CRANFIELD UNIVERSITY

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Analysis of quality management requirements for product design in small and medium-sized enterprises (SMEs)

SCHOOL OF INDUSTRIAL AND MANUFACTURING SCIENCE

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In Memory of My Late Father

Ching-Shan Fang

(1915 - 1992)

ABSTRACT

The use of a quality management approach in the product design/development process is to control and monitor the design activities to improve the consistency of design, and further help to produce quality products that meet the customer needs. This is of particular importance to the small and medium-sized enterprises (SMEs) due to their natural constraints.

The aim of this study has been firstly to examine relationship between the ISO 9000 approach and the Quality Award Business Excellence Models to see to what extent they can be applied in the SMEs. Secondly, several different techniques including metrics of the new view of value engineering using a design process "model" as framework were developed theoretically and applied in practical terms during the product design process to improve the efficiency of quality management on design for the SMEs.

The conclusions are that, in the case of the ISO 9000 approach and the Models, it is appropriate for the SMEs to use in order to maintain competitiveness provided they are considered as process management disciplines. The concept of the new view of value engineering can be widely and consistently used to facilitate the generation process of design efficiency for the SMEs through a two-level of validation processes including a checklist. Such concept can only be fulfilled in practice with the positive recognition that achieving high worth instead of high value for the stages in the design process is a key factor.

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SECTION 1 INTRODUCTION, BACKGROUND AND METHODOLOGY

CHAPTER 1 Introduction, background and methodology

This chapter presents the introduction and background of the Thesis, including aim, scope, research methodology and structure of the research work with a diagraphically illustrated logical sequence.

1.1 Aim

The aim is to improve quality management of design for the small and medium-sized enterprises (SMEs)[1], explicitly focusing on products that are engineered, discrete and physical, and to develop metrics for assessing this. For the purpose of the research, product design is used interchangeably with "product design and development".

There is a significant interest in quality management and its effect on competitive performance in any size of company, large or small. Product design is an important dimension of quality management. The greatest source of product failure often lies in design weakness, with failure costs multiplying when discovered in the field (cited by Flynn *et al.*, 1994). Sound product design meets or exceeds the needs and desires of customers better than competitors, leading to increased market share.

According to a recent ISO TC 176 study, over 80% of the businesses in the world are small and medium-sized businesses (Wilson, 1996). Small businesses

[1] This study defines the SMEs as firms with less than 500 employees. Details can be referred to Chapter 5.

normally have less formality and structure than their larger counterparts. Employees often have more than one area of responsibility, even performing in a number of functional and structural system elements. Although there are generally fewer resources, small businesses can quickly respond to internal needs and emergencies.

1.2 Scope

Design, like other activities in an organisation, must be carefully managed. Different tools such as management philosophy/approach, design tools, and quality tools are applicable to the product design process so that design problems are solved by choosing the best solution(s). The research focuses on analysing quality management requirements for product design in the SMEs, not the application of professional design skills or tools, e.g. DFMA, CAD.

On the other hand, design activities required for product design in a company generally start from initial user needs and stop with manufacturing instructions in the form of drawings, written instructions, or electronic data.

Although several different techniques are considered to identify critical stages in the design process, this research concentrates on developing a metric to improve the quality management of design for the SMEs.

1.3 Research methodology

The aim of the research is to improve quality management of design for the SMEs. There are a number of possible routes to this situation such as extensive survey and analysis of a company via interviews and/or discussions, etc., or detailed study of one or two company. However, since there is a considerable amount of literature around, it was felt that a detailed literature review could provide data or information needed. From the review, we are able to develop a generic model of the design process which forms the basis for development of metrics. A validation process of selected metrics is then carried out. Following is how and why we achieve the afore-mentioned main stages of the research programme:

1. Survey of literature on relevant topics: the product design process, concept of quality management, specific application to quality management of design, special characteristics of the SMEs. Accordingly, a generic best practice model of design process is developed to establish the logical steps to incorporate all the activities that affect quality in the process and to show how the process integrates with the rest of business in the SMEs.
2. Analysing the design process model using three different techniques - labelling and grouping, categorisation, and importance level - to identify the critical stages in the established design process.
3. Utilisation of the possible measurement methods including a "new view of value engineering system" for identifying metrics in order to measure the critical factors in the design process.
4. Conducting some partial validations including a checklist responded by an independent group on selected metrics with a real example to advantage in improving the efficiency and consistency of quality management on design.

1.4 Structure of the Thesis

Chapter 2 starts to review the first part of the most relevant literature. It describes the nature of design and design process, discusses the characteristics, duration, and challenges of product design. The use of quality tools in the design process is discussed.

Chapter 3 reviews the concept of quality management and their concerns with issues that relate to product design. In particular, total quality management (TQM) which are aptly illustrated by various business excellence models and the ISO 9000 quality system standards are discussed. Possible application to the SMEs is investigated. Relationship between quality systems and operational tools, and between business excellence models and the ISO 9000 approach are identified respectively.

Chapter 4 presents specific application to quality management of design. It discusses details on established quality tools required for product design and applicability to the SMEs. Quality control activities through the product design process are also considered.

Chapter 5 describes some special features or characteristics of the SMEs including success factors.

Chapter 6 presents the outcome of literature review. It discusses both possible constraints on the SMEs of "big company" approach for quality management of design, and quality models/techniques used for the SMEs from literature. The development of a generic model for the design process is discussed.

Chapter 7 discusses the need for identification of critical control issues in the model of the design process. It presents three different techniques for defining the critical control issues for the purpose of developing metrics. Possible limitations of the three techniques are investigated.

Chapter 8 carries out analysis of the value engineering concept applied in the design process, and discusses the applicability of the modified value engineering concept.

In Chapter 9, a design situation is given to demonstrate validation of the value engineering metrics through a two-level of validation processes and to address impact of value engineering on the control of design, including limitation and suggested modification to the metrics.

Conclusions and suggestions for further work are given in Chapter 10.

The logical progression of the research work is shown in Figure 1.

SECTION 2 LITERATURE REVIEW

This section (Chapters 2 to 6) covers a critical analysis of the subjects that relate to quality management of design under the following:

- The product design process (Chapter 2)
  - the nature of design and its associated characteristics, duration, and challenges in the design process
  - quality tools for product design

- The concept of quality management (Chapter 3)
  - the Quality Award business excellence models and the ISO 9000 approach, their concerns with issues that are pertinent to design

- Specific application to quality management of design (Chapter 4)
  - the applicability of quality management on design

- Special characteristics of the SMEs (Chapter 5)
  - weakness in nature and possible success factors

- Outcome of literature review (chapter 6).
  - possible constraints on the SMEs of "big company" approach on quality management of design
  - the development of a generic model for the design process

CHAPTER 2 The product design process

2.1 The nature of design

It is commonly accepted that design is an integrated activity that operates closely with overall functional units in the organisation such as production, sales/marketing, purchasing, and quality during the product design/development process. But what is "design"? According to *BS 7000, 1989: Guide to managing product design*, design (in the context of product design) is defined as:

- (verb). To generate information from which a required product can become a reality.
- (noun). The set of instructions (e.g. specifications, drawings and schedules) necessary to construct a product.

On the other hand, *ISO 8402, 1994: Quality management and quality element - Vocabulary* defines design as:

"A process of originating a conceptual solution to a requirement and expressing it in a form from which a product may be produced or a service delivered."

Brown and Chandrasekaran (1989) state that design is a very complex activity and covers a wide variety of phenomena such as planning a day's errands, theory constraints in science, and composing a fugue are all design activities. A designer is charged with specifying how to make an artefact which satisfies or delivers some goals. The design problem is formally a search problem in a very large spread for objects that meet various constraints, and is to find a holistically suitable form for the product to fulfil the given function(s). An efficient designer must do everything possible to define the problem at the beginning, or to discover the problem as rapidly as possible.

Roozenburg and Eekels (1995) indicate design is a process of goal-directed reasoning. The reasoning from function to form is a form of reductive reasoning. A product is a material system, which is made by people for its properties. Because of these properties it can fulfil one or more functions. Figure 2 shows, by fulfilling functions, a product satisfies needs and provides one or more values to customers.

It seems therefore that design, progressing from the initial user needs to the final manufacturable product, can be viewed not only as a stage where design decisions are made which in turn create the design solutions against the goal but also as a learning process that collects, analyses, and generates information and knowledge and drawings about the product being designed. This required information can provide techniques for the designers to introduce the related constraints into the successful development of product design process until the final solution is in place and meets the initial needs.

2.2 Product design

Rosenthal (1992) states that the process by which a product idea becomes a commercial reality brings regular life-and-death challenges for almost any manufacturing company. Companies are forced to respond to these challenges by changing their way of product design and development to be more effective which means doing the right thing. Figure 3 lists the decisions that are associated with the product design and development. Further, as shown in Figure 4, both the form and the information content of a "product design" evolve in conjunction with the design and development decisions. Whilst agreeing to acknowledge that product design and development is a complex business process, Rosenthal concludes that it is a continuing series of discrete projects with important continuing relationships to other business activities such as R&D, marketing, manufacturing, and field service. During the period, three aspects of complexity and centrality -

how product design supports business strategy, how product design requires speed and discipline, and how product design effects costs - can be seen in connections with overall business strategy, time-based competition, and cost structures.

Ettlie and Stoll (1990), in demonstrating the product design from the design for change viewpoint which best starts at the early stages of the original design, present a simple three-step procedure as a general approach for implementing design for change which is as follows:

1. Evaluate the proposed product concept and process plan.
2. Analyse the result of the evaluation and develop ideas and approaches in the design for accommodating expected change.
3. Improve the product design and process plan according to the idea adopted and re-analysed. Iterate until satisfied.

Pugh (1990) addresses his total design concept in the product design arena which is defined as the systematic activity necessary, from the identification of the market/user need, to the selling of the successful product to satisfy the need - an activity that encompasses product, process, people and organisation. Total design may be construed as having a design core, which consists of different activities such as market (user needs), product design specification, conceptual design, detailed design, manufacture and sales.

Comments made by the above-mentioned authors on product design are dominated by the various concepts regarding the product design and its overall relationships with other business activities. There is an important lack of evidence on how to measure the success of the product design by the key factors such as cost spent on the design effort, quality of the product, and the cycle-time required for developing the product. In order to better understand the various aspects of product design, we now continue to discuss this subject in terms of characteristics, duration, and challenges.

2.2.1 Characteristics

The successful product design and development results from products that meet the expectations concerning technical and commercial feasibility. Effective product design and development can be the key to profitability and growth. But the process is complex and getting it wrong can put a company's future at risk. Ulrich and Eppinger (1995) present five specific dimensions to assess the performance of a product design and development effort:

1. *Product quality*

- How good is the product resulting from the development efforts?
- Does it satisfy customer needs?
- Is it robust and reliable?

Product quality is ultimately reflected in market share and the price that customers are willing to pay.

2. *Product cost*

- What is the manufacturing cost of the product?

Product cost includes spending on capital equipment and tooling as well as the incremental cost of producing each unit of the product.

3. *Development time*

- How quickly did the team complete the product development effort?

Development time determines how responsive the firm can be to competitive forces and to technological development, as well as how quickly the firm receives the economic returns from the team's efforts.

4. *Development cost*

- How much did the firm have to spend to develop the product?

Development cost is usually a significant fraction of the investment required to achieve the profits.

5. *Development capability*

- Are the team and the firm better able to develop future products as a result of other experience with a product development project?

Development capability is an asset the firm can use to develop products more effectively and economically in the future.

On the other hand, from Takeuchi and Nonakas' interviews (1986) with organisation members in some leading companies, the results show that six characteristics, once taken as a whole, can bring about speed and flexibility and dominate the managing of product design and development process:

1. *Built-in instability*

Top management signals a broad goal or a general strategic direction to kick off the product development process. It both offers the project team great freedom and also establishes challenging requirements.

2. *Self-organising project teams*

Operating like a start-up company, the project team creates its own self-organising character as it is driven to a state of "zero information" - where prior knowledge does not apply.

3. *Overlapping development phases*

By sharing knowledge about the marketplace and the technical community and synchronising their pace to meet project deadlines, the team works as a unit and the individual and the whole are inseparable. The rhythm of overlapping varies in different phases of design and development.

4. *Multilearning*

The members of the project team would involve continual feedback with outside sources of information but would also need to acquire broad knowledge and diverse skills, which respond quickly to changing market conditions and help them solve problems fast.

5. *Subtle control*

Although team members emphasise "self-control", "control through peer", management establishes suitable checkpoints to prevent the development process turning into instability, ambiguity, and tension. At the same time, management avoids impairing the creativity and spontaneity of the project team.

6. *Organisational transfer of learning*

Transfer of learning to subsequent new product design and development projects to other divisions in the organisation takes place regularly. Knowledge also transmitted in the organisation by converting project activities to standard practice.

Moreover, Figure 5 drafts a characteristic programme which presents a more concrete form for product design and development, and is based upon case studies of Roozenburge and Eelels (1995) in the field of engineering product development. The programme states that not every activity will be equally important in every product development project, nor does one find all activities that might be relevant. In this programme, the steps from the basic design cycle as well as the phases of product design process can be recognised. This cycle can be seen in the repeated occurrence of establishing specifications (specification 1, 2, 3), developing designs (design 1, 2, 3), and testing them (trial 1, 2, 3), both as regarding technical functioning, use and market, and as regarding manufacturing and costs.

From an analysis of these literature, there are many factors influencing quality in the product design and development process. Characteristics or specific dimensions presented in literature reflect the general requirements for larger companies in the design and development process, or were based on the particular industrial experience of the authors. Definition of the characteristics may also differ in the size of companies and their types of ownership.

2.2.2 Duration

The timing of investment on product design and development can be as important as the magnitude of the investment. Either too long or too short is inappropriate which can result in lost opportunities or ignore key issues and cause failure. The time required to develop a product is difficult to estimate in advance. Due to global competitiveness, it is critical for manufacturing companies to achieve faster design and development time if they are to remain competitive. In this regard, Haffenden (1990) states that reducing time-to-market for a product is one of the top three factors (the others are "quality" and "cost") which are driving businesses. He emphasises that there should be no barriers between the design and manufacturing process of a product. Additionally, new product time-to-market must also be short if manufacturers are to incorporate the latest technology (e.g. personal computers) into their products. Reducing time-to-market would involve the shop floor and the entire design-manufacturing process. This means concurrent engineering (CE) is essential requirement for manufacturing industry. Figures 6 and 7 show the traditional system for introducing new products from concept to manufacture, and the new concurrent method involves many concurrent functions to reduce time-to-market.

Based upon publicly available information and company sources, Ulrich and Eppinger (1995) present Table 1 showing the approximate scale of the associated product design and development efforts along with some distinguishing characteristics including development time and cost of five engineered, discrete products. They conclude:

- The reality is that very few products can be developed in less than one year.
- The cost of product development is roughly proportional to the number of people on the project team and to the duration of the project.
- Production investment including tooling and equipment is often as large as rest of the product development budget, and may be regarded as part of the fixed cost of production.

One of the significant characteristics inherited in the CE environment is the reduction of product design and development time. This is a crucial and valuable tool for the SMEs due to pressure from global competitiveness and their weaknesses in limited time invested in the design and development effort. The latter is a relevant issue that will be taken into account later in Section 5.1. On the other hand, the core concept in Table 1 is that product design and development activities, regardless of the industrial situations, start from initial customer needs and stop with manufacturable products that meet customers' requirements. The aim and scope of the research are to improve the quality management of design for the SMEs through identifying the critical factors affecting quality in the design process. The features shown in this Table provide some meaningful information for the companies. However, proper selection and application of quality management approach can enable the SMEs to perform these features in a cost-effective manner and remain competitive.

2.2.3 Challenges

The business environment has been increasingly more global in its outlook with much greater emphasis on world class performance and profitability. The pressure is on to employ practices which provide customers with what they want more efficiently and more cheaply (Barthorpe, 1994).

Ulrich and Eppinger (1995) present some of the challenging features in the product design and development process:

- Trade-offs: Decision trade-offs are difficult to recognise, understand, and manage with which the success of the product may maximise.
- Dynamics: Decision making in an environment of constant change, e.g. technologies improve, customer performance involves, and competitors introduce new products.
- Details: Developing a product of even modest complexity may require thousands of detail choices.
- Time pressure: Product design and development decisions are most usually made quickly and without complete information.

Hollins and Pugh (1990) state that product design and development process is hard. There has been much written regarding the failure rates of design/new products. The majority of new products are failures. Figure 8 shows the failure rates of many products from several of their research studies. Although it has been necessary to demonstrate the high rate of failure, the reasons for new product failures are probably of greater interest in any attempt to improve the design of a product and its management. They conclude the most common reason for product failure was found to be overwhelmingly due to inadequate market analysis.

Bright (1968) has listed the causes of success and failure of his research in the technical innovation situation. The most critical of these are:

1. Market orientation
2. Relevance to the organiser's corporate objectives
3. An effective project selection and evaluation system
4. Effective project management control
5. A source of creative ideas
6. An organisation receptive to innovation
7. Commitment by one of a few individuals.

These findings from the literature search reveal that, due to the increasingly global business environment, tremendous pressure has enabled companies, regardless of sizes and their industrial sectors, to identify the challenging features influencing the quality in the design and development process. It is obvious that a successful design and development process starts from an initial user needs through market analysis and/or other approaches which in turn, forms the basis of a clear design input with the involvement of available resources and produces throughput more efficiently and consistently. However, the situation is people always have contradictory ideas, therefore we have to explore these ideas further into the overall design process.

2.3 Design process

One of the most critical tasks in designing is to indicate how a design process should be constructed so that the product can satisfy the customer requirements in a reliable, effective and efficient manner. Akiyama (1991) notes that product design process:

- Transforms abstract customer demands (see Figure 9) into specific product drawings.
- Is a process of function allocation that identifies product purposes - such as functions - and allocate them to a structured product.
- Manipulates information creatively.
- Is a decision-making process.

Ullman (1992) argues that only a design team takes into account all views of customer performance requirements which are gained through interviews, questionnaires, and any other means, translates these terms into engineering parameters, so that a poor design can be avoided.

According to Roozenburg and Eekels (1995), models of the design process have been developed since the early 1960s and they quote three types of models of design process:

- The first type is the phase models of the product development process (see Figure 5). The phase models of product design indicate what kinds of problems that the product designer has to solve and what the best sequence is therein. The phase models of product development teach us what aspects should be taken into account.
- In the second type, designing is conceived as a specific form of problem-solving (see Figure 10). The basic design cycle gives the logical sequence of steps in the problem-solving process within each phase of product designing. This cycle is the fundamental model of the design process.
- In the third type of models, product design is described as a process in which

the design of a product is worked out on different levels of abstraction. These levels correspond to various forms in which a design in the making can be represented.

Roozenburg and Eekels state that, when designing products, these types of models portray different "dimensions" which are in a supplementary manner and specifically, the most widely adopted version of the phase models are those of French (1985) in Figure 11, and of Pahl and Beitz (1984) in Figure 12. An example of the second type of design process model is presented by Peters *et. al.* (1997) which is a generic framework of the new product design/development (NPDD) process and activities (see Table 2) that the SMEs could alter to represent the actual phases, using the facilitation issues (see Figure 13) such as NPDD strategy and review, multidisciplinary input, information technology, etc. to enhance their NPDD understanding and improvement of the process.

Urban and Hauser (1993) suggest a proactive new product design process by representing a set of managerial responsibilities which the new product team must address - the market (opportunity definition), the product, technology, and marketing (refinement), and the business opportunity (evaluation). This process also represents a set of customer analysis, including customer measurement which provides the raw data, the summary of customer which represents the data in a format that can be used by managers, and the forecasts provide a means to evaluate the business opportunity. The managerial process draws information from and provides information to the customer analysis which represents the key summaries of customer needs and desires. The process of new product designing (see Figure 14) entails: (1) identifying an opportunity, (2) designing a product to exploit the opportunity, (3) testing the product and its marketing strategy, (4) launching and tracking the product, and (5) managing the product life-cycle.

Although the published literature on product design contains a variety of models of designing, the differences in most of the cases are terminological in nature.

From the above review, we can now realise that a generally idealised design process model usually starts from design brief supported by a feasibility study and ends with the availability of manufacturing instructions for post-design support, with a variety of factors that need to be incorporated into the design process.

2.4 The use of quality tools for product design

A product design process which begins with initial customer needs and ends with a manufacturable product is often divided into several stages (phases), not only to develop an approach for the management and control of design but also to apply appropriate tool(s) for each situation. Following is a list of established quality tools that relate to product design:

- Quality Function Deployment (QFD)
- Statistically based tool (Taguchi Methods)
- Seven basic tools:
    - Check sheets/tally charts
    - Histograms
    - Control charts
    - Pareto analysis
    - Cause and effect analysis
    - Stratification
    - Scatter diagrams
- Design verification
- Design review and validation

These tools are all applicable for control and monitoring of the design process activities to improve the consistency of design (see Figure 15). They are suitable for adding value into design process and will be discussed and critically analysed in Section 4.1.

CHAPTER 3 The concept of quality management

This chapter reviews how the concepts of quality and quality management apply to product design. In particular, the ISO 9000 series of quality system standards and total quality management (TQM), as described by the various business excellence models for quality awards, are discussed.

3.1 Definition of terms

3.1.1 Quality

The meaning of quality management cannot be precisely appreciated without clearly understanding the adequate definition of the term "quality". A number of literature sources have attempt to define "quality" whilst the Oxford English Dictionary providing the definition as - degree of excellence; an attribute, property, or special feature of characteristics. Another agreed definition is from ISO 8402 (1994) - Quality: the totality of characteristics of an entity that bear on its ability to satisfy stated or implied needs. Because the theme of the chosen research theme is on quality management of design, therefore, from this point of view, the definition of ISO 8402 should be applied because it covers "the totality of characteristics". It is worth emphasising that this research explicitly focuses on the tangible products, i.e. engineered, discrete, and physical that are designed. In order to enhance the quality in the design of a product, BS 7000 (1989) requires the following features be considered from the conceptual stage:

a) Avoiding unnecessary complexity
b) Avoiding unnecessary variety
c) Avoiding unnecessary costs
d) Minimising or eliminating features known to cause of quality problems

3.1.2 Quality management (QM)

Quality Management is clearly defined by ISO 8402 (1994) as:

"All activities of the overall management function that determine the quality policy, objectives and responsibilities, and implement them by means such as quality planning, quality control, quality assurance and quality improvement within the quality system."

The important feature of this definition is that quality management includes the various concepts that relate to "quality" such as quality control, quality assurance, and extends further to cover quality policy, quality planning and quality improvement. Quality management operates throughout the quality system.

product design is one of the important dimensions in a company. It is mainly because providing a product that fits for its purpose is essential for the company's survival. Therefore, a quality management approach on product design that complies with a company's needs is required to ensure that products can be designed and produced in a consistent and effective manner.

3.1.3 Total quality management (TQM)

ISO 8402 (1994) defines total quality management (TQM) as:

"Management approach of an organisation, centred on quality, based on the participation of all its members and aiming at long-term success through customer satisfaction, and benefits to all members of the organisation and to society."

British Quality Association (BQA) gave its definition as follows:

"TQM is a corporate business management philosophy which recognises that customer needs and business goals are inseparable. It is applicable within both industry and commerce. It ensures maximum effectiveness and efficiency within a business and secures commercial leadership by putting in place processes and systems which promote excellence, present errors and ensure that every aspect of the business is aligned to customer needs and the advancement of business goals, without duplication or waste of effort". The definition of ISO 8402 is more appropriate because it is shorter but equivalent in context with that of in British Quality Foundation.

Cordata and woods (1995) give a good summary of the concerns and focuses of TQM in Figure 16. It could be said that the successful implementation of TQM on product design in a company highly hinges on its most valuable resource (i.e. staff), especially design staff, whose output in terms of both quality and quantity largely depends on their skill, training and motivation (BS 7000, 1989). Therefore particular attention should be paid to aspects such as communications, empowering of employees, team work and senior commitment required for all levels of functional units which are concerned with product design in the TQM environment.

As can be seen from the definition of quality management in ISO 8402 (1994), a quality system provides a framework in which those various concepts in relation to quality are operating, achieving and sustaining high quality products. This is the important feature of quality management and is slightly different from TQM which is centred on the management approach of a company with involvement of all its employees.

There are three well-established models of TQM - Deming prize, the Malcolm Baldrige and the European business excellence model - which are the basis of the internationally-recognised awards. These models are critically discussed in the section that follows.

3.2 TQM and business excellence models

3.2.1 Introduction

The quality awards of Japan, the USA and Europe, as mentioned already, are the major internationally recognised quality awards and all model the TQM process which can be measured by monitoring process improvements and the outcomes and results. They use evaluation criteria which are similar in nature. According to Laszlo (1996), the award criteria are intended to emphasise the key requirements to provide increased value to customers through the optimisation of overall productivity within the organisation.

3.2.2 Deming Prize

This was introduced in the early 1950s and unlike the Baldrige and European award models, the jury examination of Deming Prize constitutes the central part of the awarding framework and also emphasises the diagnosis and implementation of TQM.

According to Yoshikazu (1996), an applicant is required to present documents using the now-familiar PDCA (plan-do-check-act) cycle on implemented TQM practices such as design/development, environment, safety, etc. This perhaps is a self-learning process which provides the applicant with opportunity to look back and find out areas for improvement on the system of management and managing approach for product design. A report is followed by the examination providing comments and suggestions relevant to the product design issues for further improvement.

3.2.3 Malcolm Baldrige award model

The model was established in 1987 to improve the competitiveness of US industries. It serves as an efficient and valuable tool for a company to self-assessing its quality system with regard to the criteria (see Table 3). Whilst realising the status of quality management operations in all parts of the company including product design, more focused and more convincing planning may therefore emerge for continuous improvement based on the findings of the assessment to avoid bulk costs at post-design stages.

As indicated, the model itself takes an excellent view of quality performance strongly emphasises on the importance of improving competitiveness of a company with products that are designed, manufactured and delivered. The self-assessment process, in particular, provides credible, objective feedback and extensively enhance the high quality performance for a company from the inception of product design process.

3.2.4 European quality award model

Developed from the US Baldrige award model and introduced in 1992, this business excellence model is to help maintain the competitive edge of European industries by conducting a self-assessment process to evaluate against nine criteria (Table 3) on all the activities (including product design) in a company and allow the company to discern clearly its strengths and areas for improvement. Subsequent action can be made and monitored for progress in order to become more competitive in business performance. The rationale for the model is expressed in Figure 17.

3.2.5 Comparison

Table 4 compares the various features of Deming Prize, the Baldrige and European award from the point of view of product design. Although there are some differences in the way they are assessed, there are no significant and fundamental differences in terms of management and control of product design amongst the three well-established award models. It is worthwhile to use and apply these models on product design. Adoption of any of them does not distract or revise the scope of this research work as originally defined.

3.2.6 Possible application to the SMEs

The TQM process presented in these models is well-integrated and systematic for managing the process for producing a product, particularly in the product design stages. Although there are some slight variants amongst them, they all provide a generic framework of criteria that can be widely and equally applied to the SMEs. However, the majority of SMEs in the past would rather use the criteria for the improvement of process management and for ultimately leading to excellence in business performance rather than applying for the awards because of time-taking and costs incurred in the process.

It is worth noting that the European (UK) award criteria in 1997 (British Quality Foundation & EFQM, 1997) have been slightly modified for the independent SMEs by introducing a small business award process that requires the SMEs be scored only against the definitions of the nine criteria , not the 32 criterion parts. However, the SMEs are recommended to refer to the criterion parts as well as the "things to consider" when conducting self-assessment. Although it is still too early to say whether the SMEs "buy into" the principles that underlie the award criteria, this modification makes it easier for the SMEs because there are less work and less formality for score, and is sensible without compromising the validity and applicability of the criteria.

3.3 The ISO 9000 approach

The ISO 9000 approach is based on the concept of a quality management system, controlling the process of management in a company. The primary purpose is to prevent errors from occurring. That is the basic philosophy of the ISO 9000 approach. But according to Rogerson (1988), different quality systems, such as the Canadian standard CSA Z299, the "nuclear" system standards and military standards, are only mainly different in style and emphasis whilst addressing the same major elements and operational activities, differing in detail and in the emphasis placed on specified elements of the quality system.

Because of the international recognition in more than seventy countries all over the world, the ISO 9000 (1994) series of Standards is taken in this research as the defining set of standards for a quality management system. The series is divided into three groups as follows:

- ISO 9000-1: Quality management and quality assurance standards - Part 1: Guidelines for selection and use
- ISO 9004-1: Quality management and quality system elements - Part 1: Guidelines
- ISO 9001: Model for quality assurance in design, development, production, installation and servicing

Specifically, ISO 9000-1 and ISO 9004-1 provide guidance to clarify, develop and implement a quality system by defining and describing the elements of quality-related concepts, including those in product design. However, ISO 9001 specifies quality system requirements for use in design, development, production, installation and servicing. Their integrated relationship is illustrated in Figure 18, and Table 5 displays cross-reference list of clause numbers in the key ISO 9000 family of Standards.

3.3.1 ISO 9000-1

This Standard provides guidance for selection and use of the ISO 9000 family of International Standards on quality management and quality. Four facets that are key contributors to product design highlighted in ISO 9000-1 (1994) are defined as follows:

a) **Quality due to definition of needs for the product**
Quality due to defining and updating the product, to meet marketplace requirements and opportunities.

b) **Quality due to product design**
More precisely, it is the product design features that influence intended performance within a given grade, plus product design features that influence the robustness of product performance under variable conditions of production and use.

c) **Quality due to conformance to product design**
Quality due to maintaining day-to-day consistency in conforming to product design and in providing the designed characteristics and values for all customers and other stakeholders.

d) **Quality due to product support**
Quality due to furnishing support for design/development issues throughout the product life-cycle as needed.

For some products, the important quality characteristics include dependability characteristics. Dependability (i.e., reliability, maintainability, and availability) may be influenced by all four facets of product quality. The ISO 9000 family provides a framework for all facets that contribute to the quality of product to meet the goal and requirements for quality management (i.e., non-contractual situations) and external quality assurance (i.e., contractual situations) on product design in a company.

3.3.2 ISO 9004-1

The Standard provides guidelines in the design and implementation of a quality system for a company. The guidelines are generic and independent of any specific industry or product. It is for internal use of a company which shows no need for the company to demonstrate to customer that it has distinct forms of quality system model in place. It requires that the followings take place:

1) Meet a well-structured need, use or purpose;
2) Satisfy customers' expectations and/or needs;
3) Comply with applicable standards and specifications;
4) Comply with the requirements of society (e.g. obligations from laws, regulations, rules);
5) Reflect environmental requirements;
6) Are made available at competitive prices;
7) Are provided economically.

It can be said all the above factors have strong degree of relationship on product design/development activities whilst trying to develop a manufacturable product from an initial user need. During the design of a product, it is common that some inherent aspects have great importance for both the company and customer. For example, for the company, "cost" consideration has to be given due to marketing and design deficiencies, including unsatisfactory product, rework, repair, replacement, reprocessing, loss of production, warranties, and field repair. Other considerations include benefit and risk.

3.3.3 ISO 9001

This International Standard is one of a series of three International Standards (the others are ISO 9002 and ISO 9003). It deals with quality system requirements (as opposed to guidelines) for product design, and is for external quality assurance purpose. The Standard has broadest scope in the series of Standards and is described as follows:

- ISO 9001 Quality systems - Model for quality assurance in design, development, production, installation and servicing.

It is intended for contractual, regulatory, or certification use in which a company is required to demonstrate its capability for designing and supplying products. Confidence on the company's capability to deliver products which are comply with specified requirements, including both the original performance requirements set up by the customer and the technical (product) specified requirements developed by the company needs to be attained through the product life-cycle. Demonstration of the company's capability for designing and supplying product can be certified by a third party, or registrar.

3.3.4 Quality system requirements of ISO 9001

This International Standard states that the quality system requirements are complementary (not alternative) to the technical (product) specified requirements. These quality system requirements on product design describe what elements that a quality system has to encompass. The requirements are generic and independent of any specific industry.

The threefold reasons for discussing the quality system requirements of ISO 9001 instead of ISO 9004-1 in this section are:

- ISO 9004-1 only provides a general description of product quality in specification and design;
- ISO 9001 is a quality assurance model for use when conformance to specified requirements engaging from innovative design through to servicing;
- Most importantly, ISO 9001 has criteria which are set up precisely for product

design that form the basis of requirements for developing metrics.

Operations required in the product design process should be done in a systematic, consistent and comprehensive manner for assurance of a design. Amongst the specific requirements of ISO 9001 affecting the management of design, first of all, is "Design Control".

Design control

In "Design Control", detailed written procedures on design activities should be established, and continuously meet the design specification requirements. It is performed based on fulfilment of the following activities:

- *Perceive customer performance requirements*

1) For contract situations the company should use clear and written requirements requested in a specific customer contract pertaining to the design of a product.
2) For non-contract situations the company should conduct market research as well as benchmarking to formulate potential user needs and/or expectations and to translate them into practical designs that can fully address the market need.
3) Either cases should both consult to government regulations and regulatory agency requirements.

- *Intradepartmental and interdepartmental work for product design/development*

The company should organise design-related group(s) from various functional units to transmit and communicate the customer needs for the design of a product without disturbing the creativity of the designer(s). Make sure that "right the first time" decisions on product design are based on fulfilment of the required design specifications.

- *Design review*

The company should hold formal reviews at appropriate design stages with participants from concerned functional units including specialists if necessary, to formulate objective point of view on identifying problems from design results and proposing solutions. Write down the results of reviews to track and verify whether the identified issues are adequately reflected by the final design. The primary purpose of doing design reviews is to bring better and reliable products to the customers.

- *Design verification*

The company should conduct verification at various and appropriate times throughout the design process to ensure the design stage output conforms to the specified design stage input requirements. Both design reviews and design calculations provide evidence of design verification.

- *Design validation*

The company should perform design validation of product that follows successful design verifications (i.e. conform to design specifications). Design validation can provide confidence that the completed product fulfils the user needs and/or expectations. It is carried out at the time of product completion or earlier stages if necessary.

- *Design changes*

The company should assess possible and potential effects of design changes on the product to ensure that those changes are conducted in a consistent manner.

In addition to "Design Control", other criteria in relation to the management and control of design are as follows:

Management responsibilities

- *Quality policy*

The company must clearly define its written policy on the objectives of and commitment to the product and/or services quality throughout the entire product design process. All interested employees, particularly the designers, must understand, implement and sustain the policy whilst performing their works.

- *Organisation*

The company should establish its organisational structure, coupled with clear written job descriptions, for all the people whose work affects product quality whilst carrying out the product design/development activities.

- *Resources*

Resource requirements during the product design process include trained and experienced staff, availability of equipment, materials, and components, access to data. They must be carefully planned and provided in an appropriate and timely manner for the concerned personnel or groups to manage, perform and verify work.

- *Management review*

Periodical management reviews play an important role in assessing and ensuring the suitability and effectiveness of design activities during the product design/development process. These reviews should include the results of internal audits on design area, coupled with the corrective and preventive actions.

Quality system

- *Criteria for assessing the compatibility of design*

Criteria of the quality system are to identify problems in the design stages. Once nonconformity are observed, corrective and preventive actions can be promptly issued against a well-documented procedure to continuously improve the design quality of a product.

Contract review

- *Free from ambiguities whilst defining customer requirements*

The company should establish a procedure for reviewing a contract to sufficiently define and document the customer performance requirements. Changes to the contracts may carry out in conjunction with the customer and communicates throughout the company for assessing the designing and producing capability. The aim of both review and amendment of the contracts is to have an accurate and clear design input for supplying products that satisfy the customer requirements and/or expectations.

Purchasing

- *Reliable and consistent relationship with sub-contractors*

The company should establish and maintain a list of approved sub-contractors who have effective quality management in place and are able to supply the type(s) of products required for the design effort.

Corrective and preventive actions

- *Elimination of the causes of actual/possible problems*

Feedback from customer complaints, product returned, manufacturing yields and other pertinent indications of the product should be thoroughly investigated and analysed. Those which are identified to relate to the design deficiencies must be corrected immediately by the personnel responsible for the original design of the product. Record the root cause to eliminate the further occurring.

Control of quality records

- *Readily access to records relate to design*

Quality records such as contract reviews, design reviews, design verification measures should be available for evaluation within a promised period throughout product design process. The format of records can be of paper copy and/or on an electronic data base.

Internal quality audits

- *Performance measurement on design stages*

Internal audits should operate periodically on the activities including observation of tasks and examination of objective evidence (e.g. quality records) in relation to the design of a product to identify any nonconformity during the design process.

Training

- *Qualify personnel before assigning design tasks*

Design is a complicated process and decisions made right first time at the early stages of the process may significantly reduce the time and cost, and increase quality of the product. The company should carry out the required training to provide employees whose work affecting quality with competent skill and knowledge to implement the design/development activities.

3.3.5 Relationship between quality systems and operational tools

ISO 9000 provides the management framework for product design, but we need operational tools to perform design activities. In addition to design tools, those quality tools mentioned in Section 2.4 therefore play a vital role in improving the efficiency of a design task. This section categorises the relationships as follows:

- ***Design tools and quality systems:***

The significant contribution of design tools such as CAD, DFMA and simulation used in the design process includes ready access to information essential for evaluation of product design/development activities. This may advantage a company to reduce errors, waste, or rework. It is suggested that these benefits can only be achieved under the circumstances that design tools be deployed in the company established with a well-defined management structure.

- ***Quality tools and quality systems:***

A quality system provides built-in mechanisms with consistency for the effective management of design. The central issue here is that we need to consider when, where, and how do the quality tools fit in or work with a quality system. However, tools like QFD which begins with clear identification of the customer requirements (i.e., "voice of the customer") formulated from sales/marketing and market survey activities. Therefore, customer requirements identified through the QFD process with applicable use of other technical tools and standard techniques form the basis of a clear design input to supply products with customer satisfaction. Besides, other quality tools such as design review and verification also play a equally vital role in the managing process of product design and provide values into the process to control and monitor the design activities.

3.4 Relationship between business excellence models and the ISO 9000 approach

The International Standards in the ISO 9000 family are founded upon the understanding that all work is accomplished by a process (ISO 9001, 1994). Every process has inputs. The outputs are the results of the process with the involvement of people and other resources (see Figure 19). The ISO 9000 approach can be used for the consistent and effective implementation on company-selected activities, e.g. in the product design/development process. The business excellence models provide an overall framework for implementing quality management of operations in the whole company including product design/development, ensuring that the quality of design satisfies customers' expectations. More precisely, the models and the ISO 9000 approach focus on different points with different emphasis. But both are complementary and necessary for monitoring and controlling the design activities. A single and simple fact is that both are operating under the concept of a process management, only with a clear impression that the ISO 9000 approach is part of the business excellence models.

CHAPTER 4 Specific application to quality management of design

This chapter reviews more specifically the aspects of quality management approach on product design. In particular, it discusses how the quality tools need to interact with the management approach.

4.1 Details on quality tools for product design

4.1.1 Statistically based tools (Taguchi Methods)

As indicated in Taguchi Methods, design is an aspect of off-line quality control which belongs to "quality by design". The main objective is to ensure good functional quality using three main design measures, that is system design, parameter design, and tolerance design with the application of statistically experimental designs to reduce the noise that effects the functional quality of products.

The functional essentials of Taguchi Methods are described as follows.

1. *Noise or error factors*

Factors that are uncontrollable and may cause degree of variability from the target value specified in the product specifications. Noise factors are in three groups - external, internal and between products.

2. *Experimental design*

Designing experiment is an integral part of producing good functional quality of a product with high stability and reliability in the off-line quality control. Experimental design plays an important role in the stages of parameter design and tolerance design. Amongst the experimental designs, the factorial "orthogonal arrays" is the most consistent and efficient method that can avoid unnecessary cost and effort.

3. *System design*

System design, or functional design, is a stage for searching the existing and most suitable technology pertinent to the product which under design/development phase. The system designer is required to equip with sufficient scientific and engineering skills, knowledge, or experience to make accurate predictions.

4. *Parameter design*

Parameter design heavily applies the experimental designs by selecting the optimum setting of factor level to minimise the effect caused by the noise factors in order to improve the performance of product design. Parameter design is the most critical stage when designing a product. It is the central part of off-line quality control that provides improved quality in the design stages with lower costs.

5. *Tolerance design*

Tolerance design should only be introduced with a careful consideration of cost and environmental factors when parameter design is not reflecting sufficient results. In this stage, trade-off decisions should be made on whether to relax or narrow tolerances to reduce the effect caused by various sources of noise factors.

4.1.2 Seven basic tools

Seven basic tools were named by the Japanese quality guru Ishikawa. These tools are all applicable to the management of design process for collecting, analysing, and disseminating the data resulted from a variation of design activities to improve the consistency of design.

1. *Check sheets/tally charts - how often is it done?*

A check sheet/tally chart is used for recording data (or events) when occurring. It triggers the logical point for later presentation of the data, or may even serves as problem-solving aids.

2. *Histograms - what do variations look like?*

A histogram is diagrammatically presented in which both attribute and variable data are arranged and displayed with the relative frequency of its occurrence. In histograms, the bars are replaceable with the tally symbols in check sheets.

3. *Control charts - which variations to control and how?*

A control chart provides a clear pictorial view of current operating situations in a process control. By plotting graphs based on tabulated data, appropriate actions can be taken on whether to continue to run the process, or to adjust, or to stop for investigations and corrections.

4. *Pareto analysis - which are the big problems?*

Pareto analysis uses the bar charts type of diagrams to rank causes of incidents by relative frequency of occurrence, with the greatest percentage frequency positioned on the left. It is a technique to distinguish between the crucial and non-crucial problems.

5. *Cause and effect analysis - what causes the problems?*

Cause and effect diagram, or the fish bone diagram is coupled with a brainstorming session to input all of the possible and conceivable causes that may effect the quality of a product. A Pareto analysis may then be applied to identify those severe problems that need to be corrected and improved by using timely and appropriate actions.

6. *Stratification - how is the data made up?*

Stratification is stratifying identical groups of data according to the type of product into a meaningful manner and showing a correlation between them. This technique can be used for problem analysis and process adjustment, if necessary.

7. *Scatter diagrams - what are the relationships between factors?*

A scatter diagram is a systematic problem-solving method which may identify and display the resulting relationship between two varying factors (i.e. dependent and independent). The association status of those two factors may decide whether to collect more possibly correlating data and to re-draw the cause and effect diagram for further analysis and suggestions.

4.1.3 Design verification

A simplified question raised whilst conducting design verification is "Am I constructing the product correctly?". It is to examine and confirm whether the design stage output meets the design stage input specification requirements, such as environmental, aesthetic, and usage performance characteristics, statutory regulations and applicable standards by utilising the following alternative methods:

- Carry out alternative design calculations;
- Use an existing and similar design to compare;
- Verify by tests (e.g. MTBF - mean time between failure), analysis, simulation (of the operating equipment) or demonstrations;
- Validate product records.

These methods can be conducted by constructing a verification matrix to assure that every design requirements at the various and appropriate stages during product design process is completely verified before product is launched into production. Any changes that are made whilst undertaking design verification should be carefully examined for their effects on cost and schedule of the product.

Design verification is applied to any size of product design, large or small. Evidence of verification from methods above should be documented for any requirement of tracing a design flaw after the product has been launched into servicing.

4.1.4 Design review and validation

Characteristics such as "systematic", "comprehensive", and "documented" should be highlighted when doing the design reviews because functions that design reviews perform in the design process may revolve around these characteristics. ISO 9004 (1994) considers the elements of design reviews based on the design phase and the type of product and describes as follows:

a) ***Items pertaining to customer needs and satisfaction***

- Compare product specifications which reflect customer needs with technical specifications;
- Validate design using prototype testing;
- Ability to perform under expected conditions of use and environment;
- Unintended use and misuses;

- Safety and environmental compatibility;
- Conform to International Standards and statutory requirements;
- Benchmark competitive designs;
- Compare similar design to avoid repeating problems.

b) ***Items pertaining to product specification***

- Dependability and serviceability requirements;
- Permissible tolerances and comparison with process capabilities;
- Product acceptance criteria;
- Requirements on installing, assembly, storage and disposal of a product;
- Benign failure and fail-safe characteristics;
- Aesthetic specification;
- Diagnose and correct problems using FMEA, and fault tree analysis;
- Other requirements such as labelling, warning, traceability and user instructions.

c) ***Items pertaining to process specification***

- Ability to produce product conform to the design requirements;
- Capability to inspect and test the design;
- Specification of materials including components and sub-assemblies;
- Requirements, particularly safety factors, of packaging, handling, storage and shelf-life on incoming and outgoing items.

Members for doing design reviews are from concerned functional units with input to the design phase which is being reviewed. The data input for review is from results available at appropriate design stages. Reviewers examine the resultant data against the above elements whichever applicable, reveal the deficiencies, and feedback to the designers for correction. Often analysis performed by reviewers is required to determine the best solution before the next design phase commences for assurance of delivering better and reliable products. A design review is finalised by a written report with detail review results which represents objective evidence as a verification tool in the final design. However, a fact that should be noted is that the reviewers would never know if they have considered all potential influences, i.e. a potential weakness of the approved design on the product.

Design validation is performed to ensure that the final product fulfils defined user needs, or simply ask "Am I constructing the correct product?". Several facets that should be noted regarding design validation are as follows:

- Each successful design verification is fundamental to the undertaking of design validation;
- Validation should be operated under defined conditions to ensure that it meets various intended users' needs, if necessary;
- Validation may be conducted either at the launch of final product or earlier by the pre-released product through field tests or user group reaction;
- Assurance of the product conforms to specified user requirements and needs.

Design verification, design review and validation represent different requirements and are separated because they apply different techniques and procedures to perform their individual functional task during the product design process. These quality tools are conducted in a systematic, consistent and documented manner to control and monitor the performance of design activities. The primary aim is to provide assurance that the product is being, or will be produced and delivered with full customer satisfaction.

4.1.5 Quality function deployment (QFD)

There have been many attempts to define QFD in the literature. Some of the definitions are quoted below:

- A set of planning and communication routines. QFD focuses and co-ordinates skills within an organisation, first from design, through manufacture and to market products that customers want to purchase and will continue to purchase. The foundation of QFD is the belief that products should be designed to reflect customers' desires and tests - so marketing people, design engineers, manufacturing staff must work closely together from the time a product is conceived. (Hause and Clausing, 1988)

- QFD is an integrative process which links together customer needs, product and parts design requirements, process planning, and manufacturing specifications during product development. (Lockamy and Khurana, 1995)

- QFD can be defined as converting the customers' demands into "quality characteristics" and developing a design quality for the finished product by systematically deployed 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. The overall quality of product will be performed through this network of relationships. (Akao, 1990)

Followings are the three fundamental objectives of QFD, according to Zairi and Youssef (1995), and is depicted in Figure 20:

1. To identify the customer;
2. To identify what the customer wants;
3. How to fulfil customer's wants.

To understand the QFD implementation process, it is necessary to examine how QFD fits into key elements of the overall development cycle in terms of timing, performance, evaluation, and resources commitment. This cycle is divided as four phases that are associated with key events and managerial review stages (see Figure 21). If quality management aims at integrating all organisational activities and continuously improving the whole corporation business performance, then QFD can be thought of as an application of quality management during the product design/development process. Figure 22 shows the relationship between quality management and QFD in product design.

4.2 Applicability to the SMEs

We have analysed in previous section the contribution of these established quality tools on the management and control of product design. They are all valuable and critically important for a company, especially a SME, to monitor and control the design process activities. But it is clear to be a problem for the SME to put them together to get best solution on management of design in terms of their limitations in training and resources. Therefore prioritisation of these tools is the only alternative that complies with the uniqueness of the SMEs. For example, one of the critical features in the design process is to feedback elements from other functions inside and/or external to the company which is what design review and design validation perform. The rest of the quality tools is also taken into account as well. The main theme on prioritising leads to the core concept of the generic model for the design process developed in this research, highlighting the suitability on the application of these tools in the process. This is a relevant issue which we will take into account in Sections 6.3 and 6.4.

