

CRANFIELD UNIVERSITY



A. ANTONARAS

IMPROVING  
THE NEW PRODUCT / SERVICE INTRODUCTION PROCESS  
BY THE APPLICATION OF SYSTEM DYNAMICS

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

PhD THESIS

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Supervisor: Prof. P. J. Deasley

September 1999

This thesis is submitted in partial fulfillment of the requirements for the  
degree of Doctor of Philosophy

This thesis is dedicated to those who have marked my life with their words, their actions and above all with their love...

## ΥΠΕΡΟΧΟΣ ΥΜΝΟΣ ΤΗΣ ΑΓΑΠΗΣ

Εάν ταις γλώσσαις των ανθρώπων λαλώ καί των αγγέλων, αγάπην δέ μή έχω γέγονα χαλκός ηχών ή κύμβαλον αλαλάζον.

Καί εάν έχω προφητείαν καί ειδώ τά μυστήρια πάντα και πάσαν την γνώσιν, και εάν έχω πάσαν την πίστιν ώστε όρη μεθιστάνειν, αγάπην δέ μή έχω, ουδέν ειμί.

Καί εάν ψωμίσω πάντα τά υπάρχοντά μου, καί εάν παραδώ τό σώμα μου ίνα καυθήσομαι, αγάπην δέ μή έχω, ουδέν ωφελούμαι.

Η αγάπη μακροθυμεί, χρηστεύεται, η αγάπη ου ζηλοί, η αγάπη ου περπερεύεται, ου φυσιούται, ουκ ασχημονεί, ου ζητεί τά εαυτής, ου παροξύνεται, ου λογιζεται τό κακόν, ου χαίρει επί τη αδικία, συγχαίρει δέ τη αληθεία, πάντα στέγει, πάντα πιστεύει, πάντα ελπίζει, πάντα υπομένει.

Η αγάπη ουδέποτε εκπίπτει. Είτε δέ προφητεία, καταργηθήσονται. Είτε γλώσσαι, παύσονται. Είτε γνώσις, καταργηθήσεται. Εκ μερους δέ γινώσκομεν καί εκ μερους προφητεύομεν.

Όταν δέ έλθη το τέλειον, τότε το εκ μερους καταργηθήσεται. Ότε ήμην νήπιος, ως νήπιος ελάλον, ως νήπιος εφρόνου, ως νήπιος ελογιζόμην. Ότε δέ εγόγονα ανήρ, κατήρηκα τά τού νηπίου.

Βλέπομεν γάρ άρτι δι' εσόπτρου εν αινίγματι, τότε δέ πρόσωπον πρός πρόσωπον. Άρτι γινώσκω εκ μερους, τότε δέ επιγνώσομαι καθώς καί επεγνώσθην.

Νυνί δέ μένει πίστις, ελπίς, αγάπη, τά τρία ταύτα. Μείζων δέ τούτων η αγάπη.

Α' ΠΡΟΣ ΚΟΡΙΝΘΙΟΥΣ  
(Κεφ. ΙΓ', Στιχ. 1-13)

## EXERCISE GIFTS OF LOVE

Though I speak with the tongues of men and of angels, and have not charity<sup>i</sup>, I am become as sounding brass, or a tinkling cymbal.

And though I have the gift of prophecy, and understand all mysteries, and all knowledge; and though I have all faith, so that I could remove mountains, and have not charity, I am nothing.

And though I bestow all my goods to feed the poor, and though I give my body to be burned, and have not charity, it profiteth me nothing.

Charity suffereth long, and is kind; charity envieth not; charity vaunteth not itself, is not puffed up, doth not behave itself unseemly, seeketh not her own, is not easily provoked, thinketh no evil; rejoiceth not in iniquity, but rejoiceth in the truth; beareth all things, believeth all things, hopeth all things, endureth all things.

Charity never faileth: but whether there be prophecies, they shall fail; whether there be tongues, they shall cease; whether there be knowledge, it shall vanish away. For we know in part, and we prophesy in part.

But when that which is perfect is come, then that which is in part shall be done away. When I was a child, I spake as a child, I understood as a child, I thought as a child: but when I became a man, I put away childish things.

For now we see through a glass, darkly; but then face to face: now I know in part; but then shall I know even as also I am known.

And now abideth faith, hope, charity, these three; but the greatest of these is charity.

1 CORINTHIANS 13: 1-13

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<sup>i</sup> love

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I will always be in debt to the most wonderful person I have ever met and who has not only been around to rely on throughout these years, but also taught me the magic of living and loving. Now, I understand... I guess it is too late... Or is it not? But anyway, Chryssoula, thank you ...

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# ABSTRACT

The development and marketing of new products and services are amongst the most powerful weapons that organisations can use in order to survive and prosper under turbulent global market conditions. The successful introduction of a new product or service can assist an organisation to remain competitive by being able to sufficiently address the continuously changing market requirements. Therefore, the process of New Product / Service Introduction (NP/SI) constitutes a crucial activity for every organisation.

In an environment of ever shortening product life cycles, increased customer expectation, technology advancements and increased market competition, the only factor that remains constant within a modern manufacturing operation is change. Such changes are ultimately reflected in the products and the manufacturing processes. One particular type of change apparent within a manufacturing or assembly environment is engineering change (EC). The changes or modifications in forms, fits, materials, dimensions, functions, etc. of a product or component are usually referred to as ECs.

The aims of this thesis were fulfilled by using the technique of System Dynamics (SD) in order to model and simulate the generic structure of the NP/SI process and to identify ways to improve it. The results of the simulation were also used for developing an Engineering Change Management System which was then modelled by using the same technique of SD. In this attempt, two Greek organisations collaborated by providing data and information in order to investigate the existence of a cost-time-quality relationship throughout the NP/SI process.

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# **A**BBRIVIATIONS

AI	Artificial Intelligence
AS	Acceptance Sampling
BAH	Booz – Allen – Hamilton
BPM	Business Process Modelling
BPM&S	Business Process Modelling & Simulation
BSSM	Boardman’s Soft System Methodology
C&SS	Complaint & Suggestions Scheme
C <sup>3</sup> T	Command Control Communication Technologies Inc.
CA	Capability Analysis
CoQ	Cost of Quality
CPN	Coloured Petri Nets
CSH	Critical Systems Heuristics
CSS	Customer Satisfaction Surveys
CSSM	Checkland’s Soft System Methodology
CT	Contingency Theory
DoE	Design of Experiments
EC	Engineering Change
ECMS	Engineering Change Management Systems
FMEA	Failure Modes and Effects Analysis
GSPN	Generalised Stochastic Petri Nets
GST	General System Theory
HAI	Hellenic Aerospace Industry
HAS	Human Activity Systems
HBS	Harvard Business School
ICAM	Integrated Computer aided Manufacture
IDEF	Integrated DEfinition
IMI	Integrated Manufacture initiate

<b>IP</b>	<b>Interactive Planning</b>
<b>KBS</b>	<b>Knowledge Based Systems</b>
<b>LCA</b>	<b>Lost Customer Analysis</b>
<b>MIT</b>	<b>Massachusetts Institute of Technology</b>
<b>NP/SI</b>	<b>New Product / Service Introduction</b>
<b>NPD</b>	<b>New Product Development</b>
<b>NPDD</b>	<b>New Product Design and Development</b>
<b>OR</b>	<b>Operational Research</b>
<b>PDMA</b>	<b>Product Development &amp; Management association</b>
<b>QFD</b>	<b>Quality Function Deployment</b>
<b>R&amp;D</b>	<b>Research &amp; Development</b>
<b>RAD</b>	<b>Role Activity Diagram</b>
<b>SA</b>	<b>Systems Analysis</b>
<b>SAST</b>	<b>Strategic Assumption Surfacing &amp; Testing</b>
<b>SD</b>	<b>System Dynamics</b>
<b>SE</b>	<b>Systems Engineering</b>
<b>SPC</b>	<b>Statistical Process Control</b>
<b>SPRU</b>	<b>Science Policy Research Unit</b>
<b>SSD</b>	<b>Social Systems Design</b>
<b>SSM</b>	<b>Soft Systems Methodology</b>
<b>STST</b>	<b>Socio-Technical Systems Thinking</b>
<b>TQM</b>	<b>Total Quality Management</b>
<b>VSD</b>	<b>Viable System Diagnosis</b>

## CHAPTER 1

**INTRODUCTION**

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**1.1 A key to success**

Studying the history of our society, it is obvious that it changes year after year, decade after decade. Just as the society we live evolves, so does its wants and needs. New products and services are therefore essential to satisfy those ever changing requirements and New Product/Service Introduction (NP/SI) becomes a crucial activity within any organisation. If an organisation does not continue to grow, it dies. To grow, an organisation must continue to learn and to make a difference in its industry (pioneer). New products or services are the key to success.

The development and marketing of new products and services are amongst the most powerful weapons that organisations can use in order to survive and prosper under turbulent global market conditions. The successful introduction of a new product or service can assist an organisation to remain competitive by being able to sufficiently address the continuously changing market requirements. Therefore, the process of NP/SI constitutes a crucial activity for every organisation.

New product success for a business is a measure of its ability to enhance existing products and to develop new product lines speedily and efficiently, when that is

needed for competitive reasons. This is a much broader definition of success than the one used by analysts who focus on the success of individual product launches.

In an environment of ever shortening product life cycles, increased customer expectation, technology advancements and increased market competition, the only factor that remains constant within a modern manufacturing operation is change. Such changes are ultimately reflected in the products and the manufacturing processes.

One particular type of change apparent within a manufacturing or assembly environment is engineering change. Throughout every stage of a product's life cycle there may exist a requirement to change some parts to an existing product. The changes or modifications in forms, fits, materials, dimensions, functions, etc. of a product or component are usually referred to as engineering changes (ECs).

## **1.2 Aim of the Thesis**

The aim of this thesis is to report on the use of the System Dynamics technique in modelling and simulating the generic structure of the NP/SI process in organisations, and on ways to improve such a process.

System Dynamics is a simulation technique especially suited to modelling and analysing of the behavioural aspects of a system, i.e. the way that the system elements interact with and influence each other to generate overall system behaviour. In terms of the NP/SI process, such an analysis can reveal positive or negative feedback loops in the process, thereby allowing managers to understand the likely impact of 'local' changes on overall process cost, time, and perceived quality.



This same business process modelling and simulation technique is also used in the development of an efficient and effective Engineering Change Management System (ECMS).

Based on an exhaustive review of the literature, this is, to the best of the author's knowledge, the first attempt made in using the System Dynamics technique for the purpose of developing an ECMS.

### **1.3 Scope and Objectives of the Thesis**

The scope of this work is to model and simulate the NP/SI process for the two Greek companies collaborating in this project, brief profiles of which are provided in the following section, and to investigate the existence of a cost-time-quality relationship. The primary objective of this research is to obtain such information, as a result of the above investigation and analysis, which could facilitate the identification of potential areas for improving the NP/SI process. Furthermore, by inserting disturbances into the model and then simulating the NP/SI process, to be able to identify the effects of ECs throughout this process. Finally, to examine whether the use of the simulation process results coupled with the ECs background, can provide the basis for developing an ECMS, which when managed effectively can lead to an improved environment for product innovation and provide a favourable opportunity for increased sales and profits.

### **1.4 Companies Profiles**

As mentioned above, the two Greek companies, which have contributed to the successful undertaking and completion of this research project are:

**Command Control Communication Technologies S.A. (C<sup>3</sup>T)**

C<sup>3</sup>T is a privately owned company located in Northern Greece, at the industrial area of Kilkis, near Thessaloniki, specialising in instrument/systems calibration and testing.

It operates a series of ultra modern laboratories for (a) electrical, dimensional, temperature, relative humidity, mass, pressure and force/torque measurements, (b) testing of oil-/gas-fired boilers, electrical apparatus and non-automatic weighing instruments. C<sup>3</sup>T's near-term plans include the expansion of calibration activities to include acceleration, acoustics, volume/flow and hardness. All its laboratories follow the EN45000 series of European (CEN) Standards and are accredited by the United Kingdom Accreditation Service (UKAS-NAMAS) and the German DKD, being the first and only accredited laboratories in Greece.

C<sup>3</sup>T's unique and highly specialised calibration and testing services are offered to a wide range of customers of the private and public sectors of the Hellenic industry, including the Hellenic Armed Forces. C<sup>3</sup>T also offers specialised training courses in metrology, testing (CE marking) and accreditation, as well as consultancy services.

and

**Hellenic Aerospace Industry Ltd (HAI)**

This year, HAI, a state-owned company, has completed 24 years since its establishment in 1975. During this 24-year course, HAI succeeded in developing those capabilities, which enabled it to fully respond to what has been a national defence need for many years, i.e. self-sufficiency in providing maintenance support to the aviation equipment of the Hellenic Armed Forces and primarily to the Hellenic Air Force.

Today, HAI is one of the largest and most advanced aviation maintenance and repair centres in Europe without limiting itself to those activities only. Through an ambitious investment plan, HAI possesses the necessary technology and know-how for manufacturing activities, both in fabrication of airframe structures and engine components as well as in production of electronic and telecommunication equipment for commercial and military use.

With highly skilled and experienced human resources, state-of-the-art facilities and equipment and production methods and processes, which are in strict compliance with the most up-to-date specifications and quality standards, HAI's four lines of business possess full capabilities for:

- Depot Level Maintenance and Overhaul of a wide variety of fixed and rotary wing aircraft and the related engines, accessories and components,
- Manufacturing of airframe structures and engine parts,
- Manufacturing of customised electronic and telecommunication equipment.
- Specialised training courses covering a wide spectrum of the aviation industry's operations.

### **1.5 Thesis Structure**

The thesis is in seven chapters, including this introduction. Chapter 2 presents the background information necessary for carrying out the research and provides a review of the literature on New Product Development and Engineering Changes. Topics such as the strategic importance of the NP/SI process, the reasons for failure or success of new products or services, the available models for developing new products or services, the need for decision gates, the dimensions of success and the elements of efficient NP/SI management, as well as the importance, the main activities and the drivers of ECs are the subject of discussion and analysis of this chapter.

Chapter 3 describes the methodology to be followed in accomplishing the aim and objectives of this research. It also provides a comprehensive background on Business Process Modelling and Simulation (BPM & S) and how this may be used in improving the NP/SI process and facilitating the effective handling of ECs within such a process. The specific BPM&S technique, namely System Dynamics, used in this research along with the criteria of choosing the *iThink* software package, by High Performance Systems Inc, are also described and analysed in detail.

Chapter 4 is devoted to the description of modelling the NP/SI process using the System Dynamics technique, the selection of this business process modelling technique and the validation of the NP/SI model.

Chapter 5 elaborates on the simulation of the developed NP/SI process model described in the previous chapter, stresses the importance of process improvement and comments on the actual results of the simulation, which may form the basis of process improvement. An outline of the preparation activities for simulating the model of the NP/SI process is also included.

The application of the System Dynamics technique in developing an efficient and effective ECMS and the effects of an EC on the NP/SI process are emphasised in Chapter 6.

Finally, Chapter 7 discusses the major issues of the research, such as the use of System Dynamics for modelling and simulating the generic structure of the NP/SI process, the use of the simulation results to improve the NP/SI process, the modelling of the ECMS using again the System Dynamics technique and the conclusions that came out. Potential areas of future research are also identified.

# CHAPTER 2

## BACKGROUND INFORMATION

### New Product Development and Engineering Changes–Review of the Literature

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#### 2.1 Background on New Product Development

##### 2.1.1 Introduction

Studying the history of our society, it is obvious that it changes year after year, decade after decade. Just as the society we live evolves, so does its wants and needs. New products and services are therefore essential to satisfy those ever changing requirements and New Product / Service Introduction (NP/SI) becomes a crucial activity within any organisation. If an organisation does not continue to grow, it dies. To grow, an organisation must continue to learn and to make a difference in its industry (pioneer). New products or services are the key to success.

Recognition of the importance of new products / services development to corporate and economic prosperity, coupled with the high risk of failure in such endeavours, has triggered considerable research interest in the dynamics of NP/SI. The research, from a variety of domains including marketing, management, engineering, Research and Development (R&D) and economics, has been widely reported in a number of journals and has created a large and complex body of literature relating to the various elements involved in NP/SI [1].

In discussing new product / service introduction, the definition of "new" should be clearly understood to cover a range of classifications. It was suggested by Baker that "newness is essentially a subjective concept that depends upon one's state of knowledge or, in the case of a firm, its current range of activity" [2]. A reflection of Baker's definition can be found in the Booz-Allen and Hamilton survey, in which "new" was considered in the context of six categories:

- New to the world
- New product lines (established products or services new to the company)
- Addition to existing product lines
- Improvements / revisions to existing products or services
- Repositioning (existing products targeted to a new market segment)
- Cost reductions (new products that deliver the same benefit at a lower cost) [3]

So, "new" can be applied to a broad range of situations; new to the industry, new to the manufacturer, new to the consumer, or maybe new to all three. It is the author's intention to follow this same liberal interpretation.

### **2.1.2 Major Projects / Studies regarding NP/SI Practices**

Two of the most known and cited broad-based studies in the new product design and development field, were the ones carried out by *Booz, Allen and Hamilton* in 1968 and 1982 [3], also referred to as BAH studies. Although the representiveness of the samples on which the BAH studies were based has not been specifically addressed, both studies produced many findings that have been widely reproduced and cited as norms for the practices and performance regarding new product development (NPD).

In 1972 the Science Policy Research Unit (SPRU) of the University of Sussex initiated *Project SAPPHO*, which compared 43 pairs of innovations and revealed 41 significant differences between successes and failures [see 4-5]. The most important

discriminators included a company's "customer understanding" and the attention paid to marketing and publicity. Later, using the SPRU study as a starting point Gardiner *et al* [6] concluded that successful NPD management is based on sound strategy, long-term planning, responsiveness to change and management commitment.

Cooper [7] reported on the results of Project NewProd: an investigation into 200 successful and unsuccessful new industrial products developed in Canadian firms. Cooper concluded the study by identifying the fifteen most important factors that determined success or failure, according to his sample. These included the proficiency of the product launch, the customer-product fit relative to competition and the quality of the product.

Later research by Cooper [8] and Cooper and Kleinschmidt [9] expanded on the results obtained via the Project NewProd survey. Overall this research demonstrated the need for both marketing and technical proficiency in NPD. Interestingly Cooper ✓ [7] also reported that a "first to the market" strategy was not a determinant of success or failure. Three more recent studies have extended the work of Cooper and Kleinschmidt to Australia [10], Spain [11], and China [12].

Stevenson *et al.* [13] reported on the findings from the *Best Manufacturing Practices Program* initiated in 1985 by the Department of the US Navy. The report concerned the best practices followed in manufacturing by 31 US Navy contractors. Some of the results included the recognition of the value of concurrent engineering and teamwork, the extent of sophisticated design tools utilisation, and the identification of a lack of attention regarding the design policy and overall NPD organisation.

Studies were also performed under the framework of the Product Development and Management Association (PDMA). Page [14] reported on the findings of the first PDMA's Best Practices Study. The survey focused on the practices followed by North American companies (sample split based on location: 95.2% USA and 4.8% Canadian) and was conceived of as being a broad-based macro-level study. The

author reported that the state of practice, covering both NPD structure and process, has improved when compared with the results obtained from the first BAH surveys; although there is substantial room for further improvement.

✓ Another survey performed by Calantone *et al.* [15] focused on the views of 252 marketing and technical professionals, members of PDMA in the USA. The results obtained, revealed strong overall agreement among practitioners regarding 40 fundamental principles of NPD identified by the authors from product design and development theory. Managers believe that 80% of those principles are almost always true.

Special emphasis should be given to the work carried out by Harvard Business School (HBS) and especially Kim Clark and Steven Wheelwright [16]. HBS studied product development and consider it as a control focus of competition in the 1990s. They have identified the forces driving the importance of product development – changes in competition, customer demands, and technology and have recognised that these forces have created a competitive imperative for speed, efficiency, and high quality in the development process.

The concept of a Development Strategy (the activities companies carry out before NPD projects get started) was another major issue studied and analysed by HBS. HBS identified development strategy as a way to create an effective framework within which the problems that typically arise in product development can be solved. Development strategy, according to HBS, provides a means for senior management to interact and shape the development process in a timely and effective way.

Perhaps, one of the most important contributions of HBS, in the area of NPD, is the development of a framework and set of techniques for identifying and integrating the strategies in the functions and linking them to the overall direction of the business. They named the framework maps, and the procedure for applying it, mapping. According to HBS, a map is a graphic display of the driving forces of competition in a particular function over time relative to competitors. The basic idea



behind the mapping process is that what matters in laying the foundation for product development is the creation of a shared understanding and a common direction among the functions and the senior management of the company.

### 2.1.3 What is New Product / Service Introduction?

✓ An organisation's products or services are among its most visible assets (or liabilities). Products and/or services link the organisation with its stakeholders (i.e. customers, suppliers, owners, employees, regulators, and others interested in the organisation's performance). The way an organisation interacts with its stakeholders in its business environment through its current and planned range of products / services, defines its *business strategy*. New products / services are therefore the basis for a variety of strategic reasons that define an organisation's direction.

Business strategy entails the development of a sustainable competitive advantage in selected market segments. A sustainable advantage generates value from invested resources to facilitate future investment - in theory, a time-based process of continual renewal. The essence of strategy combines decisions about *ends* (goals or directions to pursue) and *means* (how to achieve the goals through resource allocation). Because an organisation defines itself by the products and/or services it offers to the market it chooses to serve over a planning horizon, new products / services provide a means to achieve its goals [17].

A new product or service is a multidimensional concept with need-satisfying capabilities not previously experienced by the stakeholders. The concept offers some form of value to all relevant stakeholders. The degree to which something has not been previously experienced - or its *innovativeness* - can range from incremental improvements (*extension* product or service) to significant advances (*breakthrough* products or services). Extension products or services, which often require fewer resources and entail lower risk than breakthrough products or services, tend to constitute the bulk of a firm's portfolio of new product or service development

projects. They run the gamut from simple renovations (cosmetic changes) to a strategy of incremental innovation that might eventually lead to a major breakthrough. Whether a new product is an extension or a breakthrough, the implied promise that it will lead to a sustainable competitive advantage lures firms to use the path of new product / service introduction as a means to strategically manage a business [17].

#### **2.1.4 Strategic Importance of New Product / Service Introduction**

New product success for a business is a measure of its ability to enhance existing products and to develop new product lines speedily and efficiently, when that is needed for competitive reasons. This is a much broader definition of success than the one used by analysts who focus on the success of individual product launches.

There clearly has to be a close link between a company's corporate strategy and the products and / or services it introduces into the market. The evolution of this link is discussed by Coombs and Hull (1995), who show how focus has moved from internal functional optimisation to a business process approach oriented towards serving customer need [18].

Product strategies can take several forms [19]. They can involve using related production methods, related development technologies, specific markets or as part of a developing product family [17]. It is important that the strategy drives the development activities [20].

The strategic importance of New Product / Service Introduction can be viewed as a function of several factors or bases. These factors or bases provide an indication of NP/SI's potential role in an organisation's long run performance and survival. These factors are listed below and explained in Appendix A (page 158):

- *New products / services can provide opportunities for reinforcing or changing strategic direction*
- *New products / services can enhance corporate image*

- *New products / services can capitalise on R&D*
- *New products / services can utilise production and operations resources*
- *New products / services can leverage marketing / brand equity*
- *New products / services can affect human resources [17]*

From the above, it becomes obvious that any NP/SI project to be successful requires an efficient and effective management. It must be performed in a series of well defined steps that will allow its successful completion.

### 2.1.5 Identified Reasons for Failure

Before explaining how an NP/SI project (process) should be conducted or managed, it is useful to examine which are the reasons that such projects (processes) fail. Following is a table (Table 1) which illustrates the failure rate of new product / service introduction, as tabulated by a number of leading research teams [21].

Obviously, money devoted to failures is money that might better have been spent on developing and introducing successes. Knowing causes for failure can help screen out ill-fated ventures before much time and money has been consumed [21].

Research Company	Year	Firms Studied	Failure Rate (%)
New Product Institute, Inc	1955	200	81
A. C. Nielsen	1962	103	46
Arthur Gerstenfeld	1969	158	71
A. C. Nielsen	1971	204	53
Mansfield and Wagner	1975	18	68
Booz Allen & Hamilton	1981	700	35

Table 1: Failure Rate of NP/SI projects

*Source: [21]*

In their study Cooper et al. [22] mention that in the 1970s, organisational problems were the predominant ones, with 81% of the companies surveyed reporting problems of such nature. Booz, Allen and Hamilton [3] in the 1980s, found lack of attention to

new products, emphasis on short-term profitability, inadequate market research, and delays in decision making as the primary problems cited by practitioners. All four of these problems were mentioned by 30% or more of the respondents. In the 1990s, the comparative studies performed [14,23,24] revealed a greater variety of problems cited by practitioners, though with a lesser frequency of appearance.

When UK and Japanese companies were asked by Edgett et al. [25] to indicate factors that according to their beliefs contributed to new product failure, respondents identified items less frequently than they did for success issues. A summary of the results obtained by the authors is offered in Table 2: Failure Factor of New Products

Failure Factor of New Products	% of Companies	
	Japan	UK
Failure to understand customer needs	26.7	22.1
Cost higher than predicted	26.7	20.9
Insufficient pre-launch development	25.3	25.6
Lack of differential advantage	25.0	23.3
Weak distributor co-operation	24.1	12.8
Inadequate marketing research	22.4	37.2
Aggressive competitors	19.8	14.0
Unexpected changes in demand	18.1	14.0
Bad planning or timing	16.4	10.5
Poor interdepartmental communication	14.7	11.6
Faulty product	12.9	19.8
Over-enthusiasm leading to low objectivity	12.1	27.9
Poor market communication	9.5	11.6
Poor match with company objective and image	6.9	4.7
Product orientation	6.0	4.7
Inadequate marketing mix	5.2	10.5

Table 2: Factors contributing to new product failure

Source: [25]

The UK organisations named inadequate market research as the most common failure factor by a considerable margin over the other factors. Another controllable factor, over-enthusiasm, was more of a problem to the British than the Japanese. This suggests a more disciplined approach to NPD in Japanese companies. The fact that Japanese companies indicated faulty products as not an important failure factor, reflects their high emphasis on quality. On the other hand, failure to understand customer needs was identified from both UK and Japanese companies as an important obstacle to success. Interestingly, the fact that both regarded product costs higher than predicted as a significant failure factor, may indicate that many organisations still believe that budgets are more important than beating the schedule.

#### ✓ Poor Planning

Unfortunately, poor planning is the single biggest reason for new product or service introduction failures. Too often, factors that should have been predicted are either overlooked or are ignored. Examples of poor planning are when the new product or service does not fit company strategy, expertise or distribution strength/knowledge, when the cost of entering the category is an insurmountable barrier, when the manufacturing, purchasing, quality control standards and regulatory complications are unfamiliar and when the market analysis is inadequate.

#### Poor Management

Poor planning reasons for failure are closely related with poor management. Management is responsible for the planning process and for authorising the planned programs. Although management, very often, identify poor research and poor timing as top failure factors in many surveys, the answer lies closer to home [21]. Examples of poor management are when the product does not fit the corporate or division charter guiding such activities, when there is no management "sponsor", when the product or service introduction is an unchecked management "ego trip" (i.e. the "sponsorship" is too powerful), when there is no management information system to provide two-way communication, when the management direction and goals are confusing and inconsistent, when the wrong department leads the introduction program, etc.

### Poor Concept

"Poor Concept" is a relative statement. What is meant by "poor" is that the concept itself does not appeal at the time of and/or in the form of execution being evaluated, as determined by the mode of evaluation or test used. For example: the product or service does not offer a unique benefit, it has a unique benefit but a poor price/value relationship or is out of synchronisation with the market in terms of demographic realities, it has no single strong reason for being, it is too innovative (ahead of the market) [21].

### Poor Execution

When the new product or service offered to the customer is being produced by an inefficient and ineffective production process and has an inefficient and ineffective distribution process, then it is possible, if not certain, that customers will not buy it. No matter how "brilliant" the new product or service seems to be before it is introduced to the market, poor production and distribution will offer to the customers a product or service which will be defective or has other technical problems, a product or service that is over- (under-)engineered, that is over (under) packaged, mistargeted, that has weak distribution (or the company has poor sales operations), etc. In such a case, the new product or service is condemned to fail.

### Other Reasons

There is an almost endless list of other reasons for new product or service failures, many related to the quality of management. The most successful companies have few marketplace failures, but a lot of conceptual, prototype failures at a stage where it does not cost so much.

Some of these other reasons for new product or service introduction failures are:

- Inadequate market analysis
- Poor assumptions, or misidentified opportunities
- Low product or service awareness
- Over- (under-) reaction to competition
- Regulations that limit sales

- Foreign competition
- Poor timing
- Poor use of research

### 2.1.6 Identified Reasons for Success

When UK and Japanese companies were asked by Edgett *et al.* [25] to indicate factors that according to their beliefs contributed to new product success, the most frequently cited factor overall was that successful new products were well matched to customer needs. This reflects the need for a customer-oriented approach to NP/SI programs rather than a production-oriented approach. However, despite the fact that just under 75% of the companies surveyed claimed that matching customer needs was important, only 26% considered skilful marketing to be a reason for success. A summary of the results obtained by the authors is offered in Table 3.

Success Factor of New Products	% of Companies	
	Japan	UK
Well matched to customer needs	69.8	75.6
Superior to competition in quality	79.3	59.3
Superior to competition in reliability	69.8	45.3
Superior to competition in value for money	58.6	61.6
Superior to competition in design	55.2	48.8
Highly price competitive	41.4	27.9
Well match with company objective and image	39.7	34.9
Unique	36.2	29.1
Skillfully marketed	27.6	25.6
Based on good marketing research	27.6	18.6
Launched into large markets	20.7	16.3

Table 3: Factors contributing to new product success  
Source: [25]

Compared with British companies, the Japanese rated the need to develop a superior new product significantly higher in terms of product quality, reliability and availability at competitive prices. This suggests that Japanese companies have placed stronger emphasis on not simply meeting consumer needs. In order for a new product to be successful in an increasingly cluttered marketplace, the product needs also to have a competitive advantage.

### **2.1.7 The use of Models for Developing New Products / Services**

A nine-month co-ordinated research project was carried out by Cranfield, De Montfort, Lancaster, Salford and Warwick Universities, under the auspices of the IMI Research Framework for Integrated Aerospace Manufacture [18], to identify the key business processes and critical factors for successful introduction of new products. The specific aims of the research were to gain a better understanding of the current status of the NPD process in industry and to develop a research agenda which fitted industry's needs.

Regarding current best practice, the project identified that leading UK aerospace companies:

- have mapped their processes at a whole product level and are using these process maps
- are now mapping and improving their processes at lower levels in the product breakdown structure, for use at lower levels in the organisation
- are working hard to achieve integrated product and process development across all contributors to the product introduction process
- are establishing common and relatable databases for design, manufacture, procurement, service and finance and are moving towards digital definition of new products
- have decentralised traditional functional groups into multidisciplined project teams supported by small functional groups



The capability to model the NPD process underpins industry's requirements to formalise and to optimise this core competence. However, across the industry as a whole, the NPD process is amorphous in nature, its boundaries change according to both the terminology used to describe company activities, and individual company perceptions. It was therefore, obvious that there is evidence of a need for improving the understanding of the NPD process to define and manage it.

New products / services are emerging continuously at an accelerated rate because of dynamic forces such as accelerated technology, greater customer demands, total quality management, global competition, reengineering, shared information systems, and government regulations, but most of the processes for developing them are still a series of discrete steps. NP/SI needs to be a continuous process as we move into an era of continuous innovation [26]. Concurrent Engineering provides the means for achieving a more continuous NP/SI process.

Models are used in a variety of disciplines as a way of understanding the dynamics of a process. Certainly their use is widely accepted within marketing and their application is highly recommended by a number of authors. Lillien and Kotler (1983) affirm the benefits of using models to assist decision making in a complex and difficult world. "Model-building approach proved timely and valuable support for marketing decision making" [27].

Cooper also supports this view from evidence collected from the Project NewProd research as he maintains that adoption of a "systematic process model... is one solution to correct the serious deficiencies that are common to many firms' new product efforts" [28].

However, a model's primary value comes from the systematic and logical framework which is designed to reduce the risk of failure while leaving creative talent free to create, not become overwhelmed by detail. They provide a checklist of the key activities to be undertaken and an appreciation of the whole process. This

latter point is more important where there are many disparate participants and inputs into the process.

Kraushar is not so convinced of the benefits of a new product or service development model believing that formulas should be treated with caution, each new situation demanding a new solution. In his view, the approach and process are subordinate to the opportunity, the support it attracts and the way it is implemented [29].

Therefore, although support for the use of models as a decision and processing tool is strong, it should be appreciated that there are some, like Kraushar, who believe it may be too prescriptive. This could then encourage the belief that it is the model, not the input to and output from it, that are crucial. Notwithstanding, models are widely accepted and this has led to various models representing the new product / service development process.

It has been suggested by Baker et al (1983) that "the variety of forms of product development make it difficult to use one general model to represent a wide range of circumstances" [30].

Perhaps Baker was thinking about intangible goods, like services. In the literature reviewed which covered these types of goods few models existed and they were in the main implied rather than explicit. Cowell (1988) studied the subject of services marketing extensively and suggested that "service marketers can benefit considerably from existing knowledge of the new product development and launch processes derived from studies of consumer and new industrial products" [31].

In his work he looks at the sequence of new product / service introduction events favoured by Kotler and he suggests that the conventional stages of: exploration, screening, business analysis, development, testing and commercialisation apply to services as well as goods. Nevertheless, even given his implied support of the traditional new product / service introduction model, Cowell does suggest that not

all the steps may be necessary for services due to their unique and distinctive features which may invalidate some stages.

### ✓ 2.1.8 Kotler's Model for New Product / Service Introduction

Kotler's model for new product / service introduction (development) [32] is used as the basis for this review as it offers a simple, yet comprehensive, representation of the process. Kotler's model can be graphically illustrated as follows:

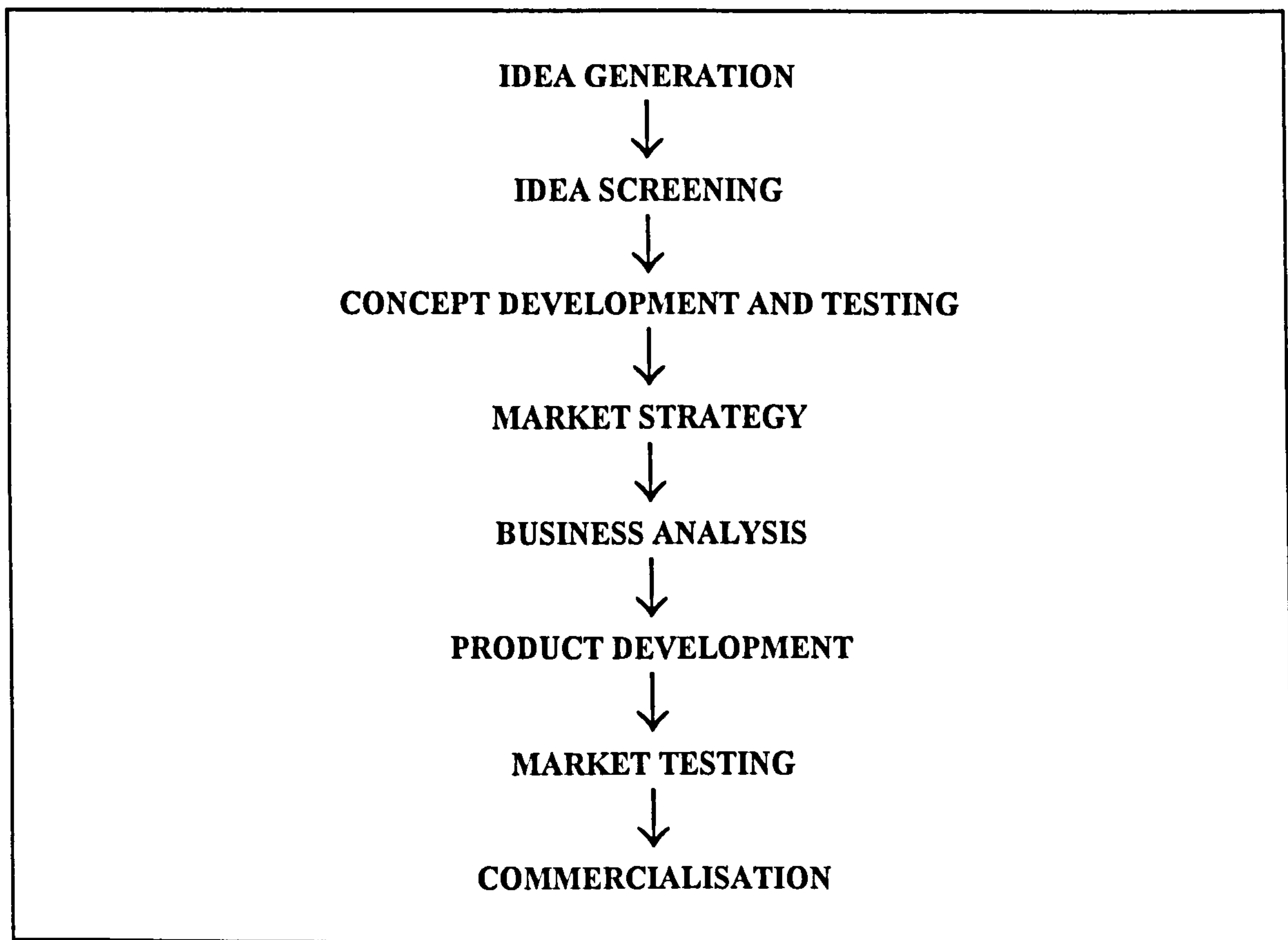


Figure 1: Kotler's Model

Source: [32]

Kotler's model is substantially the same as described in the Booz, Allen and Hamilton survey (1982) and the one that appears most regularly in other new product / service introduction literature.

The key tasks of the model are to generate as many original ideas as possible and to subject these to a number of tests in order to eliminate those that seem to be

probable failures and keep only those that seem to be probable successes. The stages of Kotler's Model are analysed in Appendix B (page 161).

### **2.1.9 New Product Design and Development Model**

Previous work at Cranfield University by Rooney and Peters [33] resulted in the development of a model for New Product Design and Development (NPDD). The NPDD model was the result of the identification and analysis of industry best practices. The models presented within the literature seem to be generic, that is, applicable to the New Product / Service Introduction process in any company, but most of them, although generic, they are too high a level to be of practical use. The aim of a generic model is to give an overview of the New Product / Service Introduction process that will be relevant to any company. The NPDD model has been derived from experience over a number of years from a wide range of businesses and market sectors in the United Kingdom.

The summary model resulting from the research is illustrated diagrammatically in Figure 2. It explicitly includes management related facilitation issues, a breakdown of the NPDD process and placement of key supporting quality tools and techniques. The stages of the NPDD process together with the facilitation issues and the tools and techniques are briefly analysed in Appendix C (page 169)

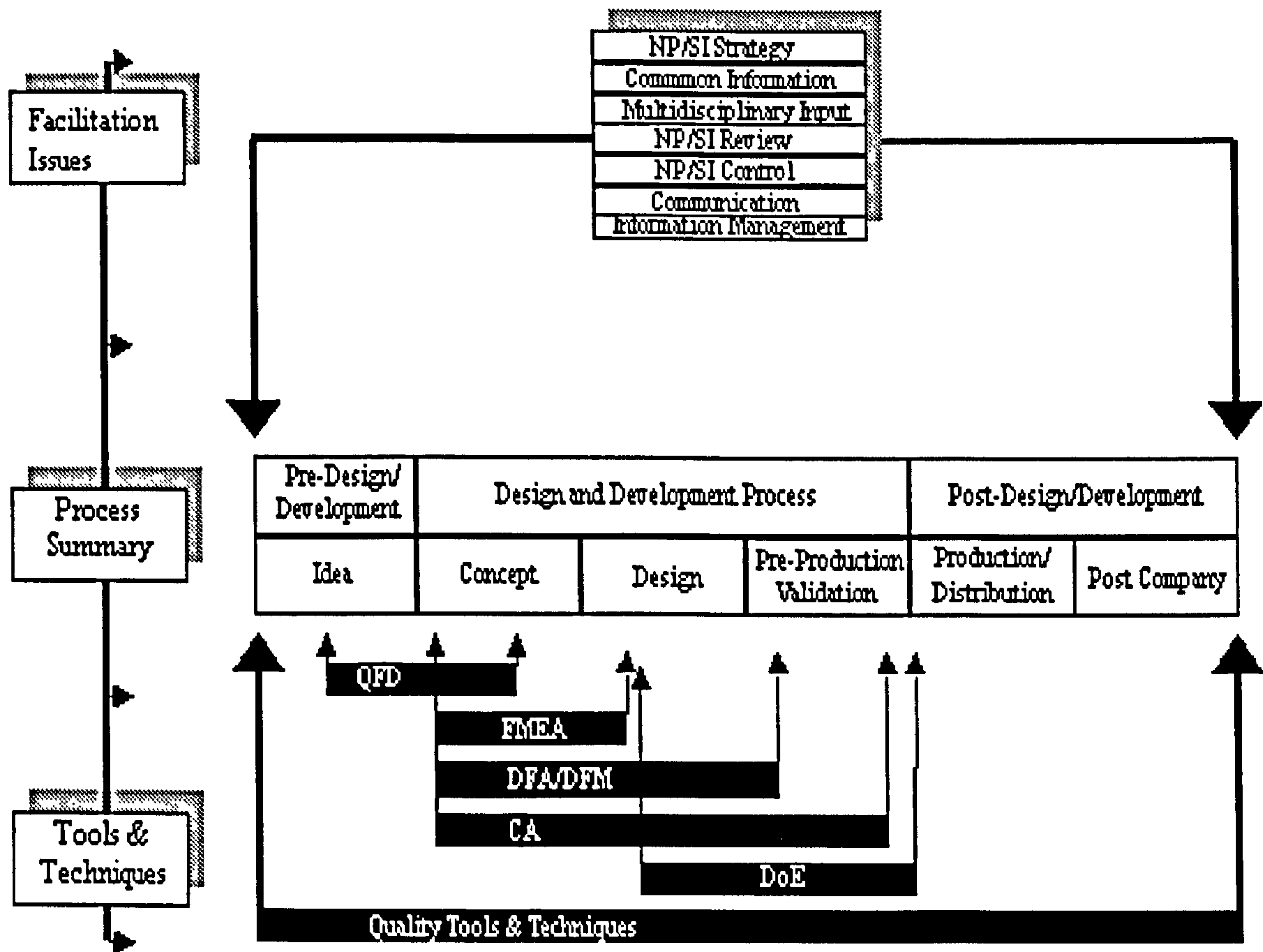


Figure 2: NPDD Model  
Source: [33]

### 2.1.10 Other Models used for NP/SI

One of the very first models for new product / service introduction suggested, was by Swindells [34] in 1971. The 'New Product Development Process model' he suggested is shown schematically in Figure 3:



Figure 3: Swindell's Steps in the New Product / Service Introduction

Source: [34]

New Product / Service Introduction is a total company activity, calling above all for a positive lead from senior company management, and demanding willing and continuous liaison between the departments involved in this activity [34].

In 1982 a NP/SI process model was developed by the consulting firm Booz-Allen & Hamilton Inc [3]. After the firm's new product strategy has been determined, the process proceeds through the following steps:

1. Idea generation
2. Screening and evaluation
3. Business analysis
4. Development
5. Testing
6. Commercialisation

Because the mortality of new product / service ideas is often too high, organisations need to generate a sufficient flow of them to achieve their growth objectives. After screening and evaluation, the ideas are submitted to a business analysis that evaluates the remaining product concepts for estimated sales, costs, profitability, and

other financial indicators. If a new product / service idea meets business analysis criteria, it enters development. Ultimately, the product is submitted to testing, such as use testing, various forms of market testing, and other procedures that will facilitate measuring market response to the new product or service. Finally, commercialisation involves the launch strategy for the new product or service, as defined by the target market segment, the marketing program, and launch timing [17].

✓ In 1986, Cooper and Kleinschmidt used a 'skeleton' of the process taken from a variety of normative and empirically based prescriptive processes developed by other authors (Booz, Allen, Hamilton 1982, Cooper 1983, Little 1970, Myers and Marquis 1969, Utterback 1971), which has thirteen activities, as detailed below:

- Initial screening
- Preliminary market assessment
- Preliminary technical assessment
- Detailed market study / market research
- Business / financial analysis
- Product development
- In-house product testing
- Customer tests of product
- Test market / trial sell
- Trial production
- Pre-commercialisation business analysis
- Production start-up
- Market launch

They found that there is a greater probability of commercial success if all of the process activities are completed. This finding is confirmed by another study which took place in Australia [10]. Unfortunately, Cooper and Kleinschmidt (1986) also found that very few of the companies studied carried out all thirteen activities [1].

A further development came in 1987, in the contingency model, of Shrivastava and Souder, as shown in Figure 4. This model recognised that the structural variables, and cultural emphasis, of an organisation affects the way new products or services could be developed and successfully introduced into the market. Therefore, they reflect the dominant organisation culture in their model as being the key to manage the development process.

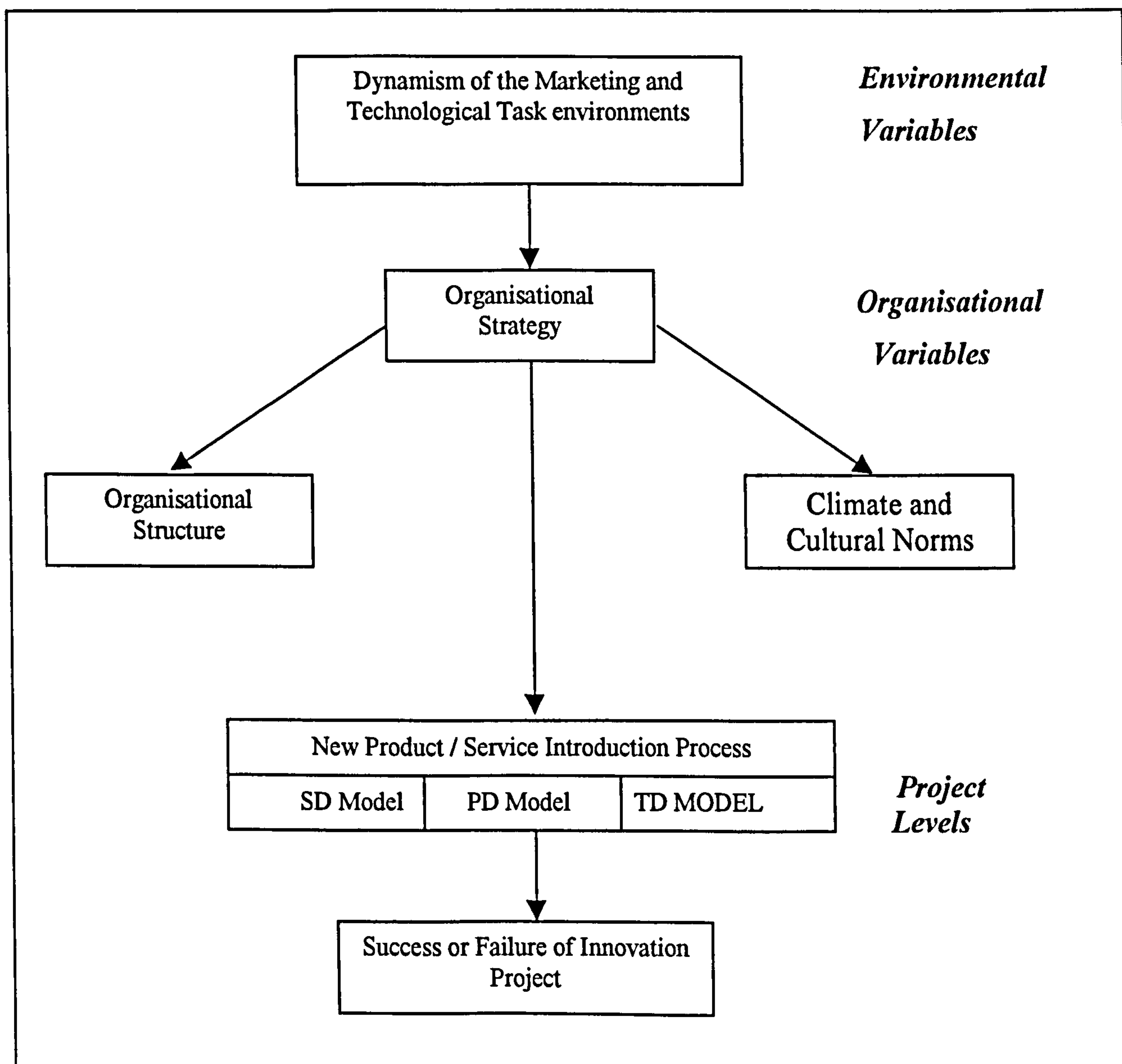


Figure 4: Contingency Model  
Source: [35]



These classifications reflect levels of communication and types of group involved and their impact on how the process can be best applied:

- *Stage Dominant (SD)*: formal groups structured on specification
- *Process Dominant (PD)*: no discrete transfer points existing between organisational groups
- *Task Dominant (TD)*: all staff strongly orientated to complete the task and achieve the end product or service.

Supporters of this model suggest that it: “includes environmental and organisational variables and can be applied across a variety of situations. A multi-disciplinary approach is needed with many parallel developments, not only between departments but also within departments. A company’s internal development process needs to be closely tied in with its corporate objectives, and linked to the external environment, to allow new ideas into the organisation” [35].

It is worth mentioning that there have been many attempts to draw up maps or models of the design process, which in some sense seems to have many similarities and commonalities with the early stages of the NP/SI process. Models of the design process are often drawn in a flowchart form, with the development of the design proceeding from one stage to the next, but with feedback loops showing the iterative returns to earlier stages which are frequently necessary. Nigel Cross [36], in his book *Engineering Design Methods* analyses and emphasises the engineering content of product design and presents many different models of the design process.

Amongst others, the most widely used design process model has been developed by French [37] based on the following activities: Analysis of problem, Conceptual design, Embodiment of schemes, and Detailing.

French’s model is illustrated in Figure 5. In the figure, the circles represent stages reached, or outputs, and the rectangles represent activities, or work in progress. A more detailed analysis of French’s model is given in Appendix D (page 173).

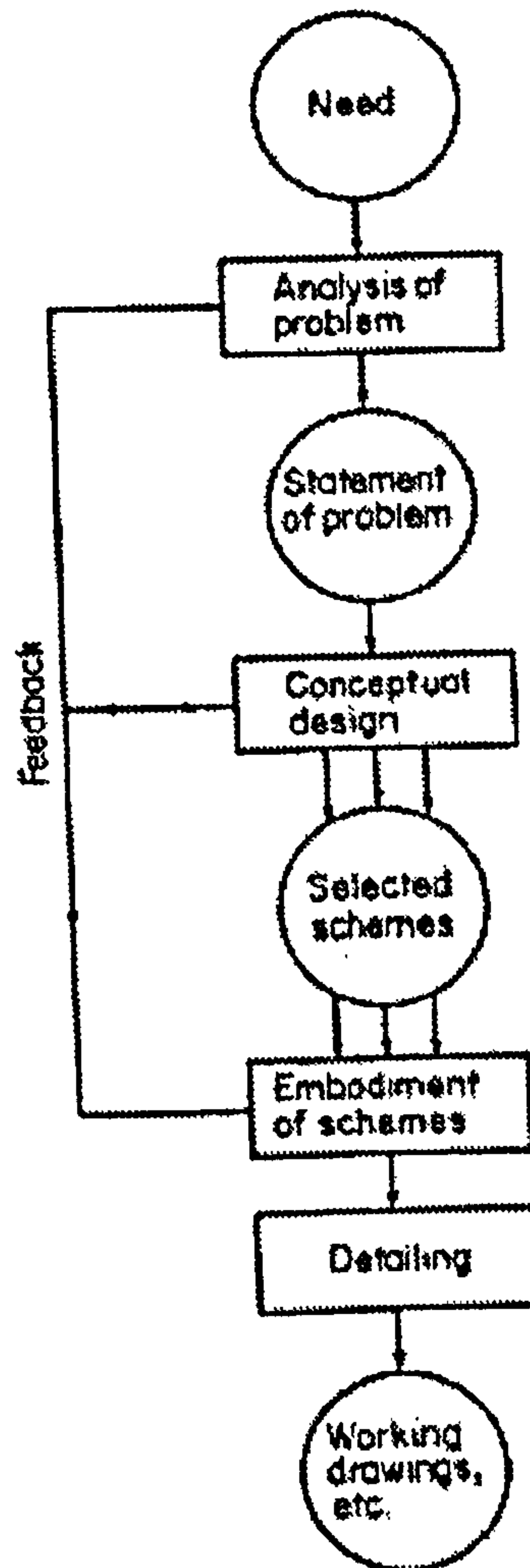


Figure 5: French's design model

Source: [37]

In his book, *Total Design*, Stuart Pugh [38] describes a concept he called the 'design core'. In this model there are six stages involved in the product development process that must be successfully completed in order for good product development to occur. The first is called 'Market', in which customer needs and relevant market factors are determined. The second is called 'Specification', in which the product is specified.

