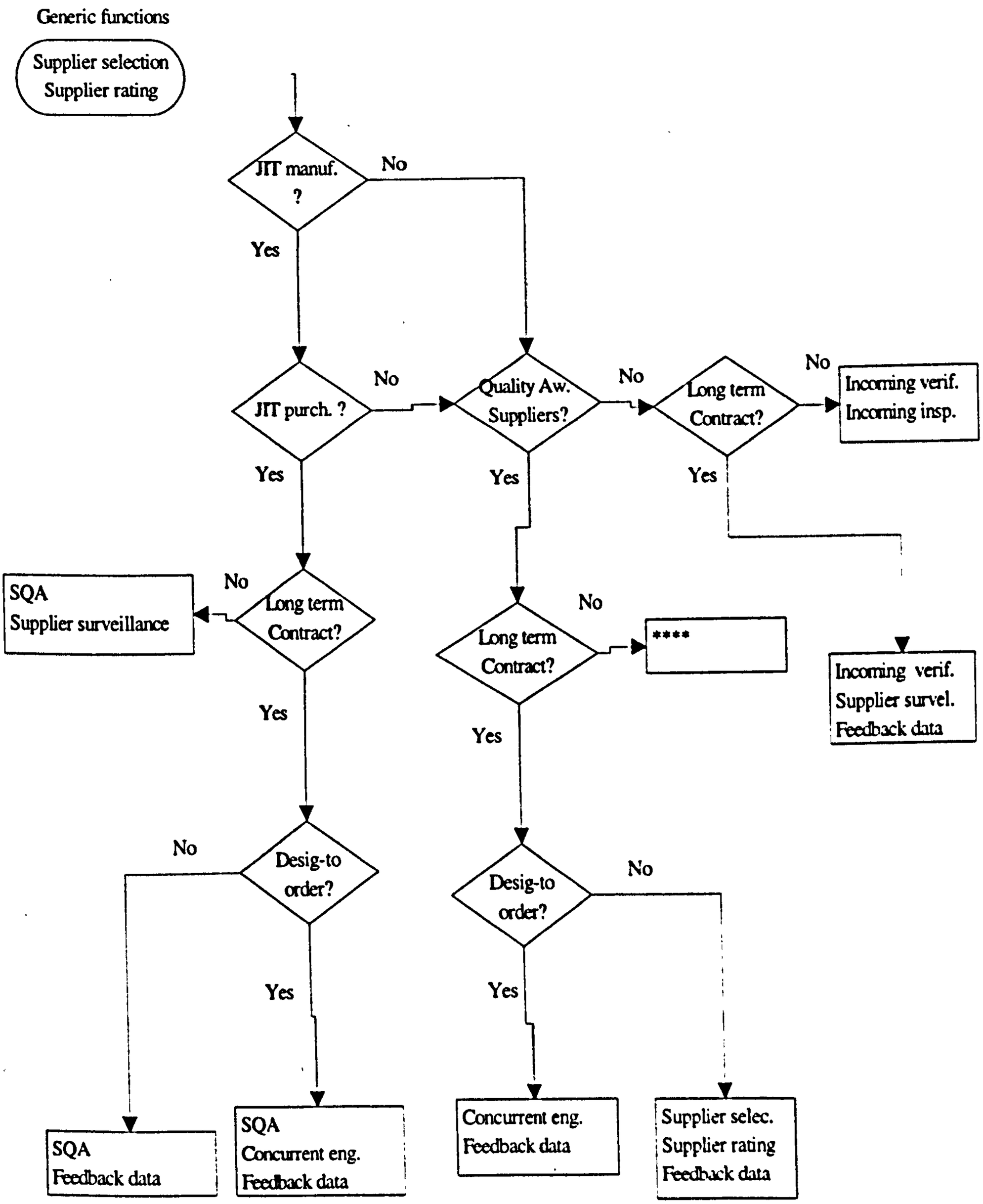

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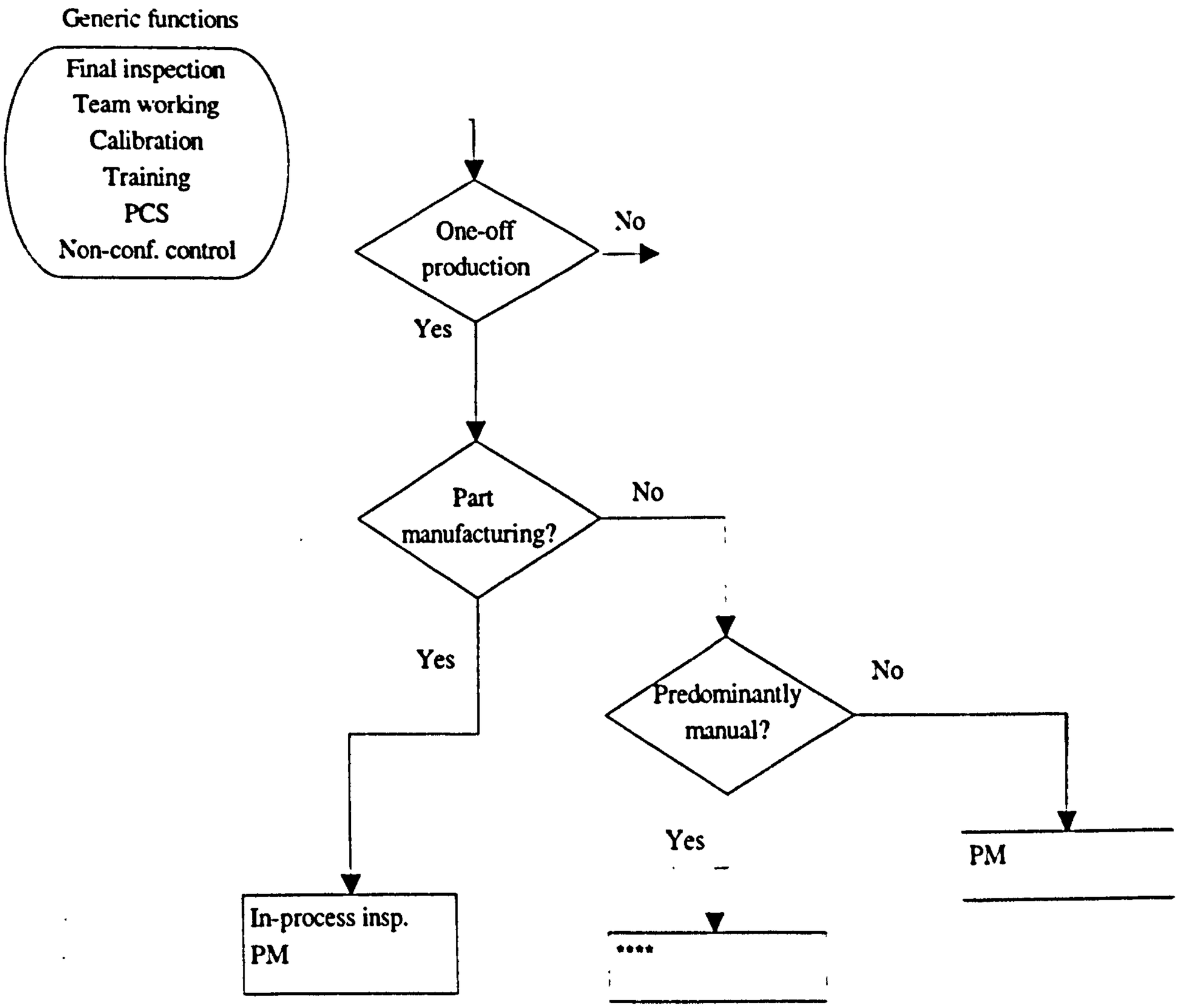

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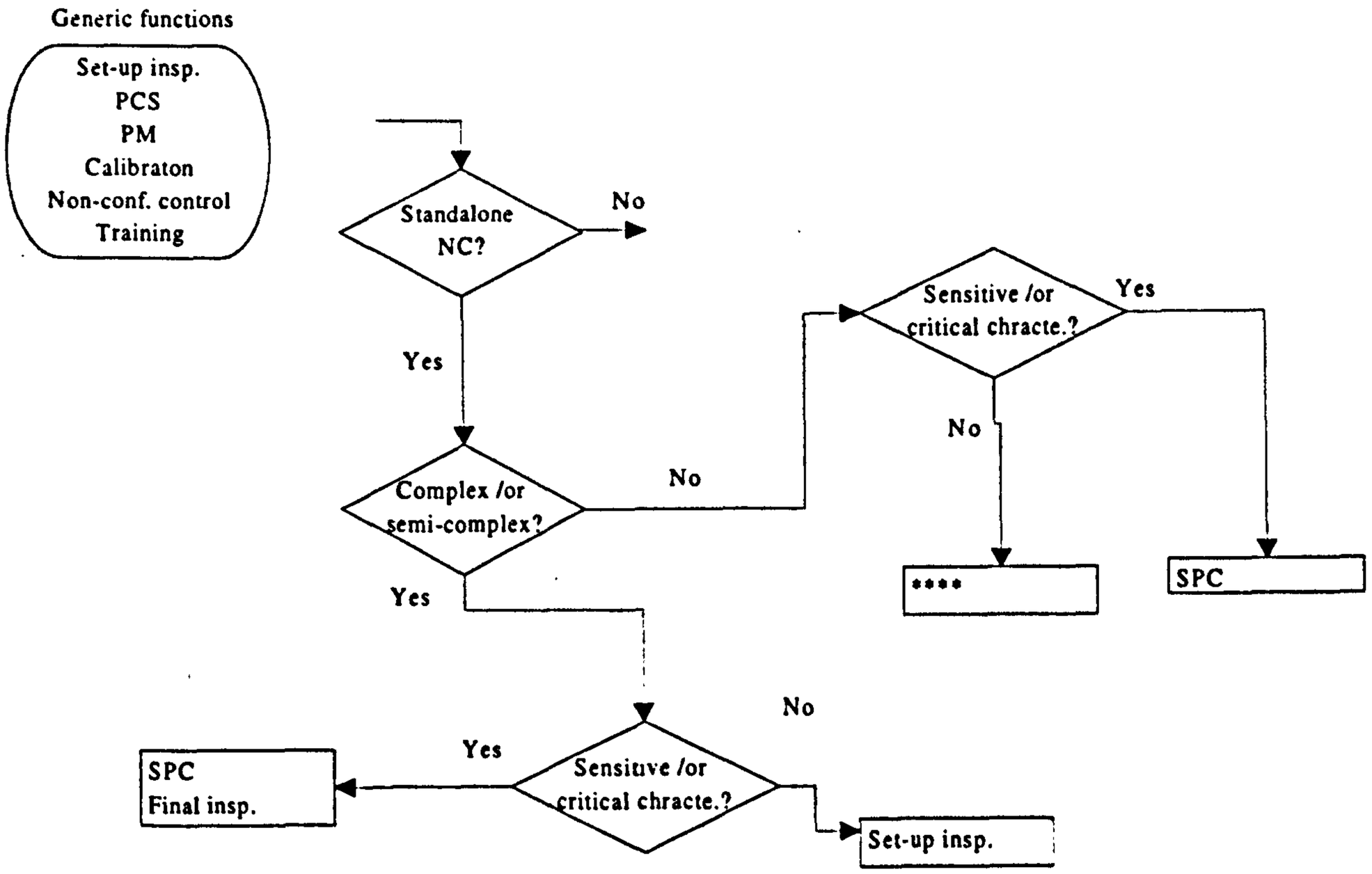

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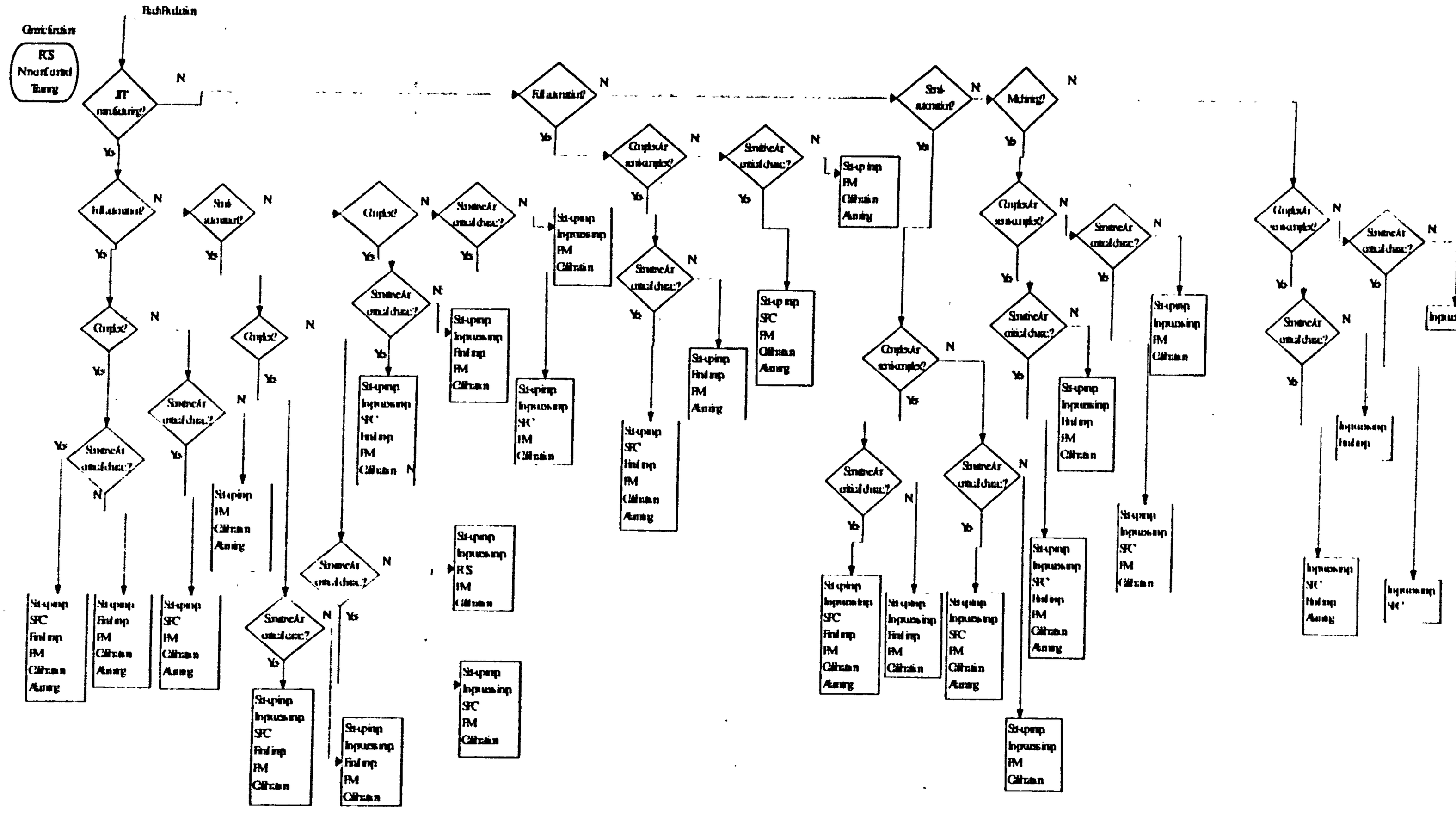

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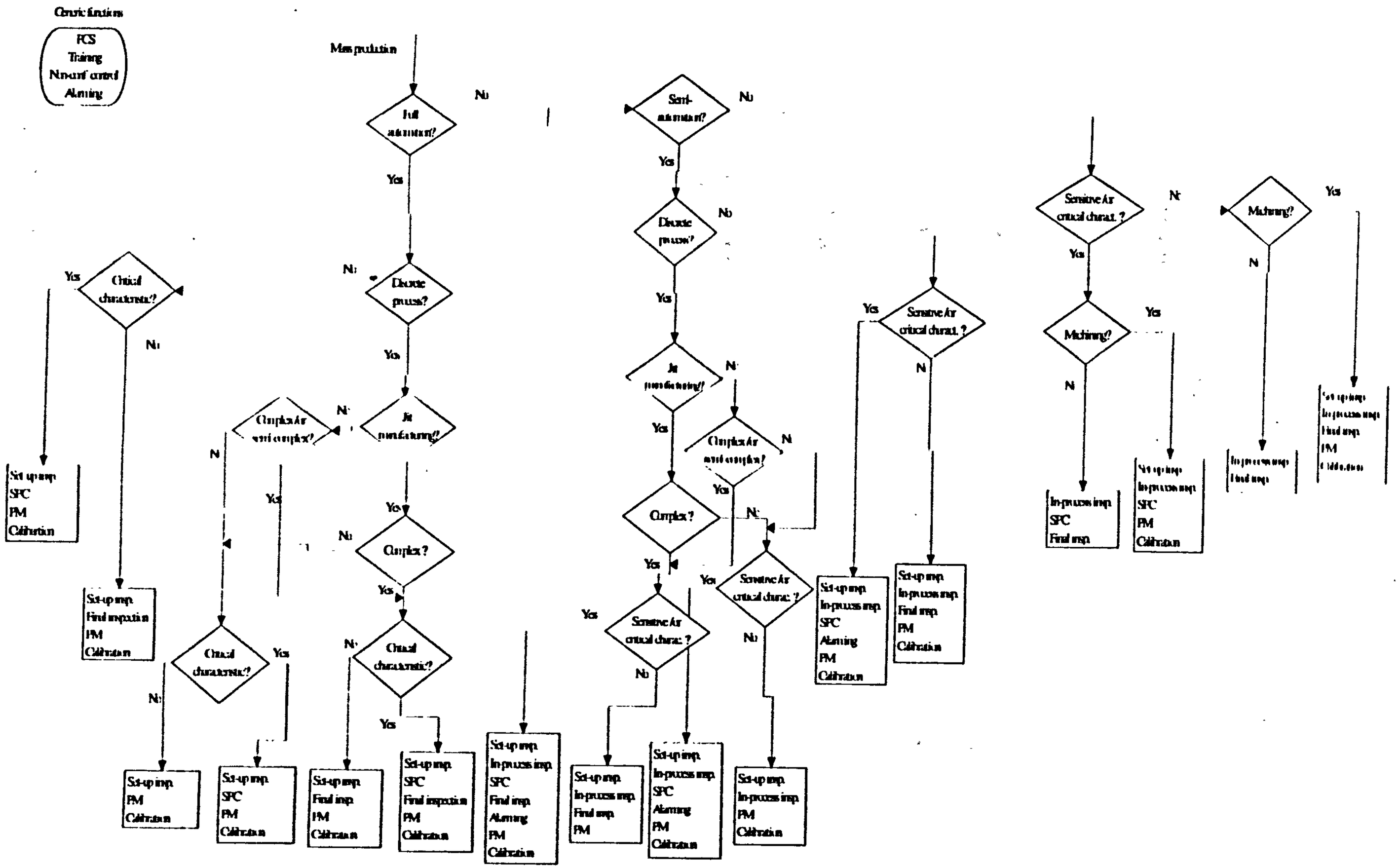