4.3 Quality control through the product design process

We have discussed the quality management and quality tools used for product design in the previous sections of this chapter. Their applicability to the SMEs including the necessity of prioritisation of the tools is also investigated. It is now appropriate to consider the sequence of the design process relevant to the management practices within the company and how to therefore improve the process using the above-mentioned techniques. To start with, we must define the term quality control. Quality control is defined in ISO 8402 (1994) as "operational techniques and activities that are used to fulfil *requirements for quality*, i.e. the expression of the needs or their translation into a set of quantitatively or qualitatively stated requirements for the characteristics of an entity to enable its realisation and examination". Cortada and Woods (1995) refer to quality control as those activities a company and its employees use to deliver high quality products or services. However, Schierhorn (1990) states that, although the majority of the literature on quality control has concentrated on the product production stage over the years, product quality is equally a function of procedures used during the product design process.

Before quality issues are considered, the phases (stages) in the design process must be specified as an approach to the management and control of design. In my opinion it should be stressed that quality control can only be applied to design if we consider design to be a series of processes. To present his exercise, Schierhorn designates the product design process into the following two stages:

- Specification stage
- Implementation stage

The division of the product design process into individual stages may be recognised as quality-enhanced measure. It is generally said that the clarity of each design stage may depend on company, project or type of product.

4.3.1 Specification stage

A product design process generally starts from identifying the customer requirements, which is also known as "voice of the customer". Once defined, the customer needs are used to establishing a set of product specifications against a study report which is originated from an economic and technical feasibility study for product design/development. Product specifications do not tell the designers how to address the customer needs, but they do represent an unambiguous agreement on what the team will attempt to achieve to satisfy the customer needs (Ulrich and Eppinger, 1995). They describe that a specification consists of a *metric* and a *value* and the term "product specifications" is the precise description of what the product has to do.

One of the duties of quality control personnel at this point is to make sure that these specifications will have a positive effect on the quality of the product (Schierhorn, 1990). The specifications should not be restricted to technical functionality of the product but should also take into account the environmental conditions and safety requirements. Once these issues have been addressed, the product concepts selected, the implementation stage will be defined for further development.

4.3.2 Implementation stage

During the implementation phase the product must be fully defined with the design output requirements. However, Schierhorn (1990) describes that this stage can be sub-categorised into a working model stage and followed by a prototype stage:

1) Working model: a rough draft of the product which contains all the main functional elements but is not yet in its final mechanical form. There are two key quality control activities that should be taken:

♦ Mean time between failure (MTBF). The main purpose is to identify the components likely to account for the greatest proportion of the total failure rate, and to find a better quality replacements.

♦ Failure mode and effect analysis (FMEA): It is another way to increase reliability which involves a group of members from the development, production, quality control and materials department at an early stage.

2) Prototype: corresponds as nearly as possible to the product in its final form. During this stage, quality staff take measurement methods and perform type testing to confirm that the product fulfils the quality requirements laid down in the specification. Followings are the critical testing that should be addressed:

- Ease of operation
- Safety - testing
- Environmental tests
- Protection tests

After the prototype has been officially approved, production may start with a complete set of drawings and a prototype model for further product development.

Logically, there is a series of tests, or demonstrations that should be carried out during this stage. But the scale of tests and trials may depend on whether a high degree of assurance on the design has been achieved at the completion of the tasks. The very purpose for keeping on testing is to observe and accumulate enough data of failures to identify, analyse and finally substantiate the product's reliability specification. Achieve conformance to specification within the design limits reduces the possibility of customer complaints to the great extent, which may appear years after products have been launched into service. That is the reason why we select these tools - MTBF, FMEA, and safety, environmental, protection tests for the management and control of design to ensure that the quality requirements defined in the product specification have been addressed.

CHAPTER 5 Special characteristics of the SMEs

This chapter specifies the characteristics most often associated with the SMEs including success factors. Contrary to their larger counterparts, SMEs have unique and special characteristics due to their sizes and types of ownership. The defining criteria of SMEs vary from one industry to another within a country, or even from one country to another. A variety of definitions have been made for the SMEs. For example:

- A business in which one or two persons are required to make all the critical management decisions: finance, accounting, personnel, purchasing, processing or servicing, marketing, selling, without the aid of internal specialists and with specific knowledge in one or two functional areas. (from Wiltshire Committee 1971 p7 and cited by Watson and Everett 1993)

- SMEs must be characteristised by a minimum of two of the following categories:

1. Management is independent and most often characteristised by the managers being the owners.
2. Equity capital is supplied by an individual or small group.
3. The operations are essentially local.
4. The business must be small compared to the largest competitors.

(from the Committee for Economic Development 1947 and cited by Hollingsworth and Hand 1979)

- A SME is not a matter of the number of employees, but rather a philosophy of the way the business is run. A SME is usually managed by a very small number of people. The single owner, two or three people in partnership, a company with three or four executives are typical examples. (ISO/TC 176 Sub-committe SC2, *Quality systems*, 1996)

Given and extended from the definitions of SMEs, following examines various aspects of the SMEs in terms of characteristics and possible success factors.

5.1 Limited times

Although times are tough and important for any size of company, they may be potentially greater for the SMEs due to their weaknesses such as lack of resources and technical skills. In order to be competitive, SMEs need to quickly respond to the fast-changing market needs by reducing time-to-market of products. To achieve this purpose, SMEs are required to involve cross-functional co-operation and expertise to cope with the requirements in the product design and development process. One of the typical examples is that products in the SMEs tend to be small batches and perhaps, varying which depend on their types of ownership. On the other hand, according to Larson *et al.* (1991), on projects in which timely completion is critical to success, costs and schedules are likely to be more tightly controlled which in turn, may tend to make compromises for the sake of completion adversely affect the long-range success of the project.

Due to the increasingly global business competitiveness, there is an underlying timing pressure for companies especially the SMEs to reduce the product delivery time by improving the quality management of design activities. This is the purpose which is originally defined in the aim of this research project.

5.2 Minimal available resources

Whilst it is a widely recognised concept that larger firms and SMEs are very different worlds in terms of their organisational structure and decision-making procedures, a number of literature also discuss the insufficient financial and human resources of SMEs. Oftentimes, individuals in the SMEs are expected to undertake multi-functional roles, in both the mainstream operations and project management. However, SMEs by their very nature are likely to be under greater pressure to share personnel and staff across projects as well as to obtain only part-time involvement of specialists who are needed for the functional operations (Larson *et al.*, 1991). Similarly, the staff shortage may include the availability of project managers who often not only serve as project leader but also the head of a mainstream department. The dual roles played by project managers and staff/personnel significantly contribute to the conflict of interest on the dedication of the functional activities throughout the product design and development process. A SME is more likely to rely on informal means of communication, co-ordination and control. According to Wu *et al.* (1995), success of the integrated product design for larger companies depends on a formal team-based working structure and also the support of practical design tools. This is because larger companies usually have sufficient capital to develop their own specific design tools. But the opposite is not true for the SMEs.

5.3 Lack of expertise

Although larger firms have sufficient resources to develop their own techniques, they are criticised for hindering personal autonomy and individual creativity because of the inertia and cumbersome structures. On the other hand, SMEs experience difficulty in combining sufficient expertise when tackling the design of new products from within the company.

Without exception of SMEs, product design activities should (and must) be carried out in conjunction with other functions very closely. As defined, decision-making in the SMEs is limited to a few people. Those two pillars are often the Technical Director (TD) and Commercial Director (CD). New product ideas are formalised from various sources such as customer requirements, market research, and technical capability. As a technical head, concepts of a new product are all in the TD's mind. He is fully aware of the company's technical capability or whether the company should seek external expertise when experiencing difficulty. After the decisions of product ideas are taken, defining responsibilities is always difficult because of limited technological capability of the company. Scott *et al.* (1996) argue that the successful exploitation of technology in a dynamic environment depends crucially on a skill base capable of identifying opportunities for, and managing, technological development. More precisely, lack of expertise and generally limited resources are the major constraints affecting the SMEs (Oakley, 1984). Literature shows training in the SMEs often gets second billing and as many as one in five UK SMEs view training as a low priority (quoted by Axland 1992 and Anonymous 1994) in the shortage case of technological skill. Deeper analysis is required to balance the conflict of interest either conducting the inter-firm training to enhance skills readily available or seeking recourse of the outside expertise. Decisions from the top management become most critical at this point.

5.4 Difficulty in understanding and applying the Standards

The term of "Standards" has been defined and presented in Section 3.3. These International Standards describe what elements on product design that a quality system should encompass. They are generic and applicable to a wide range of industry and economic sectors (ISO 9000-1, 1994). However, according to Wilson (1996), it has been stated that these Standards have been written by large businesses for large businesses, although they were not intentionally developed for large businesses. Literature surveys also indicate that the Standards should be rendered to be more user-friendly, not in concept (principle) but in application (Pengelly, 1993 and BSI, 1994). Whereas, the National Industries Liaison Group on Quality (NILGQ, 1993) suggests that revision of the Standards for the purpose of clarifying ambiguities could probably be counter-productive for the SMEs because it could eliminate the scope for flexible interpretation that makes it easier to apply the Standards to real business situations. In my opinion, the difficulty in understanding and applying the Standards for the SMEs is mainly due to the mixed messages resulted from false interpretations. Not surprisingly, an original message which is actually on a recommended basis evolve and mistakenly become mandatory requirements, raising possibilities for improper application of the Standards.

5.5 Cost involved in developing and maintaining a quality system

Another crucial problem affecting the SMEs is cost associated with developing and maintaining a quality system including ISO 9000 registration. Quality systems established against some sort of recognised quality standards, e.g. the ISO 9000 series, provide a framework for a consistent and effective management of product design. Due to the limited financial resources, SMEs need to use their own frame of reference to develop and operate a quality system tailored to their specific needs. Therefore, an effective but informal and not strictly documented approach (quality system) is obviously required and could be utilised for the SMEs not only to reduce the cost for designing and implementing a quality system but to improve the efficiency of design management.

5.6 Success factors

In spite of the above-mentioned problems, the inherent diversity and flexibility in SMEs incorporated with some effective schemes, e.g. consultancy support, adaptation of quality awards, and publicise successful performance strategies may provide the SMEs with profits. These measures form the basis of success factors in favour of the SMEs and are examined as follows.

5.6.1 Examine suitability of consultancy

Consultancy both from the public and the private sector has long been considered as a focused support for the SMEs on business management, product design and development, etc. Consultancy needs the SMEs to invest in terms of time and money. Most importantly, a company has to assess its needs and/or objectives for consultancy support on product design and development effort. Imperfection of consultants may include being inexperienced to the particular sector a SME is operating, or having little understanding on the problems facing the SMEs. This being "misled" by unethical consultancy on the SMEs not only results in poor design but also raises possibility of bureaucracy or even breakdown. Therefore, the overall success for the SMEs can not be perceived without the suitable use of proper and experienced consultants.

5.6.2 Adapt quality awards

The three well-recognised quality awards are all eligible for the SMEs, although literature shows that majority of the SMEs has been reluctant to apply for, or participate in the award due to the reasons such as time-taking and cumbersome for application and review process. However, as indicated in Section 3.2.6, in order to further cope with the uniqueness of the SMEs, the European award has been slightly modified in 1997 by introducing the small business award process (British Quality Fundation & EFQM) which requires them be scored only against the definitions of the nine criteria. This latest award criteria also provide guidance (things) for the SMEs to consider and to help them improve the efficiency of quality management on design issues.

5.6.3 Publicise small company successes

Although the SMEs are restricted with their sizes and types of ownership, they can be more dynamic and adaptable to meet the fast-changing business environment because of their organisational structure. This can provide a superior position also on quality management of design issues. The implementation of SMEs' strategies with external technical or consultancy support allows the SMEs to overcome design problems and achieve substantial business results. The evolutionary and successful process of SMEs' strategies on their efforts in dealing with the product design and development activities may seem to be worth measuring and publicising to the most extent from which information and experience can be shared with other companies.

Table 6 summarises a variety of features between SMEs and the larger firms. This is a relevant issue which we will take into account in Section 6.1.

CHAPTER 6 Outcome of literature review

This chapter presents the outcome of literature review on quality management of design. It discusses possible limitations on SMEs of their larger counterparts' approach. What are the problems that SMEs may encounter? What strategies should SMEs consider from the problem findings? It addresses the quality models/techniques and the development of a generic model for the design process. Therefore, as an outcome of the literature study, we can define a model of the design process and use this model as a "road map" to develop metrics for improving the efficiency of quality management on design.

6.1 Possible constraints on the SMEs of "big company" approach on quality management of design

In general, a design process is iterative in the design stages and varies from company to company. Whether the company is large or small, commitment to product quality from the most senior management is an essential part for a technically and economically successful product.

Although large firms are often described as huge machines embedded with inertia and bureaucracy, they have the capability to put extra efforts on quality management of design. As described in Chapter 5, the possible constraints on SMEs of the larger companies' approach to quality management of design are mainly due to insufficient financial capital and technical expertise. These constraints are conversely the "catalyst" for the large firms to conduct the so-called "big company" quality management approach of design. But it is not possible for the SMEs to implement as effectively as the larger ones because of the infrastructual weakness. These constraints are different and independent, but they both can result in poor quality management on design issues. They are, for example, frequent engineering changes and/or errors at later stages in the design/development process, insufficient allocation of financial and human resources which further leads to product failure, or financial breakdown.

6.2 Quality award models and techniques

Both the ISO 9000 approach and the quality award (business excellence) models provide mechanisms to implement quality management of product design in a consistent and effective manner. Section 3.4 has described the process management discipline which is covered in the afore-mentioned approaches and also required for the product design and development activities. They emphasise different points but play complementary part on quality management of design.

One important ingredient is the identification and subsequent interaction when using the established quality tools such as Taguchi Methods, design verification, design review, QFD to build quality into each stage during the product design process. These quality tools are an integral part of quality management of design. Their functional roles are to monitor and control the product design process activities to improve the consistency of design. Therefore, both the ISO 9000 approach and award models, as well as those major quality tools are the determinants for quality management of design. Proper selection and implementation can provide assurance of optimising the product quality at a minimum cost during the design process for the SMEs.

6.3 The development of a generic model for the design process

Although restricted by the sizes and the types of their ownership, SMEs can use their relative strengths such as flexibility, proximity to customers, and high employee participation to successfully implement quality management of design issues.

However, in order to narrow the gap in working only with or adopting either the ISO 9000 approach or the quality award models to improve the consistency of design, on the basis of the literature surveys, this research shows need for a generic model of the design process as a "road map" that can facilitate best practice for the SMEs. This model will need to contain or accommodate a number of features as follows.

6.3.1 Design and overall relationship with other functional activities

The criticality of the different design stages varies from product to product and from one industry to another. Whilst attempting to identify and control the design activities with the basic principles of the management and control of design quality, stages in the design process must be considered because they are fundamental to develop manufacturable products from initial user needs to the completion of design. Product design can not be operated in isolation, it has to receive regular and consistent feedback on a variation of views and knowledge from other activities inside the company, or is carried out on a team base using CE approach. If we define the design-related activities influencing quality in the design process as external (i.e. outside the design office) and internal (i.e. within the design office), then the relationships and/or interfaces between design and other activities will be external. Procedures for data transmission between design and other external interfaces should be well defined, controlled and documented.

External interfaces

- *Interface between design and production (i.e. manufacture and assembly)*

Output from design is input to manufacturing in which designers provide production with manufacturing instructions. On the contrary, restricted by the absence of breadth or depth of knowledge and background on various manufacturing activities of product, designers need feedback from production including request for design changes.

- *Interface between design and quality*

This interface is rather abstract than physical. It does not mean any transmission or exchange of data between design and quality. It is a concept of fitting quality upstream in the product development cycle. That leads to the saying, "build quality into the design of a product."

- *Interface between design and purchasing*

Purchasing activities play a vital role in effecting the quality of a product. A clear definition of the requirements including applicable issue of specifications, drawings, and other related technical data is to ensure that all supplies[2] procured are accurate and meet the company's needs.

- *Interface between design and commissioning and service*

A formal procedure should be established to feedback information on design changes, modification and/or requested concession due to manufacture problems or errors. After being identified, reviewed and approved, all those acceptable changes/modifications should be recorded and used to amend the working drawings accordingly.

- *Interface between design and sales/marketing*

Through a continuous information-monitoring and feedback system, sales/marketing activities provide designers with input of technical specification requirements on the quality characteristics of a product to evaluate the validity of design-change control procedures and to ensure whether product design is

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[2] Supplies include hardware, software, processed materials, services, or any combination thereof.

still valid throughout the life-cycle. Those elements provided by designers to sales/marketing are technical descriptions, specifications, and performance data of a product.

- *Interface between design and research and development (R&D)*

A formal request along with a variety of parameters and/or objectives are transmitted by design for specific R&D including tests. Results are fed back to design in the format of a formal report.

- *Interface between design and special activity groups*

Specific development work such as development of materials, special processes, and identification of special data are available from special activity groups. Amongst the cases, all the relevant requirements and parameters should be clearly defined and specified.

- *Interface between design and audit*

Audit should be formally and systematically carried out by personnel with appropriate qualification during the design process, in the forms such as design verification and design review. The purpose is to find out design problems if applicable, and to issue corrective and preventive actions accordingly.

- *Interface between design and product in testing or trial*

Product in this stage may be the final product, or a working model, or a representative prototype. Design deficiencies can be identified and evaluated through field tests and demonstrations, or intended user group's response on using the product under defined operating situations.

- *Interface between design and after-sales service*

An early warning system to record and report the customer complaints, and the occurrence of a product failure should be established to ensure that all design problems fed back from after-sales service can be reviewed and corrected rapidly.

6.3.2 Interaction and interfaces within the design activities

As mentioned in Section 6.3.1, those design-related activities occur within the design office are internal relationships/interfaces. Following is the interaction within the design activities.

Internal interfaces

- *Design concept and calculation/setting of design parameters*

Design is the first step in transmitting idea to item. After first sketch in the conceptual design is finished, calculations need to be conducted through various methods, e.g. design verification. At the completion of computation, the designers' ideas are converted to standard sizes and shapes whatever possible.

- *Between design groups*

During the design process, different design groups are interacting with each other depending on the size of a project. Interaction and interfaces between groups need to be well defined and controlled for processing of design data, specifications and other related records.

- *Design groups and drawing office*

Drawing office plays a vital part in interacting with the design groups because documents such as layout drawings, design data, or material specifications are all the essential design information that transmitted from the design groups. The role of drawing office is significant especially if CAD/CAM techniques might modify the actual procedures.

- *Design originators and design reviewers*

At the appropriate stages and the completion of design process, there is a design review, members in the design groups report their progress to the reviewers from various concerned functions with input to the design being reviewed in a formal design review meeting. Design problems and possible corrective solutions are rapidly fed back to the design originators. All review results should be documented.

6.3.3 Sub-contractor design phases

ISO 8402 (1994) defines "sub-contractor" as an "organisation that provides a product to a supplier." In English, the sub-contractor is also called the "sub-supplier". Sub-contractor describes that any organisation from which a small business purchases products or services, or both. It includes such commonly used terms as supplier or vendor (ISO/TC 176 Sub-committee SC 2, *Quality systems,* 1996). The most reason for a SME to seek sub-contracted part of design work, as mentioned in Section 5.3, is because in-house appropriate skills are not available. Thus control, co-ordination and interaction between the SME and its sub-contractor is of critical importance on product design activities. Integration of the sub-contractor design procedures into the SME's design procedures is an integral part to enhance a close working relationship and most importantly, to ensure a better quality of product design.

6.4 Model definition

Therefore we can define a model taking into account all the features as shown in Figure 23. What the model presents are straight forward and sequential design stages together with the design information flows in a general form. But in practice, it should be noted the main phases are not always so clearly defined. Throughout the process, there is invariably feedback to previous stages including those in "post-design support". From this model we can see that product design is not an isolated activity. To be successful, information through adequate communications should be input from a range of major operational activities particularly production, purchasing, sales/marketing, design/development, and the sub-contractors' design phases as well.

This generic best practice model of design process promotes the effective communication within and outside the process which in turn, reduces the time and cost spent in the process. As can be seen, there are also several different phases which are enclosed in parenthesis but are equivalent in function to the stages of the design process as well as output of the design results (in bold) available at the end of various design stages. We will use this model as the basis for the identification of design issues and the development of quantitative measures for the quality management of design (i.e. the metrics).

SECTION 3 - USING THE GENERIC MODEL TO DEVELOP METRICS

CHAPTER 7 Improving the effectiveness of quality management on design for the SMEs

Efforts have been made to achieve the purpose of improving the efficiency of design in the SMEs. In this chapter, by using the generic model of design process in Figure 23 as a framework, it is possible to identify the critical control issues in the process to define the critical issues so that useful metrics can be developed. As was indicated in Section 4.3.1, it needs metrics and the associated values to manage design in a "quality" sense.

7.1 The need for identification of critical control issues

7.1.1 Factors of various stages in the design information flows

Table 7 identifies the critical control issues required for the stages in the design information flows. Following gives examples of the critical factors that are required in some design situations:

Calculation and Setting of Design Parameters

- Trained and experienced staff
- Equipment and resources
- Availability of material and components
- Access to data
- Generate data in a useful form:

1) Software?
2) Drawings?

3) Specifications?

Design Output

- Generation of documented manufacturing instructions:

1) Working drawings
2) Manufacturing specifications and methods
3) Software
4) Purchase specifications
5) Acceptance criteria and inspections and test procedures

- Procedures and responsibility for review, record and approval of manufacturing instructions before use

Production (manufacture and assembly)

- Equipment and resources
- Capability analysis of equipment
- Trained and experienced staff
- Manufacturing specifications
- Issue control of original specifications and subsequent amendments
- Feedback procedure for design changes or requesting concessions

7.1.2 Selection of critical control issues for developing metrics

Identifying the critical issues or factors required in the design information flows is particularly a detailed elaboration of the generic model of the design process (refer to Figure 23 and Table 7). The control issues need to be all incorporated into the process, whichever is applicable, mainly because the criticality of focusing the necessarily limited resources in the SMEs on the quality management efforts for product design. But with the use and application of both the ISO 9000 approach and quality award business excellence models, we are able to analyse the interaction amongst these factors and from which to form the basis to develop metrics to improve the efficiency of design management.

7.2 Different techniques for defining the critical control issues for the purpose of developing metrics

In order to identify the critical stages in the design process in a way that allows us to develop some useful metrics, we examine three alternative techniques - "Labelling and Grouping" (based on the concept of simplified pattern of information flow), "Categorisation", and "Importance Level" to characterise the factors of each stage in the design information flows.

7.2.1 Labelling and grouping

The simplified pattern of information flow shown in Figure 25 illustrates a fundamental fact that output from one activity (stage) is input to another. Based on both Figure 23 and Figure 25, Figure 26 shows how to label and group each stage in the design information flows with capital letters (each letter may be followed by a number, if applicable) to indicate where a particular factor of a stage in Table 7 comes from. Obviously, each stage has factors which come from different information flows. These factors are grouped into three parts - "Input", "Output", and "Resources" with the purpose to identify the critical stages in the information flows. In doing the labelling and grouping, we always start from the inception of the design process, then determine how many information flows come into an individual stage and what they are. Once determined, they are labelled and grouped from top to bottom and from left to right. Sequential labelling and grouping with numbers may be applied to some activities that have diversified information flows into other activities. It should be noted that, whatever functional roles they play, all the information flows feedback design-related factors of various and appropriate activities from within and outside the design process. Most importantlt, a systematic and independent audit should be conducted over all of the activities in the design information flows to determine whether they are implemented effectively and consistently. Table 8 shows how to do the labelling and grouping.

7.2.2 Categorisation

If we have the design process closely defined together with the information flows in a generic way, then we can say all design activities take place according to the model we developed in Figure 23.

With the necessarily limited resources in the SMEs, we need to focus the quality management effort onto the critical issues. To achieve this purpose, in general, we need to:

- Remove non value-added steps
- Avoid duplication of effort
- Minimise documentation requirements
- Simplify information flows

Bearing in mind these four important factors, this section presents a more specific way, by referring to Table 7 and Figure 26, in which the factors required for the stages in the design information flows are categorised into three different groups and they are:

- ***Types***

This could include, for example, the specifications, instructions or review comments that are relevant to the design activities.

- ***Format***

This could include applied Standards abd statutory requirements, recognised procedures and records.

- *Source*

This could include staff, equipment, resources, facilities, creativity and all kinds of information/data required in the design information flows.

Table 9 shows the categorisation of factors into Types/Format/Source on the afore-mentioned basis.

7.2.3 Importance level

Adapted from the guidance given in the Canadian standard CSA Z299 for making the criticality assessments of components, sub-assemblies, etc. in order to devise the correct level of assurance needed and the correct level of quality assurance system to apply (cited by Rogerson, 1988), a rating system (on the scale from 1 to 5) is applied and referred to the factors required for stages in the design information flows (see Table 7) to determine the relative importance level of different stages for various types of products. To determine the importance level, there are six potential and critical product characteristics effecting the process of design that should be considered:

- Complexity[3] - How complicated is the design itself?
- Safety critical (or safety)
- Mass production, or small volume
- Value
- Novelty of design - Is it a new design or a modification based on an existing design?
- Cost/Competitiveness - Cost of product compares to the competitors.

According to Rogerson, "Complexity", "Novelty of design" and "Mass production, or small volume" are relevant to ***the probability of failure*** which indicates late delivery, product not performing to specification as well as component failure or breakdown. Whereas, "Safety critical", "Value" and

[3] "Complexity" means a variety of parts/components which are designed and assembled.

"Cost/Competitiveness" are relevant to ***the consequences of product failure*** which is different from the probability of failure. Each stage in the flows has different possibilities of relative importance level determined by the individual product characteristic. That is why we identify the critical design stages in conjunction with the rating system to make importance assessments for different stages in the design information flows.

In order to achieve the purpose, the technique considers two methods from different points of view. However, in both cases, each stage in the design information flows has different possibilities of relative importance level. Method *I* can identify the critical stages by the total score of each stage added up from various rating in terms of the six characteristics. Judging by the same characteristics, Method *II* indicates the importance level of a stage by spreading from 1 to 5, or signify its importance at a unique level. Followings describe the further details of these two methods.

a) Method *I* (Tables 10 to 15):

- Product characteristics will define the relative importance of different design stages.
- The higher the rating the more important the stage. The one with the highest importance level (i.e. scale "5") is a critical stage in terms of the individual product characteristic. For example, one may determine that "User Needs" in the flows is of fundamental importance in terms of "Complexity". Therefore the importance level goes to "5", etc.
- The total scores of a stage is then added up from the scores determined by the different product characteristics. On the basis of the total score, the critical stages in the design information flows can be defined accordingly.

After grading each design stage in terms of importance, the total score for all stages is added up and the critical stages in the design information flows are identified as follows.

1) 25 - 30: User Needs
Design Input
Design Concept
Design Review
Design Output
Production
Sales/Marketing
Product
After-Sales Service
Audit

2) 20 - 24: Calculation and Setting of Design Parameters
Special Activity Groups
Detailed Manufacturing Specifications

3) 15 - 19: Purchasing

4) 10 - 14: Commissioning and Service
R&D

5) < 10[4] : Checking of Manufacturing Specifications

b) Method *II* (Tables 16 to 21):

The way to grade the total score in order in Method *I* to identify the critical stages is not applicable in Method *II* because the importance level of a stage is determined from a different point of view, and is based on the interaction between the nature of the product characteristics and the critical factors required for the stages in the design information flows. The importance level of a stage in the design information flows may range from 1 (low) to 5 (high), or shows its significance of importance at a specific level. For example, in Table 16 "User

[4] For the purpose of this study, total score under 10 means a critical stage is not justifiable.

Needs" has different level of importance justified by the product characteristic of "Complexity", and the stage of "Production" always plays the most important role in terms of the same characteristic.

7.2.4 Limitations of above techniques

The three different techniques which were presented in the previous sections were developed to identify the critical stages in the design information flows. However, each of them has been found to have some limitations. The limitations for each technique are as follows.

1) ***Labelling and grouping:***

During the process of labelling and grouping various factors into the areas of "Input", "Output" and "Resources", it is too time-consuming to determine which area a factor is relevant. For example, in the stage of "User Needs", identifying the critical factors such as "Regular evaluation with planning, assignment of personnel and documented procedures", and "Audits of sub-contractor design control procedures" to determine their relevance to any of the afore-mentioned specific areas - Input, Output, Resources - is not straight forward. On may find it difficult to summarise the required information inputs from various stages in the design information flows.

2) ***Categorisation:***

Limitations are dominated by both duplicate factors which appear in different categories and the difficulty in determining which category a factor should belong to. For example, factors in Group A: Product Verification such as "Segregation action taken to prevent further unintended use or installation", "Disposition taken as soon as practical" and "Avoidance of recurrence" are difficult to identify and determine their precise category in a formal manner due to the lack of summarised evidence for classification.

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On the other hand, duplicate factor such as "Establishment of an early warning system for product shortcomings" in Group G1: After-sales service is both categorised into "Format" and "Source".

3) ***Importance level:***

It is not uncommon to see that both of the two methods in the "Importance Level" technique presented in Section 7.2.3 display a variation of subjective judgements when trying to determine the importance level of a stage in the design information flows.

However, the concept that this technique applies (e.g. the rating system from 1 to 5, and the six critical product characteristics) is a major development of the research work. It should be given a high priority on the efforts which this technique takes into account for identifying the critical stages in the design process to improve the efficiency of product design as originally defined. It is the one of the three different techniques that we use as the basis to highlight the connection between the functions of design activities and the product characteristics for developing useful metrics in the chapter that follows.

CHAPTER 8 Development of metrics

This chapter presents the new view of value engineering in which the established philosophy is developed to define a new metric to more efficiently and effectively manage the control of product design with some degree of qualification in respect of the critical or priority activities.

8.1 Analysis of the value engineering concept

In Chapter 7, we have characterised the critical control issues required for the major design stages using three alternative identification techniques such as "Labelling and Grouping", "Categorisation", "Importance Level", and further discussed the limitations of these techniques. Although judgements of subjectivity bring difficulty to some extent in identifying the critical product design stages, the technique of "Importance Level" can act as the basis for developing a new metric with the aim to maintain the connection between the functions of design activities and product characteristics. This leads to a decision to use value engineering as a new tool for development of useful metrics on quality management of design.

But why do we choose value engineering instead of other well-established metrics?

Value engineering was developed for and used to improve the value and reduce the total cost of a product in the manufacturing process. Value engineering works for analysing process because it is the concept of "process" that value engineering bases on. Further, we are using value engineering to the process itself, not the product. Since our generic model shows the design process is logical to try to adopt the concept of design process, we would like to see the idea that "value is equal to the worth over cost" can be applied to the design process steps themselves rather than the product design. That is why we choose value engineering to develop metrics for improving efficiency of design in upstream of product manufacturing.

8.1.1 Philosophy

Value engineering was developed in the late 1940s. The underlying philosophy of value engineering, according to Roberts (196?), is: "There is always a better way to obtain equivalent quality at lower cost. We must find it." However, value engineering is more than cost reduction (BSI PD 6470). Based on the reasons indicated in Section 8.1 and the generic model of the design process in Figure 23, this research work applies the key techniques *Function Analysis* and *Function Analysis System Technique (FAST)* in value engineering to determine the worth and cost of a stage in the model and consequently try to identify the critical stages.

The key reference on value engineering is *BSI PD 6470 (1981): The management of design for economic production.* It states that the philosophy and technique of value engineering of a new product or an existing one is based on simple concepts, but its efficacy can be realised only through the co-ordinated effort of teams of specialists. The overall aim of value engineering is to measure value of a product in terms of quality, performance and reliability at an acceptable price, or in other words, customer satisfaction. This guide categorises all value engineering exercises into six major sequential steps:

1. Selection.

Selection of the product, sub-assembly or component is of prime importance and can be aided by identification of high absolute cost items, comparison with competitors' products or s sudden material rise or shortage.

2. Information.

Involvement of all relevant facts about the product such as design criteria, production methods, detailed costs, etc. and the fullest co-operation of all those involved in the design, manufacture, quality control and marketing of the product are both required.

3. Analysis.

The next step is to analyse the functions the product performs to rank them in order of priority and to assign the accurate costs attributable to each function. The purpose is to identify items of poor value for further investigation.

4. Speculation.

A broad knowledge of alternative design strategies, materials and manufacturing techniques is required for speculation on ways of improving poor value of items selected. Generally it is agreed that this stage should be as unconstrained as possible.

5. Evaluation.

Most effort is normally expended at this stage because the great reward for correct evaluation of a good idea. Detailed information is required on the performance, cost and availability of alternative materials.

6. Implementation.

If the value engineering investigation has been an integrated company activity then this stage will be relatively simple, but not conversely correct if remotely conducted by outside consultants.

Therefore, whatever the precise technique in value engineering is applied to identify the critical stages in the design process, emphasis of the co-ordinated effort of teams of specialists based on the afore-mentioned steps should be fully taken into account to achieve the efficacy of management and control of design.

8.1.2 Techniques

The prime purpose to use and apply techniques of value engineering in the design process is to:

- Determine the various functions of a design stage and value of the stage;
- Eliminate function or simplify or combine with another, or replace with standard mass-produced item.

8.1.2.1 Function analysis

The application of function analysis to determine functions of a design stage needs to include the following steps:

1. List the description of a design stage.
2. Define action verb and measurable noun.

A verb and a noun are used to identify what a function in a design stage performs.

3. Identify basic (primary) or secondary (supporting) function.

Decide whether a function is essential for performing the product characteristics. If yes, then the function is basic.

Functions for doing some design stages selected from the generic model of the design process in Figure 23 have been identified using function analysis technique (see Table 22). For example, in the stage of "Calculation and Setting of Design Parameters", the essential function that should be identified is to establish parameters because of its primary position to achieve the design task. Job description in this stage is a supporting function, although it is required for performing the product characteristics.

The Identification of functions in a design stage is the first step to determine the value of the stage, but it forms the basis for further identifying more detailed functions of the stage using FAST technique which expands the function analysis structure to the far right.

8.1.2.2 Function analysis system technique (FAST)

Function analysis translates the worksheet of a design stage into verb and noun descriptions (see Table 22). When conducting a FAST diagram, however, the co-ordinated effort of teams of specialists concentrates on what a function does rather than what it is to further structure the functions in a design stage into a logically related groups based on a "how-why" relationship (BSI PD 6470 1981 and Fowler 1990).

During the expansion of the diagram to the far right, design task needs to be iteratively verified according to the momentum of the "how-why" relationship until satisfied. From the result of initial identification of some design stages shown in Table 22, the FAST technique expands the basic function "Product Specifications" in the "Detailed Manufacturing Specifications" stage into three more detailed functions which are "Assess product manufacturing options", "Demonstrate traditional physical model" and "Conduct rapid prototype" by following the logical "how-why" relationship (see Figure 27).

We now can see that both function analysis and FAST techniques are of fundamental importance in formalising the solidarity to determine the value of a design stage in the generic model of the design process.

8.1.3 Differences between a new view of value engineering and design tools

Although the scope of the research work focuses on the quality management requirements of product design for the SMEs, not the technical or professional issues, still there is a compelling need to compare this new view of value engineering with design tools such as CAD/CAM, DFMA from various aspects in terms of fundamentality, objectives, application, and possible benefits. Table

23 summaries the differences between this "new" view of value engineering and design tools - CAD/CAM, DFMA. This Table demonstrates that there is no incompatibility because of their close interactions during the product design process.

8.1.4 Reasons to develop value engineering as a new tool

8.1.4.1 Judgement of worth

As shown in both Table 22 and Figure 27, different design stages have different collections of functions. Function analysis and FAST techniques are applied to eventually determine the value of a design stage.

As indicated in Table 23, value is the ratio of worth over cost. But first of all, we need to know how to determine the worth of a function? What are the critical factors effecting worth? and most importantly, how to collectively determine the worth of a design stage in the generic model of the design process?

Based on the experiences and achievements developed from the "Importance Level" technique for identifying the critical stages in the design process in Section 7.2.3, factors that influence the worth of a design stage are:

- ***Safety***
- ***Environment***
- ***Functionality***
- ***Cost***

To determine the worth of a design stage, a generic worth rating scheme with a similar rating system (i.e. on the scale from 1 to 5) in Section 7.2.3 is again applied but buttressed with a general description for determining the worth ratings of a design stage. This scheme centres on asking the following question:

"how worthwhile is it to do a design stage in terms of the four critical factors - *safety, environment, functionality, and cost*?". Tables 24 to 51 explain the detailed work.

But in order that this method remains in a general form, those general descriptions for deciding worth ratings, which are similar in form and associated with various design stages and the four critical factors as well, can serve as aids to determine the worth level of a design stage. The higher the rating, the more worthwhile to do the design stage. For example, in "Design Input" stage, if products translated for customer requirements or market analysis do not anticipate any potential safety hazards, then it is least worthwhile (scale "1" in this case) to this design stage in terms of "Safety" factor. On the other hand, it has a very high degree of worth level (scale "5") to do the "Design Input" from the point of view of "Cost" factor if products where an efficient and economic design solution cannot be decided without clearly defined design input in terms of performance, use, aesthetic, technical details, reliability, maintainability and disposal.

Once the worth of the stage is determined, then we can decide whether to undertake the stage or not. This is a relevant issue which we will take into account in Section 9.2.

8.1.4.2 Evaluation of cost

As indicated previously, on a value engineering model, "value" is the ratio of worth over cost. Having described the method to determine the worth of a design stage, we now have to evaluate the cost of a stage using a two-level division in FAST diagram shown in Figure 28. According to Fowler, alternative routes (functions) at the far right of a FAST diagram are independent and qualify for cost allocation. More precisely, cost will determine which alternative routes do we take and the one with least cost is selected. However, to achieve the purpose, it is of importance to firstly determine the possible activities required for doing an alternative route to evaluate the cost that is associated with. In other words, we need to define what is done in this alternative route. As known, it is mostly the labour cost that forms the major part of cost for doing an alternative route. But labour cost may vary between products, companies, or industries, therefore the activities required for doing the alternative routes in a design stage are generic because of their high product dependency. Tables 52 to 58 explain the detailed work.

The FAST technique uses the "how-why" relationship to firstly break the structure of a design stage down to the "Sub-stage" level, and then the "Alternative Routes" level. Note that some of the sub-stages have no associated alternative routes. Following gives the descriptions of the two-level division of a FAST diagram on some stages in the generic model of the design process. Detailed work is presented in Figures 29 to 35.

- ***Design Input***

Level 1	Level 2
Perceive Customer Requirements	- Customer specifications (tender documents) - Written market research report - Interviews (including lead users) - Focus groups - Observing the product in use
Document Requirements	- Hard copy - Electronic media - Both
Technology Capability Analysis	- Company audit - Feasibility study

Supervise Competitors	- Conduct benchmarking (analyse competitive product)
Supervise Design Document	- Identify statutory and regulatory documents - Review documents selection

- ***Detailed Manufacturing Specifications***

Level 1	Level 2
Define Responsibilities	
Produce Specifications	- Assess product manufacturing options - Traditional physical model - Rapid prototyping

- ***Design Output***

Level 1	Level 2
Release Documents	- Paper-typed documents reviewed, approved, displayed, and distributed - Through electronically control procedures
Amend Documents	- Change/modifications approved by the originators - Specifically designated other functions/organisations

In other words, a FAST diagram can help the co-ordinated effort of teams of specialists to divide the possible solutions in different levels into independent categories which are used to evaluate the cost of an alternative route at the far right of the diagram and consequently the cost of a design stage using the reference list of possible and generic activities in Tables 52 to 58.

We now can see that, although activities required for doing the alternative routes at the right are different, the cost of a sub-stage is determined by one of the alternative routes that has the minimum cost. Once the cost of a sub-stage is determined, the total cost of a design stage is added up. This is a relevant issue which we will discuss in Section 9.2.

8.2 Applicability of the modified value engineering concept

On a theoretical basis, we can say that "value" of a design stage on a value engineering model is determined by the ratio of worth over cost. But, in practice, there are two critical questions that should be addressed:

1. Does the new view of value engineering need to be modified in order to apply to the design process? and
2. Does this modified value engineering concept give a metric for improving the consistency and efficiency of quality management on design?

A validation exercise is therefore needed on a practical situation. The following chapter describes a partial validation process using a real example.

SECTION 4 - VALIDATION OF THE VALUE ENGINEERING METRICS

CHAPTER 9 Validation

This chapter describes a two-level of validation processes, including a checklist, carried out on the metrics developed from the new view of value engineering. As naturally understood, a comprehensive validation is an extensive project in itself. This study has not been able to do this because of time and resource limitations. What have been done are:

1) Taken a design situation and shown that the value engineering concept as we have developed in Chapter 8 can be applied.
(This is the first level of validation process conducted by the author which is shown in Section 9.2)
2) Taken a small group of quality professionals who do not "know" the system and shown that they can apply it and give relatively consistent results.
(This is the second level of validation with the results shown in Section 9.3)

This is obviously only a partial validation but none the less a valid exercise. To prove the value engineering system fully, we need to carry out a much more comprehensive field trial.

9.1 Aim

The aim of validation of the metrics is to provide objective and reasonable evidence on whether the new view of value engineering can fulfil the practical application to improve quality management of design using a particular product design situation.

The particular design example taken for the validation exercise is the redesign of an automotive headlamp assembly[5]. It is a well-established example already developed in other programme (EUREKA 1995, also refers to APPENDIX II).

9.2 The first level of validation

In order that the metrics be validated to see if the results tell the best way to manage product design using the automotive headlamp assembly example, several steps of the first level of validation process are addressed as follows:

1. Calculate worth of each design stage.
2. Calculate cost of sub-stages (and consequently the design stage). Try to calculate the cost of an alternative route based on man hours at a constant labour rate.
3. Try to calculate value of each stage from step 1 and 2.
4. Can we then identify critical stages?
5. Is the exercise adding value and confidence to the design process?

Step 1: Calculate worth of each design stage

As shown in Table 24 to 51, the four critical factors - *safety, environment, functionality, and cost* - are presented to grade the worth level of various stages in the design process. We determine the worth ratings by "*Very low*", "*Low*", "*Moderate*", "*High*" *to* "*Very high*" with associated numerical ratings range from 1 to 5. For example, "1" stands for "Very low" and "5" for "Very high". After grading, we then multiply the worth ratings of all factors for doing a design stage. We can see that the resultant is an indicator of worth for each design stage (Table 59). For example, in the "Design Input" stage, if redesigned exercises of the automotive headlamp assembly are translated from customer needs or market requirements but may become unsafe with the increased size,

[5] See APPENDIX I.

complexity of the design, then the worth rating "2" (Low) is assigned for doing the "Design Input" in terms of "Safety" (Table 24). Rating "3" (Moderate) goes to "Environment" factor because product itself is normally unstable to avoid the degradation of environment, both direct or indirect (Table 25). Rating "4" (High) is assigned to "Functionality" factor for doing the same design stage of the headlamp example because product itself is capable of causing unstable functional performance such as reliability, maintainability and quality (Table 26). Moreover, because the nature of characteristics for redesigning the headlamp assembly where an efficient and economic design solution cannot be decided without clearly defined design input requirements in terms of performance, use, aesthetic, etc., worth rating "5" (Very high) goes to the "Cost" factor (Table 27). The ratings being assigned are multiplied then to achieve worth of the "Design Input" stage in the headlamp assembly example which totally is "120".

Step 2: Calculate cost of sub-stages (and consequently the design stage). Try to calculate the cost of an alternative route based on man hours at a constant labour rate.

The next step is to calculate the cost of a sub-stage by firstly calculating the cost of an alternative route using the FAST diagrams in Figures 29 to 36 in conjunction with the tabulated lists of possible and generic activities required for doing that alternative route. The cost of a sub-stage is then determined by the one with minimum cost in the alternative routes. Consequently, the cost of a design stage is added up from the various costs of its sub-stages (Table 60).

Step 3 and 4: Calculate value of each stage and identify critical design stages

The value of a design stage is determined by the ratio of worth and cost which are based on the figures in Table 59 and 60. Theoretically, the criticality ranking of a design stage is reflected by its associated value. The higher the value, the more critical the design stage. Table 61 shows value of each design stage and the identification of critical stages for the automotive headlamp assembly.

Step 5: Is the exercise adding value and confidence to the design process?

Based on the findings from the initial validation in Steps 1 to 4, some conclusions can be drawn as follows:

- All stages are high worth so they cannot be eliminated (see Table 59).
- Relate to cost implications and indicate where to look and make trade-off of stages (see Table 60).
- Some stages have low values because of their high costs (see Table 61). However, from the point of view of cost reduction on the stage with low value, can we do it in a different way? Results might be different for different products.
- Does the validation highlight area(s) for cost reduction?
- Need more examples to further decide whether the validation leads to matching decisions of quality improvement on design by indicating:

1. Which design stage should we do?
2. Which design stage should we try to reduce cost of (by seeking alternatives)?
3. How do we do to reduce the cost of a design stage?

Finally and most importantly, results from the initial analysis of validation also show that value engineering only provides partial benefits whilst trying to identify the critical design stages. More precisely, "Value" is misleading because high worth is not proportional to high value. As shown in Table 61, there are stages with high worth but have low values because of their high costs, or have high values derived from low worth/low costs. Therefore the key factor is to achieve high worth for a design stage because high value may not be the correct measure from the results shown in Table 61. It is of fundamental importance that high worth is what we should really look at, not high value. What we should determine is to have high worth but achieved with a minimum cost. That is the very reason why we consider ***"Cost"*** as one of the four critical factors to determine the worth ratings of a design stage in this research work. Prior to the second level of validation, a further re-evaluation is still conducted in the form of the worth rating scheme (Tables 24 to 51). As shown in the stage of "Design Input" in Table 62, for example, worth rating "4" (Moderate) instead of "3" (Low) in terms of "Environment" factor. Moreover, worth rating "5" (Very high) instead of "4" (High) and "4" instead of "5" in terms of "Functionality" and "Cost" factors respectively. Apparently, the initial worth and worth rating figures to identify critical stages of the design process model could be different from time to time because of involvement of judgements.

The standard value engineering system was identified by its provision of partial benefits with the clear recognition that "Value" is misleading. This weighs up the necessity in which to determine or estimate worth (worth ratings) of a design stage in a consistent manner. To further explore this issue, it is decided to ask an independent group using the same rating scheme with the same redesigned example. A checklist which serves as the second level of validation process is then designed.

9.3 The second level of validation - A checklist design

The main objective for using this checklist is to see if concept of the new view of value engineering can be widely and consistently used to advantage in improving the efficiency of design management. The redesign of the automotive headlamp assembly again is applied and buttressed with a background information (see APPENDIX II). A proposed worth rating checklist (see APPENDIX III), adapted from Tables 24 to 51 in Section 8.1.4.1, is presented in which participants are asked to address specifically the following question: "how worthwhile is this design stage (on the scale from 1 to 5) in terms of the four critical factors - safety, environment, functionality and cost?" Each level of rating is followed by a general description. The higher the rating, the more worthwhile the design stage is.

For example,

Level of worth rating	Stands for
1	Very low
2	Low
3	Moderate
4	High
5	Very high

The anticipation is to see how consistent such a rating scheme would be when used by knowledgeable "quality professionals".

The checklist was devised and sent in June 1996 to 28 postgraduate quality management research students at Cranfield University and University of Paisley in Scotland. A total of 13 usable replies was received and generated a response rate of 46 per cent. This response rate can be considered high to very high, particularly given that the checklist was 28 pages long.

9.3.1 Analysis and discussion on response from the checklist

The response for the question, after collapsing the worth ratings from each design stage, are presented in Table 63. The data from the checklist are discussed and analysed in the followings.