After this comes the 'Concept Design' stage, in which overall design approaches to the problem in hand are decided. The 'Detailed Design' stage follows in which the overview design of the previous section becomes detailed and specific. This phase ends with the bills of materials fully prepared and all drawings complete. There is a

wealth of difference in the level to which the product is specified between these two phases. After this 'Manufacture' begins and, with it, the last phase of 'Sell'. This structure is shown diagrammatically in Figure 6:

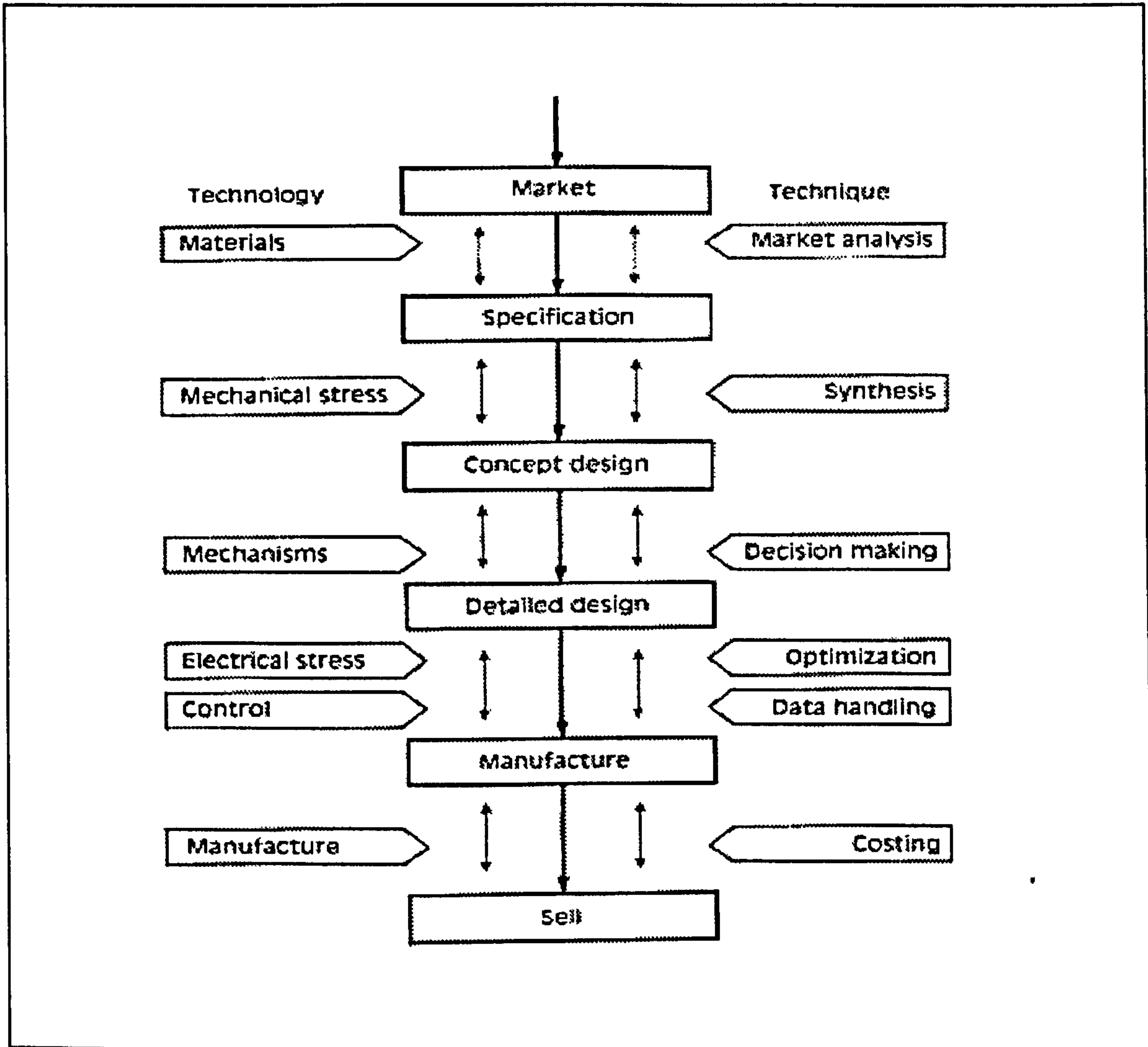


Figure 6: The design core [38]

Source: [38]

So important is the successful regulation of the product development process that there is a British Standard (BS 7000) [42] defining good practice. The standard uses phases through which a product development must go in order for a successful conclusion to be likely. In the standard the first phase is 'Motivation', in which a trigger or need for the product is identified. The second phase is 'Creation', in which all the creative design takes place. In the text of the standard, a distinction is made

between the early phases of design when definition is poor and the end of the design phases when detailed drawings are finished, together with bills of materials and the product definition is high. The third phase is 'Operation', in which the product is owned by its customer and is put to the use for which it was designed. Lastly, the product enters the 'Disposal' phase when the customer discards the product perhaps recycling it, perhaps trading it in or simply throwing it away. Figure 7 shows the idealised product evolution process according to BS 7000:

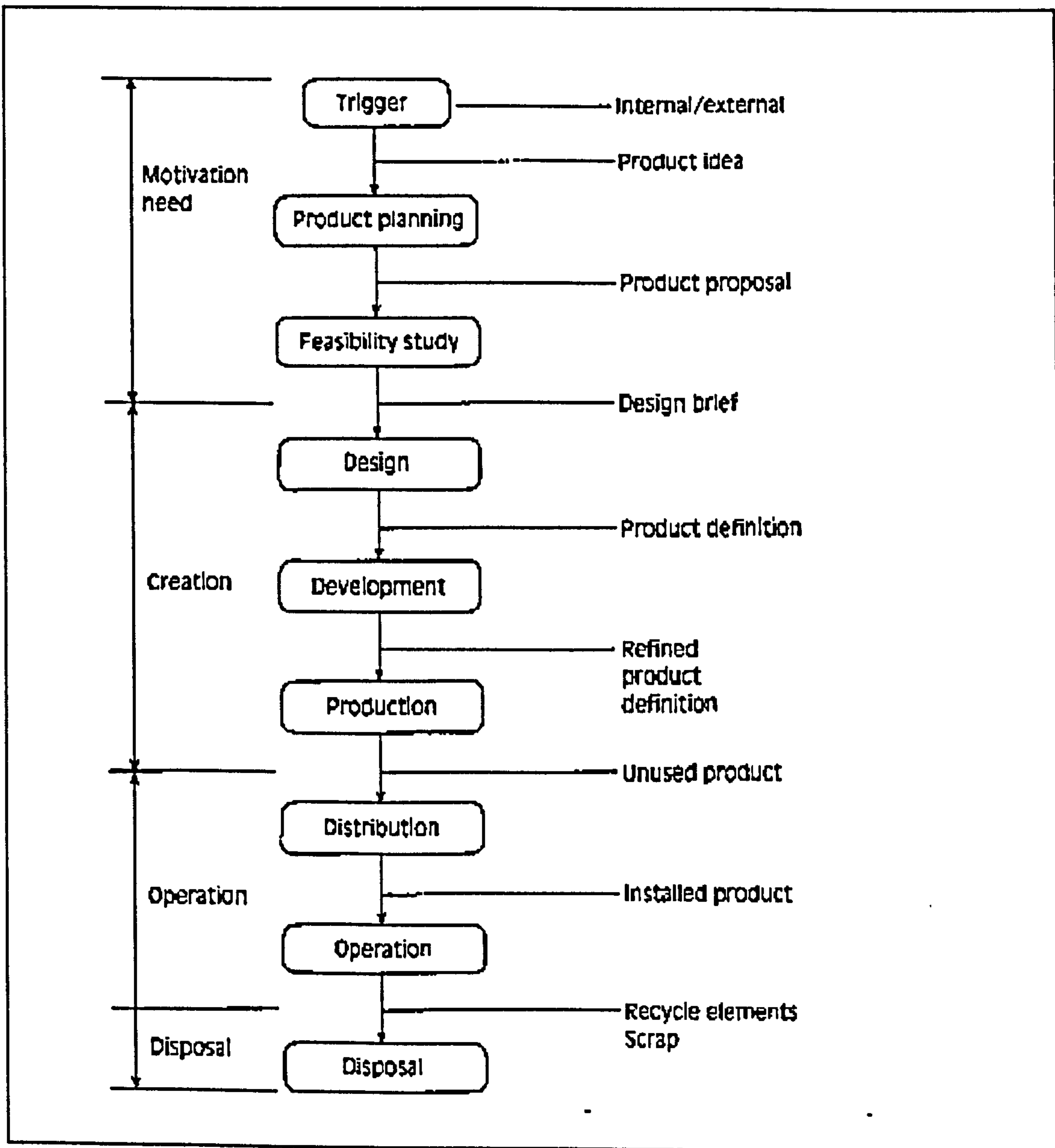


Figure 7: The idealised product evolution process  
Source: [39]

### 2.1.11 The Need for Decision Gates

One of the hallmarks of the new product / service introduction process is the constant checking both with the internal environment and the consumer. There is a clear need for evaluation points throughout this process, in order to weed out poor new product / service projects at the early stages of the process, where the cost of cancelling a project is not so high as it is at the later stages. These important evaluation points are termed "gates" where, "GO/KILL/HOLD decisions are made"[40].

✓ Many new products or services are not developed because the organisation does not have the requisite skills and expertise to create them. Others fail because, although they are technically feasible, they are not commercially viable. It is vital that organisations measure the various stages of development against their own criteria. Kotler's model provides these decision gates and insists that organisations look inward as well as outward for future success.

The most recent NewProd<sup>1</sup> study, undertaken in late 1985, involved a retrospective analysis of 203 industrial new products in 120 firms: 123 commercial successes and 80 failures [9, 22, 41, 42]. All 203 products had been launched into the market; commercial success or failure was judged in terms of a number of financial criteria. This study looked at the characteristics of new product projects in an attempt to understand what separates winners from losers. The study also looked at the new product process in detail. In particular, the focus was on what activities were undertaken, the quality of execution, and major gaps in the new product process [40].

The above research study revealed that the evaluation points or "gates" are either missing or fairly ineptly handled in the majority of new product projects. The results provide a glimpse of some significant weaknesses and holes in the way in which

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<sup>1</sup> NewProd: The NewProd series of research studies, begun in 1977 by Robert G. Cooper, have typically looked at large samples of successful and unsuccessful new industrial products to determine what distinguishes successful innovations.

new product projects are controlled and evaluated. These project evaluation gates are clearly poorly executed in most firms, and omitted altogether in other areas [40].

To overcome this problem, organisations need to build their New Product / Service Introduction process around a series of pre-set evaluation points or gates. These gates are analogous to quality control inspection points on a production / assembly line. Each gate has its own set of measures and criteria for passing the gate. For example:

1. Does the project continue to make economic and business sense?
2. Have the essential steps been completed - those steps or activities necessary to pass through the gate? Is the quality of execution of these activities adequate?
3. Is the project on time and on budget?
4. Are resources in place for succeeding phases?

Each of the above global questions is broken down into a longer and more detailed list of questions that forms the basis of the measures used at each gate. The output of the gate decision is one of three options:

**KILL** : if the answers to question 1 are negative

**GO** : if the answers to questions 1-3 are positive

**HOLD**: if the answer to question 2 is negative [40]

The work by Rachel Cooper [44] on 'stage-gates' is also worth mentioning since the 'stage-gate' approach applies a consistent planning and review procedure throughout the NPD process.

Phase Reviews are conducted at the end of each Phase with the aim of reviewing the work executed in the Phase, approving progress to the next Phase, and planning the resourcing and execution of the next Phase. Cooper [43], in his third generation process, saw the need for 'conditional-go' decisions at phase gates, to accommodate aspects of concurrency. This philosophy is translated in the development of the Protocol's phase gates. Phase gates are classed as either soft or hard, with the 'soft gates' allowing the potential for concurrency in the process, whilst ensuring that the

key decision points in the process are respected. The potential benefit of this approach is fundamentally the progressive fixing and/or approval of information throughout the NPD process [44].

Decision gates are very important for they operate as a tool for controlling the New Product / Service Introduction process, and as Cooper [8] suggested they prevent NP/SI projects from moving to the next stage until all critical activities have been completed, and the quality of execution is considered adequate

### 2.1.12 Dimensions of Success of New Product / Service Introduction

The review of the literature so far has suggested that the use of formal NP/SI process models provides benefits. However, it is not beneficial to rely entirely on the model to guarantee success by slavishly carrying out each step as prescribed. Instead it should be used as a framework in which steps can be undertaken or ignored. The point is that stages are omitted by a conscious decision not by default and as a result of some examination as to their consequences. The use of a model assists in the new product development procedure in that it creates a cohesive framework for organising the way we think. It does not inhibit creativity, it systemises the routines and leaves creativity free to innovate.

Time is a critical factor in the development process of new products / services. There are two aspects to be considered: 1. *Lead time* is the term used to describe the duration of the new product / service development process from idea generation to commercialisation. The shorter the lead time the greater the competitive advantage gained. It is important to be there first as well as getting the product or service right first time. 2. *Window of time*, is a launch opportunity that exists within a given time frame. A lot of products benefit from their launch date coinciding with a large event, for example, a car launched at an international motor show [21].

New products are only worthwhile developing if there is a consumer need. The heavy consumer bias in the development cycle means that products that do not meet consumers' wants and needs are not developed just for the sake of technological advance. Therefore, one of the model's objectives, to continually test against internal and external objectives, reduces the chances of unrequired product or service developments.

Although new product success requires careful execution of research and marketing, there may also be less obvious signs that management considers the new product important. In a survey of five new product consultants, *New Product Development*, a Point Pleasant, NJ, newsletter, came up with 19 critical questions to determine if management will support the effort. According to the newsletter: "Fifteen or more affirmative answers mean the product's success is almost assured. Eleven to 14 suggest probable success and eight to ten indicate a 'coin toss' " [21]. Here are the questions:

1. Has the product been in development for a year?
2. Does your company now make a similar product?
3. Does your company now sell to a related customer market?
4. Is research and development at least one-third of the product budget?
5. Does the person in charge have a private secretary?
6. Will the advertisement budget be at least 5 % of anticipated sales?
7. Will a recognised brand name be on the product?
8. Would the company take a loss on it for the first year?
9. Does the company "need" the product more than it "wants" it?
10. Have three samples of advertising copy been developed?
11. Is the product really new, as opposed to improved?
12. Can the decision to buy it be made by only one person?
13. Is the product to be made in fewer than five versions?
14. Will the product not need service and repair?
15. Does the development team have a working code name?
16. Will the company president see the project leader without an appointment?
17. Did the project leader make a go of the last two projects?



18. Will the product be on the market for more than ten years?

19. Would the project leader quit and take the item with him or her if the company says it will not back it?

It is obvious that successful new products projects are a balanced mixture of good planning, good management, appealing concepts, research well employed but used with discretion, good timing, appropriate risk-taking, and a modicum of just plain good luck [21].

To improve our understanding of the company-level drivers of NP/SI success, Robert Cooper and Elko Kleinschmidt carried out a multi-firm benchmarking study. A total of 135 firms known to be active in new product / service introduction, from Europe and North America, participated in this study. The study considered new product / service successes in different ways, and included 10 measures of the company's new product / service program performance (here the term new product program refers to the totality of new product efforts of the company):

- *success rate*
- *percent sales*
- *profitability relative to spending*
- *technical success rating*
- *sales impact*
- *profit impact*
- *success in meeting profit objectives*
- *profitability relative to competitors*
- *overall success*

A performance map (see figure 8) was constructed based on the 10 performance metrics. Not surprisingly, the 10 performance metrics were closely connected to each other. Two clear, easy to interpret performance factors emerged from the analysis, were the following:

1. *Program impact*, comprising (in rank order): percentage sales by new products; the impact the program had both on company sales and profits; the success rate; and the technical success rating.
2. *Program profitability*, comprising: the program's actual profitability rating and the overall success rating, both relative to competitors; whether the program met profit objectives; the program profitability relative to spending; the impact of the program on the firm's profits; and whether the program met sales objectives [45].

These two performance factors become the Y and X axes of the performance map, on which the 135 companies were located.

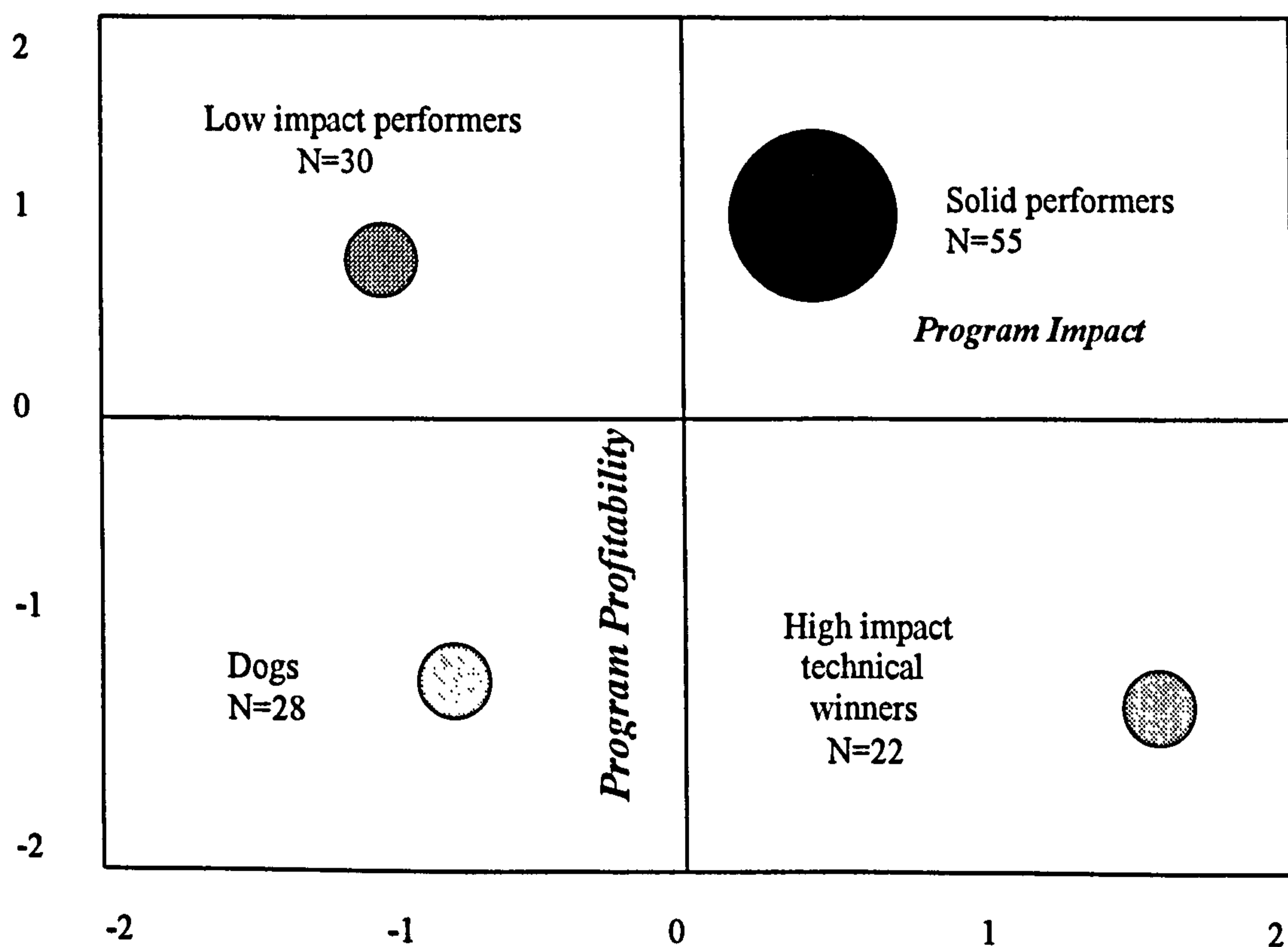


Figure 8: Performance Map  
Source: [45]

According to the results of this study, in rank order of importance, the *main performance drivers* that separated the Solid Performers from the Dog firms, are the following:

1. A high-quality new product process

2. A clear and well-communicated new product strategy for the company
3. Adequate resources for new products
4. Senior management commitment to new products
5. An entrepreneurial climate for product innovation
6. Senior management accountability
7. Strategic focus and synergy
8. High-quality development teams
9. Cross-functional teams

### 2.1.13 Elements of Efficient NP/SI Management

A major issue which needs to be addressed by managers, is whether to invest in new products or improve the efficiency of already established operations. Sands [46] suggests that the development of new products cannot be considered separately from the management of existing products. Varadarajan [47] goes one step further to propose , that the management of new products may be usefully viewed as an extension of the management of existing products. If one accepts these arguments, then the factors which determine efficiency in managing an existing business, will be broadly similar to those underlying efficiency in new product development.

Johne *et al.* [48] propose the use of the McKinsey Seven Ss Framework, popularised by T.J. Peters and R.H. Waterman [49] as a comprehensive framework for the examination of efficient product management practices. As pointed out by the authors, the seven Ss framework has the advantage of parsimony: efficiency factors are encompassed under only seven headings, all of which are readily understood by and meaningful to practitioners. Table 4, summarises how the seven Ss framework can be adopted with respect to NP/SI.

A successful NP/SI program needs to be managed and controlled so that a stream of new products are launched into the marketplace at the right time to counter

competitive threats and ensure the firm's survival and growth. Two studies have demonstrated how success can be a combination of both formality and flexibility.

In a study of innovators with varying expertise Johne [50], demonstrated that successful innovators apply largely informal and non-standardised procedures in the initiation stage of the NP/SI process. In this, the tasks of idea generation, screening and concept development are carried out in a flexible way, promoting creative problem-solving and feedback. However, once the product proposition is crystallised, more formal and rigid controls are exercised as the NP/SI process reaches its launch dates. At that point, tight co-ordination and control were identified as necessary, in order to successfully time the launch into the marketplace.

Framework Element	<i>Original Explanation</i>	<i>NP/SI Adoption</i>
Skills	The distinctive capabilities acquired by key personnel	What specialist knowledge and techniques are applied for existing NP/SI tasks?
Strategy	The plan leading to the allocation of resources	Is there a product development strategy which defines the sort of new products to be developed and the resources to be released for that purpose?
Structure	The characteristics of the organisation chart	What type of formal organisational structure is used to implement the NP/SI activities?
Shared Values	The goals shared by the organisation's members	Is there in the firm as a whole, an acceptance of the need to pursue a particular NP/SI strategy?
Style	The cultural style of the organisation	Do top managers provide active support for those involved in a key task such as NP/SI, or is a 'divide and rule' management style practised?
Staff	The type of functional specialists employed	What type of functional specialists are there for executing NP/SI tasks?
Systems	The nature of proceduralised control processes	What type of control and co-ordination mechanisms are used for executing NP/SI tasks?

Table 4: Principal factors underlying effective NP/SI

Source: [48]

In their study of Japanese innovators Takeuchi et al. [51] reported how project teams are left to create their own modus operandi, within the context of the overall company aims. Once procedures that were developed in that way prove to be successful, they become standardised and included in the company's NP/SI control procedures. Nevertheless, the systemisation applies only for procedures, which are not project-specific.

### 2.1.14 Conclusions

New Product / Service Introduction is a complete system involving most departments in a company. At the same time, the characteristics of a new product / service influence the operations of the rest of the company once the product / service is in production. The benefits of getting it right are company wide:

- if a new product or service meets the expectations of the customer it will be easier and more profitable to sell
- research and development efforts can be focused on the requirements for future product ranges and not just on challenging new technologies
- tools and techniques for improving the internal and external engineering processes involved in designing, testing and manufacturing new products must be acquired
- a product designed for ease of manufacture will be easier to deliver profitably to customers and will make the overall task of running a manufacturing operation easier both technically and from a personnel viewpoint
- the regular launching of products planned to position a company effectively against its competitors in international markets will ensure the success of that company
- the components of a product, created with the help of suppliers, will be cheaper to buy and to produce in volume with quality and reliability of supply [52].

What successful NP/SI projects seem to have in common are: 1. Support of top management; 2. Qualified, experienced leadership with decision making authority;

3. Formal organisation of a group or team responsible for the project; 4. Training programs to teach the skills and techniques of new product / service development; 5. A diverse, co-operative team; 6. Adequate staffing, funding, and vendor assistance [53].

In other words the company's overall new product / service introduction performance depends on:

1. Process: the firm's NP/SI process and the specific activities within this process
2. Organisation: the way the new product / service introduction efforts are organised
3. Strategy: the firm's total new product / service strategy
4. Culture: the firm's internal culture and climate for innovation, and
5. Commitment: senior management's involvement with and corporate commitment to new product / service introduction [45].

The NP/SI process is at last receiving the attention it deserves. This is shown by the large number of academic and business books and articles in journals describing best practices in the area of NP/SI found in the most successful companies both Japanese and Western.

New product success remains the critical challenge as we move into the next century. In the 1990s, many companies have awakened to the major role new products must play in their future quest for prosperity; some have even gone as far as trying to revitalise, restructure, and redesign their new product practices and processes for better results. Benchmarking against other firms is a popular first step [45].

## **2.2 Background on Engineering Change**

### **2.2.1 Introduction**

In an environment of ever shortening product life cycles, increased customer expectation, technology advancements and increased market competition, the only factor that remains constant within a modern manufacturing operation is change. Such changes are ultimately reflected in the products and the manufacturing processes.

One particular type of change apparent within a manufacturing or assembly environment is engineering change. Throughout every stage of a product's life cycle there may exist a requirement to change some parts to an existing product. The changes and modifications in forms, fits, materials, dimensions, functions, etc. of a product or component are usually referred to as engineering changes (ECs) [54].

In today's environment of ever decreasing new product introduction times and shorter life-cycles it is difficult to distinguish an Engineering Change for an existing product from the introduction of a new product for industry in general. What makes this all the more difficult is that a company's Engineering Change procedure is likely to use major parts of the new product design & development procedure. Thus there is a great deal of overlap between how the two tasks are managed. The boundary between the two is a somewhat grey area when the following arise:

- Enhancements/ permutations to an existing product, maybe created for a select few customers
- Extensions of an already existing product range, i.e. increases in the variety of a specific product type
- Evolutions of a product incorporating a few, but none the less significant, number of modifications and/or new components
- A 'generous' new top-level assembly number generation procedure which is triggered for even the smallest change

A product's engineering complexity also blurs the distinction. For example, the change to the plastic casing and button layout on a portable cassette player may well warrant the 'new product' tag, whereas a change to the fuel-pump system on a Boeing jumbo jet would not create a 'new' jet.

Regardless of the distinctions between the two definitions there is a need to manage a product's development throughout its life-cycle.

Engineering Changes are the method of implementing modifications to a product's design, documentation, and/or method of manufacture and arise for a number of reasons:

- *Design Enhancements*: to extend the product's life-cycle, broaden its range of applications or improve technical performance in order to improve manufacturability
- *Manufacturing Process Developments*: to redesign a component to meet process capability constraints or improve productivity
- *Materials Advancements*: materials with superior engineering properties or cheaper manufacturing costs may become available
- *Documentation Errors*: the storage of product information is susceptible to integrity problems and transposition errors.
- *Re-work*: incorrect design and/or un-manufacturable design

An EC can be desirable and add value to a product, such as an enhancement. It can extend the life expectancy of a product or enable that product to be more marketable. Engineering change can also be undesirable and non-value adding. It can be the result of poor initial design, badly selected suppliers or rushed new product introduction as a result of poor project management.

An EC can be as simple as a documentary amendment, or as complicated as a complete re-organisation. If ECs are handled properly and proactively, a company can gain significant competitiveness in the market place. This is clearly a move towards agile manufacturing. The essence here is the ability to change quickly and



easily. Failure to control ECs can lead to lost time and money, as well as a loss of control over the configuration of products, leading to a situation of low profitability [55] and the damaging of the company's reputation. Therefore, in order to manage such changes, procedures need to be in place to co-ordinate and control change in an effective manner.

There is a noticeable lack of literature on the subject of Engineering Change some of the main reasons for which might be:

- The strong interest in concurrent engineering to eliminate, or greatly reduce, the need for Engineering Changes
- The stigma attached to Engineering Changes, which are perceived to be patching-up solutions
- The belief that there is not much to understand about the subject [56], e.g. it is relatively straightforward and hence of little academic interest
- The growing popularity of Engineering Data Management systems which are perceived to have considered all the difficulties associated with engineering Change and thus have 'solved' the problem.

A comprehensive review of the literature on the area of Engineering Changes and their management was carried out. In this research the author used all available means including major CD-ROM databases, libraries, company data and the Internet. However, the literature on ECs proved to be extremely limited, in comparison with topics like New Product / Service Introduction, Concurrent Engineering, Quality Management and Process Improvement.

The review has found only a couple of dozen articles on the topic. A study by Wright [57] seems to be the most comprehensive review on the area of ECs as it was based on 15 relevant papers. Huang et al. [54] have reported, in a more recent study, the current best practices of EC management in UK manufacturing industries. Harmozi [58] has reported that the existence of an effective EC management system offers numerous benefits. A study by Terwiesch et al. [59] was also concerned with

the management of ECs. Another interesting research was carried out by Saeed et al. [60] in which they have tried to explore the avoidance of ECs through Focused Manufacturing Knowledge.

### 2.2.2 Importance of Engineering Changes

Understanding the implications of Engineering Changes is a very important part of streamlining the NP/SI process. Once the detailed design process begins, time pressures will start to be felt as each design refinement brings the planned launch date nearer. Excessive complexity is another pressure which can lead to many design changes [61].

As the Design Council explained in its “Organising product design and development” booklet, missing the date or entering the market with the wrong product may endanger the entire future of the organisation. Studies have shown that an important issue for successful product launches is the up-front effort of completing Engineering Changes early in the NP/SI process. In Japan, over 60 per cent of Engineering Changes occur during the definition stage and only 10 per cent during a redesign period prior to launch. In contrast, the characteristics displayed by UK and USA companies showed only 17 per cent of the changes to be during the early stages of the process compared to over 50 per cent during the period prior to launch.

The nearer to production release, the more difficult it is to influence (i.e. reduce) the overall cost of the product, especially when 70 to 80 per cent of the cost has been pre-defined during the design phase. In addition, the actual cost of making any changes accelerates rapidly as release approaches. The potential impact of early design for manufacturability, for example, can be represented as follows.

The cost of a change at:

- Concept stage = x

- Design stage = 10x
- Development stage = 100x
- Testing stage = 1,000x
- Post-release = 10,000x [61]

During 1993 the Design Council and EDS (Consulting Services) carried out a survey with the aim of discovering how well industry is performing. Responses to questionnaires represented 512 very different manufacturing companies, with a good spread between large and small ones and a spread of personnel from managing director right down and across the company. The major findings of this survey were the following:

- 50% of all products are late to market
- development costs overrun by 17%
- Between 10 and 20% of changes in product development occur after release to manufacture [62].

### **2.2.3 Engineering Change: Main Activities**

To change effectively one must map out the entire process from beginning to end – in every activity one needs to understand what the processes are and what they should be [63]. It is therefore obvious, that Engineering Change will involve a large number of activities. The main Engineering Change activities are listed and explained below:

- The justification of an Engineering Change
- The derivation of the effectivity date
- The management of the Engineering Change implementation
- The traceability/ recording of the Engineering Change

### Justification of an Engineering Change

People often confuse the reason for an Engineering Change with its purpose. The purpose of an Engineering Change may be to improve the performance of a product. However, that alone is not sufficient justification for implementing change to an adequately performing product. The reason for an Engineering Change must relate to the inadequacy of the product in some aspect of its performance.

It was proposed by Balcerak & Dale [64] that the reason for an Engineering Change can be defined as endings to the following: “The reason for this Engineering Change is that the present specification...”

An important element in the justification process is the classification of an Engineering Change to relay some sense of both the urgency & importance and size/complexity of change.

Vieth [65] proposes a three class system which views an Engineering Change from the aspects of cost, of implementation and frequency:

- Class A types are of low cost and can be implemented quickly
- Class B are the standard
- Class C are specials which appear infrequently and have high implementation costs.

Balcerak & Dale [64] identified three types of Engineering Change according to whether the specifications of finished components, assemblies, or both are affected:

#### Type 1 Components only

A change to the manufacturing specifications of one or more components. The change should have no effect on where the modified component can be used and therefore does not warrant a new part number.

**Type 2 Assemblies and New Components**

A change to an assembly which incorporates one, or more, new part numbers

**Type 3 Assemblies only**

A change to the content and/or configuration of an assembly. Includes changes to the Bill of Materials and assembly drawings which do not involve any new part numbers.

**Derivation of the effectivity date**

The term “effectivity date” is used in many cases to signify the date on which a part will become “live”, or better, available for use. Some possible definitions of the effectivity date as given by Balcerak & Dale [64] are:

- The date on which the first product to incorporate the change will be built
- The date from which customers will receive products incorporating the change
- The date from which the parts will be manufactured to the modified drawing
- The date on which inspection can dispose old drawings and inspect incoming purchased parts to the latest drawings
- The date from which new parts will be pulled from inventory

But, as Balcerak and Dale support, clearly since parts cannot be manufactured, inspected, booked in and out of stores, assembled and shipped to the customer all within one day, these different interpretations are incompatible.

Balcerak and Dale then give the definition of Effectivity Date for the three types of Engineering Change they have identified:

“The effectivity of a type 1 change is the date by which all tooling modifications must be complete, and from which the affected component will be manufactured according to the revised specification.

However, the effectivity of type 2 and 3 changes is defined at a higher level in the product structure:

The effectivity of type 2 and 3 change is the date by which all tooling and components must be available in sufficient quantity to satisfy demand, and the date from which components will be picked from stock, and assembly started according to the revised specification.”

Balcerak and Dale identified a number of determinants of the effectivity date: market forces, drawing office workload, availability of replacement parts, stock run-out, availability of replacement tools and tool wear out. All these should be taken into account when deriving the effectivity date.

#### Management of Engineering Change

A popular method for managing an Engineering Change is to have an Engineering Change Committee which varies in both the seniority of people who sit on it, and the stages throughout an Engineering Change life cycle in which it is involved.

Decisions made by the committee involve:

- Whether to implement the Engineering change
- Derivation of urgency/ effectivity date
- Resource allocation
- Review of progress against plan

There are a number of factors which contribute to the ineffectiveness of such an approach:

- The effectiveness of the committee is dependent upon senior representatives from all departments involved in Engineering Changes. The repeated absence of one or more representatives detracts from the committee’s ability to provide a company-wide perspective on any important issues arising.

- The dependency built into the Engineering Change procedure that nothing significant can happen until the committee says so. Thus the procedure requires the continual input of the committee and is seen as highly bureaucratic.
- Lack of timely and/or adequate information

#### Traceability/ recording of an Engineering Change

The act of implementing an Engineering Change generates two types of information: one which explains the details (technical, etc) of the change, and one which records that a change has taken place. The latter is sometimes known as “work history management” or “metadata” and gives rise to the issues of traceability and document control. The International Standard ISO9001 and in particular clauses 4.4.9, 4.5, can be a very useful aid for managing such kind of information as metadata.

#### **2.2.4. The Drivers of Engineering Change**

There are many reasons for the introduction of a change to a design or a product. Some changes are necessary for the survival of the product and some are discretionary in nature. Some examples of reasons for engineering changes, identified by Hormozi [58], are listed below:

1. Competition
2. Design Failure
3. Manufacturing
4. Purchasing
5. Government Regulation
6. Management

ECs are a reflection of a company’s ability to respond to external changes through the way it organises its internal company structure, manages its resources and derives its management policies to minimise the required internal changes.

ECs are largely perceived as a necessary evil that a company must do. However, they can also present opportunities to:

- Increase a product's technical performance to gain new customers
- Reduce manufacturing costs through design for manufacture
- Reduce, or eliminate, the need for service for a persistent problem area

ECs affect many operations, departments, and documents. Minor modifications from a customer perspective can turn into a difficult task for those implementing that modification. Once a change has been decided upon and approved, the impact of the change to downstream organisations and processes can be overbearing and costly. Consequently, an effective engineering management system is needed [58].

### **2.2.5 Conclusions**

The negative impact of ECs has been reported in a number of studies. ECs consume one-third to one-half of engineering capacity] and represent 20-50% of tool costs, which can easily account for over US\$ 100M in large development projects. However, the management of ECs is not well understood despite this importance. In the past, both practitioners and researchers have tended to view EC-related problems more as a tragedy than as a sign of process management. In particular, the support process administering ECs has received little attention, although it has been identified as one of the root causes of ECs cost. [59]

The key to successful management of ECs, from initiation and approval to actual implementation and follow-up, is the design of a formal engineering change management system (ECMS) and faithful adherence to its policies and procedures. Every organisation confronted with Ecs should design an ECMS consistent with its structure, products, and operations [58].



## CHAPTER 3

**METHODOLOGY OF THE RESEARCH****The Use of Business Process Modelling and Simulation**

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**3.1 Introduction**

The previous chapter gave a broad introduction and background into the areas of new product / service development and introduction to the market, and engineering changes and their management. This chapter, will explain and analyse the approach to the issues of NP/SI and ECs to satisfy the objectives of this research and achieve its aims; and also identify and describe the tools and techniques to be used for the successful completion of the research.

In the rest of this chapter, the methodology to be followed in order to accomplish these aims and objectives of the research is given, and also a comprehensive background on Business Process Modelling and Simulation (BPM & S), and how these can be used in order to improve the NP/SI process and effectively handle ECs within the NP/SI process. The specific technique for BPM&S, namely System Dynamics, which is going to be used in this research, is explained together with the criteria for choosing the software package *iThink* by High Performance Systems Inc.

### **3.2 Methodology of the Research**

This section describes the methodology followed in order to accomplish the aim and scope of the project. The author used all available sources of information (library, CD-ROM Databases, Internet, etc.) to complete an extensive literature review which equipped him with the necessary background knowledge to thoroughly understand the issues behind NP/SI process and ECs.

Using the knowledge gained by completing the literature review, the two sponsoring organisations in Greece were studied in order to investigate their NP/SI process and their EC procedure and ultimately collect information regarding real and actual cases of both NP/SI and ECs practices within these organisations. A large number of extensive interviews and discussions with appropriate personnel of the organisations were carried out. The interviews and discussions were carefully planned in order to ensure that all necessary and important aspects of NP/SI process and EC practices within these organisations would be identified, and included interviews and discussions from top level managers to lower level employees and designers.

The two organisations that were investigated were: the Hellenic Aerospace Industry (HAI) and C<sup>3</sup>T. Due to HAI's very large size, it was decided to separately investigate the Electronics Manufacturing Division and the Engines & Aircraft Maintenance Division.

By combining the knowledge gained by the visits to the organisations, the work-in-progress studies and the literature review, an attempt has been made to use BPM&S in order to map and model the generic structure of the NP/SI process and then use actual information and data from the two organisations in order to simulate the process and identify areas for potential improvement. Several disturbances were injected into the model, in various points, in order to understand the effect of ECs in terms of cost, time and quality for particular organisation. Following that, further work has been carried out in order to develop a generic Engineering Change

Management System (ECMS) to be adopted by any organisation for managing the EC actions effectively and efficiently. Again, using BPM&S and specifically the methodology of System Dynamics, the author developed a generic ECMS in such a way and format that it can be simulated and therefore be improved for the different cases of each organisation.

### **3.3 Business Process Modelling and Simulation**

#### **3.3.1 Types and Importance of a Process**

A process is “a series of actions which are carried out in order to achieve a particular result” [66]. In the field of business process modelling & simulation, a process has been, as follows:

“A process is a set of actions that, taken together, produces a result of value to a customer – developing a new product for example” [67]. “A process is a set of linked activities that take an input and transform it to create an output” [68]. “A process is simply a structured and measured set of activities designed to produce a specific output for a particular customer or market. It implies a strong emphasis on how work is done within an organisation, in contrast to a product’s focal emphasis on what is done. A process is thus a specific ordering of work activities across time and place, with a beginning, an end, and clearly defined inputs: a structure for action” [69].

Davenport and Short [70] suggest that a business process is: “the logical organisation of people, materials, energy, equipment and procedures into work activities designed to produce a specified end result.”

Using these definitions, you can see that almost everything we do is part of a process and that business processes play an important role in the economic survival of

organisations. The definitions are relatively simple, but most processes are not. Edward J. Kane, former director of quality for IBM Corporation, stated:

“Just taking a customer order, moving it through the plant, distributing these requirements out to the manufacturing floor – that activity alone has thirty sub-process steps to do it. Accounts receivable has over twenty process steps. Information processing is a whole discipline in itself, with many challenging processes integrated into a single total activity. Obviously, we do manage some very complex processes separate from the manufacturing floor itself” [71].

It is useful to divide business processes into three broad types: 1. Core processes; 2. Support processes; 3. Management processes, as shown in Figure 9:

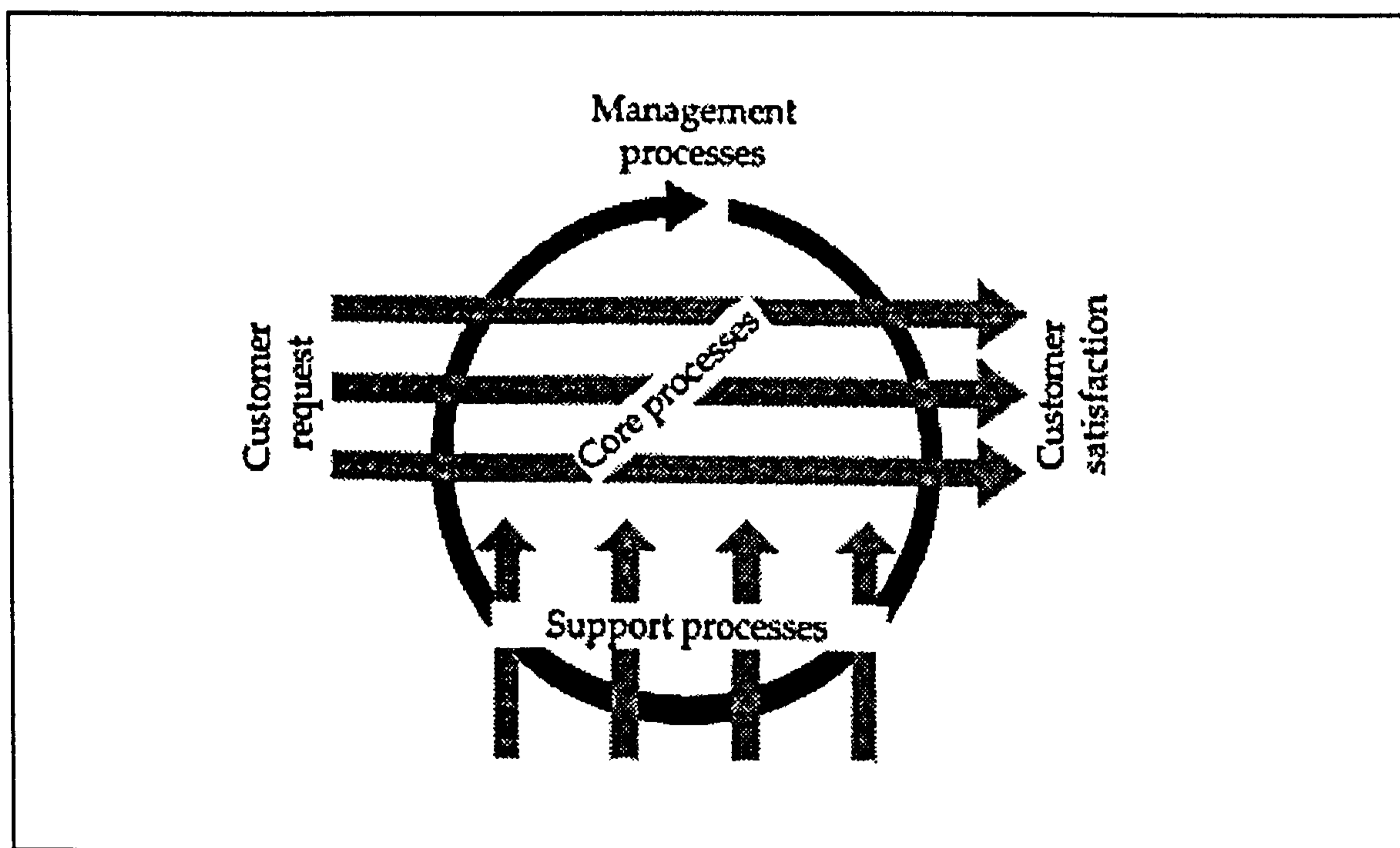


Figure 9: The three types of business processes

Source: [72]

Core processes concentrate on satisfying external customers. They directly add value in a way perceived by the customer of the business. They respond to a customer request and generate customer satisfaction [72].

Support processes concentrate on satisfying internal customers. They might add value to the customer indirectly by supporting a core business process, or they might add value to the business directly by providing a suitable working environment [72].

Management processes concern themselves with managing the core processes or the support processes, or they concern themselves with planning at the business level [72].

There have been a number of “movements” in the 1980s and early 1990s that have made people recognise that processes exist in companies, and that these processes are what the organisation is about. In each the central notion is that of process and consequently there is a need to be able to picture a process, through process modelling. The importance of a process can be identified by looking at various situations:

- Situations where there is a need for shared *understanding* of what the business does and how it does it.
- Situations where a *common approach* is to be adopted and perhaps mandated, for instance through a Quality Management System.
- *Incremental improvement* programmes, such as might be initiated under the banner of TQM.
- *Radical change* programmes, such as might be carried out using the principles and techniques of Business Process Re-engineering.
- Situations where the alignment of information technology systems with the needs of the business is being questioned.
- Situations where new forms of process technology such as workflow management systems and workgroup computing systems are to be applied to give active support to the business process [72].

### 3.3.2 The Need for Process Modelling

Any business can be viewed as a collection of processes. These processes change as organisations evolve over time in response to their business environments. To keep ahead of the market competition, new ideas and change of business tactics have to be achieved quickly and efficiently. Process modelling has evolved as a technology for describing processes such that they may be understood and evolved with greater ease, and increased organisational visibility [73].

Mark Greenwood [74] has a useful categorisation of reasons for modelling:

#### *1. To describe a process*

This is what we do when we want:

- to define a process
- to communicate it to others
- to share it across a group of people
- to negotiate around it

If, for example, a group is seeking ISO9001 certification for its Quality Management System it will want to define its processes in its Quality Manual. A descriptive process model - in some form - will therefore be found in such a Manual. In a sense, it acts as a work instruction to people in the organisation. Text is very often used to describe how things are done, but it is hard in the serial nature of text to describe something that has possibly many threads, decisions, concurrent activities and so on. A diagram is a traditional way of dealing with this [72].

#### *2. To analyse a process*

Once having a model of a process, one may well want to use the model to explore the properties of the process itself. Such a qualitative and quantitative analysis is a common precursor to improving the organisation by:

- changing the ordering of activities
- changing responsibilities for activities or decisions

- changing scheduling mechanisms
- increasing or decreasing the amount of parallel activity
- removing (or inserting) buffers or stores for materials between steps in a process
- restructuring functions to align them better with the process
- and so on [72].

### 3. *To enact a process*

By modelling business processes it is possible to give a computer system the process model and have it enact, i.e. “run” the model, supporting the participants in the process as the process proceeds, handling their agendas, supporting their interactions, and perhaps playing its own part in the process. Systems that provide this sort of support are termed enactment systems and they provide us the third motive for process modelling: they require a process model whose “meaning” is sufficiently well defined to allow them to enact the process without further human intervention to define it.

Ould [72] has identified eight ‘laws’ which capture some general needs of the process modeller:

1. If abstractions are necessary, they have to be concrete ones
2. The real world is messy, therefore notation must be able to model mess when necessary
3. A model must mean something and only one thing.
4. Process models are about people, and for people; the notation must make sense to people.
5. It must be possible to model both what people actually do and what they effectively do
6. A model must capture both processes and functions
7. A process is about doing, deciding, and co-operating. Not about data.
8. There are some basic business patterns, and these need to be identified

### 3.3.3 Basic Concepts in Process Modelling

The challenge for aerospace, and in general, engineering organisations is not only to advance science and technology through its products but to develop world class product development processes in the application of new and existing technology [75]. It was said by Hammer and Champy that “it is not products but the processes that create long term success. Good products do not make winners; winners make good products”.

Engineering businesses are very complex organisations, and embarking on a programme involving process modelling is not a trivial event, as many industrialists will testify. Revealing the complex array of interrelated activities in a way that provides insight for improvement is a huge challenge and one which requires the same systems engineering skills which are used to develop a product applied to the definition of a process [18].

Engineering businesses have traditionally documented their project operations as company procedures; however these suffer on three counts:

1. They are rarely written from a process perspective, they are more like a collection of instructions about how to proceed with a task in hand, but nothing of how these tasks fit together into a coherent whole.
2. They are usually written at the lowest level of operation, and as such are very prescriptive, detailing how things are to be done, rather than what is to be achieved and why.
3. They are infrequently referred to and not respected by the employees. [18]

Modelling is an abstraction of reality. Abstraction means limiting the view of reality to consider only those aspects of a situation that are of interest. Modelling of any system may be advantageous, as it enables knowledge to be consolidated and understanding to be gained. Coherent representations, models, or analytic



frameworks, which exist in the conceptual world, can help debate in the real world, without assuming that these models are in fact descriptions of empirical reality [18].

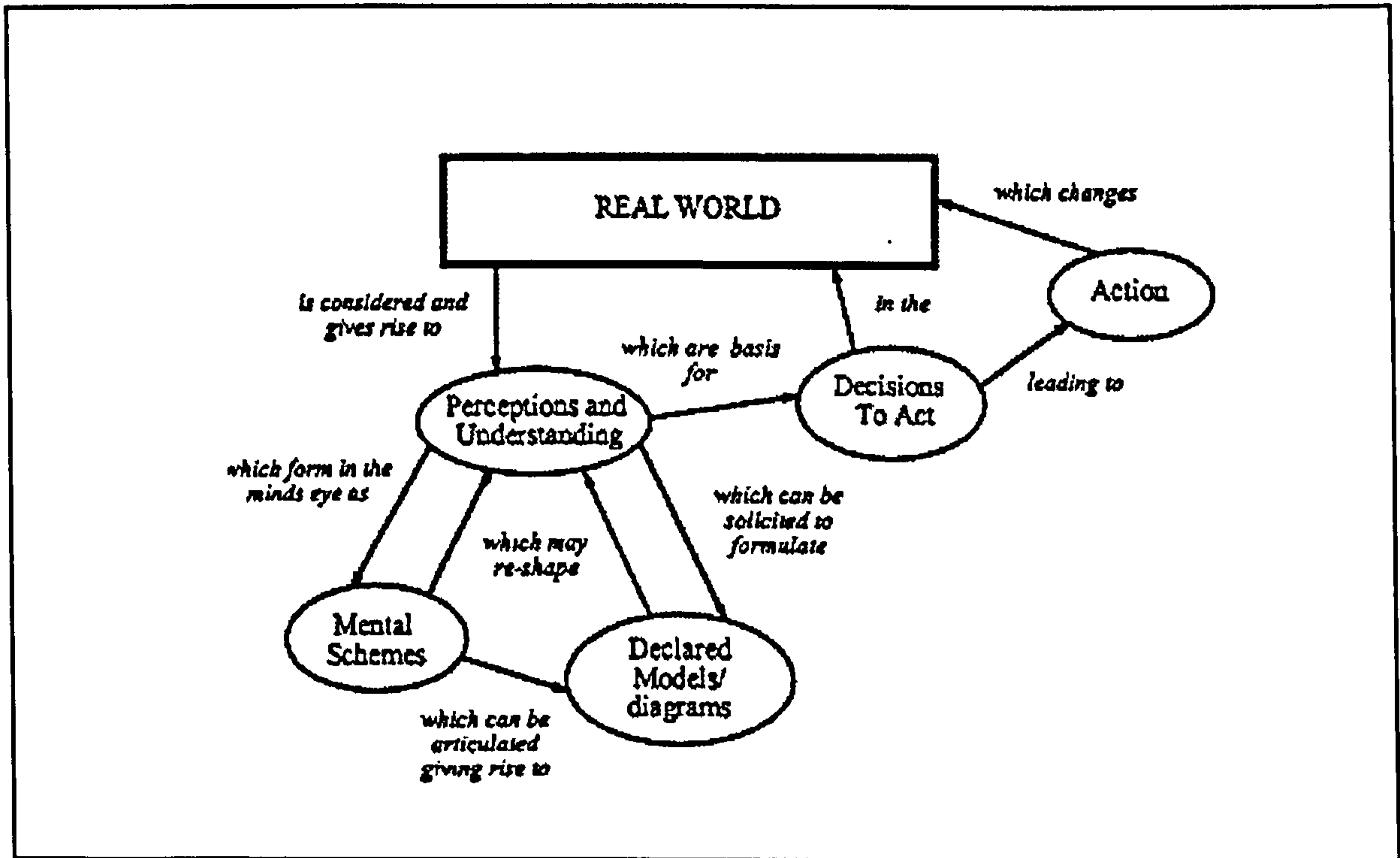


Figure 10: How we use models

Source: [18]

The above figure reveals how models are used in order to form and re-form perceptions and understandings about things that are going on in the real world. If each member of a project team holds the same perceptions and understanding of a process then the decisions made to act in the real world are made on the same premise. *The aim of process modelling*, in this context, is to acquire shared perceptions and understanding about the project process in order for unambiguous dialogue to take place, and effective decisions about actions to be formulated [18].

The importance of understanding a process and its internal and external structure and relationships may be realised by looking at the results it may have, like the unification of all functional divisions by a common aim and purpose which enables activity to be guided so that it meets the process objective.

Business process modelling usually deals with different views of a company. The key to success is to deal with the interaction between them. Figure 11 illustrates these different views of a company interacting with business process modelling.