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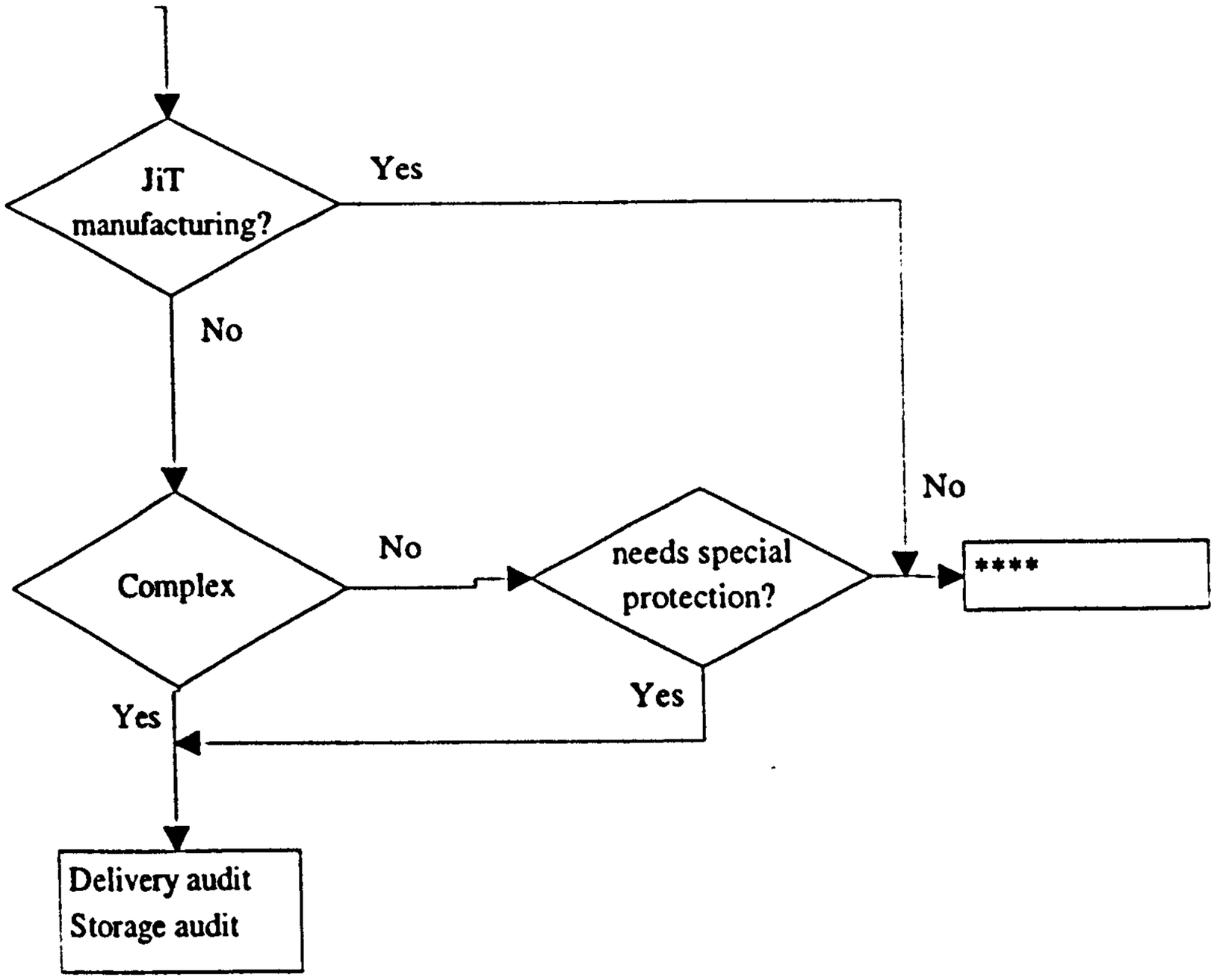

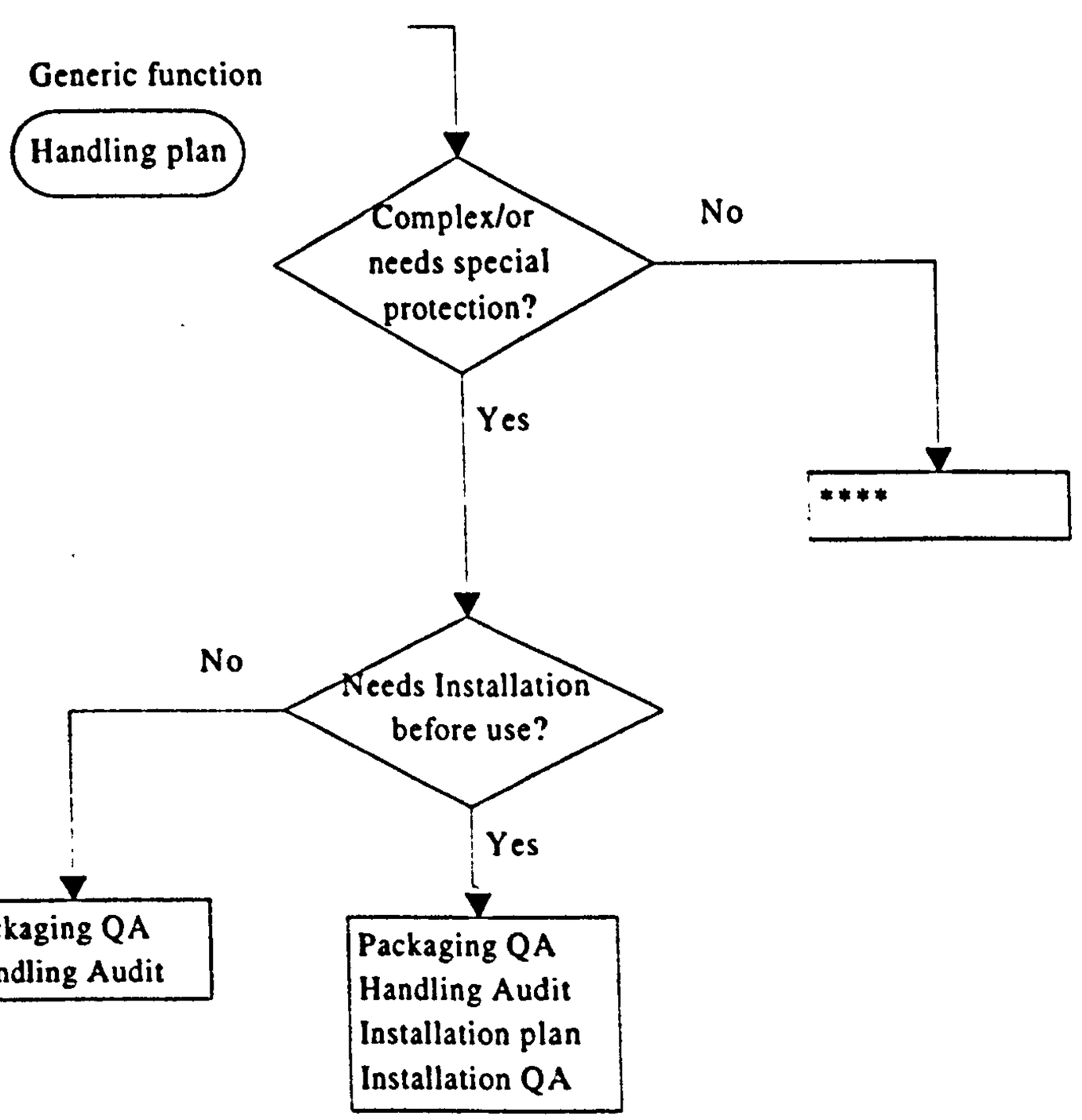

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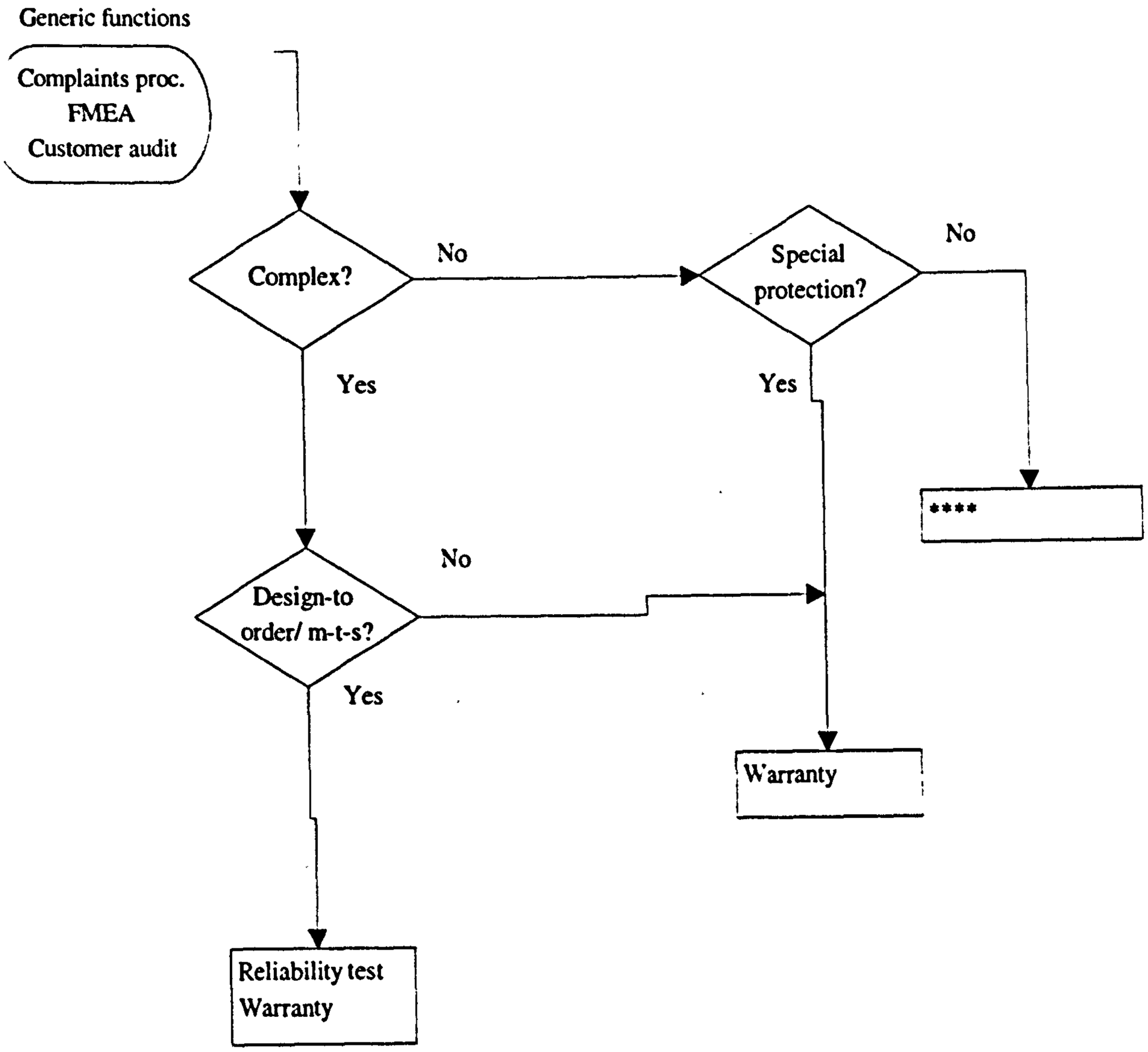


**** Representing no recommendation

Appendix VI

About Leonardo Object frame

Object Frame:

Typically, there will be much more information to be associated with a given object than its name and value. In order to keep the Main RuleSet unconfiused with this object information, a structure known as an object frame is provided for storage of this information in Leonardo.

Figure A6.1 is a typical leonardo object frame representation. It consists of several slots which define objects. The exmple used here is the object called ' Strategy '.

```
1 :          Name :    Strategy
2 :      LongName:     Manufacturing strategy
3 :          Type :    Text

4 :  Allowed Value :   DTO,ETO,MTO,ATO,MTS

5 :  Quary Prompt :  Which manufacturing strategy is your company's strategy?

6 :  Quary Perface :   There are five manufacturing strategy, they are:

                        1- Design to order(DTO)
                        2-Engineer to order(ETO)
                        3-Make to order(MTO)
                        4-Assemble to order(ATO)
                        5-Make to stock(MTS)

7 :       Expansion :
8 :     Introduction :
9 :     Conclusion  :
```

Fig. A6-1: A typical Leonardo Object Frame Representation

RuleSet:

Each object in Leonardo can own a frame and the frame may contain a special slot called RuleSet. A RuleSet contains of a set of rules that is used to derive the value of an object. As an example of this structure, Figure A6-2 referes to two objects 'Model' and 'System' of the post-production section.