- ***Design Input***

In Table 63 we see a strong degree of agreement amongst respondents (77%) that the "Design Input" stage has high to very high level of importance in terms of "Functionality" and "Cost". Whereas, nearly one-half (46%) of respondents considered it is of moderate importance in terms of "Safety" and other 15% said it is of most importance, as highlighted from comments of one respondent: '...However, in design input, safety is of greater importance than cost. So once safety is taken care of initially, greater emphasis should be placed on cost reduction without compromising quality.'

As to judge from the factor of "Environment", although little diverted, 77% of respondents are convinced that "Design Input" is important.

- ***Design Concept***

Table 63 shows that over one-half of respondents (54%) agreed "Design Concept" has high importance level when considering "Environment" factor, whereas the same degree of agreement (38%) on importance level was shown in terms of "Safety" and "Cost".

- ***Design Review***

A review of the worth rating spread in Table 63 suggests that, however, almost all of the factors do not dominate the high degree of agreement on determining how worthwhile the "Design Review" is. But with the exception that when considering "Cost" factor, 68% of respondents said that it has a high level of importance.

- ***Calculation and Setting of Design Parameters***

Table 63 also indicates that most respondents believe "Calculation and Setting of Design Parameters" stage is a stage with medium to very high degree of importance in terms of "Functionality" and "Cost" (77% and 85% respectively) compared to 77% and 69% against factors of "Safety" and "Environment".

- ***Detailed Manufacturing Specifications***

Thirty-one percent of respondents stated that they have same level of agreement on determining the importance level of "Detailed Manufacturing Specifications" stage in terms of "Safety", "Functionality" and "Cost" but with the absence of "Environment" factor.

- ***Checking of Manufacturing Specifications***

It can be seen that "Checking of Manufacturing Specifications" is considered to be of medium to high importance level in terms of "Cost". However, the checklist does not show significant degree of agreement on how worthwhile this stage is from reviewing the remaining factors.

- ***Design Output***

According to the respondents, 46% and 54% are convinced that "Design Output" stage is of high degree of importance in terms of "Functionality" and "cost". Eighty-three percent of respondents said "Design Output" is of medium to very high importance in terms of "Safety", whereas there is no significant degree of agreement on determining how worthwhile the "Design Output" is in terms of "Environment" factor.

Based on figures from Table 63, Table 64 indicates the worth range (percentage) of the various design stages. The range is determined by multiplying the worth ratings for doing a design stage in terms of the four critical factors and, for the purpose of this study, the worth ranges are categorised into a set of groups to describe the percentage of worth range amongst the respondents. In addition, Figure 36 to 42 diagraphically illustrate the percentage of worth range of each design stage using the data of worth ratings listed in Table 64. These figures clearly show a variety of weights based on spread of worth range groups in the stages of the design process. Respondents' perceptions on how worthwhile a design stage is can therefore be measured, and further show that a significant majority of respondents believes that almost all of the stages have high worth when redesigning the automotive headlamp assembly.

Although Table 64 shows the worth rating scheme is generally not as consistent as expected in determining how worthwhile a design stage is in terms of the critical factors, results of the checklist not only provide support for the proposition that all design stages are high worth which cannot be eliminated but share the same degree of agreement with the results obtained from the conclusions of the initial validation.

Most importantly, the results are quite positive which suggest that concept of the new view of value engineering can be widely and consistently used to facilitate the efficiency generation of design management through the two-level of validation processes, in which to achieve high worth is the key factor.

9.4 Impact of value engineering on the control of design

Results of partial validation process presented in previous sections suggest that value engineering can only provide partial benefits because the concept of "Value" is misleading. The possible limitation and suggested modification of value engineering are therefore discussed.

9.4.1 Limitation

Improvement on control and management of design may go through the following steps with the proper use and application of the established quality tools:

- Eliminating (design) stages
- Doing stages concurrently

- Doing stages more simply

The question is: "how to put these tools together to get best solutions for improving the efficiency of design management?" We further need to determine whether it is worthwhile to use these tools in a SME and on what basis to decide this.

From results of the afore-mentioned two-level of validation processes, high value may not be the correct measure to determine worth of design stages and consequently to identify the critical stages. More precisely, high worth is what we should really look at, not high value. This is obviously the possible limitation of value engineering on the control of design.

9.4.2 Suggested modification to the metric

Because the positive findings from practical evaluation show that high "Value" may not be the correct measure to identify the critical design stages, value engineering needs to be further modified when applied in the design process to see if it can be widely and consistently used to advantage in improving the efficiency of design management. The key point is to achieve high worth of a design stage, not high value. This is a major development that should be stressed as an important outcome of this research work.

CHAPTER 10 Conclusions and suggestions for further work

1. From a comprehensive survey of literature on relevant topics, we have developed a generic best practice model of the design process as a "road map" to establish the logical steps to incorporate all the activities that affect quality in the process and to show how the process integrates with the rest of business in SMEs.

2. We have examined three different techniques - "Labelling and Grouping", "Categorisation" and "Importance Level" - to fulfil the need for identification of critical control issues. Although restricted by the subjectivity, one of the three techniques can be used to form the basis for development of metrics.

3. Results in the quantitative metrics developed from the new view of value engineering applied in the design process show that value engineering can be applied but needs to be modified based on the positive recognition that worth, not value is really what we want.

4. There is a need for more real examples to conduct more extensive validations to demonstrate that value engineering is an efficient and worthwhile tool to improve quality management of design. In doing this, we must recognise that there will always be some subjectivity in using metrics for this purpose.

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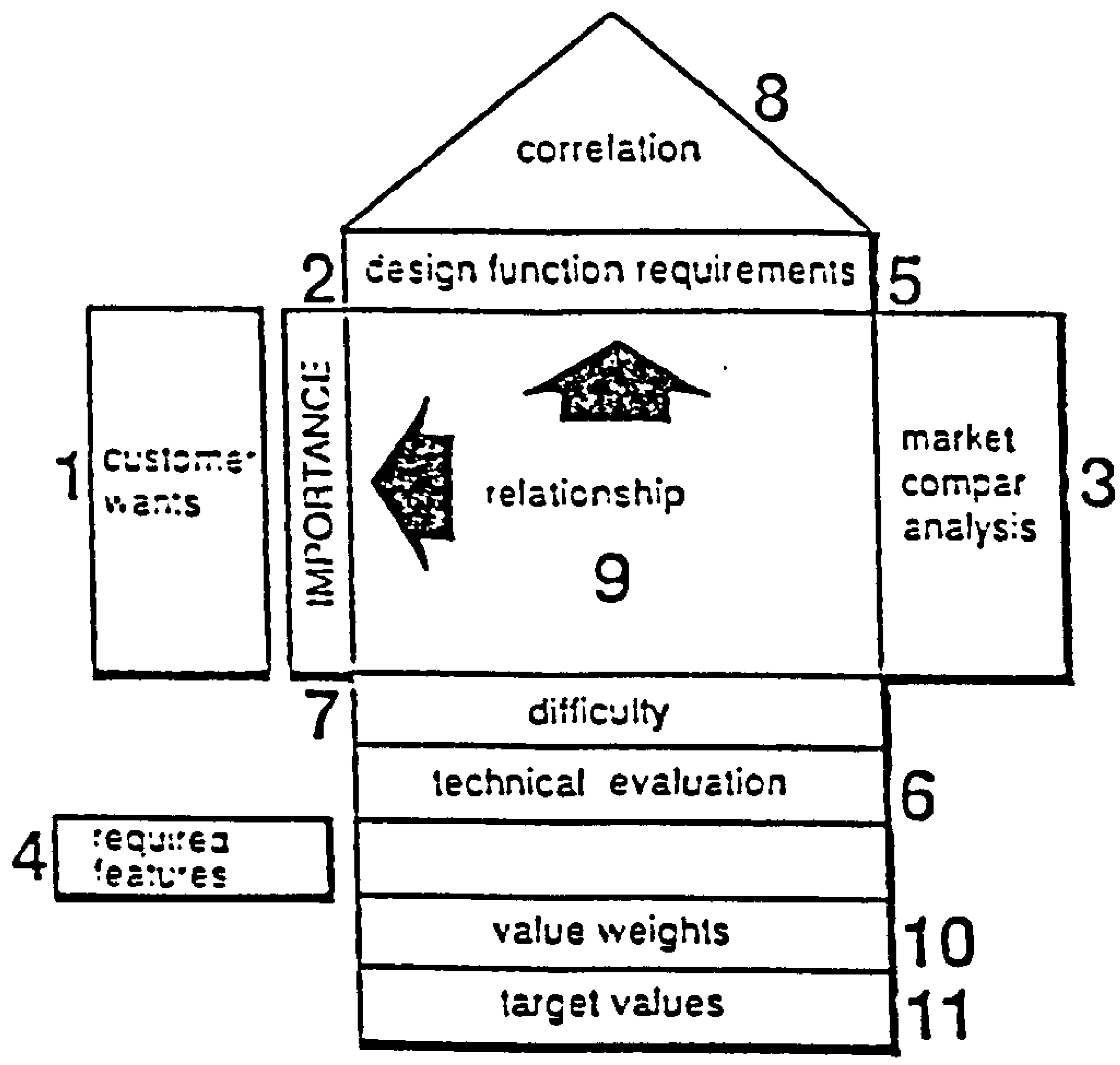
5.2 Quality Function Deployment (QFD) - Automotive Headlamp Assembly, Carello Lighting

QFD is an advanced quality planning technique. It is a means of translating customer needs into the appropriate technical requirements at every stage of product development and production. It requires significant effort to carry it through to a conclusion, but it is a valuable method of logically collecting all the necessary requirements and then communicating them to the project team in a clear and standard format. The method is summarised below in Figure 5.2.1 and 5.2.2.

In this example QFD is used to optimise important features of an adhesively bonded automotive headlamp, in particular the design of the bonded joint, materials and processing details. Details of the assembly process are tabulated in APPENDIX A.



The team 1 brainstorms customer wants
2 determines the relative importance of these wants
3 evaluates market competitiveness
4 identifies required standards
5 generates design requirements to meet customer wants
6 evaluates technical competitiveness
7 determines degree of difficulty of requirements
8 identifies how well the requirements relate to customer wants
9 determines how well the requirements relate to customer wants
10 prioritizes by value weighting the requirements to satisfy the customer better than the competition

Fig. 5.2.1 The QFD product planning matrix (courtesy of SMMT)

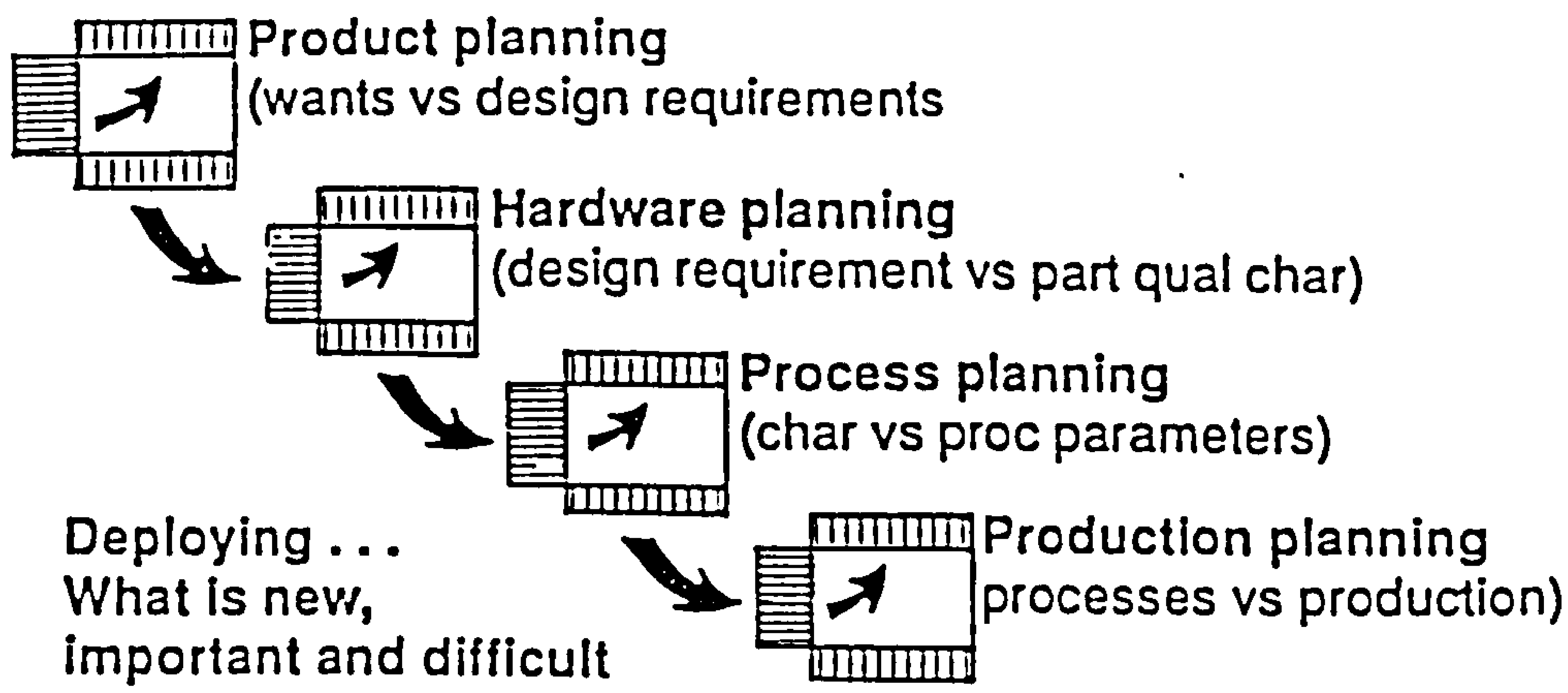


Fig. 5.2.2 The QFD process (courtesy of SMMT)

Building the house

The foundation of house of quality is the customer's needs and requirements. Building the house starts with defining these requirements.

What do customers want?
The customer's requirements, called customer attributes (CAs), are phrases that customers use to describe products, or product characteristics. A typical list of such attributes for a bonded headlamp is shown in Table 5.2.1. These primary attributes can be sub-divided to provide a clearer definition of the fundamental features. In this example, the characteristics that represent the customer's requirements in relation to the adhesive bonded joint (body to lense) have been selected, i.e. No Leaking , Durable Joint and Ease of Repair. These attributes are placed in rows in the far left column of the house (Figure 5.2.3).

Are all CAs equally important?
Rarely can a design solution be found to satisfy all needs. Usually, designers have to trade off one benefit against another. To bring the customer's viewpoint into the design process, CAs are weighted according to team members' direct experience. Table 5.2.1 shows such a weighting in the column 'Relative Importance' (RI).

Table 5.2.1 Customer attributes for a headlamp

Primary	Secondary	Tertiary	R.I %	Customer Perception 1	2	3	4	5
Appropriate lighting	Light	L - Lucas 197 - 5 - 1/2/3	17				# +	
Strong	Strength	B - high strength	10			#	+	
		B - light weight	7				# +	
		B - black / dark grey	1.5			+	#	
		B - high distortion temp.	4.5			# +		
		J - strong joint	5			#		+
Correctly fitted lenses	Insulation	J - no leaking	16			+	#	
		J - durable	18			# +		
Maintenance	Service	J - ease of repair	6			#		+
		B - ease of bulb fitting	5					# +
L = Lenses; B = Body		R.I = Relative Importance; J = Joint	100	# A's product; + Our product				

Will delivering the perceived needs yield a competitive advantage?
Manufacturers who aim to match or exceed their competition must first know where they stand in relative terms. Therefore, on the right side of the house, opposite the CAs, the customer perceptions of competitive product matched to our own should be listed. Comparison with the competition can identify opportunities for improvement. When the ratings for No Leaking are compared, we are in an inferior position. This problem has to be tackled if we want to be competitive. However, for the **Joint Durability**, our product is no different from that of the competitor. An advantage can be gained here by improving the durability of our product. Comparing the Ease of Repair perceptions, we have a very strong position which should be maintained.

How can a product be improved?
So far, we have been informed of customers' desires and the market situation. The customers tell us what they want, the market position tells us what to do against competition and the engineering knowledge tells us how to do it. The first house of quality, **House of Design** maps the relationship between these domains and to do this we must describe the product in engineering terms.

Along the top of the house of design, the design team lists those engineering characteristics, ECs, that are likely to effect one or more of the customer attributes. Engineering characteristics should describe the product in measurable terms and should directly affect customer perceptions. The ECs defined to address the customer's requirements in this example areas follows.

1– Tolerance in the dimension of the bonding channel width
2– Tolerance in the dimension of the bonding channel depth
3– Bead weight of sealant
4– Tolerance in the bead weight of sealant
5– The angle of the edge of the moulding
6– Durability of the sealant (exposed to oil, water, heat, vibration)
7– Strength of the sealant, measured as peeling strength

What influences can be linked with customers' perceived qualities?
When the engineering parameters are defined the interfunctional team should fill in the body of the house. This 'relationship matrix' represents the degree of influence that ECs have on CAs. Based on engineering expertise, customer responses and data from statistical studies or controlled experiments, the working party will be able to fill in the body of the house with reasonable confidence. This can be done using numbers or symbols to establish the strength of these relationships. In this example six abbreviations are used to indicate the following relationships.

SP = Strong Positive	SN = Strong Negative
MP = Medium Positive	MN = Medium Negative
WP = Weak Positive	WN = Weak Negative

A change to one engineering parameter generally requires some alteration in the other parameters. In the roof of the house the correlation between ECs can be displayed. The correlation section of the matrix helps the designer to balance the engineering parameters with the customer perceptions. For example, to improve the integrity of our product against leaks, the tolerance of the bonding channel width can be reduced. However, reduction of bonding channel width tolerance has a strong but negative relationship with lense dimension, which in turn could jeopardise our strong position with respect to the strength of the joint.

Using the House

Once the core of the house is filled, it can be used to help set the targets which will be displayed on the bottom row of the house. To set targets for ECs realistically, first we should review our market position and how customer perception can be changed in our favour.

With respect to No Leaking, there are two ECs which are strong positive influences. Despite restrictions on reducing the bonding channel width, due to its negative effect on several other parameters, there is room for improving the current value of 8.0 to 9.0 mm without incurring significant disadvantage on the other ECs. The next step is to define the technical difficulty in achieving such a target, with the degree of difficulty numerically scaled from 1 to 5. Then an assessment is made, based on team judgement and available data, of the value or importance of such an improvement. Finally this alteration may incur extra cost and the cost associated with such an alteration should be estimated.

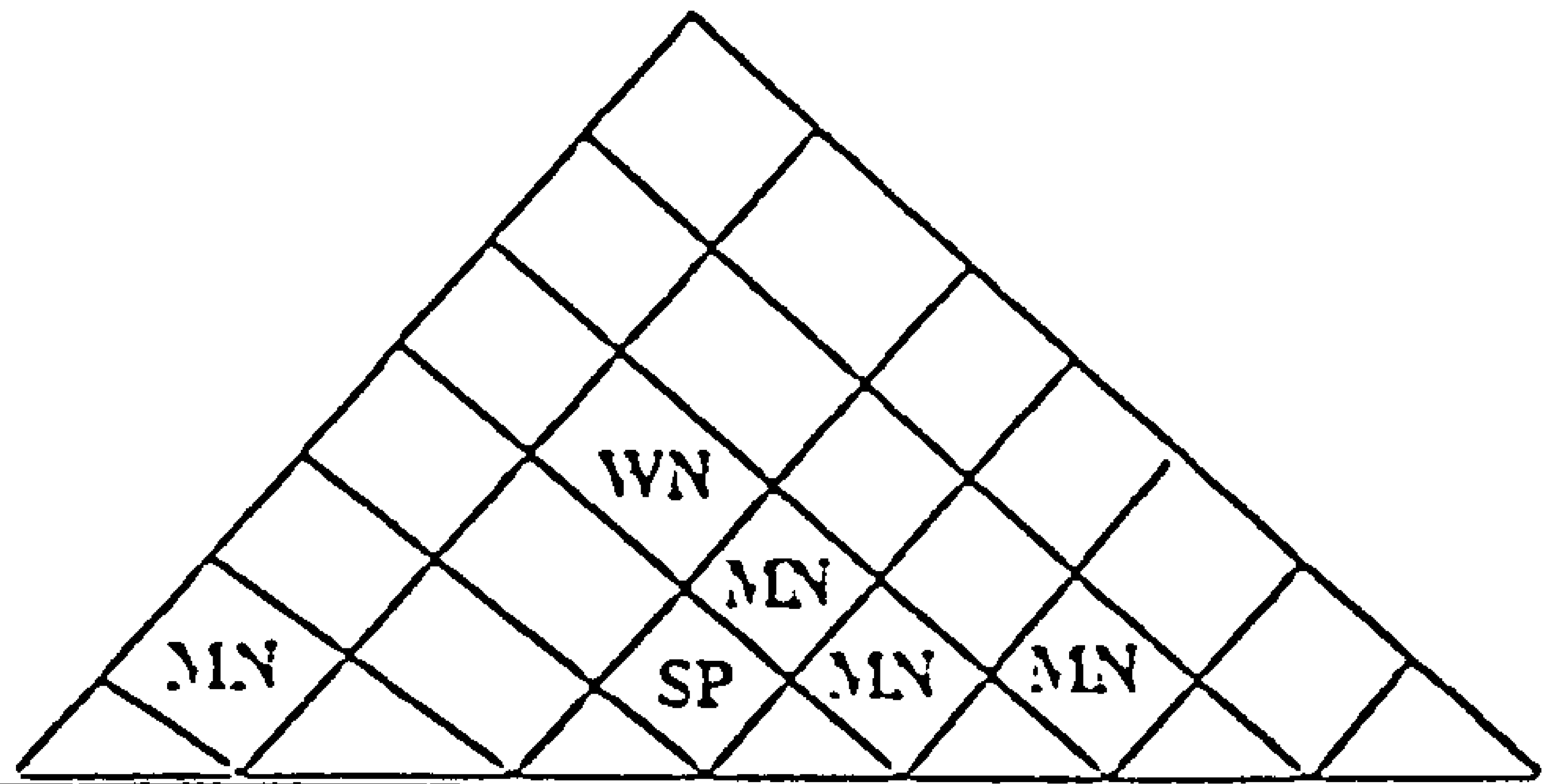
Now that a new target has been set for one EC, other targets can be defined in the same manner. Key points in setting these targets are as follows.

1 Internal relationship between ECs and CAs.
2 The EC which is most capable of turning the customer perception in our favour should be defined.
3 The degree of alteration of an EC depends on both positive and negative effects that it may have on the other ECs and consequently on customer perception.
4 The setting of realistic degrees of importance for each EC.

With that, the House of Design is completed, but the design review is not complete until the new targets have been correlated with the characteristics of materials to be used and the processing capabilities, i.e the cascade of QFD houses as shown in Figure ~~5.5.2.~~ 5.2.2

The second and third houses of quality, the House of Materials and the House of Processing can be prepared in the same way and ECs of one house become the CAs in the next house. Engineering characteristics are now on the left side of the house, along with their relative importance from the previous house (Imputed Importance values defined in the House of Design) and they are correlated with material characteristics (MCs) along the top row. Then the body of the house is filled in, targets are set again, considering customer perception and the internal influence of the MCs on the ECs. Figures 5.2.4 and 5.2.5 represent the House of Materials and the House of Processing for fabrication of the headlamp.

The major benefit of QFD is to encourage the product development team to think together and in the appropriate direction. In this study, the customer perceptions of our product in terms of the No leaking and Durability characteristics have to be improved by setting new design parameters. The House of Design tells us how this can be achieved, i.e. by reducing the bonding channel width or by changing the angle of the bonding channel edge from 90° to 45°. In order to achieve these targets, materials with new specifications may be required. The House of Materials shows what kind of materials are required to satisfy these new design targets, i.e. the percentages of filler in the composite body and additives in the adhesive are defined. Finally, the House of Processing shows what alteration in processing stages are required, if a new set of materials is to be used, i.e changes in the nozzle orifice diameter, in the heating required to keep nozzle temperature high and the reduced pump pressure that can be use with a higher viscosity adhesive.

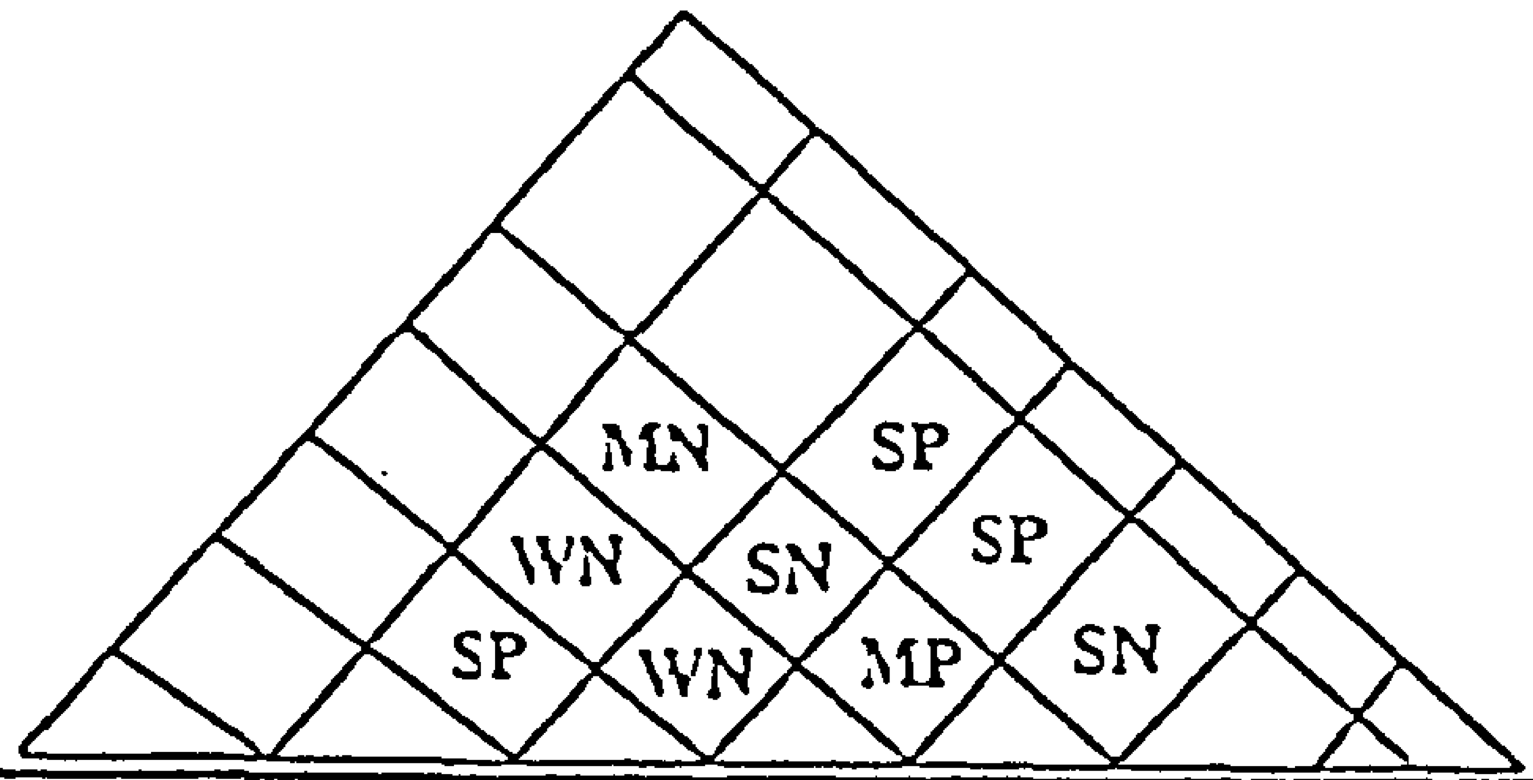


	R.I %	CW -	CD +	BW +	BT -	AE -	DS +	PS -	Customer Perception 1 2 3 4 5
No leaking	16	SP			MP			WN	+ #
Durable joint	18			MP	MP	SP	SP	WN	# +
Strong joint	5	MP	MP	SP	MP		SP		# +
Ease or repair	6							SP	# +
Measurement Units		mm	mm	g	g	deg.	scale	MPa	
Our product (+)		9.0	6.5	29	±3.0	90	p	4	
A's product (#)		8.0	6.0	28	±2.5	90	g	6	
Technical difficulty		1	1	0	2	1	2	0	In scale of 1- 5
Imputed Importance		8	6	6	4	4	17	5	%
Estimated Cost		-0.04	0.04	0.0	0.1	0.01	0.1	0.0	% increase cost
Targets		8.0	6.8	29	±2.5	45	g	4	

Key for the House of Design

Scale	Resistance (measured by reduction in shear strength after 200h exposure in the various conditions)	Abbreviation
Excellent	Less than 4 %	e
Good	Between 4 to 10 %	g
Moderate	Between 10 to 18 %	m
Fair	Between 18 to 28 %	f
Poor	Over 28 %	p
Relative Importance		R.I
Bonding Channel Width		CW
Bonding Channel Depth		CD
Bead Weight		BW
Bead Tolerance		BT
Angular Edge		AE
Check Durability of the Sealant		DS
Peeling Strength		PS

Figure 5.2.3 QFD, The House of Design

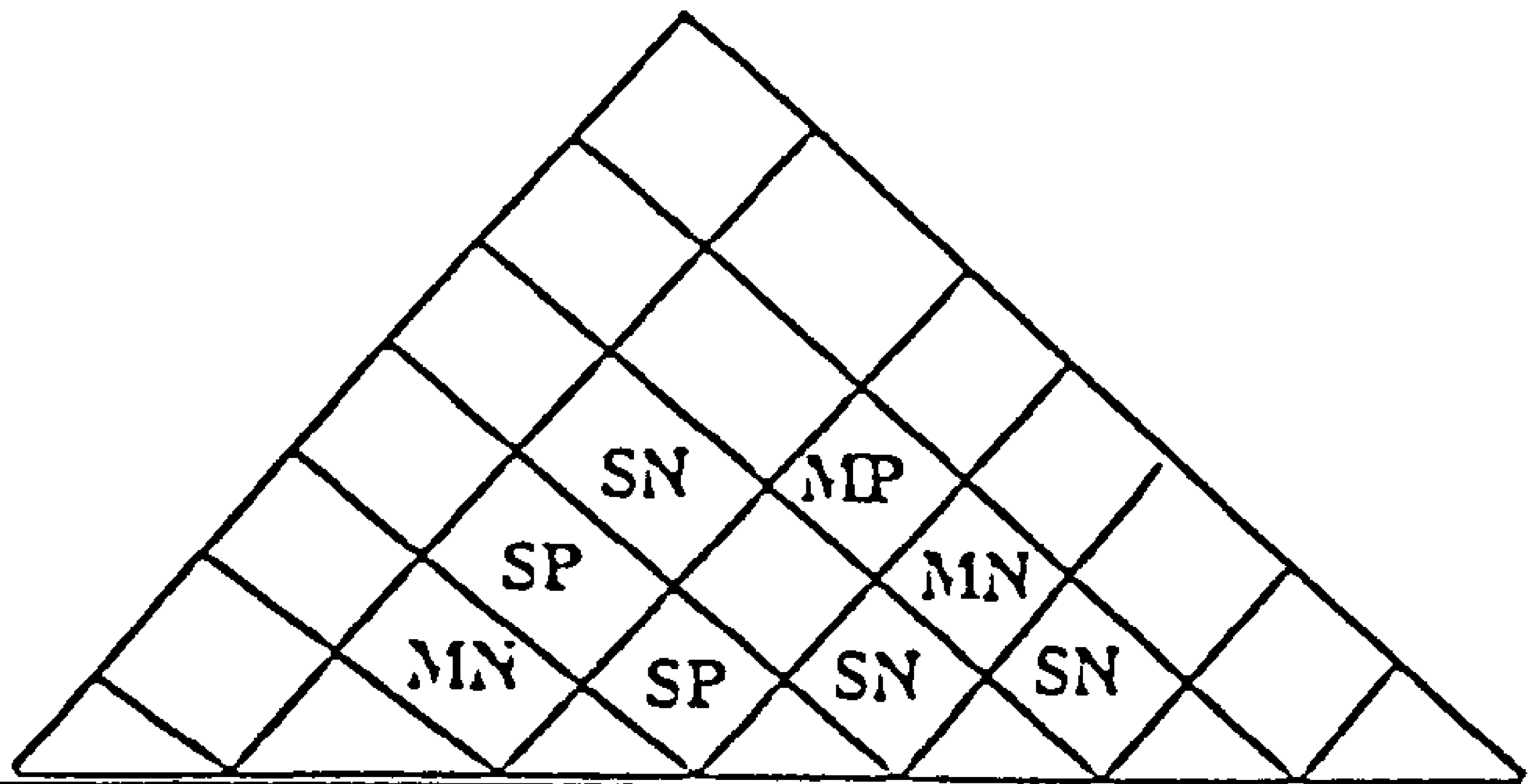


	R.I %	Filler additive(B)	Viscosity	Wax additive	PA	Melt point	Gap filling		Customer Perception 1	2	3	4	5
CW	8	MP					SP				+	#	
CD	8										+ #		
Bead Weight	6					WN					+ #		
Bead Tolerance	3		SP	WP	MP	MN	MP				+ #		
Angular Edge	4	WP					WN				+ #		
Durability of Sealent	4			SP	MP		MP				+	#	
Peeling Strength	5			MN							#	+	
Measurement Units		%	KmPa.s	%	%	°C	mm						
Our product (+)		40	22-30 E3	4.0	68.0	170	0.4-0.8						
A's product (#)		30	26-33E3	6.0	70.0	175	0.8-1.0						
Technical difficulty		1	1	1	1	1	0		In scale of 1- 5				
Imputed Importance		5	8	7	6	10	8		%				
Estimated Cost		-0.07	0.08	-0.02	0.05	0.1	0.0		% increase cost				
Targets		35	24-32E3	4.5	70	175	0.4-0.8						

Key for the House of Materials

Parameters	Abbreviation
Polymer Additive	PA
Bonding Channel width	CW
Bonding Channel Depth	CD

Figure 5.2.4 QFD, The House of Materials



	R.I %	MP	NT	PP	DR	NO	NH		Customer Perception 1	2	3	4	5
Filler Additive (B)	5	SN										+ #	
Viscosity (A)	8			SP	SP	MN	SP						
Wax Additive (A)	7				SP	MN	MP				+	#	
Polymer Additive(A)	6				MN	WP							
Melting Point	10		SP	MN	WN		MP						
Gap filling	8		MP				MN						
Measurement Units		Ton	°C	Bar	g·Min	mm	°C						
Our product (+)		7.2	146	4.6	650	3	25						
A's product (#)		6.1	150	4.4	700	3	60						
Technical difficulty		1	1	1	2	2.	2		In scale of 1 - 5				
Imputed Importance		10	2	4	5	4	16		%				
Estimated Cost		-0.01	0.0	-0.02	0.01	0.03	0.07		% increase cost				
Targets		6.8	146	4.4	700	2.5	80						

Key to the House of Processing

Process	Abbreviation
Moulding Pressure	MP
Nozzle Temperature	NT
Pump Pressure	PP
Dispensing Rate	DR
Nozzel Orifice Diameter	NO
Nozzel Heated Temperature	NH

Figure 5.5.5 QFD, The House of Processing

APPENDIX II

Background information of an automotive headlamp assembly

An automotive headlamp is a mass produced item specific to a particular model of automobile and contains a body, lens, lamp, electrical systems. With application from a QFD (Quality Function Deployment) analysis which is showing the customer attributes for different features of the product and comparing it with a design from a competitor.

The company needs to redesign the headlamp and the objective of this exercise is to identify the relative importance of the various design stages.

Primary	Secondary	Tertiary	R.I(%)	Customer Perception				
				1 (low)	2	3	4	5 (high)
Appropriate lighting	Light	L-Lucas 197-5-1/2/3	17				# +	
	Strength	B - high strength	10			#	+	
Strong		B - light weight	7				# +	
		B - black/dark grey	1.5			+	#	
		B - high distortion temp	4.5			# +		
		J - strong joint	5			#		+
Correctly fitted lenses	Insulation	J - no leaking	16			+	#	
		J - durable	18			# +		
Maintenance								
	Service	J - ease of repair	6			#		+
		B -ease of bulb fitting	5					# +
L = Lenses **B = Body**	**R.I = Relative Importance** **J = Joint**		**100**	**# Competitor's product** **+ This product**				

In order to logically evaluate the worth level of design stage in design process, five categories (scaled from 1 to 5) and four critical factors have been chosen. Therefore, in this headlamp example, what we would like you to do when determining the worth rating of each design stage is to ask the following question: **"how worthwhile is this design stage in terms of safety; secondly, environment; thirdly, functionality; and finally cost".**

APPENDIX III

Following is a proposed rating checklist for determining the worth of the various design stages in terms of the four critical factors - **safety, environment, functionality and cost.**

Determine the Worth Rating of ***Design Input (Customer Performance Requirements)*** with Headlamp Example in terms of Safety

Rating	Description

PLEASE TICK A BOX AS APPROPRIATE:

1 ☐ Products which translated from customers or market requirements do not anticipate any potential safety hazards

2 ☐ Products which translated from customers or market requirements may become unsafe with the increased size, complexity of the design

3 ☐ Products designed based on customer requirements which require specific measures to ensure safety

4 ☐ Products which could by their nature cause injury to people or damage to equipment

5 ☐ Products which will involve significant safety hazards at normal condition and involvement of safety specialists early in the design process is required

Determine the Worth Rating of ***Design Input (Customer Performance Requirements)*** with Headlamp Example in terms of Environment

Rating	Description
1 ☐	Products which translated from customer or market needs are well-planned and made environmentally benign
2 ☐	Products which in themselves do not contribute to the degradation of the environment internally and externally but which may cause environmental effects to some extent with the increased size, complexity and criticality of the design
3 ☐	Products which in themselves normally unable to avoid the degradation of the environment, both direct or indirect
4 ☐	Products which contains ecologically unfriendly materials in the design and are capable of leading to environmental effects
5 ☐	Products which in themselves are readily capable of causing environmental effects such as waste, pollution, and other specific parts of the environment

Determine the Worth Rating of ***Design Input (Customer Performance Requirements)*** with Headlamp Example in terms of Functionality

Rating	Description
1 ☐	Products which clearly fit the purpose or customer needs for which it is intended in a cost-effective manner
2 ☐	Products which in themselves work as it is supposed to work, i.e. functional and workable, but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 ☐	Products which in themselves meet only some of functional requirements or are uneconomic
4 ☐	Products which in themselves are capable of causing unstable functional performance, such as reliability,maintainability, producibility, usability, durability and quality
5 ☐	Products which in themselves are unable to satisfy all aspects of the needs in a cost-effective manner and which require the use of experienced specialist individually or in groups to provide input for clear needs

Determine the Worth Rating of ***Design Input (Customer Performance Requirements)*** with Headlamp Example in terms of Cost

Rating	Description
1 ☐	Products for simple, orderly, and low cost products
2 ☐	Products for simple products but where changes in product size, complexity translated from customer needs could increase cost
3 ☐	Products where proper analysis of all aspects of manufacturer and user resources could lead to cost reduction
4 ☐	Products where to get the most efficient and economic design solution in which a clear design input is needed
5 ☐	Products where an efficient and economic design solution cannot be decided without clearly defined design input requirements in terms of performance, use, aesthetics, technical details, packaging, reliability, maintainability and disposal

Determine the Worth Rating of ***Design Concept*** with Headlamp Example in terms of Safety

Rating	Description
1 ☐	Products which comparably are free from exposure to danger, injury, or loss, to a person or thing, i.e. generally recognised as safe, although there is no such thing as being absolutely safe
2 ☐	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, complexity of the design
3 ☐	Products designed based on customer requirements which require specific measures to ensure safety. This applied regardless of whether threat is foreseeable or avoidable
4 ☐	Products which could by their nature cause injury to people or damage to property
5 ☐	Products which will involve significant safety hazards at normal condition, and safety needed to be built into products at the conceptual stage based on a before-the-fact philosophy

Determine the Worth Rating of ***Design Concept*** with Headlamp Example in terms of Environment

Rating	Description
1 ☐	Products which are normally environmental friendly internally and externally
2 ☐	Products which are normally environmental friendly internally and externally but which may cause environmental influences to some extent with the increased size, complexity and criticality of the design
3 ☐	Products which in themselves normally lead to some environmental influences, both internal and external
4 ☐	Products which in themselves are capable of leading to environmental influences
5 ☐	Products which in themselves are readily capable of causing environmental effects, such as withdrawal of raw materials and energy from the resources available in the environment, emissions (in the air, water, and oil) and solid waste or the other specific parts of the environment

Determine the Worth Rating of ***Design Concept*** with Headlamp Example in terms of Functionality

Rating	Description
1 ☐	Products which clearly satisfy all aspects of intentions and functions in a cost-effective manner
2 ☐	Products which satisfy all aspects of intentions and functions economically but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 ☐	Products which satisfy only some of functional requirements
4 ☐	Products which in themselves are capable of causing unstable functional performance, such as reliability and maintainability, producibility, usability, durability and quality
5 ☐	Products which in themselves are unable to satisfy all aspects of intentions and functions in a cost-effective manner and which require designers conceive of the most efficient, functional requirements

Determine the Worth Rating of ***Design Concept*** with Headlamp Example in terms of Cost

Rating	Description
1 ☐	Simple, orderly, and low cost products
2 ☐	Simple products but where changes in product size, complexity translated from customer needs could increase cost
3 ☐	Products where proper analysis of all aspects of manufacturer and user resources could lead to cost reduction
4 ☐	Products where to get the most efficient and economic design solution in which a significant cost reduction method that could bring the costs in line is needed
5 ☐	Products where the maximum and desired cost objective is strongly influenced by decision(s) taken at conceptual stage

Determine the Worth Rating of ***Design Review*** with Headlamp Example in terms of Safety

Rating	Description
1 ☐	Products which comparably are free from exposure to danger, injury, or loss, to a person or thing, i.e. generally recognised as safe, although there is no such thing as being absolutely safe
2 ☐	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, complexity of the design
3 ☐	Products which in themselves are normally unsafe and readily cause some sort of threat to personal safety. This applies regardless of whether threat is foreseeable or avoidable
4 ☐	Products which in themselves are capable of causing harm, injury, or loss to the person or property
5 ☐	Products which are readily capable of causing the exposure of a person or thing to harm, damage, or injury at normal condition

Determine the Worth Rating of ***Design Review*** with Headlamp Example in terms of Environment

Rating	Description
1 ☐	Products which are normally not only free from adverse things that can happen to damage the products internally as a result of changes in the surrounding environment, but are also averting the adverse effects which the design can have to cause dangers to things extended to the products
2 ☐	Products which in themselves are normally out of reach of adverse things internally and externally but which may cause environmental effects to some extent with the increased size, complexity and criticality of the design
3 ☐	Products which in themselves normally lead to some environmental effects, both direct or indirect, regardless how well those effects are defined
4 ☐	Products which in themselves are capable of leading to environmental effects
5 ☐	Products which in themselves are readily capable of causing environmental effects, such as waste, air or water pollution, contamination of land, and noise, odour, dust, vibration and visual impact or other specific parts of the environment or ecosystems

Determine the Worth Rating of ***Design Review*** with Headlamp Example in terms of Functionality

Rating	Description
1 ☐	Products which clearly satisfy all aspects of the requirements in a cost effective manner
2 ☐	Designs which in themselves satisfy all aspects of the requirement economically but in which changes of functionality can develop with the increased size, complexity, and criticality of the product
3 ☐	Designs which meet only some of functional requirement or are uneconomic
4 ☐	Designs which in themselves are capable of causing unstable functional performance, such as reliability and maintainability requirements, durability and quality
5 ☐	Designs which in themselves are unable to satisfy all aspects of the requirement in a cost effective manner and which require the use of experienced specialists who take the formal review meetings

Determine the Worth Rating of ***Design Review*** with Headlamp Example in terms of Cost

Rating	**Description**
1 ☐	Designs for simple, low cost products
2 ☐	Designs for simple products but where changes in product size, complexity could increase cost
3 ☐	Designs where proper analysis of all aspects of manufacturer and user resources could lead to cost reduction
4 ☐	Designs where to get the most efficient and economic design solution in which a design review forum is needed
5 ☐	Designs where an efficient and economic design solution cannot be decided without rigorous and independent review of the design

Determine the Worth Rating of ***Calculation and Setting of Design Parameters*** with Headlamp Example in terms of Safety

Rating	Description
1 ☐	Products which comparably are free from exposure to danger, loss to a person or property by taking the advantage of the insight provided from the computational results
2 ☐	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, shape, complexity of the design
3 ☐	Products which require specific measures to ensure safety. This applied regardless of whether threat is predicable or avoidable
4 ☐	Products which could by their nature cause injury to people or damage to property
5 ☐	Products which will involve significant safety hazards at normal condition, and the factors of safety to be used must be adequately specified

Determine the Worth Rating of ***Calculation and Setting of Design Parameters*** with Headlamp Example in terms of Environment

Rating	Description
1 ☐	Products which are normally free from unintended environmental side-effects, led by technical actions, whatever internally and/or externally
2 ☐	Products which internally and/or externally, are normally free from unintended environmental side-effects but which may change with the increased size, complexity and criticality of the design
3 ☐	Products which in themselves normally lead to some environmental influences, both direct or indirect
4 ☐	Products which in themselves are capable of leading to environmental influences
5 ☐	Products which in themselves are readily capable of causing environmental effects and designers should be aware of the extensive literature presently available regarding the requirements for a environmentally friendly product

Determine the Worth Rating of ***Calculation and Setting of Design Parameters*** with Headlamp Example in terms of Functionality

Rating	Description
1 ☐	Products which clearly meet all practical, useful and aesthetic requirements economically
2 ☐	Products which clearly meet all practical, useful and aesthetic requirements economically but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 ☐	Products which satisfy only some of functional requirements or are uneconomic
4 ☐	Products which in themselves are unable to meet functional performance requirements, such as reliability, maintainability, producibility, serviceability, durability, appearance and quality
5 ☐	Products which in themselves are unable to satisfy all aspects of functional requirements in a cost-effective manner and which require the extensive, rigorous calculation and setting of design parameters

Determine the Worth Rating of ***Calculation and Setting of Design Parameters*** with Headlamp Example in terms of Cost

Rating	*Description*
1 ☐	Simple, orderly, and low cost products which provide high performance per dollar of cost
2 ☐	Simple products but where changes of calculation and setting of parameters in product size, complexity could increase cost
3 ☐	Products where proper analysis of all aspects of calculations and setting of parameters could lead to cost reduction
4 ☐	Products where to get the most efficient and economic calculation and setting of parameters in which some dramatic changes of the size, shapes and contours are needed
5 ☐	Products where an efficient and economic design solution cannot be obtained without rigorous calculation and setting of parameters

Determine the Worth Rating of ***Detailed Manufacturing Specifications*** with Headlamp Example in terms of Safety

Rating	Description
1 ☐	Products which not only comply with accepted industry or user requirements but also consider all aspects of possible unsafe conditions
2 ☐	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, complexity of the design
3 ☐	Products designed based on customer requirements which require specific measures to ensure safety. This is regardless of whether threat is predicable or avoidable
4 ☐	Products which could by nature cause injury to people or damages to equipment
5 ☐	Products which will involve significant safety hazards at normal condition

Determine the Worth Rating of ***Detailed Manufacturing Specifications*** with Headlamp Example in terms of Environment

Rating	Description
1 ☐	Products which are normally meet the recorded parameters and specifications requirements, following the statutory regulations and recognised design procedures as a result that no unacceptable harm to the environment occurs
2 ☐	Products which in themselves are normally out of reach of any unacceptable harm to the environment but which may cause environmental effects to some extent with the increased size, complexity and criticality of the design
3 ☐	Products which in themselves normally lead to some environmental influences, both direct or indirect, regardless how well those effects are defined
4 ☐	Products which in themselves are capable of leading to environmental influences
5 ☐	Products which in themselves are readily capable of causing environmental influences with a potential for human injury, loss to property, damage to the environment or some combination of these

Determine the Worth Rating of ***Detailed Manufacturing Specifications*** with Headlamp Example in terms of Functionality

Rating	**Description**
1 ☐	Products which clearly satisfy all aspects of requirements in a cost-effective manner
2 ☐	Products which economically meet all aspects of the requirements but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 ☐	Products which satisfy only some of functional requirements
4 ☐	Products which in themselves are unable to meet functional performance requirements such as reliability, maintainability, serviceability, durability and quality
5 ☐	Products which in themselves are unable to satisfy all aspects of the requirements in manufacturing specifications in a cost-effective manner

Determine the Worth Rating of ***Detailed Manufacturing Specifications*** with Headlamp Example in terms of Cost

Rating	Description
1 ☐	Simple, orderly, and low cost products
2 ☐	Simple products but where changes in product size, shape, complexity could increase cost
3 ☐	Products where proper analysis of all aspects of manufacturing data and type of manufacturing process used could lead to cost reduction
4 ☐	Products where to get the most efficient and economic design solution in which detailed manufacturing specifications are needed
5 ☐	Products where an efficient and economic design solution cannot be obtained without rigorous detailed manufacturing specifications of the design

Determine the Worth Rating of ***Checking of Manufacturing Specifications*** with Headlamp Example in terms of Safety

Rating	Description
1 ☐	Products which comparably are free from exposure to danger, injury, or loss to the public or property
2 ☐	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, shape and complexity of the design
3 ☐	Products which require specific measures to ensure safety, regardless of whether threat is predicable or avoidable
4 ☐	Products which could by nature cause injury to people, or damage to equipment
5 ☐	Products which will involve significant safety hazards at normal condition

Determine the Worth Rating of ***Checking of Manufacturing Specifications*** with Headlamp Example in terms of Environment

Rating	Description
1 ☐	Products which are normally not only free from adverse things that can happen to damage the products internally as a result of changes in the surrounding environment, but are also averting the adverse effects which the design can have to cause dangers to things extended to the products
2 ☐	Products which in themselves are normally out of reach of adverse things internally and externally but which may cause environmental effects to some extent with the increased size, complexity and criticality of the design
3 ☐	Products which in themselves normally lead to some environmental effects, both direct or indirect, regardless how well those effects are defined
4 ☐	Products which in themselves are capable of leading to environmental effects
5 ☐	Products which in themselves are readily capable of causing environmental effects such as waste, air or water pollution, contamination of land, and noise, odour, dust, vibration and visual impact or other specific parts of the environment or ecosystems

Determine the Worth Rating of ***Checking of Manufacturing Specifications*** with Headlamp Example in terms of Functionality

Rating	**Description**
1 ☐	Products which clearly achieve a desired level of functional requirement in a cost-effective manner
2 ☐	Products which in themselves satisfy all aspects of the requirement economically but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 ☐	Products which meet only some of functional requirement or are uneconomic
4 ☐	Products which in themselves are capable of causing unstable functional performance such as reliability, maintainability, producibility, serviceability, durability and quality
5 ☐	Products which in themselves are unable to satisfy all aspects of the requirement in a cost-effective manner and which require rigorous checking of manufacturing specifications

Determine the Worth Rating of ***Checking of Manufacturing Specifications*** with Headlamp Example in terms of Cost

Rating	Description
1 ☐	Simple, orderly, and low cost products
2 ☐	Simple products but where checking of manufacturing specifications could reduce cost
3 ☐	Products where proper analysis of all aspects of manufacturing specifications and use of manufacturing methods could lead to cost reduction
4 ☐	Products where to get the most efficient and economic design solution in which a checking of manufacturing specifications is needed
5 ☐	Products where an efficient and economic design solution cannot be obtained without structured procedures for checking the manufacturing spcifications of the design

Determine the Worth Rating of ***Design Output (Final Manufacturing Instructions)*** with Headlamp Example in terms of Safety

Rating	Description
1 ☐	Products which produced with usage of design output documents highlight safety considerations and comparably are free from exposure to danger, injury or loss to the person or property
2 ☐	Products which produced with usage of design output documents highlight safety considerations but which may become unsafe with the increased size, shape and complexity of the design
3 ☐	Products which require specific measures to ensure safety, regardless of whether threat is stated as input requirements
4 ☐	Products which could by nature cause injury to people or damage to equipment
5 ☐	Products which will involve significant safety hazards at normal condition

Determine the Worth Rating of ***Design Output (Final Manufacturing Instructions)*** with Headlamp Example in terms of Environment

Rating	Description
1 ☐	Products which produced with usage of design output documents highlight environment considerations and are normally free from adverse effects both internally and externally
2 ☐	Products which in themselves are normally out of reach of adverse things internally and externally but which may cause environmental effects to some extent with the increased size, shape, complexity and criticality of the design
3 ☐	Products which in themselves normally lead to some environmental effects, both direct or indirect, regardless how well those effects are defined
4 ☐	Products which in themselves are capable of leading to environmental effects
5 ☐	Products which in themselves are readily capable of causing environmental effects or other specific parts of ecosystems

Determine the Worth Rating of ***Design Output (Final Manufacturing Instructions)*** with Headlamp Example in terms of Functionality

Rating	Description
1 ☐	Products which clearly satisfy all aspects of the requirements in a cost-effective manner
2 ☐	Products which in themselves satisfy all aspects of the requirement economically but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 ☐	Products which meet only some of functional requirement or are uneconomic
4 ☐	Products which in themselves are capable of causing unstable functional performance such as reliability, maintainability, producibility, durability and quality
5 ☐	Products which in themselves are unable to meet all aspects of the requirements in a cost-effective manner unless there is a formal verification and validation of design input requirements

Determine the Worth Rating of ***Design Output (Final Manufacturing Instructions)*** with Headlamp Example in terms of Cost

Rating	Description
1 ☐	Simple, orderly, and low cost products
2 ☐	Simple products but where changes in product size, shape and complexity could increase cost
3 ☐	Products where proper analysis of all aspects of design output documents could lead to cost reduction
4 ☐	Products where to get the most efficient and economic design solution in which design output documents are needed
5 ☐	Products where an efficient and economic design solution cannot be obtained without well-defined design output documents

N. B.: Have you any comment on the rating model provided in this checklist?

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Thank you for your time in completing this checklist.