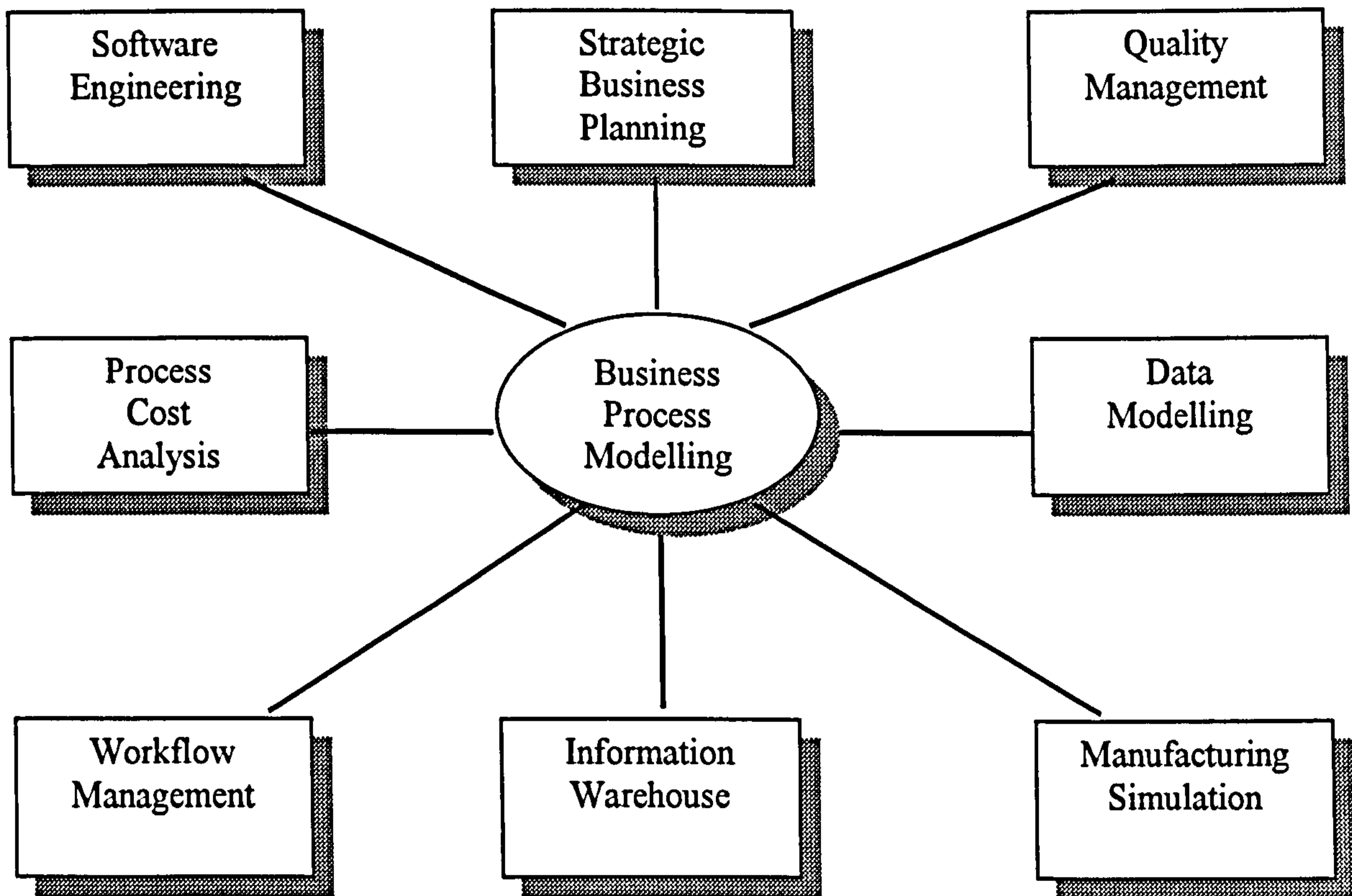


Figure 11: The different views of a company interacting with business process modelling.

Source: [76]

Process modelling plays an essential part in challenging existing processes by helping to pose a variety of critical questions including:

- Is the complexity necessary?
- Are simplifications possible?
- Are there too many interdepartmental transfers?
- Is the process effective?
- What drives the process cost?
- How is quality assured? [68]

### 3.3.4 Methods and Notations for Business Process Modelling

Due to the complex and dynamic nature of organisations, it has been argued that carefully developed models are necessary for understanding their behaviour in order to be able to design new systems or improve the operation of existing ones [77, 78, 79]. However, this very complexity of business processes can make modelling an arduous and problematic task [80].

Within process modelling there are many methods and notations which may be used in order to describe the process under careful examination. These methods range from formal (mathematical) rigorous notations, to more graphical (easier to understand) notations. Each of these kinds of notations has its own advantages and problems. Typically formal notations, may be executed on a computer and run (as programs) to study in detail the behaviour of processes. However, the main problem with such notations, is that they are difficult to present to anyone other than an expert. Hence, it is difficult to validate process scenarios with users. In contrast, diagrammatic or graphical notations are excellent for process elicitation and presentation, since they may be understood with relative ease in a short space of time. However, they do not provide the benefits of rigorous process experimentation which can be gained with enactable notations [73].

A model that makes the process visible to the parties concerned can bring great value to itself [72]. In many professions modelling has been a proven method for translating information. Architects use models and engineers use blueprints to provide graphic representation of a completed structure. Models can be used to help visualise current and future business processes. To aid communication, it is necessary to build descriptive models that attempt to represent the business 'as is' or 'as desired'.

Modelling tools should be capable of capturing the high-level processes and the context of the business within its market place. A properly chosen process modelling tool satisfies the following criteria [69]:

- It is fast and easy to use at a high-level;
- It is applicable to the portrayal and analysis of the new process, enabling new and old processes to be compared in the same formats and perhaps even driven by the same set of simulation variables;
- It provides not only a descriptive, but also an analytical, model of the process, facilitating an understanding of such factors as time, cost, and other resources consumed by the process; and
- It supports the addition of successive levels of systems and data-oriented detail, enabling it ultimately (and seamlessly) to serve a useful purpose during the systems design and/or prototyping stages.

Business Process Modelling is nothing new. Management and operations engineers have attempted to model activities for many years. Whatever tool is employed, an immediate advantage of the graphical representation is that possible simplifications become apparent. These may arise from:

- Elimination of duplicated or redundant activities
- Avoiding unnecessary data collection
- Avoiding unnecessary decision points
- Moving from a serial process to a parallel
- Combining or separating process flows
- Avoidance of unnecessary movement

Giaglis [81] explained how the concept of ‘modelling techniques’ fits within hierarchical decomposition of modelling elements (the same line of thought has been followed by Kettinger [82]). According to this decomposition (see Figure 12), Business Process Modelling can be thought of as being supported by one or more

methodologies. Methodologies are taken to refer to modelling paradigms (for example, data-focused, object-oriented, soft-systems, and so on), which are outside the scope of this project. Regardless of the methodology used, modelling can be supported by a number of techniques that provide the main focus of the rest of this section. Techniques are taken to refer to diagrammatic or other notations for studying and analysing modelled systems. Specific techniques, as well as their underlying methodologies, can be supported (and in most cases are supported) by software modelling tools, such as CASE tools, Workflow Management Systems, process modelling software, and others. Like methodologies, the study of modelling tools falls outside the scope of this research project.

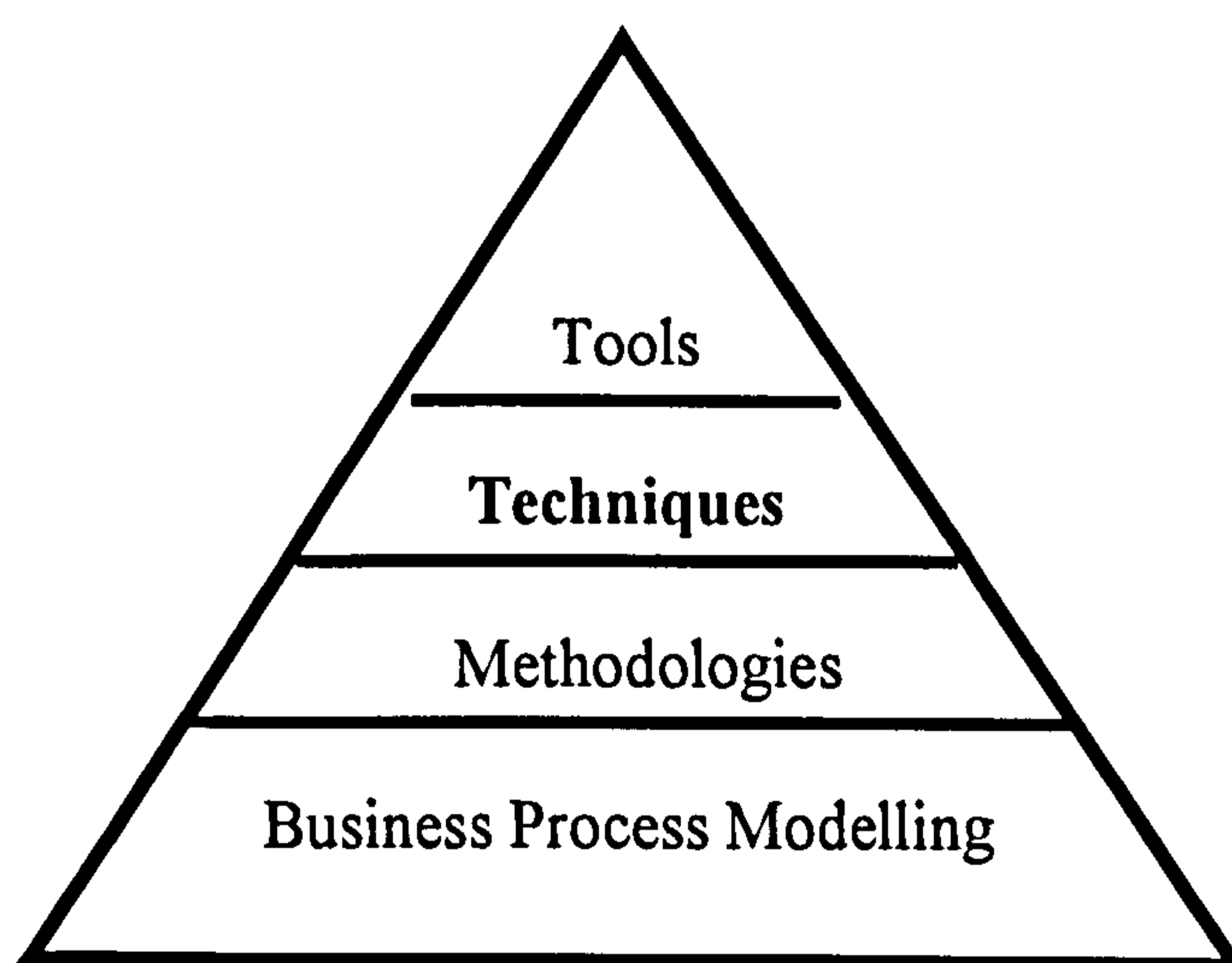


Figure 12: Business Process Modelling, Methodologies, Techniques and Tools

*Source: [81]*

Business process models can be used in a variety of contexts. The goals and objectives of a particular study will necessarily impact the uses to which a model will be put and therefore influence the requirements posed on the process representation formalisms to be employed [79]. Table 5 illustrates typical BPM goals and objectives, along with associated requirements for modelling techniques in each case [83].

Modelling Goals & Objectives	Requirements for Modelling Techniques
<i>Support Human Understanding and Communicating</i>	Comprehensibility, Communicability
<i>Support Process Improvement</i>	Model Process Components, Reusability, Measurability, Comparability, Support Technology Selection and Incorporation, Support Process Evolution
<i>Support Process Management</i>	Support Reasoning, Forecasting, Measurement, Monitoring, Management, and Co-ordination
<i>Support Process Development</i>	Integrate with development environments, Support for Process Documentation, Reusability
<i>Support Process Execution</i>	Automate Process Tasks, Support Co-operative Work, Automate Performance Measurement, Check Process Integrity

Table 5: BPM Goals and Objectives

Source: [83]

To be able to accommodate the aforementioned goals and objectives, a model must be capable of providing various information elements to its users. Such elements include, for example, what processes comprise the activities, who is performing these activities, when and where are these activities performed, how and why are they executed, and what data elements they manipulate. Modelling techniques differ in the extent to which their constructs highlight the information that answers these questions. To provide this information, a modelling technique should be capable of representing one or more of the following ‘process perspectives’ [83]:

- a) *Functional perspective*: represents *what* process elements (activities) are being performed
- b) *Behavioural perspective*: Represents *when* activities are performed, as well as aspects of *how* they are performed through feedback loops, iteration, decision-making conditions, entry and exit criteria, and so on.
- c) *Organisational perspective*: Represents *where* and *by whom* activities are performed, the physical communication mechanisms used for transfer of entities, and the physical media and locations for storing entities.
- d) *Information perspective*: Represents the informational entities (data) produced or manipulated by a process and their relationships.

The combination of modelling goals and objectives (Table 5) with the perspectives of modelling can provide the basis of an evaluation framework for studying, analysing, and comparing extant and new business process modelling techniques. This framework, suggested by Giaglis [81], is illustrated in Figure 13. The framework suggests three evaluation variables to classify and evaluate modelling techniques: Breadth (the modelling goals typically addressed by the technique), Depth (the modelling perspectives that are adequately covered), and Fit (typical projects to which the technique can be fitted). The analytical power of the framework lies in its ability to match project characteristics to the modelling goals and perspectives typically associated with them.

<b>DEPTH</b>							<b>FIT</b>
Informational (Data)	SYSTEMS DOCUMENTATION	SYSTEMS DESIGN	SYSTEMS PROJECT MANAGEMENT	SOFTWARE REENGINEERING / SYSTEMS DEVELOPMENT	SYSTEMS OPERATION / MAINTENANCE		
Organisational (Where, Who)	ORGANISATIONAL STRUCTURE MODELLING	ROLE DESIGN	HUMAN RESOURCE MANAGEMENT	WORKPLACE DESIGN	-		
Behavioural (When, How)	BUSINESS PROCESS DOCUMENTATION	BUSINESS PROCESS REENGINEERING	BPR PROJECT MANAGEMENT	WORKFLOW DESIGN	WORKFLOW EXECUTION		
Functional (What)	TASK DOCUMENTATION	TASK REDESIGN	CPI/TQM PROJECT MANAGEMENT	TASK QUALITY ASSURANCE / CONTROL	AUTOMATED TASK EXECUTION		
	Understanding & Communicating	Process Improvement	Process Management	Process Development	Process Execution		
						<b>BREADTH</b>	

Figure 13: An Evaluation Framework for BPM Techniques

Source: [81]

As different companies have attempted to improve their operations and academia to contribute to knowledge, many different BPM techniques have evolved, including the following ones.

#### **3.3.4.1 Soft Systems methodology**

In Figure 12 it was shown how the concept of modelling techniques fits within hierarchical decomposition of modelling elements. BPM is being supported by one or more methodologies. At this stage it is important to mention the soft systems thinking methodology developed by Peter Checkland [84].

Hard systems thinking relies on starting from careful description of something that is required and then finding the most appropriate (efficient, economic, elegant) means to achieving that end (“means-end”). It is necessary to work back from the purpose or objective to create a “system” that will achieve the desired objective. However, this is sometimes difficult, especially when there are many views and perceptions to resolve. Peter Checkland searched for an approach that would cope with defining objectives in messy situations with lots of human interaction. He developed soft systems thinking for analysing human activity systems (HAS) [84]. Soft Systems thinking is applied in situations where human involvement is the most crucial aspect for successful operation and its application queries the function and objectives of the HAS [85]

It is probably the “means-end” and “system” discoveries that more than anything led Checkland to conclude that there are two paradigms in systems thinking, the second of which is the paradigm inhabited by SSM. With paradigm 1, the hard paradigm, the real world is assumed to be systemic and the methodologies that are used to investigate that reality are systematic. Paradigm 2, the soft paradigm, turns things around stating that the real world is problematical but the processes of enquiring into



it, the methodologies, may be systemic. This transfers the notion of systemicity from the world to the process of enquiry into the world. [86]

As Cole & Boardman [85] explain, Checkland developed his Soft Systems Methodology (SSM) as a modelling framework supporting his philosophy of Soft Systems Thinking. SSM fluctuates between the boundaries of the ‘real world’ and the conceptual modelling world, as shown in Figure 14. SSM is not usually concerned with well-defined (often technical) problems in organisations – such as to maximise the output from a manufacturing facility – but with the ill-structured problem situations with which managers of all kinds and at all levels have to cope [87]. More information about the emergence of SSM can be found on ‘Soft System Methodology in Action’ by Checkland and Scholes [88].

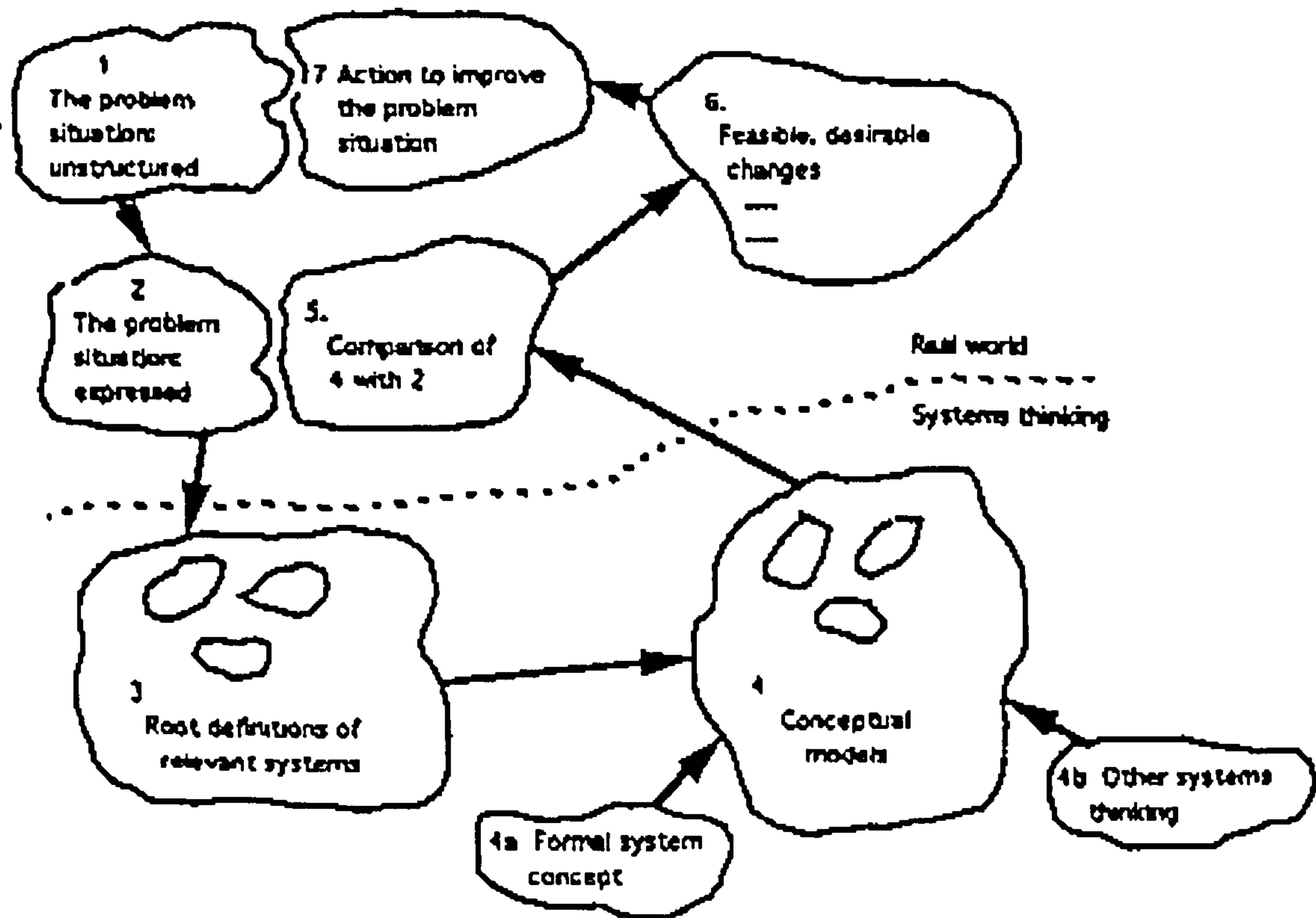


Figure 14: Checkland’s Soft Systems Methodology (CSSM)

Source: [84]

Peter Checkland describes his SSM as a methodology which contains two kinds of activity, the 'real world' activities and the 'system thinking' activities. He divided these activities into 7 stages, which he describes [84] as follows: Stages 1 and 2 are an 'expression' phase during which an attempt is made to build up the richest possible picture, not of 'the problem' but of the situation in which there is perceived to be a problem, by gathering information based on human perceptions and understanding of how the system functions. Stage 3 then involves naming some systems which look as though they might be relevant to the putative problem and preparing concise definitions ('root definitions') of what these systems are. Stage 4 consists of making conceptual models of the human activity systems named and defined in the root definitions. Model building is fed by stages 4a and 4b: 4a is the use of a general model of any HAS which can be used to check that the models built are not fundamentally deficient; 4b consists of modifying or transforming the model, if desired, into any other form which may be considered suitable in a particular problem. In stage 5 the models are then 'brought into the real world' and set against the perceptions of what exists there. The purpose of this 'comparison' is to generate a debate with concerned people in the problem situation which, in stage 6 will define possible changes which simultaneously meet two criteria: that they are arguably desirable and at the same time feasible given prevailing attitudes and power structures, and having regard to the history of the situation under examination. Stage 7 then involves taking action based on stage 6 to improve the problem situation.

Boardman carried out Checkland's work on SSM and he developed the Boardman Soft Systems Methodology (BSSM). BSSM embraces Checkland's soft systems philosophy of analysing HAS; taking views from the real world, translating these views into the conceptual world of systems thinking, creating and examining models, and comparing these with the real world situations [89]. It is similar in parts to the CSSM, but differs in respect of stages of approach and the unique form of the model. Boardman divided his SSM into six stages, as illustrated in Figure 15.

The first stage of the BSSM is concerned with a broad understanding of the process area to be modelled – Definition of Process System Under Observation. The second stage involves obtaining the data from documents and by interviewing process agents – Data Solicitation. The third stage concerns systematically organising the process data – data Structuring. The fourth stage provides guidance for constructing the process systemigram (unique pictorial representation which supports key descriptions of the system) – Process Model Creation. The fifth stage involves integrity checking the models and the referral of the model to the audience from which the data was extracted in order to ensure that it is a faithful representation of the views held – Process Validation & Verification. The final stage refers to the way in which the model can be used to benefit the participants in the process and the process itself – Process Improvement [85].

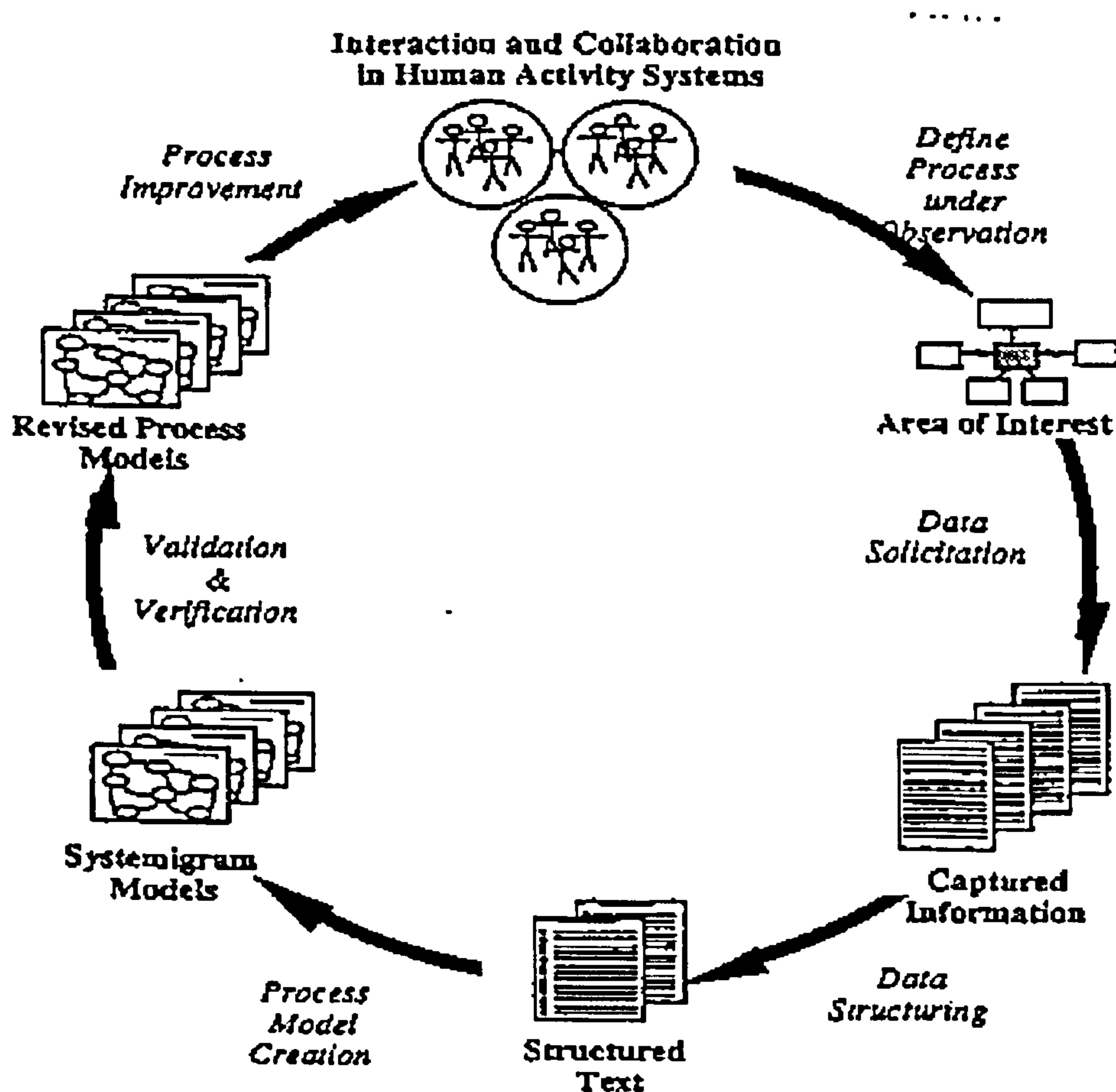


Figure 15: Boardman Soft System Methodology – Process Modelling Technique  
Source: [85]

### 3.3.4.2 Flowcharts

When a business decides to take on the task of modelling processes for itself, rather than calling in consultants to do it for them, the most common representation used is a process flowchart. A process flowchart represents the sequence of operations in a process. It is readily accepted by most people in business, it is clear and logical [18] and is readily understood.

Flowcharting is amongst the earliest graphical modelling techniques, dating back to the 1960s [90]. It is a static graphical technique that can be used to depict processes by illustrating their components (individual activities) and the relationships between them. The purpose of flowcharting is to help in visualising and presenting a process in an unambiguous way that cannot be achieved by textual descriptions. The advantages of flowcharts centre on their ability to show the overall structure of a system, to trace the flow of information and work, to depict the physical media on which data are input, output, and stored, and to highlight key processing and decision points [91].

A good flowchart provides a clear line of communication between its originator and the user. The flowchart defines each step as it proceeds from operation to operation illustrating the work that is to be done. The flow chart does not describe the steps in detail, but only represents the workflow. Communication is further facilitated because unique symbols are used to depict similar operations.

The flow charts are read in the same manner that we learned to read a page, from the upper left-hand corner of a page, left to right and top to bottom. The symbols used are simple and easy to learn.

When drawing a flow chart it is important to keep in mind that a flow chart is like a road map – with this exception: the ground the originator is travelling over has never

been previously mapped; once drawn, it is the path everyone who follows must travel to arrive at the correct destination.

### **3.3.4.3 IDEF Techniques (IDEF0, IDEF3)**

IDEF0 is a graphical modelling language and method for describing processes. It is one of the Integrated DEFINition (IDEF) methods developed by the United States Air Force. The IDEF methods were developed for the integrated computer aided manufacture (ICAM) programme and are powerful tools for analysis, specification and design of integrated manufacturing systems. The IDEF method is often preferred for manufacturing systems analysis over other information systems analysis techniques, because it handles material flow as well as information flow [18].

The IDEF methodology consists of methods for modelling the process structure, the data needed to support the processes and the dynamic behaviour of processes of a manufacturing enterprise. The original intentions were to model, in a structured representation, the characteristics of manufacturing which would enhance the understanding of manufacturing and how to improve it.

The IDEF family of modelling techniques was developed as a set of notational formalisms for representing and modelling process and data structures in an integrated fashion [76]. IDEF methods are used to perform modelling activities in support of enterprise integration. The original IDEF Methods were developed for the purpose of enhancing communication among people who needed to decide how their existing systems were to be integrated. IDEF0 (Function Modelling Method) was designed to allow a graceful expansion of the description of a system's functions through the process of functional decomposition and categorisation of the relations between functions. IDEF1 (Information Modelling Method) was designed to allow the description of the information that an organisation deems important to manage to

accomplish its objectives. IDEF2 (Dynamic Modelling Method) was developed to assist in the design of a dynamics model. IDEF3 (Process Flow and Object State Description Capture Method) has been developed to support the structuring of descriptions of the user view of a system; and IDEF5 (Ontology Description Capture Method) serves as a method for fact collection and knowledge acquisition.

The second class of IDEF methods that have been developed are focused on the design portion of the system development process. That is, they encapsulate the best known method for design with a particular technology (or class of technology). Currently, there are two IDEF design methods; IDEF1X (Data Modelling Method) and IDEF4 (Object-Oriented Design Method). IDEF1X was developed to assist in the design of semantic data models. IDEF4 was developed to address the need for a design method to assist in the production of quality designs for object-oriented implementations.

The use of IDEF0 for process modelling of systems is widespread though it does have its critics. Some claim that the decomposition can obscure as much as it clarifies, others claim that it is insufficiently precise (e.g. it does not show conditional paths), though this lack of precision can be an advantage, allowing the modeller to skate over areas of marginal interest [92].

#### **3.3.4.4 RAD (Role Activity Diagram)**

Role Activity Diagrams (RADs) are diagrammatic notations that concentrate on modelling individual or group roles within a process, their component activities and their interactions, together with external events and the logic that determines what activities are carried out and when [93].

This method of modelling processes is to observe the process from the point of view of the roles capturing the interactions within a diagram. Roles carry out actions

(activities) and make decisions about what to do and when, according to the business rules. RADs illustrate the roles that are taken in a process (which are entirely related to the people, positions or departments involved), the activities they undertake and the decisions that are taken to control the process. In some ways, this form of modelling is not necessarily the best for the organisational design because [92]:

- Much of the detailed knowledge in the precise interaction of roles may not be necessary to identify opportunities for improvement;
- Behaviour within a process can vary according to the interpretation by individuals.

### 3.3.4.5 Gantt Chart

A technique that is very widely used in the industry for modelling activities and tasks is the Gantt chart. Gantt chart is a very easy and useful technique, which is mostly used for project planning. A Gantt chart is a bar chart that shows the relationship of activities over time. Table 6 gives the symbols often used in a Gantt chart. An open bracket indicates the scheduled start of the activity, and a closing bracket indicates the scheduled completion. A heavy line indicates the currently completed portion of the activity. A caret at the top of the chart indicates current time.

Symbol	Meaning
[	Start of an activity
]	End of an activity
[—]	Actual progress of the activity
V	Point in time where the project is now

Table 6: Gantt chart symbols

Henry L. Gantt developed Gantt charts around 1900, as an objective method for project planning. Gantt chart can be considered as a model of a project or process,

which clearly presents all activities and tasks within the project and clearly showing the progress of the project over time.

#### **3.3.4.6 Petri Nets**

Amongst the techniques traditionally used for systems modelling, perhaps the one that has received the most attention as a potential candidate for business process modelling as well, is Petri Nets [94]. Basic Petri Nets are mathematical/graphical representations of systems, aiming at assisting analysis of the structure and dynamic behaviour of modelled systems, especially systems with interacting concurrent components [95]. A basic Petri Net graph is composed of a set of states and a set of transitions.

Petri Nets have been used in such application areas as modelling of computer hardware and software. However, it has been recognised that basic Petri Nets are not succinct and manageable enough to become useful in modelling more high-level, complex business processes [96]. As a result, a number of extensions to the basic Petri Net formalism (usually to include the notions of ‘colour’, ‘time’, and ‘hierarchy’) have been proposed [81]. These extensions are collectively referred to as ‘high-level Petri Nets’ [97]. Such extensions include, for example, Generalised Stochastic Petri Nets (GSPN), Coloured Petri Nets (CPN), and others [81].

#### **3.3.4.7 Knowledge-based Techniques**

In the last few years, techniques based on Artificial Intelligence (AI) have started to appear as building blocks in business process modelling applications [98]. These techniques are mainly targeted to addressing the issue of linking business processes to organisational rules and business objectives in a formal manner [99]. Amongst the AI techniques that have been proposed, Knowledge Based Systems (KBS) and



qualitative simulation seem to have attracted the most attention by researchers and will be reviewed here.

### Knowledge-based Systems

Ba et al [100] present a knowledge-based enterprise modelling framework to support organisational decision-making in the context of strategic change. This framework bases its reasoning about a particular organisation upon a 'library of knowledge' representing significant organisational phenomena from different perspectives and at different levels of detail. The authors also present an Intranet-based prototype implementation of their framework to illustrate its ideas and concepts [81].

In a similar vein, Compatangelo and Rumolo [101] advocate the use of knowledge-based techniques, with emphasis on automated reasoning, to address enterprise modelling at the conceptual level. They claim that their approach could form the foundation of a framework for the development of computer-aided modelling tools endowed with automatic reasoning capabilities. The authors present the concepts of the EDDL<sub>DP</sub> language, which is a concept language based on description logics, and discuss (on the basis of a practical example) how the language could be used for creating an enterprise knowledge base.

### Qualitative Simulation

Nissen [102-103] follows a similar approach and employs the AI technology of qualitative simulation for developing models of organisational processes for the purpose of informing the process of analysis and redesign. Qualitative Simulation is the fundamental technology of the common-sense reasoning branch of AI and exploits the use of knowledge to support 'intelligent' reasoning about modelled phenomena. Qualitative simulation is similar to discrete-event simulation in that both techniques seek to develop models in order to abstract away from the complexity of real-world phenomena, but they are also fundamentally different regarding the amount and detail of information needed to specify models. Indeed,

qualitative simulation enables entities and relationships to be modelled and codified even with only minimal understanding or information regarding them. The output of qualitative simulation is an 'environment', or, in other words, a description of all possible behaviours for the modelled process [81].

Despite its potential advantages, qualitative simulation presents a number of limitations when applied to modelling business systems and processes. Its inherently qualitative nature makes qualitative simulation more suitable for modelling general classes of phenomena, as opposed to specific instances. Nissen [103] recognises that qualitative and quantitative simulations should complement each other if a comprehensive picture of the organisational processes is to be drawn. The author also recognises that 'the environment ... suffers from considerable ambiguity, and provides nowhere near the level and amount of information we would expect from a quantitative simulation model'. Moreover, the simulation generates a very large state space, even for simple processes, and therefore may represent a complex and laborious process even for simple model development efforts [81].

#### **3.3.4.8 Process Simulation Modelling**

Simulation is the process of constructing a model of a system which contains a problem and conducting experiments with the model, usually on a computer, for a specific purpose of experimentation to solve the problem [104]. Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose, either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system [105].

Practical simulation modelling usually originates in a management perception of a problem requiring some decision or understanding [106]. The problem may concern or involve the operation of some complex system on which direct experimentation

may be impractical on grounds of cost, time or some human restriction [107]. Simulation models provide a potentially powerful tool for conducting controlled experiments by systematically varying specific parameters and re-running the model.

The most important advantages of simulation over other operational research techniques are described by Law and Kelton [108] as follows:

- Most complex, real-world systems with stochastic elements cannot be accurately described by a mathematical model that can be evaluated analytically. Thus, simulation is often the only type of investigation possible.
- Simulation allows estimation of the performance of an existing system under some projected set of operating conditions.
- Alternative proposed system designs can be compared via simulation to see which best meets a specified requirement.
- In a simulation we can maintain much better control over experimental conditions than would generally be possible when experimenting with the system itself.
- Simulation allows us to study a system with a long time frame in compressed time.
- Simulation, especially when combined with graphical animation and interaction capabilities, facilitates better understanding of a system's behaviour, of the impact of proposed changes and allows for better communication of results.

Simulation has been identified as a suitable technique for Continuous Improvement projects. Once in use, simulation models encourage a culture of measurement that supports continuous process improvement. Some characteristics of simulation that make it ideal for business process modelling and improvement tools, were identified by Giaglis and Paul [107] and include:

- Simulation helps to define deficiencies early in the design process when correction is easily and inexpensively accomplished.

- Simulation models can be easily updated to follow changes in the actual system, thus enabling model maintenance and reusability.
- Simulation models can improve decision quality through their consistency and objectivity.
- Simulation models can help the decision makers generate and communicate ideas and interact with the model to immediately assess the impact of proposed changes.
- The stochastic nature of business processes can be modelled in a simulation study.
- The analysis of results can be targeted to match the objectives of specific studies.
- Simulation allows the decision maker to obtain a ‘system-wide’ view of the effects of ‘local’ changes in a system and allows for the identification of implicit dependencies between parts of the system.
- Finally, simulation encourages a cultural shift in the way modelling is perceived in an organisation, by means of continuous measurement and evaluation of business activities.

The basic idea behind simulation is simple [109]: We wish to acquire knowledge and reach some informed decisions regarding a real-world system. But the system is not easy to study directly. We therefore proceed indirectly by creating and studying another entity (the simulation model), which is sufficiently similar to the real-world system that we are confident that some of what we learn about the model will also be true of the system. Simulation can have many forms (for example, discrete-event simulation, continuous simulation, system dynamics, Monte-Carlo simulation, qualitative simulation, etc.). In relation to BPM, discrete-event simulation and system dynamics seem to have received most attention, and will be reviewed here.

### **Discrete-event Simulation**

Shannon [105] has defined discrete-event simulation as *‘the process of designing a model of a real system and conducting experiments with this model for the purpose,*

*either of understanding the behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system'* . Practical simulation modelling will usually originate in a management perception of a problem requiring some decision or understanding [110]. The problem may concern or involve the operation of some complex system on which direct experimentation may be impractical on grounds of cost, time or some human restriction [81].

The very definition of simulation reveals its theoretical potential as a tool for BPM. Indeed, simulation modelling of an organisation's processes can help towards understanding the behaviour of the existing business system, identifying problematic tasks, and making experimentation with alternative processes easier, directly comparable and less risky [81].

#### **3.3.4.9 System Dynamics**

System Dynamics was originally developed in the 1950's and 1960's at MIT by Jay Forrester as a set of tools for relating the internal structure of complex systems to their behaviour over time, via the use of simulation. Forrester developed a theory of information feedback and control as a means of evaluating business and other organisational and social contexts. The System Dynamics methodology was based on ideas of feedback systems, as encountered in electrical and mechanical control.

The System Dynamics methodology examines the behaviour of complex systems over time by representing the processes, structure, strategies and information flows of systems. A definition of the method can be stated as follows [111]:

**A rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organisational boundaries and strategies; which**

**facilitates quantitative simulation modelling and analysis for the design of system structure and control.**

Over the past three decades System Dynamics has been applied broadly in such areas as environmental change, economic development, social unrest, urban decay, psychology and physiology. There has been a corresponding growth in the base of tools being developed and applied including things such as causal loop diagramming, chaos theory, statistical analysis and interactive learning environments [112].

Though eclectic in content and methods, System Dynamics retains certain underlying principles that form an important bridge between reality and our ability to understand [111]:

- Concentration on dynamics and feedback relationships
- Representation of decision making behaviour based on actual information availability
- Explicit recognition of disequilibrium and the process of adjustment
- Incorporation of non-linear relationships when appropriate
- Quantification of unmeasured but important concepts and relationships

In more words system dynamics is characterised by [112]:

- Searching for useful solutions to real problems, especially in social systems (businesses, schools, governments, etc.) and the environment
- Using computer simulation models to understand and improve such systems
- Basing the simulation models on thought processes, qualitative knowledge and numerical information
- Using methods and insights from feedback control engineering and other scientific disciplines to assess and improve the quality of models
- Seeking improved ways to translate scientific results into actual implementation

System Dynamics began as Industrial Dynamics, which was defined as the study of the information-feedback characteristics of industrial activity to show how organisational structure, amplification (in policies), and time delays (in decisions and actions) interact to influence the success of the enterprise [113]. The essential ideas are very basic. It is argued that any situation can be considered as complex, but mainly in terms of elements and “flows”; flows being the relationships between elements. All influential elements may form loops and hence feedback analysis is considered very important. [86]

System Dynamics focuses on policy and how policy determines behaviour. By policy, Forrester means the criteria for decision-making. Policy is the rationale that determines how a stream of decisions will be modulated in response to changing inputs of information. To describe policy means that one must describe the output and purpose of the decision stream that is controlled by the policy, and the inputs of information to the policy. That is, one must describe the setting of interrelated policies and therefore the structure of the system. So, SD deals with policy and structure, and with the resulting behaviour [114].

According to Forrester [113] SD should provide a basis for the design of more effective industrial and economic systems. A SD approach to enterprise design progresses through several steps:

- Identify a problem
- Isolate the factors that appear to interact to create the observed symptoms
- Trace the cause-and-effect information-feedback loops that link decisions to actions to resulting information changes and to new decisions
- Formulate acceptable formal decision policies that describe how decisions result from the available information streams
- Construct a mathematical model of the decision policies, information sources, and interactions of the system components.

- Generate the behaviour through time of the system as described by the model (usually with a computer)
- Compare results against all pertinent available knowledge about the actual system
- Revise the model until it is acceptable as a representation of the actual system
- Redesign, within the model, the organisational relationships and policies which can be altered in the actual system to find the changes which improve system behaviour
- Alter the real system in the directions that model experimentation has shown will lead to improved performance [113]

Wolstenholme [115-122] has made significant contributions to the use and application of SD. Wolstenholme used qualitative models interactively with different groups of participants in the problem domain. The purpose was to develop a shared understanding of how culture, power and politics combine to affect the behaviour of a process, when subjected to externally superimposed changes in responsibility [115]. In different studies, he addressed the difficult tasks of creating SD models and developing a starting point for model analysis by suggesting the adoption of a clear, standardised, stepwise approach [116], and he applied SD as a modelling methodology to create a feedback perspective of army defence situations [117]. By constructing a continuous simulation model (using SD) capable of providing a laboratory assessment of alternative managerial control policies based on alternative sources and levels of aggregation of information, he investigated the information usage in the control of colliery operations [118]. In 1983 he tried to demonstrate the use of SD in resolving control problems of engineering systems design nature. The relevance of SD to the engineering systems design control problems is that it provides a generalised modelling framework capable of dealing with both information and its use in control [119]. Wolstenholme also described a routine procedure for general system description, which facilitates problem recognition, understanding and qualitative analysis [120] and the use of SD in the understanding and analysis of large, complex and multiple ownership systems [121].



Another significant application of SD was the development by Wolstenholme of a SD model of an international mineral industry, aimed at providing a basis for analysis of the interrelationship of supply, consumption and price over time, under different production and stocking policies [122].

The SD view is one that places emphasis on structure, and the process within that structure, assuming that this is how dynamic behaviour in the “real world” can best be characterised. SD considers behaviour as being principally caused by structure and therefore it is a theory of structure of systems and dynamic behaviour. Based on that general view, SD assumes that analysis of a situation can be undertaken from an external objective viewpoint and that the structure and dynamic processes of the “real world” can be re-created in both systems diagrams and mathematical models. [86]

Earlier in chapter 3, the hierarchical decomposition of modelling elements was analysed (see Figure 12 in page ) and SSM was mentioned and briefly explained. As Towill [123] explains, SD can be considered as a technique, which can be used to model, design and improve ‘hybrid’ hard/soft systems. Figure 16 shows how SD spans the gap between system theory (in the hardware sense) and system thinking (in the philosophical sense) as a function of certainty of response prediction. Thus, according to Towill, provided that adequate experiments are undertaken on all the artefacts constituting a servomechanism, then for nominal operating conditions, given the inputs and disturbances, the outputs will be entirely predictable. At the other end of the spectrum, an example of a system which is totally people oriented is a football team, and it is well known that football is hardly noted for its predictability of outcome.

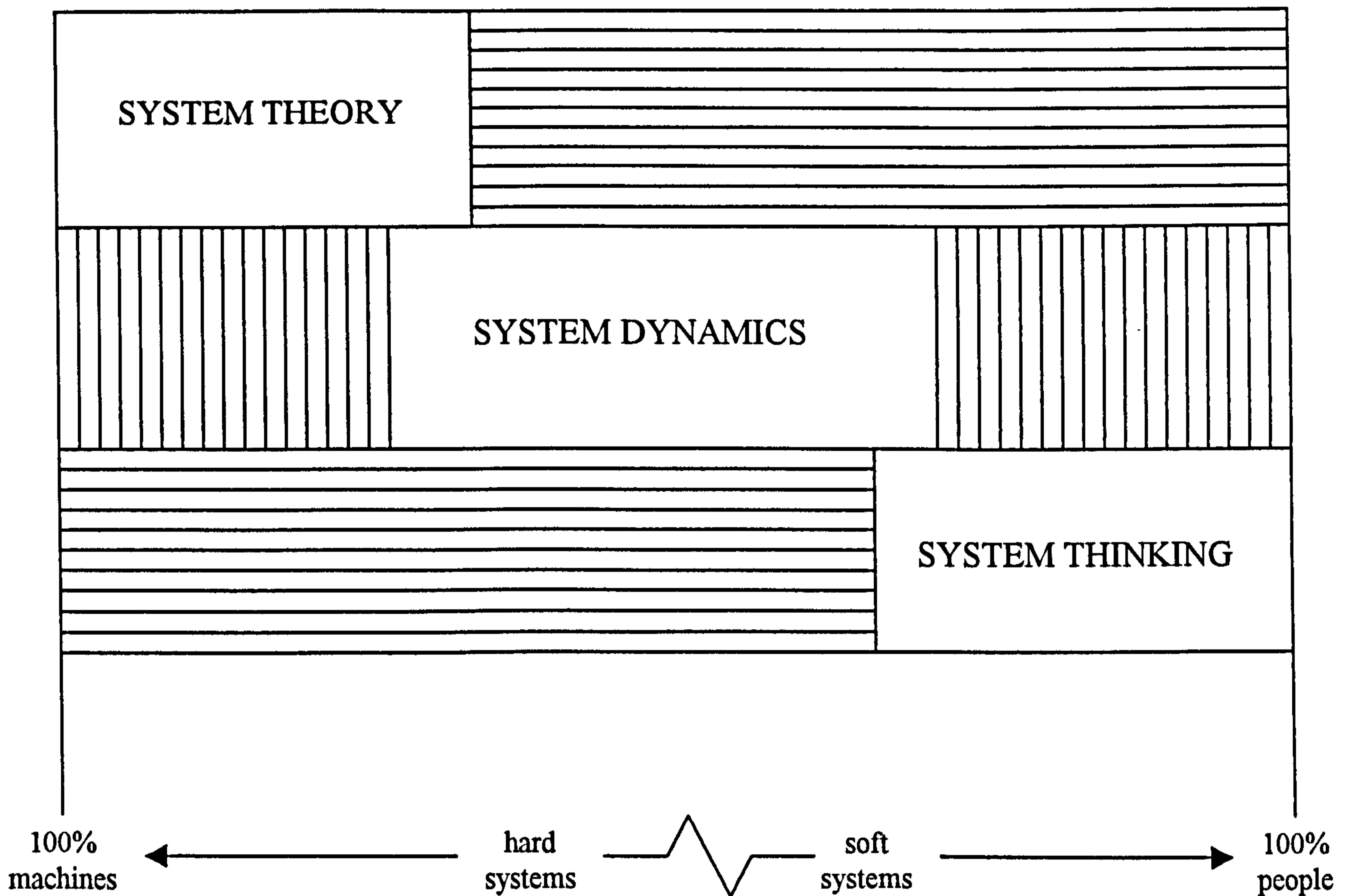


Figure 16: Relationship between system theory, system dynamics and system thinking

Source: [123]

When using SD, the idea of ‘conceptual distance’ is important. Towill’s [124] argument is that, in order to see positive and negative loops in the persistent causal structure underlying events and decisions, it seems essential to be at a distance from everyday details, but not too far. Having this in mind, Towill developed the hybrid system dynamics approach illustrated in figure 17.

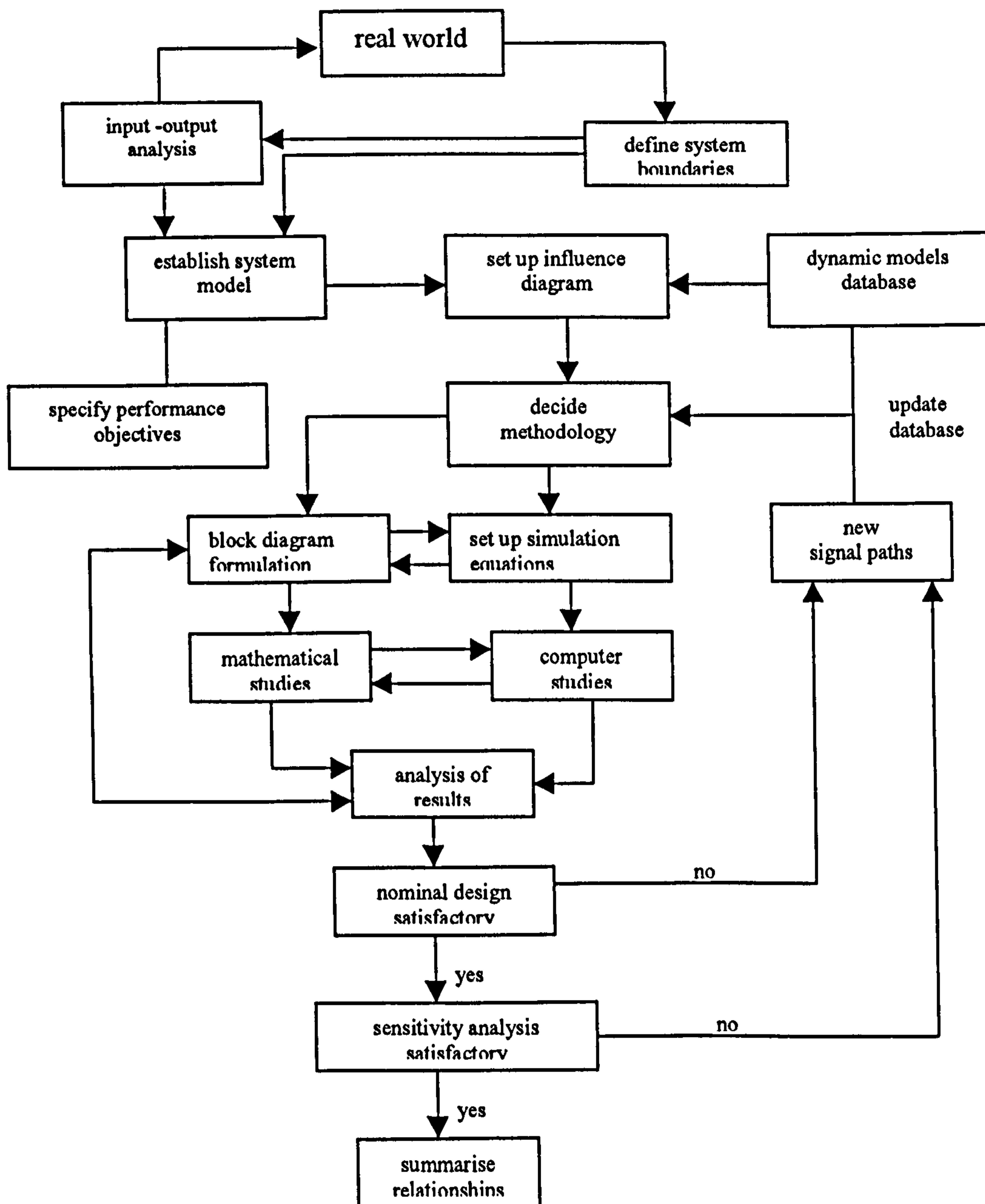


Figure 17: Towill's system dynamics modelling and design methodology

Source: [124]

Although, there are plenty of criticisms of SD which have appeared in the literature since Forrester formulated this approach, most points of critique against SD arise from the approach being used in problem contexts where it does not have competence. Therefore, it is necessary to use SD only in cases where this approach can actually help reduce the “difficulties” of the real world system. When used in appropriate cases, SD can be drawn upon and found to contribute in a very useful way.

### **3.4 The Use of BPM and Simulation for Improving the NP/SI Process and Managing ECs**

It is obvious that organisations are engaged in assessing ways in which their productivity, product quality, and operations can be improved, and thus most of these organisations are turning to the view that quality of products and services can best be addressed by focusing on improvement of the processes that create these products and services, rather than just on the products and services themselves. The quality of products and services can be improved by placing careful attention on the management of the important processes by which an organisation carries out its business. It is not enough just to improve the efficiency at each stage of a process. Organisations have to make sure that each process stage adds value to the final product or service. Value added work can be defined as work that the customer would be willing to pay for, if he knew organisations were doing it.

Process improvement refers to taking advantage of opportunities to move a process from a current state to another state of higher performance. Measures of process improvement include product quality, process flexibility, work-in process inventory, lead times, material handling, and throughput [125].

As mentioned earlier, by modelling business processes it is possible to give a computer system the process model and have it enact, i.e. “run” the model, supporting the participants in the process as the process proceeds, handling their agendas, supporting their interactions, and perhaps playing its own part in the process. Simulation allows us to estimate the performance of an existing system or process under some projected set of operating conditions.

By using both BPM and Simulation is possible to describe a process so that it could be better understood, to model the process so that it could be possible to explore its properties and finally to simulate the process in order not only to estimate its performance but also to study the system or process with a long time frame in

compressed time. These give the opportunity to examine how a process is going to behave in the future under present conditions, and therefore it may be possible to identify some specific areas, within the process, that are either problematic or questionable and therefore need to be improved. Business process modelling and simulation have proved to be powerful tools for identifying potential areas for improvement and they have been widely used as an improvement tool in many manufacturing and/or engineering organisations for many years now.

**CHAPTER 4****MODELLING THE NP/SI PROCESS****A System Dynamics Approach**

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**4.1 Introduction**

The aim of this chapter is to report on the selection of System Dynamics from amongst the alternative BPM techniques described in chapter 3, and its use in order to model the generic structure of the New Product/Service Introduction (NP/SI) process in organisations. System Dynamics is a simulation technique that is especially suited to modelling and analysing the behavioural aspects of a system, i.e. the way that the system elements interact with and influence each other to generate overall system behaviour. In terms of the NP/SI process, such an analysis can reveal positive or negative feedback loops in the process, thereby allowing managers to understand the likely impact of 'local' changes on overall process cost, time, and perceived quality.

**4.2 The New Product / Service Introduction Process**

As previously discussed (page 1), the development and marketing of new products and services are amongst the most powerful weapons that organisations can use in

order to survive and prosper under turbulent market conditions. The successful introduction of a new product or service can assist an organisation to remain competitive by being able to sufficiently address the continuously changing market requirements. Therefore, the process of NP/SI constitutes a crucial activity for every organisation.

Numerous studies have investigated why some new products and/or services succeed, while others fail. These studies have proved extremely valuable in that they have identified a myriad of success factors at the project level. What is missing in this analysis, however, is a broader or more macro view of the determinants of success. That is, we must move from the micro, or project level of analysis, to the company or macro level [45].

Despite the importance of the NP/SI process and the subsequent attention it has received by researchers and managers alike, relatively little attention has to date been paid on developing comprehensive models of the process itself to support understanding, analysis, and decision making. Such models can be a useful means of studying the dynamics of the process and identifying the factors that influence the overall process effectiveness (measured in terms of cost, time, and quality metrics). Prior to any process improvement activity, the NP/SI process, and in general any process, needs to be understood, described and analysed. Perhaps the easiest, fastest and best way for achieving this is by using business process modelling.