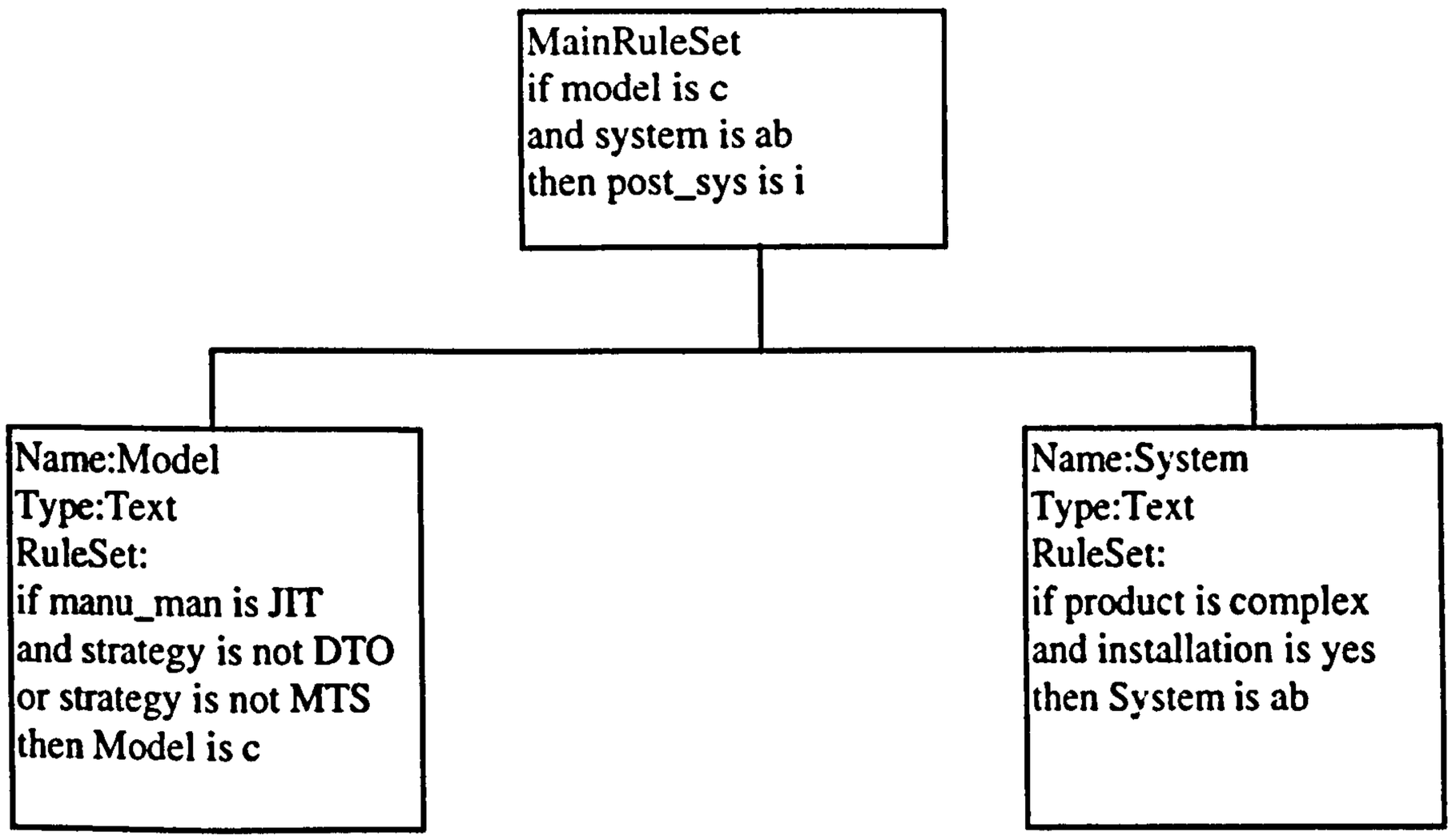


Fig. A6-2: MainRuleSet with two subsidiary RuleSets

Appendix VII

Reference Programme

```
B0A-0
BOX 0;
        NAME '<CR><CR><CR><CR><CR><CR>Total<CR>quality-based information<CR>system';
        BOX COORDINATES (0.437. 0.834) (0.571, 0.375);
        DETAIL REFERENCE N A0;
        ENDBOX;


I1A-0
ARROWSEG 1;
        SOURCE BORDER:
        PATH (0.084, 0.466) (0.440, 0.466);
        LABEL 'Enquiry';
        LABEL COORDINATES (0.040, 0.469);
        SINK BOX 011;
        ENDSEG;

I2A-0
ARROWSEG 2;
        SOURCE BORDER:
        PATH (0.127, 0.499) (0.440. 0.499);
        LABEL 'Request to tender';
        LABEL COORDINATES (0.040, 0.499);
        SINK BOX 012:
        ENDSEG:

I3A-0
ARROWSEG 3;
        SOURCE BORDER;
        PATH (0.076, 0.532) (0.440. 0.532);
        LABEL 'Order';
        LABEL COORDINATES (0.044, 0.536);
        SINK BOX 013;
        ENDSEG:

I4A-0
ARROWSEG 4;
        SOURCE BORDER:
        PATH (0.117, 0.567) (0.440. 0.567);
        LABEL 'Signed contract';
        LABEL COORDINATES (0.039, 0.570);
        SINK BOX 014;
        ENDSEG:

I5A-0
ARROWSEG 5;
        SOURCE BORDER;
        PATH (0.176, 0.663) (0.440, 0.663);
        LABEL 'Request &enquiry for repair';
```

```
        LABEL COORDINATES (0.039, 0.668);
        SINK BOX 016;
        ENDSEG;

I6A-0
ARROWSEG 6:
        SOURCE BORDER;
        PATH (0.128, 0.710) (0.440, 0.710);
        LABEL 'Technical enquiry';
        LABEL COORDINATES (0.038, 0.716);
        SINK BOX 017;
        ENDSEG;

I7A-0
ARROWSEG 7;
        SOURCE BORDER;
        PATH (0.177, 0.764) (0.440, 0.764);
        LABEL 'Customer complaint & claim';
        LABEL COORDINATES (0.039, 0.770);
        SINK BOX 018;
        ENDSEG;

O8A-0
ARROWSEG 8;
        SOURCE BOX 0O1;
        PATH (0.568, 0.462) (0.824, 0.462);
        LABEL 'Quotation';
        LABEL COORDINATES (0.822, 0.466);
        SINK BORDER;
        ENDSEG;

O9A-0
ARROWSEG 9;
        SOURCE BOX 0O2;
        PATH (0.568, 0.501) (0.825, 0.501);
        LABEL 'Tender';
        LABEL COORDINATES (0.823, 0.508);
        SINK BORDER;
        ENDSEG;

O10A-0
ARROWSEG 10;
        SOURCE BOX 0O3;
        PATH (0.568, 0.545) (0.828, 0.545);
        LABEL 'Delivery promise';
        LABEL COORDINATES (0.825, 0.552);
        SINK BORDER;
        ENDSEG;

O11A-0
ARROWSEG 11;
        SOURCE BOX 0O4;
        PATH (0.568, 0.590) (0.828, 0.590);
        LABEL 'Contract';
        LABEL COORDINATES (0.825, 0.597);
```

```
        SINK BORDER;
        ENDSEG;

O12A-0
ARROWSEG 12;
        SOURCE BOX 0O5;
        PATH (0.568, 0.636) (0.828, 0.636);
        LABEL 'Signed contract';
        LABEL COORDINATES (0.825, 0.643);
        SINK BORDER;
        ENDSEG;

O13A-0
ARROWSEG 13;
        SOURCE BOX 0O7;
        PATH (0.568, 0.725) (0.827, 0.725);
        LABEL 'Warranty';
        LABEL COORDINATES (0.824, 0.732);
        SINK BORDER;
        ENDSEG;

O14A-0
ARROWSEG 14;
        SOURCE BOX 0O8;
        PATH (0.568, 0.774) (0.828, 0.774);
        LABEL 'Product manual';
        LABEL COORDINATES (0.826, 0.780);
        SINK BORDER;
        ENDSEG;

O15A-0
ARROWSEG 15;
        SOURCE BOX 0O6;
        PATH (0.568, 0.681) (0.831, 0.681);
        LABEL 'Purchase orders';
        LABEL COORDINATES (0.828, 0.688);
        SINK BORDER;
        ENDSEG;

I16A-0
ARROWSEG 16;
        SOURCE BORDER;
        PATH (0.129, 0.613) (0.440, 0.613);
        LABEL 'New supplier data';
        LABEL COORDINATES (0.039, 0.617);
        SINK BOX 0I5;
        ENDSEG;

O17A-0
ARROWSEG 17;
        SOURCE BOX 0O9;
        PATH (0.568, 0.812) (0.828, 0.812);
        LABEL 'Customer Audit';
        LABEL COORDINATES (0.825, 0.820);
        SINK BORDER;
```

```
        ENDSEG;

O18A-0
ARROWSEG 18;
        SOURCE BOX 0O1;
        PATH (0.568, 0.416) (0.825, 0.416);
        LABEL 'Feedback data';
        LABEL COORDINATES (0.823, 0.420);
        SINK BORDER;
        ENDSEG;

EA-0
ENDDIAGRAM;

DA0
DIAGRAM GRAPHIC A0;
STATUS WORKING;

B1A0
BOX 1:
        NAME '<CR><CR>Management<CR>support<CR>system';
        BOX COORDINATES (0.273, 0.443) (0.407, 0.236);
        ENDBOX;

B2A0
BOX 2:
        NAME '<CR><CR><CR><CR><CR><CR>Quality Assurance<CR>Manufacturing<CR>System';
        BOX COORDINATES (0.595, 0.916) (0.729, 0.523);
        DETAIL REFERENCE N A2;
        ENDBOX;

OC1A0
ARROWSEG 1;
        SOURCE BOX 1O1;
        PATH (0.404, 0.321) (0.700, 0.321) (0.700, 0.528);
        LABEL 'Strategic<CR>  plan';
        LABEL COORDINATES (0.503, 0.479);
        SQUIGGLE COORDINATES (0.534, 0.456) (0.557, 0.321);
        SINK BOX 2C4;
```

```
        ENDSEG;
OC2A0
ARROWSEG 2;
        SOURCE BOX 1O2;
        PATH (0.404, 0.354) (0.672, 0.354) (0.672, 0.528);
        LABEL 'Quality <CR> policy';
        LABEL COORDINATES (0.460, 0.459);
        SQUIGGLE COORDINATES (0.492, 0.436) (0.509, 0.354);
        SINK BOX 2C3;
        ENDSEG;
OC3A0
ARROWSEG 3;
        SOURCE BOX 1O3;
        PATH (0.404, 0.389) (0.649, 0.389) (0.649, 0.528);
        LABEL 'Marketing <CR> policy';
        LABEL COORDINATES (0.422, 0.435);
        SQUIGGLE COORDINATES (0.464, 0.416) (0.475, 0.389);
        SINK BOX 2C2;
        ENDSEG;
OC4A0
ARROWSEG 4;
        SOURCE BOX 1O4;
        PATH (0.404, 0.418) (0.621, 0.418) (0.621, 0.528);
        LABEL 'Quality<CR>objectives';
        LABEL COORDINATES (0.547, 0.503);
        SQUIGGLE COORDINATES (0.592, 0.490) (0.621, 0.458);
        SINK BOX 2C1;
        ENDSEG;
OC5A0
ARROWSEG 5;
        SOURCE BOX 2O3;
        PATH (0.727, 0.561) (0.828, 0.561) (0.828, 0.157) (0.337, 0.157) (0.337, 0.240);
        LABEL 'Sales report';
        LABEL COORDINATES (0.660, 0.216);
        SQUIGGLE COORDINATES (0.680, 0.197) (0.657, 0.157);
        SINK BOX 1C2;
        ENDSEG;
OC6A0
ARROWSEG 6;
        SOURCE BOX 2O2;
        PATH (0.727, 0.551) (0.815, 0.551) (0.815, 0.172) (0.353, 0.172) (0.353, 0.240);
        LABEL 'Market survey data';
        LABEL COORDINATES (0.568, 0.219);
        SQUIGGLE COORDINATES (0.602, 0.200) (0.583, 0.172);
        SINK BOX 1C3;
        ENDSEG;
OC7A0
ARROWSEG 7;
        SOURCE BOX 2O4;
        PATH (0.727, 0.576) (0.853, 0.576) (0.853, 0.141) (0.324, 0.141) (0.324, 0.240);
        LABEL 'Results of audits';
        LABEL COORDINATES (0.717, 0.228);
        SQUIGGLE COORDINATES (0.752, 0.209) (0.744, 0.141);
        SINK BOX 1C1;
        ENDSEG;
```

```
OC8A0
ARROWSEG 8;
        SOURCE BOX 2O1;
        PATH (0.727, 0.538) (0.793, 0.538) (0.793, 0.188) (0.367, 0.188) (0.367, 0.240);
        LABEL 'Production data';
        LABEL COORDINATES (0.484, 0.222);
        SQUIGGLE COORDINATES (0.540, 0.203) (0.547, 0.188);
        SINK BOX 1C4;
        ENDSEG;
I9A0
ARROWSEG 9;
        SOURCE BORDER I1 (0.003, 0.544);
        PATH (0.019, 0.536) (0.129, 0.536) (0.129, 0.623) (0.599, 0.623);
        LABEL 'Enquiry';
        LABEL COORDINATES (0.000, 0.578);
        SINK BOX 2I2;
        ENDSEG;

I10A0
ARROWSEG 10;
        SOURCE BORDER I2 (0.004, 0.635);
        PATH (0.013, 0.642) (0.599, 0.642);
        LABEL 'Request to tender';
        LABEL COORDINATES (0.000, 0.667);
        SINK BOX 2I3;
        ENDSEG;

I11A0
ARROWSEG 11;
        SOURCE BORDER I4 (0.001, 0.746);
        PATH (0.016, 0.739) (0.599, 0.739);
        LABEL 'Signed contract';
        LABEL COORDINATES (0.000, 0.769);
        SINK BOX 2I5;
        ENDSEG;

I12A0
ARROWSEG 12;
        SOURCE BORDER I6 (0.001, 0.880);
        PATH (0.016, 0.874) (0.599, 0.874);
        LABEL 'Request &enquiry for repair';
        LABEL COORDINATES (0.000, 0.899);
        SINK BOX 2I7;
        ENDSEG;

I13A0
ARROWSEG 13;
        SOURCE BORDER I7 (0.003, 0.931);
        PATH (0.013, 0.938) (0.172, 0.938) (0.172, 0.894) (0.599, 0.894);
        LABEL 'Technical enquiry';
        LABEL COORDINATES (0.000, 0.965);
        SINK BOX 2I8;
        ENDSEG;

I14A0
```

ARROWSEG 14;
SOURCE BORDER I8 (0.011, 0.351);
PATH (0.027, 0.348) (0.153, 0.348) (0.276. 0.348);
LABEL 'Customer complaint & claim';
LABEL COORDINATES (0.000, 0.385);
SINK BOX 111;
ENDSEG;

I16A0
ARROWSEG 16;
SOURCE BORDER I8 (0.011, 0.351);
PATH (0.027, 0.348) (0.153, 0.348) (0.153, 0.588) (0.599, 0.588);
LABEL 'Customer complaint & claim';
LABEL COORDINATES (0.000, 0.385);
SINK BOX 2I1;
ENDSEG;

O17A0
ARROWSEG 17;
SOURCE BOX 2O5;
PATH (0.727, 0.594) (0.972, 0.594);
LABEL 'Quotation';
LABEL COORDINATES (0.942, 0.623);
SINK BORDER O1 (0.970, 0.602);
ENDSEG;

O18A0
ARROWSEG 18;
SOURCE BOX 2O6;
PATH (0.727, 0.629) (0.975, 0.629);
LABEL 'Tender';
LABEL COORDINATES (0.952, 0.659);
SINK BORDER O2 (0.972, 0.636);
ENDSEG;

O19A0
ARROWSEG 19;
SOURCE BOX 2O7;
PATH (0.727, 0.669) (0.973, 0.669);
LABEL 'Delivery promise';
LABEL COORDINATES (0.912, 0.698);
SINK BORDER O3 (0.971, 0.673);
ENDSEG;

O20A0
ARROWSEG 20;
SOURCE BOX 2O8;
PATH (0.727, 0.712) (0.972, 0.712);
LABEL 'Contract';
LABEL COORDINATES (0.947, 0.742);
SINK BORDER O4 (0.970, 0.719);
ENDSEG;

O21A0
ARROWSEG 21;

SOURCE BOX 2O9;
PATH (0.727, 0.760) (0.975, 0.760);
LABEL 'Signed contract';
LABEL COORDINATES (0.921, 0.788);
SINK BORDER O5 (0.973, 0.767);
ENDSEG;

O22A0
ARROWSEG 22;
SOURCE BOX 2O11;
PATH (0.727, 0.839) (0.973, 0.839);
LABEL 'Warranty';
LABEL COORDINATES (0.943, 0.864);
SINK BORDER O7 (0.971, 0.843);
ENDSEG;

.....

Appendix VIII

Programs listings

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

main()
{
char buffer[14];
char str[14];
char string[14];

int k,u;

FILE *in1,*in2,*in3,*out;


if((in1=fopen("c:\\leonardo\\runtime\\model1.txt","r"))==NULL)

{
printf("cannot open input file.\n");
exit(0);
}

if((in2=fopen ("c:\\leonardo\\runtime\\model2.txt","r"))==NULL)

{
printf("cannot open output file.\n");
exit(0);
}

if((in3=fopen ("c:\\leonardo\\runtime\\model3.txt","r"))==NULL)

{
printf("cannot open output file.\n");
exit(0);
}

if((out=fopen ("c:\\leonardo\\test.txt","w"))==NULL)

{
printf("cannot open reference file.\n");
exit(0);
}
```

```
k=0;
do

{
fgets(str,14,in1);

if (strlen(str)==0) goto L1;
fprintf(out,"%s",str);
k=k+1;
}

while(!feof(in1));

L1:fclose(in1);
fclose(out);

if((out=fopen ("c:\\leonardo\\test.txt","a"))==NULL)

{
printf("cannot open reference file.\n");
exit(0);
}

u=0;
do
{

fgets(string,14,in2);

if (strlen(string)==0) goto L2;



fprintf(out,"%s",string);
u=u+1;
}
while(!feof(in2));



L2:fclose(in2);
```

```
fclose(out);

if((out=fopen ("c:\\leonardo\\test.txt","a"))==NULL)

{
printf("cannot open reference file.\n");
exit(0);
}

 u=0;
do
{

fgets(buffer,14,in3);
if (strlen(buffer)==0) goto L3;



 fprintf(out,"%s",buffer);

u=u+1;
}
while(!feof(in3));



L3:fclose(in3);


 fclose(out);

return 0;
}
```

```
#include <stdio.h>
#include <stdlib.h>
#include <string.h>

main()
{

char buffer[98];
char str[14];

int k,u,m;

FILE *in,*ref, *out;



if((in=fopen("c:\\leonardo\\test.txt","r"))==NULL)

{
printf("cannot open input file.\n");
exit(0);
}

if((out=fopen ("c:\\idef37\\o.idl","w"))==NULL)

{
printf("cannot open output file.\n");
exit(0);
}

k=0;
do

{
fgets(str,14,in);
if (strlen(str)==0) goto L3;

if((ref=fopen ("c:\\idef37\\p2.txt","r"))==NULL)

{
printf("cannot open reference file.\n");
exit(0);
}

u=0;
```

```
do
{

fgets(buffer,98,ref);

if(strcmp(str,buffer)==0) goto L1;

u=u+1;
}
while(!feof(ref));

L1:m=1;
do

{

fgets(buffer,98,ref);

if (strlen(buffer)==0) goto L2;
fprintf(out,"%s", buffer);

m=m+1;

}
while(m<9);

L2:fclose(ref);



k=k+1;
}
while(!feof(in));