TABLES

	Stanley Tools Jobmaster Screwdriver	Rollerblade Bravoblade In-Line Skates	Hewlett-Packard Deskjet 500 Printer	Chrysler Concorde Automobile	Boeing 777 Airplane
Annual production volume	100,000 units/year	100,000 units/year	1.5 million units/year	250,000 units/year	50 units/year
Sales lifetime	40 years	3 years	3 years	6 years	30 years
Sales price	$3	$200	$365	$19,000	$130 (million)
Number of unique parts (part numbers)	3 parts	35 parts	200 parts	10,000 parts	130,000 parts
Development time	1 year	2 years	1.5 years	3.5 years	4.5 years
Internal development team (peak size)	3 people	5 people	100 people	850 people	6,800 people
External development team (peak size)	3 people	10 people	100 people	1400 people	10,000 people
Development cost	$150,000	$750,000	$50 million	$1 billion	$3 billion
Production investment	$150,000	$1 million	$25 million	$600 million	$3 billion

Table 1 Attributes of five products and their associated development efforts (from Ulrich and Eppinger)

PROCESS SUMMARY	PRE-DESIGN/ DEVELOPMENT	DESIGN AND DEVELOPMENT PROCESS			POST- DESIGN/ DEVELOPMENT	
GENERIC PHASES	IDEA	CONCEPT	DESIGN	PREPRODUCTION VALIDATION	PRODUCTION/ DISTRIBUTION	POST COMPANY
GENERIC PHASE ACTIVITIES	Sourcing Collation Prioritisation Idea introduction	Conceptualisation Feasibility Studies Peripherals	Design (incl. Industrial/ Peripheral) Prototyping Tooling Testing	Trial Production Batch testing Beta/Gamma testing Launch planning	Assembly Manufacture Launch Sales Delivery	Performance Sales Disposal
PHASE REVIEW	INITIAL REVIEW	PRELIMINARY DESIGN REVIEW	DETAILED DESIGN REVIEW	FINAL DESIGN REVIEW	PRODUCT REVIEW	PRODUCT PERFORMANCE REVIEW
REVIEW CRITERIA	Requirements Impact on Company Initial Project Definition	Idea realisations Evaluation-Market -Technical -Business Concept definition	Design schemes Evaluation Design activities review Design definition	Batch analysis Reliability/reproducibility Project review Product definition	Production schemes Sales /Marketing literature Aftercare support schemes	Market/Customer response Legislation New technologies Competition Sales/Orders
PHASE DEFINITION/ CONTROL	PROJECT DEFINITION	CONCEPT DEFINITION	DESIGN DEFINITION	PRODUCT DEFINITION	PRODUCT	END CUSTOMER
CONTROL CRITERIA	Time constraints Resourcing Project (team) personnel Project Priority	Initial specifications Detailed project plan Time constraints Resource allocations	Specifications/ Drawings Prototypes/models Conformability Reliability	Production methods Packaging/Peripherals Product Specifications	Product specifications Peripherals/Packaging Delivery/Storage Guarantees Product support	Product use Product disposal Requirements from replacement!

Table 2 Summary of the NPDD process and process activities (from Peters *et.al.*)

European Award	Baldrige Award	Deming Prize
1. Leadership	1. Leadership	1. Company policy and planning
2. Policy and strategy	2. Information and analysis	2. Organisation and its management
3. People management	3. Strategic planning	3. Quality control education and dissemination
4. Resources	4. Human resource development and management	4. Collection, transmission, and utilisation of information on quality
5. Processes	5. Process management	5. Analysis
6. Customer satisfaction	6. Business results	6. Standardisation
7. People satisfaction	7. Customer focus and satisfaction	7. Control
8. Impact on society		8. Quality assurance
9. Business results		9. Effects
		10. Future plans

Table 3 The European, Baldrige, and Deming awards criteria

	European Award	Baldrige Award	Deming Prize
Measures of performance	Self-assessment	Self-assessment	Self-learning. Examination of jury
Structure	Prescriptive on philosophy and values but non-prescriptive on practices and procedures		
Overall management approach	Management of organisation quality	Total quality as a management	Management of quality
Purpose	Enhance the awareness of TQM principles and benefits	Educational - encourage spreading of competitiveness learning	Develop concepts of TQM through Prize jury
Benefit	Feedback report for measurement of process , and strengths and areas for improvement	Integration/deployment and co-operation	Self learning through "TQM Diagnosis". Examination report as reconstructed, suitable TQM model
Long-term strategy	Completeness, continuity and competitiveness		

Table 4 The three quality awards compared

Table 5 Cross-reference list of clause numbers in the key quality system standards

External quality assurance				Clause title in	QM guidance	Road map
	Requirements		Application guide			
ISO 9001	ISO 9002	ISO 9003	ISO 9000-2	ISO 9001	ISO 9004-1	ISO 9000-1
4.1 ■	■	O	4.1	Management review	4	4.1;4.2;4.3
4.2 ■	■	O	4.2	Quality system	5	4.4;4.5;4.8
4.3 ■	■	■	4.3	Contract review	X	8
4.4 ■	X	X	4.4	Design control	8	
4.5 ■	■	■	4.5	Document and data control	5.3; 11.5	
4.6 ■	■	X	4.6	Purchasing	9	
4.7 ■	■	■	4.7	Customer-supplied product	X	
4.8 ■	■	O	4.8	Product identification and traceability	11.2	5
4.9 ■	■	X	4.9	Process control	10; 11	4.6; 4.7
4.10 ■	■	O	4.10	Inspection and testing	12	
4.11 ■	■	■	4.11	Control of inspection, measuring, and test equipment	13	
4.12 ■	■	■	4.12	Inspection and test status	11.7	
4.13 ■	■	O	4.13	Control of nonconforming product	14	
4.14 ■	■	O	4.14	Corrective and preventive action	15	
4.15 ■	■	■	4.15	Handling, storage, packaging, preservation, and delivery	10.4;16.1; 16.2	
4.16 ■	■	O	4.16	Control of quality audits	5.3;17.2;17.3	
4.17 ■	■	O	4.17	Internal quality audits	5.4	4.9
4.18 ■	■	O	4.18	Training	18.1	5.4
4.19 ■	■	X	4.19	Servicing	16.4	
4.20 ■	■	O	4.20	Statistical techniques	20	
				Quality economics	6	
				Product safety	19	
				Marketing	7	

Key: (N.B. This Table is adapted from ANSI/ASQC Q9000-1, 1994)

■ = Comprehensive requirement

O = Less-comprehensive requirement than ISO 9001 and ISO 9002

X = Element not present

Factor	Larger firms	SMEs
Organisational structure	More formal and rigid. Generally with inertia	Flexible structure. Decisions made more quickly
Role of employees	Mostly single-functional role. Tasks are assigned based on individual expertise	Multi-functional role. Do more with less
Time constraints	Tough and important, but may tolerate more delay for late-launching products	Potentially greater compared to large firm. Involvement of cross-functional co-operations required
Product	Main components only. most sub-contracted	Small batches and varying in types. Few may from sub-contracted
Resources/ expertise	Sufficient financial and human resources and good balance of skill. Depends on a formal team-based environment	Generally limited human resources and financial constraints. Difficulty in combining sufficient expertise
Training	Generally is formal, systematic and consistent based on the objective of the company and product produced	Low priority. Difficult to determine whether inter-firm and/or recourse of outside resources

Table 6 Features on quality management of design between SMEs and the larger firms

Factor	Larger firm	SMEs
Application of quality system standards	Less difficulty including registration because of the nature of the standards	Mixed messages from false interpretation make it more difficult both to understand and apply
Costs in developing a quality system	Adjust more easily and appropriately based on the nature of a company's activity, resources, etc.	Focuses on an effective but informal and not strictly documented approach to reduce costs due to financial constraints and limited internal resources

Table 6 Features on quality management of design between SMEs and the larger firms (continued)

Stage	Factors
User Needs	Customer specification needs and/or requirements Applied standards and statutory requirements Recognised design procedures Known physical parameters Results of contract review activities Marketing information Competitors' data
Design Input (customer performance requirements)	Trained and experienced staff Documented user needs
Design Concept	Trained and experienced staff Documented design input Creativity Clear idea of design concept

Table 7 Factors required for the stages in the design information flows

Stage	Factors
Calculation and Setting of Design Parameters	Trained and experienced staff Equipment and resources Availability of material and components Access to data Generate data in a usable form: • Software ? • Drawings ? • Specifications ?
Design Review	Independent reviewers representing different interests (e.g. sales, purchasing, quality, etc.) Statement of the design requirements Consideration of design review elements: • Items pertaining to customer needs and satisfaction (e.g. comparison of customer needs, validation of design through prototype tests, safety and environmental compatibility, compliance with regulatory requirements and Standards, etc.) • Items pertaining to product specifications (e.g. dependability and serviceability requirements, tolerances, FMEA, aesthetic specifications and acceptance criteria, etc.)

Table 7 Factors required for the stages in the design information flows (continued)

Stage	Factors
	• Items pertaining to process specifications (e.g. ability to produce product to the design, conforming capability to inspect and test the design, specification of material and components, packaging, handling and shelf-life requirements, etc.) Generate report in a usable form: • Hard copy ? • Electronic media ? Consideration for recommendations and initiate corrective actions
Detailed Manufacturing Specifications	Recorded parameters and specifications Documented design review report Layout drawings for new engineering designs and advice from specialist Trained and experienced staff Recognised design procedures Equipment and resources Manufacturing capability data
Checking of Manufacturing Specifications	Trained and experienced staff Equipment and resources Access to drawings and specifications data Clear idea of drawings and specifications

Table 7 Factors required for the stages in the design information flows (continued)

Stage	Factors
	Feedback to original drawings and/or specifications and initiate corrective action
Design Output	Generation of documented manufacturing instructions: • Working drawings • Manufacturing specifications and methods • Software • Purchase specifications • Acceptance criteria and inspection and test procedures Procedures and responsibility for review, record and approval of manufacturing instructions before issue
Commissioning and Service	Formal procedures for requesting changes Acceptable changes recorded
Purchasing	Technical and material specifications and working drawings Issue control with records of the documents
R & D	Specific research requirements or test with parameters and objectives Generate formal reports with firm conclusions

Table 7 Factors required for the stages in the design information flows (continued)

Stage	Factors
Sales/Marketing	Potential customers' technical specifications Technical descriptions and schedules Specifications and performance data Formal procedure of issue control of document Customer problems Customer intentions (desires) Market share Value for money
Special Activity Groups	Specified requirements Defined parameters Identification of a source of particular components A request for development of a material or process Information about proprietary components
Production (manufacture and assembly)	Equipment and resources Capability analysis of equipment Trained and experienced staff Manufacturing specifications Issue control of original specifications and subsequent amendments Feedback procedures for design changes or requesting concessions

Table 7 Factors required for the stages in the design information flows (continued)

Stage	Factors
Product:	
1) Product Verification	Incoming materials and parts verified based on: • the importance to quality • the state of control • Information from sub-contractor • Impact on costs In-process verification for conformance Finished product verification: • Acceptance inspections • Product-quality auditing
2) Control of Inspection, Measuring, and Test Equipment	Documented procedures for measurement control Elements of control such as suitable specification, initial calibration, periodic recall, documentary evidence, and traceability Sub-contractor measurement controls Evaluation of corrective actions Outside testing to avoid costly duplication
3) Control of Non - conforming Product	Identification and recording of occurrence(s) Segregation action taken to prevent further unintended use or installation Review for actions Disposition taken as soon as practical Avoidance of recurrence

Table 7 Factors required for the stages in the design information flows (continued)

Stage	Factors
4) Corrective and Preventive Action	Assignment of responsibility and authority Evaluation of importance Investigation of possible causes Documented permanent changes records Analysis of problem Appropriate steps for elimination of causes Process controls to avoid recurrence
After-Sales Service	Specified storage methods Protection of the quality of product during delivery phases Documented installation procedures Comprehensive and timely supplied servicing Establishment of an early warning system for product shortcomings Information on complaints, the occurrence and modes of failure and so on which are available for review and corrective action feedback for possible change of design concept and manufacturing specifications, for example Market feedback system available for monitoring product quality to ensure customer satisfaction
Audit	Defined and implemented quality programme Feedback from organisational changes, market, nonconformity reports, and surveys

Table 7 Factors required for the stages in the design information flows (continued)

Stage	Factors
	Trained and experienced staff Regular evaluation with planning, assignment of personnel and documented procedures Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up

Table 7 Factors required for the stages in the design information flows (continued)

Stage	Factors
User Needs	
1) Input	Incoming materials and parts verified based on: • the importance to quality • the state of control • information from sub-contractor • impact on costs In-process verification for conformance **(Group A: Product - Product Verification)** Documented procedures for measurement control Elements of control such as suitable specification, initial calibration, periodic recall, documentary evidence and traceability Sub-contractor measurement controls **(Group A: Product - Control of Inspection, Measuring, and Test Equipment)** Defined and implemented quality programme Feedback from organisational changes, market, nonconformity reports, and surveys Regular evaluation with planning, assignment of personnel and documented procedures **(Group P: Audit)**
2) Output	Documented and permanent records of changes **(Group A: Product - Corrective and Preventive Action)** Audits of sub-contractor design control procedures Testing of prototype

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows

Stage	Factors
	Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
3) Resources	Outside testing to avoid costly duplication **(Group A: Product - Control of Inspection, Measuring, and Test Equipment)** Trained and experienced staff **(Group P: Audit)**
Design Input	
1) Input	Customer specification needs and/or requirements Applied standards and statutory requirements Recognised design procedures Known physical parameters Results of contract review activities Marketing information Competitors' data **(Group B: User Needs)** Statement of the design requirements Consideration of design review elements: • Items pertaining to customer needs and satisfaction (e.g. comparison of customer needs, validation of design through prototype tests, safety and environmental compatibility, compliance with regulatory requirements and Standards, etc.)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	• Items pertaining to product specifications (e.g. dependability and serviceability requirements, tolerances, FMEA, aesthetic specifications and acceptance criteria, etc.) • Items pertaining to process specifications (e.g. ability to produce product conforming to the design, capability to inspect and test the design, specification of material and components, packaging, handling and shelf-life requirements, etc.) **(Group C1: Conceptual Design Review[6])** Capability analysis of equipment Manufacturing specifications Issue control of original specifications and subsequent amendments Feedback procedures for design changes or requesting concessions **(Group D: Production)** Technical and material specifications and working drawings Issue control with records of the documents **(Group D: Purchasing)** Formal procedures for requesting changes **(Group D: Commissioning and Service)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

[6] Although there are different terminologies for design reviews in the design process model together with information flow, they contain identical factors and are applied to the appropriate extent.

Stage	Factors
	Potential customers' technical specifications
	Technical descriptions and schedules
	Specifications and performance data
	Formal procedure of issue control of document
	Customer problems
	Customer intentions (desires)
	Market share
	Value for money
	(Group D: Sales/Marketing)
	Specific research requirements or test with parameters and objectives
	(Group D: R&D)
	Specified requirements
	Defined parameters
	(Group D: Specialist Activity Groups)
	Procedures and responsibility for review, record and approval of manufacturing instructions before issue
	(Group E1: Design Output)
	Defined and implemented quality programme
	Feedback from organisational changes, market, non-conformity reports, and surveys
	Regular evaluation with planning, assignment of personnel and documented procedures
	(Group P: Audit)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
2) Output	Acceptable changes recorded **(Group D: Commissioning and Service)** Generate formal reports with firm conclusions **(Group D: R&D)** Generate reports in a usable form: • Hard copy • Electronic media? Consideration for recommendations and initiate actions **(Group C1: Conceptual Design Review)** Generation of documented manufacturing instructions: • Working drawings • Manufacturing specifications and methods • Software • Purchase specifications • Acceptance criteria and inspection and test procedures **(Group E1: Design Output)** Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
3) Resources	Identification of a source of particular components A request for development of a material or process Information about proprietary components **(Group D: Specialist Activity Groups)** Independent reviewers representing different interests (e.g. sales, purchasing, quality, etc.) **(Group C1: Conceptual Design Review)** Trained and experienced staff **(Group P: Audit)**
Design Concept	
1) Input	Documented user needs: • Customer specification needs and/or requirements • Applied standards and statutory requirements • Recognised design procedures • Known physical parameters • Results of contract review activities • Marketing information • Competitors' data **(Group F: User Needs)** Statement of the design requirements Consideration of design review elements: • Items pertaining to customer needs and satisfaction (e.g. comparison of customer needs, validation of design through prototype tests, safety and environmental compatibility, compliance with regulatory requirements and Standards, etc.)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	• Items pertaining to product specifications (e.g. dependability and serviceability requirements, tolerances, FMEA, aesthetic specifications and acceptance criteria, etc.)
	• Items pertaining to process specifications (e.g. ability to produce product conforming to the design, capability to inspect and test the design, specification of material and components, packaging, handling and shelf-life requirements, etc.)
	(Group C1: Conceptual Design Review)
	Capability analysis of equipment
	Manufacturing specifications
	Issue control of original specifications and subsequent amendments
	Feedback procedures for design changes or requesting concessions
	(Group D: Production)
	Technical and material specifications and working drawings
	Issue control with records of the documents
	(Group D: Purchasing)
	Formal procedures for requesting changes
	(Group D: Commissioning and Service)
	Potential customers' technical specifications
	Technical descriptions and schedules

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Specifications and performance data
	Formal procedure of issue control of document
	Customer problems
	Customer intentions (desires)
	Market share
	Value for money
	(Group D: Sales/Marketing)
	Specific research requirements or test with parameters and objectives
	(Group D: R&D)
	Specified requirements
	Defined parameters
	(Group D: Specialist Activity Groups)
	Procedures and responsibility for review, record and approval of manufacturing instructions before issue
	(Group E2: Design Output)
	Specified storage methods
	Protection of the quality of product during delivery phases
	Documented installation procedures
	(Group G1: After-Sales Service)
	Defined and implemented quality programme
	Feedback from organisational changes, market, non-conformity reports, and surveys
	Regular evaluation with planning, assignment of personnel and documented procedures
	(Group P: Audit)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
2) Output	Generate reports in a usable form: • Hard copy? • Electronic media? Consideration for recommendations and initiate corrective actions **(Group C2: Conceptual Design Review)** Acceptable changes recorded **(Group D: Commissioning and Service)** Generate formal reports with firm conclusions **(Group D: R&D)** Generation of documented manufacturing instructions: • Working drawings • Manufacturing specifications and methods • Software • Purchase specifications • Acceptance criteria and inspection and • Test procedures **(Group E2: Design Output)** Comprehensive and timely supplied servicing Establishment of an early warning system for product shortcomings Market feedback system available for monitoring product quality to ensure customer satisfaction **(Group G1: After-Sales Service)** Audits of sub-contractor design control procedures

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
3) Resources	Trained and experienced staff **(Group F: Design Input, Group D: Production and Group P: Audit)** Equipment and resources **(Group D: Production)** Identification of a source of particular components A request for development of a material or process Information about proprietary components **(Group D: Special Activity Groups)** Information on complaints, the occurrence and modes of failure and so on which are available for review and corrective action feedback for possible changes of design concept and manufacturing specifications, for example **(Group G1: After-Sales Service)**
Conceptual Design Review	
1) Input	Documented design input **(Group H: Design Concept)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Capability analysis of equipment
	Manufacturing specifications
	Issue control of original specifications and subsequent amendments
	Feedback procedures for design changes or requesting concessions
	(Group D: Production)
	Technical and material specifications and working drawings
	Issue control with records of the documents
	(Group D: Purchasing)
	Formal procedures for requesting changes
	(Group D: Commissioning and Service)
	Potential customers' technical specifications
	Technical descriptions and schedules
	Specifications and performance data
	Formal procedure of issue control of document
	Customer problems
	Customer intentions (desires)
	Market share
	Value for money
	(Group D: Sales/Marketing)
	Specified research requirements or test with parameters and objectives
	(Group D: R&D)
	Specified requirements
	Defined parameters
	(Group D: Special Activity Groups)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Defined and implemented quality programme Feedback from organisational changes, market, non-conformity reports, and surveys Regular evaluation with planning, assignment of personnel and documented procedures **(Group P: Audit)**
2) Output	Acceptable changes recorded **(Group D: Commissioning and Service)** Generate formal reports with firm conclusions **(Group D: R&D)** Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
3) Resources	Trained and experienced staff **(Group H: Design concept, Group D: Production and Group P: Audit)** Creativity **(Group H: Design Concept)** Equipment and resources **(Group D: Production)** Identification of a source of particular components A request for development of a material or process

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Information about proprietary components **(Group D: Special Activities Groups)**
Calculation and Setting of Design Parameters	
1) Input	Statement of the design requirements Consideration of design review requirements: • Items pertaining to customer needs and satisfaction (e.g. comparison of customer needs, validation of design through prototype tests, safety and environmental compatibility, compliance with regulatory requirements and Standards, etc) • Items pertaining to product specifications (e.g. dependability and serviceability requirements, tolerances, FMEA, aesthetic specifications and acceptance criteria, etc.) • Items pertaining to process specifications (e.g. ability to produce product conforming to the design, capability to inspect and test the design, specification of material and components, packaging, handling and shelf-life requirements, etc.) **(Group C3 and I1: Conceptual and Preliminary Design Review)** Procedures and responsibility for review, record and approval of manufacturing instructions before issue

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	(Group E3: Design Output)
	Capability analysis of equipment
	Trained and experienced staff
	Manufacturing specifications
	Issue control of original specifications and subsequent amendments
	Feedback procedures for design changes or requesting concessions
	(Group D: Production)
	Formal procedures for requesting changes
	(Group D: Commissioning and Service)
	Technical and material specifications and working drawings
	Issue control with records of the documents
	(Group D: Purchasing)
	Specific research requirements or test with parameters and objectives
	(Group D: R&D)
	Potential customers' technical specifications
	Technical descriptions and schedules
	Specifications and performance data

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Formal procedure of issue control of document Customer problems Customer intentions (desires) Market share Value for money **(Group D: Sales/Marketing)** Specified research requirements or test with parameters and objectives **(Group D: R&D)** Specified requirements Defined parameters **(Group D: Special Activity Groups)** Defined and implemented quality programme Feedback from organisational changes, market, non-conformity reports, and surveys Regular evaluation with planning, assignment of personnel and documented procedures **(Group P: Audit)**
2) Output	Generate report in a usable form: • Hard copy? • Electronic media? Consideration for recommendations and initiate corrective actions **(Group C3 and I1: Conceptual and Preliminary Design Review)** Generation of documented manufacturing instructions:

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	• Working drawings • Manufacturing specifications and methods • Software • Purchase specifications • Acceptance criteria and inspection and test procedures **(Group E3: Design Output)** Acceptable changes recorded **(Group D: Commissioning and Service)** Generate formal reports of the documents **(Group D: R&D)** Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
3) Resources	Independent reviewers representing different interests (e.g. sales, purchasing, quality, etc.) **(Group C3 and I1: Conceptual and Preliminary Design Review)** Trained and experienced staff **(Group D: Production and Group P: Audit)** Identification of a source of particular components A request for development of a material or process

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Information about proprietary components
	(Group D: Special Activity Groups)
Preliminary Design Review	
1) Input	Availability of material and components
	Access to data
	Clear idea of design concept
	Documented design input
	(Group J: Calculation and Setting of Design Parameters)
	Capability analysis of equipment
	Trained and experienced staff
	Manufacturing specifications
	Issue control of original specifications and subsequent amendments
	Feedback procedures for design changes or requesting concessions
	(Group D: Production)
	Formal procedures for requesting changes
	(Group D: Commissioning and Service)
	Technical and material specifications and working drawings
	Issue control with records of the documents
	(Group D: Purchasing)
	Specific research requirements or test with parameters and objectives
	(Group D: R&D)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Potential customers' technical specifications Technical descriptions and schedules Specifications and performance data Formal procedure of issue control of document Customer problems Customer intentions (desires) Market share Value for money **(Group D: Sales/Marketing)** Specified requirements Defined parameters **(Group D: Specialist Activities Groups)** Defined and implemented quality programme Feedback from organisational changes, market, non-conformity reports, and surveys Regular evaluation with planning, assignment of personnel and documented procedures **(Group P: Audit)**
2) Output	Generate data in a usable form: • Software ? • Drawings ? • Specifications ? **(Group J: Calculation and setting of Design Parameters)** Acceptable changes recorded **(Group D: Commissioning and Service)** Generate formal reports of the documents

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	(Group D: R&D) Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
3) Resources	Equipment and resources **(Group J: Calculation and setting of Design Parameters and Group D: Production)** Trained and experienced staff **(Group D: Production and Group P: Audit)** Identification of a source of particular components A request for development of a material or process Information about proprietary components **(Group D: Specialist Activities Groups)**
Detailed Manufacturing Specifications	
1) Input	Statement of the design requirements Consideration of design review elements: • Items pertaining to customer needs and satisfaction (e.g. comparison of customer needs, validation of design through prototype tests, safety and environmental

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	compatibility, compliance with regulatory requirements and Standards, etc.) • Items pertaining to product specifications (e.g. dependability and serviceability requirements, tolerances, FMEA, aesthetic specifications and acceptance criteria, etc.) • Items pertaining to process specifications(e.g. ability to produce product conforming to the design, capability to inspect and test the design, specification of material and components, packaging, handling and shelf-life requirements, etc.) **(Group I2 and K1: Preliminary and Critical Design Review)** Capability analysis of equipment Manufacturing specifications Issue control of original specifications and subsequent amendments Feedback procedures for design changes or requesting concessions **(Group D: Production)** Formal procedures for requesting changes **(Group D: Commissioning and Service)** Technical and material specifications and working drawings Issue control with records of the documents **(Group D: Purchasing)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Specific research requirements or test with parameters and objectives
	(Group D: R&D)
	Potential customers' technical specifications
	Technical descriptions and schedules
	Specifications and performance data
	Formal procedure of issue control of document
	Customer problems
	Customer intentions (desires)
	Market share
	(Group D: Sales/Marketing)
	Specified requirements
	Defined parameters
	(Group D: Special Activity Groups)
	Procedures and responsibility for review, record and approval of manufacturing instructions before issue
	(Group E4: Design Output)
	Specified storage methods
	Protection of the quality of product during delivery phases
	Documented installation procedures
	(Group G2: After-Sales Service)
	Defined and implemented quality programme
	Feedback from organisational changes, market, non-conformity reports, and surveys

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Regular evaluation with planning, assignment of personnel and documented procedures **(Group P: Audit)**
2) Output	Generate report in a usable form: • Hard copy ? • Electronic media ? Consideration for recommendations and initiate corrective actions **(Group I2 and K1: Preliminary and Critical Design Review)** Acceptable changes recorded **(Group D: Commissioning and Service)** Generate formal reports of the documents **(Group D: R&D)** Generation of documented manufacturing instructions: • Working drawings • Manufacturing specifications and methods • Software • Purchase specifications • Acceptance criteria and inspection and • test procedures **(Group E4: Design Output)** Comprehensive and timely supplied servicing Establishment of an early warning system for product shortcomings Market feedback system available for monitoring

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	product quality to ensure customer satisfaction **(Group G2: After-Sales Service)** Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group Q: Audit)**
3) Resources	Independent reviewers representing different interests (e.g. sales, purchasing, quality, etc.) **(Group I2 and K1: Preliminary and Critical Design Review)** Equipment and resources **(Group D: Production)** Trained and experienced staff **(Group D: Production and Group P: Audit)** Identification of a source of particular components A request for development of a material or process Information about proprietary components **(Group D: Special Activity Groups)** Information on complaints, the occurrence and modes of failure and so on which are available for review and corrective action feedback for possible change of design concept and manufacturing specifications, for example **(Group G2: After-Sales Service)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
Critical Design	
Review	Documented design review report
1) Input	Layout drawings for new engineering designs and advice from specialist
	Recognised design procedures
	Manufacturing capability data
	(Group L: Detailed Manufacturing Specifications)
	Capability analysis of equipment
	Manufacturing specifications
	Issue control of original specifications and subsequent amendments
	Feedback procedures for design changes or requesting concessions
	(Group D: Production)
	Formal procedures for requesting changes
	(Group D: Commissioning and Service)
	Technical and material specifications and working drawings
	Issue control with records of the documents
	(Group D: Purchasing)
	Specific research requirements or test with parameters and objectives
	(Group D: R&D)
	Potential customers' technical specifications
	Technical descriptions and schedules
	Specifications and performance data

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Formal procedure of issue control of document
	Customer problems
	Customer intentions (desires)
	Market share
	(Group D: Sales/Marketing)
	Specified requirements
	Defined parameters
	(Group D: Special Activity Groups)
	Defined and implemented quality programme
	Feedback from organisational changes, market, non-conformity reports, and surveys
	Regular evaluation with planning, assignment of personnel and documented procedures
	(Group P: Audit)
2) Output	Recorded parameters and specifications
	Acceptable changes recorded
	(Group D: Commissioning and Service)
	Generate formal reports of the documents
	(Group D: R&D)
	Audits of sub-contractor design control procedures
	Testing of prototypes
	Results recorded and issued to concerned functional units
	Timely and appropriate corrective actions and follow-up
	(Group P: Audit)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
3) Resources	Trained and experienced staff **(Group D: Production, Group L: Detailed Manufacturing Specifications and Group P: Audit)** Equipment and resources **(Group D: Production)** Identification of a source of particular components A request for development of a material or process Information about proprietary components **(Group D: Specialist Activities Groups)**
Checking of Manufacturing Specifications **1) Input**	Statement of the design requirements Consideration of design review elements: • Items pertaining to customer needs and satisfaction (e.g. comparison of customer needs, validation of design through prototype tests, safety and environmental compatibility, compliance with regulatory requirements and Standards, etc.) • Items pertaining to product specifications (e.g. dependability and serviceability requirements, tolerances, FMEA, aesthetic specifications and acceptance criteria, etc.)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	• Items pertaining to process specifications (e.g. ability to produce product conforming to the design, capability to inspect and test the design, specification of material and components, packaging, handling and shelf-life requirements, etc.) **(Group K2 and M1: Critical and Final Design Review)** Procedures and responsibility for review, record and approval of manufacturing instruction before issue s **(Group E5: Design Output)** Capability analysis of equipment Manufacturing specifications Issue control of original specifications and subsequent amendments Feedback procedures for design changes or requesting concessions **(Group D: Production)** Formal procedures for requesting changes **(Group D: Commissioning and Service)** Technical and material specifications and working drawings Issue control with records of the documents **(Group D: Purchasing)** Specific research requirements or test with parameters and objectives **(Group D: R&D)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Potential customers' technical specifications Technical descriptions and schedules Specifications and performance data Formal procedure of issue control of document Customer problems Customer intentions (desires) Market share **(Group D: Sales/Marketing)** Specified requirements Defined parameters **(Group D: Special Activity Groups)** Defined and implemented quality programme Feedback from organisational changes, market, non-conformity reports, and surveys Regular evaluation with planning, assignment of personnel and documented procedures **(Group P: Audit)**
2) Output	Generate report in a usable form: • Hard copy ? • Electronic media ? Consideration for recommendations and initiate corrective actions **(Group K2 and M1: Critical and Final Design Review)** Recorded parameters and specifications Acceptable changes recorded **(Group D: Commissioning and Service)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Generate formal reports of the documents **(Group D: R&D)** Generation of documented manufacturing instructions: • Working drawings • Manufacturing specifications and methods • Software • Purchase specifications • Acceptance criteria and inspection and test procedures **(Group E5: Design Output)** Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
3) Resources	Independent reviewers representing different interests (e.g. sales, purchasing, quality, etc.) **(Group K2 and M1: Critical and Final Design Review)** Trained and experienced staff **(Group D: Production, Group L: Detailed Manufacturing Specifications and Group P: Audit)** Equipment and resources **(Group D: Production)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Identification of a source of particular components
	A request for development of a material or process
	Information about proprietary components
	(Group D: Specialist Activities Groups)
Final Design Review	
1) Input	Access to drawings and specifications data
	Clear idea of drawings and specifications
	(Group N: Checking of Manufacturing Specifications)
	Capability analysis of equipment
	Manufacturing specifications
	Issue control of original specifications and subsequent amendments
	Feedback procedures for design changes or requesting concessions
	(Group D: Production)
	Formal procedures for requesting changes
	(Group D: Commissioning and Service)
	Technical and material specifications and working drawings
	Issue control with records of the documents
	(Group D: Purchasing)
	Specific research requirements or test with parameters and objectives
	(Group D: R&D)
	Potential customers' technical specifications
	Technical descriptions and schedules
	Specifications and performance data

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Formal procedure of issue control of document
	Customer problems
	Customer intentions (desires)
	Market share
	(Group D: Sales/Marketing)
	Specified requirements
	Defined parameters
	(Group D: Special Activity Groups)
	Defined and implemented quality programme
	Feedback from organisational changes, market, non-conformity reports, and surveys
	Regular evaluation with planning, assignment of personnel and documented procedures
	(Group P: Audit)
2) Output	Feedback to original drawings and/or specifications and initiate corrective actions
	Recorded parameters and specifications
	Acceptable changes recorded
	(Group D: Commissioning and Service)
	Generate formal reports of the documents
	(Group D: R&D)
	Audits of sub-contractor design control procedures
	Testing of prototypes
	Results recorded and issued to concerned functional units
	Timely and appropriate corrective actions and follow-up
	(Group P: Audit)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
3) Resources	Trained and experienced staff **(Group P: Audit)** Equipment and resources **(Group N: Checking of Manufacturing Specifications and Group D: Production)** Identification of a source of particular components A request for development of a material or process Information about proprietary components **(Group D: Special Activity Groups)**
Design Output	
1) Input	Statement of the design requirements Consideration of design review elements: • Items pertaining to customer needs and satisfaction (e.g. comparison of customer needs, validation of design through prototype tests, safety and environmental compatibility, compliance with regulatory requirements and Standards, etc.) • Items pertaining to product specifications (e.g. dependability and serviceability requirements, tolerances, FMEA, aesthetic specifications and acceptance criteria, etc.) • Items pertaining to process specifications(e.g. ability to produce product conforming to the design, capability to inspect and test the design, specification of material and components, packaging, handling and shelf-life requirements, etc.) **(Group M2: Final Design Review)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Capability analysis of equipment
	Manufacturing specifications
	Issue control of original specifications and subsequent amendments
	Feedback procedures for design changes or requesting concessions
	(Group D: Production)
	Formal procedures for requesting changes
	(Group D: Commissioning and Service)
	Technical and material specifications and working drawings
	Issue control with records of the documents
	(Group D: Purchasing)
	Specific research requirements or test with parameters and objectives
	(Group D: R&D)
	Potential customers' technical specifications
	Technical descriptions and schedules
	Specifications and performance data
	Formal procedure of issue control of document
	Customer problems
	Customer intentions (desires)
	Market share
	(Group D: Sales/Marketing)
	Specified requirements
	Defined parameters
	(Group D: Special Activity Groups)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Defined and implemented quality programme Feedback from organisational changes, market, non-conformity reports, and surveys Regular evaluation with planning, assignment of personnel and documented procedures **(Group P: Audit)**
2) Output	Generate formal reports of the documents **(Group D: R&D)** Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
3) Resources	Independent reviewers representing different interests (e.g. sales, purchasing, quality, etc.) **(Group M2: Final Design Review)** Identification of a source of particular components A request for development of a material or process Information about proprietary components **(Group D: Special Activity Groups)** Trained and experienced staff **(Group P: Audit)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
Product	
1) Input	Procedures and responsibility for review, record and approval of manufacturing instructions before issue **(Group E6: Design Output)** Specified storage methods Protection of the quality of product during delivery phases Documented installation procedures **(Group G3: After-Sales Service)** Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
2) Output	Generation of documented manufacturing instructions: • Working drawings • Manufacturing specifications and methods • Software • Purchase specifications • Acceptance criteria and inspection and test procedures Comprehensive and timely supplied servicing Establishment of an early warning system for product shortcomings Market feedback system available for monitoring product quality to ensure customer satisfaction **(Group G3: After-Sales Service)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Audits of sub-contractor design control procedures Testing of prototypes Results recorded and issued to concerned functional units Timely and appropriate corrective actions and follow-up **(Group P: Audit)**
3) Resources	Information on complaints, the occurrence and modes of failure and so on which are available for review and corrective action feedback for possible change of design concept and manufacturing specifications, for example **(Group G3: After-Sales Service)** Trained and experienced staff **(Group P: Audit)**
After-Sales Service	
1) Input	Incoming materials and parts verified based on: • the importance to quality • the state of control • information from sub-contractor • impact on costs In-process verification for conformance **(Group A1: Product -Product Verification)** Documented procedures for measurement control Elements of control such as suitable specification, initial calibration, periodic recall, documentary evidence, and traceability

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Sub-contractor measurement controls **(Group A1: Product - Control of Inspection, Measuring, and Test Equipment)**
2) Output	Finished product verification: • Acceptance inspections • Product-quality auditing **(Group A1: Product -Product Verification)** Evaluation of corrective actions **(Group A1: Product - Control of Inspection Measuring, and Test Equipment)** Identification and recording of occurrence(s) Segregation action taken to prevent further unintended use or installation Review for actions Disposition taken as soon as practical Avoidance of recurrence **(Group A1: Product - Control of Non-conforming Product)** Evaluation of importance Investigation of possible causes Analysis of problem Appropriate steps for elimination of causes Process controls to avoid recurrence Documented permanent changes records **(Group A1: Product - Corrective and Preventive Action)**

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Stage	Factors
	Audits of sub-contractor design control procedures
	Testing of prototypes
	Results recorded and issued to concerned functional units
	Timely and appropriate corrective actions and follow-up
	(Group P: Audit)
3) Resources	Outside testing to avoid costly duplication
	(Group A1: Product - Control of Inspection, Measuring, and Test Equipment)
	Assignment of responsibility and authority
	(Group A1: Product - Corrective and Preventive Action)
	Trained and experienced staff
	(Group P: Audit)

Table 8 Labelling and grouping factors of Input/Output/Resources in different design information flows (continued)

Category	Factors
a) Types:	Incoming materials and parts verified based on: • the importance to quality • the state of control • information from sub-contractor • impact on costs In-process verification for conformance Finished product verification: • Acceptance inspections • Product-quality auditing **(Group A: Product - Product Verification)** Evaluation of corrective actions **(Group A: Product - Control of Inspection, Measuring and Testing)** Review for actions **(Group A: Product - Control of Non-conforming Product)** Evaluation of importance **(Group A: Product - Corrective and Preventive Action)** Customer specification needs and/or requirements **(Group B: User Needs)** Statement of the design requirements Consideration of design review elements: • Items pertaining to customer needs and satisfaction (e.g. comparison of customer needs, validation of design through prototype tests, safety and environmental compatibility, compliance with regulatory

Table 9 Categorisation of factors into Types/Format/Source in the design information flows

Category	Factors
	requirements and Standards, etc.) • Items pertaining to product specifications (e.g. dependability and serviceability requirements, tolerances, FMEA, aesthetic specifications and acceptance criteria, etc.) • Items pertaining to process specifications (e.g. ability to produce product conforming to the design, capability to inspect and test the design, specification of material and components, packaging, handling and shelf-life requirements, etc.) **(Group C1: Design Review)** Manufacturing specifications **(Group D: Production)** Technical and material specifications and working drawings **(Group D: Purchasing)** Specific research requirements with firm conclusions **(Group D: R&D)** Potential customers' technical specifications Technical descriptions and schedules Specifications and performance data **(Group D: Sales/Marketing)** Specified requirements

Table 9 Categorisation of factors into Types/Format/Source in the design information flows (continued)

Category	Factors
	Defined parameters **(Group D: Special Activity Groups)** Generation of documented manufacturing instructions: • Working drawings • Manufacturing specifications and methods • Software • Purchase specifications • Acceptance criteria and inspection and test procedures Regular evaluation with planning, assignment of personnel and documented procedures **(Group P: Audit)** Layout drawings for new engineering designs and advice from specialist **(Group L: Detailed Manufacturing Specifications)** Feedback to original drawings and/or specifications and initiate corrective actions **(Group N: Checking of Manufacturing Specifications)**
b) Format	Documented procedures for measurement control Sub-contractor measurement controls **(Group A: Product-Control of Inspection, Measuring and Test Equipment)** Identification and recording of occurrence(s) Segregation action taken to prevent further unintended use or installation Disposition taken as soon as practical

Table 9 Categorisation of factors into Types/Format/Source in the design information flows (continued)

Category	Factors
	Avoidance of recurrence
	Investigation of possible causes
	Analysis of problem
	Appropriate steps for elimination of causes
	Process controls to avoid recurrence
	Documented permanent changes records
	(Group A: Product - Corrective and Preventive Action)
	Applied standards and statutory requirements
	Recognised design procedures
	Known physical parameters
	Results of contract review activities
	(Group B: User Needs)
	Statement of the design requirements
	Generate report in a usable form: • Hard copy? • Electronic media?
	Consideration for recommendations and initiate corrective actions
	(Group C1: Design Review)
	Capability analysis of equipment
	Issue control of original specifications and subsequent amendments
	Feedback procedures for design changes or requesting concessions
	(Group D: Production)

Table 9 Categorisation of factors into Types/Format/Source in the design information flows (continued)

Category	Factors
	Issue control with records of the documents
	(Group D: Purchasing)
	Formal procedures for requesting changes
	Acceptable changes recorded
	(Group D: Commissioning and Service)
	Generate formal reports with conclusions
	(Group D: R&D)
	Formal procedures of issue control of document
	(Group D: Sales/Marketing)
	A request for development of a material or process
	(Group D: Special Activity Groups)
	Procedures and responsibility for review, record and approval of manufacturing instructions before issue
	(Group E1: Design Output)
	Defined and implemented quality programme
	Audit of sub-contractor design control procedures
	Testing of prototypes
	Results recorded and issued to concerned functional units
	Timely and appropriate corrective actions and follow-up
	(Group P: Audit)
	Documented user needs
	(Group F: Design Input)
	Specified storage methods
	Protection of the quality of product during delivery phases