### **4.3 Business Process Modelling Technique Selection**

The review of the different techniques used in business process modelling, discussed in the previous chapter, can lead to some interesting observations. Firstly, the various techniques differ significantly in the extent to which they provide the ability to model different business and system perspectives. Some techniques focus primarily on functions, some others on roles, and yet some others on data. Ideally,

what might be needed is the development of a single, ‘holistic’ technique that could effectively represent all perspectives in a rigorous and concise fashion, and hence be applicable in all modelling situations [81].

To assist in technique evaluation and selection depending on the characteristics of individual projects, Giaglis [81] presented an attempt to combine the characteristics of the modelling techniques reviewed earlier, with the evaluation framework of Figure 12, in order to develop a taxonomy of BPM techniques. As a starting point, Figure 18 illustrates the degrees to which the techniques reviewed in Chapter 3 provide support for representing the process modelling perspectives of the evaluation framework (Depth of modelling).

BPM Techniques	Modelling Perspectives (Depth)			
	Functional	Behavioural	Organisational	Informational
Flowcharting	Yes	No	No	Limited
IDEF0	Yes	No	Limited	No
IDEF3	Limited	Limited	No	Limited
Petri Nets	Yes	Yes	No	No
Discrete-event simulation	Yes	Yes	Yes	Limited
System Dynamics	Limited	Yes	Yes	Limited
Knowledge-based Techniques	No	Yes	No	No
Role Activity Diagramming	No	Limited	Yes	No

Figure 18: Modelling Depth of BPM Techniques

Source: [81]

Based on this classification, Giaglis [81] proposed a classification of BPM techniques (illustrated in Figure 19) in terms of the evaluation framework of Figure 13. The taxonomy is not intended to be rigid, since the lines between modelling depth and breadth are by definition blurred and cannot be subjected to strict separation. However, the taxonomy is helpful as it can provide the basis for selecting appropriate techniques to use depending on either their *Fit* with individual projects or the *Depth* and *Breadth* required in a specific modelling exercise.



<b>DEPTH</b>	<b>FIT</b>				
Informational (Data)	(Flowcharting) (IDEF3)	(Simulation)	Simulation	Simulation	Simulation
Organisational (Where, Who)	(IDEF0) (Simulation) System Dynamics RAD	(IDEF0) (Simulation) System Dynamics RAD	(IDEF0) (Simulation) System Dynamics RAD	Simulation	-----
Behavioural (When, How)	(IDEF3) Simulation System Dynamics RAD	(IDEF3) Simulation System Dynamics RAD	(IDEF3) Simulation System Dynamics RAD	Petri Nets Simulation System Dynamics Knowledge-based	Petri Nets Simulation Knowledge-based
Functional (What)	Flowcharting IDEF0 (IDEF3) Simulation (System Dynamics)	Flowcharting IDEF0 (IDEF3) Simulation System Dynamics	Flowcharting IDEF0 (IDEF3) Simulation	IDEF0 Petri Nets Simulation	Petri Nets Simulation
	Understanding & Communicating	Process Improvement	Process Management	Process Development	Process Execution
					<b>BREADTH</b>

Figure 19: A Taxonomy of BPM Techniques

Source: [81]

Using the taxonomy of BPM techniques by Giaglis, it becomes obvious that for the purposes of this research, the necessary modelling perspectives are the organisational, the behavioural and the functional. Since the modelling goals of this research are the (better) understanding and communicating the NP/SI process and its improvement, it seems that the only possible modelling technique to be used is System Dynamics.

At this point, it is worthy to mention the work of Flood *et al* [86] on grouping the different methodologies. Flood *et al* [86] have first grouped real world problem contexts according to two dimensions: systems and participants.

The systems dimension refers to relative complexity in terms of the “system” or “systems” that make up the problem situation. The participants dimension refers to the relationship (of agreement or disagreement) between the individuals or parties who stand to gain (or lose) from a systems intervention.

Systems, according to Flood *et al*, can be classified or categorised in a variety of ways. At one end are the relative simple “systems” and at the other end are “systems” which are highly complex.

Simple systems have the following characteristics:

- a small number of elements;
- few interactions between the elements;
- attributes of the elements are predetermined;
- interaction between elements is highly organised;
- well-defined laws govern behaviour;
- the system does not evolve over time;
- “sub-systems” do not pursue their own goals;
- the “system” is unaffected by behavioural influences;
- the “system” is largely closed to the environment.

Complex systems have the following characteristics:

- a large number of elements;
- many interactions between the elements;
- attributes of the elements are not predetermined;
- interaction between elements is loosely organised;
- they are probabilistic in their behaviour;
- the system evolves over time;

- “sub-systems” are purposeful and generate their own goals;
- the “system” is subject to behavioural influences;
- the “system” is largely open to the environment.

Participants have been classified as unitary, pluralist and coercive. These can be defined as follows:

### Unitary

- they share common interest;
- their values and beliefs are highly compatible;
- they largely agree upon ends and means;
- they all participate in decision making;
- they act in accordance with agreed objectives.

### Pluralist

- they have a basic compatibility of interest;
- their values and beliefs disagree to some extent;
- they do not necessarily agree upon ends and means, but compromise is possible;
- they all participate in decision making;
- they act in accordance with agreed objectives.

### Coercive

- they share a common interest;
- their values and beliefs are likely to conflict;
- they do not agree upon ends and means, and “genuine” compromise is not possible;
- some coerce others to accept decisions;
- no agreement over objectives is possible given present systemic arrangements.

If the dimensions of systems and participants are combined to yield a six-celled matrix, problem contexts can be seen to fall into the following ideal-type categories, as shown in figure 20.

	UNITARY	PLURALIST	COERCIVE
SIMPLE	Simple - Unitary	Simple - Pluralist	Simple – Coercive
COMPLEX	Complex - Unitary	Complex – Pluralist	Complex – Coercive

Figure 20: An “ideal type” grouping of problem contexts

Source: [86]

A major difficulty to use systems thinking is knowing how to employ the range of different systems approaches available. These different systems approaches are:

- Operational Research (OR)
- Systems Analysis (SA)
- Systems Engineering (SE)
- System Dynamics (SD)
- Viable System Diagnosis (VSD)
- General System Theory (GST)
- Socio-Technical Systems Thinking (STST)
- Contingency Theory (CT)
- Social Systems Design (SSD)
- Strategic Assumption Surfacing & Testing (SAST)
- Interactive Planning (IP)
- Soft Systems Methodology (SSM)

- Critical Systems Heuristics (CSH)

Flood *et al* [86] have logically grouped together what is otherwise a bewildering array of system methodologies. This grouping of system methodologies is illustrated in Figure 21.

	UNITARY	PLURALIST	COERCIVE
SIMPLE	<u>S-U</u> OR SA SE SD	<u>S-P</u> SSD SAST	<u>S-C</u> CSH
COMPLEX	<u>C-U</u> VSD GST STST CT	<u>C-P</u> IP SSM	<u>C-C</u> ?

Figure 21: A grouping of systems methodologies

Source: [86]

Therefore, for the purposes of modelling the NP/SI process in this research, the System Dynamics modelling technique was chosen as it satisfies all the aforementioned criteria and it is widely acknowledged as one of the most effective techniques for modelling the ‘strategic’ behaviour of dynamic systems.

#### 4.4 System Dynamics

It was discussed earlier, in chapter 3 (page 79), that the conception and development of system dynamics (first called industrial dynamics) took place during the late 1950s at The Massachusetts Institute of Technology under J Forrester, and although early work was in the management field, the subject became primarily known during the late 1960s for its applications at the macro level in urban and global modelling by Forrester and Meadows. Although macro applications are still in evidence, the scale of individual applications has significantly reduced and diversified during the 1970s. During this period the subject has also developed its armoury of sub-techniques and its overall philosophy and moved some way in defining its relationships with other enquiry methods [126].

Despite its long history, in simulation terms at least, many management scientists are sceptical of its value. Possibly there are two reasons for this. First, *Industrial Dynamics* by Forrester was an ambitious book, perhaps too ambitious. This is particularly seen in Forrester's claim that it presented a revolutionary approach to management. With hindsight, this does seem rather an exaggeration. Even at the time of publication, its mechanistic approach must have seemed a limiting factor to practising managers [127].

Another possible reason for the commonly found scepticism is that system dynamics is definitely not a highly refined and accurate tool. The aim is to explore the dynamics of feedback systems in terms of their stability and responses to external shocks. In many cases, the presenting instability may be so gross that exact analyses are not required. System Dynamics presents a way of approximately simulating such systems [127].

System dynamics has over many years been applied to a wide variety of situations with either an implicit belief that the approach was correct or without, in general, too much detailed concern by the analyst as to how the systems studied related to any

general classification. The usefulness of such studies has provided their own justification for the approach. On the other hand, the development of the subject in this way has enhanced its insularity as a specific systems modelling technique, and there is a genuine need to relate its general attributes within the broader systems field [126].

Wolstenholme described system dynamics as a system methodology capable of assisting with practical problem definition, analysis and change in a wide range of systems and with a potential to provide a more significant contribution to current general system practice than presently achieved. It is felt that the major reasons why this potential has been inhibited stems from its misperception and the wide range of issues to which it has some relevance. In the extreme case, this results in its perception by soft system methodologists as a hard system modelling technique and in its perception by hard system modellers as a soft system approach. In practice it combines some of the better features of both worlds [126].

#### 4.4.1 SD as a Method of System Description and Qualitative Analysis

The need for a system description method, which is simple, compact and easily understood, is a prime requisite of any approach to system enquiry. A good system diagram can formalise and communicate a modeller's mental image and hence understanding of a given situation in a way that the written language cannot [126].

System dynamics utilises a specific method of system description based on *rates*, *delays* and *levels* to analyse feedback systems.

##### Delays

It is important to realise that information and materials (or whatever make up the 'stuff' of the system) are rarely transmitted and received instantaneously. To give a simple example, orders may be sent by customers to their supplier by ordinary mail,

thus introducing a delay of at least one day. Similarly, a company may have good reason to increase its production by 30% but face a lead time of four weeks to do so because of the need to train more employees. Delays occur for all sorts of legitimate reasons and often these may be reduced at a cost. For example, a company with geographically dispersed distribution depots may choose to transmit information about stock levels by facsimile transfer rather than by using the normal mail [127].

### Levels

Organisational systems contain accumulations of one kind or another. In system dynamics these are usually called *levels*. The current conditions of the levels within a system correspond to the system state. Often, levels are clearly recognisable as such (for example, stocks of various types). Another example might be cash balances which are produced by inflows and outflows of funds. A slightly less obvious example might be a labour force with numbers of employees at different grades and experience. This too could be regarded as a level or accumulation within the system. Levels continue to exist even if all activity ceases [127].

### Rates

Activity continues in any dynamic system. This activity may be represented by the flow rates which control the levels. Thus, cash balances are affected by the rates at which money flows into and out of the organisation. The labour force is affected by the rate at which people are hired and leave. These flow rates vary continuously and must be represented in such a way as to capture this variation. Flows occur instantaneously but can be usefully measured as average rates over a period. If the period is made small enough, then the rate changes will appear to occur smoothly and will thus capture something of the continuous variation [127].



#### 4.4.2 System Dynamics Simulation

Having obtained a system dynamics diagram of a particular system, this is sufficiently rigorous to be directly translated into a set of mathematical equations capable of being handled by a computer.

The simulation method incorporated into all system dynamics packages is essentially a time slicing simulation applied to continuous variables and incorporating continuously adaptive information feedback facilities [126].

There are a number of tools associated with system dynamics that help modellers to simulate and understand how dynamic systems operate. In the early days of system dynamics, most models were developed using the DYNAMO system, which is described in Forrester [113]. Since the mid-1980s there have been a number of significant developments in this area, mainly due to the widespread availability of MacIntosh computers and IBM PC compatibles running different versions of Windows. The tools, of which the best known is iThink, rely on graphical user interfaces to support model building and simulation. They thus parallel the development of visual interactive modelling systems [127].

Diagrammatic representations of systems dynamics models are based on cause and effect diagrams (known as *causal loop* or *influence diagrams*) and *pipe diagrams*. The purpose of these diagrams is to allow mental models about system structure and strategies to be made explicit. The word 'structure' here is taken to imply the information feedback structure of the system, and hence system dynamics models are often described as taking a feedback perspective of a situation [6]. The underlying premise is that the feedback structure of a system is a direct determinant of its behaviour. Figure 22 illustrates typical examples of notational conventions used in pipe diagrams.

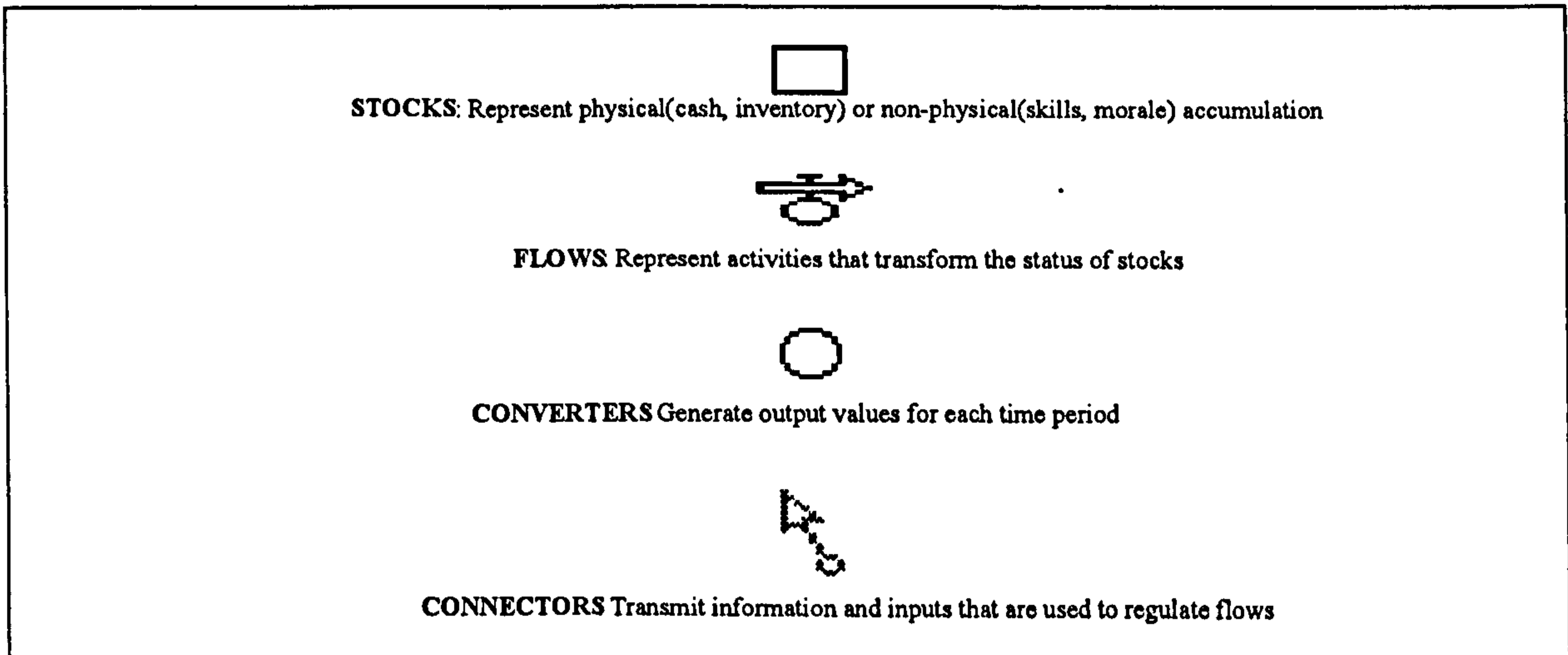


Figure 22: System Dynamics Notation (Pipe Diagram)

An extensive study was carried out, evaluating the available to the market software packages for SD simulation modelling. The selection process was based on three criteria: the capability of the s/w package to perform the activities decided to be necessary for the research, the cost of the s/w package and the user friendliness of the package. Among the identified software packages, *iThink* of High Performance Systems Inc. was chosen. *iThink* is a powerful simulation tool, designed to improve performance, profitability and organisational learning. *iThink* gives the ability to quickly build sophisticated dynamic models of business process and also simulate these processes using a simple 3-step progression (process mapping, process modelling, and process simulation).

#### 4.5 The NP/SI Process Model

As it was discussed in Chapter 2, previous work at Cranfield University by Rooney and Peters [33] resulted in the development of a model for New Product Design and Development (NPDD). The NPDD model was the result of the identification and analysis of industry best practices. None of the models presented within the literature seem to be truly generic, that is, applicable to the New Product/Service Introduction process in any company. The aim of a generic model is to give an overview of the New Product/Service Introduction process that will be relevant to any company. The NPDD model has been derived from experience over a number of

years from a wide range of businesses and market sectors in the United Kingdom. The model was illustrated in Figure 2, while the main stages of the model were discussed in Chapter 2.

Appendix E, in page 175, contains further analysis of each one of the six stages of this model. Specifically, each stage of the NPDD model is graphically represented in order to provide better understanding and communication.

#### **4.6 Modelling the New Product / Service Introduction Process**

The System Dynamics modelling technique was used to transform the generic NPDD model illustrated in Figure 2 into a computer-based model that could be dynamically run and analysed. The main aims of this modelling endeavour were to gain additional insight into the dynamics of the generic NP/SI process, and to identify ‘hidden’ or difficult to establish inter-relationships between the various activities which constitute the whole process. The ultimate objective is to use customised versions of this model in order to measure the effectiveness of specific instances of the NP/SI process in particular organisations, and to guide (in an informed manner) managerial decision-making with reference to the optimal arrangement of activities and use of quality tools and techniques within the NP/SI process.

Figure 23 illustrates a small part of the overall NP/SI model developed. This part depicts stage four of the NPDD model (pre-production validation). Products or services pass through different ‘states’ (for example, from Prototype A to Prototype B) according to different rates, which are regulated by the connecting ‘flows’ (for example, the ‘debug prototype’ time). The values of flows themselves are determined by the ‘converters’ (for example, the number of hours spent in

debugging), which determine the rate of flow of new products/services through the NP/SI process.

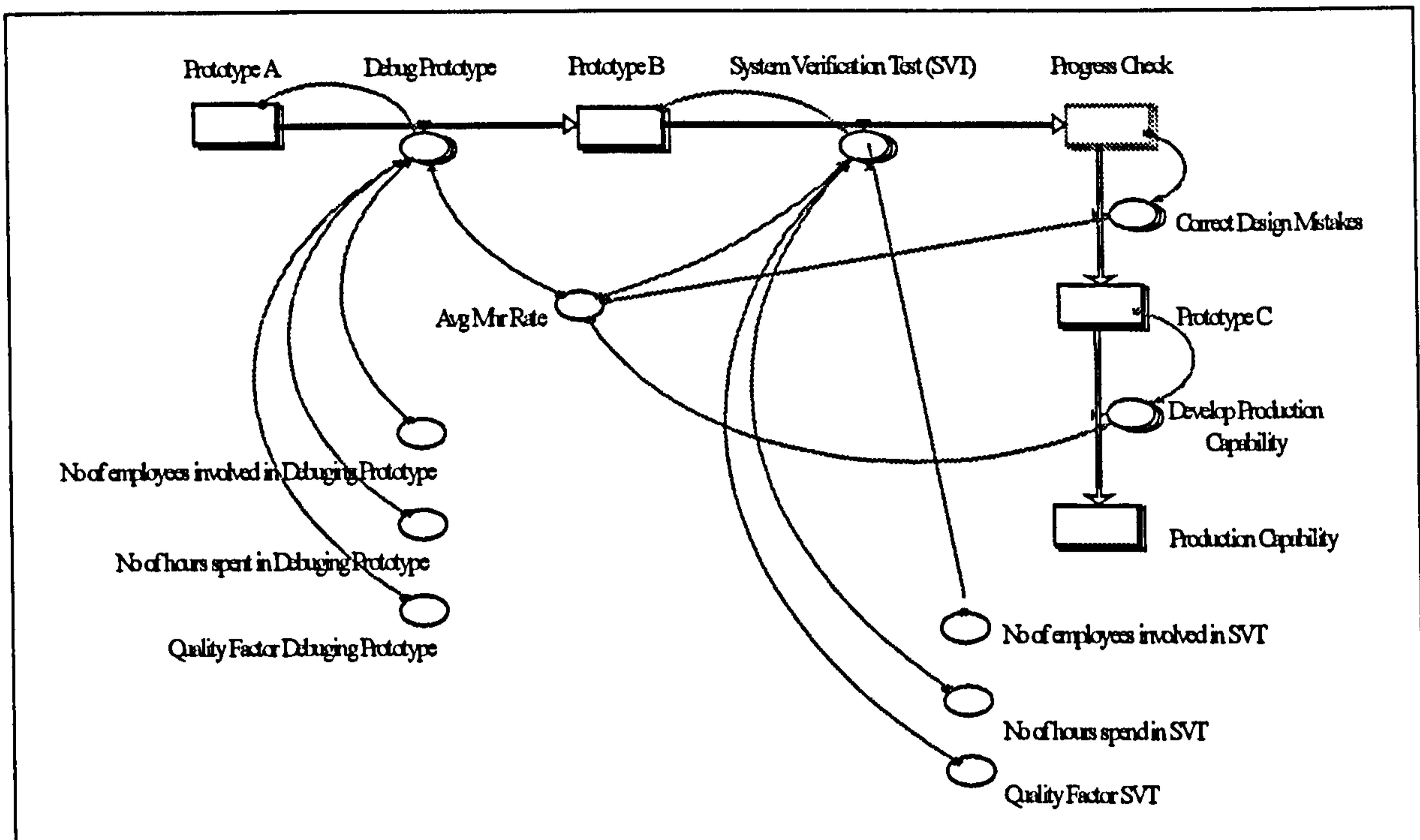


Figure 23: Modelling the NP/SI Process using iThink (Pre-production validation stage)

By quantifying the relationships implied by the links in the System Dynamics model, it is possible to simulate the model and gain quantitative information on model dynamics. For example, modellers and decision-makers can experiment with different options for arranging activities or for using different quality tools and techniques, and assess (in real-time) the effects of their decisions on the overall NP/SI process. The Key Performance Indicators that can be measured through this process are Time (the duration of the whole NP/SI process or of the individual stages it consists of), Cost (depending on the cost drivers as determined by each particular company), and Quality.

For example, one can experiment with different options regarding the number of employees and the number of hours spent on debugging a product prototype (to use the example of Figure 17), and evaluate the best balance between additional costs (due to time and manpower spent in debugging) and increased quality of the final

product. It should, however, be noted that in order for the System Dynamics model to be used in such a quantitative fashion, a significant amount of data should be collected, analysed, and used within the model. Since these data has to come from particular organisational settings, it is not possible to quantitatively simulate the model in a generic case (i.e. for every company). The generic model can be used for qualitative evaluation of the NP/SI process, as well as a baseline for the development of 'customised' models for individual organisations.

The whole model of the NP/SI process, using the modelling technique of SD and particularly the software package *iThink*, is illustrated in Appendix F in page 182. The stages of the NP/SI process (i.e. Idea stage, Concept stage, Design stage, etc.) have been modelled together, but for illustration purposes they are presented separately in Appendix E.

It is the author's opinion that the use of this particular software package (*iThink*) can provide the modeller with a powerful tool for modelling any business process. *iThink* can be used easily and is very user friendly. It was found that it was relatively easy and straightforward not only to model the NP/SI process but also to build in all the mathematical equations for the model to be simulated.

The only difficulty observed by the author during the modelling of the NP/SI process was the computing performance (execution speed) of the software. That is, although the recommended computer requirements for using *iThink* are a pentium processor, 16 Mb RAM and a VGA display, the execution speed by which one can perform modelling activities is not so fast. Although, the author used a pentium processor at 233MMX MHz, 64 Mb RAM and a SVGA display the software's execution speed was not so fast as he would expect. The reason for this might be the relatively very large size of the NP/SI process, since at the earlier stages of the modelling process (when the model was not that large) the software seemed to perform better.

#### 4.7 Validation of the NP/SI Model

In some sense or other, management scientists strive to be scientific in their work, although what this can mean will vary somewhat between individuals and may depend on the work they are doing. One important aspect of this scientific ideal is the notion that models should be thoroughly tested or validated before use. The idea is that the management scientist should ensure that the model is wholly adequate and appropriate for the task for which it is intended [127].

Prior to simulation and experimentation and use of the model, it is necessary for the model to be validated. Validation is the process by which the modeller and the user satisfy themselves that the model is suitable for use within its defined experimental frame.

There are many approaches to validation and extremely thorough accounts of the various techniques available are to be found in Balci [104] and Sargent [128]. However, it is important to note that complete validation is never possible. This is because most simulation models are used to investigate things that are not clearly understood. Does this mean that simulation approaches are, therefore, a complete waste of time? Not really. When used in an extrapolatory mode they are devices for thinking about how things might be and they need to be subject to the same rigorous analysis as would be any other proposals about possible futures [127].

Validity as meaning confidence in a model's usefulness is inherently a relative concept. One must always choose between competing models. Often a model with known deficiencies may be chosen, if it inspires greater confidence than its alternatives. This is especially true when decisions must be made. Validity is also relative in the sense that it can only be properly assessed relative to a particular purpose. It is pointless to try to establish that a particular model is useful without specifying for what purpose it is to be used. Experience has repeatedly shown that

debates over the relative merits of different models are often irresolvable if the purpose of the model application has not been clearly stated [129]

In 1980, Forrester et al. [129] described in a research paper the validation tests for model building. Three different categories of tests were identified, including tests of model structure, tests of model behaviour and tests of policy implications. Table 7 summarises the validation tests for model building.

Despite the fact that it might not always be possible or cost-effective to conduct all the confidence-building tests, the existence of a wide variety of tests increases the likelihood that more tests will be conducted and that more people can be involved in the overall validation process. In fact, one of the key features of the tests is the extent to which they can be readily carried out by many types of evaluators. Virtually all tests can be either conducted or understood by an interested nontechnical model user. [129 ]

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**Tests of Model Structure**

Structure Verification

Parameter Verification

Extreme Conditions

Boundary Adequacy

Dimensional Consistency

**Tests of Model Behaviour**

Behaviour Reproduction

Behaviour Prediction

Behaviour Anomaly

Family Member

Surprise Behaviour

Extreme Policy

Boundary Adequacy

Behaviour Sensitivity

**Tests of Policy Implications**

System Improvement

Changed-Behaviour Prediction

Boundary Adequacy

Policy Sensitivity

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Table 7: Validation Tests for Model Building

Source: [129]

The validation of the NP/SI model took place by closely co-operating with the organisations for which this research has been carried out. The author visited the organisations several times during and after the development of the NP/SI model. During these visits, it was possible to discuss the development stage of the NP/SI process model with appropriate personnel from the organisations and therefore, get their views and recommendations regarding the model.

Once the model was complete, the author visited the organisations once more and had a final meeting with the companies' executives and staff in order to agree about the validity of the model developed. Several validation tests were carried out, including structure verification test, parameter verification, extreme conditions, boundary adequacy, dimensional consistency, behaviour anomaly, behaviour sensitivity and changed-behaviour prediction. Having obtained the organisations' confirmation and agreement on the validity of model, it was then possible to start thinking and considering the next phase, which was the simulation of the system that the model represents.

#### **4.8 Discussion**

The generic NP/SI model presented in this chapter can provide a 'benchmark' for evaluating the behaviour and performance of individual NP/SI process arrangements. In other words, organisations can use the results of the modelling process to compare their own NP/SI activities with that of the generic model. Such a comparison can reveal potential factors that inhibit the efficiency of the process and hence be useful tools for change initiation and process improvement. Furthermore, new process designs can be tested prior to implementation, providing managers with a 'laboratory' situation where they can generate and experiment with ideas for process improvement without bearing the cost of applying them in the organisational workplace.



## CHAPTER 5

**SIMULATING THE NP/SI PROCESS MODEL****Improving the NP/SI Process by using the SD Methodology**

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**5.1 Introduction**

In this chapter, the developed model of the NP/SI process will be simulated for both organisations participating in this research. The software to be used for the simulation is the same one used for the modelling of the process. By simulating the NP/SI process it is possible to get a picture of the behaviour of this process in the different divisions of the participating organisations and at the same time to identify the areas for potential improvement.

In the rest of this chapter, the importance of process improvement is stressed, together with the actual results of the simulation, which can be used as a means for process improvement. The preparation activities for simulating the model of the NP/SI process are also described.

## 5.2 Process Improvement

All organisations committed to quality will strive to improve the quality of their goods and services, and having improved it they need to maintain it and further improve it. The question that arises is: what are the motivations and opportunities that lead organisations to this journey of continuous quality improvement. Lascelles and Dale [130] report that the quality improvement journey is often triggered by one or more of the following: the chief executive, competition, demanding customers and a greenfield venture.

Most of the writers on the subject of quality agree that unless there is *top management commitment* to improve quality within an organisation, attempts and gains made by individuals and departments will be short-lived. In other words, the chief executive has to take the first step of the journey and lead the organisation towards continuous quality improvement. However, most chief executives do not start this journey unless they have a tangible proof of the need for quality improvement. Such proof of the need for quality improvement is provided by intense competition and demanding customers.

Today's business environment is considered to be the most competitive of all times. The *competition* is fierce and product or service quality is becoming increasingly recognised as the prime consideration in most of the purchasing decisions. It is clear that nowadays quality is an essential part of the marketing mix as companies seek to achieve product / service differentiation in order to gain the competitive advantage.

An organisation needs to have customers in order to stay in business. To keep its customers, an organisation has to make them happy, i.e. to have satisfied customers. But because customers, satisfied or not, have experienced the product quality of the Japanese, they now demand quality in everything. To try and satisfy a *demanding customer*, in terms of quality, will force the organisation towards quality improvement.

As mentioned earlier, many organisations are engaged in assessing ways in which their productivity, product quality, and operations can be improved, and thus most of these organisations are turning to the view that quality of products and services can best be addressed by focusing on improvement of the processes that create these products and services, rather than just on the products and services themselves. The quality of products and services can be improved by placing careful attention on the management of the important processes by which an organisation carries out its business. This process for improving an organisation's processes is known as Business Process Management (BPM).

BPM is a systematic, structured approach to analyse, improve, control, and manage processes with the aim of improving the quality of products and services. BPM, therefore, is the method by which an organisation's "quality" program is carried out. The quality of the organisation's products and/or services is a direct reflection of its ability to improve its processes via BPM [12].

BPM begins with goal setting for the organisation. The vision, mission and goals of the organisation are formulated, and critical success factors determined. With these factors in mind, the processes of the organisation are evaluated, and a specific process for the application of BPM is selected. The selected process is then described and quantified. Based on that, opportunities for process improvement are identified and implemented. Following implementation, the cycle of selection, description, quantification, improvement selection, and implementation is repeated to carry out continuous improvement. Benchmarking can be a valuable tool to guide the entire BPM effort [12].

### 5.3 Preparing for Simulating the NP/SI Process

Having built the NPD process model, the next step is to render the model simulatable. In doing so, a systematic process was followed using a sequence of four steps: 1. characterise the flows (characterising the flows means determining the nature of the process at work in producing the inflow(s) and outflow(s) of a stock.), 2. specify the algebra (after characterising the flows, the algebraic equations associated with each flow need to be determined), 3. close loops (this means looking for feedback relationships that regulate the various flows), 4. Numerate (give numeric values to the variables and constants of the equations).

To run (simulate) the NP/SI process model or, in fact, any other model, the software (iThink) uses standard numerical methods to solve the system of equations that comprise the NP/SI process model. When the computer is used to simulate the model of systems such as the NP/SI process model, it is not possible to get an exact solution. Instead, a set of discrete calculations (the only kind that digital computers are capable of producing) is used to approximate the idealised curve. The software divides the time axis into equally-spaced intervals, each of a width of  $dt$  (or 'delta time'). In the software, the equation structure underlying the model diagram is of vital importance. The equations created behind the scenes as one hooks together stocks and flows are known as "Finite Difference Equations". In a model, each stock equation is a finite difference equation. Conceptually, solving finite difference equations is straightforward. It involves a two step initialisation phase, and a three step iterative evaluation phase:

#### *Initialisation Phase*

Step 1. Create a list of all equations in required order of evaluation

Step 2. Calculate initial values for all stocks, flows, and converters

#### *Iteration Phase*

Step 1. Estimate the change in stock over the interval  $dt$ ; Calculate new values for stocks based on this estimate.

**Step 2. Use new values of stocks to calculate new values for flows and converters.**

**Step 3. Update simulation time by an increment of dt.**

It should be noted that as dt approaches to zero, the approximate solution approaches the exact solution.

Because of the nature of the NP/SI process, it was decided not to use the cycle-time function of the simulation software, since we are only interested to find out how the NP/SI process will behave at its present status for the next new product/service. This will give us the opportunity to identify potential areas for improvement, which then can be applied to the actual NP/SI process in the organisations. Therefore, by repeating the simulation using the improved model of the process it is possible to continuously improve the NP/SI process.

The objective of the simulation was to determine the relationships between cost, time and quality of the NP/SI process of C<sup>3</sup>T and of the Electronics Manufacturing Division and the Aircraft & Engines Maintenance Division of the Hellenic Aerospace Industry, in order to identify possible areas for improvement. At this point, it is important to note that the cost-time-quality relationship of the NP/SI process refers to the process itself, and not to any other factor or element that can influence the process. For example, the cost of raw materials is not considered an NP/SI process cost. In other words, the major interest of this study falls to the process itself and not the product(s) that the process develops.

For cost and time the procedure was a straightforward one: during the simulation, the software adds up the numeric values of cost and time for each 'stage' of the process. For example, "number of hours spent in acceptance sampling" plus "number of hours spent in production" plus "number of hours spent in SPC & CA".

For quality, things were not so simple since the issue was how to measure quality. The methodology, which was decided to be used, is based in assigning a quality factor for each particular activity of the generic NPD process. The total sum of these

quality factors adds up to 100, and gives the 'ideal' values of quality factors of the process. Therefore, to measure the quality of the NPD process of the divisions of the organisations under examination, it was necessary to decide upon the quality factors to be assigned for each activity of the NPD of the division. By visiting the organisations and interviewing employees of the divisions, it was possible to agree on the 'true' values of quality factors of the activities of the NPD. For example, a quality related activity during the design stage of the NP/SI process is the Initial Generic Design (IGD). A quality factor has been assigned for this quality related activity and is presented in the model (Appendix F) as Initial Generic Design QF. For this QF the ideal value was decided by the author and the appropriate personnel of the organisations and it is 3. Therefore, if the organisation under examination, was performing the Initial Generic Design activities in the best possible way the maximum value for the IGD QF would be 3. For the particular case of the A/C & Engines Division of HAI the interviews with appropriate personnel revealed that the true value for the IGD QF is 2.5.

Extensive interviews were carried out to collect all necessary data in order to put them into the model so that it would be possible to simulate. The kind of data that had to be collected involved the number of hours spent in each activity, the number of employees involved in each activity, the average man hour rate of the division and so on. All these data are presented in Appendix G (page 195). Once all data were available, the NP/SI process was simulated. The results of the simulation are illustrated in Figures 24 and 25 for the Electronics Manufacturing Division of HAI, Figures 26 and 27 for the Aircraft & Engines Division of HAI, and Figures 28 and 29 for C<sup>3</sup>T. Figures 24, 26 and 28 illustrate the 'ideal' and 'true' values of the quality actors of the process, while Figures 25, 27 and 29 show the relationship between cost, time and quality of the process.

Figures 24-29 were developed by plotting the actual values of cost, time and the 'true' and 'ideal' values of the quality factors level, at each particular stock of the model of NP/SI process. This was possible because of a software function which

enables us to get the readings of these values at each stock of the model. So, by collecting all these values it is very simple to use MS Excel in order to plot them. The vertical axes of Figures 24-29 represent cost, time and quality values in arbitrary values while the horizontal axes represent the stages of the NP/SI process.

#### 5.4 Simulating the NP/SI process

##### Electronics Manufacturing Division - HAI

By looking at Figures 24 and 25, it is obvious that there are some possible areas for improvement throughout the NP/SI process of the organisation's division. Figure 24 clearly shows that there is potential for improvement since the division's ('true') quality factors level is lower than the 'ideal' level. The greatest potential for improvement is at the design stage as well as at the pre-production validation and post-company stages, since at these three stages the 'true' quality factors levels seems to decline from the 'ideal'. It can be argued that Figure 24 could have been developed by using a simple s/w for spreadsheets. Although this is true, the use of the SD NP/SI process model gives to the user (i.e. the organisation) other possibilities, which are not available when using spreadsheets. These could include the analysis and study of different scenarios and the resulting cost-time-quality relationship, a basis for comparison with different organisations or different lines of businesses in the same organisation, and so on.

Figure 25 substantiates the above observations since it is obvious that at the design and pre-production validation stages of the NP/SI process the cost increases significantly. Improvement efforts should focus at these two stages in order to increase the quality factors level and at the same time to decrease the cost. The post-company stage also deserves some attention. The reason for this seems to be that during this stage, the division is not spending enough time for the post-company activities (it looks like they do not spend any time at all - i.e. time not measured) and therefore the contribution to the quality factors level is almost zero. It may be better

to increase the cost by a fraction in order to increase significantly the quality factors level.

Therefore, the real value of the SD NP/SI process model is that it provides a method for the development and identification of quality factors and cost/benefit relationship and analysis in a generic manner, although based on actual case studies, which can be used for the identification of potential areas for improvement.

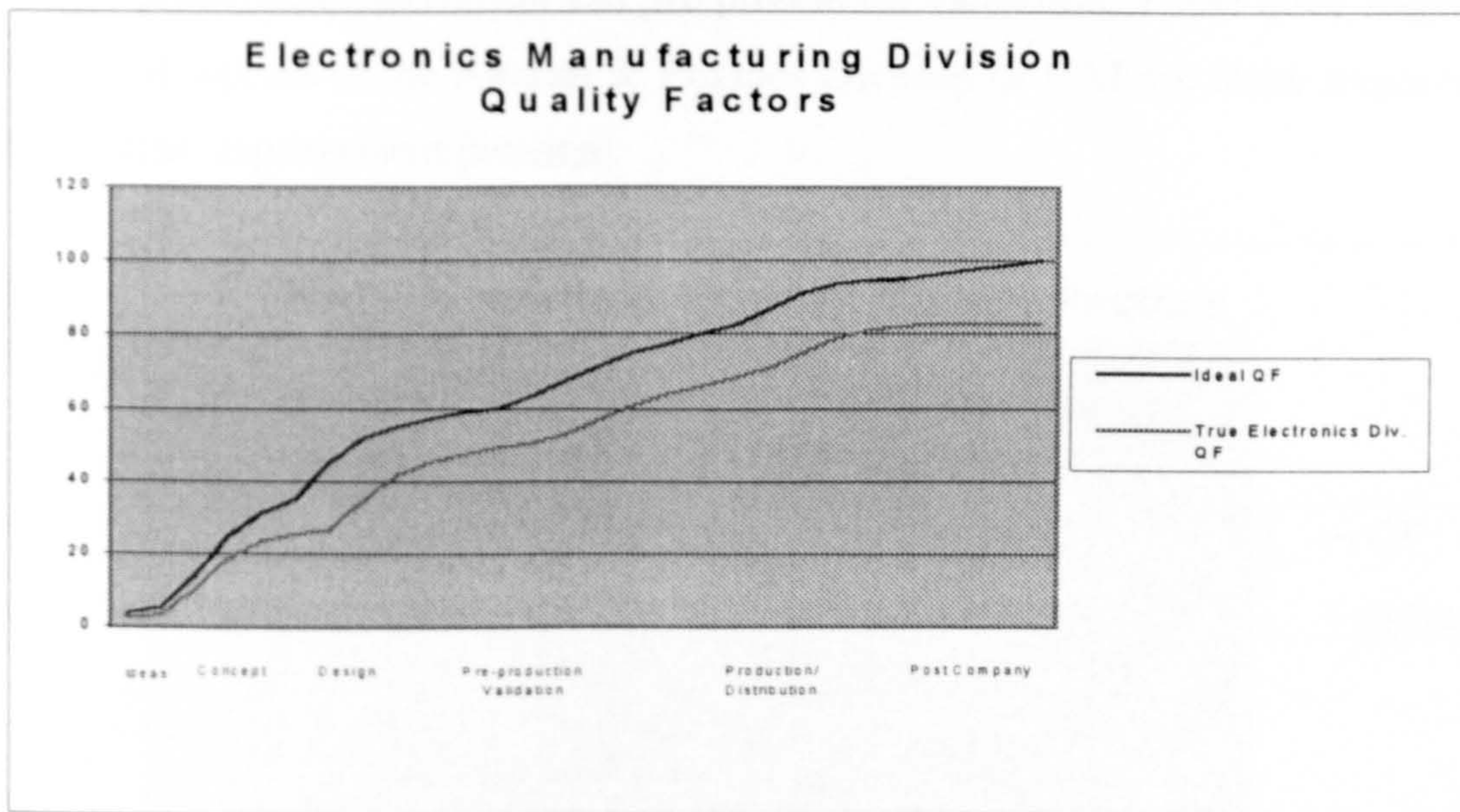


Figure 24: Quality Factors of the NPD process of the Electronics Mfg. Division

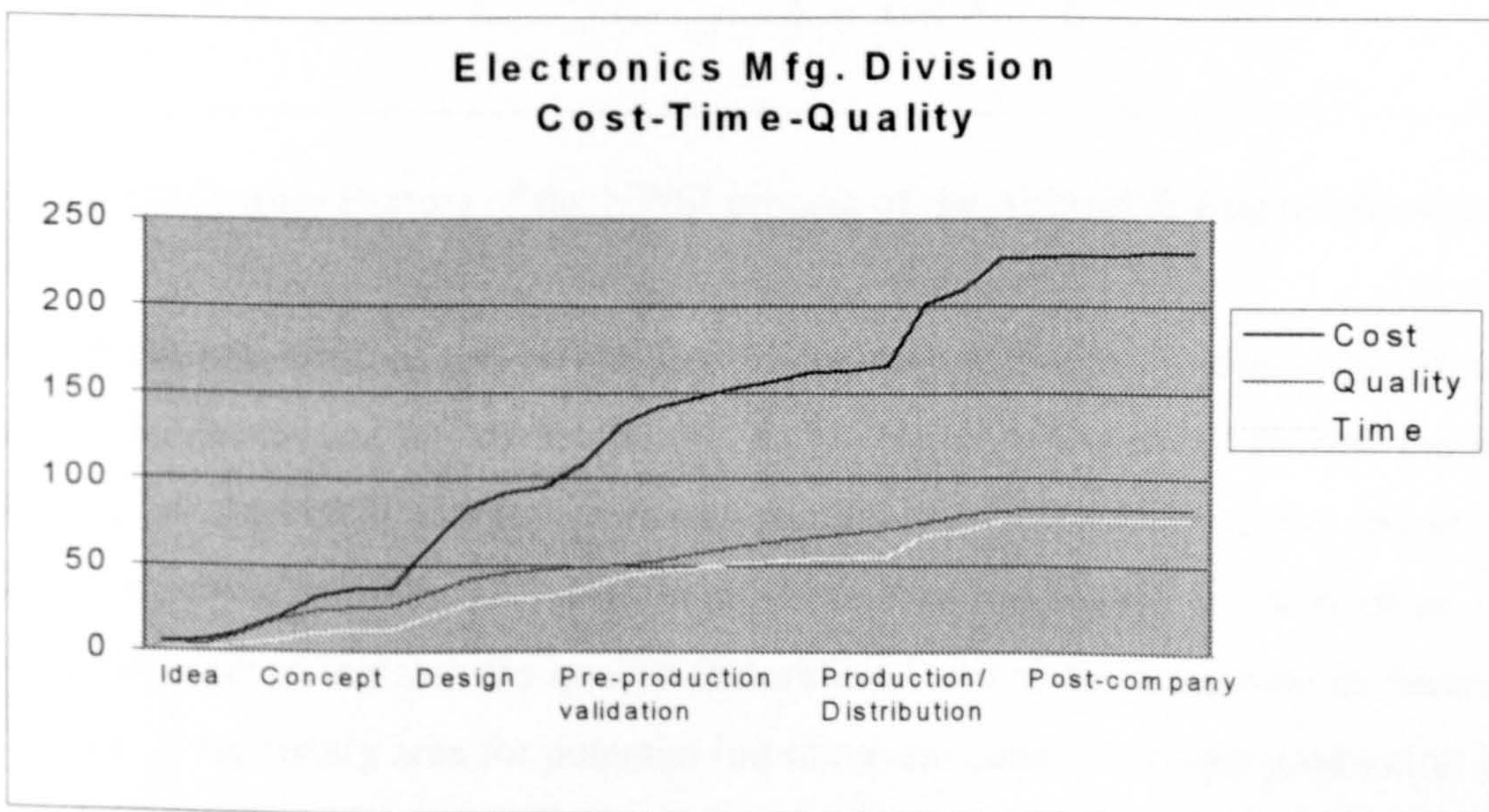


Figure 25: Cost-Time-Quality relationship of the NPD process of the Electronics Mfg. Div.



Aircraft & Engines Maintenance division - HAI

Again, as in the case of the Electronics Manufacturing Division, it is clearly shown by observing Figures 26 and 27 that there are areas throughout the NP/SI process of the Aircraft & Engines Maintenance Division that could be improved. Figure 26 gives us the opportunity to identify that there is potential for improvement since again the division's ('true') quality factors level is lower than the 'ideal' level. The 'true' quality factor level seems to decline from the 'ideal' at the stages of the design, production/distribution and pre-production validation. These three stages of the NP/SI process of the Aircraft & Engines Division of HAI are those stages with the greatest improvement potential.

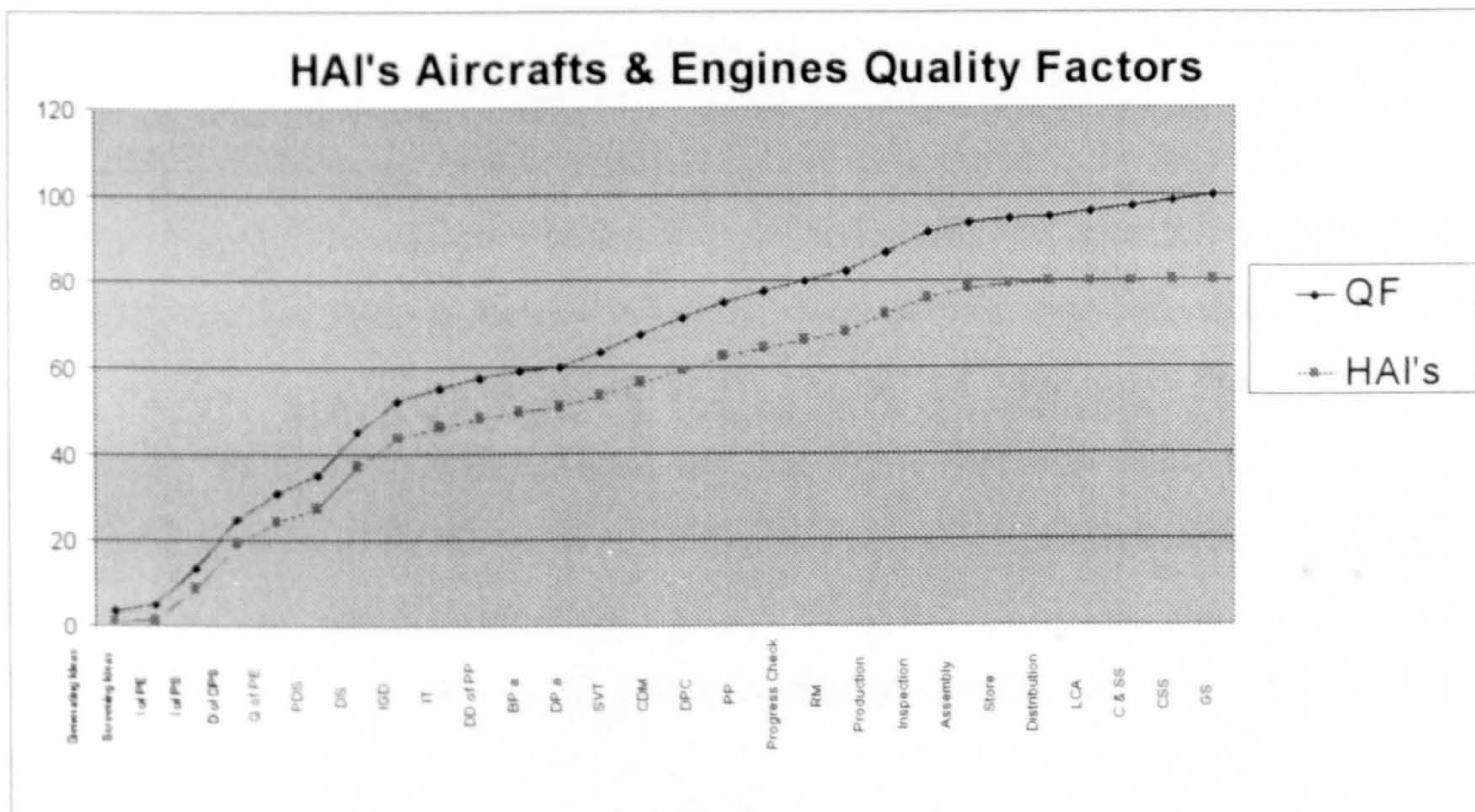


Figure 26: Quality Factors of the NP/SI process of the Aircraft & Engines Division

The above observations can be justified by looking at Figure 27, since it is obvious that at the design and pre-production validation stages of the NP/SI process the cost element of the NP/SI process increases significantly (especially at the end of the design stage). Therefore, all initial improvement efforts should focus at these two stages in order to increase the quality factors level and at the same time to decrease the cost. A secondary area for potential improvement seems to be the production and distribution stage of the NP/SI process. The post-company stage also deserves some attention for the same reason as in the Electronics Manufacturing Division case.

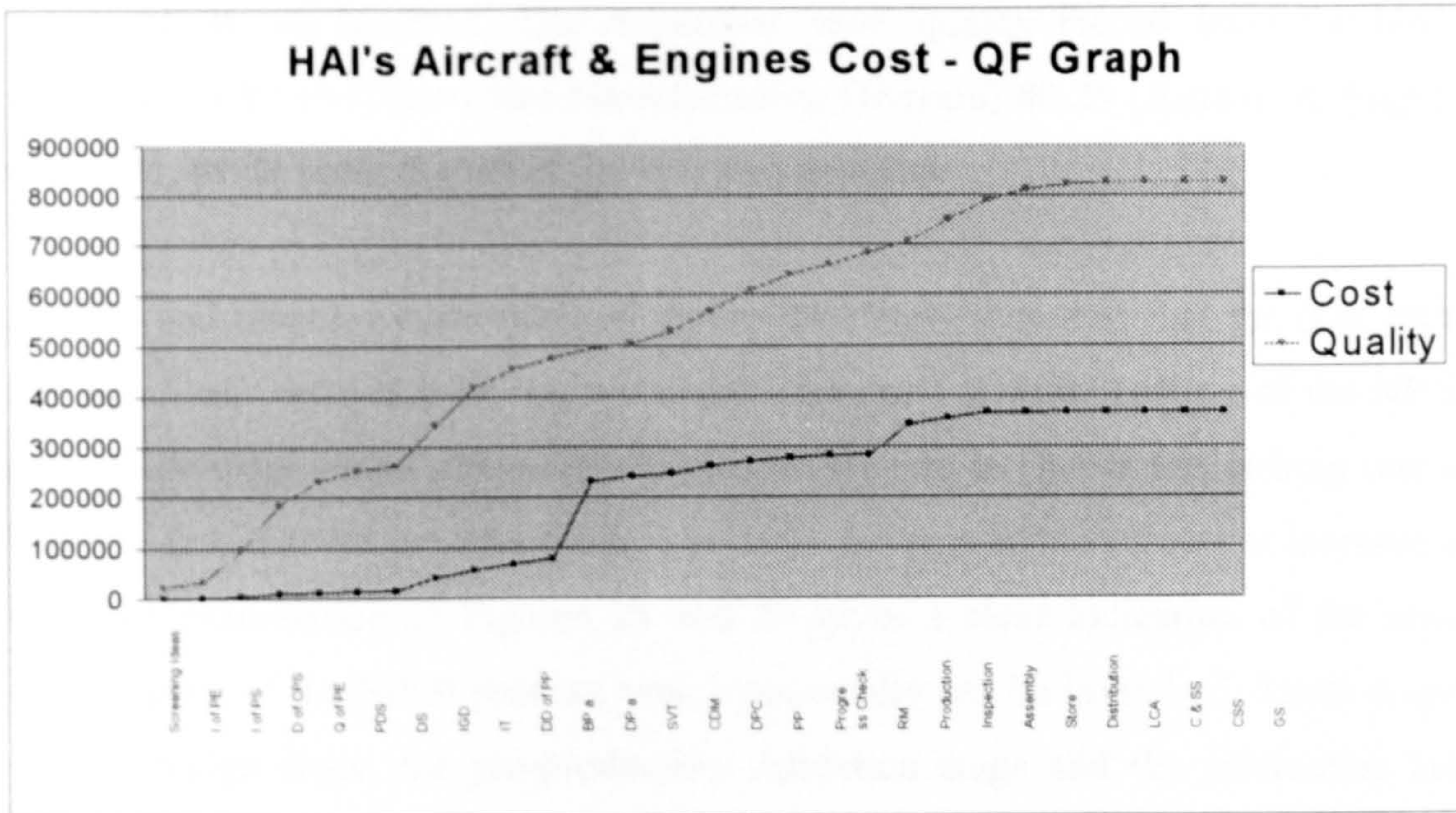


Figure 27: Cost-Quality relationship of the NP/SI process of the Aircraft & Engines Div.

It is worth noting that the time function is not illustrated in Figure 27. The reason for this being the fact that the time element has exactly the same behaviour as the cost element, since cost, for these cases, is the product of time times the average man hour rate. An ideal scenario should include delay times as well, but it was not possible to estimate the delay times for the two organisations that participated in this research. In any case, delay times do not influence the behaviour of the NP/SI significantly, and therefore it is still possible to identify the potential areas for improvement.