L3:

fclose(in);
fclose(out);



return 0;
}
```

Appendix IX

Illustrative example of DSDQAIS

Illustrative example:

A proof-of-concept DSDQAIS implementation study is carried out in this Appendix in order to illustrate the application of the designed DSDQAIS methodology. As has been described before and was shown in the schematic model, the input for the system is the profile of a business. After processing the data according to the knowledge based algorithm, the output of the system is an integrated structural model of the quality assurance information system recommended for that particular business.

The profile specification which may affect design of the quality assurance information system has been discussed in chapter 7. The specification of a company used in this example is shown in table A9.1:

Table A9.1: The profile specification of the company

Profile factor name	Explanation
Manufacturing strategy	Make to order
Product complexity	Non complex
Critical quality characteristics	yes
Company size	Medium
Production management system	Order point system
Method of production	Batch production
Design	Company-design
Supplier reputation	Qualified
Supplier relationship	Long term
Technology	Semi-automation
Special protection	No
Product needs installation	No

The knowledge-based systems, through the dialogue sub-system, collect the above data. Then, using a top-down search, it recommends those quality assurance based activities

and information requirements which suite the input profile. The knowledge-based system recommendation is in a special code format(Table A9.2).

Table A9.2: The recommendation of KBS in special code format

M100	O18A-0	O20A0	OI9A2	O33A2
M110	EA-0	O21A0	OC10A2	O34A2
M120	DA0	O22A0	OC11A2	O35A2
DA-0	B1A0	O23A0	OC12A2	O36A2
B0A-0	B2A0	I24A0	OC13A2	O37A2
I1A-0	OC1A0	O25A0	OC14A2	O38A2
I2A-0	OC2A0	I26A0	OC15A2	O40A2
I3A-0	OC3A0	O27A0	OC16A2	O41A2
I4A-0	OC4A0	O28A0	OI17A2	OC43A2
I5A-0	OC5A0	EA0	OC19A2	O44A2
I6A-0	OC7A0	DA2	OC20A2	I45A2
I7A-0	OC8A0	B1A2	OI22A2	I46A2
O8A-0	I9A0	B2A2	OI23A2	I47A2
O9A-0	I10A0	B3A2	OC24A2	C48A2
O10A-0	I11A0	C1A2	OC25A2	O49A2
O11A-0	I12A0	C2A2	I26A2	O50A2
O12A-0	I13A0	C3A2	I27A2	EA2
O13A-0	I14A0	OC4A2	I28A2	.....
O14A-0	I16A0	OC5A2	I29A2	
O15A-0	O17A0	OI6A2	I30A2	
I16A-0	O18A0	OI7A2	O31A2	
O17A-0	O19A0	OI8A2	O32A2	

Table A9.3: The list of recommended activities and information

Competitor studies	Non-conforming product
Tender review	instruction
Contract review	On-line process control alarm
Process capability study evaluation	Preventive maintenance
Supplier selection	Inspection instruments calibration
Supplier rating	Training
Feedback data	FMEA
Set-up inspection	Customer complaints system
Statistical process control	Customer audits
Process capability study	Handling plan
	....

Table A9.3 shows the complete list of activities or information recommended by the three knowledge-based sub-systems, pre-production, production, post-production.

In the next step, these codes are transferred into IDL language by a transformation tool(table A9.4). The IDL format of the activities and information make it possible to create a functional structure in the form of an IDEF0 model. Figure A9.1 shows the IDEF0 model.

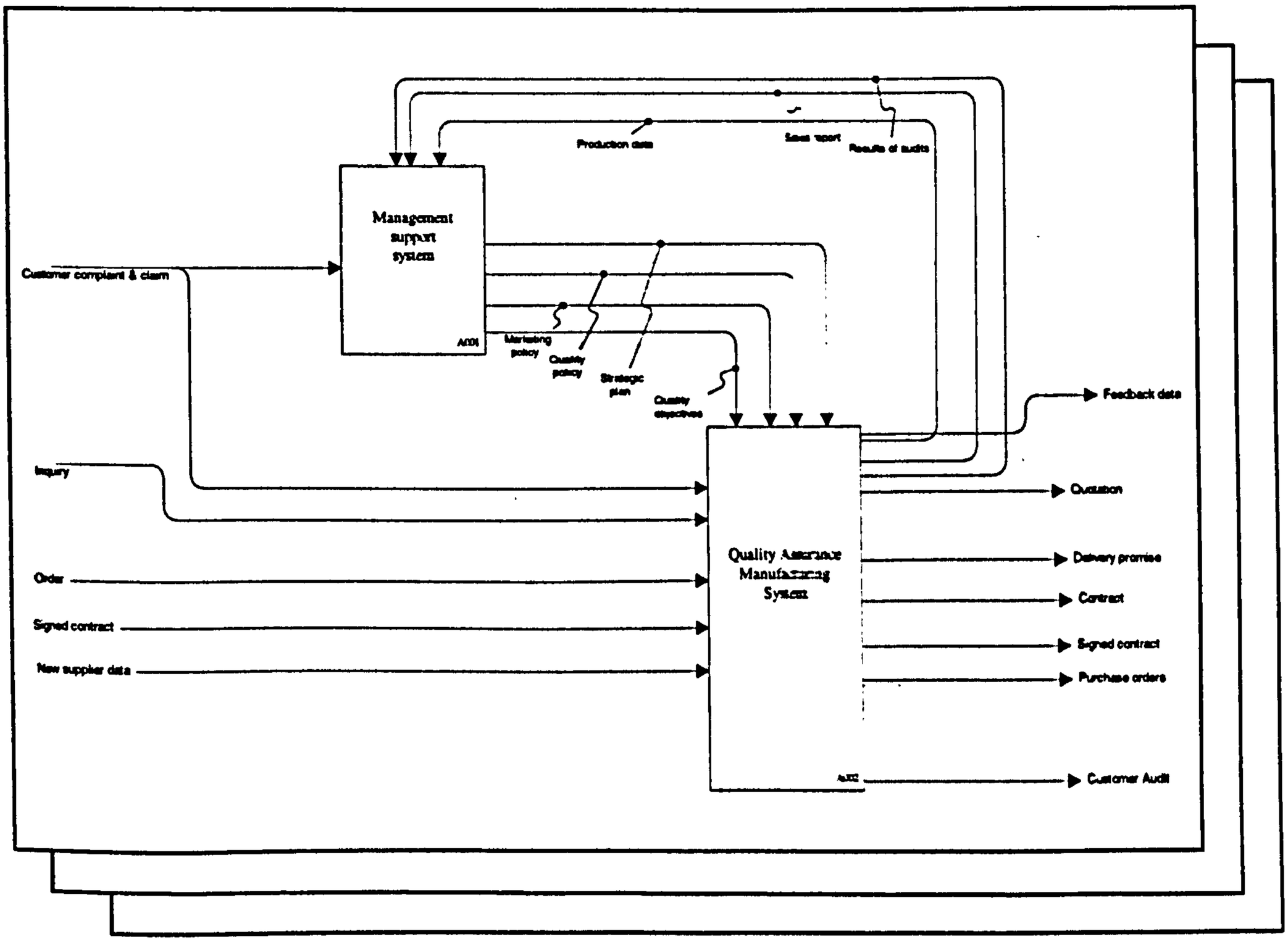
Table A9.4: part of the transformed quality based information.

```
BOX 0;
NAME '<CR><CR><CR><CR><CR><CR>Total<CR>quality-based
information<CR>system';
BOX COORDINATES (0.437, 0.834) (0.571, 0.375);
DETAIL REFERENCE N A0;
ENDBOX;

ARROWSEG 1;
SOURCE BORDER;
PATH (0.084, 0.466) (0.440. 0.466);
LABEL 'Enquiry';
LABEL COORDINATES (0.040, 0.469);
SINK BOX 0I1;
ENDSEG;