Table 9 Categorisation of factors into Types/Format/Source in the design information flows (continued)

Category	Factors
	Documented installation procedures Comprehensive and timely supplied servicing Establishment of an early warning system for product shortcomings Market feedback system available for monitoring product quality to ensure customer satisfaction **(Group G1: After-Sales Service)** Documented design input **(Group H: Design Concept and Group J: Calculation and Setting of Design Parameters)** Generate data in a usable form: • Software? • Drawings? • Specifications? **(Group J: Calculation and Setting of Design Parameters)** Recorded parameters and specifications Documented design review report Recognised design procedures **(Group J: Detailed Manufacturing Specifications)**
c) Source	Elements of control such as suitable specification, initiate calibration, periodic recall, documentary evidence, and traceability Outside testing to avoid costly duplication **(Group A: Product - Control of Inspection, Measuring and Test Equipment)** Assignment of responsibility and authority **(Group A: Product - Corrective and Preventive Action)**

Table 9 Categorisation of factors into Types/Format/Source in the design information flows (continued)

Category	Factors
	Marketing information Competitors' data **(Group A: User Needs)** Independent reviewers representing different interests (e.g. sales, purchasing, quality, etc.) Consideration for recommendation and initiate corrective actions **(Group A: Design Review)** Trained and experienced staff **(Group D: Production, Group P: Audit, Group H: Design Concept, Group J: Calculation and Setting of Design Parameters, Group L: Detailed Manufacturing specifications and Group N: Checking of Manufacturing Specifications)** Equipment and resources **(Group D: Production, Group J: Calculation and Setting of Design Parameters, Group L: Detailed Manufacturing Specifications and Group N: Checking of Manufacturing Specifications)** Customer problems Customer intentions (desires) Market share Value for money **(Group D: Sales/Marketing)** Identification of a source of particular components Information about proprietary components **(Group D: Special Activity Groups)**

Table 9 Categorisation of factors into Types/Format/Source in the design information flows (continued)

Category	Factors
	Feedback from organisational changes, market, non-conformity reports, and surveys
	(Group P: Audit)
	Establishment of an early warning system for product shortcomings
	Information on complaints, the occurrence and modes of failures and so on which are available for review and corrective action feedback for possible change of design concept and manufacturing specifications, for example
	Market feedback system available for monitoring product quality to ensure customer satisfaction
	(Group G1: After-Sales Service)
	Creativity
	(Group H: Design Concept)
	Availability of material and components
	Access to data
	Clear idea of design concept
	(Group J: Calculation and Setting of Design Parameters)
	Manufacturing capability data
	(Group L: Detailed Manufacturing Specifications)
	Access to drawings and specifications data
	Clear idea of drawings and specifications
	(Group N: Checking of Manufacturing Specifications)

Table 9 Categorisation of factors into Types/Format/Source in the design information flows (continued)

1) **Method *I*:**

Product Characteristic	**Importance Level** 1 (low)	2	3	4	5 (high)
• **Complexity**					User Needs
					Design Input
					Design Concept
					Calculation & Setting of Design Parameters
			Detailed Mfg. Specifications.		
	Checking of Mfg. Specifications.				
			Design Output		
					Production
		Commissioning and Service			
				Purchasing	
			Sales/Marketing		
		R&D			
			Special Activity Groups		
					Product
					After-Sales Service
					Audit

Table 10 Determine relative importance of stages in the design information flows in terms of "Complexity" (Method *I*)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• **Safety critical**					User Needs
					Design Input
					Design Concept
			Calculation & Setting of Design Parameters		
					Design Review
			Detailed Mfg. Specifications		
	Checking of Mfg. Specifications				
				Design Output	
			Production		
		Commissioning and Service			
		Purchasing			
					Sales/Marketing
		R&D			
					Special Activity Groups
					Product
					After-Sales Service
					Audit

Table 11 Determine relative importance of stages in the design information flows in terms of "Safety critical" (Method *I*) (continued)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• Mass production, or small volume					User Needs
					Design Input
					Design Concept
				Calculation & Setting of Design Parameters	
					Design Review
				Detailed Mfg. Specifications.	
		Checking of Mfg. Specifications			
					Design Output
					Production
		Commissioning and Service			
			Purchasing		
			Sales/Marketing		
		R&D			
			Special Activity Groups		
					Product
					After-Sales Service
					Audit

Table 12 Determine relative importance of stages in the design information flows in terms of "Mass production, or small volume" (Method *I*) (continued)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• **Value**					User Needs
					Design Input
					Design Concept
					Calculation & Setting of Design Parameters
					Design Review
			Detailed Mfg. Specifications		
	Checking of Mfg. Specifications				
			Design Output		
				Production	
		Commissioning and Service			
	Purchasing				
					Sales/Marketing
		R&D			
			Special Activity Groups		
					Product
					After-Sales Service
					Audit

Table 13 Determine relative importance of stages in the design information flows in terms of "'Value" (Method *I*) (continued)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• **Novelty of design**					User Needs
					Design Input
					Design Concept
			Calculation & Setting of Design Parameters		
				Design Review	
			Detailed Mfg. Specifications		
		Checking of Mfg. Specifications			
			Design Output		
					Production
		Commissioning and Service			
		Purchasing			
				Sales/Marketing	
		R&D			
			Special Activity Groups		
					Product
					After-Sales Service
					Audit

Table 14 Determine relative importance of stages in the design information flows in terms of "Novelty of design" (Method *I*) (continued)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• **Cost/ Competitiveness**					User Needs
					Design Input
					Design Concept
					Calculation & Setting of Design Parameters
					Design Review
				Detailed Mfg. Specifications	
	Checking of Mfg. Specifications				
			Design Output		
			Production		
		Commissioning and Service			
			Purchasing		
					Sales/Marketing
		R&D			
		Special Activity Groups			
					Product
					After-Sales Service Audit

Table 15 Determine relative importance of stages in the design information flows in terms of "Cost/Competitiveness" (Method *I*) (continued)

2) Method *II*:

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• **Complexity**	User Needs	User Needs	User Needs	User Needs	User Needs
	Design Input	Design Input	Design Input	Design Input	Design Input
	Design Concept	Design Concept	Design Concept	Design Concept	Design Concept
	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters
	Design Review	Design Review	Design Review	Design Review	Design Review
	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications
			Checking of Mfg. Specifications		
				Design Output	
					Production
	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service
	Purchasing	Purchasing	Purchasing	Purchasing	Purchasing
	Sales/Marketing	Sales/Marketing	Sales/Marketing	Sales/Marketing	Sales/Marketing
	R&D	R&D	R&D	R&D	R&D
	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups
	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit

Table 16 Determine relative importance of stages in the design information flows in terms of "Complexity" (Method *II*)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• Safety critical	User Needs	User Needs	User Needs	User Needs	User Needs
	Design Input	Design Input	Design Input	Design Input	Design Input
	Design Concept	Design Concept	Design Concept	Design Concept	Design Concept
	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters
					Design Review
	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications
	Checking of Manufacturing. Specifications	Checking of Manufacturing Specifications	Checking of Manufacturing Specifications	Checking of Manufacturing Specifications	Checking of Manufacturing Specifications
	Design Output	Design Output	Design Outpu t	Design Output	Design Output
					Production
	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service
	Purchasing	Purchasing	Purchasing	Purchasing	Purchasing
	Sales/Marketing	Sales/Marketing	Sales/Marketing	Sales/Marketing	Sales/Marketing
					R&D
	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups
	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit

Table 17 Determine relative importance of stages in the design information flows in terms of "Safety critical" (Method *II*) (continued)

Product Characteristic	1 (low)	2	3	4	5 (high)
• Mass production ,or small volume					User Needs Design Input Design Concept
					Calculation & Setting of Design Parameters
	Design Review	Design Review	Design Review	Design Review	Design Review
	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications
	Checking of Mfg. Specs. Design Output	Checking of Mfg. Specs. Design Output	Checking of Mfg. Specs. Design Outpu t	Checking of Mfg. Specs. Design Output	Checking of Mfg. Specs. Design Output Production
	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service
	Purchasing	Purchasing	Purchasing	Purchasing	Purchasing
					Sales/Marketing R&D
	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activit Groups
	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit

Table 18 Determine relative importance of stages in the design information flows in terms of "Mass production, or small volume" (Method *II*) (continued)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• **Value**	User Needs Design Input Design Concept	User Needs Design Input Design Concept	User Needs Design Input Design Concept	User Needs Design Input Design Concept	User Needs Design Input Design Concept
					Calculation & Setting of Design Parameters
					Design Review
	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications
	Checking of Mfg. Specs. Design Output Production	Checking of Mfg. Specs. Design Output Production	Checking of Mfg. Specs. Design Output Production	Checking of Mfg. Specs. Design Output Production	Checking of Mfg. Specs. Design Output Production
	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service
	Purchasing	Purchasing	Purchasing	Purchasing	Purchasing
					Sales/Marketing R&D
	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups
	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit	Product After-Sales Service Audit

Table 19 Determine relative importance of stages in the design information flows in terms of "Value" (Method *II*) (continued)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• **Novelty of design**	User Needs	User Needs	User Needs	User Needs	User Needs
	Design Input	Design Input	Design Input	Design Input	Design Input
	Design Concept	Design Concept	Design Concept	Design Concept	Design Concept
	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation& Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters
	Design Review	Design Review	Design Review	Design Review	Design Review
	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications	Detailed Mfg. Specifications
	Checking of Mfg. Specs.	Checking of Mfg. Specs.	Checking of Mfg. Specs.	Checking of Mfg. Specs.	Checking of Mfg. Specs.
	Design Output	Design Output	Design Outpu t	Design Output	Design Output
	Production	Production	Production	Production	Production
	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service
	Purchasing	Purchasing	Purchasing	Purchasing	Purchasing
	Sales/Marketing	Sales/Marketing	Sales/Marketing	Sales/Marketing	Sales/Marketing
					R&D Special Activity Group
	Product After-Sales Service	Product After-Sales Service	Product After-Sales Service	Product After-Sales Service	Product After-Sales Service
					Audit

Table 20 Determine relative importance of stages in the design information flows in terms of "Novelty of design" (Method *II*) (continued)

Product Characteristic	Importance Level 1 (low)	2	3	4	5 (high)
• **Cost/ Competi-tiveness**	User Needs	User Needs	User Needs	User Needs	User Needs
	Design Input	Design Input	Design Input	Design Input	Design Input
	DesignConcept	DesignConcept	Design Concept	Design Concept	Design Concept
	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation& Setting of Design Parameters	Calculation & Setting of Design Parameters	Calculation & Setting of Design Parameters
					Design Review
	Detailed mfg. Specifications	Detailed mfg. Specifications	Detailed mfg. Specifications	Detailed mfg. Specifications	Detailed mfg. Specifications
	Checking of Mfg. Specs.	Checking of Mfg. Specs.	Checking of Mfg. Specs.	Checking of Mfg. Specs.	Checking of Mfg. Specs.
	Design Output	Design Output	Design Output	Design Output	Design Output
	Production	Production	Production	Production	Production
	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service	Commissioning and Service
	Purchasing	Purchasing	Purchasing	Purchasing	Purchasing
	Sales/Marketing	Sales/Marketing	Sales/Marketing	Sales/Marketing	Sales/Marketing
	R&D	R&D	R&D	R&D	R&D
	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups	Special Activity Groups
	Product After-Sales Service	Product After-Sales Service	Product After-Sales Service	Product After-Sales Service	Product After-Sales Service
					Audit

Table 21 Determine relative importance of stages in the design information flows in terms of "Cost/Competitiveness" (Method *II*) (continued)

Stage	Function	Basic	Secondary
Calculation and Setting of Design Parameters	Define responsibilities Establish parameters	 **B**	**S**
Detailed Manufacturing Specifications	Define responsibilities Produce specifications	 **B**	**S**
Checking of Manufacturing Specifications	Define responsibilities Check validity Retain results	 **B** 	**S** **S**

Table 22 Application of function analysis in some design stages

Feature	CAD/CAM	DFMA	Value engineering (as a new tool)
Fundamentality	A design tool and also a power variant product of information technology (IT) but with limited capability in generating conceptual design of a product	A design tool that brings manufacturing considerations into the design stage. It is a design-review method that identifies the optimal part design, materials choice, assembly and fabrication operations to produce an efficient and cost-effective product	A new tool combined with ISO 9000 aiming to improve the quality management approach of design (i.e. how to best management design)
Aims/ Objectives	Provide timing and precise access to evaluate information which is essential for effective product design	Identify product concepts that are inherently easy to manufacture and assemble, and to integrate manufacturing process into design	Develop the value of each design stage by determining the worth of the stage against critical factors and calculate cost of stages with greater cost benefits by seeking alternatives (with the concept of value relates to worth and costs in value engineering which is $\text{Value} = \frac{\text{Worth}}{\text{Cost}}$) and improve the efficiency of management of design

Table 23 Differences between a new view of value engineering and design tools

Feature	CAD/CAM	DFMA	Value engineering (as a new tool)
Application	An application of computerised techniques in the concurrent engineering (CE) environment for collection, processing, storage and dissemination of information, and can be a significant aid to a successful product evaluation, design and manufacturing	Techniques that can be applied to focus on component design for ease of manufacture and assembly in the early stages of the product design, which results in the reduction of parts needed and ultimately, in the reduction of cost	A technique to analyse the design management
Possible Benefits	Reduce the likelihood of problems or errors resulted from poor communication Less resultant waste and rework Reduced late engineering problems Reduced develpoment time Increased product quality Increased customer satisfaction	Reduce manufacturing costs and increase productivity at design stages Create competitive products and reduce time to market	Identify critical stages in design process Better allocation of resources Improve efficiency of design management Reduce product development cycle time Lead to the reduction of product development cost

Table 23 Differences between a new view of value engineering and design tools (continued)

- ***Design Input (customer performance requirements)***

Rating	Description
1 (Very low)	Products which translated from customers or market requirements do not anticipate any potential safety hazards
2 (Low)	Products which translated from customers or market requirements may become unsafe with the increased size, complexity of the design
3 (Moderate)	Products designed based on customer requirements which require specific measures to ensure safety
4 (High)	Products which could by their nature cause injury to people or damage to equipment
5 (Very high)	Products which will involve significant safety hazards at normal condition and involvement of safety specialists early in the design process is required

Table 24 Determine the worth rating for doing the "Design Input" in terms of "Safety"

Rating	Description
1 (Very low)	Products which translated from customer or market needs are well-planned and made environmentally benign
2 (Low)	Products which in themselves do not contribute to the degradation of the environment internally and externally but which may cause environmental effects to some extent with the increased size, complexity and criticality of the design
3 (Moderate)	Products which in themselves normally unable to avoid the degradation of the environment, both direct or indirect
4 (High)	Products which contains ecologically unfriendly materials in the design and are capable of leading to environmental effects
5 (Very high)	Products which in themselves are readily capable of causing environmental effects such as waste, pollution, and other specific parts of the environment

Table 25 Determine the worth rating for doing the "Design Input" in terms of "Environment""

Rating	Description
1 (Very low)	Products which clearly fit the purpose or customer needs for which it is intended in a cost-effective manner
2 (Low)	Products which in themselves work as it is supposed to work, i.e. functional and workable, but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 (Moderate)	Products which in themselves meet only some of functional requirements or are uneconomic
4 (High)	Products which in themselves are capable of causing unstable functional performance, such as reliability,maintainability, producibility, usability, durability and quality
5 (Very high)	Products which in themselves are unable to satisfy all aspects of the needs in a cost-effective manner and which require the use of experienced specialist individually or in groups to provide input for clear needs

Table 26 Determine the worth rating for doing the "Design Input" in terms of "Functionality"

Rating	Description
1 (Very Low)	Products for simple, orderly, and low cost products
2 (Low)	Products for simple products but where changes in product size, complexity translated from customer needs could increase cost
3 (Moderate)	Products where proper analysis of all aspects of manufacturer and user resources could lead to cost reduction
4 (High)	Products where to get the most efficient and economic design solution in which a clear design input is needed
5 (Very high)	Products where an efficient and economic design solution cannot be decided without clearly defined design input requirements in terms of performance, use, aesthetics, technical details, packaging, reliability, maintainability and disposal

Table 27 Determine the worth rating for doing the "Design Input" in terms of "Cost"

- *Design Concept*

Rating	Description
1 (Very low)	Products which comparably are free from exposure to danger, injury or loss, to a person or thing, i.e. generally recognised as safe, although there is no such thing as being absolutely safe
2 (Low)	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, complexity of the design
3 (Moderate)	Products designed based on customer requirements which require specific measures to ensure safety. This applied regardless of whether threat is foreseeable or avoidable
4 (High)	Products which could by their nature cause injury to people or damage to property
5 (Very high)	Products which will involve significant safety hazards at normal condition, and safety needed to be built into products at the conceptual stage based on a before-the-fact philosophy

Table 28 Determine the worth rating for doing the "Design Concept" in terms of 'Safety'

Rating	Description
1 (Very low)	Products which are normally environmentally friendly internally and externally
2 (Low)	Products which are normally environmentally friendly internally and externally but which may cause environmental influences to some extent with the increased size, complexity and criticality of the design
3 (Moderate)	Products which in themselves normally lead to some environmental influences, both internal and external
4 (High)	Products which in themselves are capable of leading to environmental influences
5 (Very high)	Products which in themselves are readily capable of causing environmental effects, such as withdrawal of raw materials and energy from the resources available in the environment, emissions (in the air, water, and oil) and solid waste or the other specific parts of the environment

Table 29 Determine the worth rating for doing the "Design Concept" in terms of 'Environment'

Rating	Description
1 (Very low)	Products which clearly satisfy all aspects of intentions and functions in a cost-effective manner
2 (Low)	Products which satisfy all aspects of intentions and functions economically but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 (Moderate)	Products which satisfy only some of functional requirements
4 (High)	Products which in themselves are capable of causing unstable functional performance, such as reliability and maintainability, producibility, usability, durability and quality
5 (Very high)	Products which in themselves are unable to satisfy all aspects of intentions and functions in a cost-effective manner and which require designers conceive of the most efficient, functional requirements

Table 30 Determine the worth rating for doing the "Design Concept" in terms of 'Functionality'

Rating	Description
1 (Very low)	Simple, orderly, and low cost products
2 (Low)	Simple products but where changes in product size, complexity translated from customer needs could increase cost
3 (Moderate)	Products where proper analysis of all aspects of manufacturer and user resources could lead to cost reduction
4 (High)	Products where to get the most efficient and economic design solution in which a significant cost reduction method that could bring the costs in line is needed
5 (Very high)	Products where the maximum and desired cost objective is strongly influenced by decision(s) taken at conceptual stage

Table 31 Determine the worth rating for doing the "Design Concept" in terms of "Cost"

- *Design Review*

Rating	Description
1 (Very low)	Products which comparably are free from exposure to danger, injury, or loss, to a person or thing, i.e. generally recognised as safe, although there is no such thing as being absolutely safe
2 (Low)	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, complexity of the design
3 (Moderate)	Products which in themselves are normally unsafe and readily cause some sort of threat to personal safety. This applies regardless of whether threat is foreseeable or avoidable
4 (High)	Products which in themselves are capable of causing harm, injury, or loss to the person or property
5 (Very high)	Products which are readily capable of causing the exposure of a person or thing to harm, damage, or injury at normal condition

Table 32 Determine the worth rating for doing the "Design Review" in terms of "Safety"

Rating	Description
1 (Very low)	Products which are normally not only free from adverse things that can happen to damage the products internally as a result of changes in the surrounding environment, but are also averting the adverse effects which the design can have to cause dangers to things extended to the products
2 (Low)	Products which in themselves are normally out of reach of adverse things internally and externally but which may cause environmental effects to some extent with the increased size, complexity and criticality of the design
3 (Moderate)	Products which in themselves normally lead to some environmental effects, both direct or indirect, regardless how well those effects are defined
4 (High)	Products which in themselves are capable of leading to environmental effects
5 (Very high)	Products which in themselves are readily capable of causing environmental effects, such as waste, air or water pollution, contamination of land, and noise, odour, dust, vibration and visual impact or other specific parts of the environment or ecosystems

Table 33 Determine the worth rating for doing the "Design Review" in terms of "Environment"

Rating	Description
1 (Very low)	Products which clearly satisfy all aspects of the requirements in a cost-effective manner
2 (Low)	Designs which in themselves satisfy all aspects of the requirement economically but in which changes of functionality can develop with the increased size, complexity, and criticality of the product
3 (Modearte)	Designs which meet only some of functional requirement or are uneconomic
4 (High)	Designs which in themselves are capable of causing unstable functional performance, such as reliability and maintainability, serviceability, durability and quality
5 (Very high)	Designs which in themselves are unable to satisfy all aspects of the requirement in a cost-effective manner and require the use of experienced specialists who take the formal review meetings

Table 34 Determine the worth rating for doing the "Design Review" in terms of "Functionality"

Rating	Description
1 (Very low)	Designs for simple, low cost products
2 (Low)	Designs for simple products but where changes in product size, complexity could increase cost
3 (Moderate)	Designs where proper analysis of all aspects of manufacturer and user resources could lead to cost reduction
4 (High)	Designs where to get the most efficient and economic design solution in which a design review forum is needed
5 (Very high)	Designs where an efficient and economic design solution cannot be decided without rigorous and independent review of the design

Table 35 Determine the worth rating for doing the "Design Review" in terms of "Cost"

- ***Calculation and Setting of Design Parameters***

Rating	Description
1 (Very low)	Products which comparably are free from exposure to danger, loss to a person or property by taking the advantage of the insight provided from the computational results
2 (Low)	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, shape, complexity of the design
3 (Moderate)	Products which require specific measures to ensure safety. This applied regardless of whether threat is predicable or avoidable
4 (High)	Products which could by their nature cause injury to people or damage to property
5 (Very high)	Products which will involve significant safety hazards at normal condition, and the factors of safety to be used must be adequately specified

Table 36 Determine the worth rating for doing the "Calculation and Setting of Design Parameters" in terms of "Safety"

Rating	Description
1 (Very low)	Products which are normally free from unintended environmental side-effects, led by technical actions, whatever internally and/or externally
2 (Low)	Products which internally and/or externally, are normally free from unintended environmental side-effects but which may change with the increased size, complexity and criticality of the design
3 (Moderate)	Products which in themselves normally lead to some environmental influences, both direct or indirect
4 (High)	Products which in themselves are capable of leading to environmental influences
5 (Very high)	Products which in themselves are readily capable of causing environmental effects and designers should be aware of the extensive literature presently available regarding the requirements for a environmentally friendly product

Table 37 Determine the worth rating for doing the "Calculation and Setting of Design Parameters" in terms of "Environment"

Rating	Description
1 **(Very low)**	Products which clearly meet all practical, useful and aesthetic requirements economically
2 **(Low)**	Products which clearly meet all practical, useful and aesthetic requirements economically but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 **(Moderate)**	Products which satisfy only some of functional requirements or are uneconomic
4 **(High)**	Products which in themselves are unable to meet functional performance requirements, such as reliability, maintainability, producibility, serviceability, durability, appearance and quality
5 **(Very high)**	Products which in themselves are unable to satisfy all aspects of functional requirements in a cost-effective manner and which require the extensive, rigorous calculation and setting of design parameters

Table 38 Determine the worth rating for doing the "Calculation and Setting of Design Parameters" in terms of "Functionality"

Rating	Description
1 (Very low)	Simple, orderly, and low cost products which provide high performance per dollar of cost
2 (Low)	Simple products but where changes of calculation and setting of parameters in product size, complexity could increase cost
3 (Moderate)	Products where proper analysis of all aspects of calculations and setting of parameters could lead to cost reduction
4 (High)	Products where to get the most efficient and economic calculation and setting of parameters in which some dramatic changes of the size, shapes and contours are needed
5 (Very high)	Products where an efficient and economic design solution cannot be obtained without rigorous calculation and setting of parameters

Table 39 Determine the worth rating for doing the "Calculation and Setting of Design Parameters" in terms of "Cost"

- ***Detailed Manufacturing Specifications***

Rating	Description
1 (Very low)	Products which not only comply with accepted industry or user requirements but also consider all aspects of possible unsafe conditions
2 (Low)	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, complexity of the design
3 (Moderate)	Products designed based on customer requirements which require specific measures to ensure safety. This is regardless of whether threat is predicable or avoidable
4 (High)	Products which could by nature cause injury to people or damages to equipment
5 (Very high)	Products which will involve significant safety hazards at normal condition

Table 40 Determine the worth rating for doing the "Detailed Manufacturing Specifications" in terms of "Safety"

Rating	Description
1 (Very low)	Products which are normally meet the recorded parameters and specifications requirements, following the statutory regulations and recognised design procedures as a result that no unacceptable harm to the environment occurs
2 (Low)	Products which in themselves are normally out of reach of any unacceptable harm to the environment but which may cause environmental effects to some extent with the increased size, complexity and criticality of the design
3 (Moderate)	Products which in themselves normally lead to some environmental influences, both direct or indirect, regardless how well those effects are defined
4 (High)	Products which in themselves are capable of leading to environmental influences
5 (Very high)	Products which in themselves are readily capable of causing environmental influences with a potential for human injury, loss to property, damage to the environment or some combination of these

Table 41 Determine the worth rating for doing the "Detailed Manufacturing Specifications" in terms of "Environment"

Rating	Description
1 (Very low)	Products which clearly satisfy all aspects of requirements in a cost- effective manner
2 (Low)	Products which economically meet all aspects of the requirements but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 (Moderate)	Products which satisfy only some of functional requirements
4 (High)	Products which in themselves are unable to meet functional performance requirements such as reliability, maintainability, serviceability, durability and quality
5 (Very high)	Products which in themselves are unable to satisfy all aspects of the requirements in manufacturing specifications in a cost- effective manner

Table 42 Determine the worth rating for doing the "Detailed Manufacturing Specifications" in terms of "Functionality"

Rating	**Description**
1 (Very low)	Simple, orderly, and low cost products
2 (Low)	Simple products but where changes in product size, shape, complexity could increase cost
3 (Moderate)	Products where proper analysis of all aspects of manufacturing data and type of manufacturing process used could lead to cost reduction
4 (High)	Products where to get the most efficient and economic design solution in which detailed manufacturing specifications are needed
5 (Very high)	Products where an efficient and economic design solution cannot be obtained without rigorous detailed manufacturing specifications of the design

Table 43 Determine the worth rating for doing the "Detailed Manufacturing Specifications" in terms of "Cost"

- *Checking of Manufacturing Specifications*

Rating	Description
1 (Very low)	Products which comparably are free from exposure to danger, injury, or loss to the public or property
2 (Low)	Products which in themselves are comparably out of reach of danger but which may become unsafe with the increased size, shape and complexity of the design
3 (Moderate)	Products which require specific measures to ensure safety, regardless of whether threat is predicable or avoidable
4 (High)	Products which could by nature cause injury to people, or damage to equipment
5 (Very high)	Products which will involve significant safety hazards at normal condition

Table 44 Determine the worth rating for doing the "Checking of Manufacturing Specifications" in terms of "Safety"

Rating	Description
1 (Very low)	Products which are normally not only free from adverse things that can happen to damage the products internally as a result of changes in the surrounding environment, but are also averting the adverse effects which the design can have to cause dangers to things extended to the products
2 (Low)	Products which in themselves are normally out of reach of adverse things internally and externally but which may cause environmental effects to some extent with the increased size, complexity and criticality of the design
3 (Moderate)	Products which in themselves normally lead to some environmental effects, both direct or indirect, regardless how well those effects are defined
4 (High)	Products which in themselves are capable of leading to environmental effects
5 (Very high)	Products which in themselves are readily capable of causing environmental effects such as waste, air or water pollution, contamination of land, and noise, odour, dust, vibration and visual impact or other specific parts of the environment or ecosystems

Table 45 Determine the worth rating for doing the "Checking of Manufacturing Specifications" in terms of "Environment"

Rating	Description
1 (Very low)	Products which clearly achieve a desired level of functional requirement in a cost-effective manner
2 (Low)	Products which in themselves satisfy all aspects of the requirement economically but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 (Moderate)	Products which meet only some of functional requirement or are uneconomic
4 (High)	Products which in themselves are capable of causing unstable functional performance such as reliability, maintainability, producibility, serviceability, durability and quality
5 (Very high)	Products which in themselves are unable to satisfy all aspects of the requirement in a cost-effective manner and which require rigorous checking of manufacturing specifications

Table 46 Determine the worth rating for doing the "Checking of Manufacturing Specifications" in terms of "Functionality"

Rating	Description
1 (Very low)	Simple, orderly, and low cost products
2 (Low)	Simple products but where checking of manufacturing specifications could reduce cost
3 (Moderate)	Products where proper analysis of all aspects of manufacturing specifications and use of manufacturing methods could lead to cost reduction
4 (High)	Products where to get the most efficient and economic design solution in which a checking of manufacturing specifications is needed
5 (Very high)	Products where an efficient and economic design solution cannot be obtained without structured procedures for checking the manufacturing spcifications of the design

Table 47 Determine the worth rating for doing the "Checking of Manufacturing Specifications" in terms of "Cost"

- ***Design Output (final manufacturing instructions)***

Rating	Description
1 (Very low)	Products which produced with usage of design output documents highlight safety considerations and comparably are free from exposure to danger, injury or loss to the person or property
2 (Low)	Products which produced with usage of design output documents highlight safety considerations but which may become unsafe with the increased size, shape and complexity of the design
3 (Moderate)	Products which require specific measures to ensure safety, regardless of whether threat is stated as input requirements
4 (High)	Products which could by nature cause injury to people or damage to equipment
5 (Very high)	Products which will involve significant safety hazards at normal condition

Table 48 Determine the worth rating for doing the "Design Output" in terms of "Safety"

Rating	Description
1 (Very low)	Products which produced with usage of design output documents highlight environment considerations and are normally free from adverse effects both internally and externally
2 (Low)	Products which in themselves are normally out of reach of adverse things internally and externally but which may cause environmental effects to some extent with the increased size, shape, complexity and criticality of the design
3 (Moderate)	Products which in themselves normally lead to some environmental effects, both direct or indirect, regardless how well those effects are defined
4 (High)	Products which in themselves are capable of leading to environmental effects
5 (Very high)	Products which in themselves are readily capable of causing environmental effects or other specific parts of ecosystems

Table 49 Determine the worth rating for doing "Design Output" in terms of "Environment"

Rating	Description
1 (Very low)	Products which clearly satisfy all aspects of the requirements in a cost-effective manner
2 (Low)	Products which in themselves satisfy all aspects of the requirement economically but in which changes of functionality can develop with the increased size, complexity and criticality of the product
3 (Moderate)	Products which meet only some of functional requirement or are uneconomic
4 (High)	Products which in themselves are capable of causing unstable functional performance such as reliability, maintainability, producibility, durability and quality
5 (Very high)	Products which in themselves are unable to meet all aspects of the requirements in a cost-effective manner unless there is a formal verification and validation of design input requirements

Table 50 Determine the worth rating for doing the "Design Output'in terms of "Functionality"

Rating	Description
1 (Very low)	Simple, orderly, and low cost products
2 (Low)	Simple products but where changes in product size, shape and complexity could increase cost
3 (Moderate)	Products where proper analysis of all aspects of design output documents could lead to cost reduction
4 (High)	Products where to get the most efficient and economic design solution in which design output documents are needed
5 (Very high)	Products where an efficient and economic design solution cannot be obtained without well-defined design output documents

Table 51 Determine the worth rating for doing the "Design Output" in terms of "Cost"

Activity	Time	Cost
• Assemble a small planning team from marketing, technical and other related fields • Identify and interpret customer requirements (such as economy, reliability, durability, ease of use, easy maintenance, safety, price and delivery and achieving a certain performance), by using some efficient and effective tools • Carry out the necessary investigation to get useful information to support design task • Complete a prime mission and a life-cycle profile for the new product • Initiate the feasibility study to describe a recommended, preferred design approach • Review customer requirements in the contract • Understand how the contract (final agreement) is different from the initial offer • Identify how an amendment to the contract is made • Correctly transfer amendments to functions concerned within the firm • Present capability for new product design • Quantify critical success factors • Forecast technology trend • Analyse the competitive status of the company if this product is successfully introduced		
Total		

Table 52 Reference list of possible and generic activities required for doing alternative routes in the "Design Input" stage

Activity	Time	Cost
• Analyse competitive threats and responses • Prepare a product marketing plan including sales and market share forecasts • Prepare a product development plan (costs, timing, and organisations to be involved) • Observe Standards (international, internal and others relevant to the design process) and requirements including customer specifications, design codes, manuals of standard procedures, calculation methods, research reports, legal, safety, environmental requirements, etc. • Maintain the procedures for initiation, approval of modifications, updating and additions to the design documents • Identify the relevance of all of those standards and requirements including those mandated by law • Control and document the source of the design requirements and constraints and record changes		
Total		

Table 52 Reference list of possible and generic activities required for doing alternative routes in the "Design Input" stage (continued)

Activity	Time	Cost
• Develop flow of ideas in a brainstorming session individually or by a group • Establish an overview of each idea • Conduct the selection criteria (i.e. effectiveness and ease of implementation) • Use a so-called trigger word substituted by a list of synonyms for a given function that may lead to a creative design output • Select a random verb and try to force it into the problem, to see if a creative idea results • Prepare suitable equipment and resources • Conceive design requirements (i.e. ideas and working principles) for the product • Spell out the required and desired functional needs of a design on the product specification sheet • Establish design parameters in compliance with customer requirements and/or applicable standards • Strive to build a climate (or an environment) that encourage ideas and changes • Develop a positive approach to stimulate and encourage each individual's creativity • Give recognition to good new ideas • Write a design brief which includes constraints on cost and timescale • Discuss design brief carefully by all concerned (including designers) before design work commences		
Total		

Table 53 Reference list of possible and generic activities required for doing alternative routes in the "Design Concept" stage

Activity	Time	Cost
• Identify designers' legal liabilities from patents in similar product,and projected environment, health and safety requirements from government regulations • Undertake appropriate and effective evaluation of the concepts against the design requirements • Judge which concept, or combination of the features of two or more concepts should be adopted • Retain ideas that are developed but rejected on file for a possible second look • Carry out evaluation in terms of both market acceptance of the product and compliance with relevant mandatory standards • Collect input from technical and commercial feasibility studies, market surveys or specialist consultant to arrive at the preferred solution • Minimise or eliminate features known to cause quality problems e.g.feedback from manufacturer and end user for the product which is a 'one-off' or being designed for series production • Review the current workflow in practices • Identify the strengths and weaknesses of the workflow lie in the line of design • Initiate proposed solutions for modification from the cost and technical standpoint, their benefits and disadvantages • Simplify product design to avoid unnecessary complexity • Use existing components of known cost and reliability to reduce the cost in product design and testing wherever appropriate • Avoid overspecification of tolerances, materials, etc. for cost reduction • Design and specify components for common usage to avoid unnecessary variety		
Total		

Table 53 Reference list of possible and generic activities required for doing alternative routes in the "Design Concept" stage (continued)

Activity	Time	Cost
• Review the needs of the marketplace and the initial specifications and associate them with development plan at conceptual design stage • Factor the issues of producibility, appearance, and features into the plan after layout drawings have been completed • Ensure that the number of loose end is as close to zero as possible after prototype testing • Identify current problems or expected problems, on the technical, artistic, ergonomic, and economic aspects • Develop problem-solving approaches used on current problems • Bring together specialists from major functional areas such as design, manufacturing, quality, marketing, purchasing, field service, etc. • Assign a chairman not associated with the project • Use experience and expertise of review staffs to avoid repeating errors in methods and standard • List and describe the key specification requirements of a design • Identify and classify critical characteristics and dimensions • Generate a checklist to determine if a particular requirement has been met or if a new item should be added • Revise and update the requirements as needed to reflect any necessary changes that occur • Review and approve the realistic specification requirements of a design		
Total		

Table 54 Reference list of possible and generic activities required for doing alternative routes in the "Design Review I" and "Design Review II" stages

Activity	Time	Cost
• Review whether there are plans for each design and development activity and update as the design evolves • Identify whether design and development activities are assigned to qualified personnel equipped with adequate resources • Check whether arrangements are required to evaluate the effectiveness of the design team and individual designers • Evaluate designers' skills and request professional training if needed • Identify the design nonconformities • Investigate the related cause of nonconformities • Determine the appropriate corrective actions needed • List advantages of the actions from cost and functional standpoint • List disadvantages which include the expenses associated with proving the idea, in both design and testing • Appreciate the role of each of the organisations with input into the design being reviewed in reaching goals or targets • Establish an effective communication system for all concerned within and outside the firm		
Total		

Table 54 Reference list of possible and generic activities required for doing alternative routes in the "Design Review I" and "Design Review II" stages (continued)

Activity	Time	Cost
• Receive appropriate technical training • Understand the challenges and opportunities • Obtain appropriately trained and qualified designers • Develop an effective management structure • Establish a set of design procedures • Provide adequate support facilities • Ensure that the layout, architecture or general arrangement takes form • Ensure that the risky and difficult areas are pinpointed and are examined • Ensure that manufacture of models takes place where appropriate • Identify alternative design calculations together with the implication of each • Conduct the calculations by different groups or individuals • Identify critical design features compared to similar design • Evaluate and analyse the design features, covering performance, quality, cost, and time factors • Identify critical performance characteristics • Establish test routines(or procedures) • Produce prototype model(s) • Carry out tests • Analyse and maintain records • Write job descriptions to clearly allocate each individual's role within the department Appreciate the role of other departments, groups or individuals in reaching goals or targets • Establish an effective communication system for all concerned within and outside the firm		
Total		

Table 55 Reference list of possible and generic activities required for doing alternative routes in the "Calculation and Setting of Design Paramenters" stage

Activity	Time	Cost
• Select staff and provide technical training • Establish orgnisation-wide policies for designers' performance incentives and career structures • Consider the environment of the accommodation to ensure the best conditions for efficient staff operation • Obtain appropriately trained and qualified designers • Develop an effective management structure • Establish a set of design procedures • Provide adequate support facilities • Seek approval of the originators of the design brief for changes in the product design plan • Communicate and involve the related functions within the organisation and external to it • Ensure compatible interfaces between different components within the product and other products • Standardise and rationalise parts or components where beneficial • Apply change-control procedures formally during drawings production stages • Review and approve the revised drawings • Document the specifications for subsequent checking • Write job descriptions to clearly allocate each individual's role within the department • Appreciate the role of other departments, groups or individuals in reaching goals or targets • Establish an effective communication system for all concerned within and outside the firm		
Total		

Table 56 Reference list of possible and generic activities required for doing alternative routes in the "Detailed Manufacturing Specifications"stage

Activity	Time	Cost
• Check the specs (i.e. dimensions, tolerances, and calculations) inversely to confirm that the product design meets specified requirements • Do prototype testing under realistic conditions of manufacture and use • Perform redesign work to correct deficiencies whenever required • Create and test physical models through various alternatives • Validate the latest design to settle on a workable design before moving to early production phase • Do prototype testing under realistic conditions • Present evidence that the customer response to the new product is positive • Identify the end user or customer of the product and the associated requirements • Conduct simulated test whenever applicable, under various conditions that approximate customer usage environment • Review product as they are being designed • Consider how they could be produced in volume • Recommend what tolerances would be desirable • Determine which shapes are more easily fabricated		
Total		

Table 57 Reference list of possible and generic activities required for doing alternative toutes in the "Checking of Manufacturing Specifications" stage

Activity	Time	Cost
• Prepare a checklist that includes factors such as dimensions, scale, tolerance, standards, surface texture and material before release • Make necessary revisions to an existing drawings and re-issue to the shop for production • Maintain a clear record of all drawings • Register each and every revisions on the drawing which includes: • Carry a change (e.g. errors or omissions) or revision table • Make provision for recording a revision symbol, a zone location, an issue number, a date, and the approval of the change • Write job descriptions to clearly allocate each individual's role within the department • Appreciate the role of other departments, groups or individuals in reaching goals or targets • Establish an effective communication system for all concerned within and outside the firm		
Total		

Table 57 Reference list of possible and generic activities required for doing alternative routes in the "Checking of Manufacturing Specifications" stage (continued)

Activity	Time	Cost
• Review and approve critical instructions for adequacy by authorised personnel prior to issue • Avoid advance release unless it is clear that requirement for adequacy has been met • Conduct prompt and accurate release of manufacturing instructions (information) to the workshop, particularly bills of matrerials (BOM) • Document the procedures for instructions release • Deliver and control the pertinent issues of documents to all locations where appropriate • Ensure invalid and/or obsolete documents are removed from all points of issue or use • Identify any obsolete documents that are retained for legal and/or knowledge-preservation purposes • Ensure that all design parameters and specs, manufacturing data, acceptance criteria and inspection and test procedures are documented • Establish short and effective communication links between designers and manufacturers of products • Prepare manufacturing instructions, irrespective of drawings, written or electronic data that are suitable for the manufacture of the product in design and manufacturing area		
Total		

Table 58 Reference list of possible and generic activities required for doing alternative routes in the "Design Output" stage

Activity	Time	Cost
• Check whether all aspects of the instructions are simple, clear, accurate and are ready for initiating • Write job descriptions including level of authorisation for document release to clarify each individual's role within the organisation • Review and update with each individual concerned to ensure relevance • Establish an effective communication system for information • Locate unclear or incorrect instructions (i.e. drawings, specifications, methods or procedures) • Correct and eliminate any variations in the instructions that will not satisfy the functional, aesthetic, or economic requirements • Construct a master list or equivalent document control procedure to identify the current revision status of document • Record all the changes and modifications • Follow up and maintain long-term channels between design and manufacturing in case changes or modification of released information is necessary • Establish procedures for approval to develop consistency and to avoid possible loss of control over deviation acceptance • Establish procedures to approve all rejections due to nonconformance to instructions		
Total		

Table 58 Reference list of possible and generic activities required for doing alternative routes in "Design Output" stage (continued)

Factor / Stage	Safety	Environment	Functionality	Cost		Worth
Design Input	2	3	4	5		**120**
Design Concept	2	3	3	5		**90**
Design Review (I:Concept)	2	3	4	4		**96**
Design Review (II: Detailed)	2	4	2	5		**80**
Calculation & Setting of Design Parameters	2	2	4	5		**80**
Detailed Manufacturing Specifications	2	2	4	4		**64**
Checking of Manufacturing	2	2	4	3		**48**
Design Output	2	3	4	3		**72**

Table 59 Worth matrix of design stages for the automotive headlamp assembly

Stage	Alternative routes in sub-stages	Cost of alterna-tives	Cost of sub-stages	Cost of stages
Design Input				**34**
	Perceive customer requirements:		**2**	
	1.Customer specifications (tender documents)	4		
	2.Written market research report	8		
	3. Interviews	2		
	4. Focus groups	6		
	5.Observing the product in use	2		

Table 60 Calculate the cost of a design stage for the automotive headlamp assembly

Stage	Alternative routes in sub-stages	Cost of alterna-tives	Cost of sub-stages	Cost of stages
Design Input				
	Document requirements:		**2**	
	1. Hare copy	6		
	2. Electronic media	2		
	3. Both	8		
	Techonology capability analysis:		**4**	
	1. Company audit	4		
	2. Feasibility study	16		
	Supervise competitors:		**24**	
	1. Conduct benchmarking (Analyse competitive products)	24		
	Supervise design documents:			
	1. Identify statutory and regulatory documents		**2**	
	2. Review document selection	2		
		2		
Design Concept	**Develop parameters:**			**25**
	1. Design brief			
			2	
		2		

Table 60 Calculate the cost of a design stage for the automotive headlamp assembly (continued)

Stage	Alternative routes in sub-stages	Cost of alterna-tives	Cost of sub-stages	Cost of stages
Design Concept	2. Customer needs list	4		
	3. Preliminary product target specifications	6		
	Describe constraints:		**3**	
	1. Comparison of other similar products	6		
		3		
	3. Analysis of capability			
	Conduct evaluation:		**4**	
	1. Alternative calculation	8		
	2. Review	4		
	3. Comparison	6		
	Simplify design concept:		**16**	
	1. Apply QFD	16		
	2. Process analysis	32		
Design Review (I: Concept)				**18**
	Define responsibilities	6	**6**	
	Identify potential improvements:		**4**	
	1. Alternative calculation	8		
	2. Comparison of an existing design	4		
	3. Undertaking tests and demonstrations	12		

Table 60 Calculate the cost of a design stage for the automotive headlamp assembly (continued)

Stage	Alternative routes in sub-stages	Cost of alternatives	Cost of sub-stages	Cost of stages
	4. Overall design document review	4		
	Initiate corrective and preventive actions	8	**8**	
Design Review (II: Detailed)				**28**
	Define responsibilities	8	**8**	
	Verify parameters:			
	1. Alternative theories to perform design calculation	12	**4**	
	2. Comparing the new design with a similar proven design	8		
	3. Accepted tests, or simulation of the equipment in operation	18		
	4. Overall design document review	4		
	Initiate corrective and preventive actions	16	**16**	
	Define responsibilities			
Calculation & Setting of Design Parameters	**Establish parameters:**	8	**8**	**12**
			4	

Table 60 Calculate the cost of a design stage for the automotive headlamp assembly (continued)

Stage	Alternative routes in sub-stages	Cost of alterna-tives	Cost of sub-stages	Cost of stages
	1.Review and adopt preliminary target specifications (if design is simple and orderly) 2. Trade-off analysis	4 8		
Detailed Manufactu-ring Specifica-tions	**Define responsibilities** **Product specifications:** 1. Access product manufacturing options 2. Traditional physical model 3. Rapid prototyping	 8 18 32 10	 **8** **10**	**18**
Checking of Manufatu-ring Specifica-tions	**Define responsibilities** **Check validity:** 1. Direct checking of specifications (including calculation, dimensions, and tolerances) 2. Inverse or backward checking of specifications **Retain results:** 1. Hard copy 2. Electronic media	 4 6 8 6 2	 **4** **6** **2**	**12**

Table 60 Calculate the cost of a design stage for the automotive headlamp assembly (continued)

Stage	Alternative routes in sub-stages	Cost of alterna-tives	Cost of sub-stages	Cost of stages
	3. Both	8		
Design Output				8
	Release documents:		4	
	1. Paper-types documents reviewed, approved, displayed and distributed	16		
	2. Through electrically control procedures	4		
	Amend documents:		4	
	1. Change/modifications approved by the organisations	4		
	2. Specifically designated other functions /organisations	6		

Table 60 Calculate the cost of a design stage for the automotive headlamp assembly (continued)

Stage	Worth	Cost	Value= Worth/ Cost	Criticality ranking of design stages
Design Input	120	34	**3.5**	**6**
Design Concept	90	25	**3.6**	**5**
Design Review (I: Concept)	96	18	**5.3**	**3**
Design Review (II: Detailed)	80	28	**2.9**	**7**
Calculation & Setting of Design Parameters	80	12	**6.6**	**2**
Detailed Manufacturing Specifications	64	18	**3.5**	**6**
Checking of Manufacturing Specifications	48	12	**4.0**	**4**
Design Output	72	8	**9.0**	**1**

Table 61 Values and criticality ranking of design stages for the automotive headlamp assembly

Factor / Stage	Safety	Environment	Functionality	Cost		Worth
Design Input	2	4	5	4		**160**
Design Concept	1	3	3	4		**36**
Design Review (I:Concept)	2	3	5	5		**150**
Design Review (II: Detailed)	2	4	5	4		**160**
Calculation & Setting of Design Parameters	2	4	5	4		**160**
Detailed Manufactu-ring Specifi-cations	2	4	4	4		**128**
Checking of Manufactu-ring	1	3	4	4		**48**
Design Output	2	4	5	4		**160**

Table 62 Restructured worth matrix of design stages using the automotive headlamp assembly example

Factor / Stage	Safety					Environment					Functionality					Cost				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Design Input		15	46	23	15	8	15	31	31	15	23		15	31	31		23	31	46	
Design Concept		8	38	23	31	8	15	8	54	8	31		15	31	8		8	38	31	23
Design Review	15	15	23	31	15	8	23	38	23	8	23	8		46	23	8		15	69	8
Calculation & Setting of Design Parameters	15	8	46	8	23	15	15	23	38	8	15	8		46	31		15	31	54	
Detailed Manufacturing Specifications		15	38	31	31	8	31	31	38	8	15	15		38	31	8		25	42	31
Checking of Manufacturing Specifications		25	33	16	25	8	46	33	16		15	25	8	46	8		15	46	33	8
Design Output	8	15	25	33	25	8	33	33	33		15	8	8	46	25		1 5	25	54	8

Table 63 Worth rating spread (percentage)[7] of the various design stages from respondents (n=13) in the automotive headlamp assembly

[7] Percentage of worth rating spread against the four critical factors based on the number of respondents (which is n=13).