Command Control Communications Technologies – C<sup>3</sup>T

The results of the simulation of the NP/SI process of C<sup>3</sup>T seem to be more clear and easier to understand than of those of HAI’s divisions. Figures 28 and 29 illustrate the Quality Factors and the Cost - Quality relationship of the NP/SI process of C<sup>3</sup>T. By observing Figure 28 it is very obvious that there is a significant difference between the ‘true’ quality factors level and the ‘ideal’ quality factor level. This suggests that there are possibilities for improving the NP/SI process of C<sup>3</sup>T. The potential for improvement seems to be at least double than in the cases of HAI’s divisions. The ‘true’ quality factors level of the NP/SI process of C<sup>3</sup>T is 57.25 while

the 'ideal' is one hundred. The respective 'true' quality factors level for HAI's divisions are 82.65 (Electronics Manufacturing Division) 80.25 (Aircraft & Engines Division), while again the 'ideal' level is one hundred.

A close and careful examination of Figure 29 clearly indicates that the cost curve has significant and relatively high increases ('jumps') at certain stages of the NP/SI process. At these stages, the quality factors level seem to have a diminishing rate of increase and in some extreme cases it actually remains stable (does not increase at all). The examination of Figures 28 and 29 gives a clear indication of the areas and/or stages of the NP/SI process, which potentially can be improved. These stages are the design stage, the pre-production validation stage and the production and distribution stage. In C<sup>3</sup>T's case, the potential for improvement seem to be greater than in HAI's cases, and this is due to the relatively low 'true' quality factors level that C<sup>3</sup>T has, compared to both the 'true' HAI and the 'ideal' quality factors level

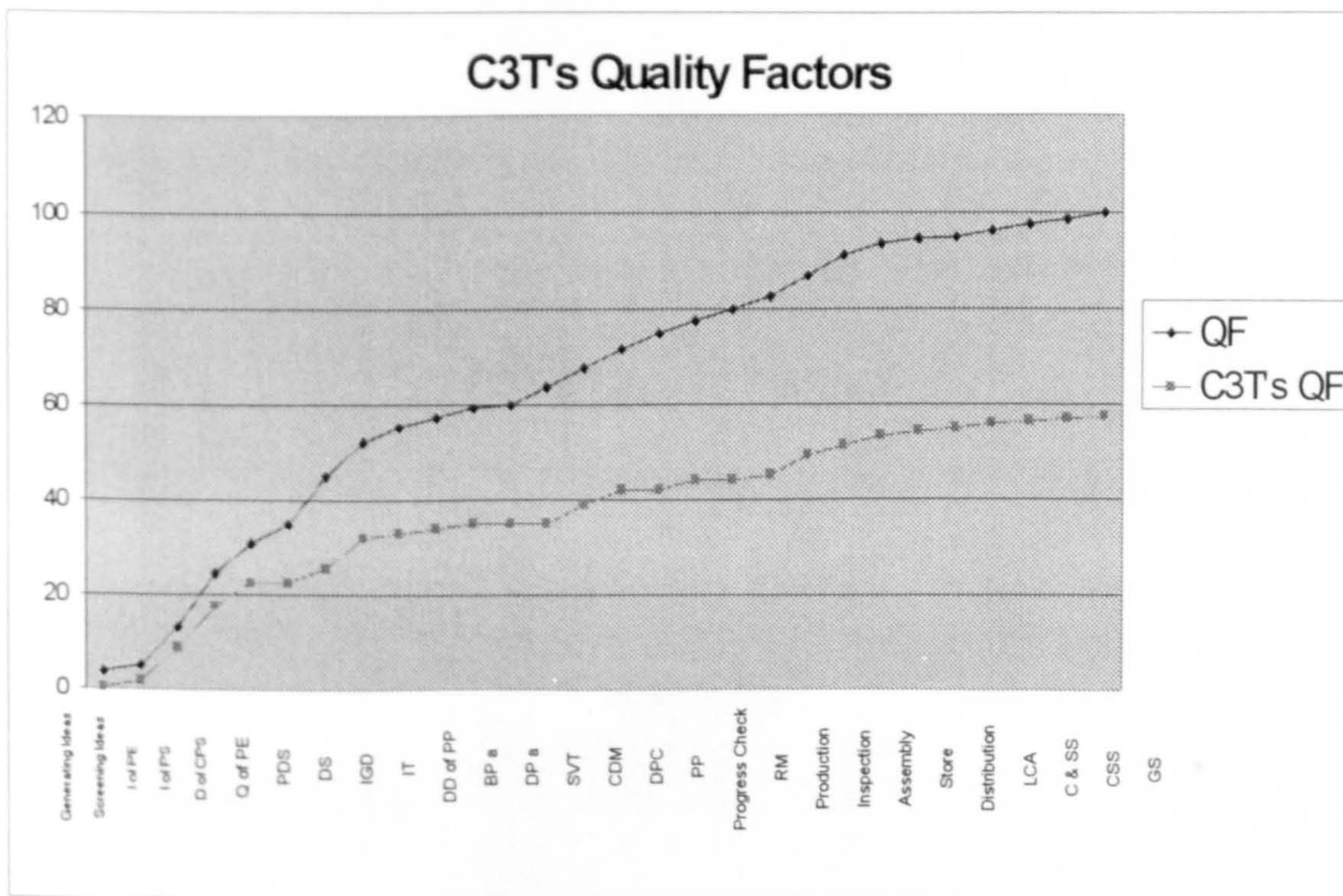


Figure 28: Quality Factors of the NP/SI process of C<sup>3</sup>T

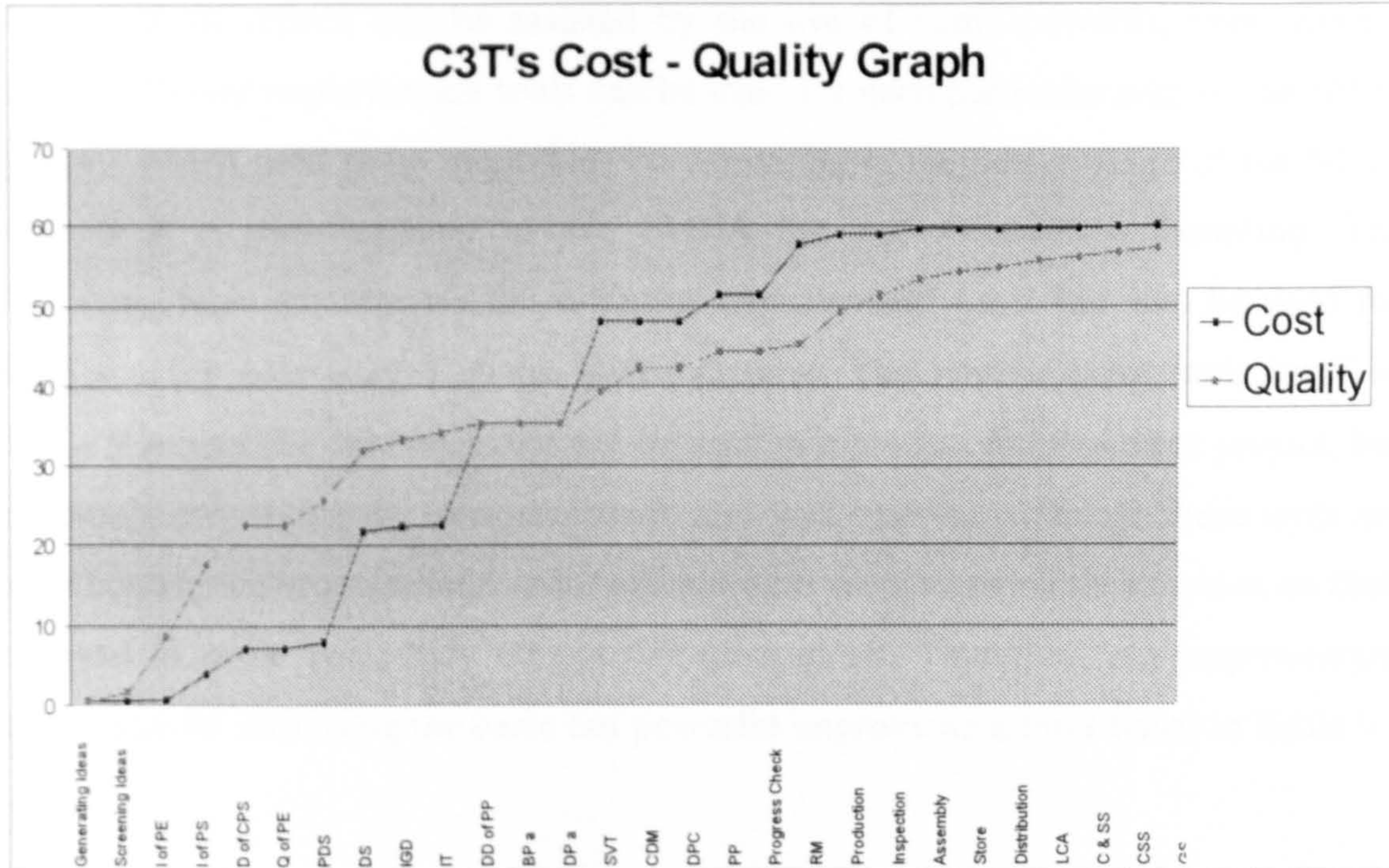


Figure 29: Cost - Quality relationship of the NP/SI process of C<sup>3</sup>T

### 5.5 Recommended Improvement Activities

Having carefully examined and analysed the simulation results and using the knowledge and understanding of the organisations' new product development activities, a set of improvement actions can be proposed for each one the companies. Table 8 summarises the major areas of the organisations' NP/SI process which hold the greatest potential for improvement.

Potential Improvement Areas		
HAI's Electronics Mfg	HAI's Aircraft & Engines	C <sup>3</sup> T
Design	Design	Design
Pre-production validation	Pre-production validation	Pre-production validation
Post Company	Production/Distribution	Production/Distribution

Table 8: Areas for Potential Improvement

Improvement actions can be assisted by the use of some powerful improvement tools. Different improvement tools can be used for each particular area of the NP/SI process which need to be improved. For example, in the design stage of the NP/SI process it is recommended to use FMEA but not Acceptance Sampling. The following table summarises the different improvement tools that can be used for each specific area (stage) of the NP/SI process. The improvement tools listed in Table 9 are not the only ones that can be used in a process improvement project, but definitely are among the most important and well known. Although these tools are well known, the organisations under examination seem to pay little attention on their use and in some cases they do not use them at all. Therefore, any improvement action should start using the basic but powerful improvement tools listed in Table 9.

### Tools for Process Improvement

Stage of NP/SI Process	Improvement Tool
Design	Quality Function Deployment (QFD) Failure Mode & Effect Analysis (FMEA) Capability Analysis (CA) Design of Experiments (DoE) Cost of Quality (CoQ)
Pre-production Validation	Capability Analysis (CA) Design of Experiments (DoE) Cost of Quality (CoQ)
Production/Distribution	Acceptance Sampling (AS) Statistical Process Control (SPC) Cost of Quality (CoQ)
Post Company	Lost Customer Analysis (LCA) Complaint & Suggestion Systems (C&SS) Customer Satisfaction Surveys (CSS)

Table 9: Tools for Improving the NP/SI process

Appendix H (page 212) describes all of the above process improvement tools that can and should be used by the two organisations under examination.

The above mentioned process improvement tools should be used effectively by the organisations in order to efficiently improve their NP/SI process. In many cases, the organisations implemented some of the improvement tools but their use seems to be rather ineffective, possibly because the appropriate emphasis and importance of their use have not been clearly understood. The following table (Table 10) illustrates the process improvement tools that are actually used in the organisations, those which are partially used and finally those which are not used at all. For the case of the two HAI divisions, a single common column has been used since it has been observed that the existence or not of a specific tool depends on a company wide practice and not on a division practice.

### Current Use of Improvement Tools

Process Improvement Tool	HAI	C <sup>J</sup> T
QFD	•	X
FMEA	•	X
CA	•	X
DoE	√	√
CoQ	•	X
AS	√	√
SPC	√	X
LCA	X	X
C&SS	•	•
CSS	X	X

√ : used      X : not used      • : partially used

Table 10: Current Use of Improvement Tools

It becomes very obvious that the two organisations should start their improvement efforts by implementing and using those tools that they are not using at the moment. For HAI, these tools are LCA and CSS, while for C<sup>3</sup>T these tools are QFD, FMEA, CA, CoQ, SPC, LCA and CSS. It is clear that C<sup>3</sup>T has to put a lot of effort in order to improve its NP/SI process and this justifies the results of the simulation. HAI, on the other hand, should try to place its improvement efforts in those tools and techniques which at the moment are partially used, like QFD, FMEA, CA, CoQ and C&SS.

### **5.6 Software Validation of the Proposed Improvement Activities**

At this point, it would be very interesting to see what the effect of the improvement activities, proposed earlier, is going to be. One way of doing so is by actually implementing these improvement activities and then updating and simulating the NP/SI process model for each one of the cases studied earlier. This approach, although it is more accurate since it is reporting on the effect of the improvement activities after their implementation, it requires a considerable amount of time (it could take many months to actually implement the improvement activities). A different approach can be used in order to report on the effectiveness of the improvement activities. It is possible to use the existing model of the NP/SI process developed earlier and adapt it to include the proposed improvement activities. Then, by updating it with new data and information concerning cost and quality it would be possible to simulate the process again. The simulation results could give an indication of the behaviour of the cost and the quality factors after the improvement activities take place. The main advantage of this approach is that it actually reports on the effectiveness of the proposed improvement activities prior to their actual implementation. In this way it is also possible to test the effectiveness of different improvement activities.

For the purposes of this thesis, the case of C<sup>3</sup>T has been chosen to be used as a pilot study because it holds the greatest potential for improvement, as explained earlier in page 117 of section 5.4. In section 5.5 it was also analysed that in order to improve the NP/SI process for the case of C<sup>3</sup>T the improvement efforts should focus on the stages of Design, Pre-Production Validation, Production / Distribution and Post Company, involving process improvement techniques like QFD, FMEA, CoQ, CA, SPC and LCA. Table 11 illustrates the specific improvement technique to be applied at the stages of the NP/SI process that need to be improved.

Design	Pre-Production Validation	Production / Distribution	Post Company
QFD	CoQ	SPC	LCA
FMEA		CoQ	
CA			
CoQ			

Table 11: Improvement techniques to be used for C<sup>3</sup>T

It is obvious that the implementation of each one of these techniques will affect the cost, the time and the quality factors level of the NP/SI process. For each one of the techniques the cost element can be calculated by using the following equation:

$$\text{No. of employees} \times \text{No. of Man Hours} \times \text{Avg. Man Hour Rate} = \text{Cost}$$

The quality factor for each one of the techniques was assigned earlier when building the model and preparing it for simulation. Table 12 illustrates the cost and quality factors effect for each one of the proposed improvement techniques.



	No. of Employees	No. of Man Hours	Avg. Man Hour Rate (£)	Cost (£)	Quality Factor
QFD	2	10	32	640	2.5
FMEA	2	10	32	640	2.5
CA	1	10	32	320	1
CoQ	1	10	32	320	1
SPC	1	10	32	320	1
LCA	1	5	32	160	1

Table 12: Cost and Quality Factor Effect of the Proposed Improvement Techniques

By including these improvement techniques into the existing NP/SI process model of C<sup>3</sup>T it is possible to simulate it again and get an indication about the behaviour of the cost and quality factors level. The following figures (Figures 35 and 36) illustrate the Cost - Quality relationship and the Quality Factors of the NP/SI process of C<sup>3</sup>T including the improvement activities.

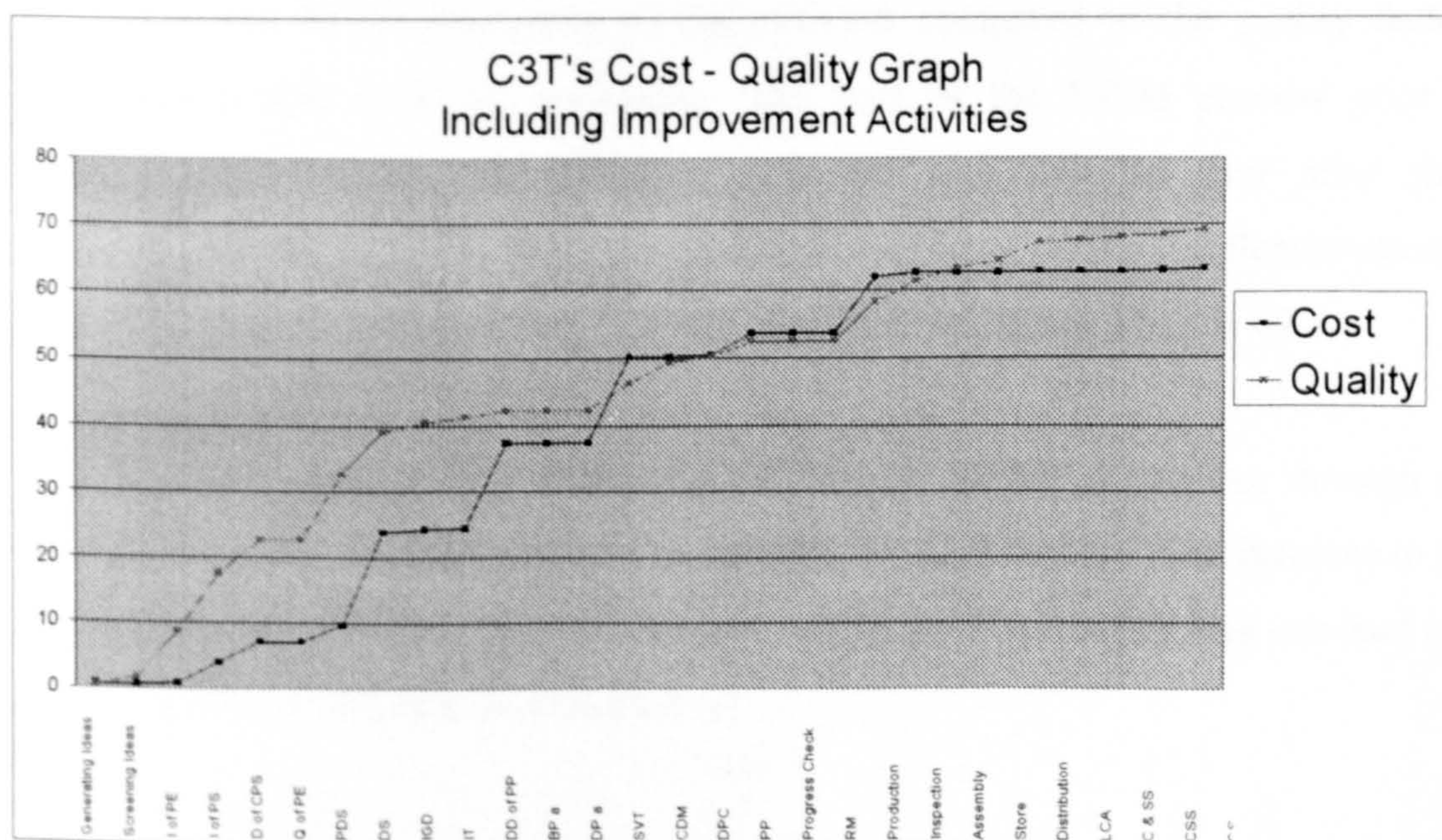


Figure 30: Cost-Quality relationship of the NP/SI process of C<sup>3</sup>T including the improvement activities

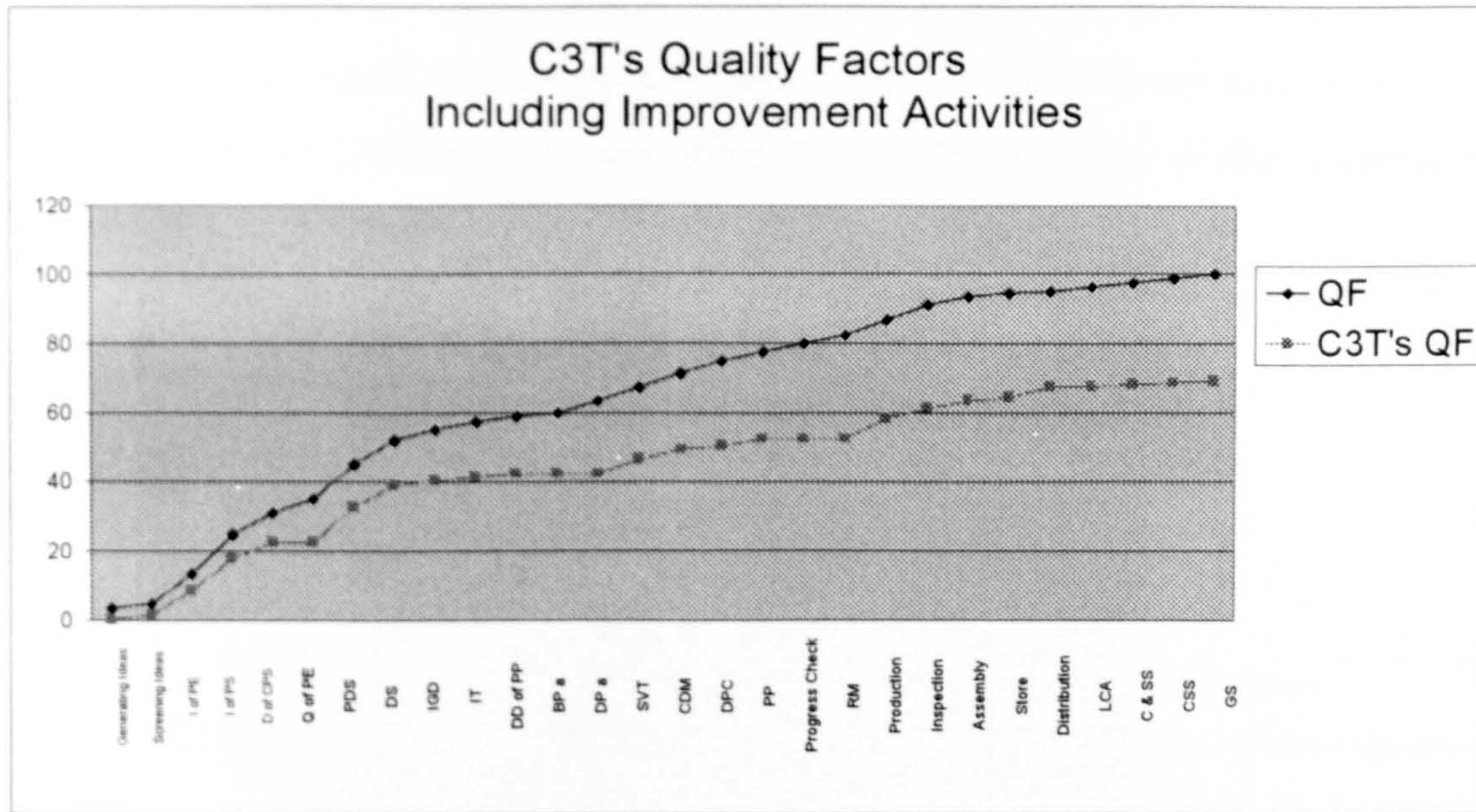


Figure 31: Quality Factors of the NP/SI process of C<sup>3</sup>T including the improvement activities

Comparing Figures 30 and 31 with Figures 28 and 29, it is obvious that there is a considerable difference in the quality factors level. At the same time the increase of the cost of the NP/SI process is so insignificant compared to the quality factors improvement that it is not noticeable. The cost of the NP/SI process prior to implementation of the improvement activities was £60,286 and after their implementation is £63,264, while the quality factors level prior to implementation of the improvement activities was 57.25 and after their implementation is 69.

Therefore, it is clear that by increasing the cost of the NP/SI process, through the implementation of the improvement techniques, by £2,978 there is an increase in the quality factors level of 11.75 units. In other words, a 4.9% cost increase can lead to a 20.5% increase in the quality factors level.

To better illustrate the significant increase of the quality factors level, the following Figure was developed, presenting the “ideal” quality factors level against the “true” of C<sup>3</sup>T’s NP/SI process prior and after the implementation of the improvement activities.

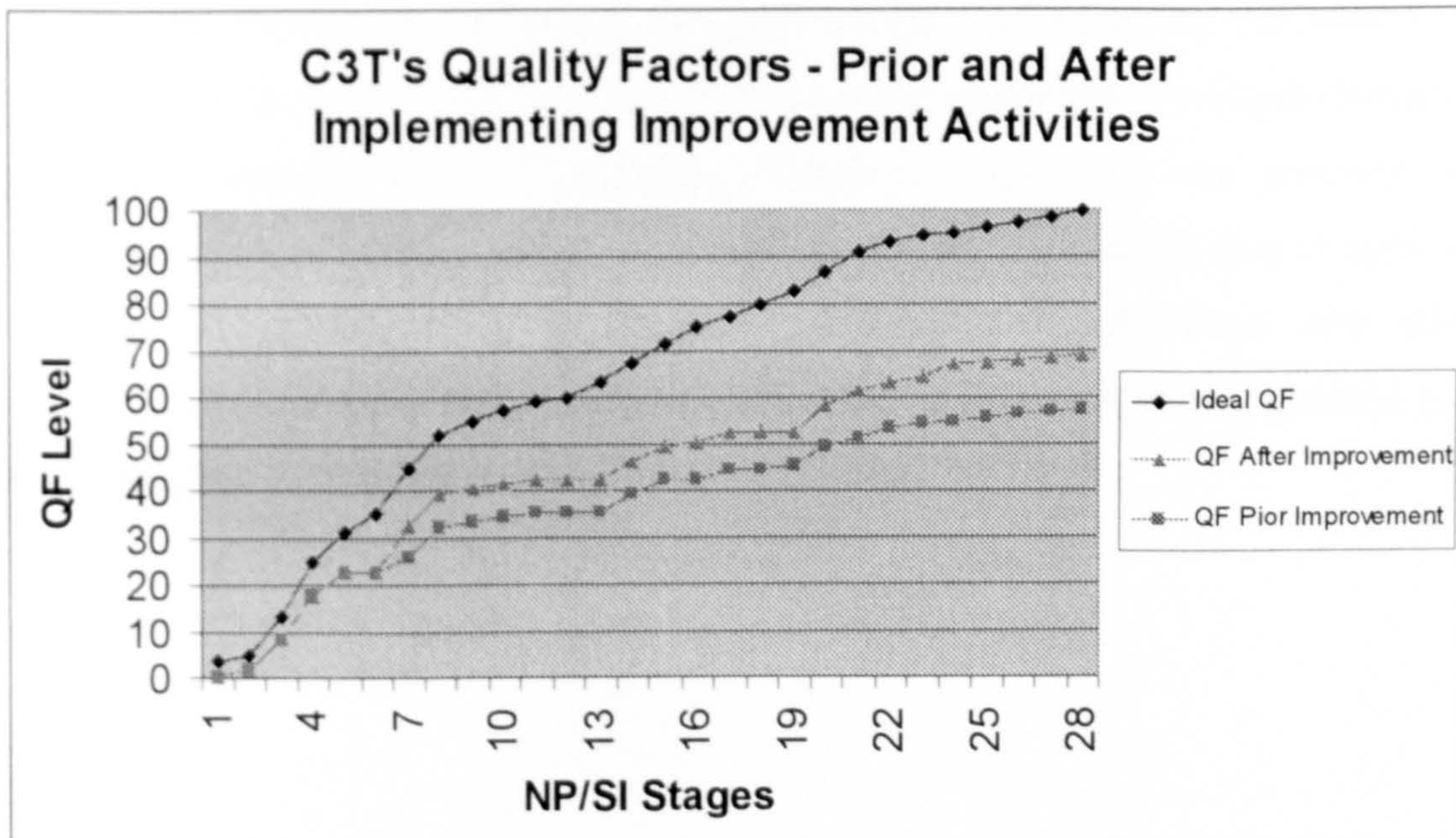


Figure 32: Quality Factors – Prior and After Implementing Improvement Activities

Observing Figure 32 one can easily recognise the significant improvement of the quality factors of the NP/SI process of C<sup>3</sup>T. The quality factors level after the implementation of the improvement activities, has closed the gap from the ideal quality factor level. Despite the significant improvement in C<sup>3</sup>T’s quality factors level, there is still considerable potential for further improvement. The same approach, as described in this chapter, can be used for further improving the NP/SI process. It is obvious that quality and process improvement is and should be a never-ending journey.

## 5.7 Conclusions

Modelling and simulation are powerful tools for process improvement. In terms of the NPSI process, modelling and simulation give the opportunity to the organisations to identify the specific stage(s) of their NPD process that need to be improved. Furthermore, improvement efforts can be tested prior to implementation, providing managers with a 'laboratory' situation where they can generate and experiment with ideas for process improvement without bearing the cost of applying them in the organisational workplace. Modelling and simulation also allow managers to understand the likely impact of 'local' changes on overall process cost, time, and perceived quality.

## CHAPTER 6

**EFFECTIVE HANDLING OF ENGINEERING CHANGES****The Use of Business Process Modelling**

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**6.1 Introduction**

Changes and modifications in forms, fits, materials, dimensions, functions, etc. of a product or part are referred to as product design changes before the design is released, or engineering changes (ECs) after the design is released. An EC usually includes a resulting series of downstream changes along the product development process. Organisational, technological and operational changes are often causes for ECs [55]. ECs are a very significant issue in any product development process and especially in any new product development process.

The scope of this chapter is to report on the use of the business process modelling and simulation technique, namely *System Dynamics*, in order to develop an efficient and effective Engineering Change Management System. System Dynamics, as explained in previous chapters, is a modelling technique that is especially suited to modelling, simulating and analysing the behavioural aspects of a system, i.e. the way that the system elements interact and influence each other to generate overall system behaviour. In terms of the New Product/Service Introduction (NP/SI) process, it has been shown earlier that such an analysis can reveal positive or

negative feedback loops in the process, thereby allowing managers to understand the likely impact of 'local' changes on overall process cost, time, and perceived quality.

To the best of our knowledge this is the first attempt to use the methodology of System Dynamics in order to develop an Engineering Changes Management System. The primary aim was to simulate the NP/SI process of the two organisations in Greece that participate in the research in order to get an indication of the relationship between cost, time and quality. Having successfully done that in chapters 4 and 5, it was decided to examine the effects of the ECs that occur throughout the NP/SI process. Therefore, by inserting disturbances (ECs) into the models and then simulating the NP/SI processes, it is possible to get an overview of the effects of ECs throughout this process. The results of the simulation process together with the ECs background, can provide the basis for developing an Engineering Change Management System, which when managed effectively can lead to an improved environment for product innovation, and provides a favourable opportunity for increased sales and profits.

## **6.2 Engineering Change Management System (ECMS)**

Using the methodology of System Dynamics a model for the NP/SI process has been developed (see chapter 4) and it has been possible to simulate it using data and information from two companies in Greece (see chapter 5) [131-132]. The objective of the simulation was to determine the relationships between cost, time and quality of the NP/SI process of the companies under examination. By inserting disturbances (ECs) into the models and then simulating again the NP/SI processes, it is possible to get an overview of the effects of ECs throughout these processes. The results of the simulation process can be summarised in the next three figures (Figures 30-32).

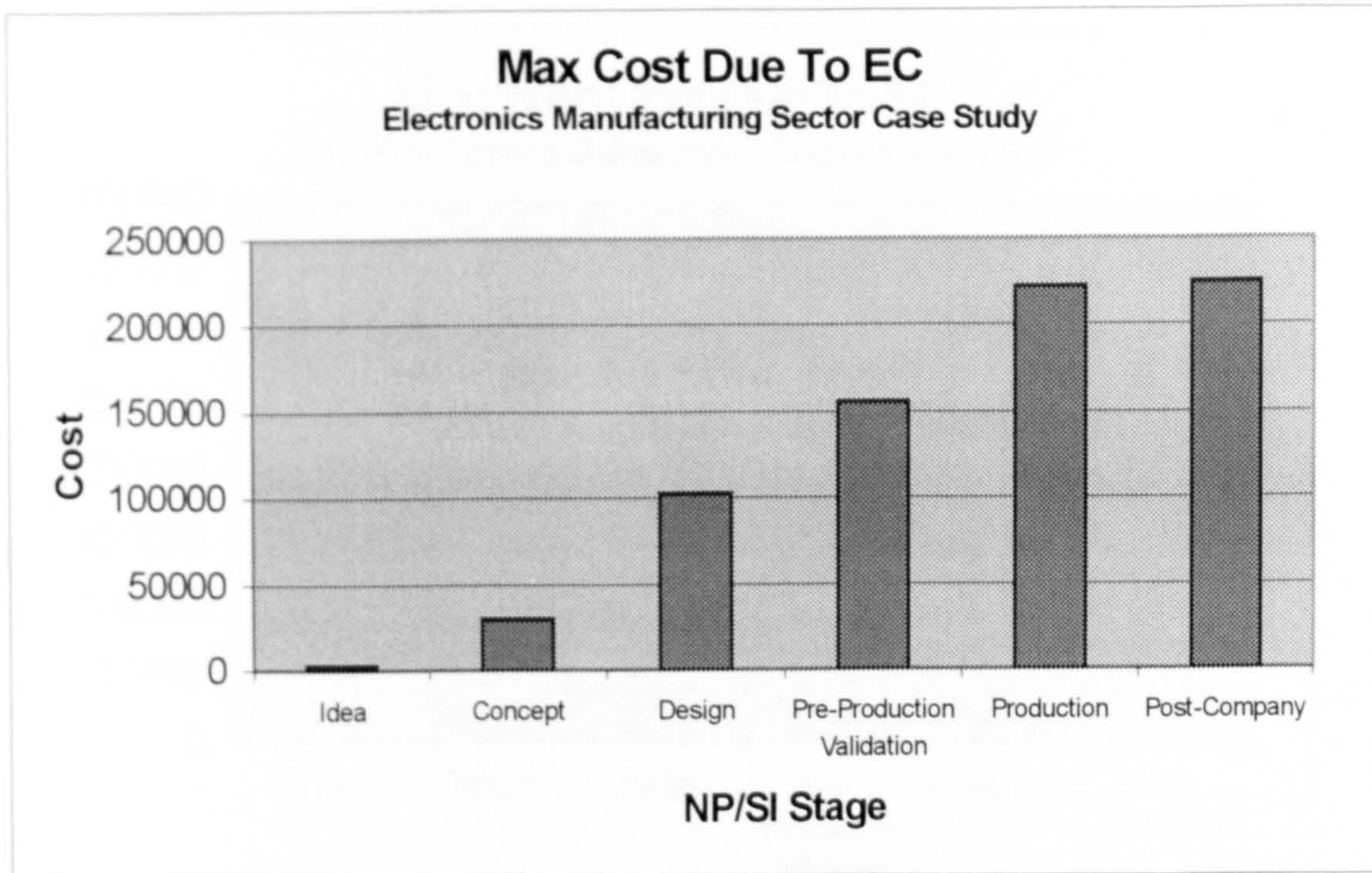


Figure 33: Maximum cost due to EC (Electronics Manufacturing Sector Case Study)

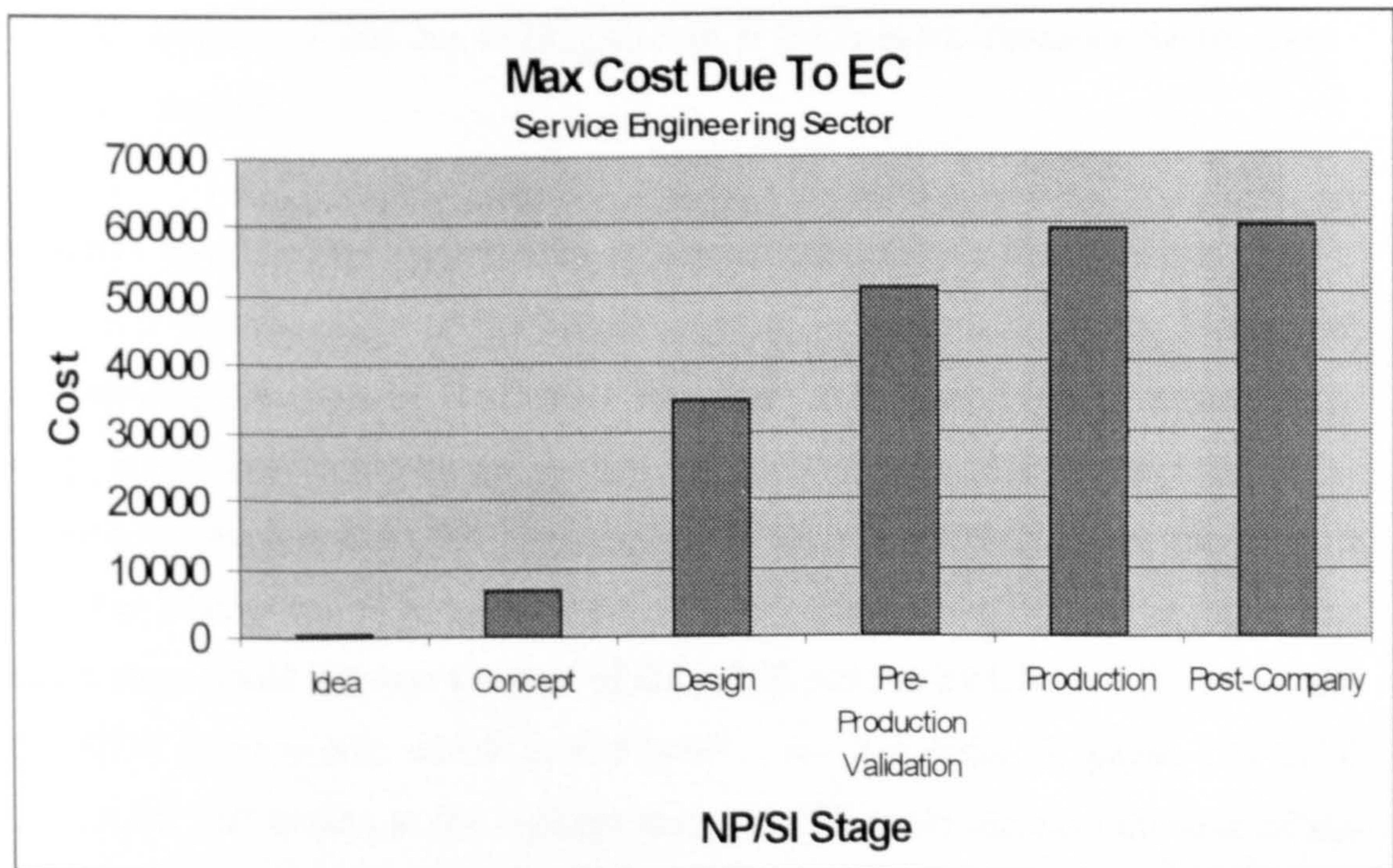


Figure 34: Maximum cost due to EC (Service Engineering Sector Case Study)

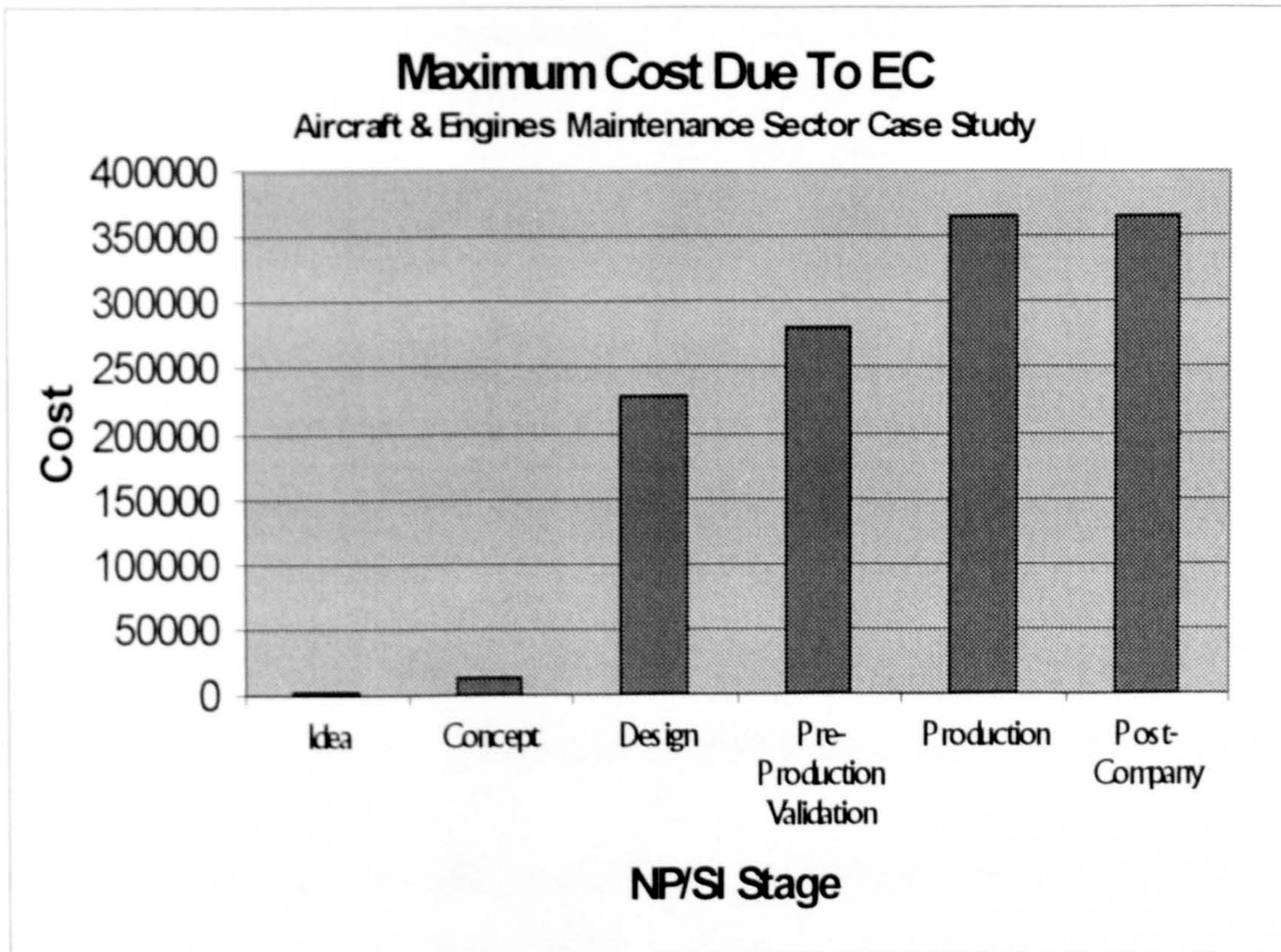


Figure 35: Maximum cost due to EC (Aircraft & Engines Maintenance Sector Case Study)

The above three figures illustrate the maximum cost effect when only just one EC occurs in a specific stage of the NP/SI process. In particular, for the Electronics Manufacturing Division of HAI, if an important and expensive EC occurs at the concept stage there could be an increase of £30,000 (i.e. 13% of the total NP/SI process cost which is £231,000 – see Appendix G, pages 199-215), for the Aircraft & Engines Maintenance Division of the same organisation an EC that occurs at the concept stage could increase the cost of the NP/SI process by £12,210 (i.e. 3% of the total NP/SI process cost which is £367,440 – see Appendix G, pages 199-215), while an EC that occurs at the concept stage of C<sup>3</sup>T could increase the cost of the NP/SI process by £6,620 (i.e. 11% of the total NP/SI process cost which is £60,286 – see Appendix G, pages 199-215). The percentage increase of the cost of the NP/SI process when ECs occur at different stages of the process is shown in Table 11.



	Electronics Manufacturing Division	A/C & Engines Maintenance Division	C <sup>3</sup> T
Idea Stage	1.3%	0.54%	0.5%
Concept Stage	13%	3.3%	11%
Design Stage	44.4%	62.43%	57.5%
Pre-Production Validation	67.3%	76.25%	84.1%
Production/ Distribution	96.3%	99.45%	98.1%
Post Company	97.3%	99.45%	99%

Table 13: Percentage increase of the cost of the NP/SI process (when only one EC occurs)

As already mentioned, the above percentage figures indicate the increase in the cost when only one EC occurs during the NP/SI process. It is clear, that the magnitude of the effect grows exponentially as the number of ECs during the NP/SI process increases, which is normally the case. Usually, in a development project there are a lot of ECs, not just one. The number of ECs depends on the complexity of the product. One could expect a lot of ECs (maybe thousands of ECs) when developing a new aircraft. When developing a less complex product, a kettle for example, one should expect less fewer ECs. At this point, it is important to note that, as in the case of the NP/SI process cost, the cost effect of an EC refers only to the process itself, and not to any other factor or element that can influence (increase) the cost of the process. For example, the cost of new materials that might need to be used due to an EC or the cost for new machines that might be necessary to buy because of an EC, are not considered to be NP/SI process cost.

In a different study, Machowski and Dale [133] reported that the average administration cost per EC, in an organisation involved in the manufacture of telecommunications equipment, was £1,000. The yearly cost of ECs was estimated to be between £168,000 to £210,000. It is worth noting that the actual cost of

making any changes accelerates rapidly as product release approaches. The potential impact of ECs, as mentioned earlier, can be represented as follows:

- Concept stage = x
- Design stage = 10x
- Pre-Production Validation stage = 100x
- Production stage = 1,000x
- Post-release = 10,000x [61]

The results of the simulation that are presented in Figures 33, 34 and 35 and are summarised in Table 13, are closely related to the above EC cost relationship, although at first sight such a relationship does not seem to exist for the three case studies. The reason is because figures 33, 34 and 35 represent the cost effect of only one EC. If the number of ECs increases the relationship will look more like the one above.

It is therefore obvious, that an effective and efficient engineering change management system (ECMS) is required to handle ECs and their effects. Engineering Change Management, like any other business process, needs to be strictly controlled. The main requirement for any manufacturing and/or engineering organisation is to reduce not only the number of ECs but also the EC cycle time, defined as the time taken from the EC being raised to its successful introduction into the product or service.

Previous research has identified a number of strategies a development organisation can adopt to reduce the negative consequences of ECs. Terwiesch and Loch [59] have classified this prior work into four groups and summarise the major findings in the form of “Four Principles of EC Management”.

*Principle 1: Avoid unnecessary changes*

Many ECs are not necessary and can be avoided if the engineer responsible spends more time on the first release of the component. Since, on average, every component

has to be changed once [134], many engineers feel no reason to provide good information to other parties in their “first shot”, as they know they will have to rework the component anyway [59].

*Principle 2: Reduce the negative impacts of an EC*

The second principle takes the occurrence of an EC as given, and focuses on minimising the negative impact of the change. This impact is a function of the magnitude of the change, its timing, and the number of components and tools that are affected by the change [59].

*Principle 3: Detect ECs early*

The third principle is based on the observation that ECs become more expensive and harder to include the later they are implemented, thus making it desirable to detect the need for changes as early as possible in the process. Recent advances in computer aided design, rapid prototyping, and computer simulation have allowed development organisations to detect ECs far earlier in the process, at substantially lower cost [59].

*Principle 4: Speed up the EC process*

The fourth principle refers to the complex decision and support process, which manages and co-ordinates the ECs. Like any other administrative or production process, the EC process often suffers the symptoms of long response times [59].

The first three principles all have their roots in the engineering domain and are related to the technical problem solving characteristics of the change, while the last one is process-driven and thus a subject of management within the organisation.

There are two extreme approaches to managing ECs. One is formal and the other ad hoc [55]. Some organisations use a formal ECMS, with well-structured procedure to handle ECs, well-defined documentation (EC Requests, EC Notices, etc.) and clearly stated authorities and responsibilities (EC Board, or EC Committee). On the

other hand, some organisations deal with ECs in a very informal approach, with no specific procedure to handle ECs. To emphasise the difference between these two approaches, the ad hoc approach is similar to leading an army into battle without having any well-planned strategy, while the ECMS approach is leading an army into battle having a well-planned strategy. The great generals of the past have proved that victory is not a matter of arms and numbers of soldiers alone, but also of tactics and well-planned strategy as well.

There is a noticeable lack of literature on the subject of ECs and ECMSs. Some of the main reasons for this might be:

- The strong interest in concurrent engineering to eliminate, or reduce, the need for ECs
- The stigma attached to ECs, which are perceived to be patching-up solutions
- The belief that there is not much to understand about the subject [56], e.g. it is relatively straightforward and hence of little academic interest
- The growing popularity of Engineering Data Management systems which are perceived to have considered all the difficulties associated with EC and thus to have 'solved' the problem.

Despite the fact that the literature on ECs and ECMSs is very limited (only about 25 papers have been found by searching over major databases) it was possible to get an overview of current ECMS practice. What seems to be common in all formal ECMSs are: a well-structured EC procedure, an EC board, an EC co-ordinator, proposal of ECs, approval of ECs, notification of ECs, recording of ECs and implementation of ECs.

Using all available knowledge and information from the literature, together with the experience gained by studying the two organisations that participated in the study, it was possible to develop a comprehensive ECMS. This ECMS, which is illustrated in Figure 36, is considered to be both generic and specific enough to be applicable to any kind of organisation.

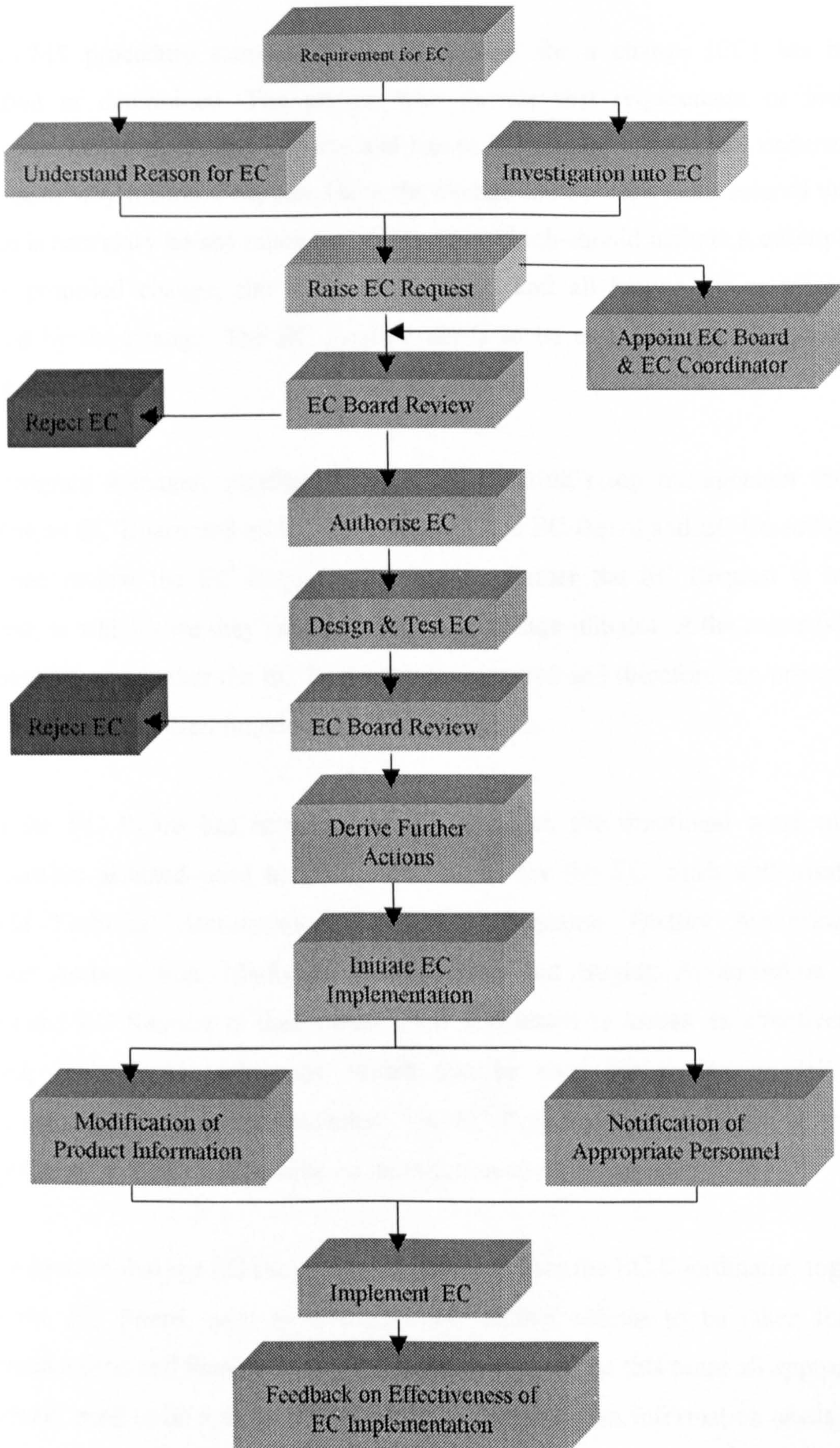


Figure 36: Engineering Change Management System

The ECMS procedure starts when a requirement for a change (EC) has been identified or determined. The person who detects that requirement or his/her supervisor, becomes the EC initiator and has to investigate the EC and understand the reasons why it should happen. Once the change initiator has been assured that a change is necessary he/she raises an EC Request which should include a description of the proposed change, the reason for change, and all known functional areas affected by the change. The EC Request needs to be transmitted to the program manager.

The program manager, together with the organisation's top management should convene an EC Board and an EC Co-ordinator. The EC Board and EC Co-ordinator will then review the EC Request and decide whether the EC Request is to be rejected, in which case they need to inform the change initiator of the reason(s) for its rejection, or whether the EC Request is to be accepted and therefore can proceed to approval by the affected functions of the organisation.

Once the EC Board has accepted the EC Request, the functional areas of the organisation affected need to give authorisation for the EC. Such authorisations include Technical Authorisation, Design Authorisation, Quality Authorisation, Service Authorisation, Marketing Authorisation and Buying Authorisation. The authorised EC Request is then investigated and tested to assess its effectiveness. Among the various techniques, which can be used for testing an EC, are manufacturing and process simulation. The EC Board needs once again to review the progress of the EC and decide on its rejection or continuation.

If it is decided that the EC should be implemented then the EC Coordinator, together with the EC Board, need to formulate any further actions to be taken for EC implementation and then to initiate EC implementation. At this point all appropriate personnel need to be notified about the EC and the product information needs to be modified. The EC is then implemented and the implementation monitored to gain maximum effectiveness.

### 6.3 ECMS using System Dynamics

The System Dynamics modelling technique was used to transform the generic ECMS illustrated in Figure 36 into a computer-based model that could be run dynamically and analysed. The main aims of this modelling were to gain additional insight into the dynamics of the generic ECMS process, and to identify 'hidden' or difficult to establish inter-relationships between the various activities which constitute the whole process. The ultimate objective is to use customised versions of this model in order to measure the effectiveness of the ECMS process in particular organisations, and to guide (in an informed manner) managerial decision-making with reference to the optimal arrangement of activities and use of quality tools and techniques within the NP/SI process.