ARROWSEG 2;
SOURCE BORDER;
PATH (0.127, 0.499) (0.440. 0.499);
LABEL 'Request to tender':
LABEL COORDINATES (0.040, 0.499);
SINK BOX 0I2;
ENDSEG;
.....
```

Figure A9.1: The A0 layer of recommended IDEF0 model



Appendix X

Report on recommended IDEF0 model of DSDQAIS

IDEF0 report:

A user of the system can generate a complete listing of all information in an IDEF0 model in the form of a report. The following is an excerpt for the IDEF0 model which was created in Appendix IX.

Total quality-based information
systemFull IDEF0 Report for: (Unnamed Document)

[Diagram: A-0]

Activity: [A0] Total quality-based information system

Arrow: Enquiry
Input From: Enquiry
Input To: [A0] Total quality-based information system

Arrow: Signed contract
Input From: Signed contract
Input To: [A0] Total quality-based information system

Arrow: Customer complaint & claim
Input From: Customer complaint & claim
Input To: [A0] Total quality-based information system

Arrow: Delivery promise
Output From: [A0] Total quality-based information system
Output To: Delivery promise

Arrow: Contract
Output From: [A0] Total quality-based information system
Output To: Contract

Arrow: Signed contract
Output From: [A0] Total quality-based information system
Output To: Signed contract

Arrow: Purchase orders
Output From: [A0] Total quality-based information system
Output To: Purchase orders

Arrow: New supplier data
Input From: New supplier data
Input To: [A0] Total quality-based information system

Arrow: Customer Audit
Output From: [A0] Total quality-based information system
Output To: Customer Audit

Arrow: Feedback data
Output From: [A0] Total quality-based information system
Output To: Feedback data

[Diagram: A0] Total quality-based information system

Activity: [A1] Management support system

Activity: [A2] Quality Assurance Manufacturing System

Arrow: Strategic plan
Output From: [A1] Management support system
Control To: [A2] Quality Assurance Manufacturing System

Arrow: Quality policy
Output From: [A1] Management support system
Control To: [A2] Quality Assurance Manufacturing System

Arrow: Marketing policy
Output From: [A1] Management support system
Control To: [A2] Quality Assurance Manufacturing System

Arrow: Quality objectives
Output From: [A1] Management support system
Control To: [A2] Quality Assurance Manufacturing System

Arrow: Sales report
Output From: [A2] Quality Assurance Manufacturing System
Control To: [A1] Management support system

Arrow: Results of audits
Output From: [A2] Quality Assurance Manufacturing System
Control To: [A1] Management support system

Arrow: Production data
Output From: [A2] Quality Assurance Manufacturing System
Control To: [A1] Management support system

Arrow: Enquiry
Input From: {I1} Enquiry
Input To: [A2] Quality Assurance Manufacturing System

Arrow: New supplier data
Input From: {I4} New supplier data
Input To: [A2] Quality Assurance Manufacturing System

Arrow: Customer complaint & claim
Input From: I8
Input To: [A1] Management support system

Arrow: Customer complaint & claim
Input From: I8
Input To: [A2] Quality Assurance Manufacturing System

Arrow: Feedback data
Output From: [A2] Quality Assurance Manufacturing System
Output To: {O1} Feedback data

Arrow: Delivery promise
Output From: [A2] Quality Assurance Manufacturing System
Output To: {O3} Delivery promise

Arrow: Contract
Output From: [A2] Quality Assurance Manufacturing System
Output To: {O4} Contract

Arrow: Signed contract
Output From: [A2] Quality Assurance Manufacturing System
Output To: {O5} Signed contract

Arrow: Signed contract
Input From: {I3} Signed contract
Input To: [A2] Quality Assurance Manufacturing System

Arrow: Purchase orders
Output From: [A2] Quality Assurance Manufacturing System
Output To: {O6} Purchase orders

Arrow: Customer complaint & claim
Input From: {I5} Customer complaint & claim
Input To: [A2] Quality Assurance Manufacturing System

Arrow: Customer Audit
Output From: [A2] Quality Assurance Manufacturing System
Output To: O9

Arrow: Feedback data
Output From: [A2] Quality Assurance Manufacturing System
Output To: {O1} Feedback data

[Diagram: A2] Quality Assurance Manufacturing System

Activity: [A21] Assure Pre-production

Activity: [A22] Assure Production

Activity: [A23] Assure Post-production

Arrow: Strategic plan
Control From: {C4} Strategic plan
Control To: [A21] Assure Pre-production

Arrow: Quality policy

Control From: {C3} Quality policy
Control To: [A21] Assure Pre-production

Arrow: Marketing policy
Control From: {C2} Marketing policy
Control To: [A21] Assure Pre-production

Arrow: Service instruction
Output From: [A21] Assure Pre-production
Control To: [A23] Assure Post-production

.....

PUBLICATIONS RELATE TO THIS RESEARCH STUDY

A generic IDEF0 model of quality assurance information systems

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Summary:
In spite of advances in manufacturing processes and technologies, and the push for integration across all functional areas towards a totally automated manufacturing system, the suggestion is that quality assurance is often neglected.[1] On the other hand, quality based competition is showing that quality management based on inspection is far from appropriate and that producing defect free products is not enough. It is necessary first to know the customers and then to satisfy or surpass their requirements. In the context of company-wide quality[2] and ISO9000[3] , this can be achieved by assuring quality in every aspect of an organisation. This paper presents a generic structural model of an information system to support integrated quality systems.

1-Introduction

Quality assurance concerns the whole life cycle of both product and process, thus covering all quality based functions, including quality planning, control and monitoring with appropriate feedback actions. The concept of company-wide quality assurance has been largely based on information management[4], and similarly, ISO9000 quality systems are heavily information dependent.
It is clear that in order to design and manufacture products that delight customers, and improve the ability to predict and detect quality problems at an early stage, there is a strong need for an information system to support all the quality-based functions from the pre-production stage through to post-production.[5]
Several tools and modelling techniques have been developed to facilitate the design and implementation of information systems for complex manufacturing environments.[6] This paper focuses on the use IDEF0 to provide a generic model of the business functions which have an impact on quality, and their structure for an integrated quality assurance information system, for a design-to-order manufacturing environment.
Generally, the major advantages of IDEF0[7] can be stated as:
1-A potential standard methodology for use in the manufacturing environment.
2-An effective model for describing a system in detail.
3-A standardised method and mechanism for decomposing a whole process into modular sub-components. Therefore, a company can focus on the specific part of a

process model and develop further levels of detail without losing its context within the whole process.[8]
The generic model that has been constructed comprises those functions or essential activities that influence quality and which must necessarily take place within any design and manufacturing process. This functional structure is a graphical static model which makes all the functions work together to produce the desired end result. The quality information and information flow requirements of any specific manufacturing business will be found within the generic model.

2-Designing the quality assurance information system(QAIS):

-The analysis is applied to the domain of the 'design to order' manufacturing environment.
-In recognition of the fact that quality is influenced by activities and decisions in all phases of product life cycle, there must be an overall organisational responsibility for quality.
-A quality information system is an organised method of collecting, storing, analysing, and reporting information on quality to assist decision makers at all levels.[9]
-The manufacturing area can be divided into four sub-sections as shown in Fig 1:

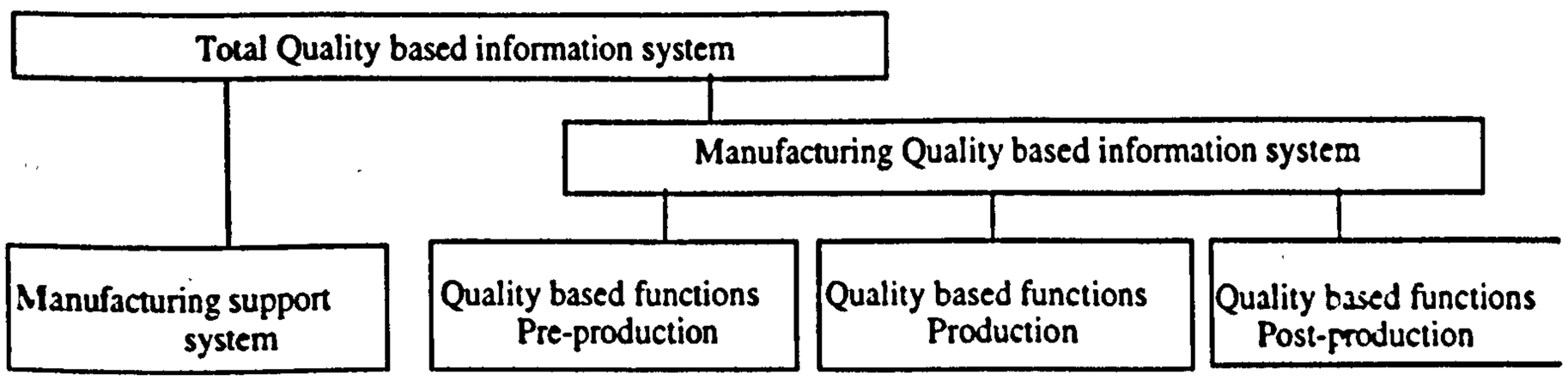

Fig. 1: The business quality-based information sub-systems

2.1-The responsibility of management in respect of the quality assurance information system encompasses all activities of the overall management function including:

- Consistent with other policies, the quality policy and quality objective should be defined, documented and implemented.
- A quality system should be developed, and implemented, in order to effectively and consistently accomplish the stated policies and objectives.
- Total quality cost should be calculated and other performance measures instituted.

Figure 2 represents the interfaces of the management support system and QAIS with other functions in a manufacturing organisation.

2.2-The information system to support QA in the pre-production phase should ensure that the product that has been designed meets customer requirements and can be produced defect free and reliable[10]. This step shall include the following matters:

- Review of tenders, contracts or orders in respect of customer requirements.
- Quality function deployment
- Identifying critical safety and functional product quality characteristics.

- Reviewing the design, and design documents before release.
- Failure mode and effect analysis, and fault tree analysis.
- Verifying the design through test, and analysis of test results.
- Assuring safety and environmental compatibility of product.
- Assuring capability of suppliers to meet contract or order requirements.
- To assure manufacturability and manufacturing capability.
- Inspection and test procedures for products and incoming materials verification.
- A non-conforming disposition procedure for both products and incoming materials.
- Establishing and maintaining quality records of sub-contractors.

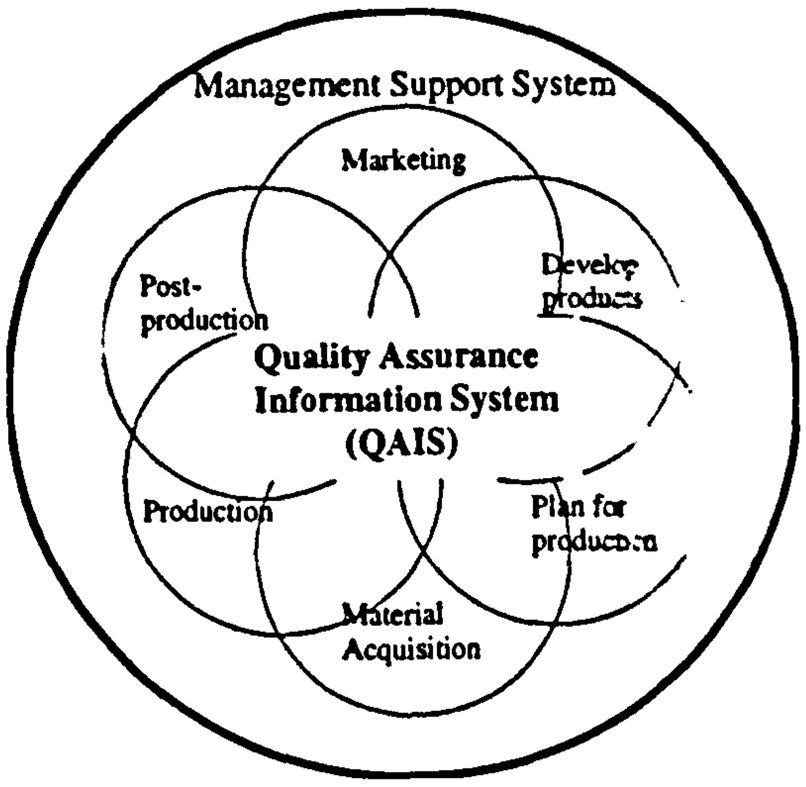

Fig. 2: The interfaces of management support system and QAIS with other functions

2.3-The information system to support QA in the production phase should include:

- Process should be verified as being capable of producing product in accordance with specifications.
- Verification of product conformance, typically by strategic inspections or tests,
- Statistical process control for detection and correction of out of control conditions.
- Assessment and disposition of non-conforming product according to procedures.
- Problem identification, analysis and corrective action.
- Control, calibrate and maintain inspection, measuring and test equipment.
- Preventive maintenance of equipment, to ensure continued process capability

2.4-The information system to support QA in the post-production phase includes:

Research has shown that more customers complaints are caused by store, handling and distribution activities, specially in packaging the product. than were caused by original manufacturing.[5]

- Design and acquisition of packaging and packaging materials
- Documented procedures for handling, storing, packaging and transport.
- Periodic audit of the condition of product in stock.
- Procedures for disposition of defective or deteriorated products.
- Periodic audit of handling and transport processes.
- Provision of necessary technical data and instructions to customers.

- Field failures, returned products and user dissatisfaction shall be recorded and analysed.
- Failure causes shall be identified and reflected in new FMEA.
- Direct auditing of customer satisfaction.
- Customer complaints procedure.

3-A generic IDEF0 model of quality assurance information system

A generic IDEF0 model introduces no specific mechanisms for its functions, and is equally valid for all possible profiles of a manufacturing business.
It is suggested that the use of generic IDEF0 modelling can help to capture a clear picture of complex aspects of a manufacturing organisation and can lead to very precise thinking about what specific people and departments are suppose to be doing[11][12], in this case in relation to quality. For a generic model the level of analysis must contain functions which are at a level of detail that is applicable to all companies.
As the level of hierarchy of system becomes lower, functions are more dependent upon many factors such as: the size of industry, manufacturing strategy, production systems, production technology, manufacturing production management and the nature and requirements of the desired end product. Figure 3 is an example of the IDEF0 model diagrams.