Range / Stage	1-29	30-59	60-89	90 - 119	120 - 179	150 - 179	180 - 209	210<
Design Input	8	15	15	8			23	31
Design Concept	8	23	15				8	46
Design Review	31	8				8	31	23
Calculation & Setting of Design Paramenters	15	23	8		8		8	38
Detailed Manufacturing Specifications	8	15	8	23	8		8	31
Checking of Manufacturing Specifications	23	15	15	8	15	8	8	8
Design Output	8	15	15		15	8	15	23

Table 64 Worth range (percentage) of the various design stages on spread of worth rating from respondents (n=13) in the automotive headlamp assembly

ILLUSTRATIONS

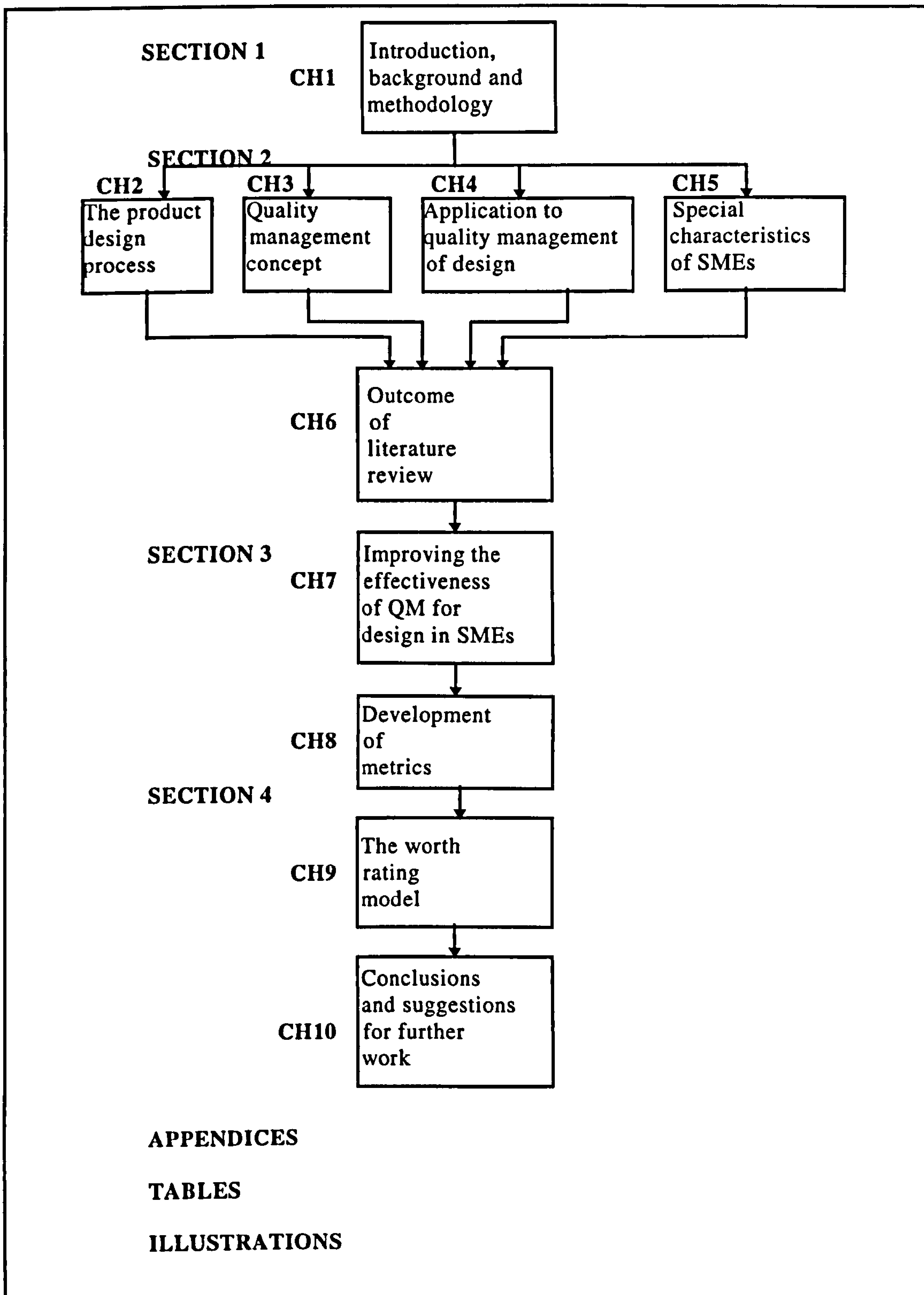

Figure 1 Analysis of quality management requirements for product design in the SMEs

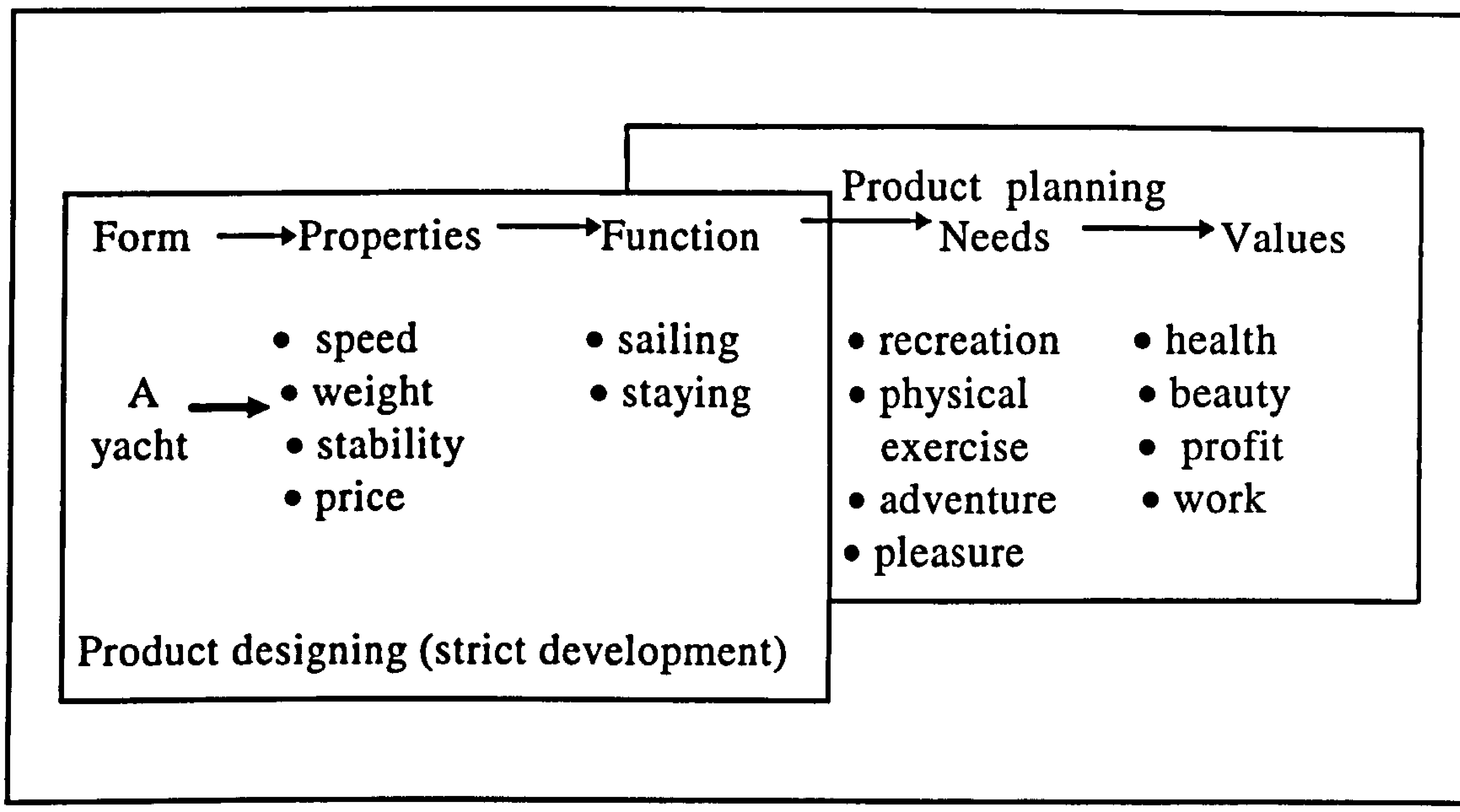

Figure 2 The function as a link between product planning and product designing (from Roozenburg and Eekels)

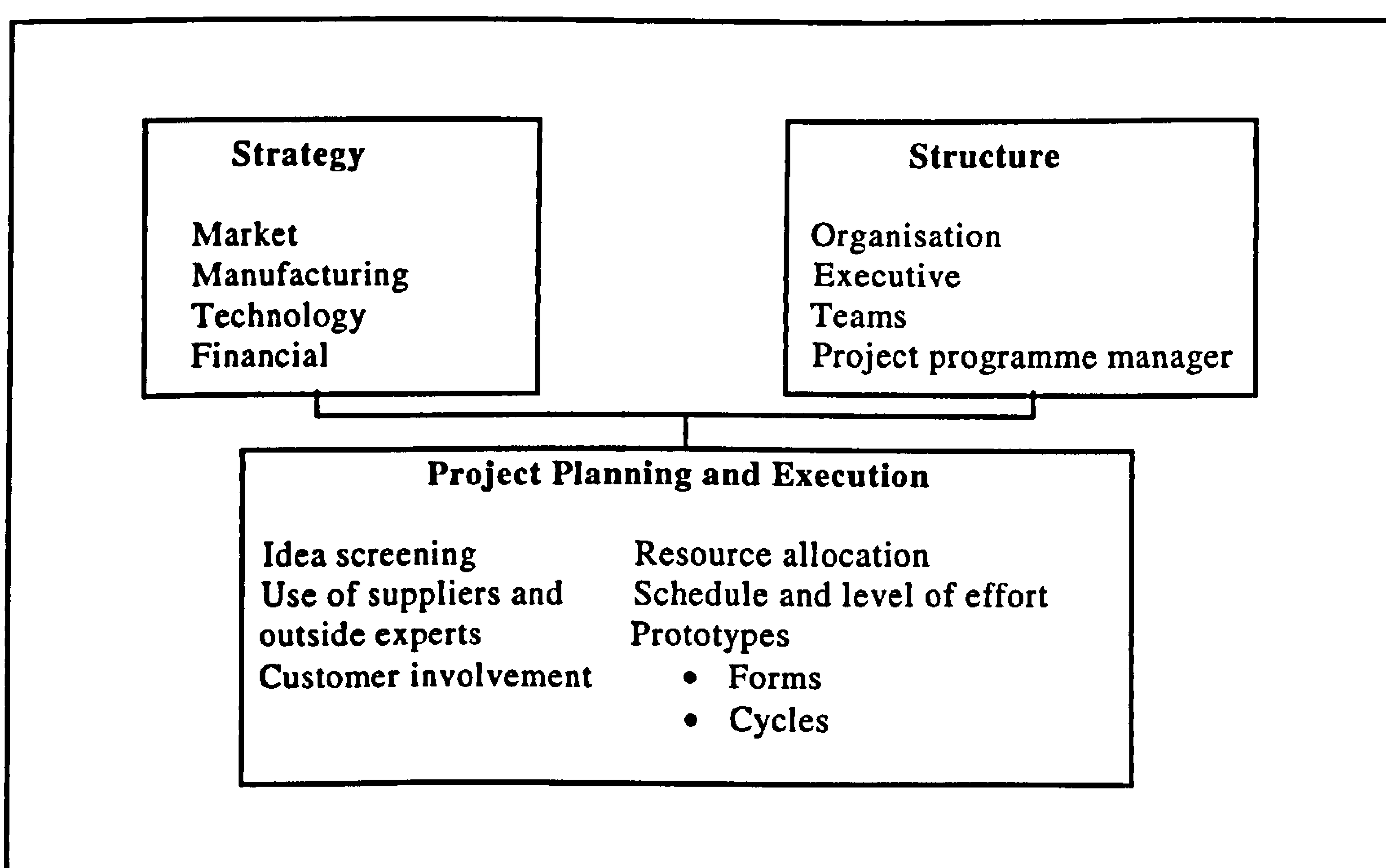

Figure 3 Decisions affecting product design and development (from Rosenthal)

Form	Description
Concept paper	Preliminary qualitative description of intended product
Sketch	Rough drawing of a product or component
Blueprint	Precise drawing of a product or component
Physical model	3-dimensional representation of shape and exterior appearance of product
Simulation model	Programmed representation of product layout or functions
CAD file	Electronic representation of parts/product geometry
Design release	Full description of product for use in designing the manufacturing bulletin process
Bill of materials	Precise list of all parts/components of end product
Process plan	Detailed description of how product is to be manufactured
Service plan	Description of field service requirements (such as replacement parts, service delivery standards, technical support procedures, test equipment)

Figure 4 Forms of a product design (from Rosenthal)

STAGE

STRATEGIC PLANNING

1 Policy formation
1. estimate strategic objectives
2. lay down outline timetables, overall budgets and guide lines for innovation

RESEARCH

[product-oriented only]

2 Preliminary research
1. select an invention, discovery, scientific principle, product idea or technological base.
2. identify an area of need, marketing opening, consumer appetite, product deficiency or value base
3. establish the existing state of the art (library and market research)
4. prepare outline performance specification (a verbal prescription for a proposed product-specification 1)
5. identify probable critical problem areas

3 Feasibility study
1. establish technical feasibility (basic calculations)
2. establish financial viability (economic analysis)
3. resolve critical problems in principle (inventions)
4. propose outline overall solution (s) (sketch designs 1)
5. estimate work content and probability of a successful outcome (risk analysis)

out of ten ideas emerging from stage 3 ....

DESIGN

4 Design development
1. expand and quantify performance specification (specification 2)
2. develop detailed design (design 2)
3. predict technical performance and product costs
4. prepare design documentation
5. design technical evaluation experiments and user trials

5 Prototype development
1. construct prototype (s), mock-ups (prototype 1)
2. conduct bench experiments with prototype
3. evaluate technical performance
4. conduct user trials with prototypes (trials 1)
5. evaluate performance in use

..perhaps three go to prototype stage...

6 Trading study
1. re-appraise market potential in light of trials
2. re-appraise costing
3. appraise marketing/production problem
4. revise basic objectives (strategic planning) and development budget
5. revise performance specification (specification 3)

Figure 5 A characteristic programme for product development (cited by Roozenburg and Eekels)

STAGE

DEVELOPMENT

7 Production development

1. develop a production design (design 3)
2. execute production design documentation
3. design technical, user and market trials
4. construct pre-production prototypes (prototype 2)
5. conduct technical, user and market field tests (trials 2)
6. appraise trials results and modify design

..and one survives for production development

8 Production planning

1. prepare market plans
2. prepare production plans
3. design packaging, promotional material, instruction manuals
4. design jigs and tools

MANUFACTURING MARKETING START-UP

9 Tooling and market preparation

1. construct jigs and tools
2. construct trial batch of products off tools (prototype 3)
3. test trial batch (trials 3)
4. produce marketing materials and print
5. install marketing machinery
6. install production control machinery

PRODUCTION

10 Production and sale

1. initiate marketing effort
2. commerce production and sale
3. collect market, user, repair and maintenance feedback
4. make recommendations for second generation designs (stages 2 to 4)
5. make recommendations for research (stages 1 and 2)

Figure 5 A characteristic programme for product development (continued)

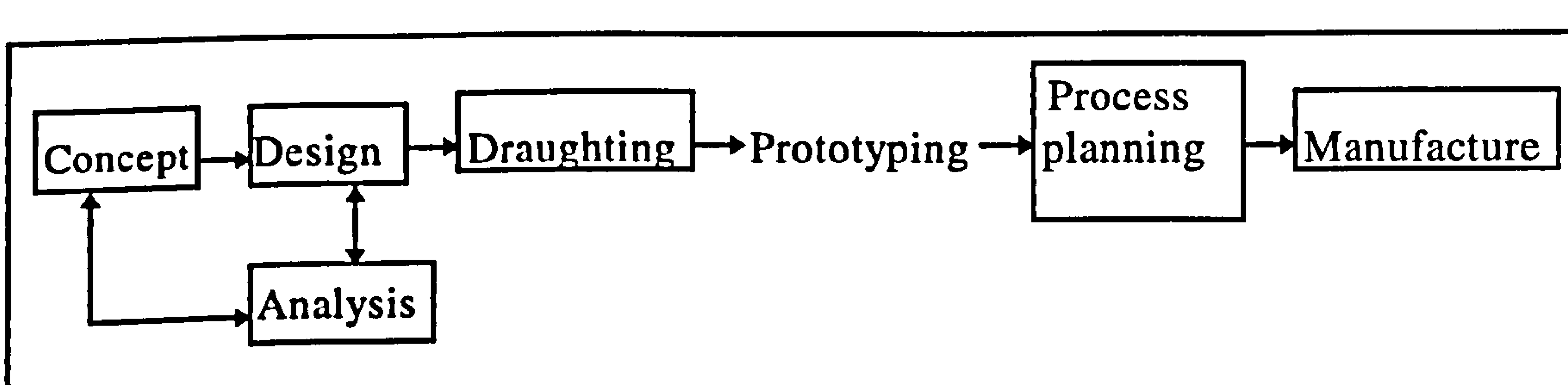

Figure 6 Traditional system for introducing new products from concept to manufacture (from Haffenden)

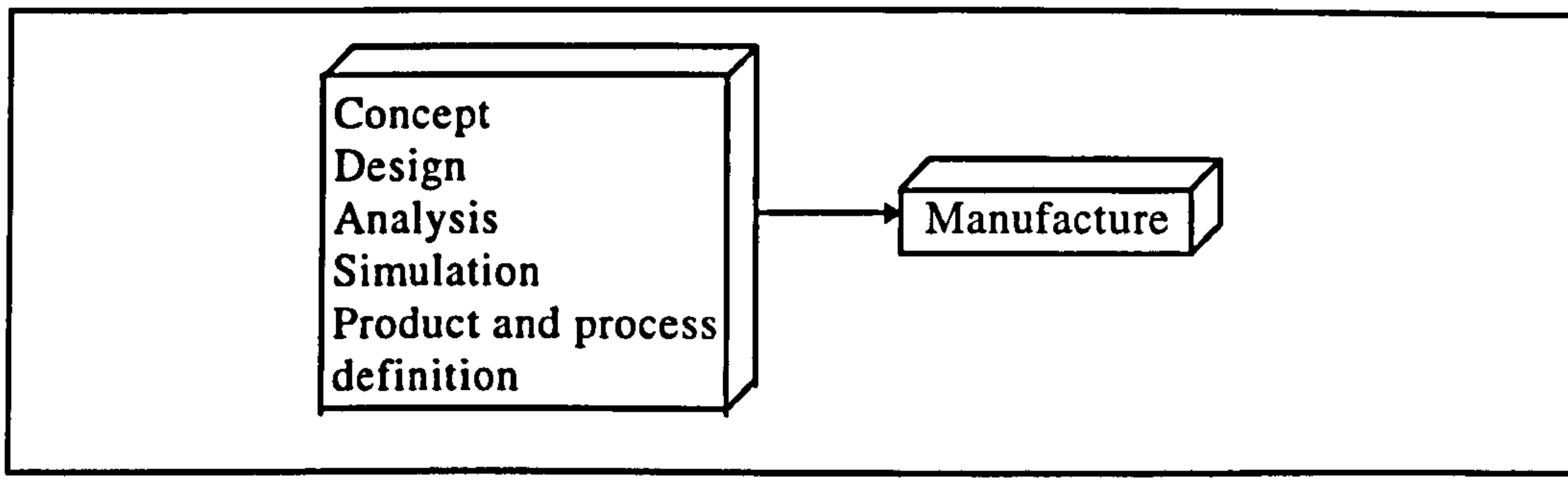

Figure 7 The new concurrent method involves many simultaneous functions to reduce time-to-market (from Haffenden)

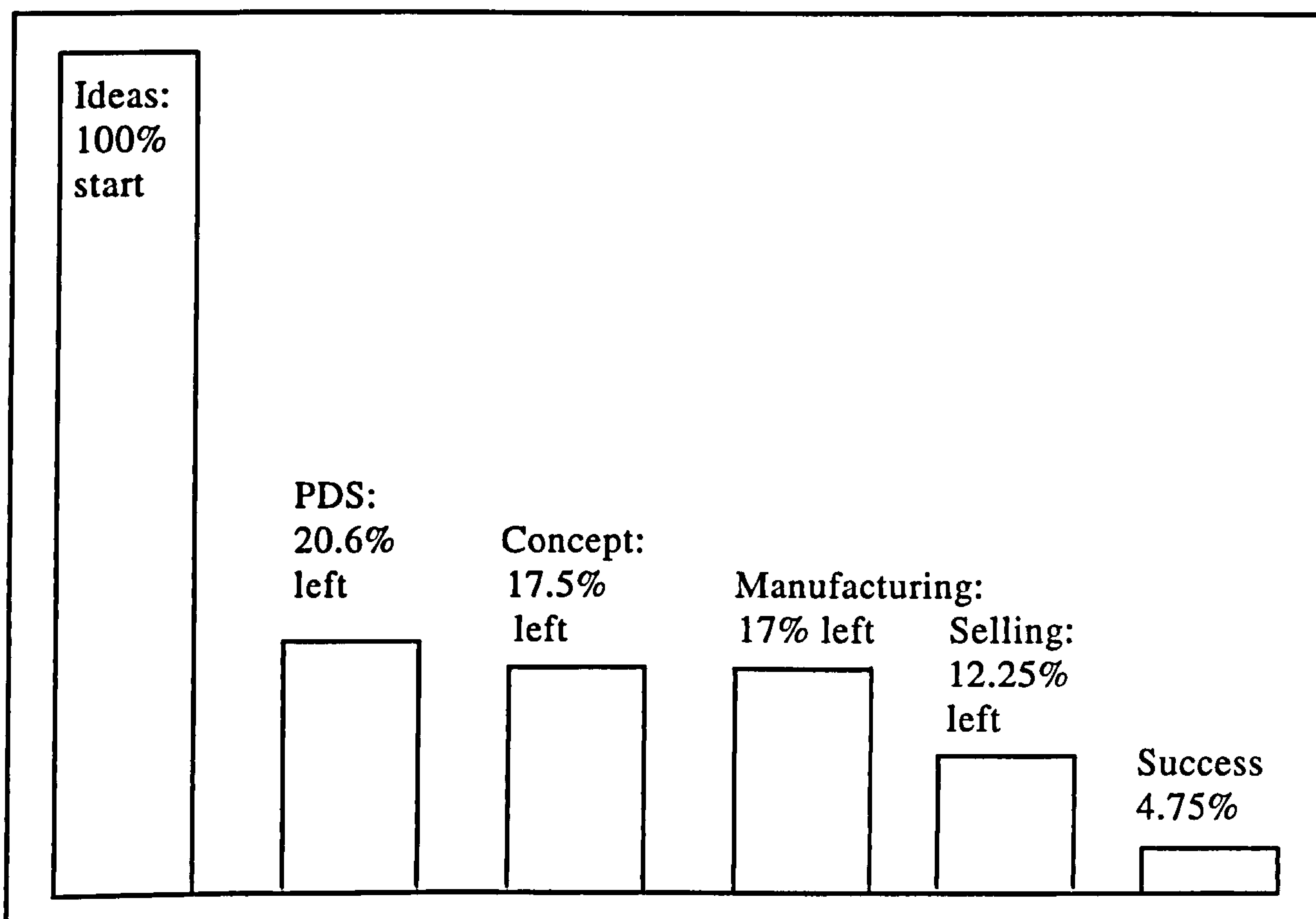

Figure 8 Where new product ideas fail. PDS = product design specification (from Hollins and Pugh)

Performance
- Functional performance
- Spatial constraints

Appearance
Time
Cost
- Capital
- Unit

Manufacture/assembly
- Quantity to be manufactured
- Company capabilities

Standards
Safety
Environmental issues

Figure 9 Types of customer requirements (from Ullman)

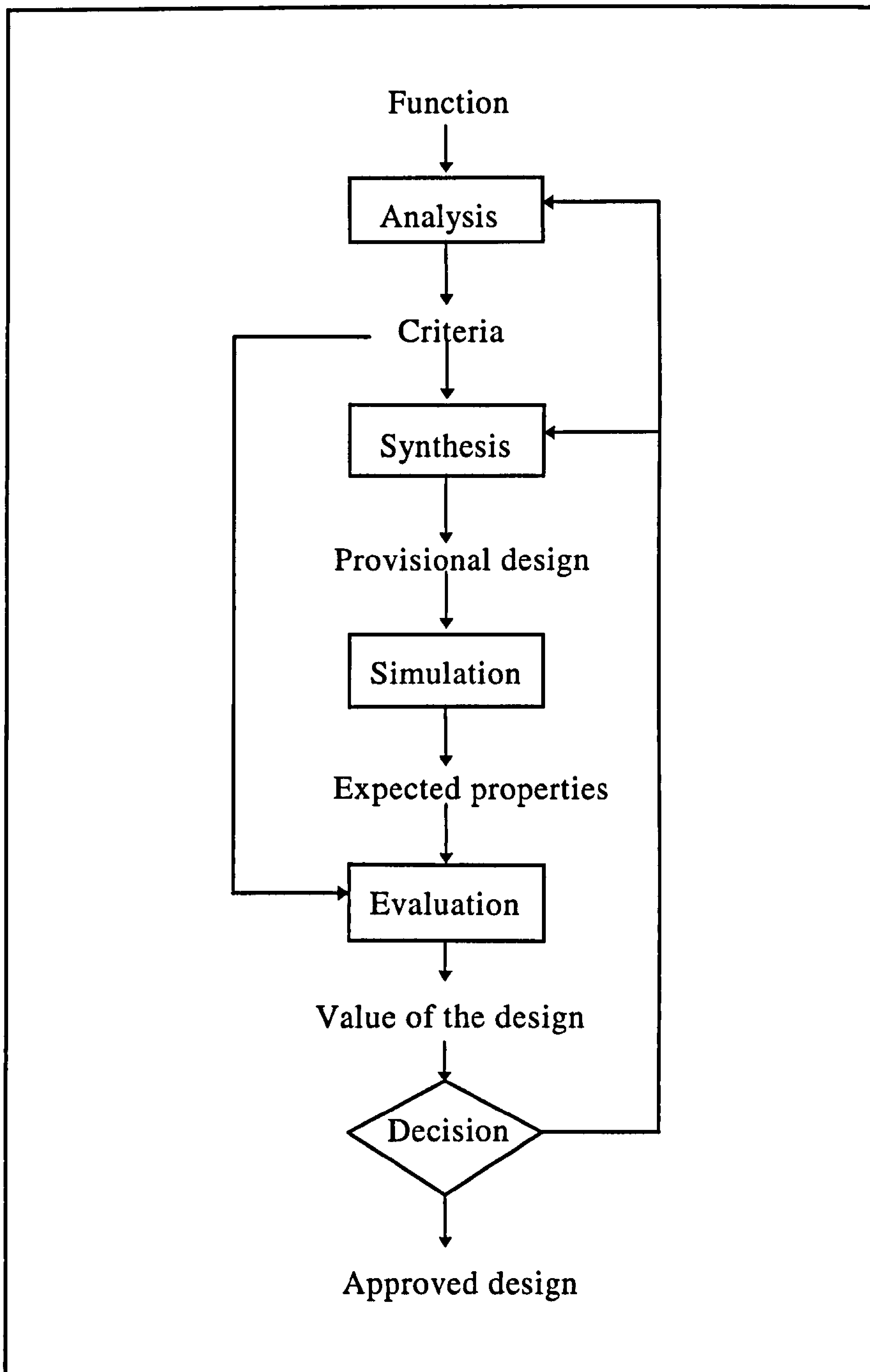

Figure 10 The basic design cycle (from Roozenburg and Eekels)

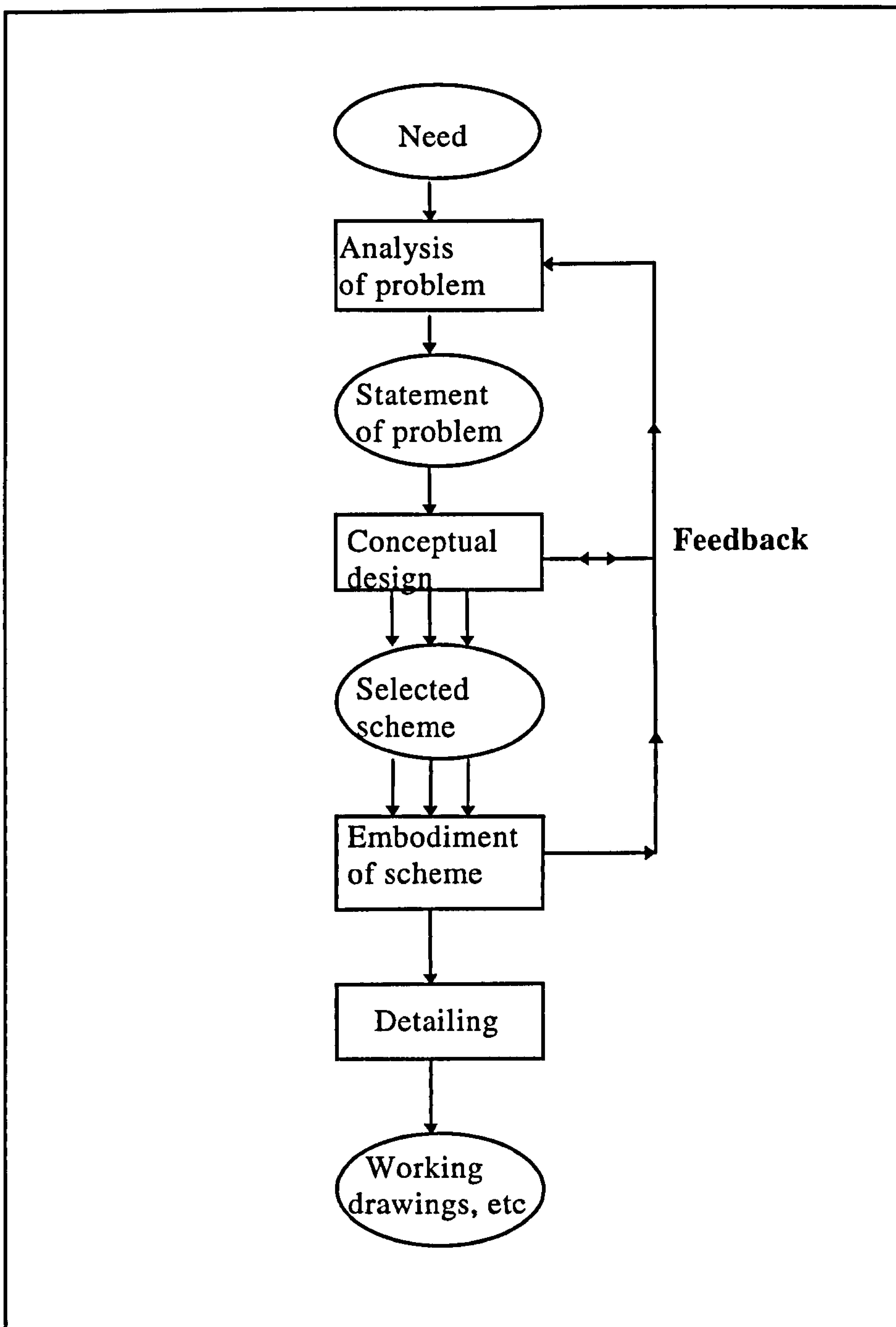

Figure 11 The phases of the design process (from French)

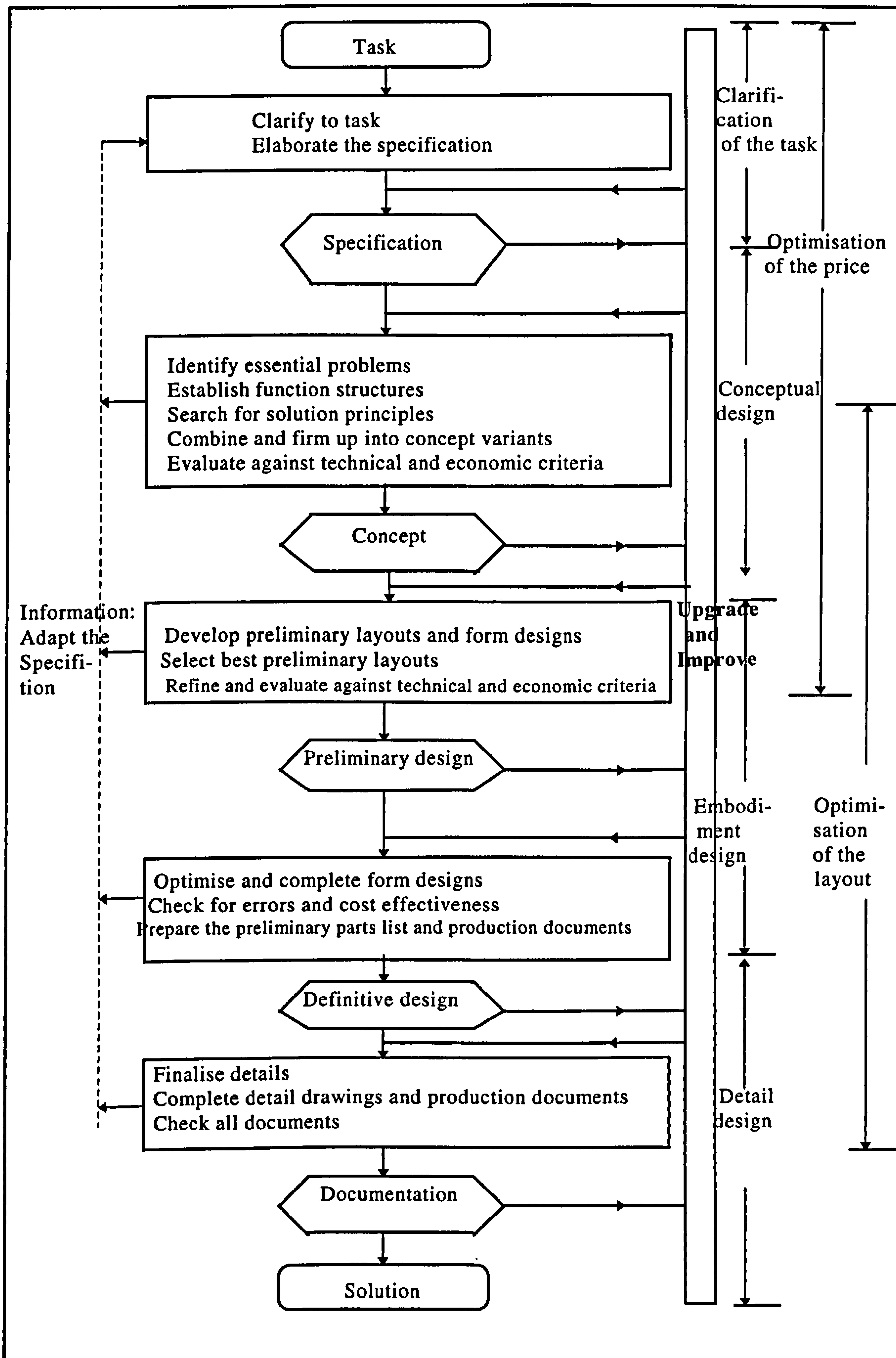

Figure 12 The phases of the design process (from Pahl and Beitz)

Figure 13 The relation of the facilitation issues to the NPDD process
(from Peters *et.al.*)

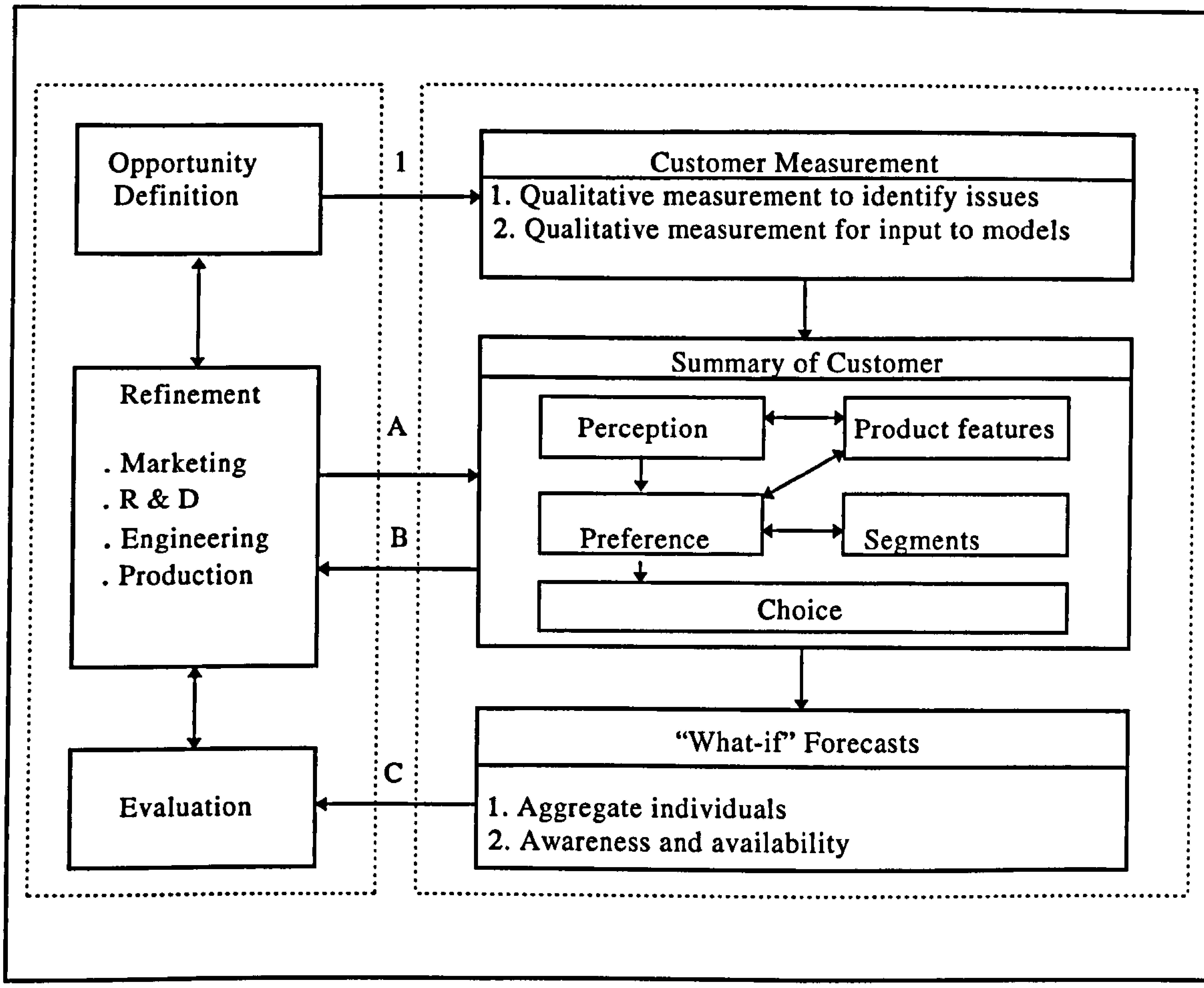

Figure 14 New product designing process (from Urban and Hauser)

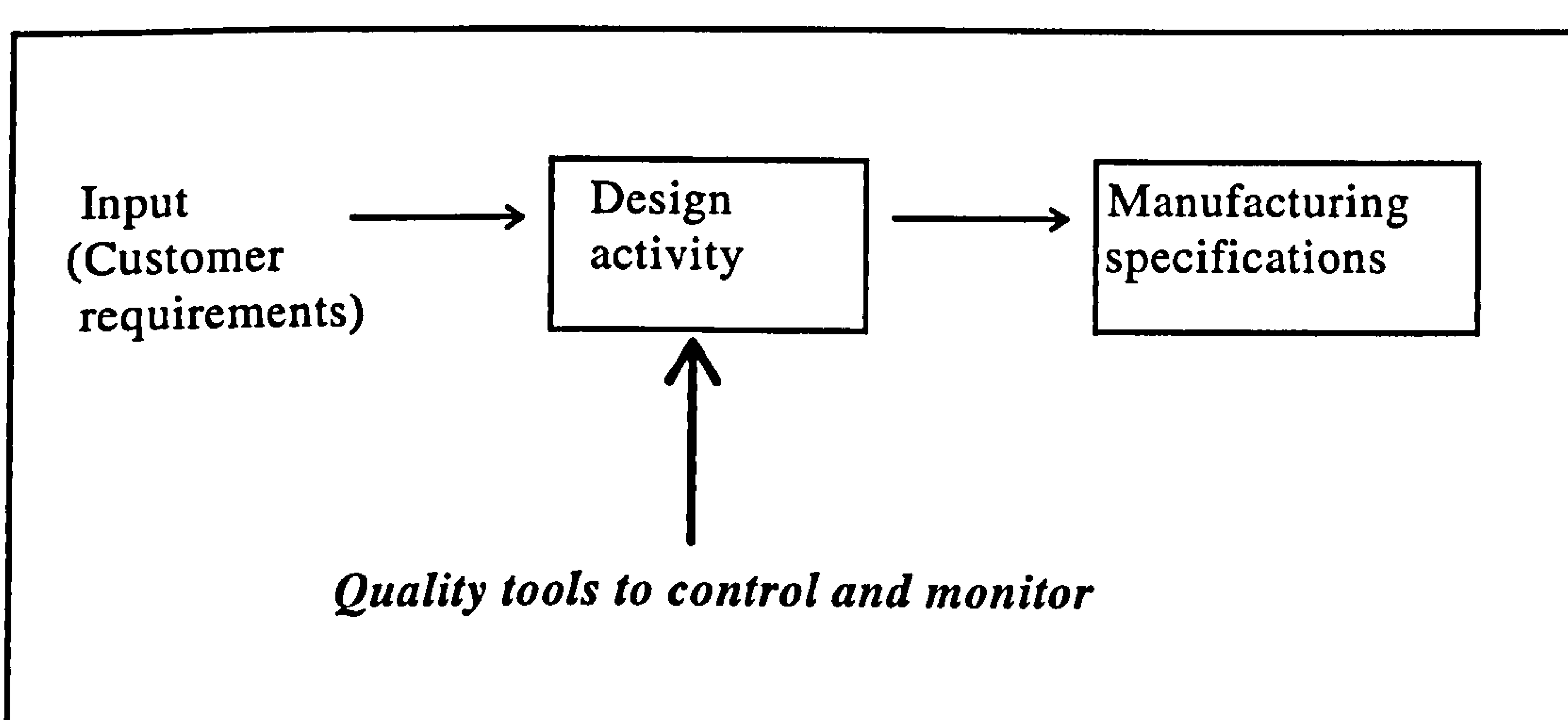

Figure 15 Functional role of quality tools in product design process

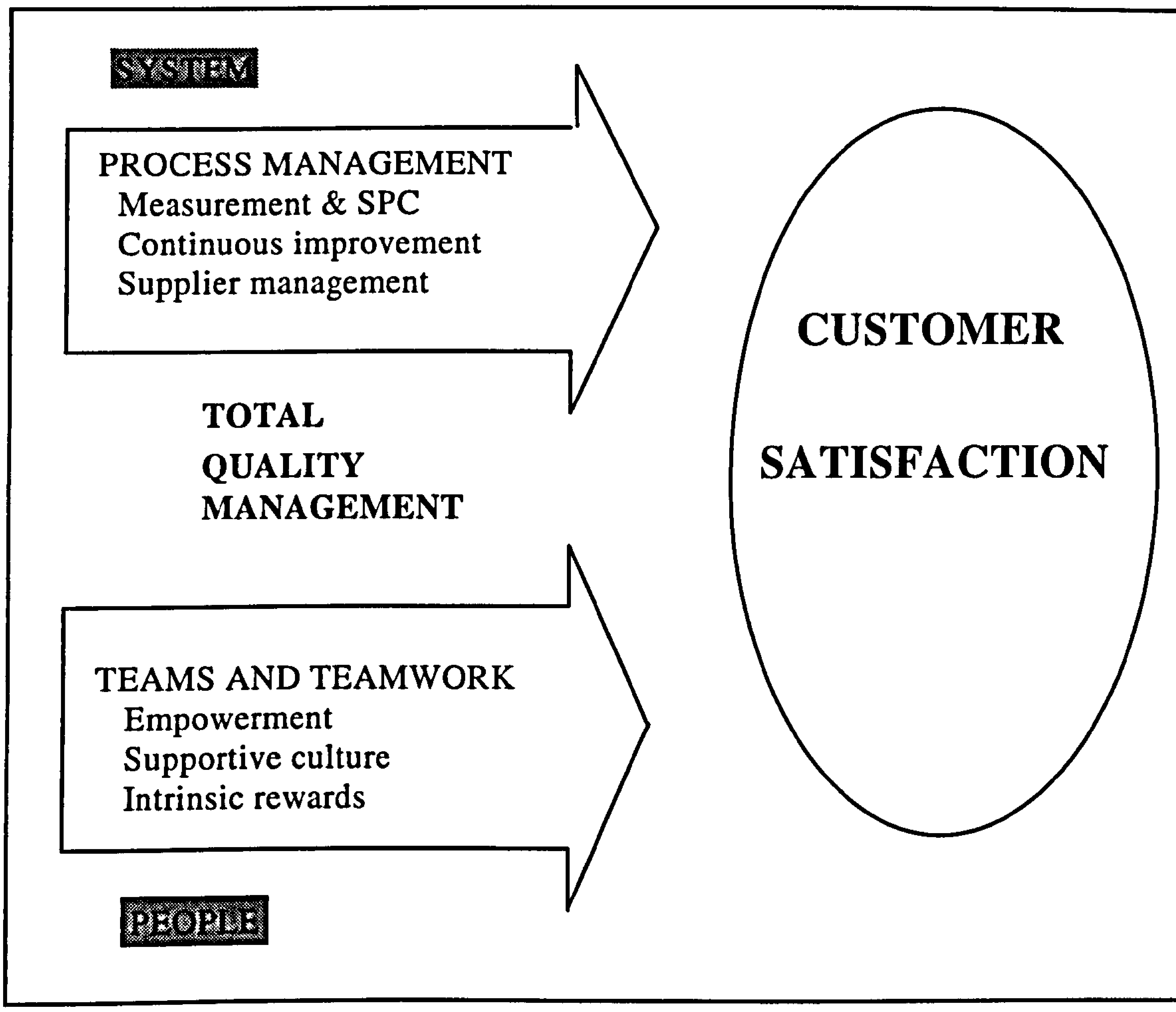

Figure 16 TQM's concerns and focuses (adapted from Cordata and Woods)