For the purposes of the modelling of the ECMS, it was decided to use the same software that was used for the NP/SI process modelling, that is *iThink* by High Performance Systems Inc.. The major reason was the experience and knowledge gained by using this particular software in modelling the NP/SI process. Another reason was the financial cost. Due to the limited financial resources it was not possible to purchase different software.

As far as the methodology for developing and validating the ECMS model is concerned, a similar approach to the one for developing the NP/SI process model, described in chapter 4, was followed. The knowledge and information provided by the literature were coupled with the experiences gained by visiting the two participating organisations and discussion with appropriate personnel. Therefore, it was possible to get an overview of how such a system should be realised in practice.

Figure 37 illustrates the overall ECMS model developed using *iThink* software.

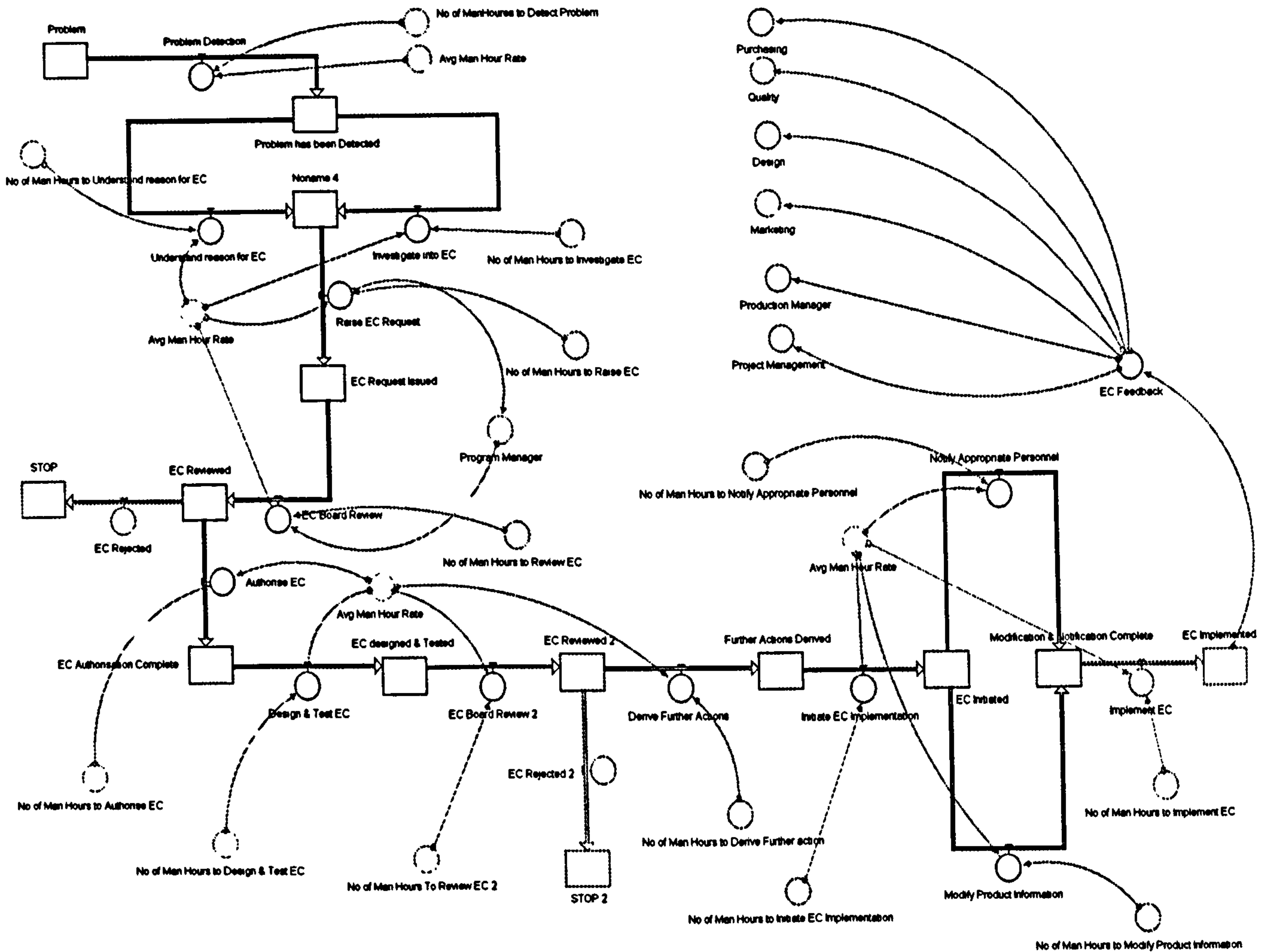


Figure 37: ECMS model using System Dynamics methodology (iThink s/w)

By quantifying the relationships implied by the links in the System Dynamics model, it is possible to simulate the model and gain quantitative information on model dynamics. For example, modellers and decision-makers can experiment with different options for arranging activities or for using different quality tools and techniques, and assess (in real-time) the effects of their decisions on the overall ECMS process. The Key Performance Indicators that can be measured through this



process are Time (the duration of the whole ECMS process or of the individual stages it consists of), and Cost (depending on the cost drivers as determined by each particular company).

For example, one can experiment with different options regarding the number of man hours spent on authorising ECs (to use the example of Figure 33), and evaluate the best balance between additional costs (due to time and manpower spent in authorising ECs) and time. It should, however, be noted that in order for the System Dynamics model to be used in such a quantitative fashion, a significant amount of data must be collected, analysed, and used within the model. Since these data have to come from particular organisational settings, it is not possible to quantitatively simulate the model in a generic case (i.e. for every company). The generic model can be used for qualitative evaluation of the ECMS process, as well as a baseline for the development of 'customised' models for individual organisations.

More specifically, organisations can use the SD ECMS model in order to better understand the behaviour of their EC system. By collecting all appropriate data and information, required by the model, it is possible to simulate it, and therefore, as in the case of the NP/SI process model, they can be in a position where they will be able to improve it, using the approach described in chapter 5.

## 6.5 Conclusions

Modeling and simulation are powerful tools for process improvement. In terms of the NP/SI process, modelling and simulation give the opportunity for organisations to identify the specific stage(s) of their NPD process that need to be improved [132]. Furthermore, new process designs can be tested prior to implementation, providing managers with a 'laboratory' situation where they can generate and experiment with ideas for process improvement without bearing the cost of applying them in the

organisational workplace. Modelling and simulation also allow managers to understand the likely impact of 'local' changes on overall process cost, time, and perceived quality.

ECs are a very significant issue in any product development process and especially those concerned with new products. It is obvious, that an effective and efficient ECMS is required to handle ECs and their effects. Using the methodology of System Dynamics a generic model of the ECMS has been developed in such a way that it is possible to simulate it and identify the relationship between cost and time to allow improvement. Future work in this area will focus on testing the ECMS model using real data from a variety of commercial organisations.

## CHAPTER 7

## CONCLUSIONS

Discussion and Future Work

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As has been shown and explained in earlier chapters, in a competitive environment that is global, intense, and dynamic, the development of new products and processes is a focal point of competition. To succeed, organisations must be responsive to changing customer demands and the moves of their competitors. This means that they must be *fast*. The ability to identify opportunities, mount the requisite development effort, and bring to market new products and processes quickly is critical to effective competition. But firms also must bring new products and processes to market *efficiently*. Because the number of new products and new process technologies has increased while product lives and life cycles have shrunk, firms must mount more development projects than has traditionally been the case utilising substantially fewer resources per project. Being fast and efficient is essential but not enough, the products and processes that a firm introduces must also meet demands in the market for value, reliability, and distinctive performance. Therefore, attention to the total product *quality* is also crucial [16].

The importance of understanding the NP/SI process and its internal and external structure and relationships may be realised by looking at the results it may have, like the unification of all functional divisions by a common aim and purpose which

enables activity to be guided so that it meets the process objective. Managing, controlling and ultimately improving the new product/service introduction process has become a necessity for successful business operation.

One way of understanding, managing and improving any business process is by using business process modelling. As the aim of this research project was to use BPM for improving the NP/SI process and effectively manage ECs, the System Dynamics BPM technique has been chosen amongst others, as described in chapter 3.

### **7.1 System Dynamics and Business Process Modelling and Simulation**

Due to the complex and dynamic nature of organisations, it has been argued that carefully developed models are necessary for understanding their behaviour in order to be able to design new systems or improve the operation of existing ones [77, 78, 79]. BPM&S plays an essential part in challenging existing processes in terms of process complexity, possible process simplifications, process effectiveness, process cost and process quality [68].

Within BPM&S there are many methods and notations which may be used in order to describe and analyse a process. According to the hierarchical decomposition of modelling elements, BPM can be thought of as being supported by one or more methodologies. Methodologies are taken to refer to modelling paradigms (for example, data-focused, object-oriented, soft-systems, and so on). Regardless of the methodology used, modelling can be supported by a number of techniques that provide the main focus of the rest of this section. Techniques are taken to refer to diagrammatic or other notations for studying and analysing modelled systems. Specific techniques, as well as their underlying methodologies, can be supported (and in most cases are supported) by software modelling tools, such as CASE tools, Workflow Management Systems, process modelling software, and others.

System Dynamics is a modelling and simulation technique especially suited to the modelling and analysis of the behavioural aspects of a system, i.e. the way that the system elements interact with and influence each other to generate overall system behaviour. SD is based on feedback control theory and it was chosen to be the BPM technique to be used in this research project for the reasons described in chapter 4. SD is a system methodology capable of assisting with practical problem definition, analysis and change in a wide range of systems and with a potential to provide a more significant contribution to current general system practice than presently achieved. It is felt that the major reasons why this potential has been inhibited stems from its misperception and the wide range of issues to which it has some relevance. In the extreme case, this results in its perception by soft system methodologists as a hard system modelling technique and in its perception by hard system modellers as a soft system approach. In practice it combines some of the better features of both worlds [126].

Using the software package *iThink*, developed by High Performance Systems Inc., the generic NP/SI process model was transformed into a computer-based model that could be dynamically run and analysed. The main aims of this modelling endeavour were to gain additional insight into the dynamics of the generic NP/SI process, and to identify 'hidden' or difficult to establish inter-relationships between the various activities which constitute the whole process. The ultimate objective was to use customised versions of this model in order to measure the effectiveness of specific instances of the NP/SI process in particular organisations, and to guide (in an informed manner) managerial decision-making with reference to the optimal arrangement of activities and use of quality tools and techniques within the NP/SI process.

By quantifying the relationships implied by the links in the System Dynamics model, it was possible to simulate the model and gain quantitative information on model dynamics. The key performance indicators that were measured through this

process were Time (the duration of the whole NP/SI process or of the individual stages it consists of), Cost (depending on the cost drivers as determined by each particular company), and Quality.

The same approach has been followed in modelling the generic structure of the Engineering Change Management System developed in chapter 6. The SD ECMS model has been developed in such a way that it could be used by organisations in order to better understand the behaviour of their EC system. As in the case of the NP/SI process model, it is possible to simulate the ECMS model and therefore identify potential areas for improvement.

## **7.2 Process Improvement using SD**

The aim of the thesis was to report on the use of the SD technique in modelling and simulating the generic structure of the NP/SI process in organisations, and on ways to improve such a process. Furthermore, by using the same technique to develop an efficient and effective ECMS.

To achieve this the NP/SI processes of the two Greek companies collaborating in this project were modelled and simulated in order to investigate the existence of a cost-time-quality relationship which could facilitate the identification of areas for potential improvement of the process under examination.

The results of the modelling and simulation attempt in all three cases (C<sup>3</sup>T and the two divisions of HAI) have indicated that there is definitely significant potential for improving the NP/SI process of the organisations under examination.

For the Electronics Manufacturing Division of HAI the greatest potential for improvement is at the design stage as well as at the pre-production validation and post-company stages, since at these three stages the 'true' quality factors level seems

to decline from the 'ideal' while the cost figure increases significantly. Improvement efforts should focus at the design and pre-production validation stages in order to increase the quality factors level and at the same time to decrease the cost. The post-company stage also deserves attention since during this stage, the division is not spending enough time for the post-company activities.

For the Aircraft & Engines Maintenance Division of HAI it was possible to identify that there is potential for improvement at the stages of the design, production/distribution and pre-production validation of the NP/SI process since again the division's ('true') quality factors level is significantly lower than the 'ideal' level and at the same time the process cost element increases. Therefore, all initial improvement efforts should focus at these stages in order to increase the quality factors level and at the same time to decrease the cost.

Improvement actions can be assisted by the use of some powerful improvement tools described in Appendix H. Different improvement tools can be used for each particular area of the NP/SI process which need to be improved. Although at HAI, some of these tools are used, some others are only partially used or they are not used at all. Therefore, for the improvement of HAI's NP/SI process, LCA, CSS and C&SS should be used for improving the post company stage, and QFD, FMEA, CA, and CoQ for improving the design, pre-production validation and production/distribution stages.

The results of the simulation of the NP/SI process of C<sup>3</sup>T seem to be more clear and easier to understand than of those of HAI's divisions. It is very obvious that there is a significant difference between the 'true' quality factors level and the 'ideal' quality factor level. This suggests that there are great possibilities for improving the NP/SI process of C<sup>3</sup>T. The potential for improvement seems to be at least double that in the cases of HAI's divisions. A close and careful examination of the simulation results clearly indicates that the cost curve has significant and relatively high increases ('jumps') at certain stages of the NP/SI process. At these stages, the quality factors

level seems to have negative rate of increase and in some extreme cases it actually remains stable (does not increase at all). These stages are the design stage, the pre-production validation stage and the production and distribution stage.

Therefore, it becomes very obvious that C<sup>3</sup>T should start its improvement efforts by implementing and using those tools that are not being used at the moment. The tools that should be used are QFD, FMEA, CA, CoQ and SPC for improving the design, the pre-production validation and the production/distribution stages of its NP/SI process, and LCA and CSS for improving the post company stage. It is clear that C<sup>3</sup>T has to put in a lot of effort in order to improve its NP/SI process and this fact is justified by the results of the simulation showing the difference between actual ('true') and 'ideal' quality factors.

The use of the SD technique for modelling and simulating the NP/SI process has indicated that Business Process Modelling and Simulation are powerful tools for process improvement. Modelling and simulation can be used for describing, understanding and analysing any business process within an organisation. BPM&S give the opportunity for organisations to identify the specific stage(s) and/or areas of their processes that need to be improved. The identification of the 'problematic' stage(s) of a process is very important since it gives an initial indication as to where improvement efforts should start. Improvement efforts can include the use of some of the available improvement tools or in some cases it may even require the fundamental re-design of the whole process. This could happen if the results of the simulation present a very bad relationship between cost, time and quality, or when the initial improvement efforts seem not to work.

Furthermore, the use of BPM&S gives the opportunity for new process designs to be tested prior to implementation, providing managers with a 'laboratory' situation where they can generate and experiment with ideas for process improvement without bearing the cost of applying them in the organisational workplace. Modelling and



simulation also allow managers to understand the likely impact of 'local' changes on overall process cost, time, and perceived quality.

### **7.3 Further Research**

Research, like new product development, is a never-ending journey. Once a researcher achieves his or her goals and objectives, he sets new ones, which are usually based on the experience and knowledge gained by the previous 'trip'. As a result and having reached a point in this research where the goals and objectives have been achieved, it is now possible to start thinking about the future work that results from these research findings.

Further research on this thesis should include the validation of the NP/SI and ECMS models, further modelling using SD technique, the use of other modelling techniques for modelling NP/SI and ECMS models and the simulation of the ECMS process model.

#### Validation of the NP/SI and ECMS models

In chapters 4 and 6, the NP/SI and ECMS models were developed by using the System Dynamics BPM technique. Both models were validated using a series of validation and verification tests, including structure verification test, parameter verification, extreme conditions, boundary adequacy, dimensional consistency, behaviour anomaly, behaviour sensitivity and changed-behaviour prediction. Apart from the use of all the above validation tests, the two models can be further and better validated by using data and information about the NP/SI and ECMS processes from more organisations. The more data and information about the processes under examination that are available, the higher the degree of confidence that the models built are realistic and suitable for use within the defined experimental frame.

Therefore, future work on this subject involves the study and modelling of the NP/SI and ECMS processes of other organisations. Organisations from different industry sectors and even from different countries may be studied and analysed, giving the possibility to obtain comparison results by industry sectors and by different countries. If the number of organisations is large enough it can be possible to compare different practices by company size as well as by industry sector and by country.

#### Further modelling using SD

In this research project, the SSM technique of system dynamics has been used for modelling the NP/SI and ECMS processes and simulating the NP/SI process. It would be interesting to use the same technique of SD in order to model and simulate other business processes within the organisations under examination or even other organisations as well. By doing so it may be possible to gain better understanding of the operation of an organisation as a whole and therefore manage the improvement all its business processes. Some examples of other business processes which can be modelled and simulated are the product delivery (to the customer) process, the material handling process, the purchasing process, the quality costing process, the project cost estimation process, the inspection process, and so on.

By modelling all business processes within an organisation it may be possible to obtain a holistic picture of the organisation. This can be achieved by consolidating all business processes in just one model. To achieve this it is necessary to perform the modelling by using several hierarchical levels. The experience of using SD in this thesis has indicated that this is not only possible but also relatively easy, although it requires a considerable amount of modelling man hours.

### The use of other BPM techniques

Another area for further research can be the use of other BPM techniques for modelling and simulating the NP/SI and ECMS processes. It would be very interesting, especially for the academia, to compare the modelling and simulation results obtained by using the SD technique, with the modelling and simulation results of other BPM techniques like the SSM, the IDEF techniques, Petri Nets, Role Activity Diagrams, Flowcharts, Knowledge-based Systems, and simulation methods like discrete-event simulation and qualitative simulation. The use of other BPM techniques for modelling and simulating the NP/SI and ECMS processes can allow not only the comparison of the findings and results of each technique but also provide the basis for a comparative evaluation analysis of the different BPM techniques.

The comparison of the results between the different BPM techniques and System Dynamics can also be used for validating the accuracy of the modelling and simulation results. If the NP/SI process is modelled using a different BPM technique, like the IDEF0, one should expect to get slightly different results from those of the SD technique. If it can be observed that there is a significant 'agreement' between the results of the two different BPM techniques, then one can argue that each one of these techniques can accurately model and simulate the process. Likewise, if there is significant difference between the results from the different BPM techniques then there is evidence that not all techniques can accurately model and simulate the process, and therefore further investigation would be necessary in order to decide which technique gives more accurate results. In such a case, the different techniques should be used to model and simulate a known case study of the process for which the results are known. The technique that gives the more accurate results would be the one whose results were closer to the actual results.

### Simulation of ECMS model

It has been shown in chapter 6 that ECs are a very significant issue in any product development process and especially those concerned with new products. It is obvious, that an effective and efficient ECMS is required to handle ECs and their effects. Using the methodology of System Dynamics a generic model of the ECMS has been developed in such a way that it is possible to simulate it and identify the relationship between cost and time to allow improvement. Future work in this area will focus on testing the ECMS model using real data from a variety of commercial organisations, starting with HAI and C<sup>3</sup>T. As in the case of the NP/SI process, simulation results can reveal the specific areas of the process, which could be potentially improved.

### **7.4 Thesis's Contributions**

As a concluding remark to this thesis, this section provides a brief summary of the primary contributions this thesis has made in the areas of new product development, engineering changes and business process modelling. The primary contributions of the thesis are:

- The use of SD to model and simulate the generic structure of the NP/SI process
- The use of SD to identify potential areas for improvement throughout the NP/SI process
- The development of an ECMS, and
- The use of SD to model the ECMS so that it could be simulated and ultimately improved.

# REFERENCES

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- [1] Hart, J. (1995), "*Where we have been and where we are going in New Product Development research*", Product Development - Meeting the Challenge of the Design-Marketing Interface, Edited by Margaret Bruce and Wim G. Biemans, John Wiley & Sons, 1995
- [2] Baker, M. J., "Marketing - An Introductory Text", Fourth Edition, Macmillan Press, London, 1985 .
- [3] Booz-Allen and Hamilton, "New Product Management for the 1980's", Booz-Allen and Hamilton Inc., New York, 1982
- [4] Johne, F.A., Snelson, P.A., "Success Factors in New Product Development", City University Working Papers, No. 87, May 1987
- [5] Rothwell, R., Freeman, C., Horsley, A., Jervis, V.T.P., Robertson, A.B., Townsend, J., "SAPPHO Updated", Research Policy, Vol.3, pp. 258-291, 1974
- [6] Gardiner, P., Rothwell, R., "Innovation: A Study of the Problems and Benefits of Product Innovation", The Design Council, London, 1985
- [7] Cooper, R.G., "Identifying Industrial New Product Success: Project NewProd", Industrial Marketing Management, Vol. 8, No. 2, pp. 124-135, 1979
- [8] Cooper, R.G., "Predevelopment Activities Determine New Product Success", Industrial Marketing Management, Vol. 17, No. 3, pp.237-247, 1988
- [9] Cooper, R. G. and Kleinschmidt, E. J., "An Investigation into the New Product Process: Steps, Deficiencies, and Impact", Journal of Product Innovation Management, Vol. 3, No. 2, 1986
- [10] Dwyer, L., Mellor, R., "Organisational Environment, New Product Process Activities and Project Outcomes", Journal of Product Innovation Management, Vol. 8, No. 1, pp.39-48, 1991
- [11] Sanchez, A.M., Elola, L.N., "Product Innovation Management in Spain", Journal of Product Innovation Management, Vol. 8, No. 1, pp.49-56, 1991
- [12] Parry, M.E., Song, X.M., "Identifying New Product Successes in China", Journal of Product Innovation Management, Vol. 11, No. 1, pp.15-30, 1994

- [13] **Stevenson, S., Dooley, K.J., Anderson, J.C.**, "The Use of Best Design Practices: An Analysis of US Navy Contractors", *Research in Engineering Design*, Vol. 6, No. 1, pp.14-24, 1994
- [14] **Page, A.L.**, "Assessing New Product Development Practices and Performance: Establishing Crucial Norms", *Journal of Product Innovation Management*, Vol. 10, No. 4, pp.273-290, 1993
- ✓ [15] **Calantone, R.J., Di Benedetto, C.A., Haggblom, T.**, "Principles of New Product Management: Exploring the Benefits of Product Practitioners", *Journal of Product Innovation Management*, Vol. 12, No. 3, pp.235-247, 1995
- ✓ [16] **Clark, K.B. and Wheelwright, S.C.**, 'Managing New Product and Process Development', Harvard Business School, Free Press, Boston, MA, USA, 1993
- ✓ [17] **Thomas, R. J.**, "New Product Development - Managing and Forecasting for Strategic Success", John Wiley & Sons Inc., USA, 1993
- [18] **IMIPIP Project Grant No. IMI/A/02/019**, Developing a Research Strategy for the IMI Integrated Aerospace Manufacture Programme, Final Report on: 'Initial Research into the Product Introduction Process', report submitted to the Innovative Manufacturing Initiative, 1997
- [19] **Cooper, R. G.**, "How new product strategies impact on performance", *Journal of Product Innovation Management*, 1, pp.5-18, 1984
- [20] **Thwaites, D.**, "Organisational influences on the new product development in financial services", *Journal of Product Innovation Management*, 9, pp. 303-313, 1992
- ✓ [21] **Gruenwald, G.**, "New Product Development - Responding to market demand", Second Edition, NTC Business Books, Illinois, USA, 1992
- [22] **Cooper, R. G. and Kleinschmidt, E. J.**, "New Products: What Separates Winners from Losers", *Journal of Product Innovation Management*, 4(3), September, 169-184, 1987c
- [23] **Gupta, A.K., Brockhoff, K and Weisenfeld, U.**, "Making Trade-Offs in the New Product Development Process: A German / US Comparison", *Journal of Product Innovation Management*, Vol. 9, No. 1, pp. 11-18, March 1992
- [24] **Kleinschmidt, E. J.**, "A Comparative Analysis of New Product Programmes: European versus N. American Companies", *European Journal of Marketing*, Vol. 28, No. 7, pp. 5-29, 1994

- [25] Edgett, S., Shipley, D., Forbes, G., "Japanese and British Companies Compared: Contributing Factors to Success and Failure in NPD", Journal of Product Innovation Management, Vol. 9, No. 1, pp.3-10, 1992
- [26] Hughes, G.D. and Chafin, D.C., "Turning New Product Development into a Continuous Learning Process", Journal of Product Innovation Management, 13: 89-104, 1996
- [27] Lillien, G. L. and Kotler, P., "Marketing Decision Making: -A Model Building Approach", Harper and Row Publishers, New York, 1983
- [28] Cooper, R. G., "Winning at New Products", Gage Educational Publishing, London, 1988a
- [29] Kraushar, P. M., "Marketing Intelligence Planning", Vol 14, No 4, pp3-14, 1986
- [30] Baker, M. J. et al, "Marketing Theory and Practice", Second Edition, Macmillan Press, London, 1983
- [31] Cowell, D., "New Service Development", Journal of Marketing Management, Vol. 3, No. 3, pp 296-312, 1988
- [32] Kotler, P., "Principles of Marketing", Third Edition, Englewood Cliffs, New Jersey: Prentice-Hall International Editions, 1986
- [33] Rooney, E.M. & Peters, A., Management of New Product Development Process in Small/Medium Enterprises, 12th NCMR, Bath, Sept. 1996.
- [34] Swindells, R., "New Product Development", Ashridge Management College, Papers in Management Studies, 1971
- [35] Barclay, I. And Benson, M., "Success in New Product Development: The Lessons From The Past", Leadership and Organisation Development Journal, Vol 11, No 6, pp 4-12., 1990
- [36] Cross, N., Engineering Design Methods – Strategies for Product Design, 2<sup>nd</sup> Edition, Wiley,UK, 1995
- [37] French, M.J., "Conceptual Desihn for Engineers", Design Council, London, 1985
- [38] Pugh, S., Total Design – Integrated Methods for Successful Product Engineering, Addison-Wesley Publishers Ltd., UK, 1991
- [39] BS 7000: Part 1: 1989, "Guide to managing product design", British Satandards Institution, Milton Keynes, 1989
- [40] Cooper, R. G., "The New Product Process: A Decision Guide for Management", Journal of Marketing Management, Vol. 3, No. 3, 1988b

- [41] **Cooper, R. G. and Kleinschmidt, E. J.**, "What Makes a New Product a Winner: Success Factors at the Project Level", *R&D Management*, 17(3), 1987a
- [42] **Cooper, R. G. and Kleinschmidt, E. J.**, "Success Factors in Product Innovation", *Industrial Marketing Management*, 16(3), August, 215-223, 1987b.
- [43] **Cooper, R. G.**, "PERSPECTIVE – Third Generation New Product Processes", *Journal of Product Innovation Management*, 11, pp.3-14, 1994
- [44] **Cooper, R., Kagioglou, M., Aouad, G., Hinks, J., Sexton, M and Sheath, D.**, "The Development of a Generic Design and Construction Process", *European PDT Days 1998, The Time is Now... , pp. 205-214, 1998*
- [45] **Cooper, R. G. and Kleinschmidt, E. J.**, "Benchmarking the Firm's Critical Success Factors in New Product Development", *Journal of Product Innovation Management*, 12, 374-391, 1995
- [46] **Sands, S.**, "Problems of Organising for Effective New Product Development", *European Journal of Marketing*, Vol. 17, No. 4, pp.18-33, 1983
- [47] **Varadarajan, P.**, "Product Diversity and Firm Performance: an Empirical Investigation", *Journal of Marketing*, Vol. 50, pp.43-57, July 1986
- [48] **Johne, F.A., Snelson, P.A.**, "Product Development Practices in Large US and UK Firms", *City University Working Papers*, No. 88, May 1987
- [49] **Peters, T.J. and Waterman, R.H.**, "In Search of Excellence", *Harper & Row*, 1982
- [50] **Johne, F.A.**, "How Experienced Product Innovators Organise", *Journal of Product Innovation Management*, Vol. 1, No. 4, pp. 210-233, 1984
- [51] **Takeuchi, H. and Nonaka, I.**, "The New Product Development Game", *Harvard Business Review*, Vol. 64, No. 1, pp. 137-146, 1986
- [52] **Allen, D.**, *Developing Successful New Products: A Guide to Product Planning*, *Financial Times*, Pitman Publishing, pp 3-4, 1993
- [53] **Heizer, J. and Render, B.**, *Productions and Operations Management – Strategies and Tactics*, *Allyn and Bacon, USA*, 1993
- [54] **Huang G.Q. & Mak K.L.**, "Current practices of engineering change management in UK manufacturing industries", *International journal of Operations & Production Management*, vol. 19, no. 1, pp.21-37, 1999
- [55] **Huang, G.Q. & Mak, K.L.**, "Computer aids for engineering change control", *Journal of Materials Processing Technology*, vol. 76, pp.187-191, 1998



- [56] **Glaza, T.**, “Engineering change control systems – their time has come”, *Manufacturing Systems*, pp. 66-68, September, 1988
- [57] **Wright, I.C.**, “A review of research into engineering change management: implications for product design”, *Design Studies*, Vol.18, No. 1, pp. 33-42, 1997
- [58] **Harmozi, A.M.**, “An Engineering Management System in a Re-manufacturing Environment”, *Annual International Conference Proceedings – American Production and Inventory Control Society*, pp. 304-307, 1997
- [59] **Terwiesch, C. and Loch, C.H.**, “Managing the process of engineering change orders: the case of the climate control system in automobile development”, *INSEAD Working Paper*, 97/116/TM, 1997
- [60] **Saeed, L., Bowen, D.M. and Sohoni, V.S.**, “Avoiding engineering changes through focused manufacturing knowledge”, *IEEE Transactions on Engineering Management*, Vol. 40, No. 1, pp. 54-58, 1993
- [61] **PA Consulting Group/Department of Trade and Industry**, *Organising product design and development – a management review*, pp.14-15, 1991
- [62] **Nichols K.**, “Benchmarking Research”, *Products for World Markets – A Design Council Conference*, pp.17-25, 1994
- [63] **McAfee, N.**, “Management Methods”, *Products for World Markets – A Design Council Conference*, pp.17-25, 1994
- [64] **Balcerak K.J. and Dale, B.G.**, “Engineering Change administration: the key issues”, *Computer Integrated Manufacturing Systems*, Vol 5, No 2, pp. 125-132, May 1992
- [65] **Vieth, W.**, “Configuration Management”, *Mechanical Engineering*, February 1967, pp 20-25
- [66] **Collins, Collins Cobuild English Dictionary, New Edition**, Harper Collins Publisher Ltd.,1995
- [67] **Hammer, M. & Champy, J.**, “Reengineering the Corporation: A Manifesto for Business Revolution”, Harper Business, 1993
- [68] **Johansson, McHugh, Pendlebury & Wheeler**, “Business Process Reengineering: Breakpoint Strategies for Market Dominance”, USA, John Wiley & Sons, 1993
- [69] **Davenport, T. H.**, “Process Innovation: Reengineering Work Through Information Technology”, Harvard Business Review Press, Boston, USA, 1993

- [70] **Davenport, T. H. & Short, J. E.**, "The New Industrial Engineering: Information Technology and Business Process Redesign", Sloan Management Review, pp. 11-27, 1990
- [71] **Harrington, H. J.**, "Business Process Improvement", McGraw-Hill, USA, 1991
- [72] **Ould, M. A.**, "Business Process: Modelling and Analysis for Reengineering and Improvement", John Wiley & Sons, UK, 1995
- [73] **Abeyasinghe, G. and Phalp, K.**, "Combining Process Modelling Methods", Department of Electronics & Computer Science, Univ. of Southampton, UK, <http://www.dsse.ecs.soton.ac.uk>, 1997
- [74] **Greenwood, M.R.**, "Process terminology - a software engineering perspective", IOPener, Vol. 2, No. 1, pp7-9, Praxis plc, Bath, UK, August 1993
- [75] **Balthazor, ,** "Managing Aerospace Projects in a Multi-disciplinary Environment", ICAS, pp.1846-1854, 1994
- [76] **Scholz-Reiter, B. and Stickel, E.**, "Business Process Modelling", Springer-Verlag, Berlin, 1996
- [77] **Bhaskar, R., Lee, H.S., Levas, A., Petrakian, R., Tsai, F. and Tulsjie, B.**, "Analysing and Re-engineering Business Processes Using Simulation", In Tew, J.D., Manivannan, S., Sadowski, D.A and Seila, A.F. (Eds.), Proceedings of the 1994 Winter Simulation Conference, Lake Buena Vista, Florida, pp. 1206-1213, December, 1994
- [78] **Gladwin, B. and Tumay, K.** "Modelling Business Processes with Simulation Tools", In Tew, J.D., Manivannan, S., Sadowski, D.A and Seila, A.F. (Eds.), Proceedings of the 1994 Winter Simulation Conference, Lake Buena Vista, Florida, pp. 114-121, December, 1994
- [79] **Liles, D.H. and Presley, A.R.**, "Enterprise Modelling Within an Enterprise Engineering Framework", In Charnes, J.M., Morrice, D.J., Brunner, D.T. and Swain, J.J. (Eds.), Proceedings of the 1996 Winter Simulation Conference, San Diego, California, pp. 993-999, December, 1996
- [80] **Streng, R.J.**, "BPR Needs BIR and BTR: The PIT-Framework for Business Re-engineering", In the Proceedings of the 2<sup>nd</sup> SISNET Conference, Barcelona, Spain, September, 1994
- [81] **Giaglis, G.M.**, "A Taxonomy of Business Process Modelling and Information Systems Modelling Techniques", International Journal of Flexible Manufacturing

Systems, Special Issue on Business Process Design, Modelling and Analysis (Forthcoming), 1999

- [82] **Kettinger, W.J., Teng, J.T.C. and Guha, S.,** “Business Process Change: A Study of Methodologies, Techniques and Tools”, *MIS Quarterly*, Vol. 21, No. 1, pp.55-80, 1997
- [83] **Curtis, W., Kellner, M.I. and Over, J.,** “Process Modelling”, *Communications of the ACM*, Vol. 35, No. 9, pp.75-90, 1992
- [84] **Checkland, P.,** *Systems Thinking, Systems Practice*, John Wiley & Sons, 1981
- [85] **Cole, A. J. & Boardman, J. T,** *Modelling Product Development Processes using a Soft Systems Methodology*, Proceedings of the 1<sup>st</sup> World Conference for Integrated Design and Process Technology, Texas, Dec. 7-9, 1995
- [86] **Flood, R.L. and Jackson, M.C.,** *Creative Problem Solving – Total Systems Intervention*, John Wiley & Sons, Chichester, 1991
- [87] **Checkland, P. and Holwell, S.,** *Information, Systems and Information Systems: making sense of the field*, John Wiley & Sons, Chichester, 1998
- [88] **Checkland, P. and Scholes, J.,** *Soft Systems Methodology in Action*, John Wiley & Sons, Chichester, 1990
- [89] **Boardman, J.T.,** *Wholes and Parts – A Soft Systems Approach*, *IEEE Transactions: Systems Man and Cybernetics*, June, 1995
- [90] **Schriber, T.J.,** *Fundamentals of Flowcharting*, Wiley, New York, 1969
- [91] **Jones, J.L.,** *Structured Programming Logic: A Flowcharting Approach*, Prentice Hall, New Jersey, 1986
- [92] **Booth, R.,** “To be or not to be: Model that process”, *Management Accounting*, pp. 20, April, 1995
- [93] **Huckvale, T. and Ould, M.,** “Process Modelling – Who, What and How: Role Activity Diagramming”, In Grover, V. and Kettinger, W.J. (Eds.), *Business Process Change: Concepts, Methods and Technologies*, Idea Group Publishing, Harrisburg, PA, pp.330-349, 1995
- [94] **Reising, W., Muchnick, S.S. and Schnupp, P. (Eds.),** *A Primer in Petri Net Design*, Springer Verlag, Berlin, 1992
- [95] **Peterson, J.L.,** *Petri Net Theory and the Modelling of Systems*, Prentice-Hall, Englewood Cliffs, NJ, 1981

- [96] **Leymann, F. and Altenhuber, W.**, “Managing Business Processes as an Information Resource”, *IBM Systems Journal*, Vol. 33, No. 2, pp. 326-348, 1994
- [97] **van der Aalst, W.M.P. and van Hee, K.M.**, “Business Process Redesign: A Petri-net-based Approach” *Computers in Industry*, Vol. 29, pp. 15-26, 1996
- [98] **Hedberg, S.R.**, “AI Tools for Business Process Modelling”, *IEEE Expert*, pp. 13-15, 1996
- [99] **Yu, E.S.K., Mylopoulos, J and Lesperance, Y.**, “AI Models for Business process Reengineering”, *IEEE Expert*, pp. 16-23, 1996
- [100] **Ba, S., Lang, K.R. and Whinston, A.B.**, “Enterprise decision Support Using Intranet Technology”, *Decision Support Systems*, Vol. 20, pp.99-134, 1997
- [101] **Compatangelo, E. and Rumolo, G.**, “Automated Reasoning about Enterprise Concepts”, *SIGGROUP Bulletin*, Vol. 18, No. 2, pp. 56-58, 1997
- [102] **Nissen, M.E.**, “Qualitative Simulation of Organisational Microprocesses”, In Numamaker, J.F. and Sprague, R.H. (Eds.), *Proceedings of the 27<sup>th</sup> Annual Hawaii International Conference on Systems Sciences*, Vol. IV, IEEE Press, Los Alamitos, CA, pp.635-644, 1994
- [103] **Nissen, M.E.**, “Designing Qualitative Simulation Systems for Business”, *Simulation and Gaming*, Vol. 27, No. 4, pp. 462-483, 1996
- [104] **Balci, O.**, “Validation, Verification, and Testing Techniques Throuout the Life Cycle of a Simulation Study”, *Annals of Operations Research*, Vol. 53, pp. 121-173, 1994
- [105] **Shannon, R. E.**, “*Systems Simulation: The art and the Science*”, Prentice-Hall, New Jersey, 1975
- [106] **Paul, R. J. and Balmer, D. W.**, “*Simulation Modelling*”, Chartwell-Bratt Publishing, Lund, Sweden, 1993
- [107] **Giaglis and Paul**, “It’s Time to Engineer Re-engineering: Investigating the Potential of Simulation Modelling for Business Process Redesign”, *Business Process Modelling*, Bernd Scholz-Reiter & Eberhard Stickel (Eds.), Springer, 1996
- [108] **Law, A. M. and Kelton, D. W.**, “*Simulation Modelling and Analysis*”, 2<sup>nd</sup> Edition, McGraw-Hill, New York, 1991

- [109] **Doran, J. and Gilbert, N.**, “Simulating Societies: An Introduction”, In Gilbert, N & Doran, J. (Eds.), *Simulating Societies: The Computer Simulation of Social Phenomena*, UCL Press, London, 1994
- [110] **Paul, R.J. and Doukidis, G.I.**, “Artificial Intelligence Aids in Discrete-Event Digital Simulation Modelling, *IEE Proceedings*, 134, D, 4, pp.278-286, 1987
- [111] **Wolstenholme, E. F. & Gavine, A.**, “The Evaluation Of Management Information Systems: A Dynamic and Holistic Approach”, John Wiley & Sons, UK, 1993
- [112] **System Dynamics Society**, “The System Dynamics Society Home Page”, [http://www. Std.com/vensim/sdmail/sdsociet.html](http://www.Std.com/vensim/sdmail/sdsociet.html), 1998
- [113] **Forrester, J.W.**, *Industrial Dynamics*, The MIT Press, Cambridge, Mass., USA, 1961
- [114] **Forrester, J.W.**, “System Dynamics – Future Opportunities”, *Studies in the Management Sciences*, Vol. 14, System Dynamics, Edited by Legasto Jn, Forrester, Lyneis, North-Holland Publishing Company, 1980
- [115] **Wolstenholme, E.F.**, “Case Study in Community Care using System Dynamics”, *Journal of the Operational Research Society*, Vol. 44. No. 9, pp. 925-934, Sep 1993
- [116] **Wolstenholme, E.F.**, “Definition and application of a stepwise approach to model conceptualisation and analysis”, *European Journal of Operational Research*, Vol. 59. No. 1, pp. 123-136, May 1992
- [117] **Wolstenholme, E.F.**, “Defence Operational Analysis using System Dynamics”, *European Journal of Operational Research*, Vol. 43. No. 1, pp. 10-18, Feb 1988
- [118] **Wolstenholme, E.F.**, “Design of Colliery Information and Control Systems”, *European Journal of Operational Research*, Vol. 20. No. 2, pp. 168-181, May 1985
- [119] **Wolstenholme, E.F.**, “Relevance of System Dynamics to Engineering System Design”, *European Journal of Operational Research*, Vol. 14. No. 1, pp. 116-126, Sep 1983
- [120] **Wolstenholme, E.F.**, “Development of System Dynamics as a Methodology for System Description and Qualitative Analysis”, *Journal of the Operational Research Society*, Vol. 34. No. 7, pp. 569-581, Jul 1983

- [121] Wolstenholme, E.F., "Managing International Mining – A Case Study in the Application of System Dynamics to Complex, Multiple Ownership System", *European Journal of Operational Research*, Vol. 9. No. 2, pp. 133-143, Feb 1982
- [122] Wolstenholme, E.F., "System Dynamics Approach to an Analysis of Factors Affecting Growth and Stability in International Mineral Industries", *Proceedings of the 16<sup>th</sup> Conference in Application of Computing and Operational Research in the Mineral Industry*, Tuscon, Arizona, pp.67-79, 1979
- [123] Towill, D.R., "System Dynamics – Background, Methodology and Applications. Part 1: Background and Methodology", *Computing & Control Engineering Journal*, pp. 201- 208, Oct 1993
- [124] Towill, D.R., "System Dynamics – Background, Methodology and Applications. Part 2: Applications", *Computing & Control Engineering Journal*, pp. 261- 268, Dec 1993
- [125] Badiru, A. B. and Ayeni, B. J., "Practitioner's Guide to Quality And Process Improvement", Chapman & Hall, London, UK, 1993
- [126] Wolstenholme, E.F., "System Dynamics in Perspective", *Journal of the Operational Research Society*, Vol. 33, No. 6, 1982
- [127] Pidd, M., *Computer Simulation in Management Science (4<sup>th</sup> Edition)*, Wiley, 1998
- [128] Sargent, R.G., "Verification and validation of simulation models". In F.E. Cellier (Eds.), *Progress in Modelling and Simulation*, Academic Press, London, UK, 1982
- [129] Forrester, J.W. and Senge, P.M., "Tests for building confidence in System Dynamics Models", *Studies in the Management Sciences*, Vol. 14, System Dynamics, Edited by Legasto Jn, Forrester, Lyneis, North-Holland Publishing Company, 1980
- [130] Lascelles, D.M. and Dale, B.G., "How Change Agents Can Effect Quality Improvement", *Proceedings of Second National Conference for Production Research*, Napier College, Edinburgh, 1986
- [131] Antonaras, A., Deasley, P. J. and Giaglis, G., "Modelling the New Product/Service Introduction Process: A System Dynamics Approach", Submitted for International Conference on Engineering Design, Munich, August 1999
- [132] Antonaras, A. & Deasley, P.J., "Product Development and Process Improvement using Modelling and Simulation: A System Dynamics Approach", Submitted for

The use of Modelling & Simulation in Product Development Conference,  
University of Salford, Salford, April 1999

- [133] Machowski F. & Dale, B.G., "Application of quality costing to engineering changes", International Journal of Materials & Product Technology, vol.10, n0.3-6, pp.378-388, 1995
- [134] Soderberg, L.G., "Facing up to the Engineering Gap", McKinsley quarterly, Spring 1989

## **APPENDIX B**

- [135] Kotler, P. , "Marketing Management: Analysis, Planning, Implementation, and Control", 8th Edition, Prentice-Hall International Editions, 1994
- [136] Stefflre, V., "Market Structure Studies: New Products for Old Markets and New Markets (foreign) for Old Products", Applications of the Sciences in Marketing, Editors: Bass, F. M., King C. W. and Pessemier, E. A., Wiley, pp251-268, New York, 1968
- [137] Stefflre, V., "New Products: Organisational and Technical Problems and opportunities", Analytic Approaches to Product and Market Planning, Editor: Shocker, A., Cambridge, Mass: Marketing Science Institute, 1979
- [138] Pilditch, J., "The Silent Salesman", London Business Books Ltd, 1961
- [139] Davies, E. J., "Experimental Marketing", Thomas Nelson and Sons Limited, London, 1970
- [140] King, S., "Developing New Brands", Pitman, London, 1973

## **APPENDIX B**

- [141] Antonaras, A, "An Analysis of the Quality Related Costs of Manufacturing in an Aerospace Industry", M.Sc. Thesis, Cranfield University, 1996
- [142] Aravindan, P. , Devadasan, S.R. , Dharmendra, B.V. and Selladurai, V., "Continuous Quality Improvement through Taguchi's online Quality control Methods", International Journal of Operations & Production Management, Vol. 15, No. 7, 1995.
- [143] Ross, J. E., "Total Quality Management: Text, Cases and Readings", Kogan Page Ltd., 1993

# APPENDIX A

## **The strategic importance factors for New Product/Service Introduction**

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Briefly, the strategic importance factors for New Product / Service Introduction are:

- *New products / services can provide opportunities for reinforcing or changing strategic direction*

New products / services can be used to reinforce a firm's strategic direction by enhancing its competitive advantage in the market. New products / services developed for this purpose are typically extensions or me-too versions of existing products that introduce additional features to accommodate changing buyer or market needs. Such products / services emerge from NP/SI processes that emphasise incremental innovations and constant improvement. New products / services can also be used to change an organisation's competitive advantage. Although this sometimes happens by chance, more often than not it is the result of a process of continually listening to the market and its major stakeholders. Recognising when new market segments emerge can create the opportunity for a new product or service.

- *New products / services can enhance corporate image*

The launch of a new product / service or family of products/services can enhance or detract from a firm's corporate image among its stakeholders. The business press does not hesitate to build articles around performance-related issues that can affect stakeholders' perceptions. The potential effects of these articles on stock price, managerial morale, and future decisions for a product or service can be substantial.

- *New products / services can capitalise on R&D*

Organisations vary in the amount of resources they allocate to research and development, as well as in their actual R&D source(s). Some maintain their own R&D capability to support new products / services, some "borrow" from others who precede them in the market, some engage in strategic alliances or research consortia, and some do all of the above. Maintaining an R&D capability does not guarantee success, but coupling it with a strong new product / service introduction proficiency can benefit the organisation in numerous ways.

- *New products / services can utilise production and operations resources*  
An organisation not operating at capacity may be able to improve its utilisation in a number of ways, but one common approach is to develop new products or services. This technique is obvious for manufacturing firms with fixed plant and equipment, but it applies to service operations as well.
- *New products / services can leverage marketing / brand equity*  
Organisations that have used their marketing programs to capitalise in a brand name can use new products / services to further capitalise on their investment. Marketing programs are typically defined by selected market segments, each with a positioning strategy, specific product features to meet segment needs, pricing, advertising, sales promotion, sales force, distribution, and customer service decisions. If the marketing program fits market segment needs better than the competition and (over time) attracts a loyal base of customers who perceive value in the brand's name, then an opportunity exists to extend new products / services under that brand.
- *New products / services can affect human resources*  
Successful new products / services can create jobs and provide opportunities for career development. Although the need to add personnel throughout the development process and after launch can be positive, the consequences of new product / service forecasts that are not achieved - or even ones that are over achieved - can be costly in both financial and human terms. Clearly, the jobs of all personnel added for a new product/service project are at risk if it does not achieve its forecast. [16]

# APPENDIX B

## **Stages of the Kotler's NP/SI Model**

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## Idea Generation

Ideas are collected from a number of sources: customers, scientists, competitors, employees, channel members, and top management.

Customers' needs and wants are the logical place to start in the search for new product ideas. Hippel has shown that the highest percentage of ideas for new industrial products originate with customers. Technical companies can learn a great deal by studying a special set of their customers, the lead users, those customers who make the most advanced use of the company's product and who recognise needed improvements ahead of other customers. Companies can identify customers' needs and wants through customer surveys, projective tests, focused group discussion, and suggestion and complaint letters from customers [3].

Companies can also rely on their scientists, designers, engineers, and their other employees for ideas that will lead to new products. Many companies have developed a culture that encourages all employees to seek new ideas for improving company's production, products, and services.

Another source for idea generation is the competitors. Companies can learn from distributors and suppliers what their competitors are doing. By taking their product and improving it, a company can come up with a new, better product.

Companies' channel members (sales representatives and middlemen) can also be a good source for new ideas. These are the people who have firsthand exposure to a customer's needs and complaints. When properly trained, they can proved to be a very good source for finding new ideas.

Top management can also be another source for new ideas, since some company executives take personal responsibility for technological innovation in their companies. Such a source for finding new ideas may lead to a major failures, since decisions may be taken by top management without knowing some critical factors or points that the customers and the company's employees know.

### Idea Screening

Obviously after the generation stage successful ideas should be screened to evaluate their potential success in the market place, and the ability of, and cost to the organisation to produce them. The further a product idea is developed the greater the cost. To assist in this evaluation a number of product idea rating devices are recommended which assign product success criteria with relative weighting and then measure these against company competencies, e.g. Quality Function Deployment (QFD), Failure Mode and Effect Analysis (FMEA), etc.

### Concept Development and Testing

Surviving ideas must be developed into product concepts. It is important to distinguish between a product idea, a product concept, and a product image. A *product idea* is an idea for a possible product that the company can see itself offering to the market. A *product concept* is an elaborated version of the idea expressed in meaningful consumer terms. A *product image* is the particular picture consumers acquire of an actual or potential product [2].

### Concept Development

Concept development will be illustrated with the following situation. Suppose a car manufacturer discovers how to design an electric car that can go as fast as 80 miles an hour and as far as 150 miles before needing to be recharged. The manufacturer estimates that the electric car's operating costs will be about half of those of a conventional car.

The above is a product idea which customers do not buy; they buy a product concept. The car manufacturer's task is to develop this idea into some alternative product concepts, evaluate their relative attractiveness to customers, and choose the best one. Among the product concepts that might be created for the electric car are the following:

- *Concept 1.* An inexpensive subcompact designed as a second family car to be used by the home maker for short shopping trips. The car is ideal for loading groceries and transporting children, and it is easy to enter.
- *Concept 2.* A medium-cost, intermediate-size car designed as an all purpose family car.

- *Concept 3.* A medium-cost sporty compact appealing to young people.
- *Concept 4.* An inexpensive subcompact appealing to the conscientious citizen who wants basic transportation, low fuel cost, and low ecological pollution [2].

### Concept Testing

The resulting concepts can then be tested both qualitatively, and quantitatively, with various consumer groups to select the products offering the greatest rewards. There are many methods to measure consumers preferences and to test various elements of the concepts such as the sophisticated conjoint analysis and the concept evaluation work by Stefflre [4-5]. Stefflre's concept evaluation work is explained in Appendix A.

### Market Strategy

Once concepts have been developed and tested, a marketing-strategy plan must now be developed for introducing the new product into the market. Essentially this is in three parts:

1. The first part describes the size, structure and behaviour of the target market, the planned product positioning, and the sales, market share, and profit goals sought in the first few years.
2. The product's planned price, distribution strategy, and marketing budget for the first year are outlined in the second part of the marketing-strategy plan.
3. The third part describes the long-run sales and profit goals and marketing-mix strategy over time.

### Business Analysis

After management develops the product concept and marketing-strategy, it can evaluate the business proposal's attractiveness. Management needs to prepare the sales, cost, and profit projections to determine whether they satisfy the company's objectives. If they do, the product concept can move to the product-development stage. As new information comes in, the business analysis will undergo further revision [3].

Sensitivity analysis, or risk analysis, is normally included in this stage to test how sensitive certain elements are to the profitability of the project. For example, if the

product relies entirely on imported raw material the rate of exchange would be a sensitivity. Technological risk is another issue that is very often studied during a risk analysis.

### Product Development

At this stage the actual development of the tangible product occurs. "This step calls for a large jump in investment, which dwarfs the idea-evaluation costs incurred in earlier stages" [3]. The implication of which is that the escalating cost of this stage has dictated the development sequence thus far.

The essential elements of producing a product are:

- The target consumer will see it as embodying the prime benefits described in the product-concept statement.
- It performs as required.
- Production costs do not exceed the manufacturing budget.

Traditional barriers between tangible and intangible products are reducing dramatically. In an effort to gain extra consumer acceptance they are both assuming additional benefits, tangible products gaining intangible elements and vice-versa. When services get to this stage the process of product development is concentrated on the tangible elements. Packaging is perhaps the most obvious and has been called the "silent salesman" [6].

### Market Testing

Once the product has been created, the next stage is to test the reality with both consumer and dealer to see how they react to its handling, using and repurchasing. It could, and often is, argued that the only way to test a product is when you sell the product to consumers in a real marketplace. Only then can one establish whether it will be a success or not. However, the purpose of this stage is to prevent launching expensive mistakes (in terms of financial cost and reputation) and also to identify any further areas for modification to maximise the chances of success.

While Kotler uses the term market testing to cover a number of different situations, there are others, like Davis [7], who argue that this term requires greater definition. Davies renames this whole area "experimental marketing" since the whole idea of this stage is to carry out an experiment to gain knowledge about a particular product. Experimental marketing has two main categories: *experimental launching*, which involves experiments with totally new to the world products or "distinctly new improved product", and *market testing*, where there are changes in the marketing mix of an existing product.

However, to return to Kotler. Kotler identified all potential consumers through the supply/distribution chain. Some products have more than one levels of consumer, the ultimate consumer, and members of the channels of distribution such as the retailer. Obviously it is important to see how they react to the product as an unwillingness to stock new products will certainly prevent success.

The methods, used in this stage, for various classes of product differ in that they very clearly recognise the potential consumer and their adoption/buying behaviour. The most obvious difference, and the one that Kotler identifies, is that of the consumer versus industrial product.

- *Consumer goods market testing.* Kotler suggests that there are four variables that need testing in order to calculate potential sales, namely trial, first repeat, adoption and purchase frequency.
- *Industrial goods market testing.* In many cases because of the cost of new product introduction in the industrial sector new products will have been designed through co-operation with one or more customers. However, Kotler does describe "product-use testing" where a company uses the new product and advises on its performance.