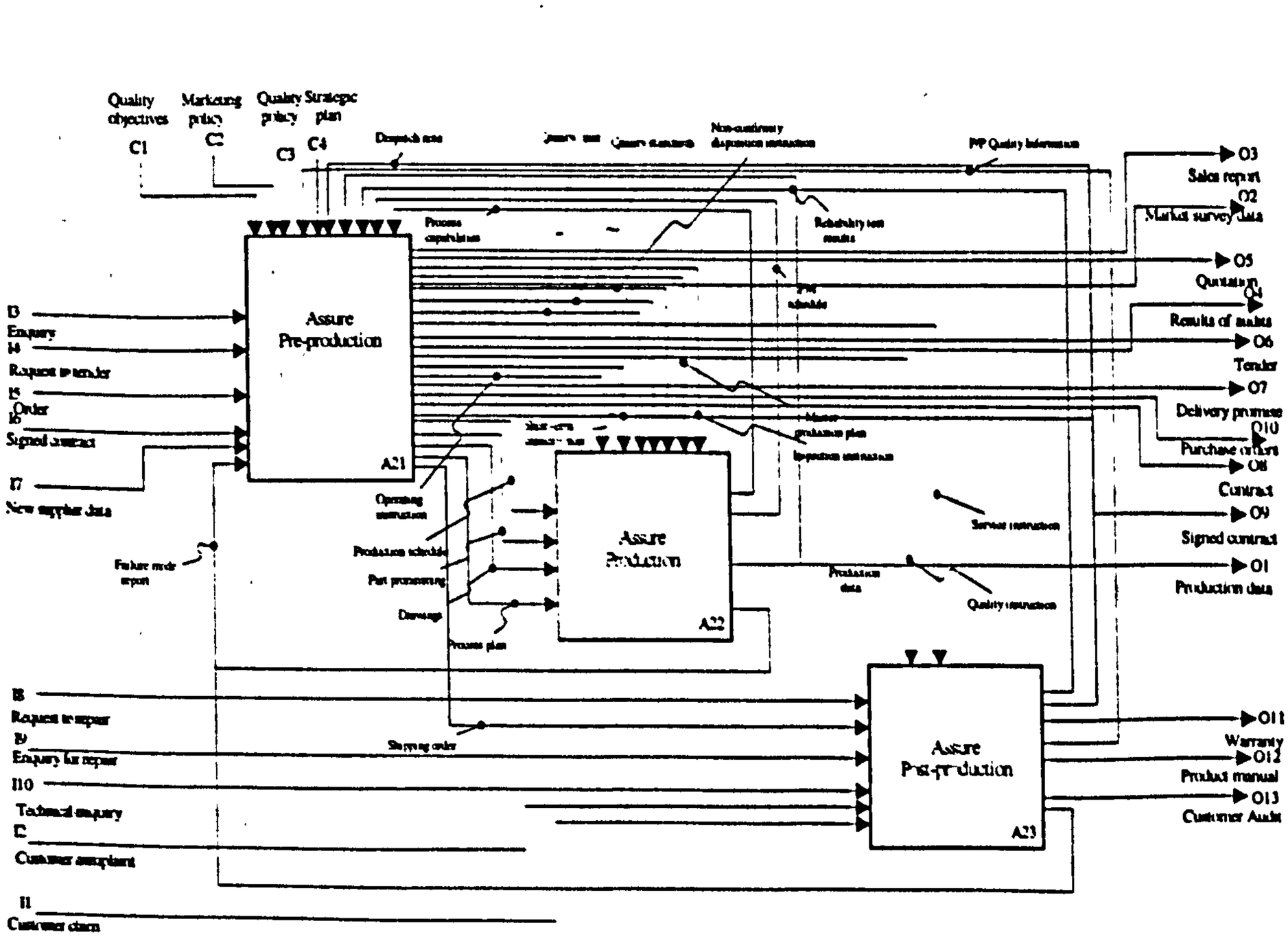

Fig. 5: Manufacturing quality-based information system

Due to the number and diversity of factors such as overhead factors that have to be considered, quality assurance system design is a complex task. It is not sufficient to evaluate each of the factors individually, since many of them are interrelated, or may be conflicting. Consequently, quality assurance system formation must be based upon an iterative and constructive process spanning multiple dimensions of analysis. Such decision making can be significantly facilitated by appropriate computer based decision support systems.

A central requirement of a DSS for successfully designing a quality assurance information system is a complete knowledge-base of information encompassing all functions that have an impact on quality. This is presently being carried out through knowledge elicitation from industry. The results will be embodied as rules in a knowledge based expert system integrated with the IDEF0 model. The DSS will recommend elements of a QAIS appropriate to specific company profiles input by the user and which will satisfy the requirements of ISO9000 and company-wide quality for that company.

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A Generic IDEF0 Model of Quality Assurance Information Systems for the Design-to-Order Manufacturing Environment

A. S. Nookabadi and John E. Middle

Abstract—**In spite of advances in computer technologies, information processing, automation technologies, manufacturing processes, and the push for integration across all functional areas toward a totally automated manufacturing system, the suggestion is that quality assurance is usually missing. On the other hand, quality-based competition is showing that quality management based on inspection is far from reality and that producing defect-free products is not enough. It is necessary to know the customers first and then to satisfy, or surpass, their requirements in order to remain competitive. In the context of company-wide quality and ISO9000, this can be achieved by designing quality into every aspect of an organization as part of an integrated quality assurance system. In this paper, a structural model for integrated quality assurance information systems (QAIS's) using IDEF0 methodology, is presented. It is intended that a knowledge-based expert system linked to this structural model will provide a DSS to assist design of quality assurance systems with appropriate information flows to suit the requirements of various business profiles.**

Index Terms— **Quality assurance information systems, company-wide quality, modeling tools, generic model, IDEF0, ISO9000, design-to-order manufacturing.**

I. Introduction

FOR A manufacturing enterprise to be successful in the highly competitive world markets of today, the primary objectives can be stipulated as: make better quality products, reduce time to market products, and make products of good value. Computer integrated manufacturing (CIM) has been established as an essential prerequisite in the drive to reach the above objective.

The idea behind CIM is that all functions of the enterprise must work together, and many of the traditional barriers between departments must be broken down to take advantage of the flexibility offered by CIM [4].

As one of the major goals in CIM, quality assurance concerns the whole life cycle of both product and process, thus covering all quality-based functions, including quality planning, control, and monitoring with appropriate feedback actions. In this domain, from the research efforts of Feigenbaum and others, the concept of company-wide quality assurance has been introduced which, in the manufacturing area, is largely based on information management [5]. Similarly, ISO9000 quality systems are heavily information-dependent.

As information systems are increasingly playing a pivotal role toward the integration of manufacturing functions, it is clear that in order to design the right products for customers and improve the ability to predict and detect quality problems at an early stage, there is a strong need for an information system to support all the quality-based functions from the pre-production stage through to post-production [6].

This paper focuses on the use of IDEF0 to provide a generic model of the business functions that have an impact on quality and their structure for an integrated quality assurance information system (QAIS) for a design-to-order manufacturing environment. IDEF0 modeling provides a structured analysis methodology capable of representing complex functional relationships graphically and identifying the information and objects that interrelate functions.

II. IDEF0 Modeling Review

IDEF0 is a modeling tool specifically developed for use in the functional modeling of complex and interrelated systems. Originally, IDEF0 was derived from another graphical model known as structural analysis and design technique (SADT) by the U.S. Air Force to describe the organization structure of complex manufacturing systems [9] and initially tested in several large aerospace manufacturers. Later, the model was redeveloped and tested against nonaerospace firms.

IDEF0 views a complex system as a combination of functions, whether implemented by using machines, people, or other means. Here, a function is to transform the inputs into the outputs, under the influence of a control, using the mechanism provided (Fig. 1). IDEF0 is applied using top–down hierarchical decomposition. At the top of the hierarchy is the overall purpose of the model (A-0 layer), the global activity that is the subject of the model. The overall activity is decomposable into components that, when taken together, comprise the global activity. The second tier of the model is the A0 layer and, similarly, the decomposition of the second and subsequent tiers continues until there is sufficient detail to serve the purpose of the model builder (Fig. 2 includes A-0, A0, A1 layers).

Generally, the major advantages of IDEF0 can be stated as:

1) a potential standard methodology for use in the manufacturing environment;
2) an effective model for describing a system in detail;

Manuscript received February 28, 1996; revised May 15, 1996.

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Publisher Item Identifier S 1083–4400(96)04491-9.

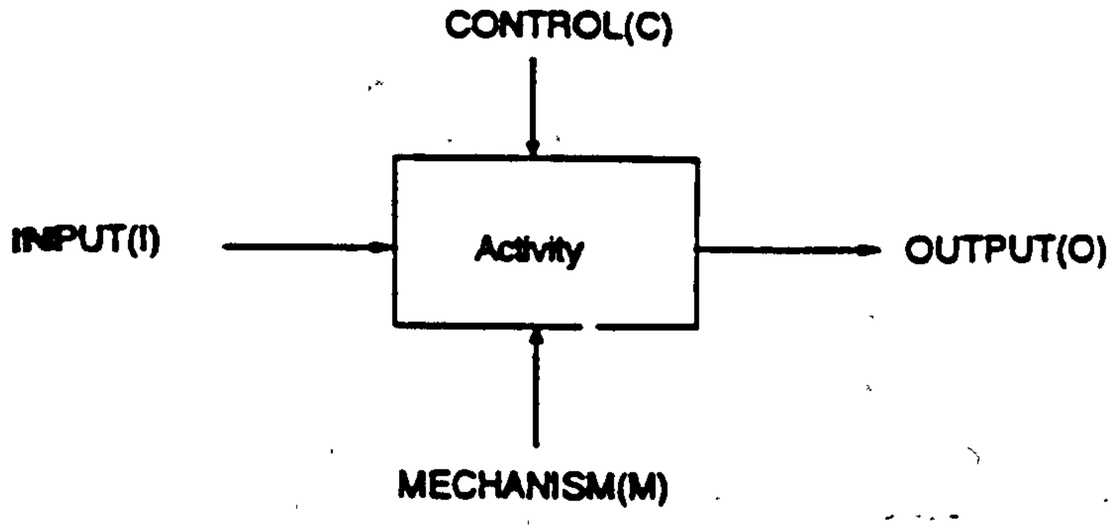

Fig. 1. The IDEF0 methodology.

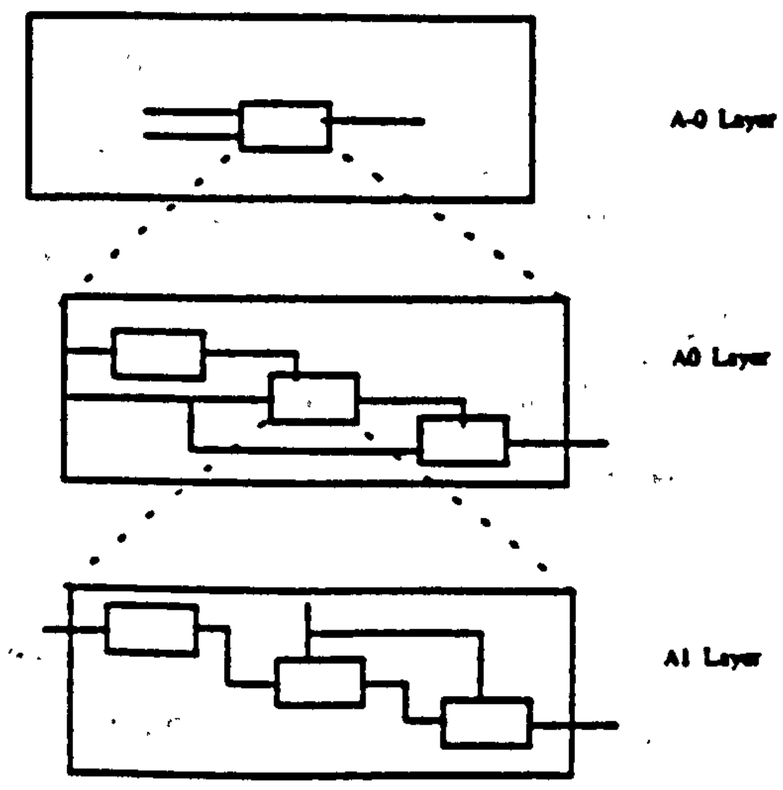

Fig. 2. IDEF0 hierarchical decomposition.

3) a standardized method and mechanism for decomposing a whole process into modular subcomponents. Therefore, a company can focus on the specific part of a process model and develop further levels of detail without losing its context within the whole process [10].

IDEF modeling is not limited to the functional aspects of systems. There are other versions that have been developed [11]:

- IDEF1 (information model methodology);
- IDEF2 (dynamic model methodology).
- IDEF1X (data modeling);
- IDEF3 (process description capture);
- IDEF4 (object-oriented design);
- IDEF5 (ontology description capture);
- IDEF6 (design rationale capture).

III. Concepts of Generic Model

One approach to solving specific problems inherent in particular systems is to construct a model of the system. The classification of models is a complex subject. Various types of models have been suggested, such as *mathematical, graphical,* and *physical* [12], *deterministic, stochastic, static,* and *dynamic* [13].

In this research, a generic model has been constructed that comprises those functions or essential activities that influence quality and must necessarily take place within any manufacturing process. This functional structure is a graphical static model that makes all the functions work together to produce the desired end result. In the same way that a facility layout and flow chart indicate how materials flow in the manufacturing area, the functional model indicates how quality information flows within the manufacturing process [14]. The quality information and information flow requirements of any specific manufacturing process will be found within the generic model.

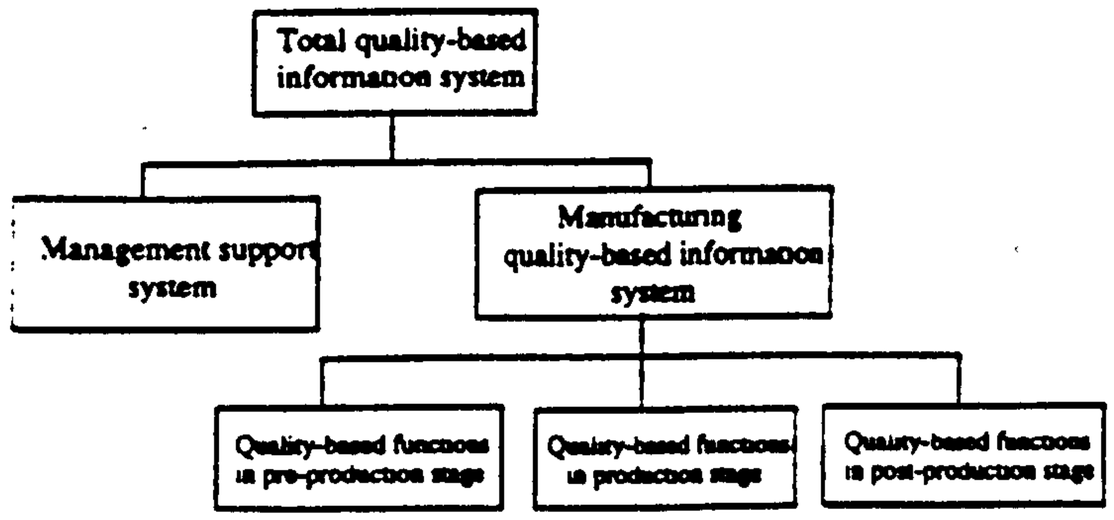

Fig. 3. The business quality-based information subsystems.

IV. Designing the Quality Assurance Information System

Before describing QAIS's in detail and their structure in manufacturing, the following few points must first be made:

1) The analysis is applied to the domain of the design to order manufacturing environment that comprises the other kinds of manufacturing strategy such as: engineer to order, make to order, and assemble to order.
2) In recognition of the fact that quality is influenced by activities and decisions in all phases of product life cycle, there must be an overall organizational responsibility for quality.
3) A quality information system is an organized method of collecting, storing, analyzing, and reporting information on quality to assist decision makers at all levels [15].
4) The manufacturing area can be divided into four subsections: management support system, pre-production, production, and post-production. Fig. 3 represents the hierarchical subsections.

A. Responsibility of Management

The responsibility of management in respect to the QAIS encompasses all activities of the overall management function including the following:

- consistent with other policies, the quality policy and quality objective should be defined and documented;
- the necessary measures should be taken at all levels of the organization to ensure that the quality policy is implemented;
- total quality cost should be calculated;
- a quality system should be developed, established, and implemented, in order to effectively accomplish the stated policies and objectives.

Fig. 4 represents the interfaces of the management support system and QAIS with other functions in a manufacturing organization.

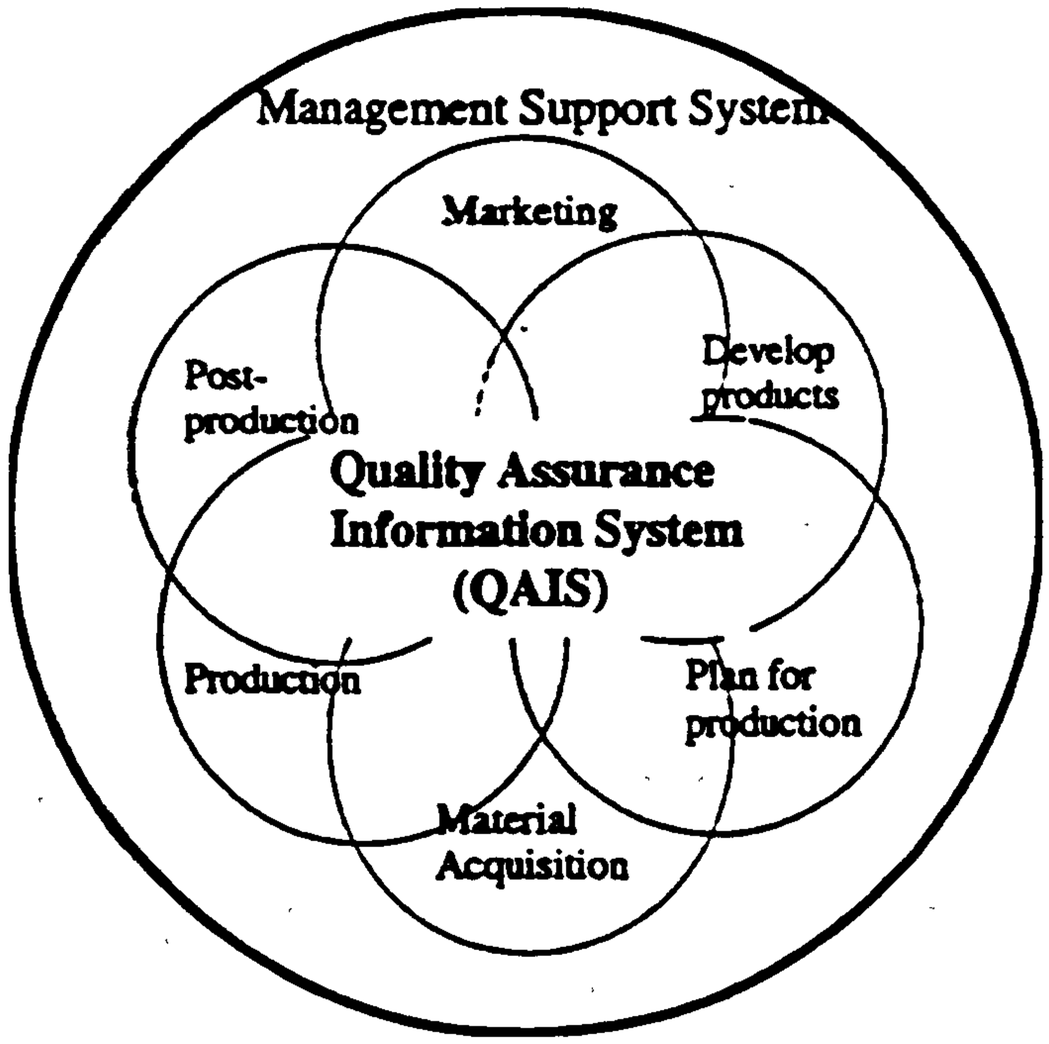

Fig. 4. The interfaces of the management support system and QIAS with other functions.

A0-Total quality-based information system
A1-Management support system
A2-Manufacturing quality-based information system
A21-Pre-production quality-based functions
A22-Production quality-based functions
A23-Post-production quality-based functions
A211-Marketing
A212-Develop product
A213-Plan for production
A214-Material acquisition

A221-Production control
A222-Convert material to products
A223-Quality control
A224-Maintenance

A231-Packaging
A232-Warehousing
A233-Shipping
A234-Post-sales

A2111-Inquiry processing
A2112-Tendering
A2113-Sales and contracts
A21131-Order processing
A21132-Contract preparing
A21133-Contract control
A2121-Develop design

A21211-Develop conceptual design
A21212-Develop preliminary design
A21213-Prototype development
A21214-Reliability control
A21215-Develop detailed design
A21216-Reviewing the design
A2122-Production engineering
A2123-Quality planning & standards

A21221-Process planning
A21222-Reviewing the process plan
A21223-Tool & fixture design
A21224-Plant layout & material handling
A21225-Industrial engineering

A21231-Product quality planning
A21232-Process quality planning
A21233-Quality planning

A212161-Product design verification
A212162-Failure mode and effect analysis

A2131-Master production scheduling
A2132-Materials requirements planning
A2133-Capacity requirements planning
A2134-Production scheduling

A2141-Purchasing
A21411-Suppliers recording & selection
A21412-Purchase processing
A21413-Supplier surveillance
A2142-Receiving
A21421-Receiving materials verification
A21422-Incoming materials inspection
A21423-Non-conformity control
A2143-Inventory management
A21431-Inventory control
A21432-Materials stores

A2231-In-process inspection
A2232-Statistical process control
A2233-Final inspection
A2234-Non-conformity control
A22341-Cause and effect analysis
A22342-Non-conforming disposition

A2341-Service/warranty
A2342-Sales/field return
A2343-Reliability lab. study

Fig. 5. Node index for a generic IDEF0 model.

B. Information System in Pre-Production

The information system to support quality assurance (QA) in the pre-production phase should ensure that the product that has been designed meets customer requirements and can be produced defect free and reliable [16]. This step shall include the following matters:

- before submission of a tender, or acceptance of a contract or order, each shall be reviewed in respect to the customer requirements;
- making sure that the suppliers have the capability to meet contract or order requirements;
- identifying those quality characteristics that are crucial to the safe and proper functioning of the product;
- reviewing the design, and design documents before release;
- failure mode and effect analysis;
- verifying the design through a prototype test;
- assuring safety and environmental compatibility of the product;
- to assure that the planned processes will produce the desired product and, in accordance with quality policy and quality objectives, quality plans, quality standards, and inspection procedures should be developed;
- nonconforming disposition instruction for both incoming materials and produced products to prevent the customer from receiving nonconforming products;
- reviewing nonconforming material in accordance with documented procedures and decision on returning, screening, scrapping, or accepting;
- evaluating and selecting subcontractors on the basis of their ability to meet subcontract requirements;
- agreement on quality assurance methods and periodic evaluation of subcontractors quality;
- establishing and maintaining quality records of subcontractors;
- in-house receiving verification and quality inspection.

C. Information System in Production

The information system to support quality assurance in the production phase should consider the following matters:

- The process should be verified as being capable of producing product in accordance with specifications.
- Verification, typically by inspections or tests, should be considered at appropriate points in the process to verify conformity. Location and frequency depend on the importance of the characteristics and ease of verification during processing.
- For detecting special causes of out of control conditions in a process and for avoiding recurrence of the problem, the process performance should be checked by analyzing historical or current data. Such analysis can also be used to identify trends in process performance and to initiate preventive control measures.
- To augment inspections and tests made during processing, the final inspection shall be carried out in accordance with the quality plan to complete the evidence of conformance of the finished product to specified requirements.
- Suspected nonconforming items or lots must be immediately identified, removed, and reported.
- A nonconforming product should be reviewed, segregated, identified and repaired, accepted, or scrapped. Repaired products must be reinspected again.
- The significance of a problem affecting quality should be evaluated in terms of its potential impact on safety,

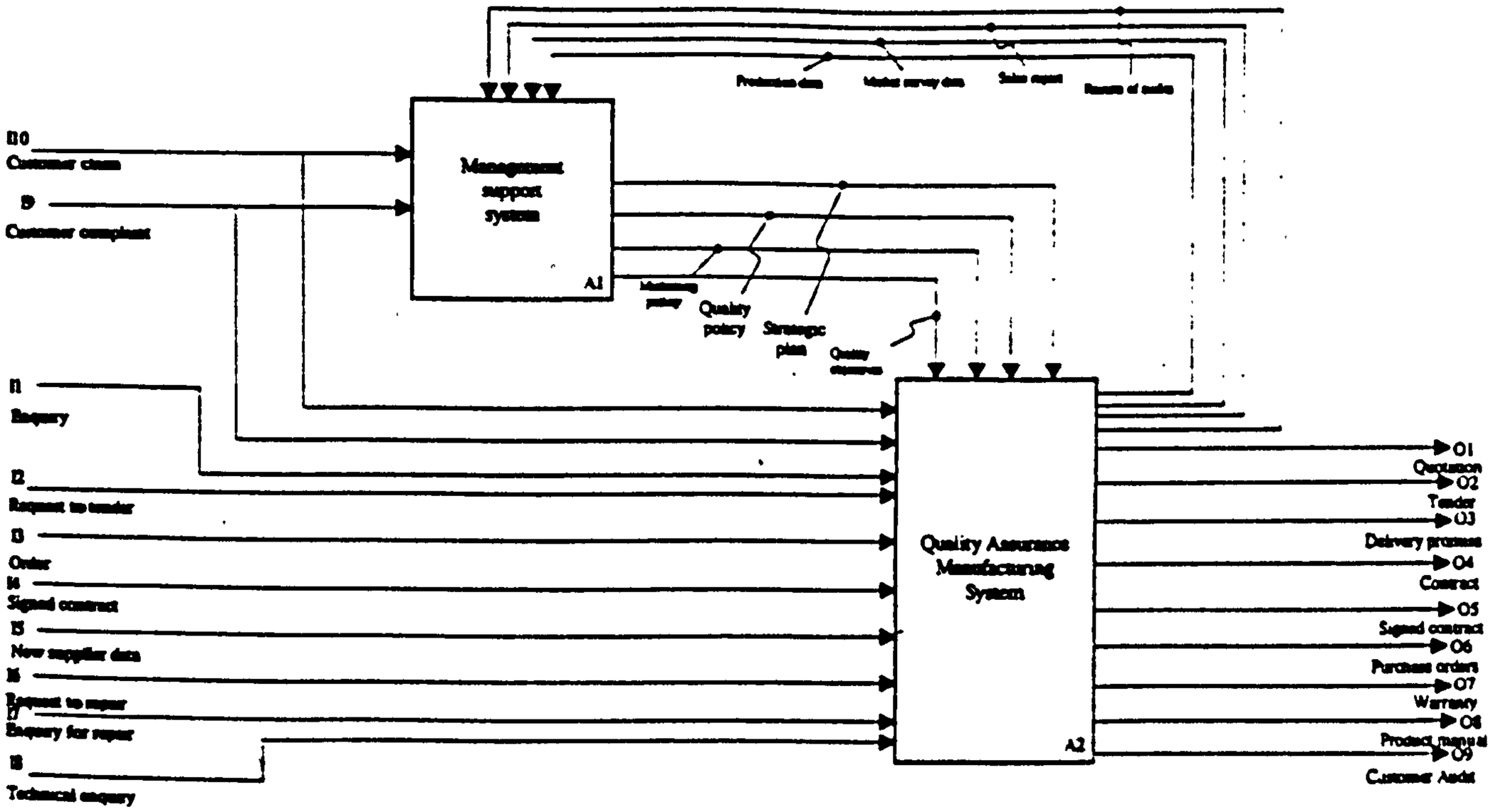

Fig. 6. Total quality-based information system.

performance, customer satisfaction, and product costs and finally, appropriate steps should be taken to eliminate that problem.

- To provide confidence in decisions or actions based on measurement data, documented procedures shall be established and maintained to control, calibrate, and maintain inspection, measuring, and test equipment.
- To ensure continued process capability, all equipment should be proved for accuracy prior to use. A program of preventive maintenance for all equipment, specifically for those equipment characteristics that contribute to product quality.

D. Information System in Post-Production

The information system to support quality assurance in the post-production phase should cover the following matters.

Research has shown that more customers complaints are caused by store activities, specially in packaging the product, than were caused by original manufacturing [6]. The most critical aspect of the quality of packaging is acquisition of effective packaging materials, packaging design, and packaging.

- Documented procedures for handling, storing, and packaging should be established and maintained;
- To ensure conformance to specified requirements, the packing and packaging shall be controlled.
- In order to detect deterioration, the condition of product in stock shall be assessed at appropriate intervals.
- Procedures should be established, documented and maintained to ensure that defective or deteriorated products are not shipped.
- Handling and transport introduce many perils to the products that are fully predictable, the condition of handling process shall be audited at appropriate times.
- All necessary technical data and instructions shall be delivered to customers in an appropriate format.
- To apply corrective action in design, processing and/or use of the product, reports of field failures, returned products, and user dissatisfaction shall be monitored, recorded, and analyzed in-depth. Customers shall be periodically audited as necessary.
- There should be a program for satisfying complaints. This program is complaint-oriented and, hence, is needed in virtually every case of complaint.
- Failure products are sent to the reliability laboratories for testing and failure analysis. The lab can examine and locate the causes of defectiveness.
- Failure causes shall be identified and reflected in new failure mode and effect analysis.

V. Generic IDEF0 Model of Quality Assurance Information System

A generic IDEF0 model introduces no specific mechanisms for its functions and is equally valid for all possible profiles of a manufacturing business.

It is suggested that the use of generic IDEF0 modeling can help to capture a clear picture of complex aspects of a manufacturing organization and can lead to very precise thinking about what specific people and departments are designated to be doing [17], [18], in this case, in relation to quality. For a generic model, the level of analysis must contain functions that are at a level of detail applicable to all companies.

In this paper, Section IV has drawn out those essential quality-based functions that need to take place within any design to order manufacturing environment. As the level

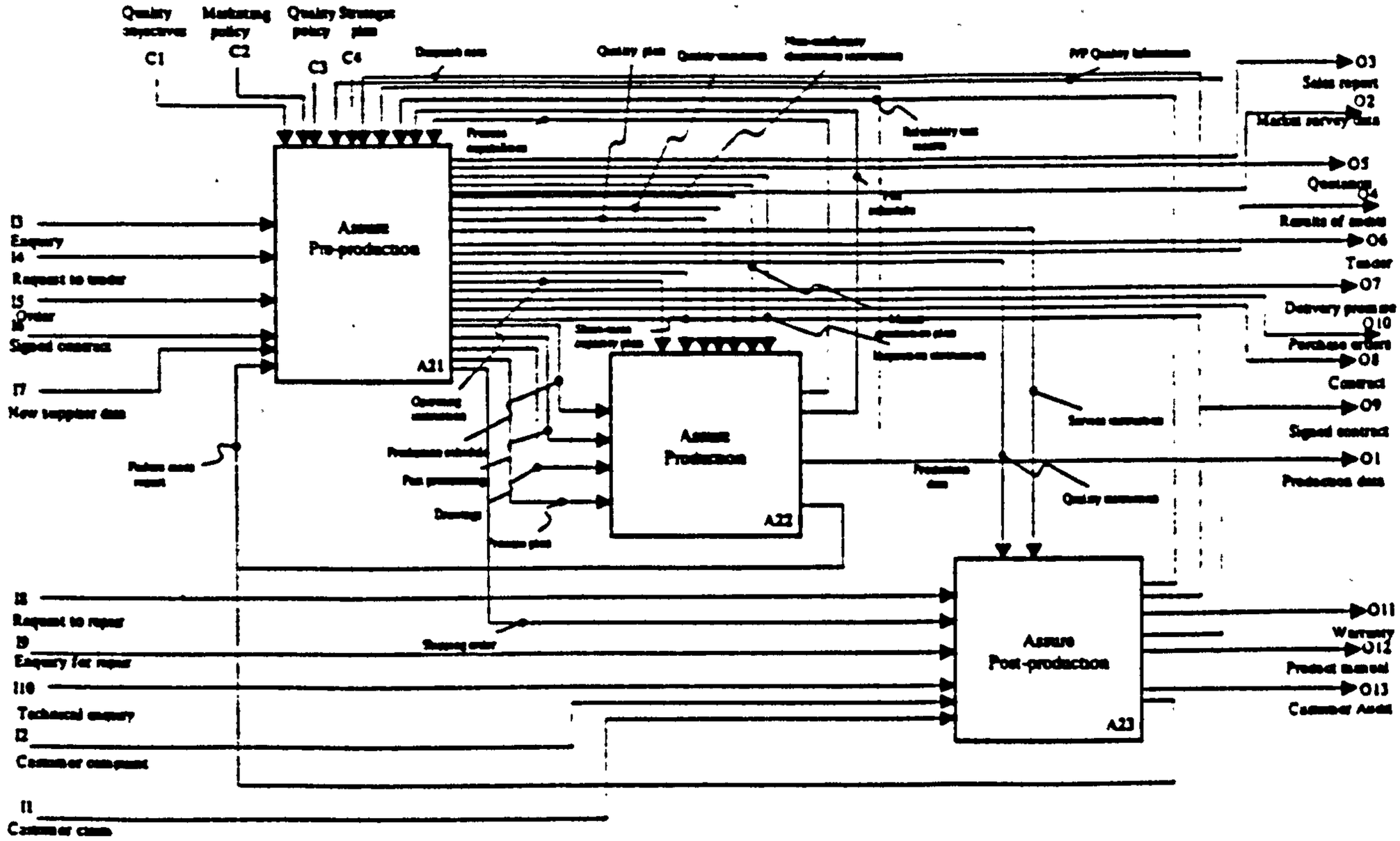

Fig. 7. Manufacturing quality-based information system.

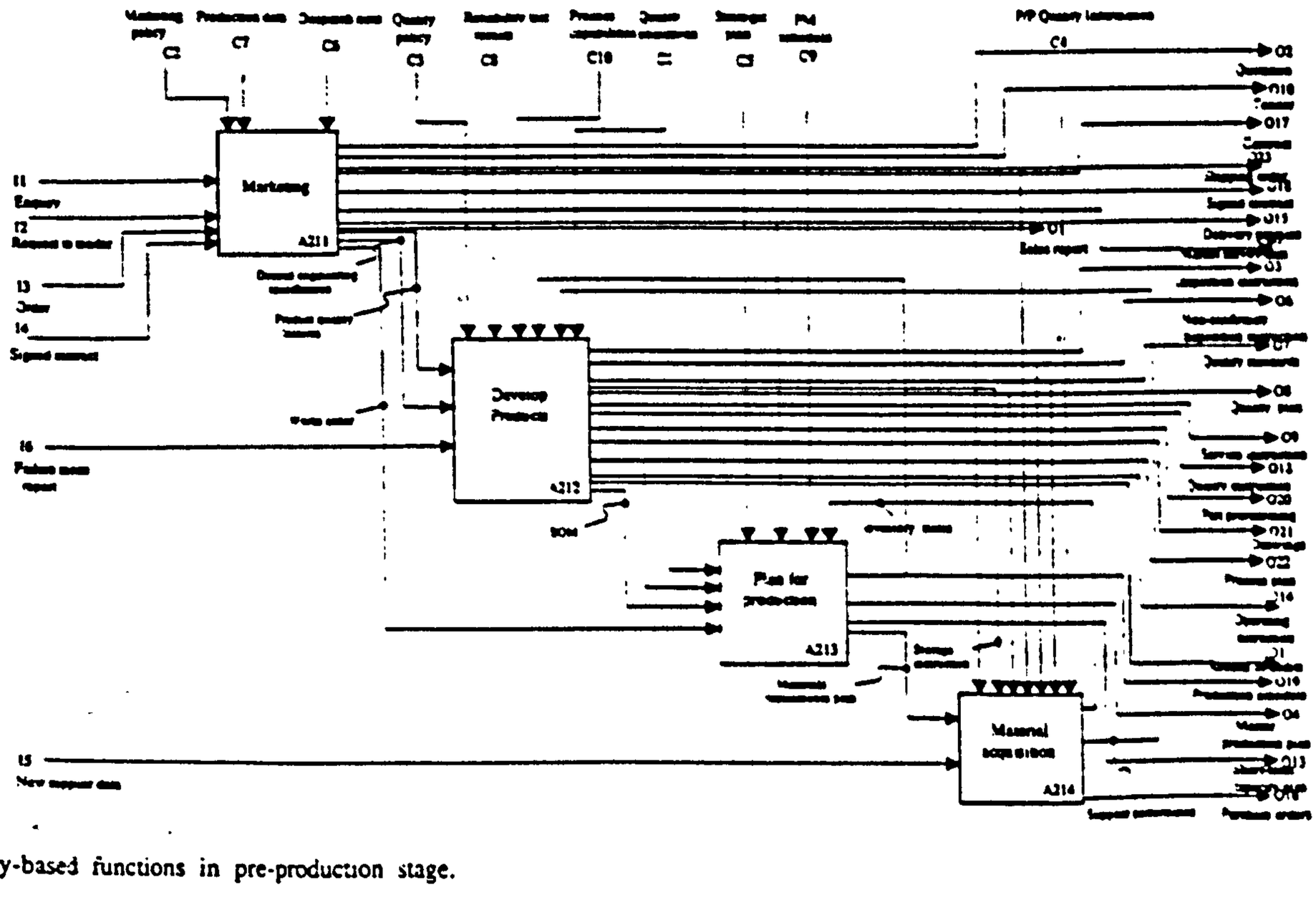

Fig. 8. Quality-based functions in pre-production stage.

of hierarchy of system becomes lower, functions are more dependent upon many factors such as: the size of industry, manufacturing strategy, production systems, production technology, manufacturing production management, and the nature and requirements of the desired end product. Fig. 5 shows the node index of the generic IDEF0 model, and Figs. 6–10 are examples of the IDEF0 model diagrams.

Due to the number and diversity of factors such as overhead factors that must be considered, quality assurance system design is a complex task. It is not sufficient to evaluate each of the factors individually, since many of them are interrelated. Furthermore, some of the factors may suggest a particular quality function while others may discourage the use of that function. Consequently, quality assurance system formation must be based upon an iterative and constructive process spanning multiple dimensions of analysis. Such decision making can be significantly facilitated by appropriate computer-based decision support systems.

A central requirement of a DSS for successfully designing a QAIS is a complete knowledge-base of information encom-

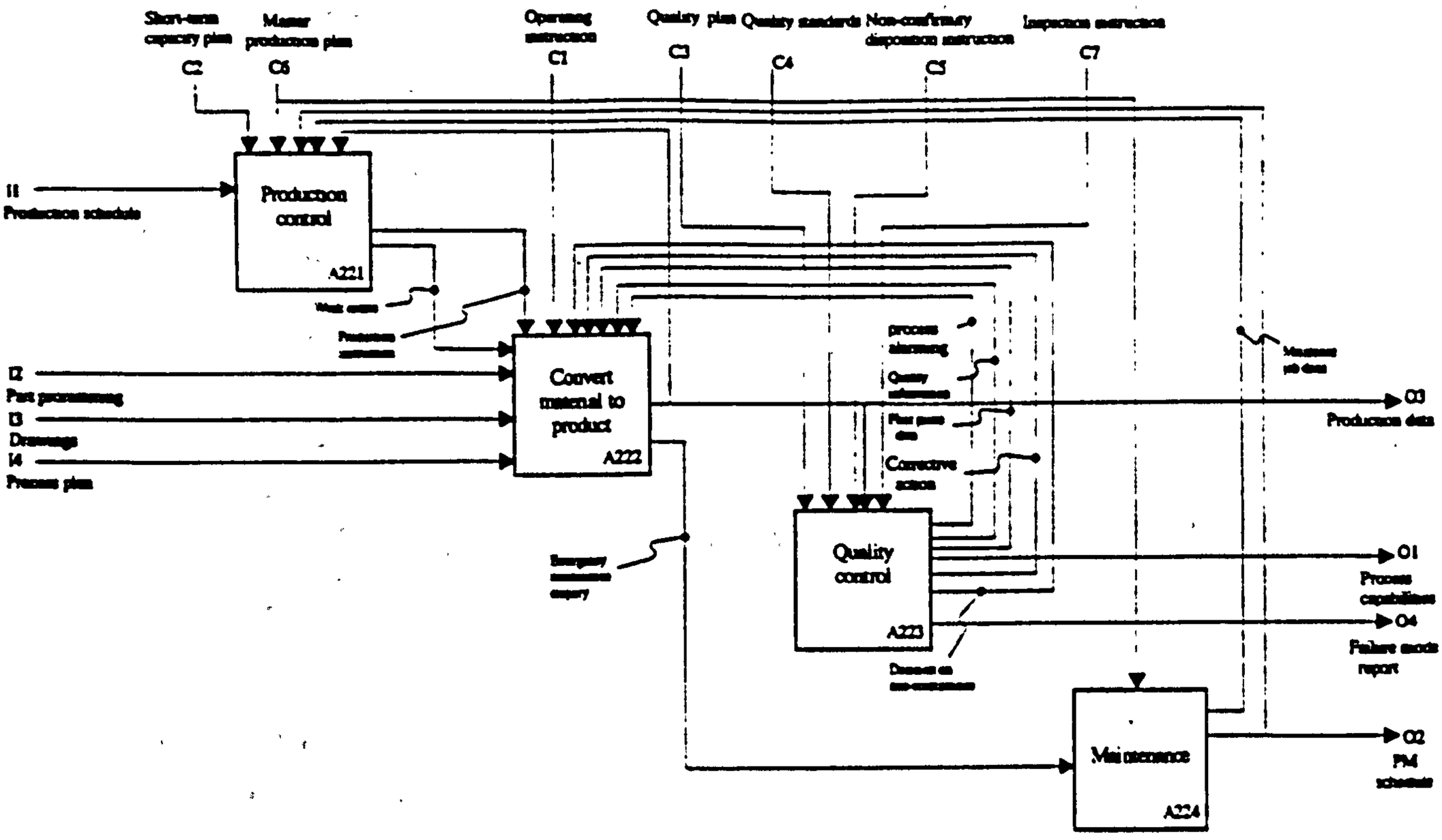

Fig. 9. Quality-based functions in the production stage.

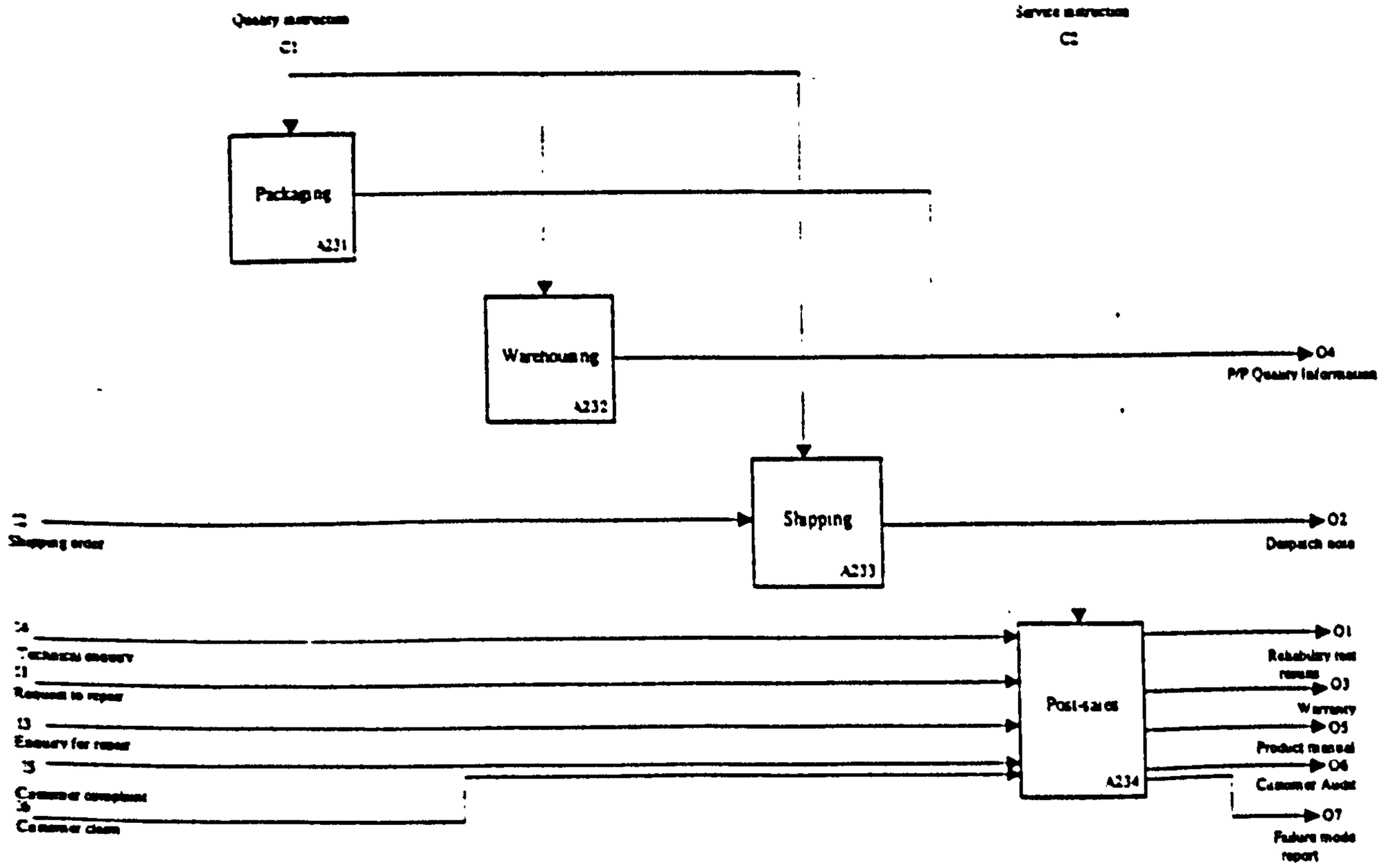

Fig. 10. Quality-based functions in the post-production stage.

passing all functions that have an impact on quality. This is presently being carried out through knowledge elicitation from industry. The results will be embodied as rules in a knowledge-based expert system integrated with the IDEF0 model. The DSS will recommend elements of a QAIS appropriate to specific company profiles input by the user and that will satisfy the requirements of ISO9000 and company-wide quality for that company.

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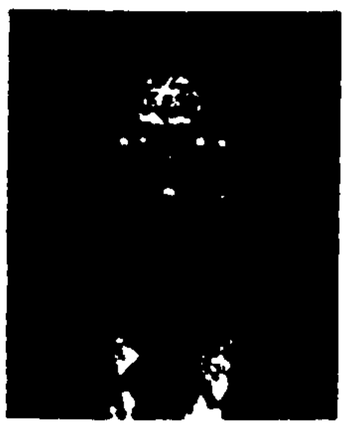

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AN ALGORITHM FOR DESIGN OF QUALITY ASSURANCE SYSTEMS FOR VARIOUS MANUFACTURING ENVIRONMENTS

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ABSTRACT

By examination of details of publicly held corporations, it has been possible to compile a list of industry types. It is clear that many of these different manufacturing situations require different quality assurance systems. In order to understand the quality assurance requirements of different companies, the available literature on quality assurance system has been reviewed. A questionnaire was also sent to more than 500 UK companies. The main objective of the study was to investigate those factors which can affect the design of a quality assurance information system.

The results of the study have shown that there is some commonality of features between different classes of companies. Accordingly, it was possible to develop an ISO-9000 based generic structural model incorporating all common quality based functions and information requirements. This generic model can become a base for designing quality assurance systems for various manufacturing industries.

The paper summarises the main results of the study in the form of an algorithm which is to be used in the formulation of the knowledge base of a KB Decision System(KBDS) for the design of company-wide quality assurance information systems to suit the specific requirements of various business profiles and manufacturing strategies.

INTRODUCTION

All industries have features which are unique to that particular industry in terms of market, manufacturing processes, raw materials, type of person employed, geographical spread and so on as well as in terms of the actual product supplied. Understanding the context of manufacturing and studying all types of manufacturing systems helps us to appreciate the needs of that environment.

There have been many attempts to classify manufacturing systems and, with regard to production processes, layout planning, production management systems, manufacturing strategies, a number of classifications have been introduced [8][9][10][11][12][13]. These are summarised in figure 1. Another way of classifying production activities is according to marketing strategy. Scott[15] has proposed the five levels of design-to-order, engineer-to-

order, make-to-stock, assemble-to-order, and make-to-stock. As a company moves from level one to five the overall lead-times will reduce.

Manufacturing industry may also be classified according to the production management system. Two basic scheduling systems have been defined: Push system and pull system. According to the manufacturing strategy, production led or market led, different material planning methods have been introduced and implemented of which the most well known are: Order-point system (OPS), MRP, and Kanban system(JIT).

None of the above classifications specifically make reference to factors which can affect the quality of product(s). and service.

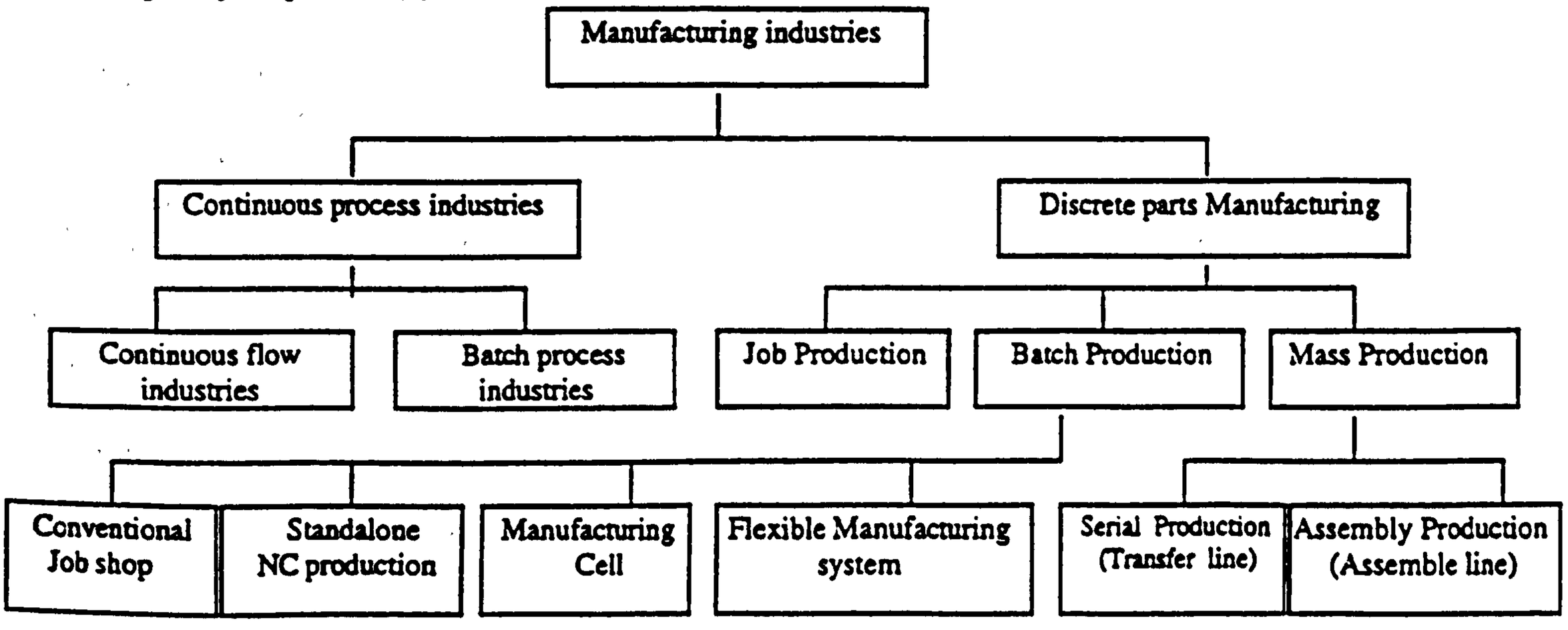

Fig. 1 : Classification of manufacturing industries in regard to production nature

QUALITY ASSURANCE SYSTEMS IN VARIOUS MANUFACTURING ENVIRONMENTS

Although there may be common features, different manufacturing situations will require quality assurance systems and supporting information systems, which in some respects are also significantly different. The design of appropriate QA systems is the focus of the paper. Reviewing of literature on manufacturing quality assurance systems[1][2][3][16], has showed that the quality functions that operate within a specific quality assurance system naturally depend on different factors such as:

1- The products which are produced: The degree of confidence required of a quality assurance system will not be the same for all products[2].
2- Design novelty and maturity: The extent to which the total design is known and proven, either by performance testing or field experience.
3- Product process complexity: Difficulty of designing the product; the availability of proven production or operation processes; need for development of new processes; number and variety of processes required; impact of process on the performance of product[5].

4- Product safety: The selection of an appropriate quality system for a given product is determined by the consequences and probability of failure which in turn comprises the probability of a fault being present and the probability of the fault being detected.