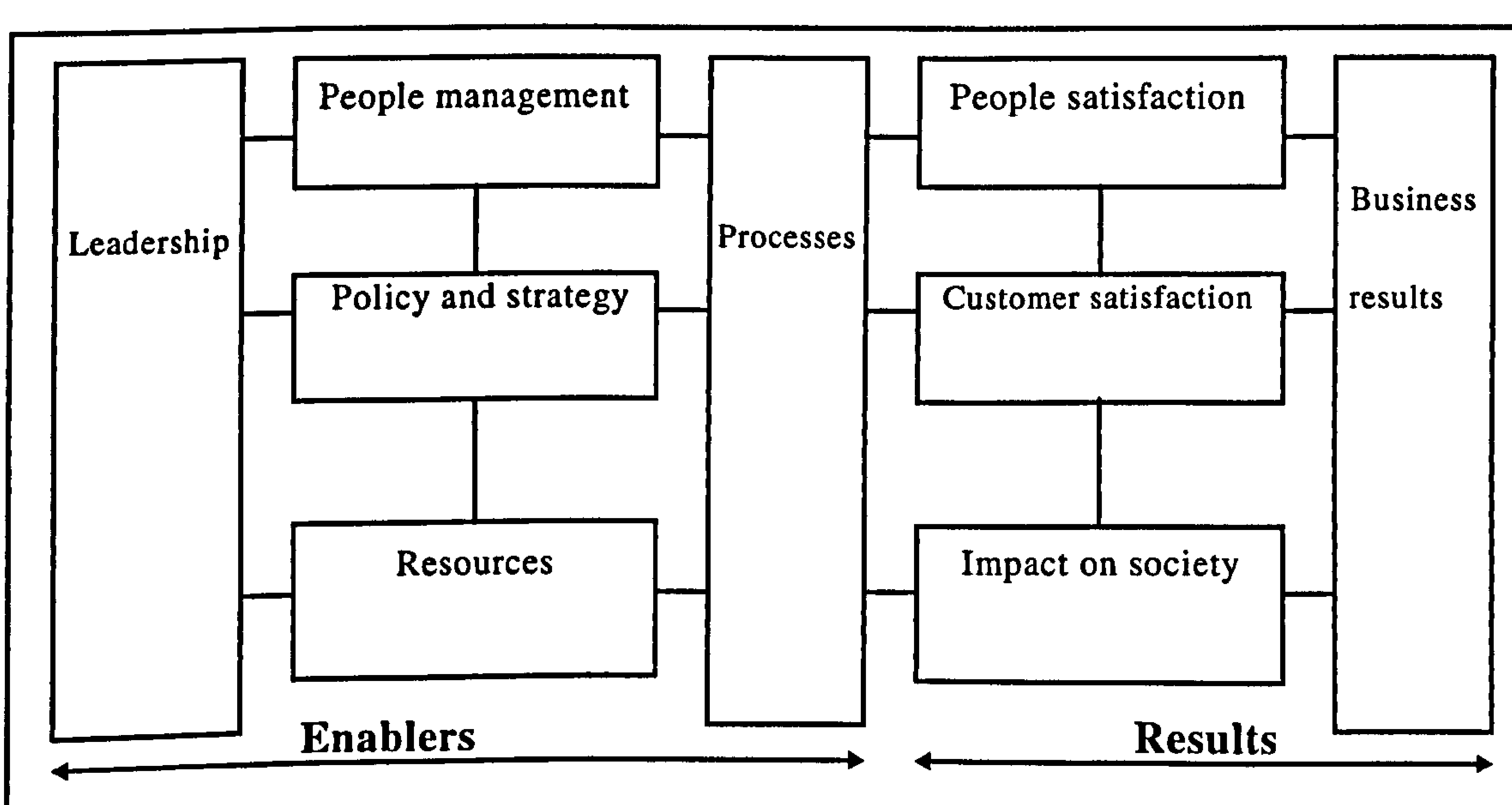

Figure 17 The European award self-assessment model

Overview/Approach (Road map)	ISO 9000-1: 1994 Guidelines for selection and use
Quality management	ISO 9004-1: 1994 Quality management guidelines
Minimum requirements	ISO 9001: 1994 Quality system model for quality assurance
Application (Guide)	ISO 9000-2: 1994 Guidelines for application of ISO 9001, ISO 9002 and ISO 9003
Additional standards	ISO 9000 parts 3, ... ISO 9004 parts 2, 3, ... ISO 10011, 12 .... Supplemental standards

Figure 18 Integrated relationship of ISO 9000 family of Interanational Standards (adapted from Peach)

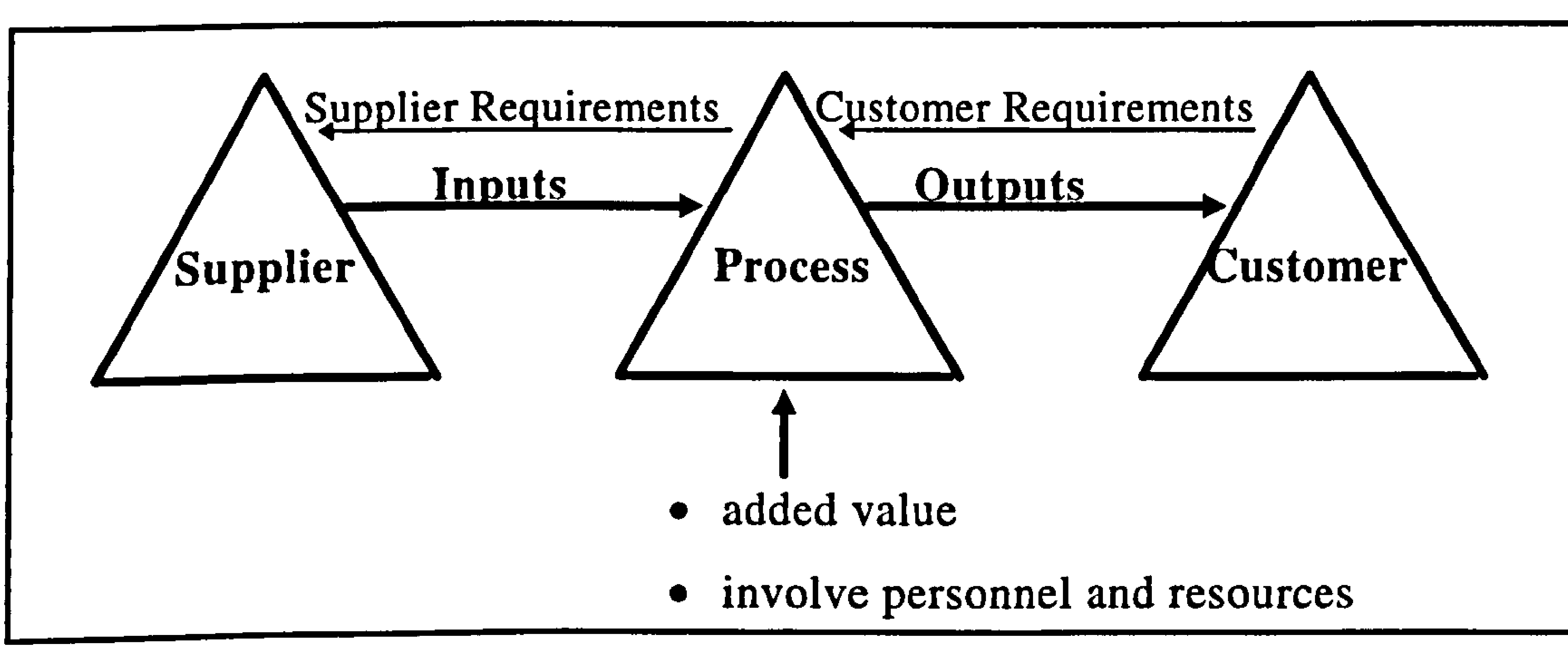

Figure 19 The customer-supplier model in the ISO 9000 approach (adapted from Beaumont, 1995)

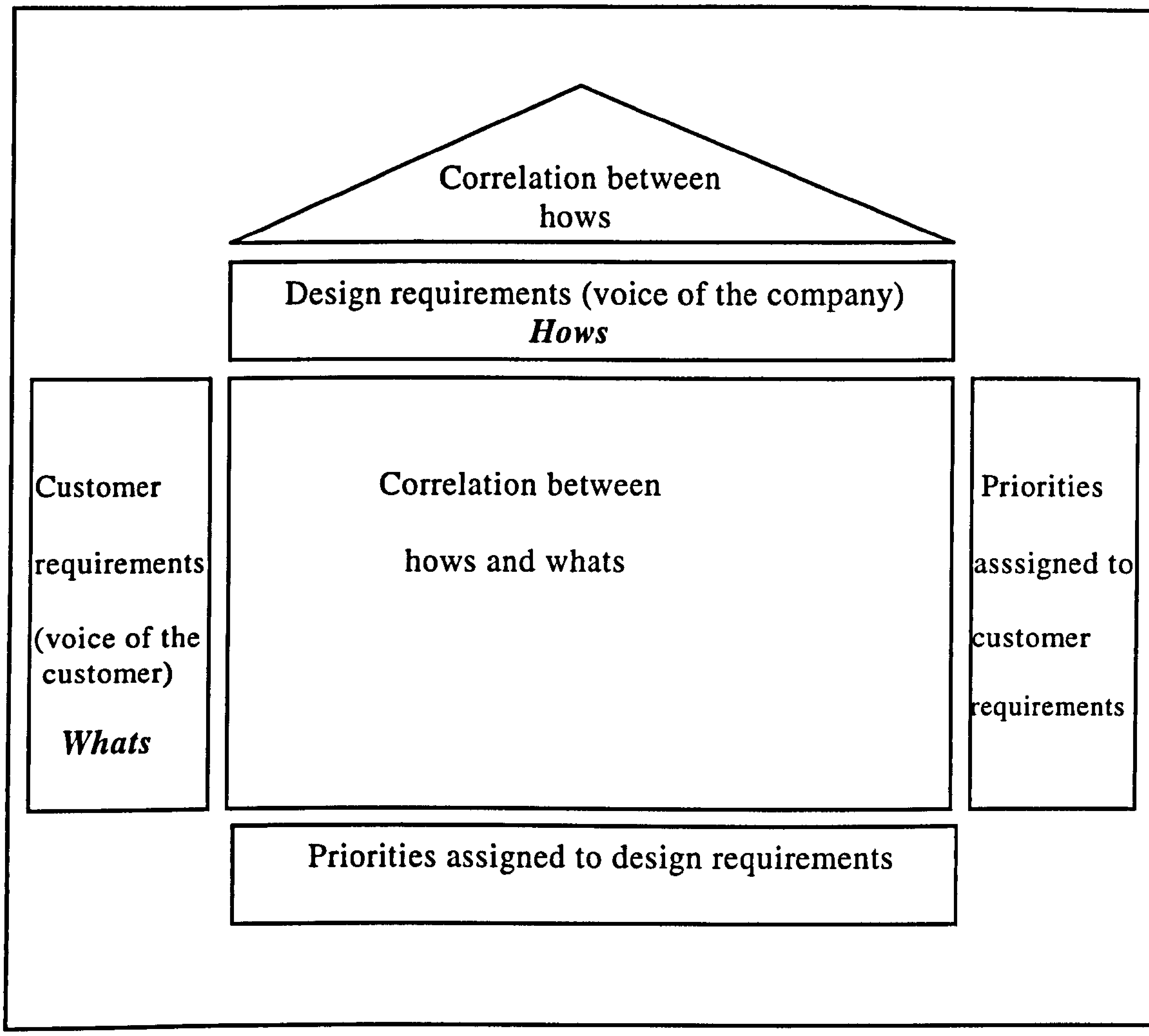

Figure 20 Basic components of QFD (from Zairie and Youssef)

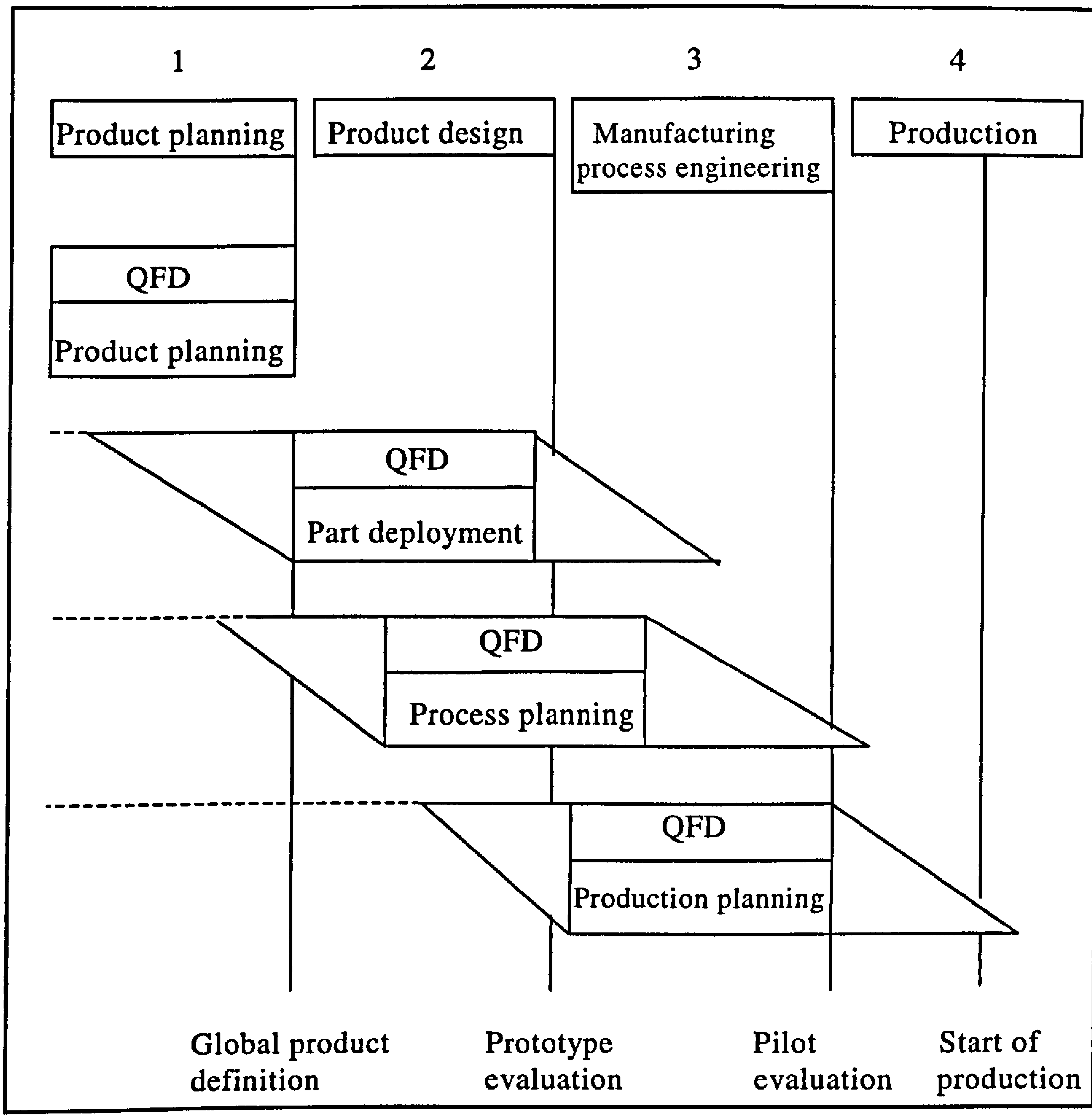

Figure 21 The product development cycle and QFD - key events (cited by Lochamy and Khurana)

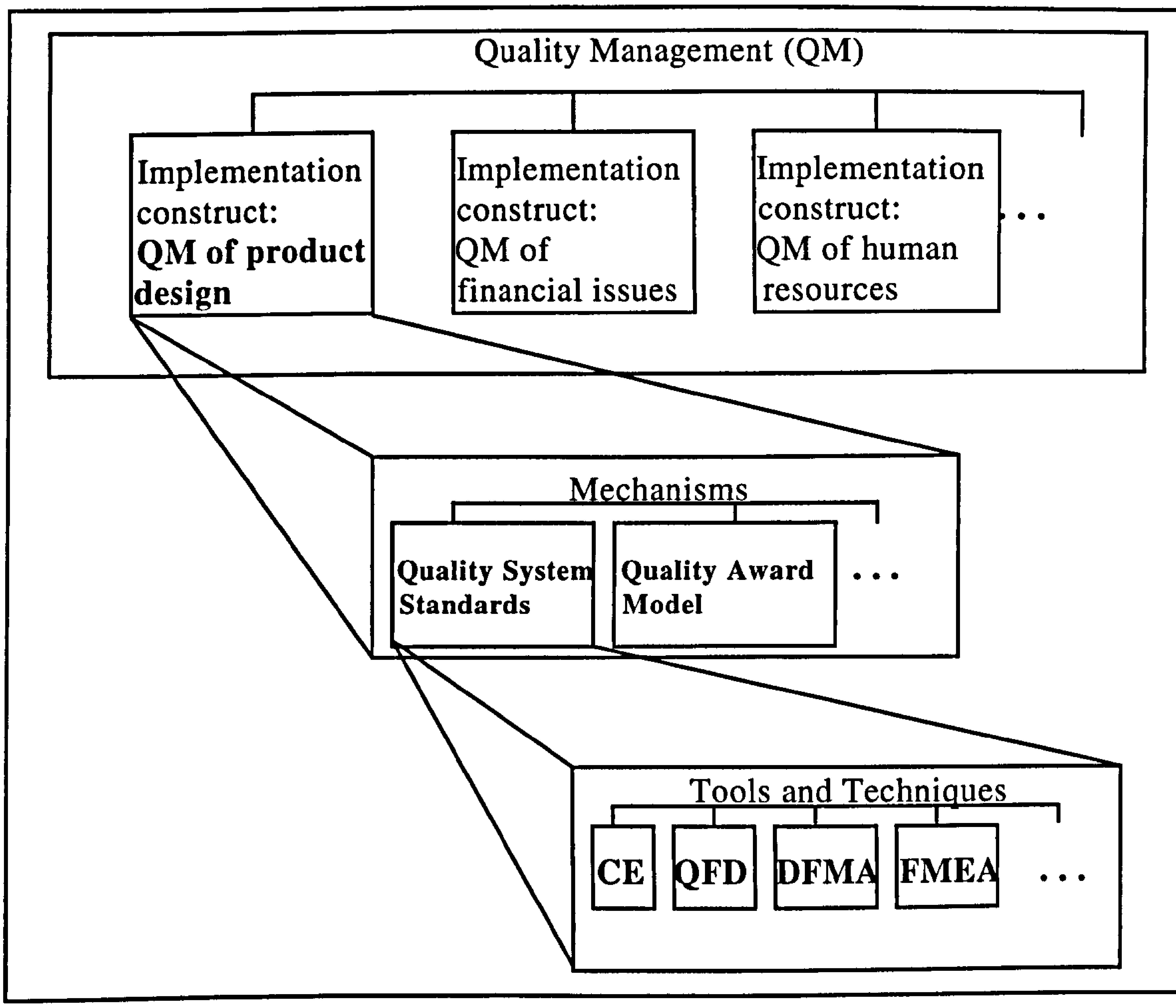

Figure 22 QM and QFD in management of product design practices

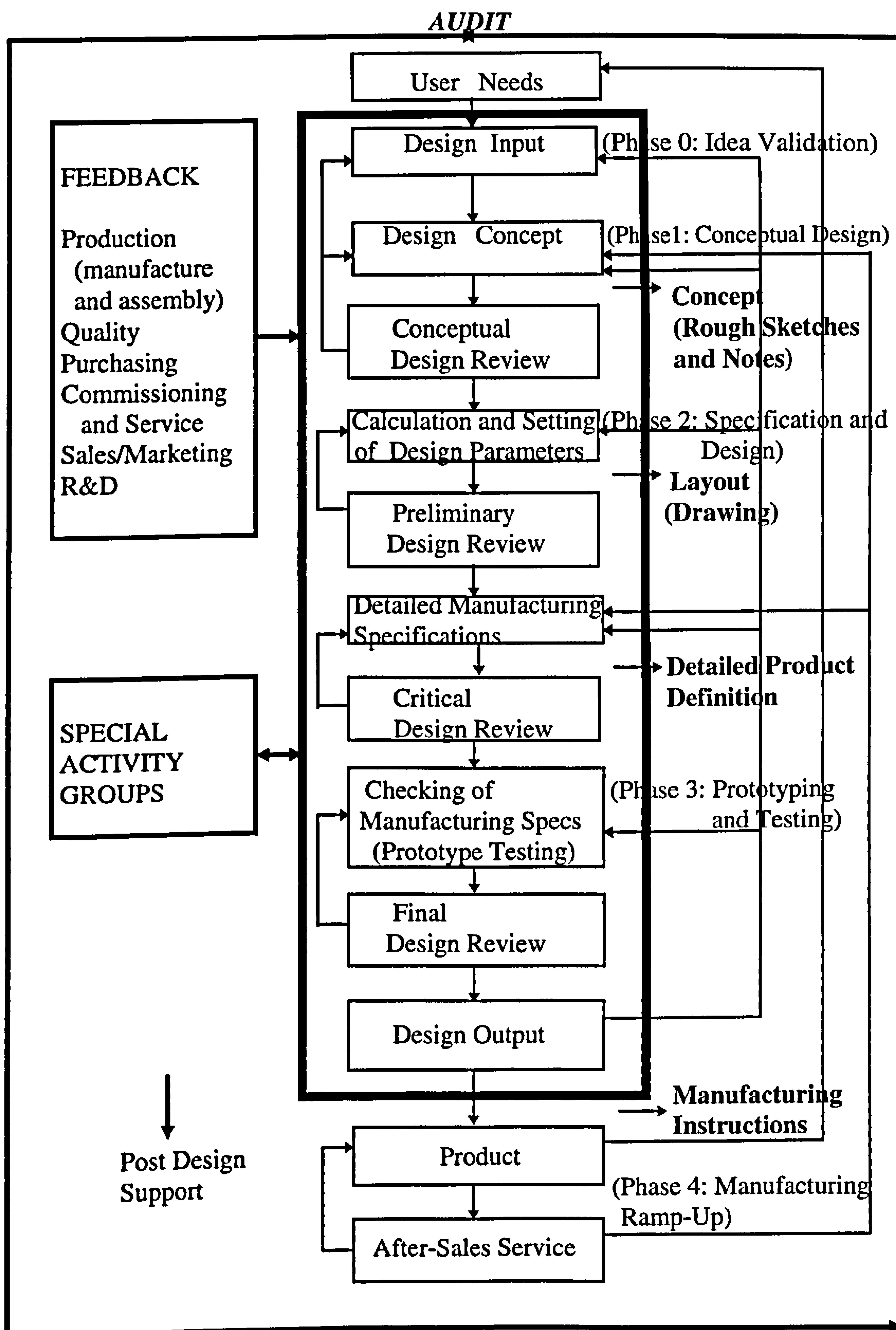

Figure 23 The product design process model and overall relationship with other activities in the SMEs

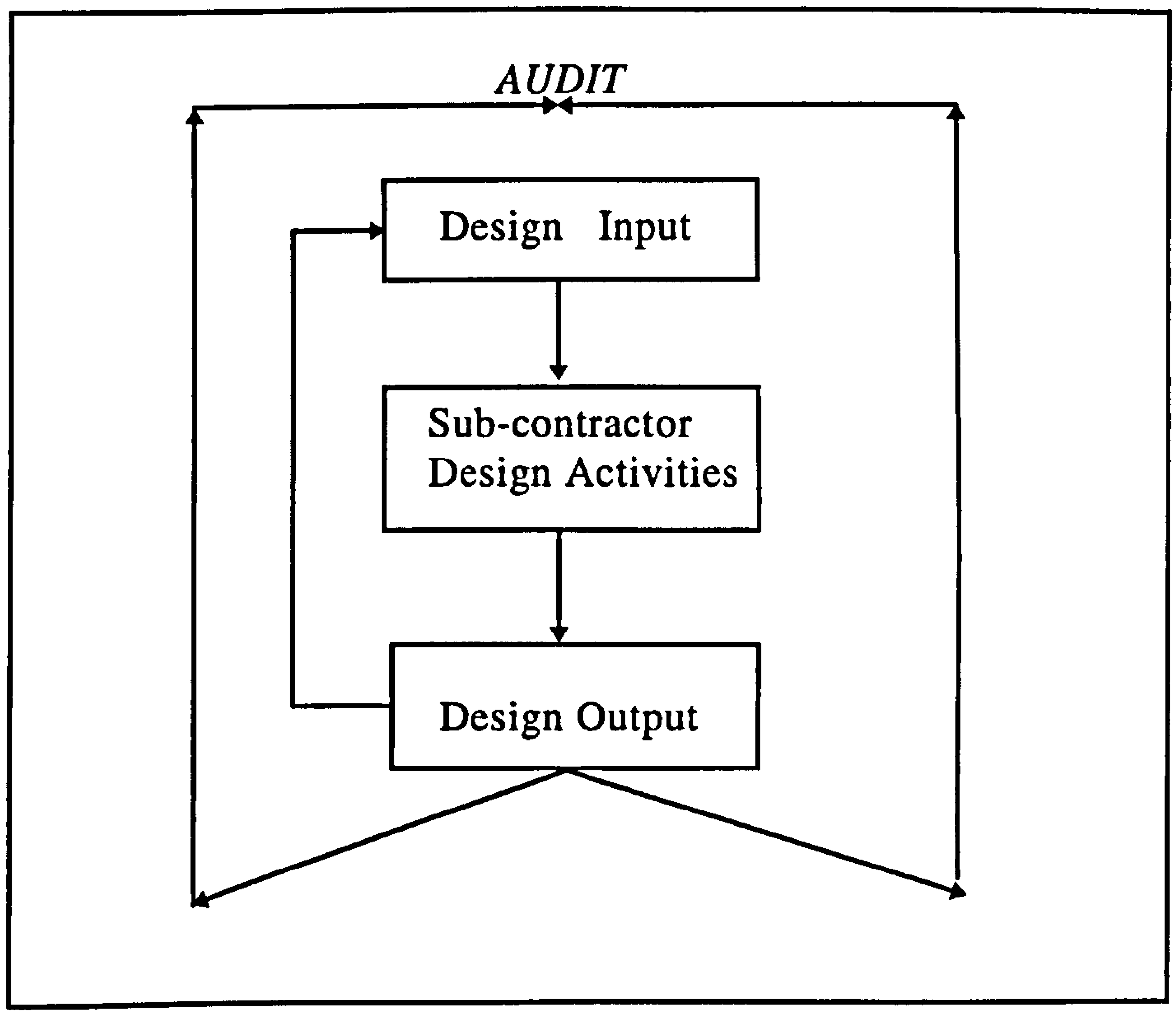

Figure 24 Sub-contractor's product design phases of the SMEs

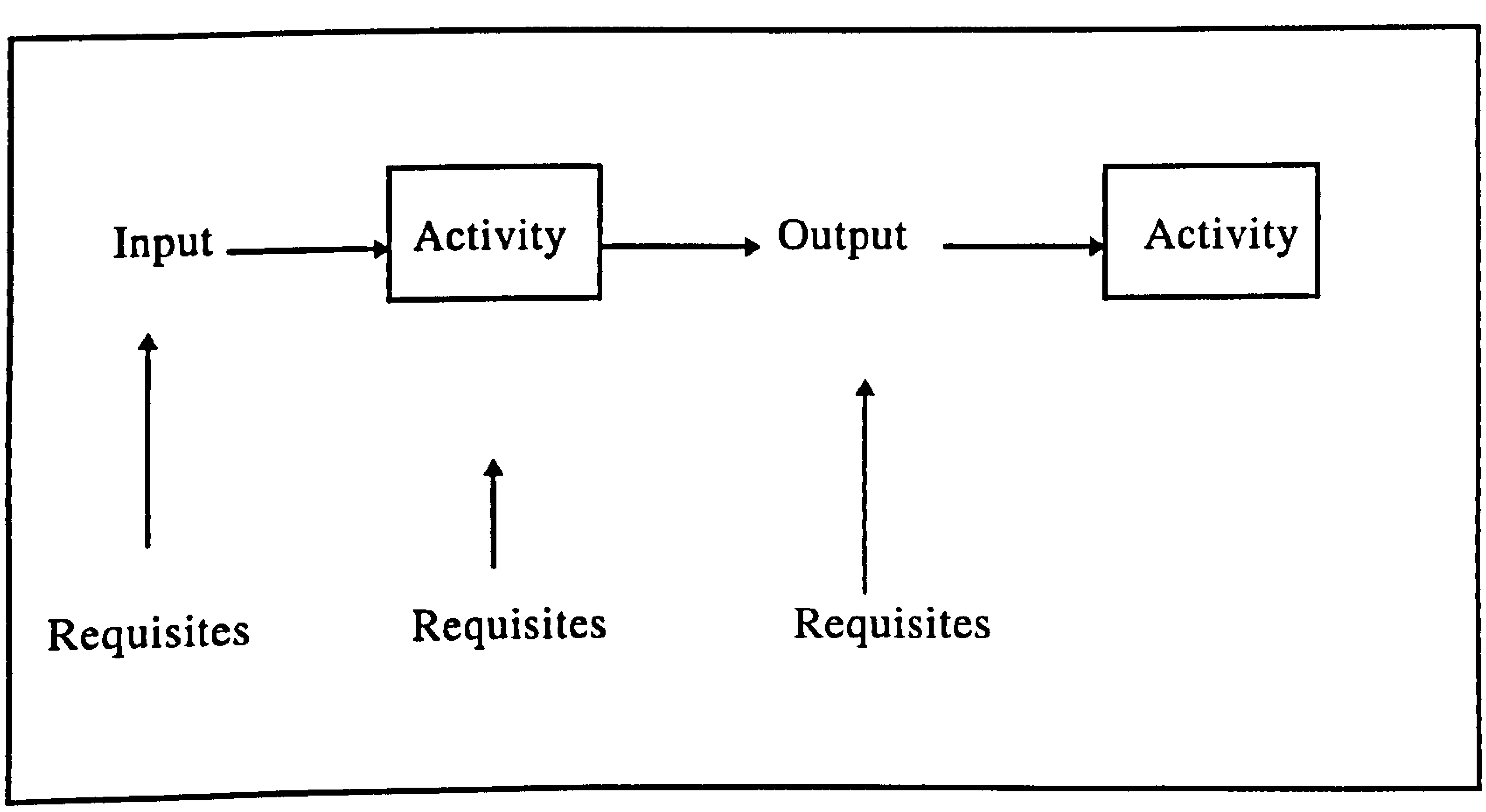

Figure 25 Simplified pattern in the product design information flows

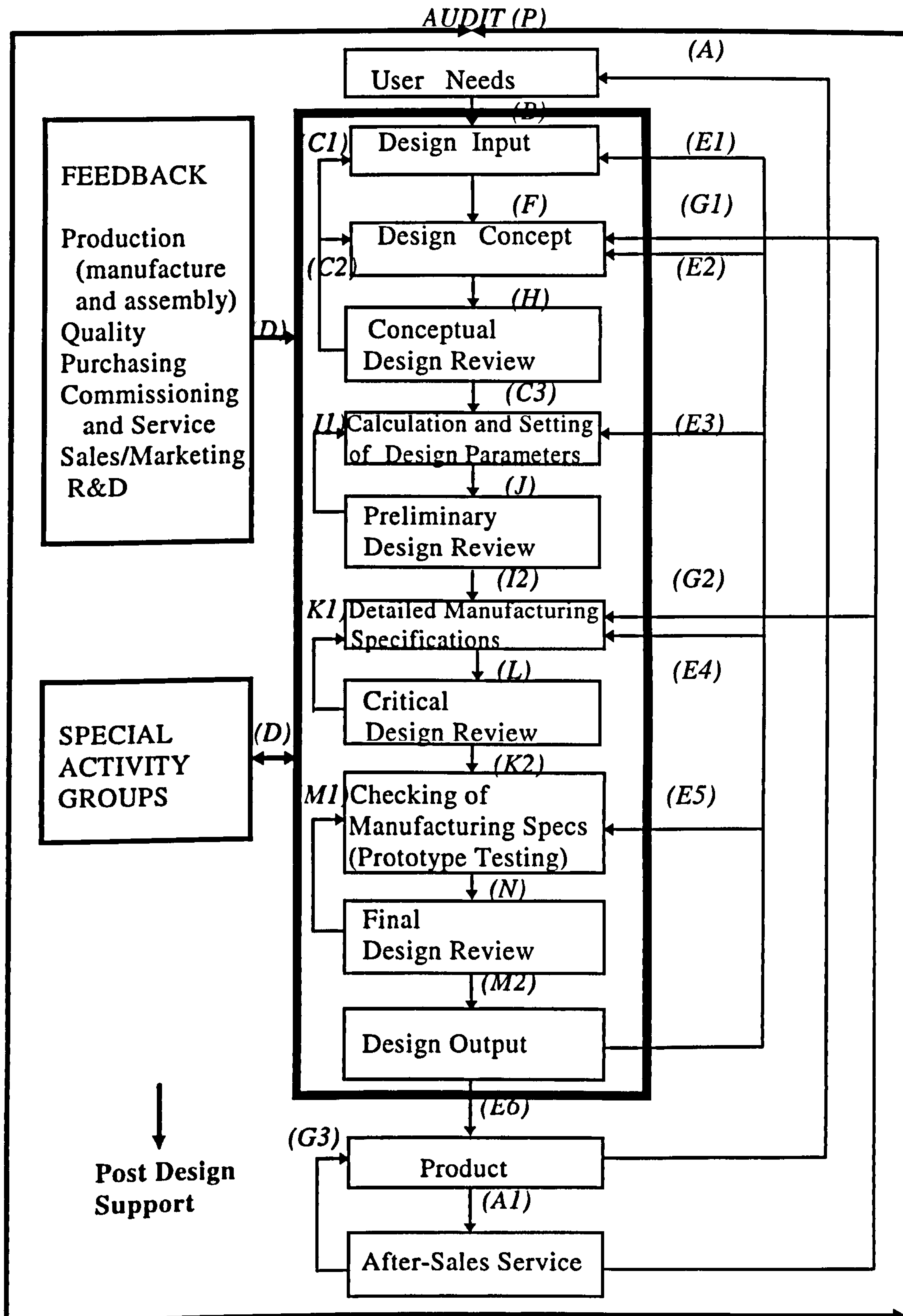

Figure 26 A pattern of design information flows in labels and groups

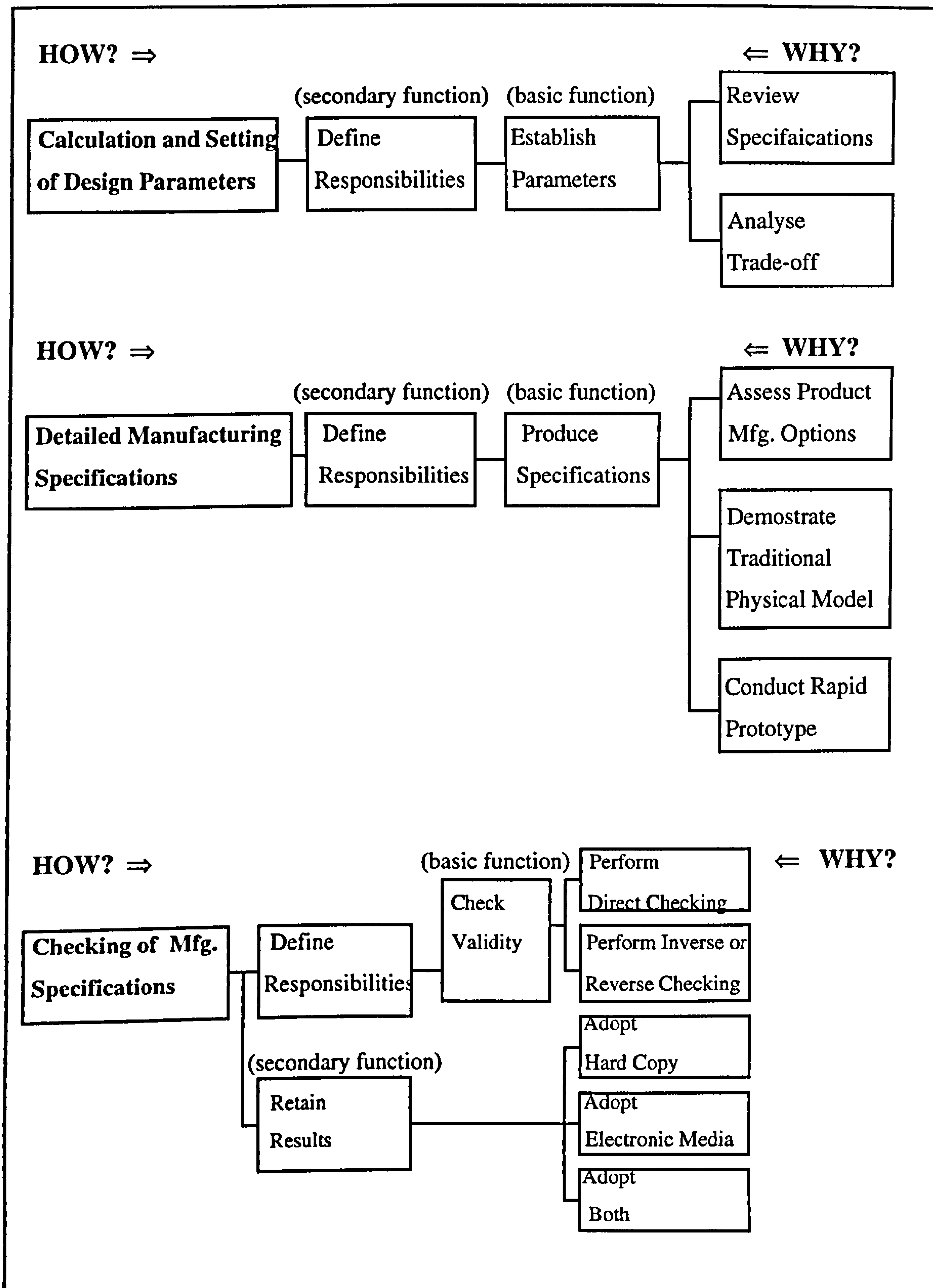

Figure 27 Function analysis system technique (FAST) diagram for some design stages

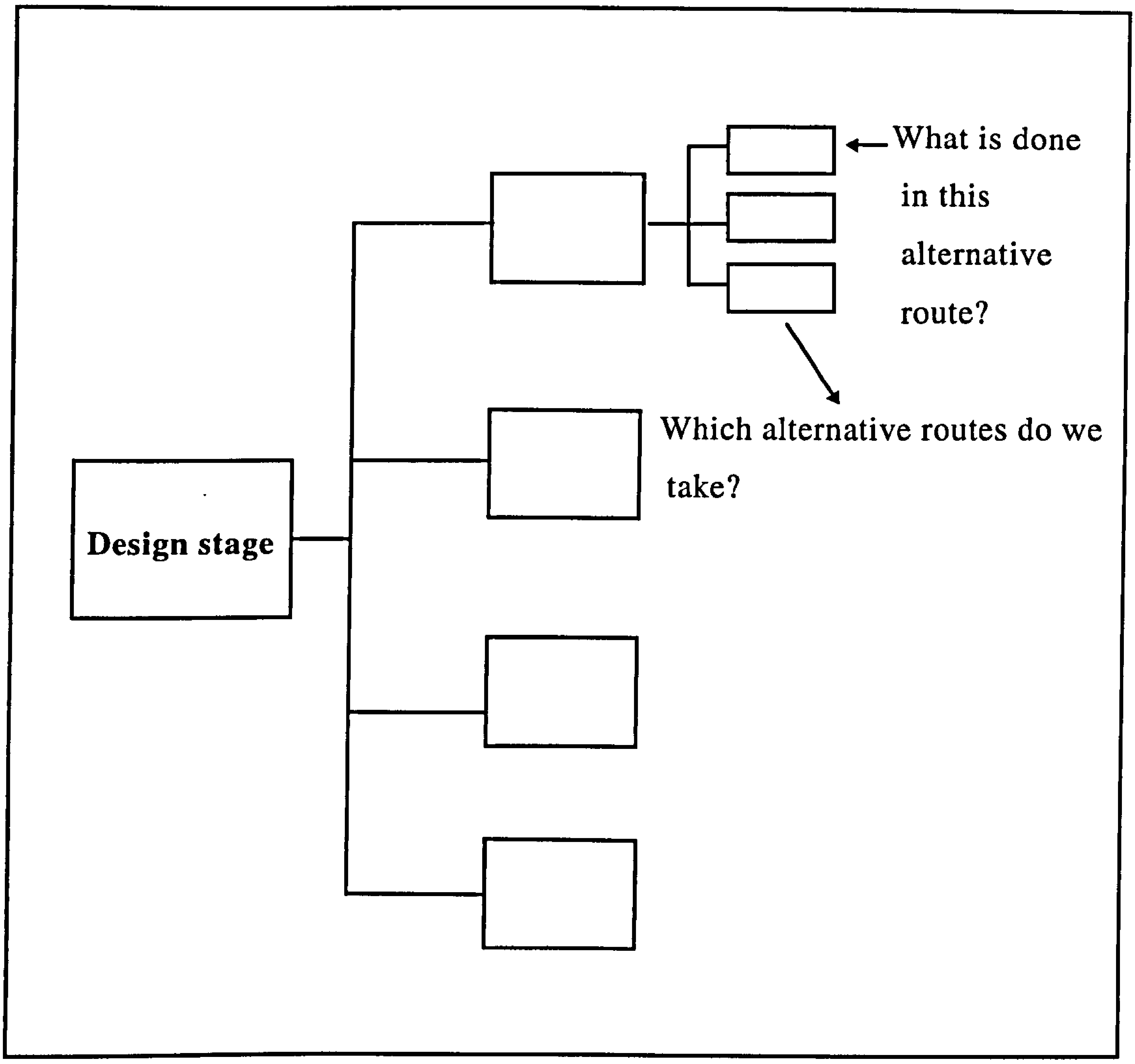

Figure 28 Evaluation of cost for a design stage using FAST technique

- *Design Input*

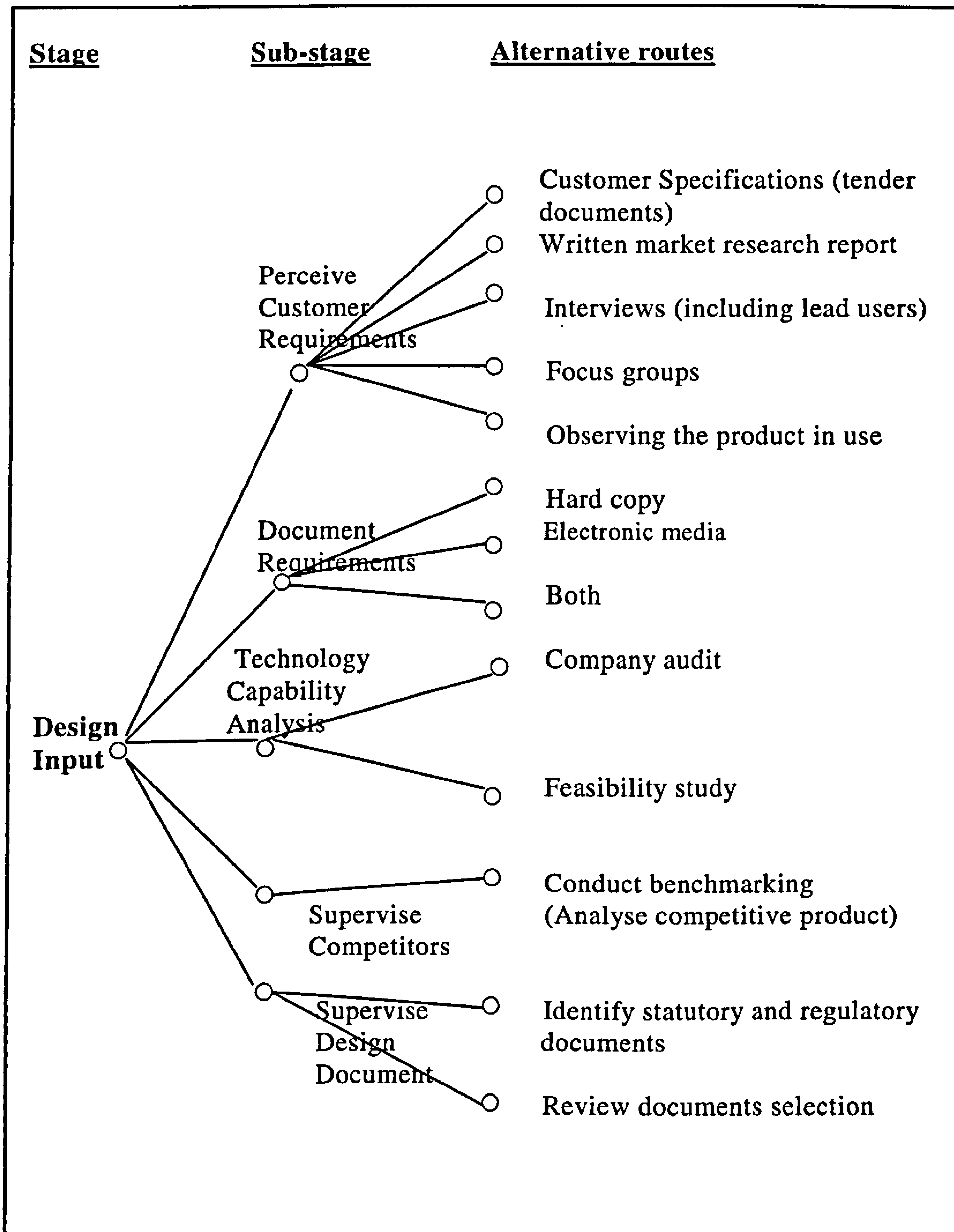

Figure 29 Evaluation of cost for the "Design Input" stage using FAST technique

- ***Design Concept***

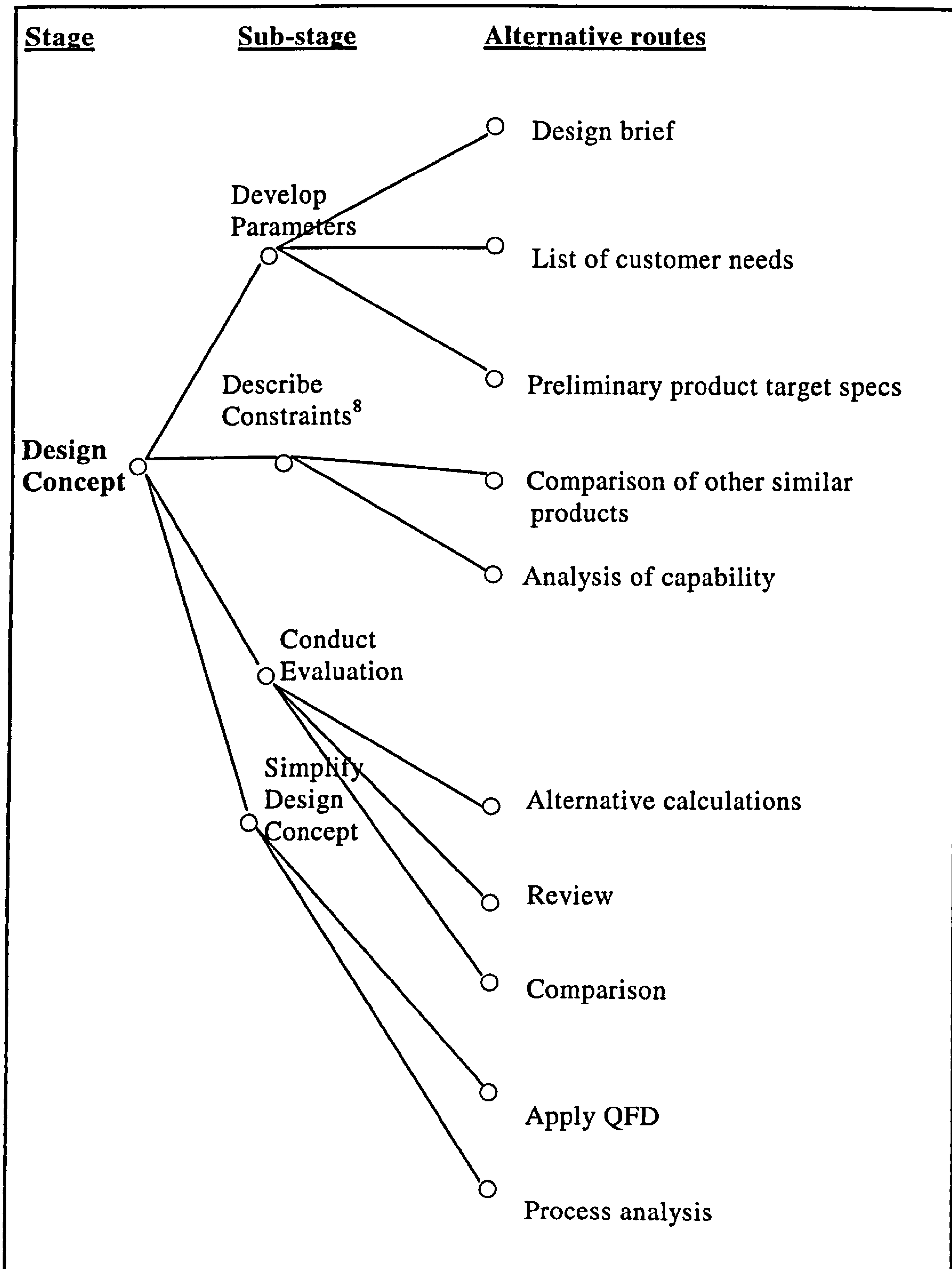

Figure 30 Evaluation of cost for the "Design Concept" stage using FAST technique

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[8] Constraints include technology, funding, resources, and pattern, etc.