Market testing is a very sensitive area and it may not always be in a company's interest to test the market if they feel that competitors may realise the potential threat the new product poses and take protective action. King [8] obviously is of this opinion as he



suggests that the delays of test marketing have often spoilt what might have been successful business. Undertaking testing in the external environment also invites copying by competitors which is especially problematic where the "entry barriers" are not strong enough.

Such is the case with the service industry. Some new services can be trialed with a potential consumer group but unfortunately, one of the characteristics of the service industry is the generally low barrier to entry by competitors. This low barrier is caused by lack of patent protection, a fast service development cycle, and relatively low cost of entry [1]. Obviously test marketing is a valuable stage, but there are drawbacks in its execution and these have to be considered in any service product development. It may be only possible to test potential consumer reaction at the concept testing stage.

### Commercialisation

This is the stage where the product is ready for launching. Even at this very last stage there are still decisions to be made; when, where, to whom and how, all of these can still make or break the product's performance in the marketplace.

## REFERENCES

- [1] Cowell, D., "New Service Development", *Journal of Marketing Management*, Vol. 3, No. 3, pp 296-312, 1988 [30]
- [2] Kotler, P., "Principles of Marketing", Third Edition, Englewood Cliffs, New Jersey: Prentice-Hall International Editions, 1986 [31]
- [3] Kotler, P. , "Marketing Management: Analysis, Planning, Implementation, and Control", 8th Edition, Prentice-Hall International Editions, 1994
- [4] Steffle, V., "Market Structure Studies: New Products for Old Markets and New Markets (foreign) for Old Products", *Applications of the Sciences in Marketing*, Editors: Bass, F. M., King C. W. and Pessemier, E. A., Wiley, pp251-268, New York, 1968

- [5] Stefflre, V., "New Products: Organisational and Technical Problems and opportunities", Analytic Approaches to Product and Market Planning, Editor: Shocker, A., Cambridge, Mass: Marketing Science Institute, 1979
- [6] Pilditch, J., "The Silent Salesman", London Business Books Ltd, 1961
- [7] Davies, E. J., "Experimental Marketing", Thomas Nelson and Sons Limited, London, 1970
- [8] King, S., "Developing New Brands", Pitman, London, 1973

# APPENDIX C

## **Stages of the NPDD Process Model**

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## FACILITATION ISSUES

Fundamental to the effective running of the NPDD process are seven key factors:

- **NPDD Strategy:** Strong strategic direction and long term vision of the requirements of the NPDD process can provide the framework which co-ordinates all facilitation and process activities. Thus enabling structure and support to be given as appropriate.
- **Common Information:** Common Information pertains to the availability and accessibility of data within the company, in order that all personnel have the information they need to enable them to complete their job in the most effective manner.
- **Multidisciplinary Input:** Multidisciplinary input ensures that as many eventualities as possible regarding the new venture are considered at all stages of the NPDD process
- **NPDD Review:** Reviewing the process aims to ensure that the requirements of the process and the product / service are at all times co-ordinated and fulfilled:
- **NPDD Control:** If process requirements are not being met for whatever reason, a means of control is needed in order to either halt or hold the process. Also control is needed in order to progress the process when the requirements for a given phase have been fulfilled to a predetermined standard.
- **Communication:** Effective communication is an essential requirement of the NPDD process, with information exchange happening across all functional, departmental and hierarchical boundaries.
- **Information Management:** Information management reinforces communication interactions, and exists to make sure that information is delivered in an optimum format at specific points in time, to the relevant personnel.

## PROCESS SUMMARY

The aim of the NPDD process is to aid managers within an organisation to become familiar with the whole process, to relate this to their own experiences, which will in turn provide a starting point for the improvement of the process (or the improvement of the management of the process). The NPDD process provides uniformity allowing

various disciplines of an organisation and suppliers to participate in the development of new products in an organised manner, and it also facilitates project management.

The NPDD process is divided into three main section descriptors, which comprise of one or a number of distinct generic phases. These phases are:

### **Pre-Design and Development**

#### **Idea**

This is the phase in which a business opportunity is identified, and evaluated with respect to the general requirements of the company.

### **Design and development**

#### **Concept**

Conversion of the business opportunity into some viable solutions that will fulfill all internal and external requirements. Within this phase the business opportunity is evaluated in detail, to determine the detailed requirements of the proposed product. Exploration of the requirements should encompass all aspects of the proposed idea, different possible solutions, and necessary activities that will support its production.

#### **Design**

The route by which a possible solution is converted to a viable set of production instructions. A decision having been reached in the previous phase about the detailed requirements of the proposed product, the aim of this phase is to determine the exact parameters of the product to fit these boundaries. Also the initial testing of any prototypes, to confirm that the physical requirements are adequate, as well as initial tests to confirm that the production requirements are being met.

### **Pre-Production Validation**

Validation of the production methods and trial products. In order to ensure the smooth transition of the detailed design, to that of the end product, account should be taken of the way in which the product is to be produced. Often by initiating a trial run of the

product, the product and its method of production can be assessed for optimal progression.

### **Post Design / Development**

#### **Production / Distribution**

Product realisation and release from company. This phase pertains to the physical manufacture of the product, as well as its subsequent release onto the market and its delivery to the market / customers.

#### **Post Company**

Study of the product outside the company environs. The progress of the product after it has left the company is vitally important. By monitoring the progress issues arising from the complaints, positive feedback, sales, aftercare enquiries, use, and disposal, may identify some crucial new ideas for improving the product itself or even for new products.

## **TOOLS & TECHNIQUES**

Methods of prompting information from people, or assessing activities, can be achieved by appropriate use of Quality Tools and Techniques. Often the information is inherent in the workplace, where it is just a matter of finding a suitable tool or technique to help elicit facts or ideas. Appropriate use of the information generated can lead to improvements throughout the company.

# APPENDIX D

## **French's design model**

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According to French, the design process begins with an initial statement of a 'need', and the first design activity is 'analysis of the problem'. French suggests that:

The analysis of the problem is a small but important part of the overall process. The output is a statement of the problem, and this can have three elements,

1. A statement of the design problem proper
2. Limitations placed upon the solution, e.g. codes of practice, statutory requirements, customers' standards, date of completion, etc.
3. The criterion of excellence to be worked to [Cross].

These three elements correspond to the goals, constraints and criteria of the design brief. The activities that follow, according to French, are then:

### Conceptual design

This phase...takes the statement of the problem and generates broad solutions to it in the form of schemes. It is the phase that makes the greatest demands on the designer, and where there is the most scope for striking improvements. It is the phase where engineering science, practical knowledge, production methods, and commercial aspects need to be brought together, and where the most important decisions are taken [French].

### Embodiment of schemes

In this phase the schemes are worked up in greater detail and, if there is more than one, a final choice between them is made. The end product is usually a set of general arrangement drawings. There is (or should be) a great deal of feedback from this phase to the conceptual design phase[French].

### Detailing

This is the last phase, in which a very large number of small but essential points remains to be decided. The quality of this work must be good, otherwise delay and expense or even failure will be incurred [French].



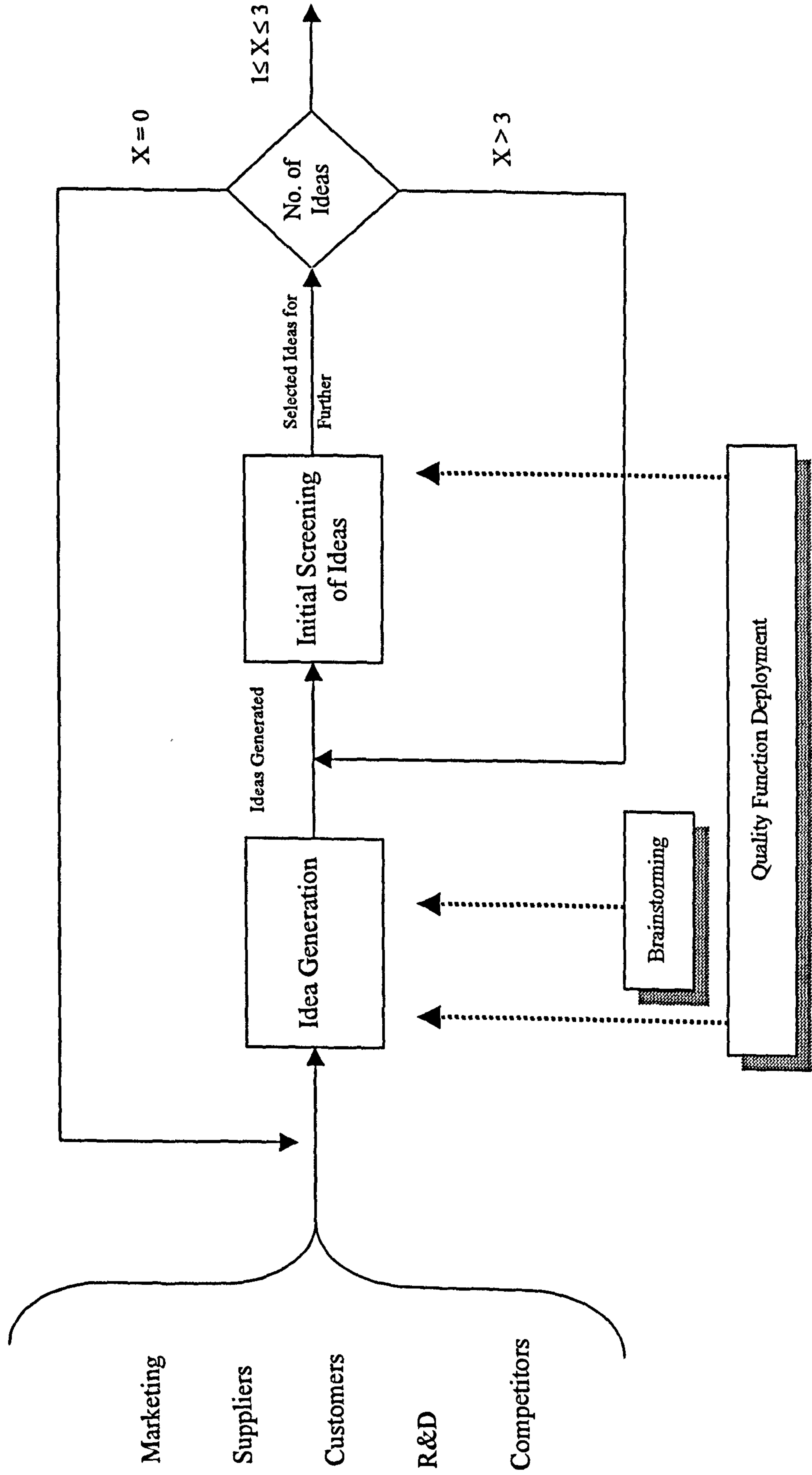
# APPENDIX E

## **Stages of the NP/SI Process**

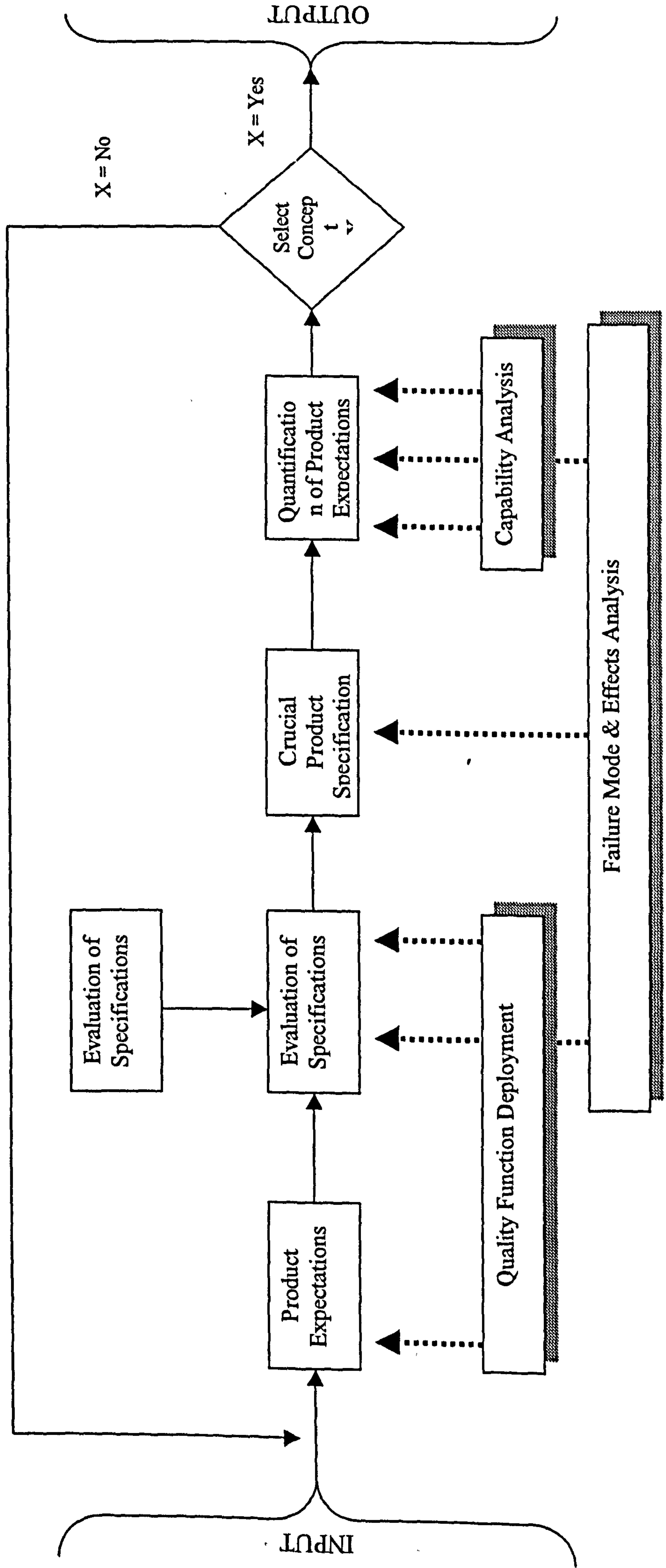
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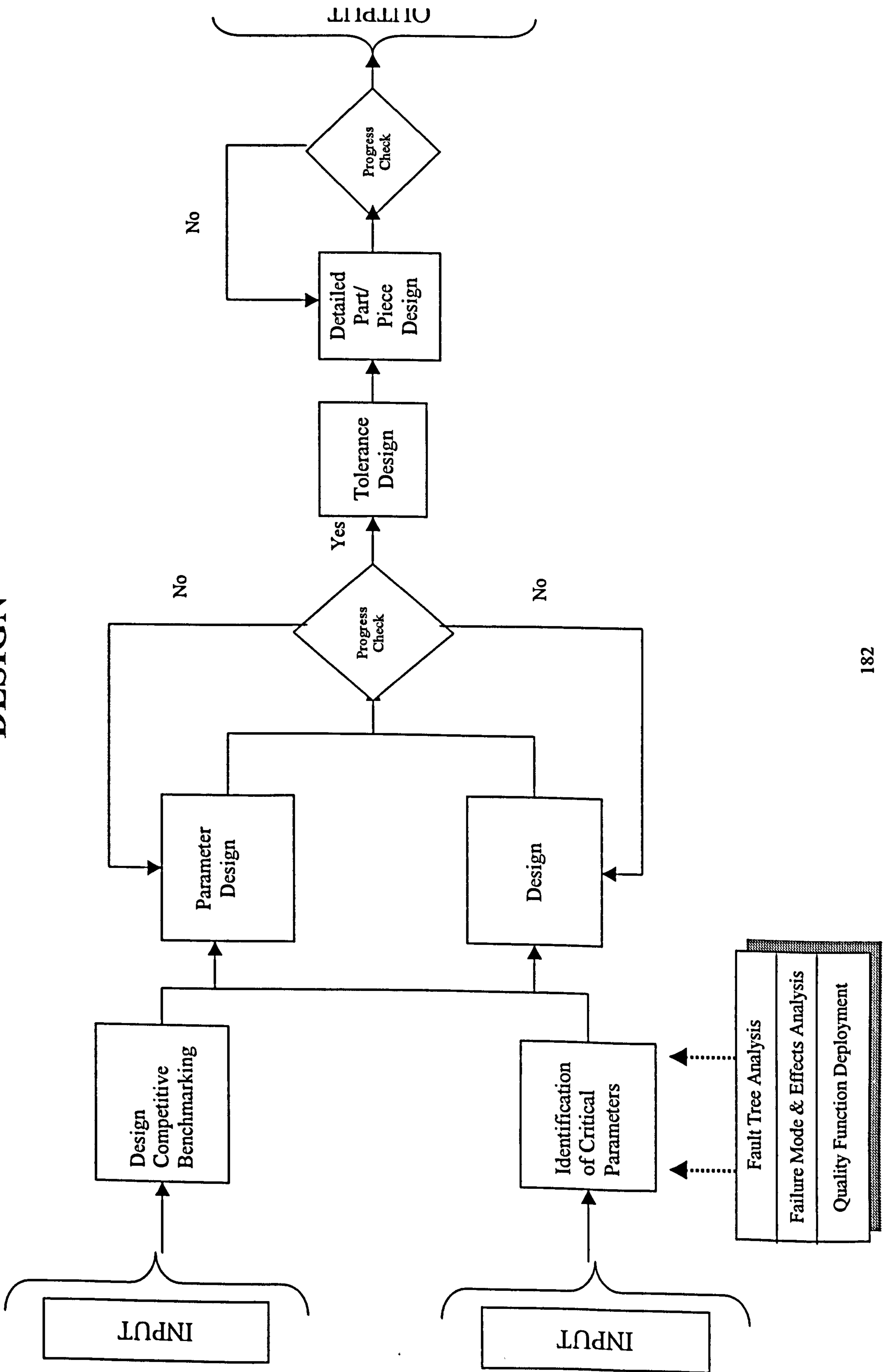
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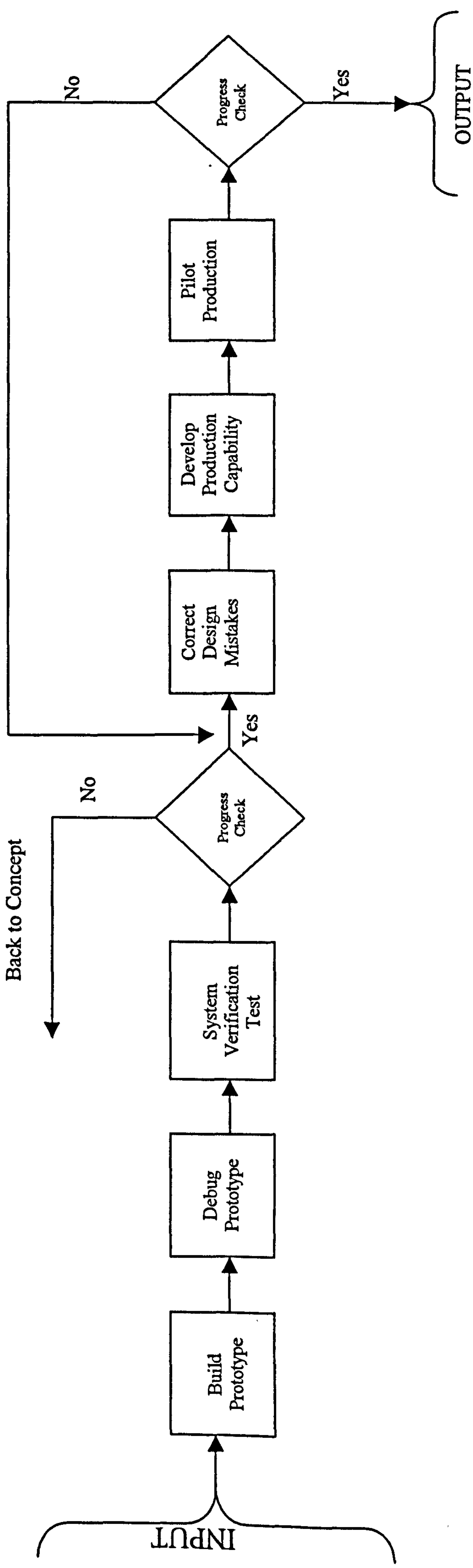
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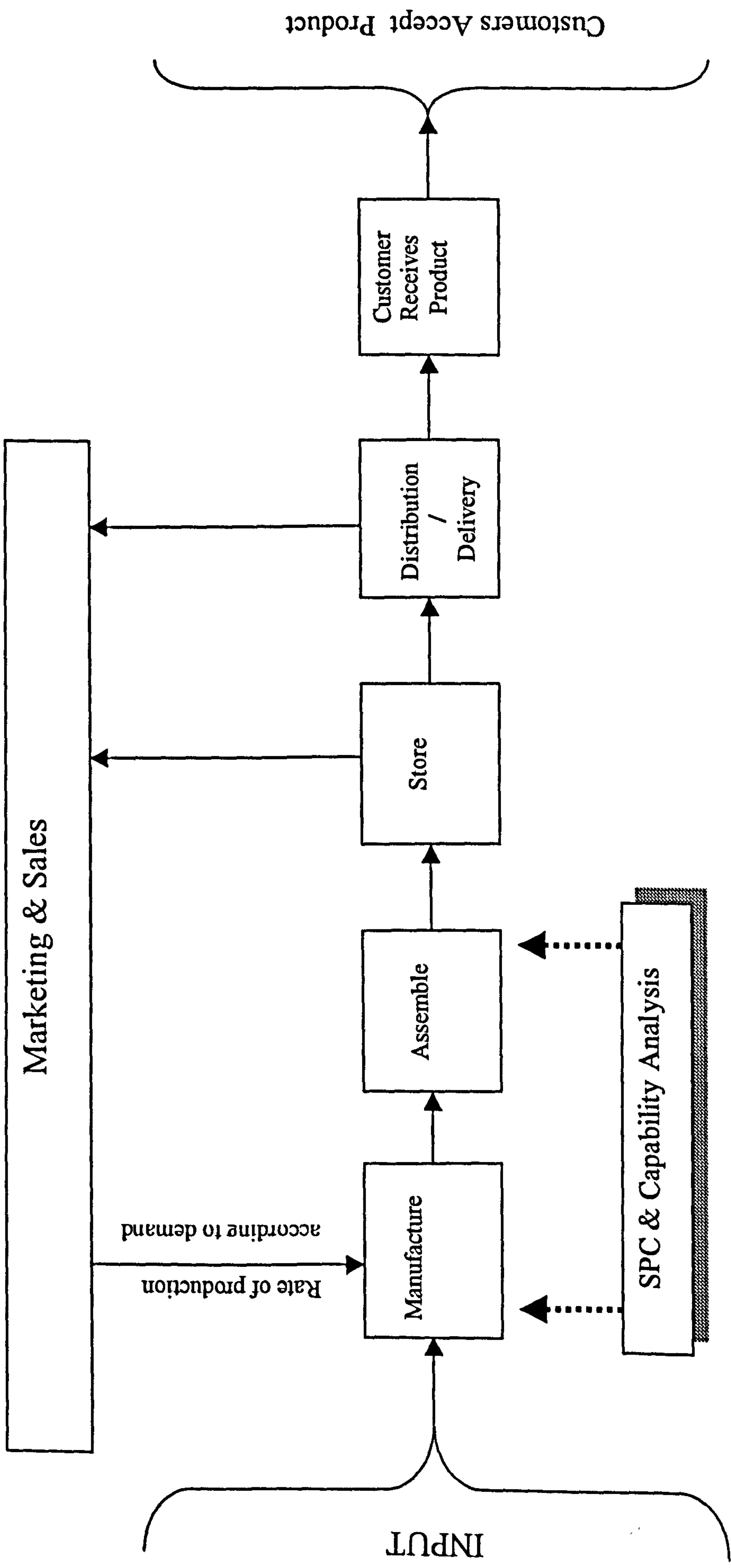
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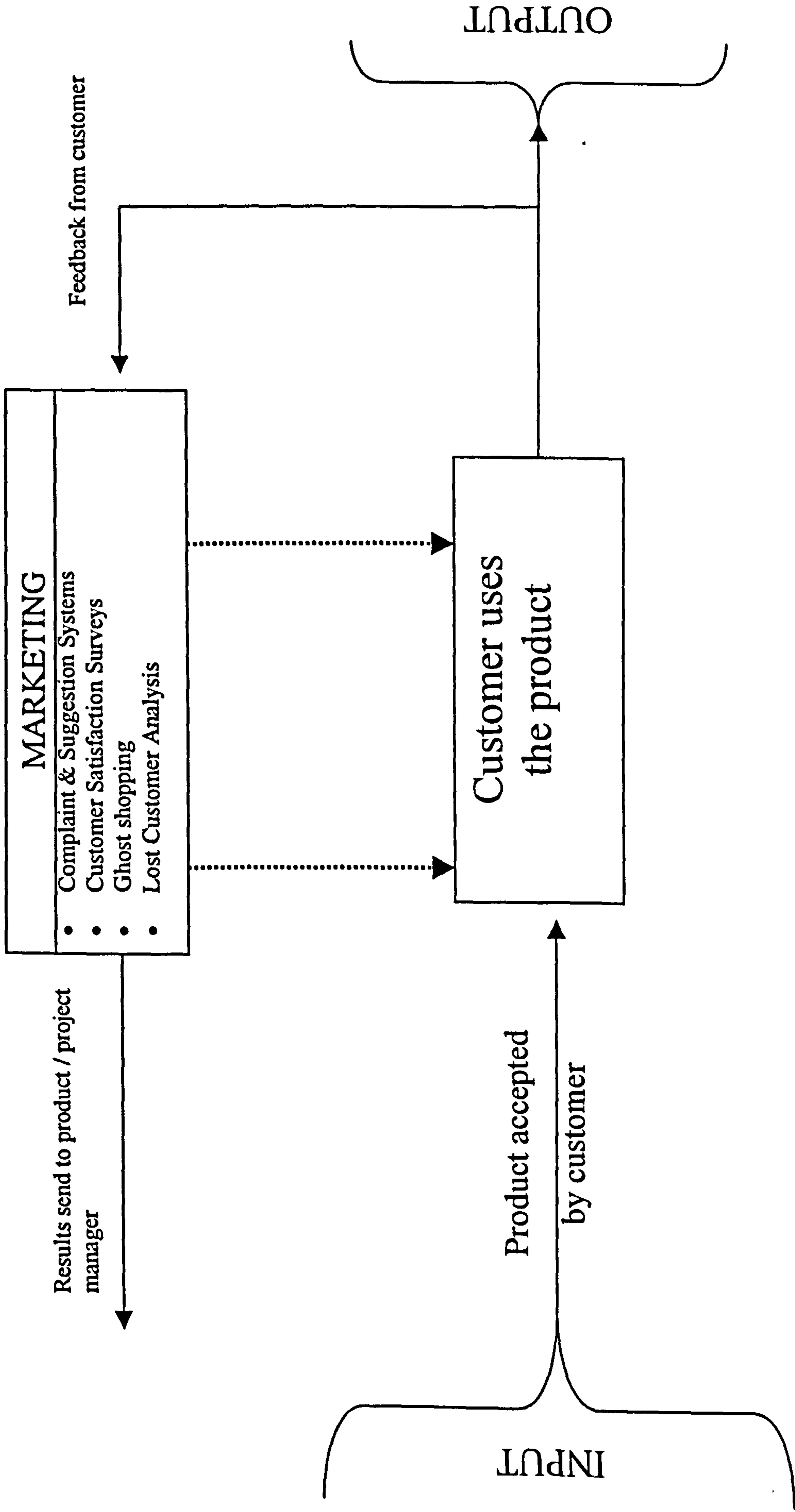
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# PRODUCTION / DISTRIBUTION



# POST COMPANY



# APPENDIX F

## **The NP/SI Process Model**

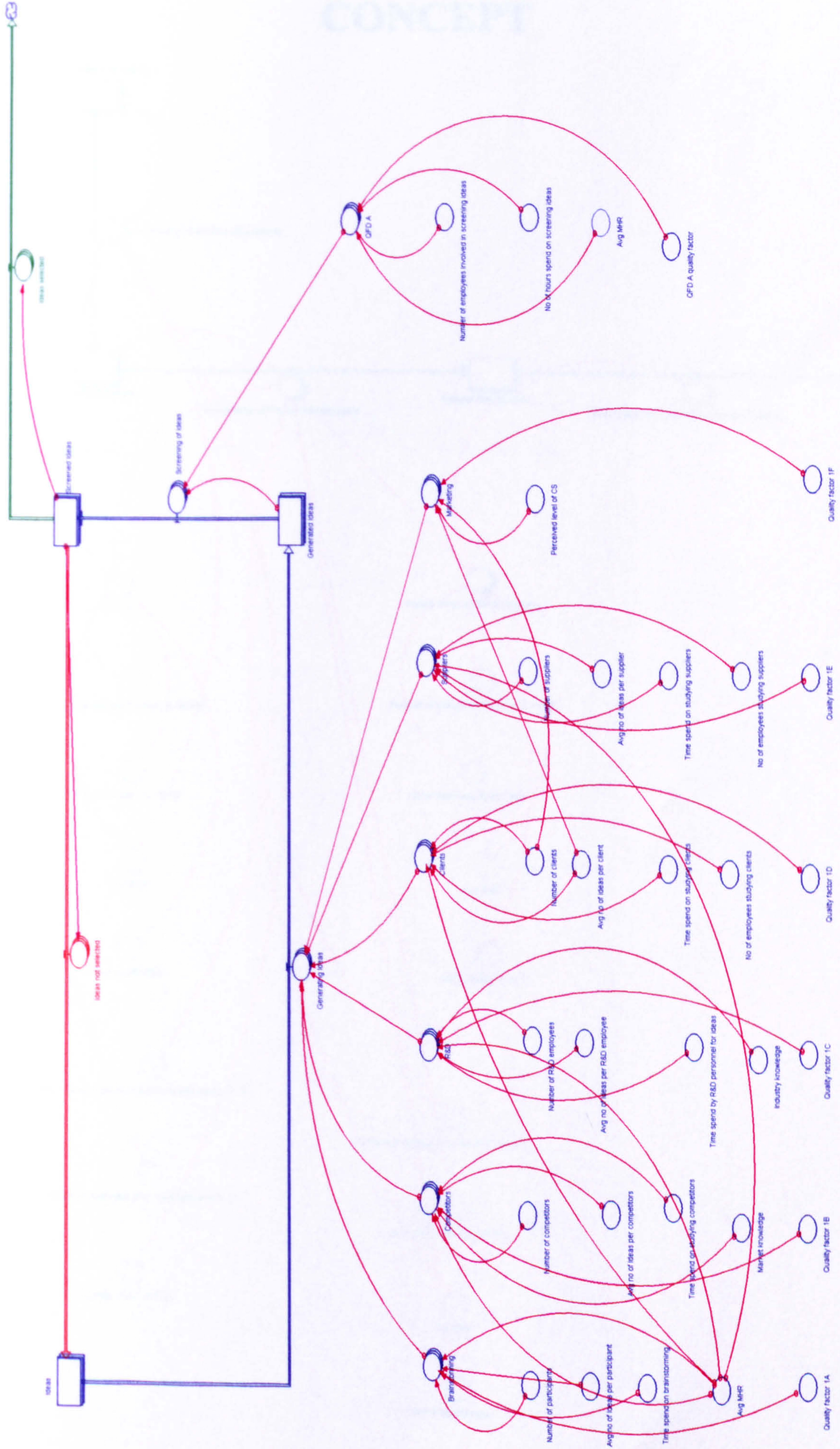
**A System Dynamics Application**

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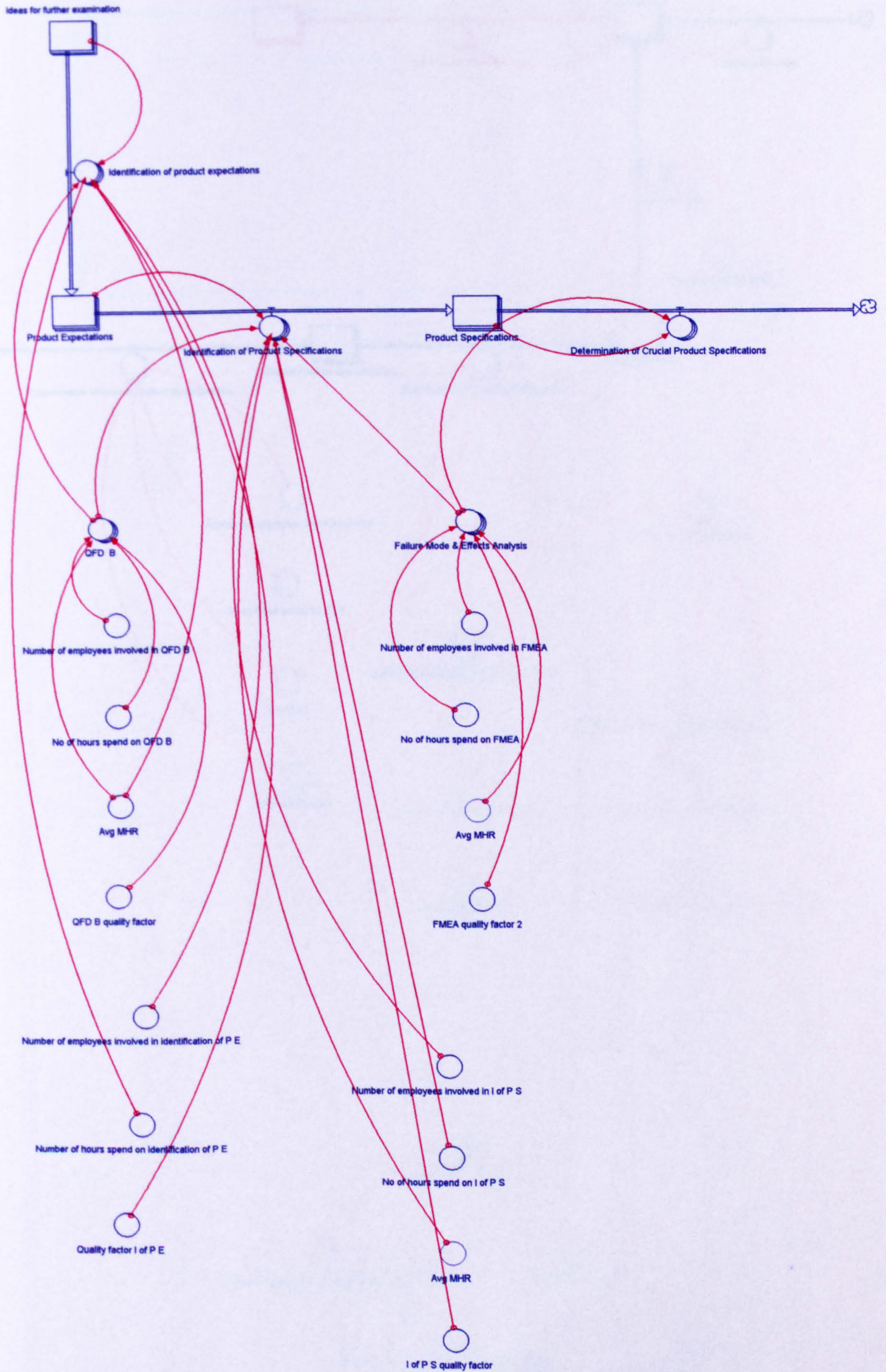
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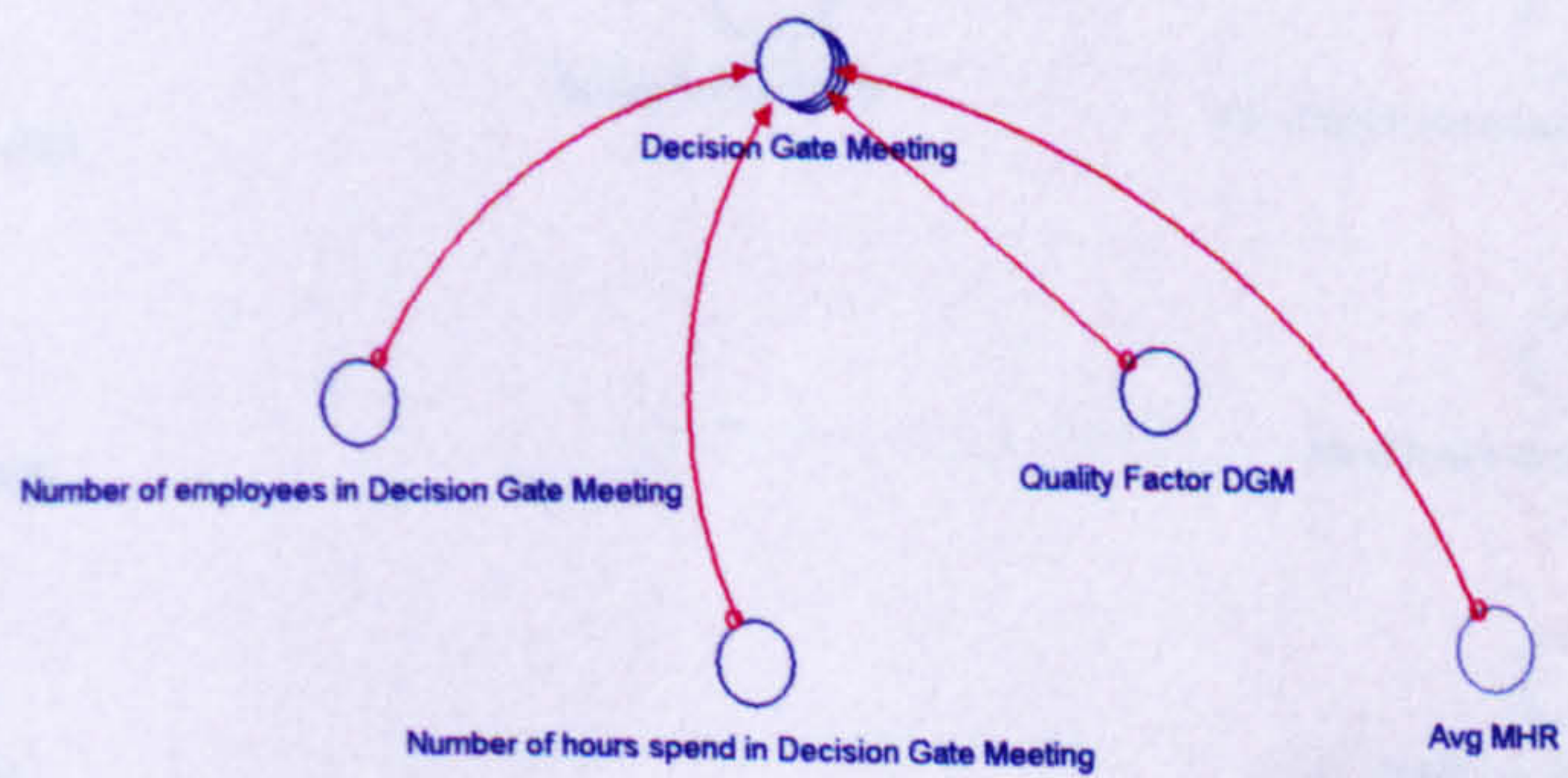
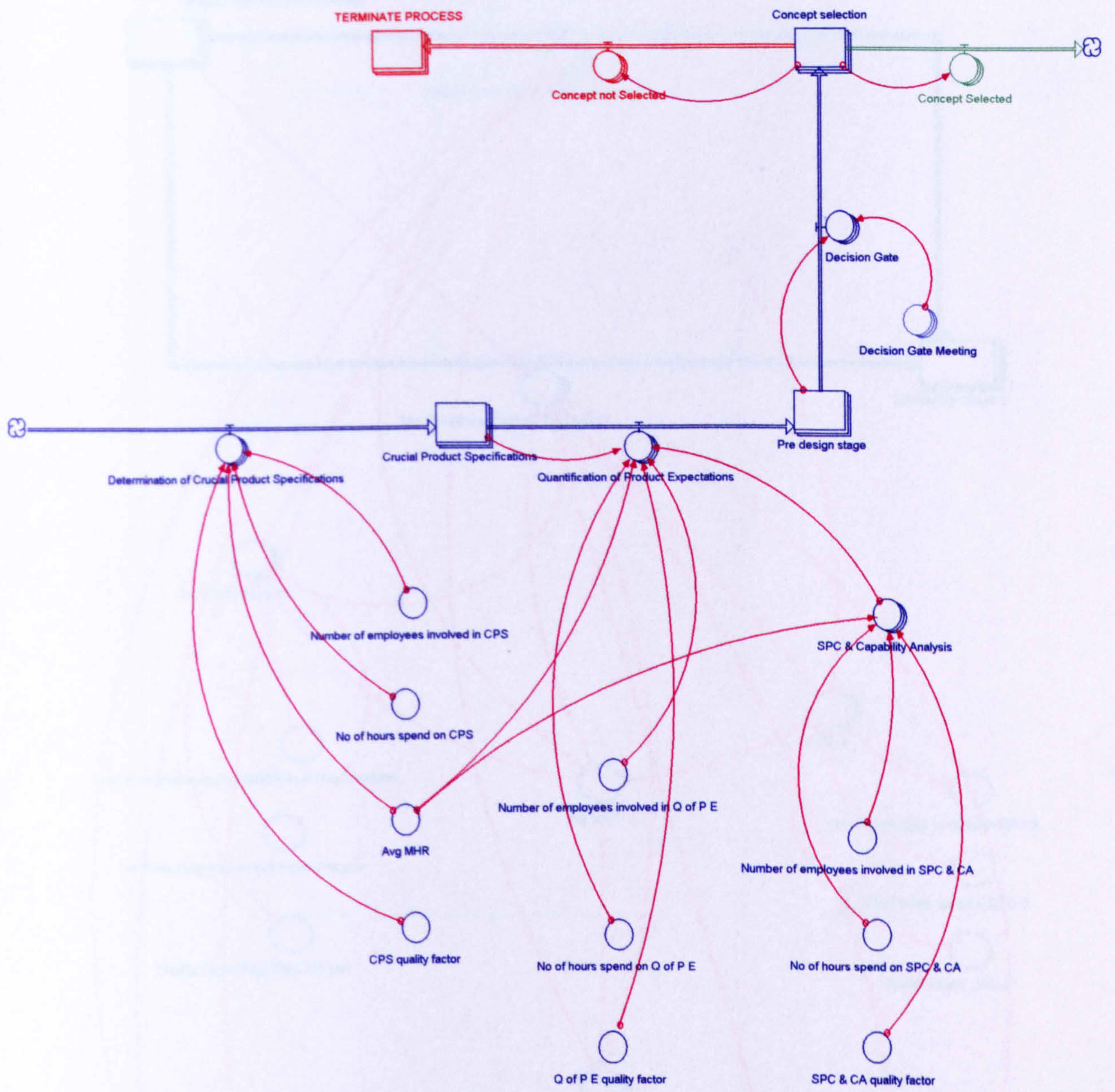
# IDEA