5- Production management: A manufacturer using the pull system will not succeed without a first-class quality system in place.
6- The method of production: The principal manufacturing function is to take inputs and convert them into products. SPC and the timing of the inspection and monitoring procedures in relation to the production process is an important consideration.
7- The size of industry: Larger companies tend to need to devote more resources to organised quality programs than smaller ones[4] and more special quality functions must be designed and integrated with the wider organisation.
8- Marketing response: Depending on which of the five levels of marketing responses applies, the selection of an appropriate total quality assurance system for a product may be different, e.g. make to order may have more customer focused or customer driven functions than make to stock.
10- Quality policy: In considering manufacturing strategy and other factors, the supplier may follow a different quality policy such as: producing error free products for general sales; satisfying specific customer requirements; delighting the customer.
9- Economics: Quality assurance systems may range from simple inspection to systems exceeding the requirements of the ISO9000. Knowledge about quality-related costs enable business decisions about quality assurance systems to be made.
The business profile factors chosen for this study are summarised in table 1.

Table 1: Manufacturing business profile factors

Business profile factor	Classification of each factor
Process	Discrete parts manufacturing, continuous process, batch process
Size	Small, medium, large
Product nature	Mechanical, electrical and electronic, chemical, biological, other
Marketing response	Design-to-order, engineer-to-order, make-to-order, assemble-to-order, make-to stock
Product complexity	Complex, semi-complex, non-complex
Plant layout	Multi-product flow line in single location, multi-product in different sections, single-product flow line in single location, one basic product in different sections
Production method	Mass production, batch production, one-off production
Material and production management	Order-point system(OPS), MRP, JIT

THE DATA COLLECTION INSTRUMENT

In order to understand the quality assurance requirements of different companies, In addition to literature review, a questionnaire was also sent to more than 500 UK qualified companies selected on the basis of good quality performance. Data about approaches to quality assurance systems used by different types of business was gathered to investigate those factors, both generic and business type or company specific, which can affect the design of a quality assurance information system.

The Questionnaire was used to classify the businesses, and asked for ratings on prescribed quality functions (table 2) based on the generic quality assurance information system developed by the authors in a previous paper[14]. The rating is based on the importance of the function to the respondents business and the extent to which it suits the specific requirements of their business profiles and manufacturing strategies.

DATA ANALYSIS

To recognise which quality function relates to which profile factor or factors and to identify if there is any interaction between profile factors on each quality function, analysis was conducted on the data. A detailed examination was done on the data to determine whether the problem being solved is parametric. It is appropriate to use parametric tests when the data fulfils two conditions[6]: the populations being sampled can be approximated to a Normal distribution: the populations all have the same variance. An analysis of variance(ANOVA) was employed to investigate the relationship among quality-based functions and business profile factors.

Table 2: Quality based functions

1-Marketing	Supplier or sub-contractor surveillance
Customer studies	Verification of receiving material
Competitor studies	Incoming materials inspection
Quality function deployment	Control of non-conforming materials
Product specification studies	
	7-Production
2-Sales	Set-up inspection
Reviewing the tender	First-off inspection
Reviewing the contract	Patrol inspection
	Fixed sampling inspection
3-Design and development	Fixed continuous inspection
Reviewing the conceptual design	Statistical process control
Functional verification through prototype test	Final inspection
Reliability, environmental and safety assessment	Control of non-conforming product
Design review	Process capability studies
Identifying the potential failures(By FMEA)	Out of control situation alarming
Reviewing the design document	Measuring equipment calibration
Developing test instruction	Preventive maintenance program
Classifying quality characteristics	Training
4-Process planning	**8-Post production**
Evaluation of process design to process capability	Control of packaging product
Evaluation of process design to inspection capability	Product in stock's audit
	Documented handling methods
5-Quality planning and standards	Delivery audit
Developing quality plans, quality standards, etc.	Providing installation procedures
Developing procedures for dealing with non-conforming materials and products	Product warranty service
	Complaints' procedure
	Failure mode and effect analysis
6-Material acquisition	Reliability testing
Supplier or sub-contractor capability study	Customer audit
Supplier or sub-contractor selection	
Supplier or sub-contractor rating	

Initial inspection of graphical plots of distributions showed a heavy skew in some of them which suggest that the conditions are violated. However, a power transformation of the raw data was enough to make them approximately Normal. The order of the observations is not changed by the transformation, and conclusion based on the transformed data are true for the original data[6].

The Levene test was used to test the null hypothesis that the groups come from populations with the same variance. Results showed that all quality functions with normal distribution did not have a small significance level. ANOVA was used to decide whether the observed differences among more than two sample means can be attributed to chance or whether there were real differences among the populations sampled.

Since each quality function was classified into different groups by business profile factor, one-way analysis of variance was needed to analyse the variability between groups and within groups. To find if there was any interaction between profile factors on each quality function, two-way analysis of variance was used.

An example of how this methodology was carried out follows. The quality function "market-studies" is analysed. Prior to conducting the statistical analysis, cases with missing data were eliminated from the data set.

Both normality and equality of variance tests were done:

- A heavy skew showed on the data histogram, so a power transformation of two squares of all data values was used to make it approximately normal.
- The result of Levene test did not reject the null hypothesis that the groups came from the same variance populations.

The observed significance level of one-way ANOVA on the 'market-studies' quality function, considering the five marketing response strategies of: design-to-order, engineer-to-order, make-to order, assemble-to-order, and make-to-stock as five different groups, was very small, so the population means of five groups are probably not all equal. This means the hypothesis that the market-study function is equally important and necessary for the five marketing response strategies can be rejected.

Since ANOVA does not say which pairs of groups appear to have different means multiple comparison procedures test was done on the data. Fisher's least significant difference procedure[7] showed that those companies which have chosen a make-to-stock strategy as a response to markets certainly need to do market studies to be successful in the market. This is obviously the intuitive judgement and shows the suitability of the procedures adopted.

The analysis also showed that those companies which assemble-to-order or make-to-order implement market studies for their business.

The results of analysis of variance on 'market-study' functions with regard to business profile factors are shown in table 3. With the exception of 'marketing response strategy' and 'production method' factors, the other factors do not show any significant difference between

the groups' means. This means that, with the exception of marketing response strategy and production method, these factors may not play any role in the decision whether on not to apply market studies.

To find any particular combination of business profile factors which can affect the decision on implementing market studies simple-factorial ANOVA was used. The only interaction that was found to be significant was the interaction between method of productions and process (table 3). Therefore, it must be appreciated that in considering effects on quality functions it is necessary to consider both variables 'method of production' and 'manufacturing process' together, and not to consider their possible effect individually.

SUMMARY OF FINDINGS

In considering both data of 'marketing response strategy' and 'method of production' together, it was clear that those companies which have chosen make-to-stock as a marketing response strategy logically don't produce products in batches of size one and vice versa.

Table 3: Summary of the results of analysis on four marketing quality functions data

Manufacturing profile factor	Market studies	Competitor studies	QFD	Product specification studies
manufacturing Process	*yes	No	No	No
Company size	No	yes	No	No
Product nature	No	No	No	No
Product complexity	No	No	No	No
Market response strategy	yes	yes	yes	yes
Process layout	No	No	No	No
Method of production	*yes	No	No	No
Production management	No	No	No	No

* Indicates interaction between profiles

The above conclusion may be expanded that, along with effects of business profiles on selecting quality functions, conversely, it can be suggested that there are some points which generally affect configuration of business profiles. One of the important points is the criteria which define each profile factor, so all the profile factors for a specific business have to be congenial with each other. The idea behind jut-in-time manufacturing is not congenial with a make-to-stock strategy, so it can be concluded that there is no company with a JIT manufacturing policy which directly serves customers from stock.

Taking into account the above points, statistical analysis was done on other quality functions. The summary of results is shown in table 4.

Table 4: the summary of the data analysis on all quality functions

Quality function	Profile factors which is effective in selecting QF
Marketing	M-strategy, size, method of production
Sales	M-strategy, product complexity
Design	M-strategy, P-complexity, Method of production
Process planning	M-strategy, P-complexity, Size
Quality planning	***

Material acquisition	M-strategy, Production management.
Production	Method of production
Post-production	M-strategy, Product nature

*** Representing no profile factors

The whole set of results may be summarised in an algorithmic form, such as has been done in figure 2 for the marketing quality functions. The algorithm is used in the formulation of the knowledge base of a Knowledge-based Decision System(KBDS) for the design of company-wide quality assurance information systems to suit the specific requirements of various business profiles and manufacturing strategies.

VALIDATION OF RESULTS (ALGORITHM)

To confirm that the algorithm is valid and reliable, the algorithm was tested by application to the questionnaire respondents' business profiles to check if there was any difference between quality functions which the algorithm recommends, and the quality functions actually operated by each specific business.

For the marketing quality function and data of twenty manufacturing factories, results showed that thirty five out of forty two recommended quality functions' cell, justify the algorithm and seventeen out of twenty sets of data cope with the results of the algorithm which seems acceptable.

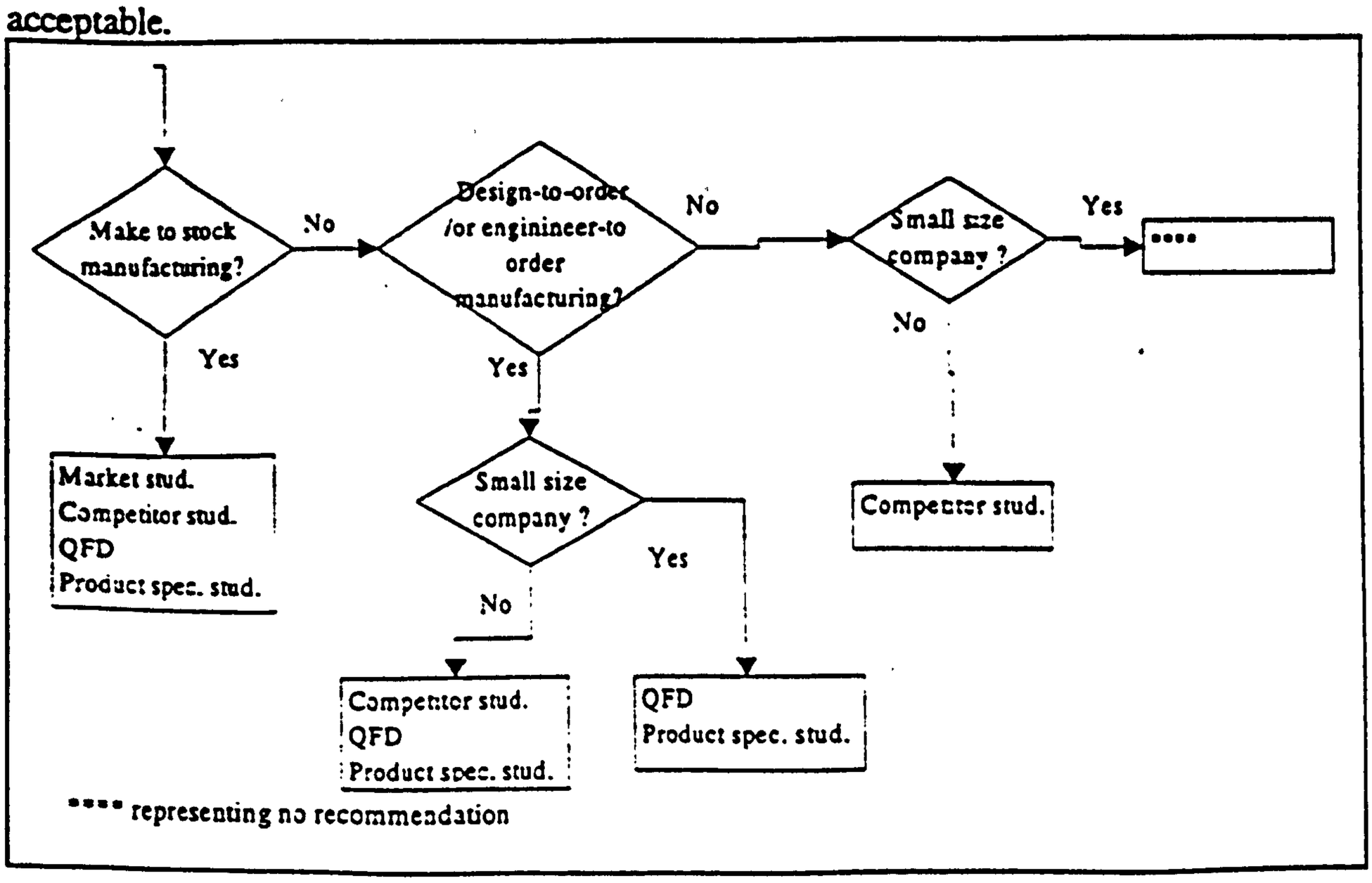

Fig. 2: The results of analysing the data of four quality functions in an algorithm form

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