- ***Design Review***

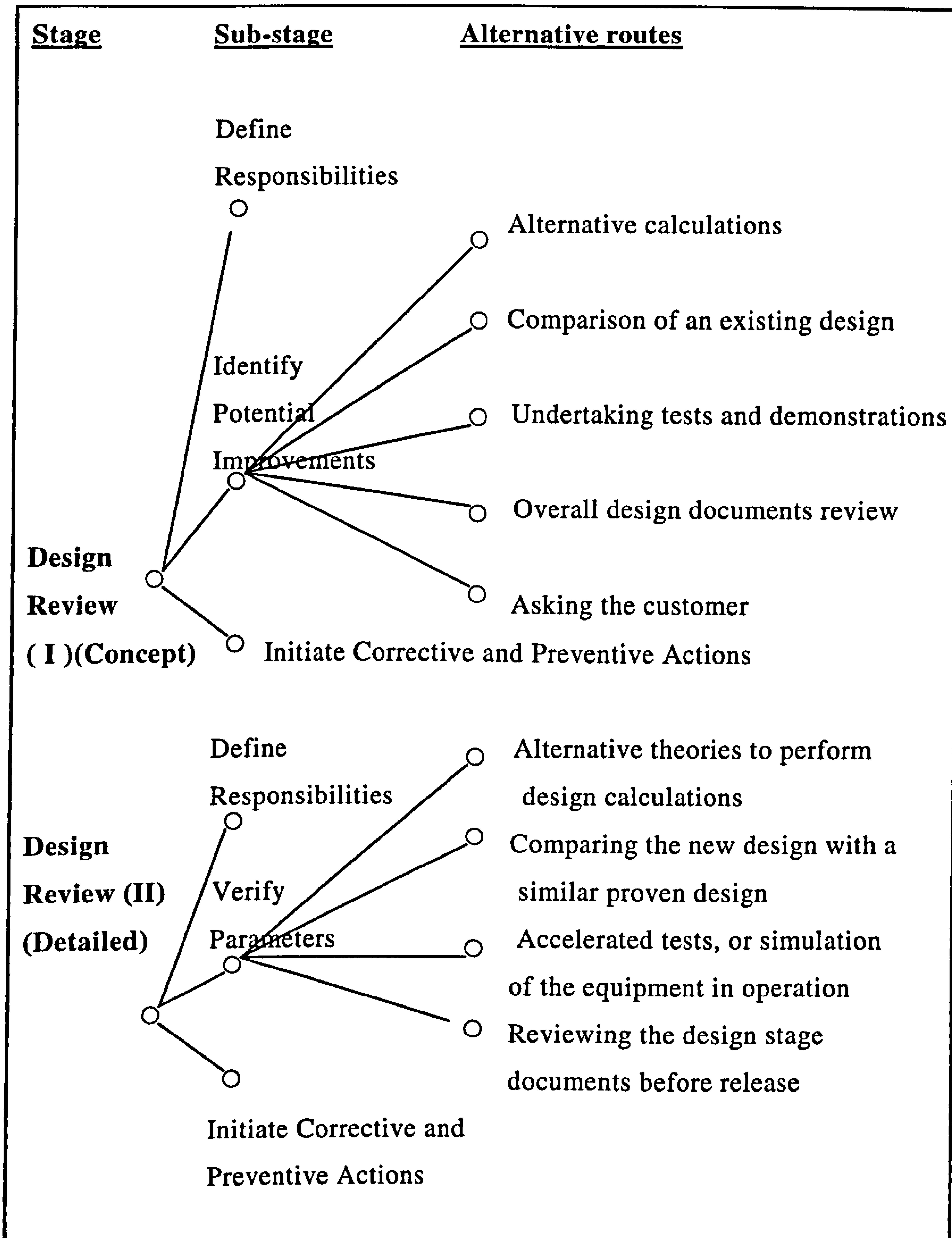

Figure 31 Evaluation of cost for the "Design Review I" and "Design Review II" stages using FAST technique

- ***Calculation and Setting of Design Paramenters***

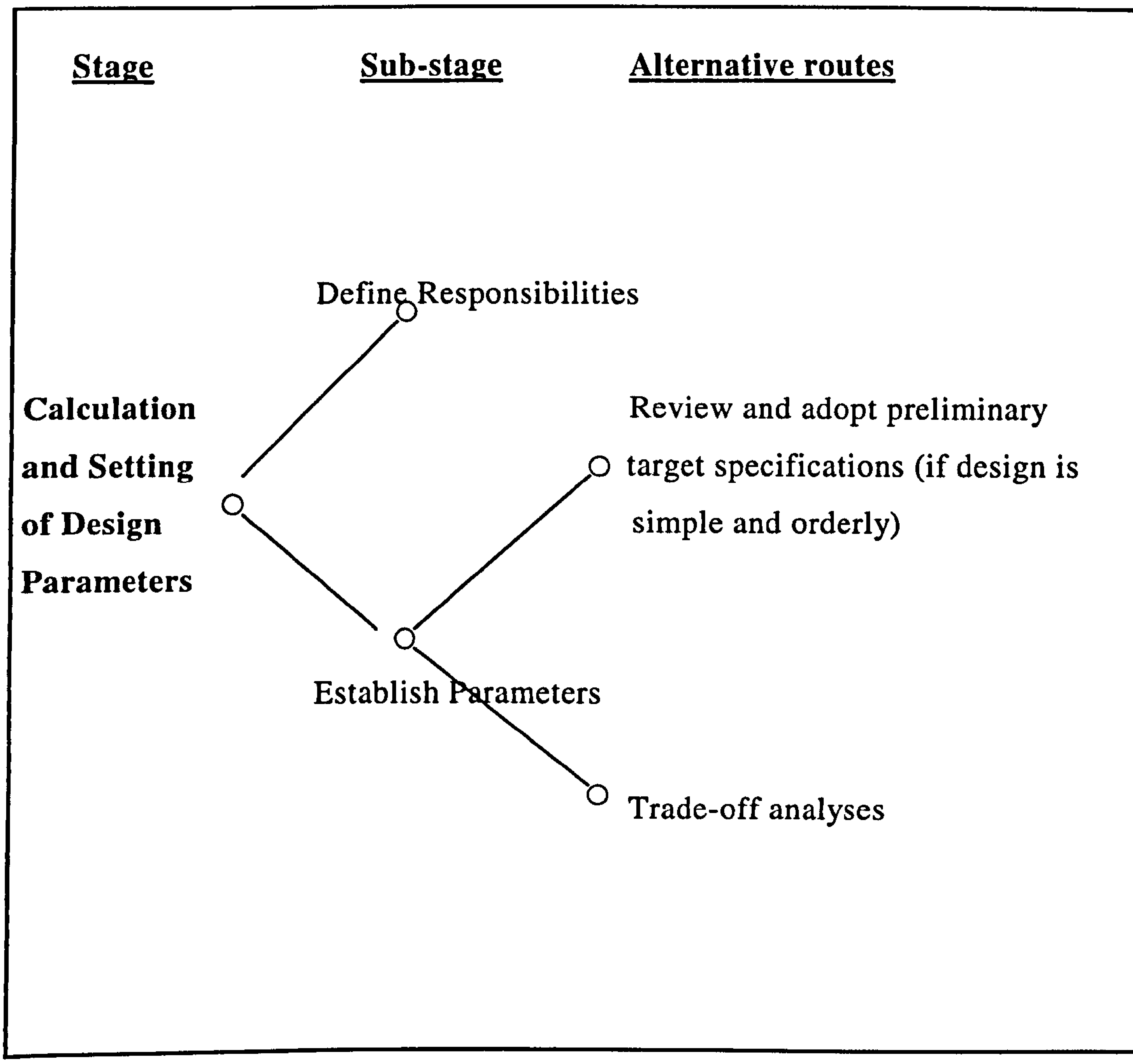

Figure 32 Evaluation of cost for the "Calculations and Setting of Design Parameters" stage using FAST technique

- ***Detailed Manufacturing Specifications***

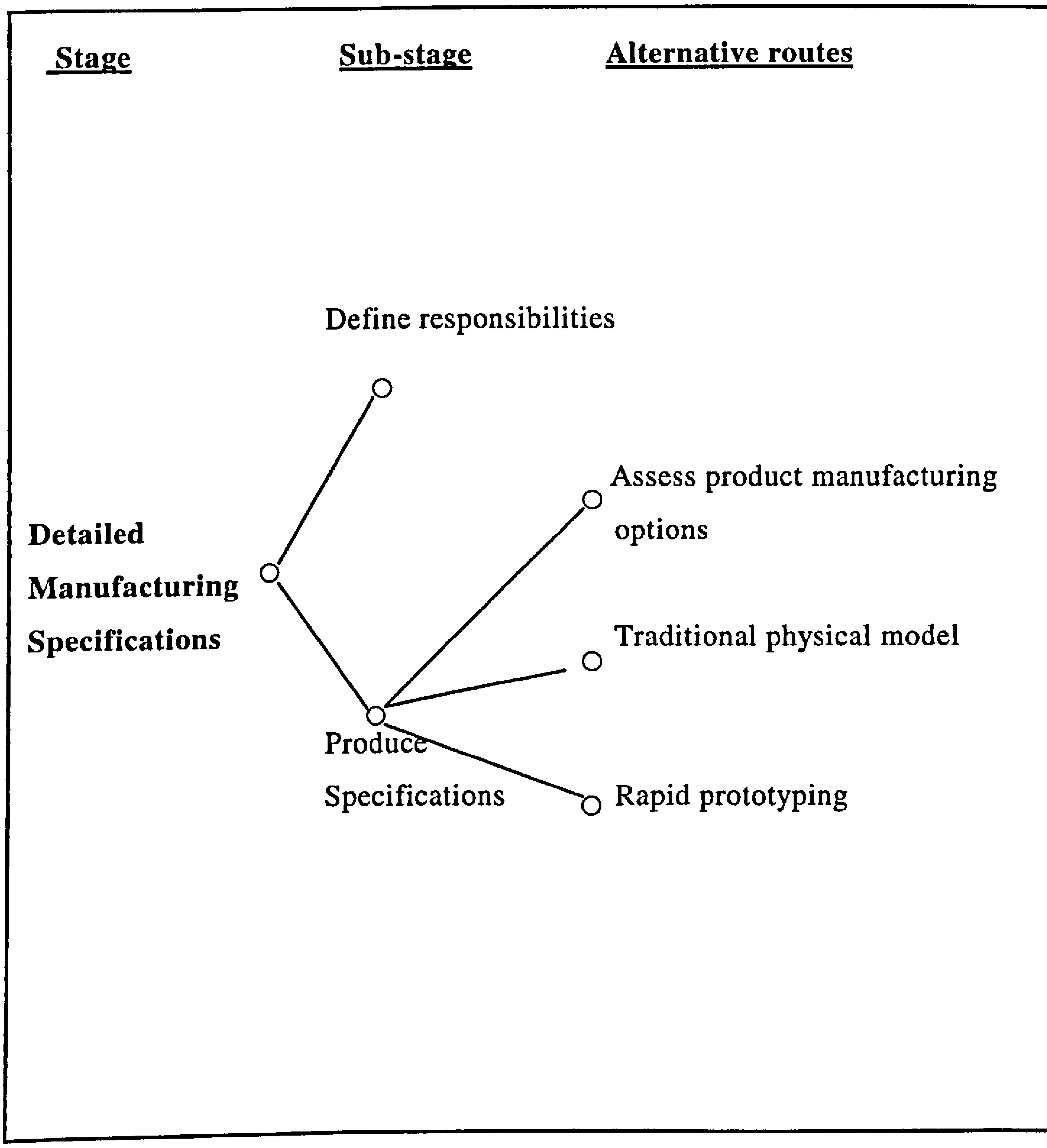

Figure 33 Evaluation of cost for the "Detailed Manufacturing Specifications" stage using FAST technique

- ***Checking of Manufacturing Specifications***

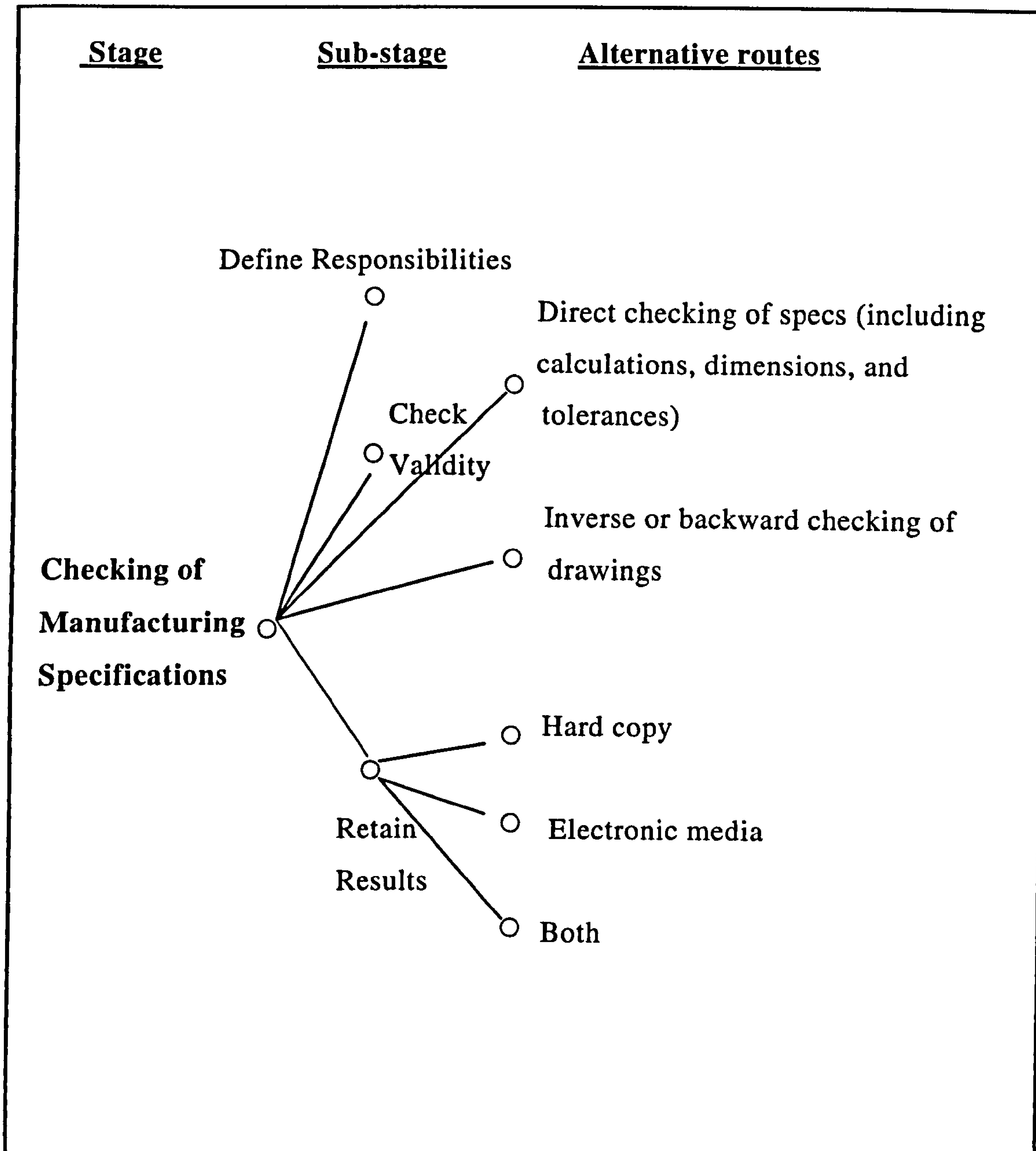

Figure 34 Evaluation of cost for the "Checking of Manufacturing Specifications" stage using FAST technique

- ***Design Output***

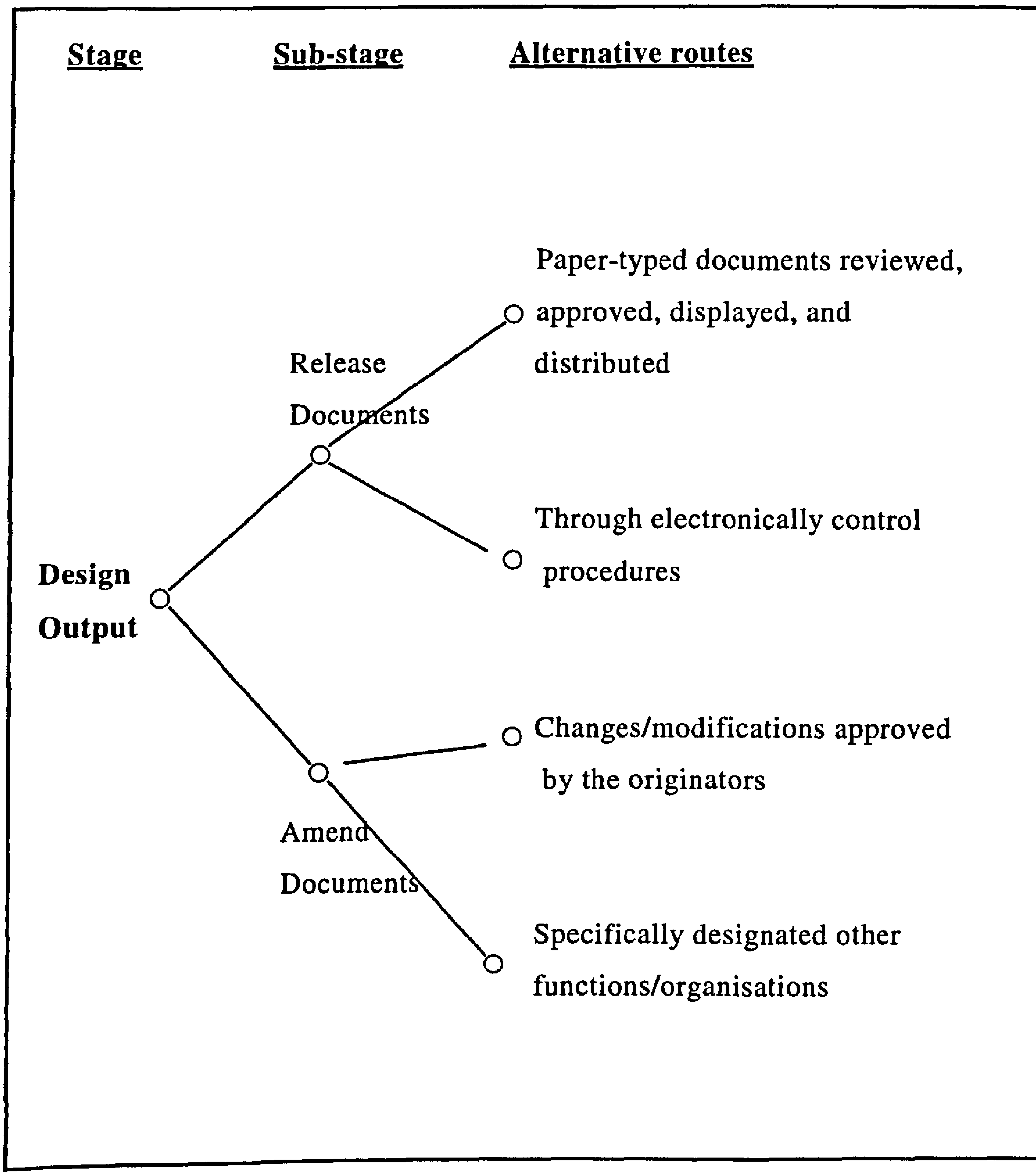

Figure 35 Evaluation of cost for the "Design Output" stage using FAST technique

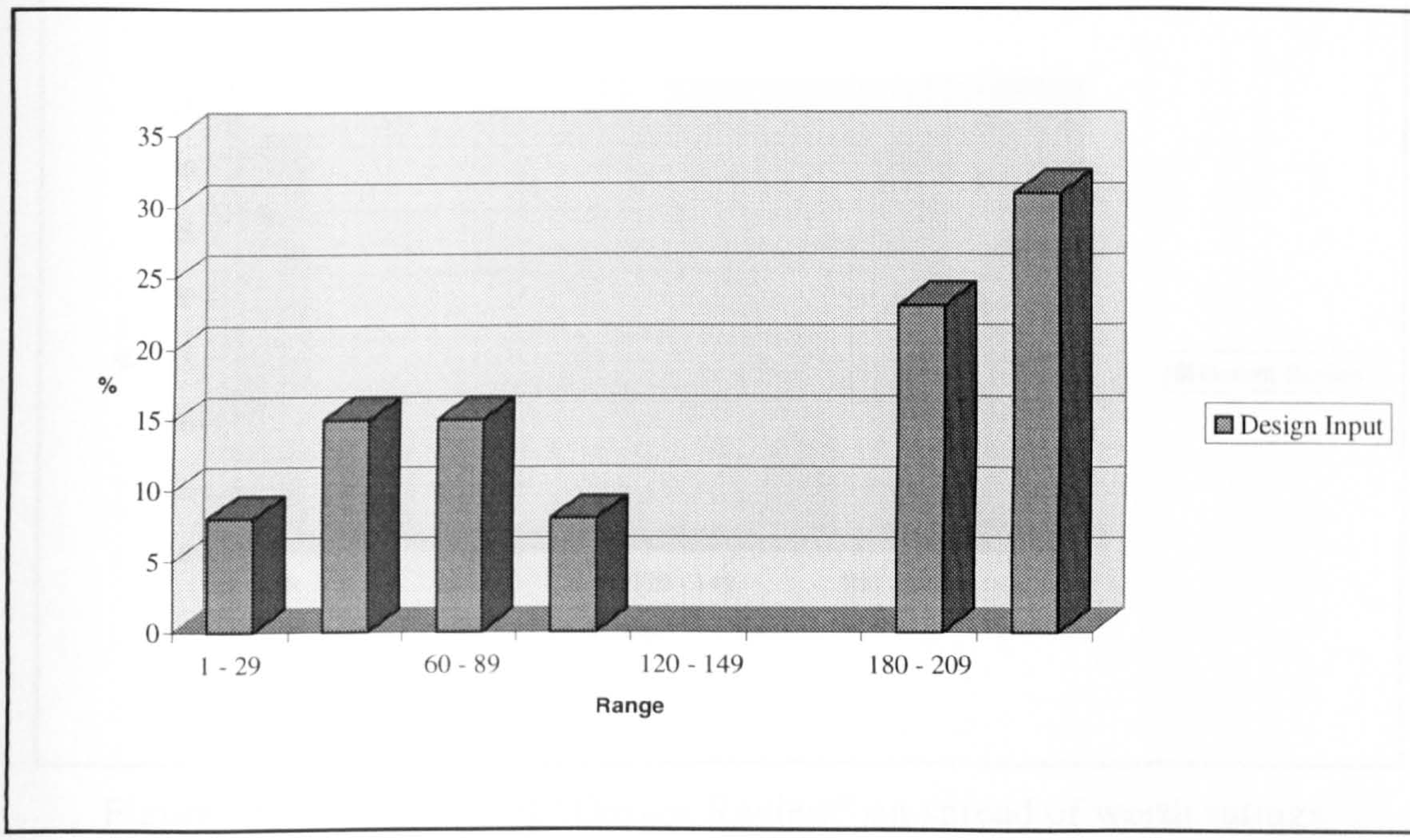

Figure 36 Worth range of "Design Input" on spread of worth ratings

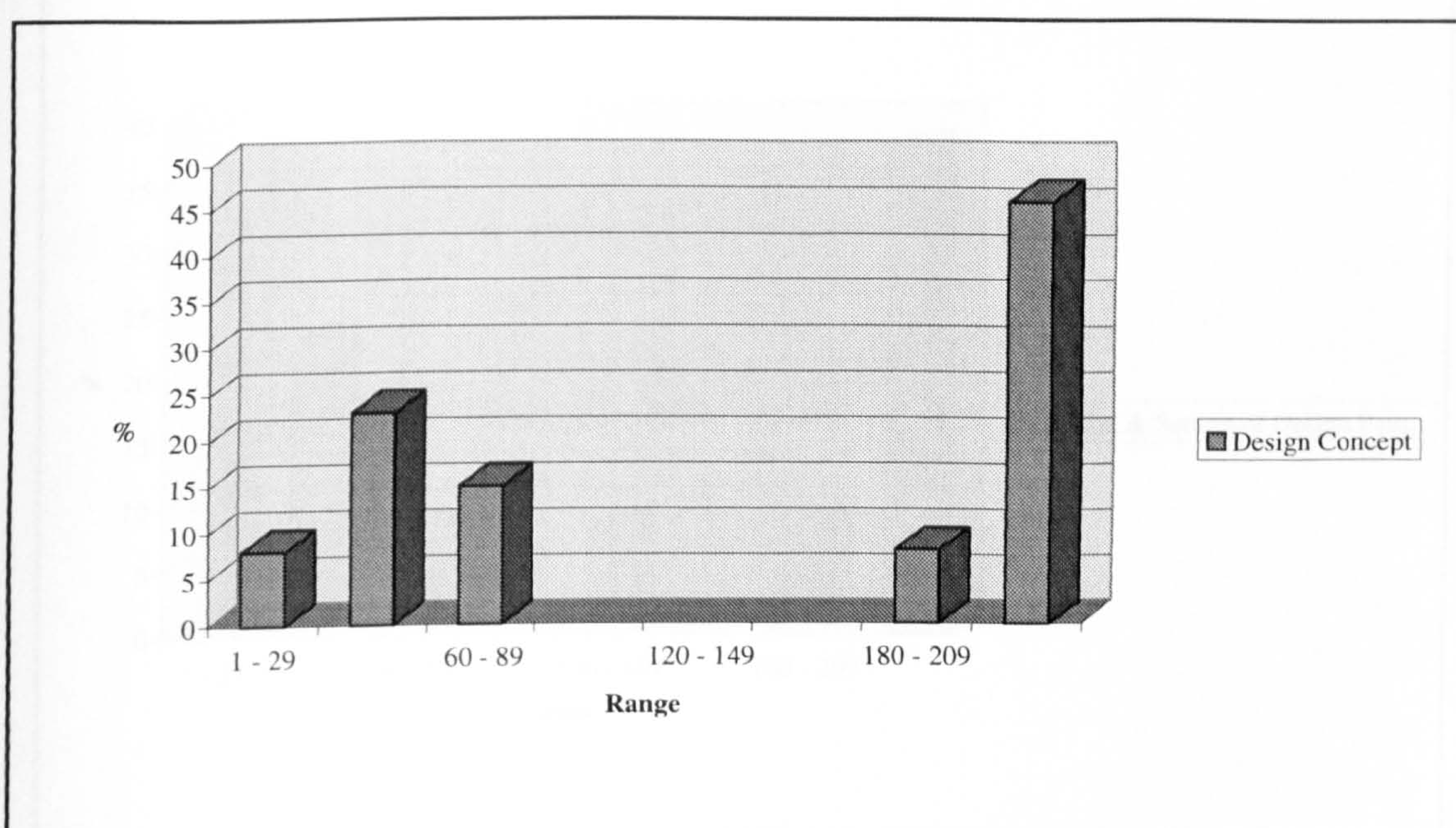

Figure 37 Worth range of "Design Concept" on spread of worth ratings

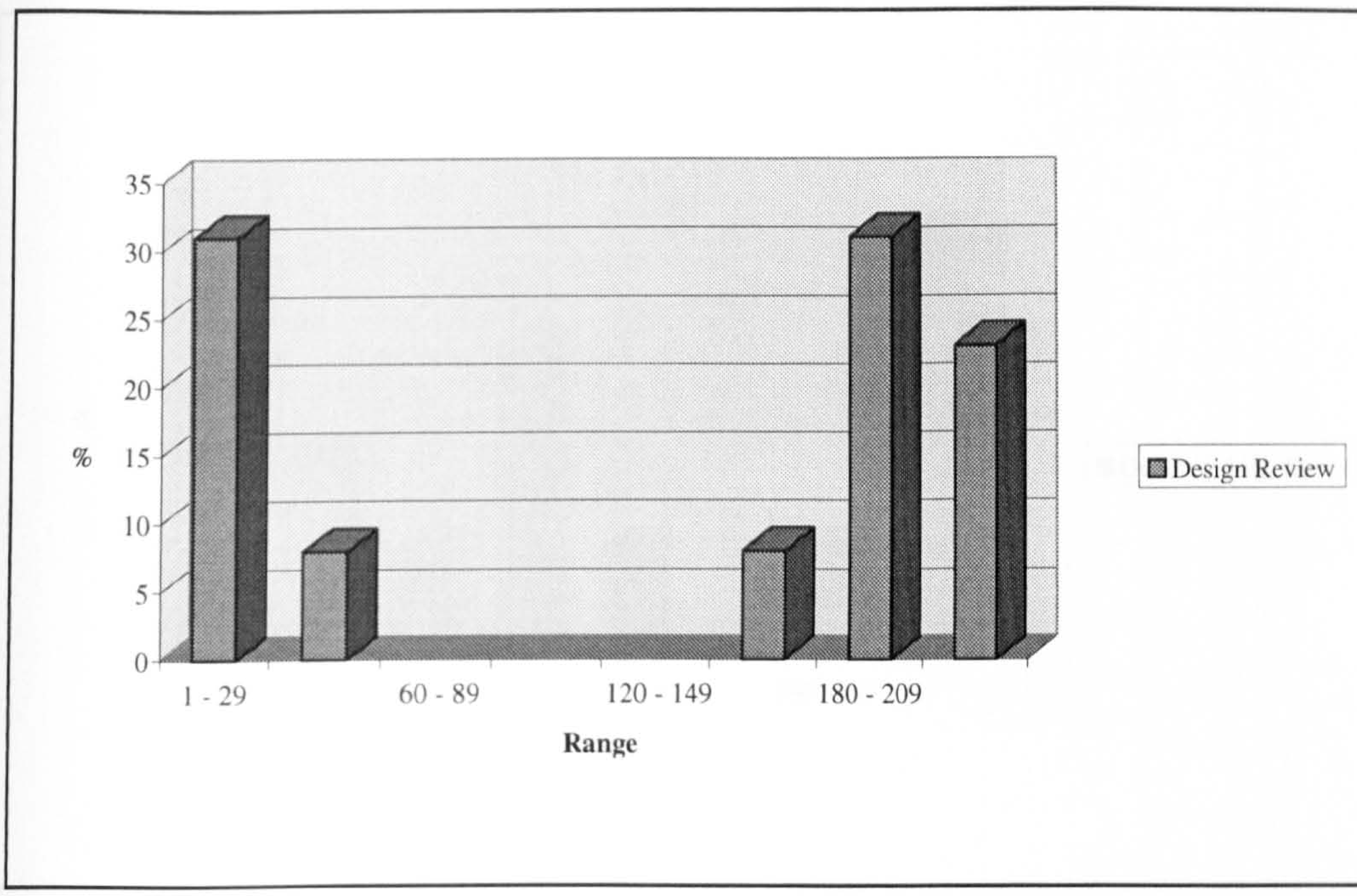

Figure 38 Worth range of "Design Review" on spread of worth ratings

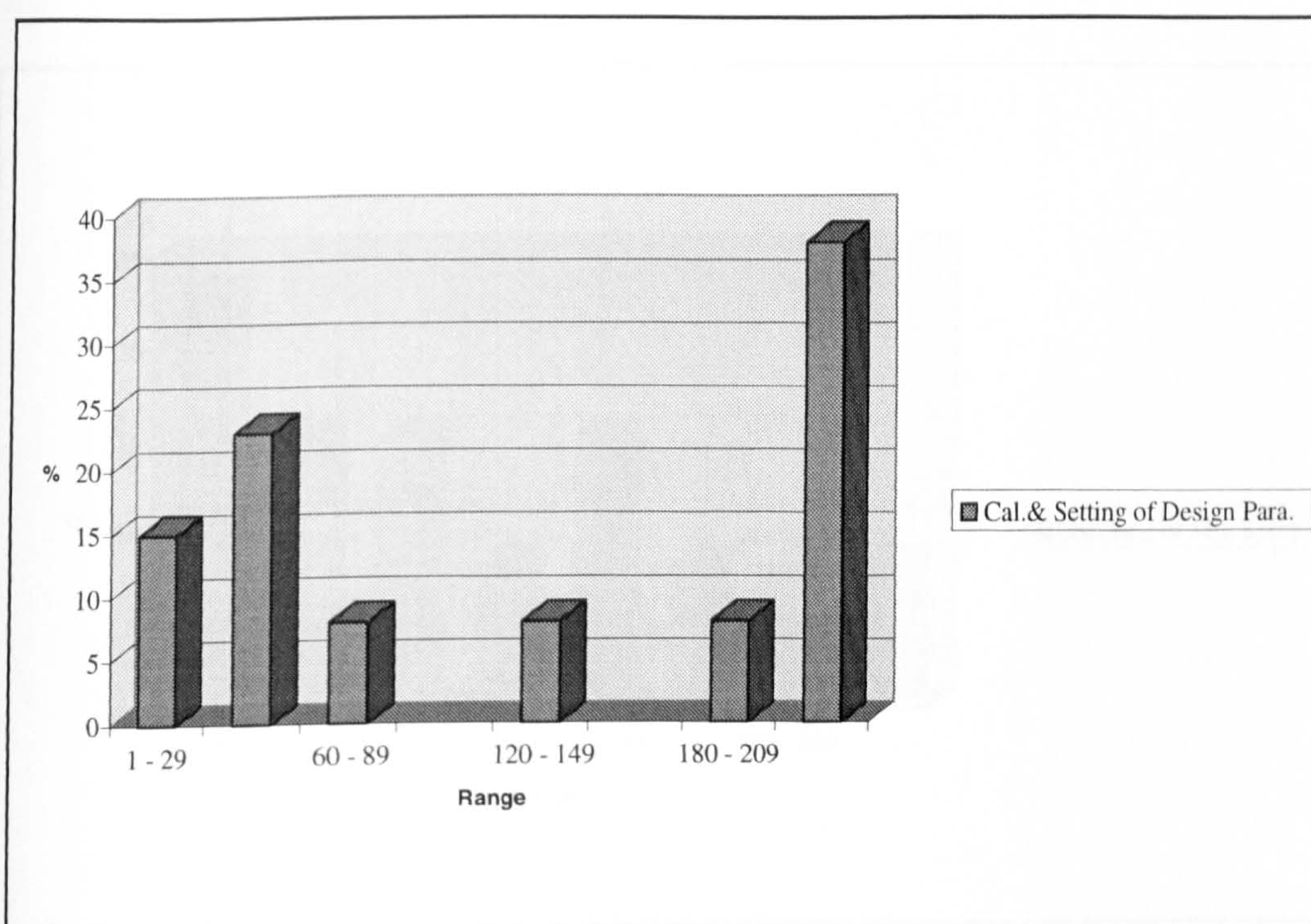

Figure 39 Worth range of "Calculation and Setting of Design Parameters" on spread of worth ratings

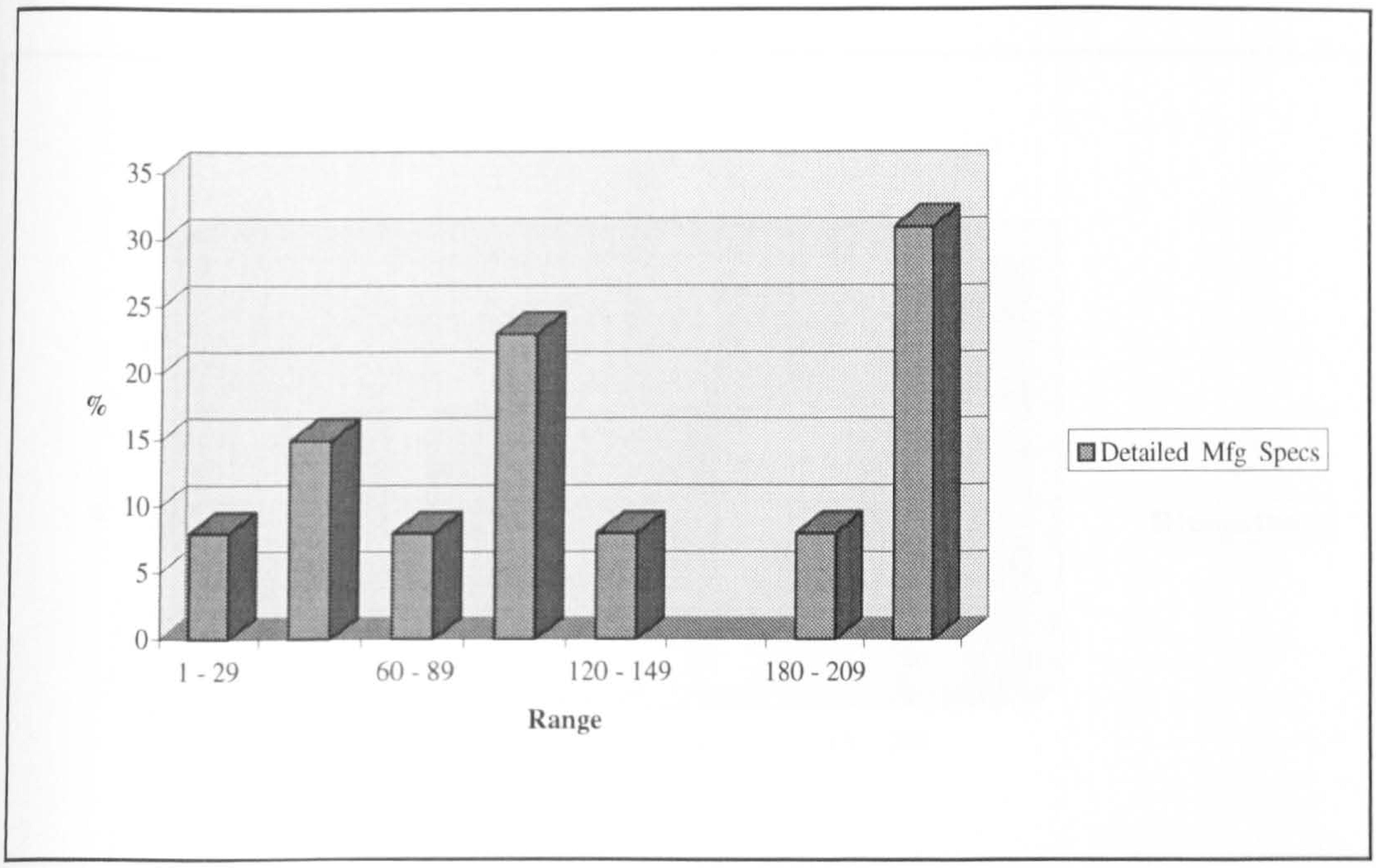

Figure 40 Worth range of "Detailed Manufacturing Specifications" on spread of worth ratings

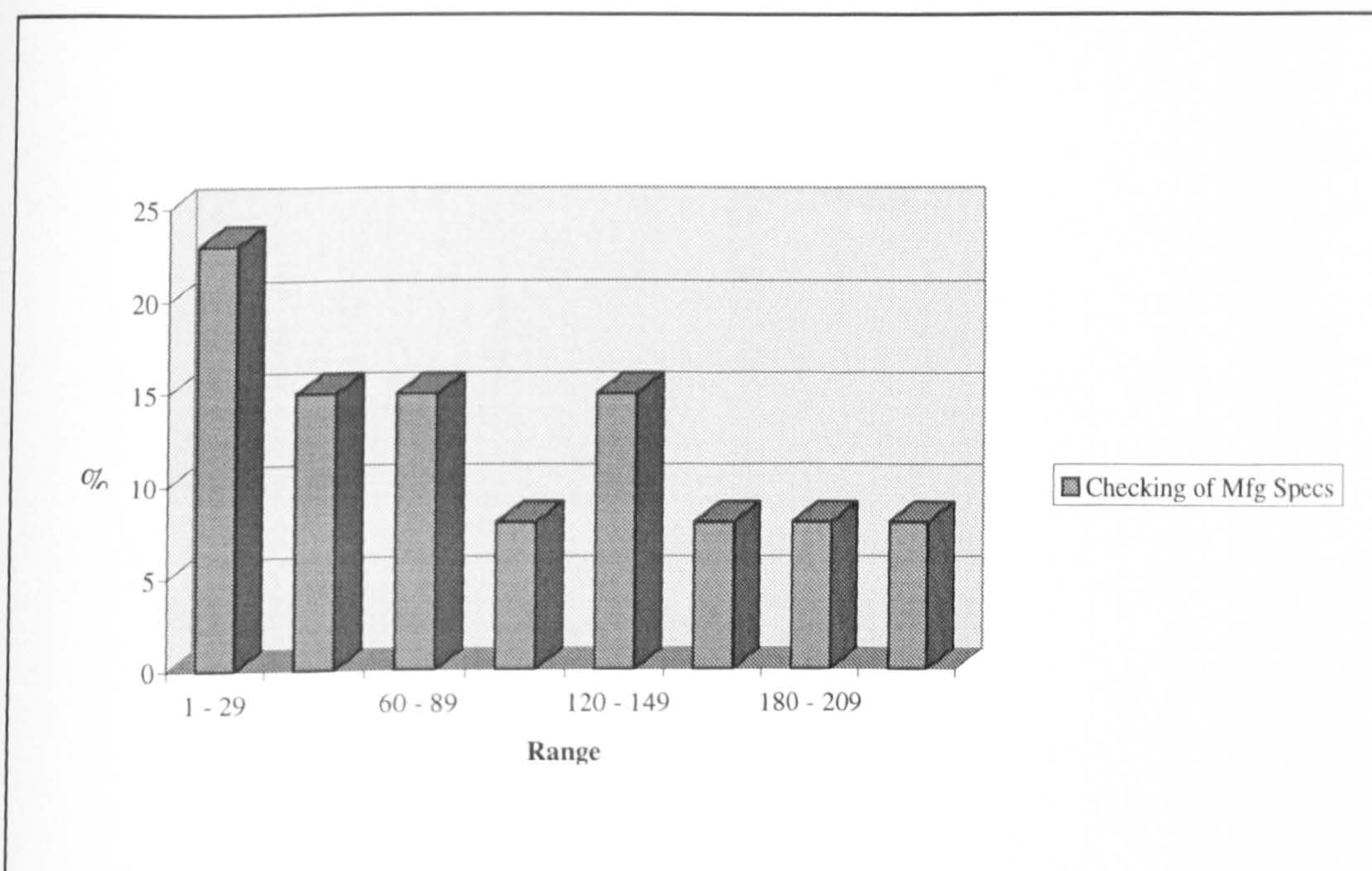

Figure 41 Worth range of "Checking of Manufacturing Specifications" on spread of worth ratings

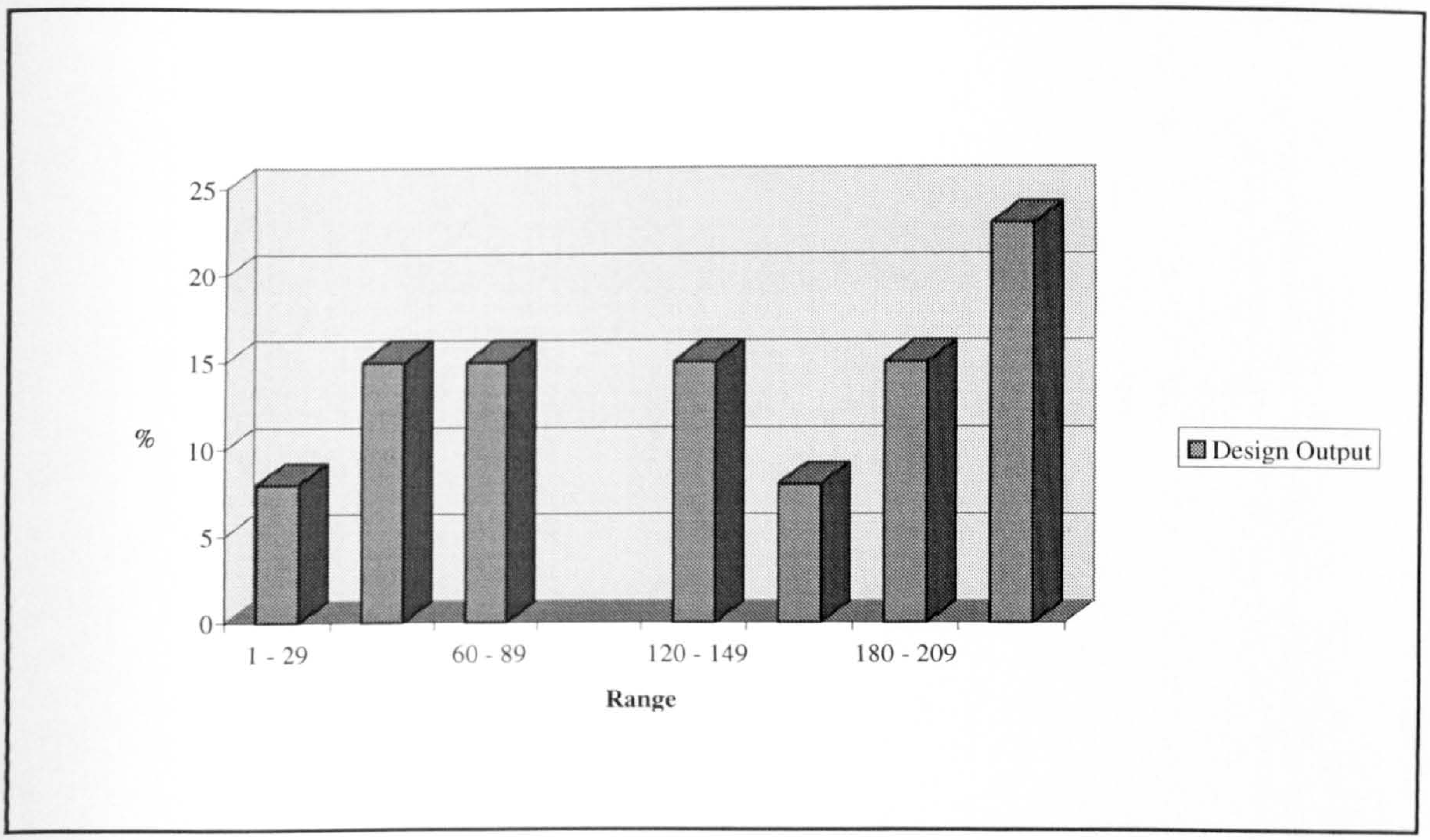

Figure 42 Worth range of "Design Output" on spread of worth ratings