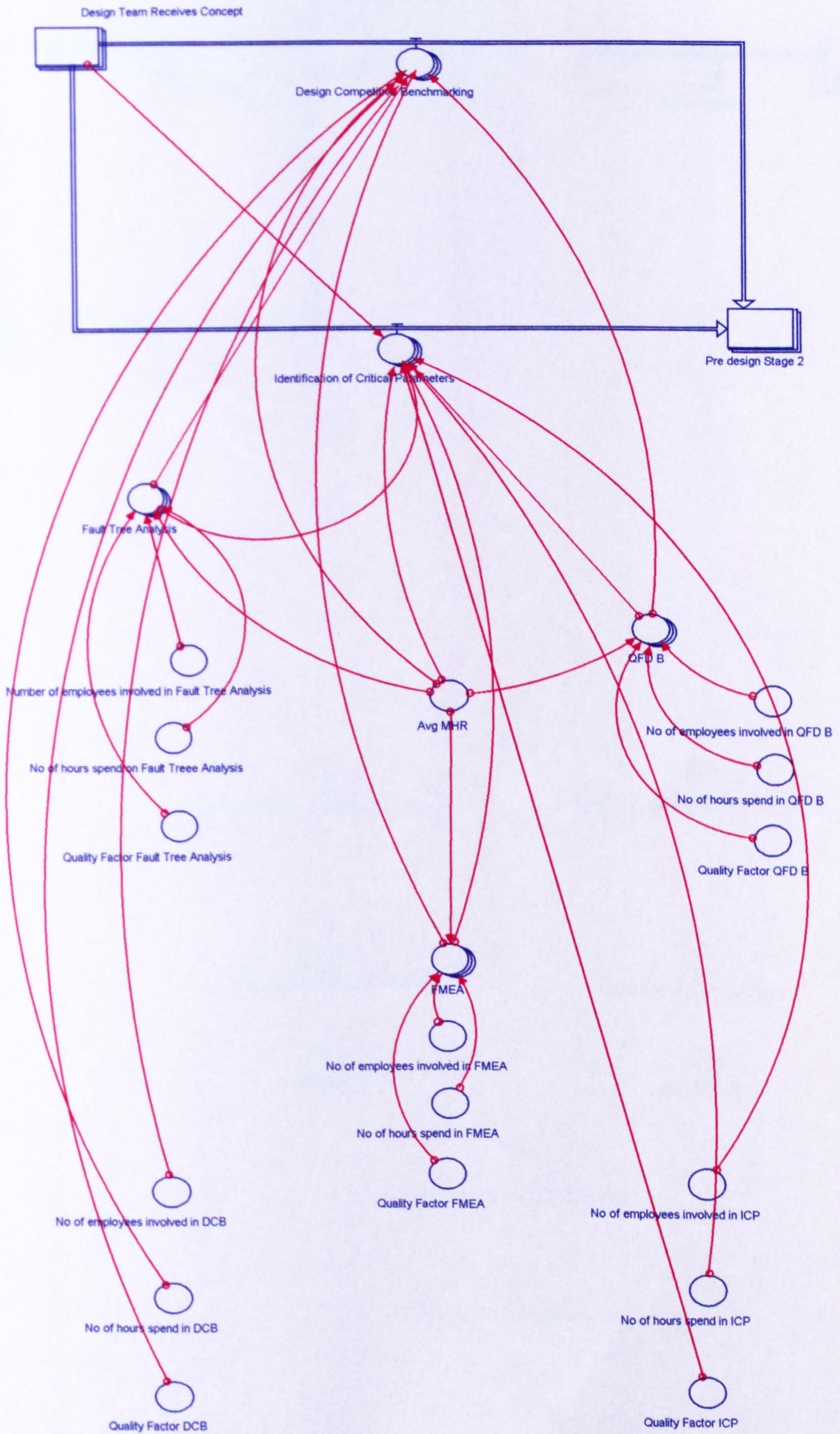
# CONCEPT



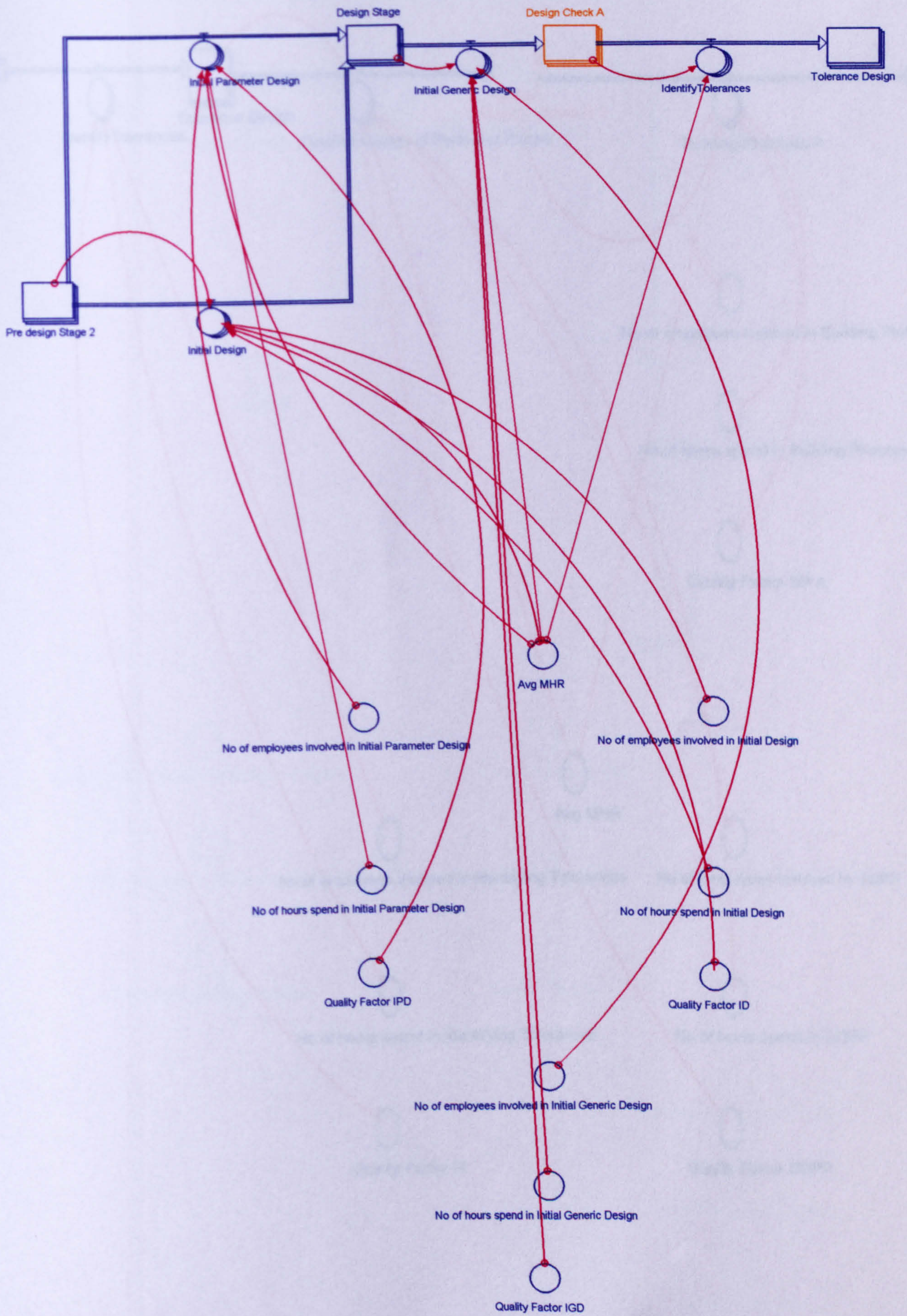
# CONCEPT



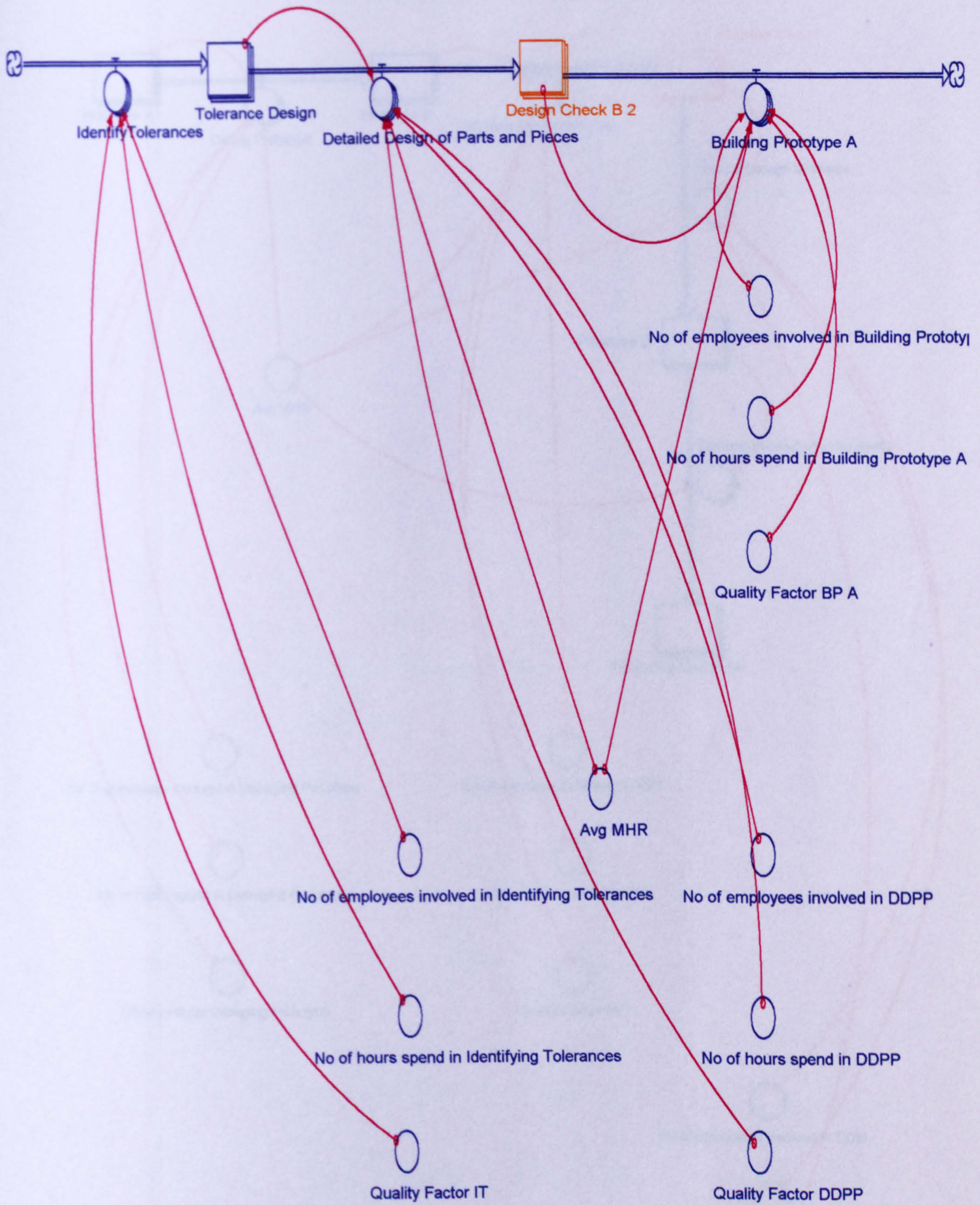
# DESIGN



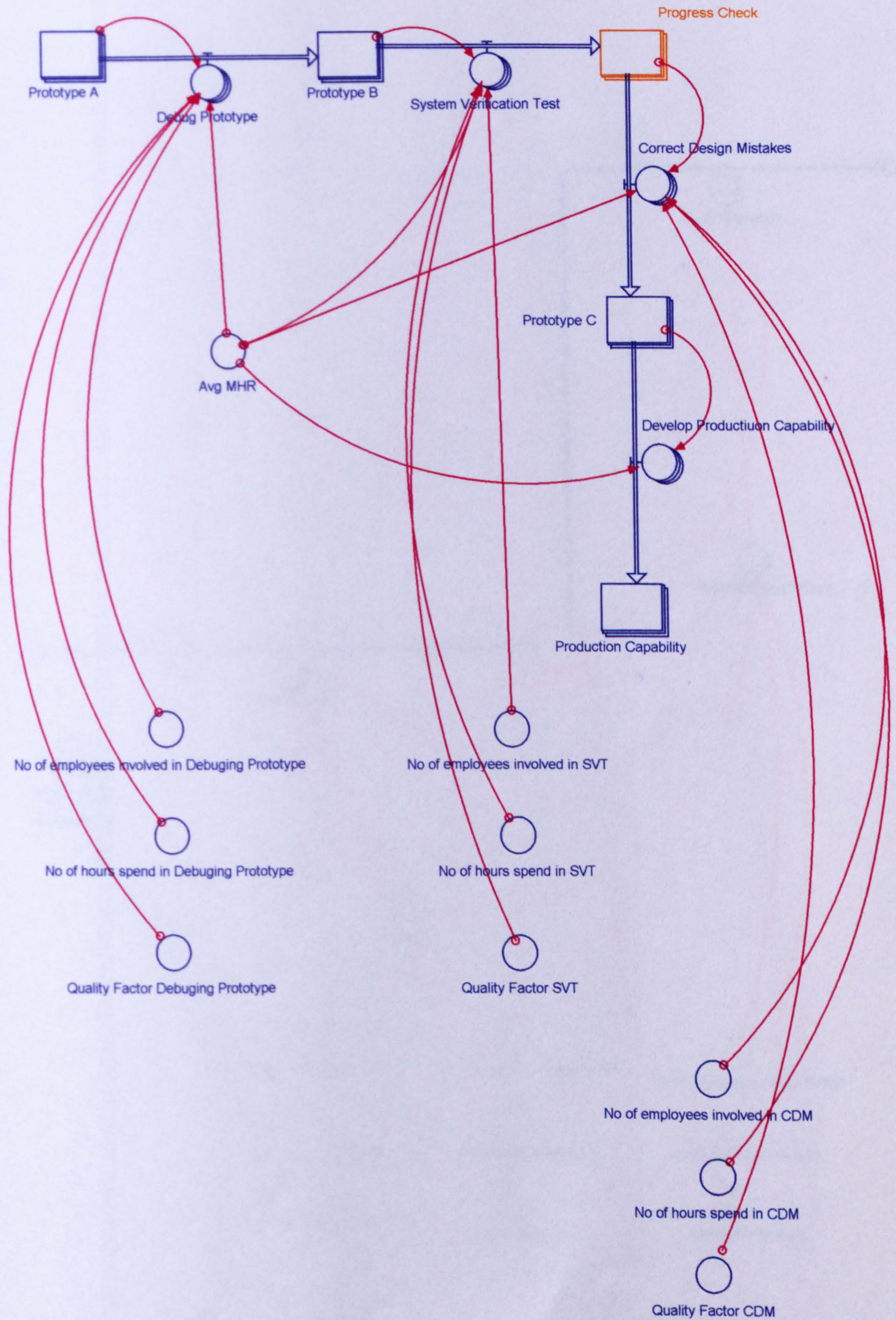
# DESIGN



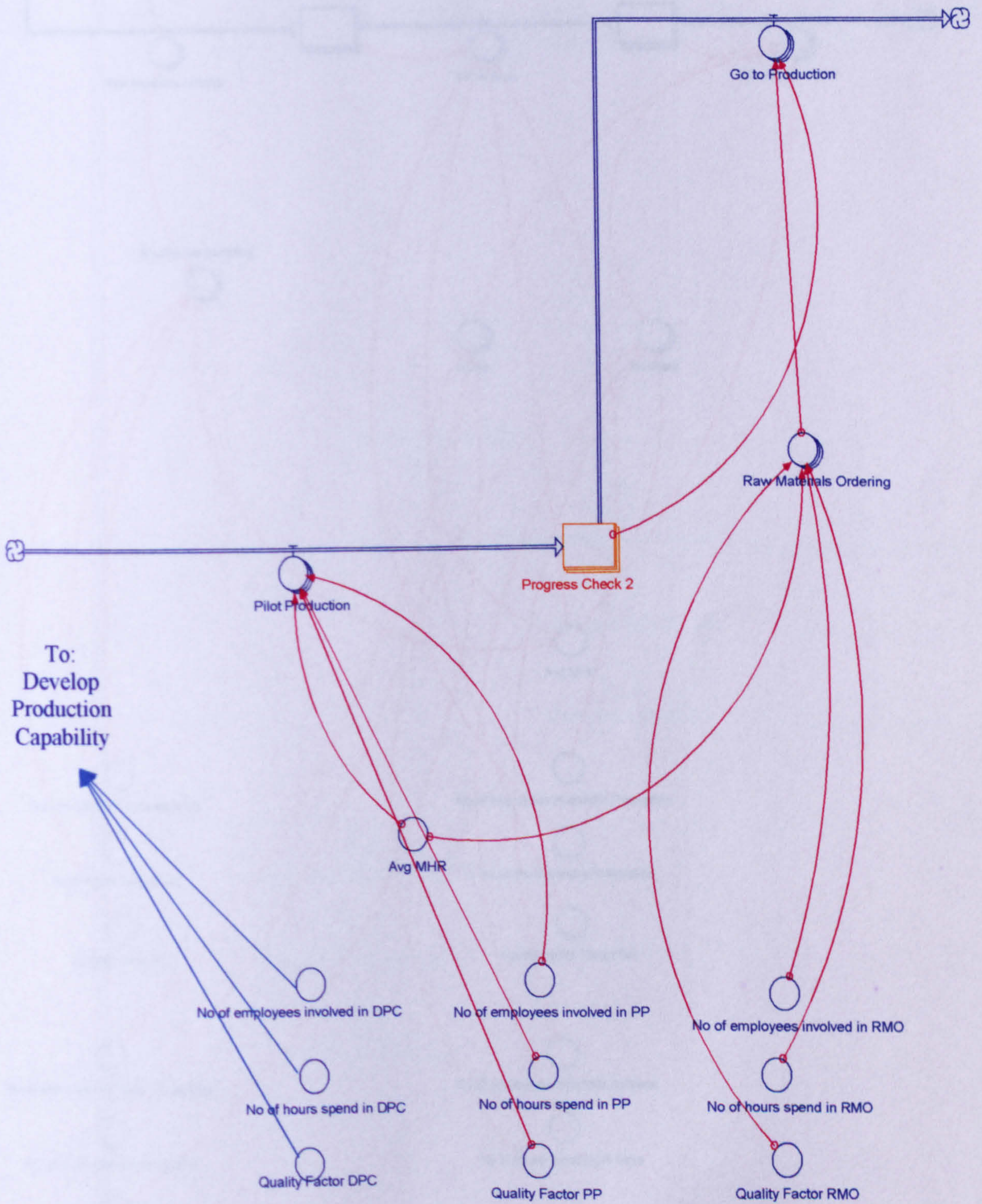
# PRE-PRODUCTION DESIGN VALIDATION



# PRE-PRODUCTION VALIDATION

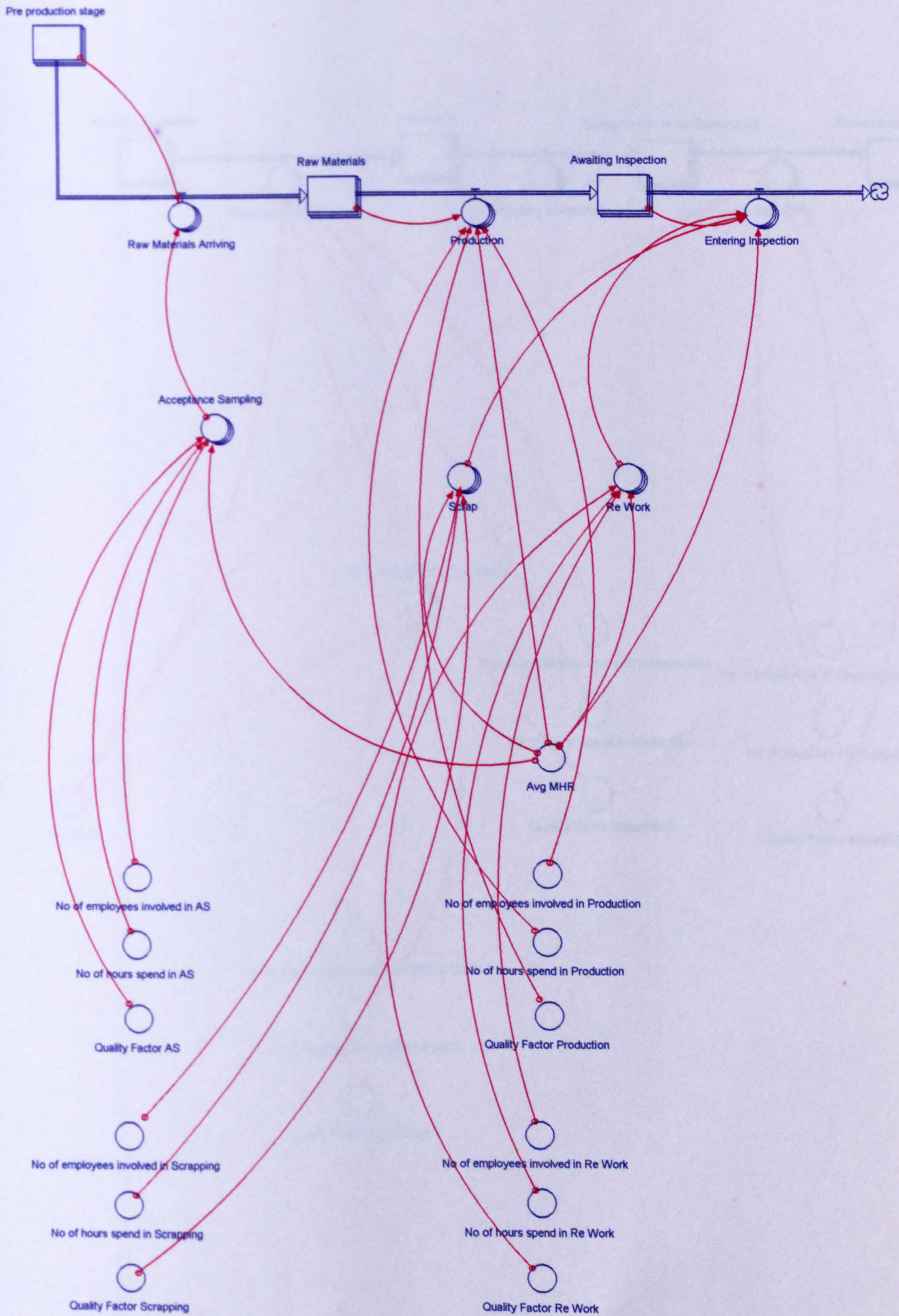


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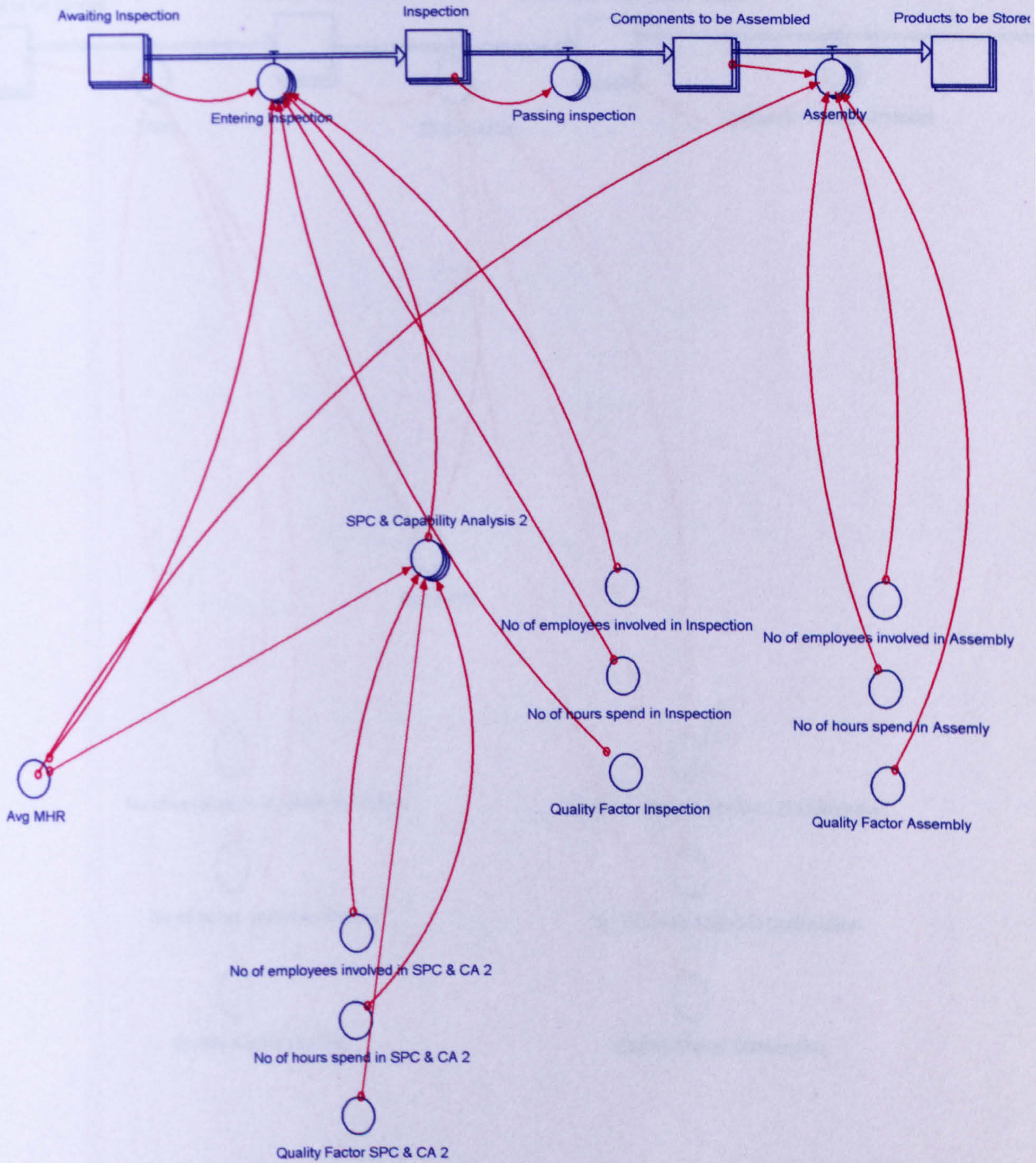




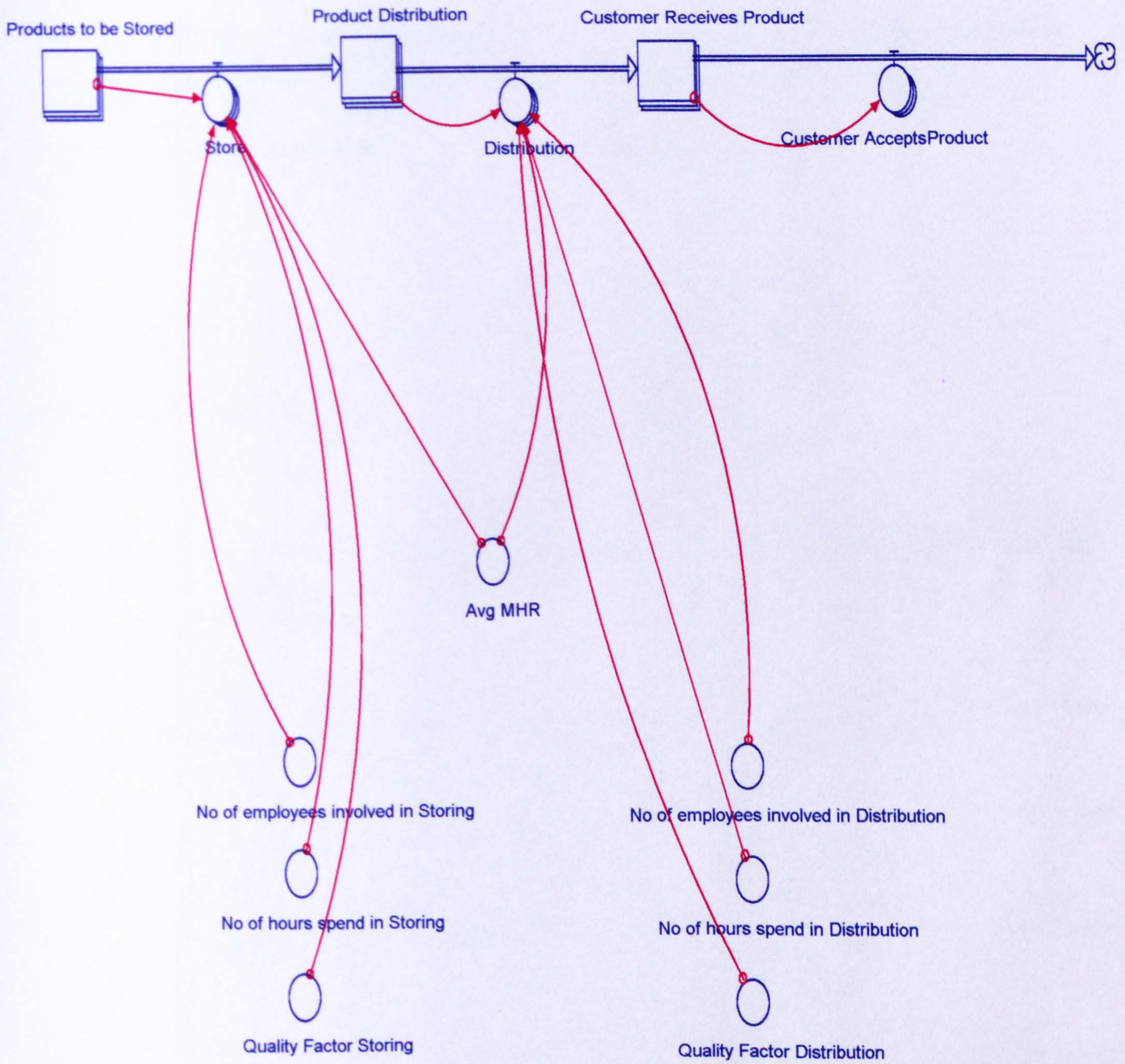
# PRODUCTION / DISTRIBUTION



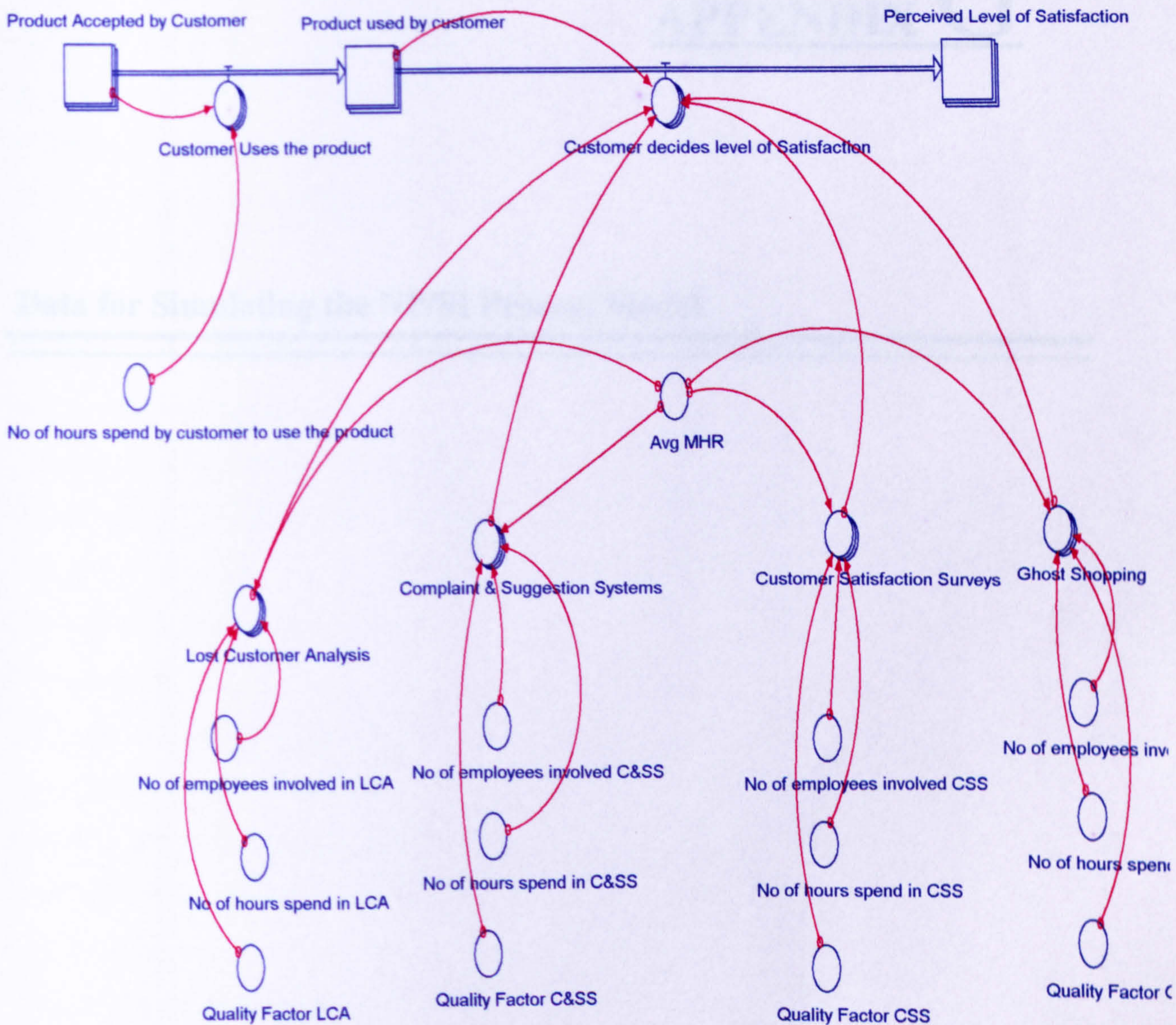
# PRODUCTION / DISTRIBUTION



# PRODUCTION / DISTRIBUTION



# POST COMPANY



# APPENDIX G

## Data for Simulating the NP/SI Process Model

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## HAI's Aircraft & Engines Division Data

No. of employees involved in brainstorming	0
Avg. no. of ideas per employee	0
No. of hours spend on brainstorming	0
Brainstorming Quality Factor	0
No. of main competitors	5
Avg. no. of ideas per competitor	0
Market knowledge	0.8
No. of hours spend on studying competitors	0
Competitors Quality Factor	0
No. of R&D employees	0
Avg. no. of ideas per R&D employee	0
Time spend by R&D personnel for ideas	0
Industry Knowledge	0.8
R&D Quality Factor	0
No. of clients	1
Avg. no. of ideas per client	1
Time spend on studying clients	19
No. of employees studying clients	1
Clients Quality Factor	1
No. of suppliers	100
Avg. no. of ideas per supplier	0
Time spend on studying suppliers	0
No. of employees studying suppliers	0
Suppliers Quality Factor	0
Perceived level of Customer Satisfaction	0.85
Marketing Quality Factor	0
No. of employees involved in screening ideas	6
No. of hours spend on screening ideas	8
QFD A Quality Factor	0.2
No. of employees involved in identification of Product Expectations	2
No. of hours spend on identification of Product Expectations	30

Identification of Product Expectations Quality Factor	6.5
No. of employees involved in QFD	1
No. of hours spend on QFD	10
QFD Quality Factor	1
No. of employees involved in identification of Product Specs	4
No. of hours spend on identification of Product Specs	40
Identification of Product Specs Quality Factor	9
No. of employees involved in FMEA	2
No. of hours spend on FMEA	20
FMEA Quality Factor	1.3
No. of employees involved in determining Crucial Product Specs	2
No. of hours spend on determining Crucial Product Specs	34
Crucial Product Specs Quality Factor	5
No. of employees involved in Quantification of Product Expectations	2
No. of hours spend on Quantification of Product Expectations	30
Quantification of Product Expectations Quality Factor	3
No. of employees involved in SPC & CA	1
No. of hours spend on SPC & CA	8
SPC & CA Quality Factor	0.5
No. of employees involved in decision gate meeting	0
No. of hours spend on decision gate meeting	0
Decision gate meeting Quality Factor	0
No. of employees involved in Fault Tree Analysis	0
No. of hours spend on Fault Tree Analysis	0
Fault Tree Analysis Quality Factor	0
No. of employees involved in Design Competitive Benchmarking	0
No. of hours spend on Design Competitive Benchmarking	0
Design Competitive Benchmarking Quality Factor	0
No. of employees involved in FMEA 2	1
No. of hours spend on FMEA 2	4
FMEA 2 Quality Factor	1
No. of employees involved in QFD B	1
No. of hours spend on QFD B	3

<b>QFD B Quality Factor</b>	<b>1</b>
<b>No. of employees involved in Identification of Critical Parameters</b>	<b>2</b>
<b>No. of hours spend on Identification of Critical Parameters</b>	<b>30</b>
<b>Identification of Critical Parameters Quality Factor</b>	<b>7.5</b>
<b>No. of employees involved in Initial Parameter Design</b>	<b>3</b>
<b>No. of hours spend on Initial Parameter Design</b>	<b>120</b>
<b>Initial Parameter Design Quality Factor</b>	<b>3</b>
<b>No. of employees involved in Initial Design</b>	<b>5</b>
<b>No. of hours spend on Initial Design</b>	<b>104</b>
<b>Initial Design Quality Factor</b>	<b>3.5</b>
<b>No. of employees involved in Initial Generic Design</b>	<b>4</b>
<b>No. of hours spend on Initial Generic Design</b>	<b>127</b>
<b>Initial Generic Design Quality Factor</b>	<b>2.5</b>
<b>No. of employees involved in Identifying Tolerances</b>	<b>4</b>
<b>No. of hours spend on Identifying Tolerances</b>	<b>93</b>
<b>Identifying Tolerances Quality Factor</b>	<b>2</b>
<b>No. of employees involved in Building Prototype</b>	<b>5</b>
<b>No. of hours spend on Building Prototype</b>	<b>1015</b>
<b>Building Prototype Quality Factor</b>	<b>1</b>
<b>No. of employees involved in Detailed Design of Parts &amp; Pieces</b>	<b>2</b>
<b>No. of hours spend on Detailed Design of Parts &amp; Pieces</b>	<b>169</b>
<b>Detailed Design of Parts &amp; Pieces Quality Factor</b>	<b>1.5</b>
<b>No. of employees involved in Debugging Prototype</b>	<b>2</b>
<b>No. of hours spend on Debugging Prototype</b>	<b>169</b>
<b>Debugging Prototype Quality Factor</b>	<b>2.5</b>
<b>No. of employees involved in System Verification Testing</b>	<b>2</b>
<b>No. of hours spend on System Verification Testing</b>	<b>85</b>
<b>System Verification Testing Quality Factor</b>	<b>3</b>
<b>No. of employees involved in Correcting Design Mistakes</b>	<b>5</b>
<b>No. of hours spend on Correcting Design Mistakes</b>	<b>101.4</b>
<b>Correcting Design Mistakes Quality Factor</b>	<b>3</b>
<b>No. of employees involved in Developing Production Capability</b>	<b>4</b>
<b>No. of hours spend on Developing Production Capability</b>	<b>84.5</b>



Developing Production Capability Quality Factor	3
No. of employees involved in Pilot Production	2
No. of hours spend on Pilot Production	85
Pilot Production Quality Factor	2
No. of employees involved in Progress Check	10
No. of hours spend on Progress Check	17
Progress Check Quality Factor	2
No. of employees involved in Raw Materials Ordering	2
No. of hours spend on Raw Materials Ordering	24
Raw Materials Ordering Quality Factor	2
No. of employees involved in Acceptance Sampling	1
No. of hours spend on Acceptance Sampling	21
Acceptance Sampling Ordering Quality Factor	0.25
No. of employees involved in Scrapping	1
No. of hours spend on Scrapping	20
Scrapping Quality Factor	0.25
No. of employees involved in Production	10
No. of hours spend on Production	190
Production Quality Factor	3.3
No. of employees involved in Re Work	1
No. of hours spend on Re Work	70
Re Work Quality Factor	0.2
No. of employees involved in SPC & CA 2	1
No. of hours spend on SPC & CA 2	40
SPC & CA 2 Quality Factor	1
No. of employees involved in Inspection	3
No. of hours spend on Inspection	122
Inspection Quality Factor	3
No. of employees involved in Assembly	4
No. of hours spend on Assembly	84.5
Assembly Quality Factor	2.25
No. of employees involved in Storing	1
No. of hours spend on Storing	19

Storing Quality Factor	1
No. of employees involved in Distribution	1
No. of hours spend on Distribution	20
Distribution Quality Factor	0.5
No. of employees involved in Lost Customer Analysis	0
No. of hours spend on Lost Customer Analysis	0
Lost Customer Analysis Quality Factor	0
No. of employees involved in Complaint & Suggestion Systems	0
No. of hours spend on Complaint & Suggestion Systems	0
Complaint & Suggestion Systems Quality Factor	0
No. of employees involved in Customer Satisfaction Surveys	0
No. of hours spend on Customer Satisfaction Surveys	0
Customer Satisfaction Surveys Quality Factor	0
No. of employees involved in Ghost Shopping	0
No. of hours spend on Ghost Shopping	0
Ghost Shopping Quality Factor	0

### **HAI's Electronics Manufacturing Division Data**

No. of employees involved in brainstorming	10
Avg. no. of ideas per employee	3
No. of hours spend on brainstorming	2
Brainstorming Quality Factor	0.5
No. of main competitors	4
Avg. no. of ideas per competitor	2
Market knowledge	0.8
No. of hours spend on studying competitors	60
Competitors Quality Factor	0.5
No. of R&D employees	5
Avg. no. of ideas per R&D employee	1
Time spend by R&D personnel for ideas	10
Industry Knowledge	0.8

<b>R&amp;D Quality Factor</b>	<b>0.6</b>
<b>No. of clients</b>	<b>5</b>
<b>Avg. no. of ideas per client</b>	<b>1</b>
<b>Time spend on studying clients</b>	<b>10</b>
<b>No. of employees studying clients</b>	<b>4</b>
<b>Clients Quality Factor</b>	<b>0.4</b>
<b>No. of suppliers</b>	<b>30</b>
<b>Avg. no. of ideas per supplier</b>	<b>0</b>
<b>Time spend on studying suppliers</b>	<b>0</b>
<b>No. of employees studying suppliers</b>	<b>0</b>
<b>Suppliers Quality Factor</b>	<b>0</b>
<b>Perceived level of Customer Satisfaction</b>	<b>0.85</b>
<b>Marketing Quality Factor</b>	<b>0.2</b>
<b>No. of employees involved in screening ideas</b>	<b>10</b>
<b>No. of hours spend on screening ideas</b>	<b>5</b>
<b>QFD A Quality Factor</b>	<b>1</b>
<b>No. of employees involved in identification of Product Expectations</b>	<b>3</b>
<b>No. of hours spend on identification of Product Expectations</b>	<b>40</b>
<b>Identification of Product Expectations Quality Factor</b>	<b>2</b>
<b>No. of employees involved in QFD</b>	<b>3</b>
<b>No. of hours spend on QFD</b>	<b>10</b>
<b>QFD Quality Factor</b>	<b>7.5</b>
<b>No. of employees involved in identification of Product Specifications</b>	<b>3</b>
<b>No. of hours spend on identification of Product Specifications</b>	<b>80</b>
<b>Identification of Product Specifications Quality Factor</b>	<b>2</b>
<b>No. of employees involved in FMEA</b>	<b>3</b>
<b>No. of hours spend on FMEA</b>	<b>10</b>
<b>FMEA Quality Factor</b>	<b>2.9</b>
<b>No. of employees involved in determining Crucial Product Specs</b>	<b>3</b>
<b>No. of hours spend on determining Crucial Product Specs</b>	<b>140</b>
<b>Crucial Product Specs Quality Factor</b>	<b>4.3</b>
<b>No. of employees involved in Quantification of Product Expectations</b>	<b>3</b>
<b>No. of hours spend on Quantification of Product Expectations</b>	<b>50</b>

Quantification of Product Expectations Quality Factor	1
No. of employees involved in SPC & CA	0
No. of hours spend on SPC & CA	0
SPC & CA Quality Factor	0
No. of employees involved in decision gate meeting	5
No. of hours spend on decision gate meeting	5
Decision gate meeting Quality Factor	1
No. of employees involved in Fault Tree Analysis	3
No. of hours spend on Fault Tree Analysis	5
Fault Tree Analysis Quality Factor	0.75
No. of employees involved in Design Competitive Benchmarking	3
No. of hours spend on Design Competitive Benchmarking	35
Design Competitive Benchmarking Quality Factor	2.25
No. of employees involved in FMEA 2	3
No. of hours spend on FMEA 2	5
FMEA 2 Quality Factor	1.25
No. of employees involved in QFD B	3
No. of hours spend on QFD B	5
QFD B Quality Factor	0.75
No. of employees involved in Identification of Critical Parameters	3
No. of hours spend on Identification of Critical Parameters	185
Identification of Critical Parameters Quality Factor	2.25
No. of employees involved in Initial Parameter Design	3
No. of hours spend on Initial Parameter Design	100
Initial Parameter Design Quality Factor	4.5
No. of employees involved in Initial Design	5
No. of hours spend on Initial Design	80
Initial Design Quality Factor	3.75
No. of employees involved in Initial Generic Design	5
No. of hours spend on Initial Generic Design	50
Initial Generic Design Quality Factor	3.75
No. of employees involved in Identifying Tolerances	4
No. of hours spend on Identifying Tolerances	25

Identifying Tolerances Quality Factor	2.25
No. of employees involved in Building Prototype	5
No. of hours spend on Building Prototype	150
Building Prototype Quality Factor	1
No. of employees involved in Detailed Design of Parts & Pieces	5
No. of hours spend on Detailed Design of Parts & Pieces	80
Detailed Design of Parts & Pieces Quality Factor	1.75
No. of employees involved in Debugging Prototype	3
No. of hours spend on Debugging Prototype	120
Debugging Prototype Quality Factor	3
No. of employees involved in System Verification Testing	3
No. of hours spend on System Verification Testing	40
System Verification Testing Quality Factor	4
No. of employees involved in Correcting Design Mistakes	5
No. of hours spend on Correcting Design Mistakes	40
Correcting Design Mistakes Quality Factor	4
No. of employees involved in Developing Production Capability	3
No. of hours spend on Developing Production Capability	40
Developing Production Capability Quality Factor	3
No. of employees involved in Pilot Production	3
No. of hours spend on Pilot Production	40
Pilot Production Quality Factor	2
No. of employees involved in Raw Materials Ordering	3
No. of hours spend on Raw Materials Ordering	8
Raw Materials Ordering Quality Factor	2.5
No. of employees involved in Acceptance Sampling	4
No. of hours spend on Acceptance Sampling	25
Acceptance Sampling Quality Factor	2.4
No. of employees involved in Scrapping	2
No. of hours spend on Scrapping	10
Scrapping Quality Factor	0.5
No. of employees involved in Production	3
No. of hours spend on Production	400

<b>Production Quality Factor</b>	<b>4.25</b>
<b>No. of employees involved in Re Work</b>	<b>3</b>
<b>No. of hours spend on Re Work</b>	<b>20</b>
<b>Re Work Quality Factor</b>	<b>0.7</b>
<b>No. of employees involved in SPC &amp; CA 2</b>	<b>2</b>
<b>No. of hours spend on SPC &amp; CA 2</b>	<b>25</b>
<b>SPC &amp; CA 2 Quality Factor</b>	<b>0.7</b>
<b>No. of employees involved in Inspection</b>	<b>3</b>
<b>No. of hours spend on Inspection</b>	<b>50</b>
<b>Inspection Quality Factor</b>	<b>2.25</b>
<b>No. of employees involved in Assembly</b>	<b>4</b>
<b>No. of hours spend on Assembly</b>	<b>150</b>
<b>Assembly Quality Factor</b>	<b>2.25</b>
<b>No. of employees involved in Storing</b>	<b>1</b>
<b>No. of hours spend on Storing</b>	<b>25</b>
<b>Storing Quality Factor</b>	<b>1</b>
<b>No. of employees involved in Distribution</b>	<b>1</b>
<b>No. of hours spend on Distribution</b>	<b>25</b>
<b>Distribution Quality Factor</b>	<b>0.5</b>
<b>No. of employees involved in Lost Customer Analysis</b>	<b>0</b>
<b>No. of hours spend on Lost Customer Analysis</b>	<b>0</b>
<b>Lost Customer Analysis Quality Factor</b>	<b>0</b>
<b>No. of employees involved in Complaint &amp; Suggestion Systems</b>	<b>0</b>
<b>No. of hours spend on Complaint &amp; Suggestion Systems</b>	<b>0</b>
<b>Complaint &amp; Suggestion Systems Quality Factor</b>	<b>0</b>
<b>No. of employees involved in Customer Satisfaction Surveys</b>	<b>0</b>
<b>No. of hours spend on Customer Satisfaction Surveys</b>	<b>0</b>
<b>Customer Satisfaction Surveys Quality Factor</b>	<b>0</b>
<b>No. of employees involved in Ghost Shopping</b>	<b>0</b>
<b>No. of hours spend on Ghost Shopping</b>	<b>0</b>
<b>Ghost Shopping Quality Factor</b>	<b>0</b>

## Command Control Communication Technologies Data

No. of employees involved in brainstorming	0
Avg. no. of ideas per employee	0
No. of hours spend on brainstorming	0
Brainstorming Quality Factor	0
No. of main competitors	10
Avg. no. of ideas per competitor	0
Market knowledge	0.8
No. of hours spend on studying competitors	0
Competitors Quality Factor	0
No. of R&D employees	0
Avg. no. of ideas per R&D employee	0
Time spend by R&D personnel for ideas	0
Industry Knowledge	0.8
R&D Quality Factor	0
No. of clients	1
Avg. no. of ideas per client	1
Time spend on studying clients	20
No. of employees studying clients	1
Clients Quality Factor	0.4
No. of suppliers	10
Avg. no. of ideas per supplier	0
Time spend on studying suppliers	0
No. of employees studying suppliers	0
Suppliers Quality Factor	0
Perceived level of Customer Satisfaction	0.8
Marketing Quality Factor	0
No. of employees involved in screening ideas	0
No. of hours spend on screening ideas	0
QFD A Quality Factor	1.2
No. of employees involved in identification of Product Expectations	1
No. of hours spend on identification of Product Expectations	5

Identification of Product Expectations Quality Factor	7
No. of employees involved in QFD	0
No. of hours spend on QFD	0
QFD Quality Factor	0
No. of employees involved in identification of Product Specifications	1
No. of hours spend on identification of Product Specifications	100
Identification of Product Specifications Quality Factor	9
No. of employees involved in FMEA	0
No. of hours spend on FMEA	0
FMEA Quality Factor	0
No. of employees involved in determining Crucial Product Specs	1
No. of hours spend on determining Crucial Product Specs	100
Crucial Product Specs Quality Factor	5
No. of employees involved in Quantification of Product Expectations	0
No. of hours spend on Quantification of Product Expectations	0
Quantification of Product Expectations Quality Factor	0
No. of employees involved in SPC & CA	0
No. of hours spend on SPC & CA	0
SPC & CA Quality Factor	0
No. of employees involved in decision gate meeting	0
No. of hours spend on decision gate meeting	0
Decision gate meeting Quality Factor	0
No. of employees involved in Fault Tree Analysis	0
No. of hours spend on Fault Tree Analysis	0
Fault Tree Analysis Quality Factor	0
No. of employees involved in Design Competitive Benchmarking	0
No. of hours spend on Design Competitive Benchmarking	0
Design Competitive Benchmarking Quality Factor	0
No. of employees involved in FMEA 2	0
No. of hours spend on FMEA 2	0
FMEA 2 Quality Factor	0
No. of employees involved in QFD B	0
No. of hours spend on QFD B	0



QFD B Quality Factor	0
No. of employees involved in Identification of Critical Parameters	1
No. of hours spend on Identification of Critical Parameters	20
Identification of Critical Parameters Quality Factor	3
No. of employees involved in Initial Parameter Design	2
No. of hours spend on Initial Parameter Design	70
Initial Parameter Design Quality Factor	2.4
No. of employees involved in Initial Design	2
No. of hours spend on Initial Design	150
Initial Design Quality Factor	4
No. of employees involved in Initial Generic Design	1
No. of hours spend on Initial Generic Design	15
Initial Generic Design Quality Factor	1.25
No. of employees involved in Identifying Tolerances	1
No. of hours spend on Identifying Tolerances	5
Identifying Tolerances Quality Factor	1
No. of employees involved in Building Prototype	0
No. of hours spend on Building Prototype	0
Building Prototype Quality Factor	0
No. of employees involved in Detailed Design of Parts & Pieces	2
No. of hours spend on Detailed Design of Parts & Pieces	200
Detailed Design of Parts & Pieces Quality Factor	1
No. of employees involved in Debugging Prototype	0
No. of hours spend on Debugging Prototype	0
Debugging Prototype Quality Factor	0
No. of employees involved in System Verification Testing	2
No. of hours spend on System Verification Testing	200
System Verification Testing Quality Factor	4
No. of employees involved in Correcting Design Mistakes	0
No. of hours spend on Correcting Design Mistakes	0
Correcting Design Mistakes Quality Factor	0
No. of employees involved in Developing Production Capability	0
No. of hours spend on Developing Production Capability	0

Developing Production Capability Quality Factor	0
No. of employees involved in Pilot Production	1
No. of hours spend on Pilot Production	100
Pilot Production Quality Factor	2
No. of employees involved in Raw Materials Ordering	1
No. of hours spend on Raw Materials Ordering	40
Raw Materials Ordering Quality Factor	1
No. of employees involved in Acceptance Sampling	0
No. of hours spend on Acceptance Sampling	0
Acceptance Sampling Ordering Quality Factor	0
No. of employees involved in Scrapping	0
No. of hours spend on Scrapping	0
Scrapping Quality Factor	0
No. of employees involved in Production	2
No. of hours spend on Production	100
Production Quality Factor	4
No. of employees involved in Re Work	0
No. of hours spend on Re Work	0
Re Work Quality Factor	0
No. of employees involved in SPC & CA 2	0
No. of hours spend on SPC & CA 2	0
SPC & CA 2 Quality Factor	0
No. of employees involved in Inspection	1
No. of hours spend on Inspection	20
Inspection Quality Factor	2
No. of employees involved in Assembly	0
No. of hours spend on Assembly	0
Assembly Quality Factor	2
No. of employees involved in Storing	0
No. of hours spend on Storing	0
Storing Quality Factor	1
No. of employees involved in Distribution	1
No. of hours spend on Distribution	5

Distribution Quality Factor	0.5
No. of employees involved in Lost Customer Analysis	1
No. of hours spend on Lost Customer Analysis	2
Lost Customer Analysis Quality Factor	1
No. of employees involved in Complaint & Suggestion Systems	1
No. of hours spend on Complaint & Suggestion Systems	3
Complaint & Suggestion Systems Quality Factor	0.5
No. of employees involved in Customer Satisfaction Surveys	1
No. of hours spend on Customer Satisfaction Surveys	3
Customer Satisfaction Surveys Quality Factor	0.5
No. of employees involved in Ghost Shopping	1
No. of hours spend on Ghost Shopping	6
Ghost Shopping Quality Factor	0.5

NP/SI stage	C3T		A/C & Engines		Electronics Mfg		Ideal QF
	Cost	Quality	Cost	Quality	Cost	Quality	
Generating Ideas	640	0.4	570	1	4800	2.2	3.6
Screening Ideas	640	1.6	2010	1.2	6300	3.2	5
Identification of Product Expectations	800	8.6	4110	8.7	10800	9.7	13.5
Ident. of Product Specs	4000	17.6	10140	19	19800	18.5	24.9
Determination of Crucial Product Specifications	7200	22.6	12180	24	31800	23.3	31
Quantification of Product Expectations	7200	22.6	14220	27.5	36300	25.3	35
Pre Design Stage	7840	25.6	16230	37	37050	26.3	45
Design Stage	21920	32	42630	43.5	62250	34.3	52
Initial Generic Design	22400	33.25	57870	46	83250	41.8	55
Ident. of Tolerances	22560	34.25	69030	48	92250	45.3	57.25
Detailed Design of Parts and Pieces	35360	35.25	79170	49.5	95250	47.55	59
Build Prototype	35360	35.25	231420	50.5	108750	49.3	60
Debug Prototype	35360	35.25	241560	53	131250	50.3	63.5
System Verification Testing	48160	39.25	246660	56	142050	52.8	67.5
Correcting Design Mistakes	48160	42.25	261870	59	147150	56.8	71.5
Developing Production Capability	48160	42.25	272010	62	153150	60.8	75
Pilot Production	51360	44.25	277110	64	156750	63.8	77.5
Progress Check	51360	44.25	282180	66	161850	65.8	80
Raw Materials	52640	45.25	283620	68	162570	68.3	82.5
Production	59040	49.25	343950	72	165570	70.7	86.75
Inspection	59680	51.25	356130	76	201570	74.95	91.25
Assembly	59680	53.25	366270	78.25	209970	78.9	93.5
Store	59680	54.25	366840	79.25	227970	81.15	94.5
Distribution	59840	54.75	367440	79.75	228720	82.15	95
Lost Customer Analysis	59902	55.75	367440	79.75	229470	82.65	96.25
Complaint & Suggestion Schemes	59998	56.25	367440	79.75	229470	82.65	97.5
Customer Satisfaction Surveys	60094	56.75	367440	80.25	231000	82.65	98.75
Ghost Shopping	60286	57.25	367440	80.25	231000	82.65	100

The above table illustrates the cumulative cost and quality factors level at each of the NP/SI process stages for each one of the organisations participating in the research.

The Average Man Hour Rate used for calculations was £32 for C<sup>3</sup>T and £30 for both the Aircraft & Engines Division and the Electronics Manufacturing Division of HAI.

Time can be calculated by dividing the Cost element by the average Man Hour Rate. The result gives the number of hours spend on each stage of the NP/SI process.

# APPENDIX H

## Tools for Process Improvement

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## **Statistical Process Control (SPC)**

SPC is a system which is used to gain better knowledge and control of a process by changing the emphasis from defect-detection to defect-prevention., and provides evidence of how a process is performing. A properly conducted SPC program recognises the importance of a never-ending search to improve quality by reducing variation in process output using some statistical techniques such as control charts, and it actually leads to improved quality, increased productivity, lower costs, predictable capability and improved competitive position.

SPC aims at achieving good quality during manufacture through prevention rather than detection. It is concerned with controlling the process which makes the product. If the process is good, then the products will automatically be good. So the process which makes the product is inspected rather than inspecting the product itself. Perhaps, confusingly at first, the best way to find out what is happening to a process is to take measurements of the products that the process is producing. Of course it is not necessary to look at every product that is produced. Instead, one can take samples, and use statistics to judge what is happening to the process. This is why it is called statistical process control. It may seem as if one is inspecting a few of the products coming out of the process, but in fact it is the process that is being inspected and controlled.

SPC is undertaken through the use of charts on which the performance of the process is plotted. If the process starts to go haywire it can be stopped in good time before many or any defectives are made.

## **Capability Analysis**

An effective SPC system includes more than control charts. It also includes a determination of whether the process is capable of meeting the specifications and if so, whether the process is actually meeting the specifications. Based on the results of the analysis, management decisions must be made on how to improve the process if required.

## **Acceptance Sampling Techniques**

Acceptance Sampling is a process in which a sample is taken from a batch of raw materials, work in progress or finished goods to be inspected and tested so as to ensure a pre-determined quality standard is consistently achieved. The whole batch will then be accepted or rejected according to whether or not the sample is of an acceptable quality level. By ensuring that always the inputs of a process or processes are of an acceptable quality level then it is almost certain that the variation of the process(es) will be reduced if the process is controlled.

## **Quality Function Deployment (QFD)**

Professor Yoji Akao (Professor of Management Engineering, Tamagawa University, Japan) who was responsible for its inception in the first place defines QFD as follows: “QFD is converting the consumers’ demands into ‘quality characteristics’ and developing a design quality for the finished product by systematically deploying the relationships between the demands and the characteristics, starting with the quality of each functional component and extending the deployment to the quality of each part and process.” This technique can improve the process of developing and producing products by deploying quality to all the functions of any organisation responsible for delivering quality goods or services to the end customer.

## **Failure Modes & Effect Analysis (FMEA)**

Failure modes and effects analysis (FMEA) is just what it says; it examines the various ways in which a product or service may fail and what the effect of each mode of failure will be. The technique leads to the identification of the most important possible modes of failure so that, hopefully, action can be taken to reduce the risks. In this respect FMEA is a Pareto type of analysis, homing in on the ‘vital few’ failure modes. FMEA can be applied to products, services, or systems.

FMEA usually begins by assembling a group who are familiar with the product, service or system. In some cases it may be useful to include customers, marketing and field service. The group will have the task of brainstorming out all the possible causes of failure. In addition to brainstorming, designers and engineers will be able



to advise on likely modes of failure and records may show failures in past performance.

### **Cost of Quality (CoQ)**

Many companies have developed quality cost reporting systems to assist them in identifying, controlling and minimising quality related costs. The information provided by a quality cost system serves several purposes.

First, quality cost information helps managers see the financial implications of poor quality. When managers are presented for the first time with a quality cost report they are often surprised because usually they are unaware of the magnitude of their quality costs. So, by reporting quality costs, an organisation can highlight areas for potential savings. Second, quality cost information helps the top management of an organisation to prioritise improvement efforts. For example, if the quality cost report indicate that the organisation is incurring excessive scrap or warranty costs for a specific product line, then quality improvement efforts can be specifically directed at the problems causing the greatest losses. Third, quality cost information provides a basis for establishing quality improvement budgets as top management seeks to reduce the total cost of quality. Fourth, quality cost information provides a basis for comparing the quality cost performance of different production lines in order to help the top management to identify and transfer successful techniques and ideas from the best performing production lines to the others. Fifth, quality cost information helps the top management of an organisation to monitor the trends of quality costs and decide which need to be reduced and determine the overall strategy.

There are a number of approaches to categorising and reporting quality costs. In this chapter the three most common approaches, known as the Prevention - Appraisal - Failure (PAF) Model, the Process Cost Model (PCM) and the CIMA Model, will be discussed. [141]

### **Design of Experiments (DoE)**

Design of Experiments is a family of techniques which enable a quality professional to home in rapidly on the most important variables in new product design or process

improvement. DoE has a long history going back to Sir Ronald Fisher in 1930, but popularised and refined by Taguchi.

A thorough literature review on Taguchi methods suggests the following as their important features: 1. Infusing quality in the design stage itself, since even stringent inspection procedures can never fully overcome bad design. 2. Increased concentration on the quality of design rather than inspection. 3. Focusing on 'robust design' which designs products so that they are not affected by disruption, either during production or service. 4. Using statistical procedures in the design phase only, at appropriate stages, and completely removing them from the production phase. 5. Relying on the models developed based on the philosophy 'loss to the society' rather than statistical techniques during production phase. Careful study of the above points indicates that quality is required to be infused during two stages, that is before and during production. The quality engineering methods proposed by Taguchi for application before production are known as offline quality control methods and those proposed for implementing during production are called on-line quality control methods. [142]

### **Post Company Tools**

Lost Customer Analysis (LCA), Complaint & Suggestion System (C&SS) and Customer Satisfaction Surveys (CSS) are three very popular tools which can assist an organisation in measuring its performance using customer feedback. LCA focuses its attention on studying customers who have stopped buying the organisations product(s). By doing so it is possible for the organisation to find out what was wrong or what dissatisfied the customer and he/she decided to stop buying the product. This technique, though, can only be used in the case of products which customers are known.

Complaint & Suggestion Systems is a method of gaining knowledge about customers' opinion concerning the product. It is a system where the customer voluntarily expresses its opinion (positive or negative) about the product or service of the organisation. A lot of useful conclusions can be reached by knowing what the

customers think about you. It may even give the organisation an idea for possible new products.

Customer Satisfaction Surveys are similar to the C&SS but they differ in the fact that CSS are not voluntarily. That means that the organisation takes the initiative to contact its customers in order to find out if they are satisfied with the performance of the organisation's product or service.

## **Other Improvement Tools**

### **Graphical Tools (CUSUM, Multi-Vari Chart, Normal Probability Paper)**

By using some simple statistical techniques, like CUSUM, Multi-Vari Chart, Normal Probability Paper, one can get some information about a process, which can be a lot different than the information he can get by using the other tools (SPC, Process Capability Analysis, etc.). For example, the CUSUM is a tool that can give a time indication on when there was a significant shift from the process average, and by examining that period may help in improving the process by removing causes of variation.

## **Benchmarking**

As discussed earlier, benchmarking is an opportunity for an organisation and individuals to learn from the experience of others. More specifically is the continuous process of measuring products, services and processes against strongest competitors or those renowned as world leaders in their field. There is no standard or commonly accepted approach to the benchmarking process. Each consulting group<sup>1</sup> and each company<sup>2</sup> uses its own method. Whatever method used, the major steps involve (1) measuring the performance of best-in-class relative to critical

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<sup>1</sup> For example, Kaiser Associates, Inc. has a seven-step process which is outlined in a company publication, *Beating the Competition: A Practical Guide to Benchmarking*, Vienna, Va.: Kaiser Associates, 1988 [143]

<sup>2</sup> For example, Alcoa's steps include (1) deciding what to benchmark, (2) planning the benchmarking project, (3) understanding your own performance, (4) studying others, (5) learning from the data, and (6) using the findings. See Alexandra Biesada, *Benchmarking*, Financial World, Sep. 1991, p.31 [143]

performance variables, (2) determining how the levels of performance are achieved, and (3) using the information to develop and implement a plan for improvement [143].

## **REFERENCES**

- [141] Antonaras, A, "An Analysis of the Quality Related Costs of Manufacturing in an Aerospace Industry", M.Sc. Thesis, Cranfield University, 1996
- [142] Aravindan, P. , Devadasan, S.R. , Dharmendra, B.V. and Selladurai, V., "Continuous Quality Improvement through Taguchi's online Quality control Methods", International Journal of Operations & Production Management, Vol. 15, No. 7, 1995.
- [143] Ross, J. E., "Total Quality Management: Text, Cases and Readings", Kogan Page Ltd., 1993