3 Design Core: The Product Design Specification[†]

3.1 INTRODUCTION

The total activity of design has already been discussed in some detail with emphasis on understanding the whole activity stemming from the design core. The establishment and evolution of the product design specification (PDS), and its acting like a mantle enveloping the whole core activity, is now considered in greater detail (Pugh, 1986a). Wherever we are in the design core, whatever the stage we are concerned with at a particular time, this specification is our basic reference. By designing in a particular product/process area, we are, or should be, attempting to meet the specification.

Note that the PDS itself is in a sense dynamic rather than static. If, during the design of a product, there is good reason for changing the basic PDS, then change it. It must be considered as an evolutionary, comprehensively written document which, upon completion of the design activity, has itself evolved to match the characteristics of the final product. Note that in some cases the PDS may be a contractual document; thus, the implications of proposed changes upon the contract should be considered.

The starting point for any design activity is thus market research, competition analysis, literature searching, patent extracting, etc., from which a comprehensive PDS must be prepared. Products based on 'blank sheet of paper' design – single ideas (Eureka's) – are unlikely to compete with, say, Japanese products, unless you are extremely fortunate and lucky. Japanese products are used as an example here, since there is direct evidence that they pay great attention to the voice of the customer embodied in the PDS and to systematic working – more so than any other industrial nation. To be successful, you have to be systematic and thorough, paying meticulous attention to detail from the beginning to the end of the total design activity. The PDS is thus the fundamental control mechanism that allows this success to manifest itself.

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The PDS is essential in all fields of design activity from architecture to shipbuilding, electronics to mechanical engineering. A PDS must be comprehensive and unambiguous. If an experienced designer is asked to design something with a less than comprehensive PDS, he will almost, without thinking, fill in the gaps based on his experience and feelings; if these happen to be at variance with the true user needs, he will be designing to the wrong base. Figure 2.1 reinforces this view.

At the end of the design activity, the design of the product must be in 'balance' with the PDS, even though the PDS may have changed on the way through. We have already discussed the effects of poor or non-existent user needs in design, the same result may be expected with inadequate PDSs. Remember that, in this day and age, the absence of a PDS will result in designs that almost without doubt will fail in the market: poor PDSs lead to poor designs; good PDSs do not necessarily result in the best designs but they do however make that goal at least attainable.

The constituent elements of a PDS are applicable to all products, irrespective of technology, be they pumps or process plants. The major primary specification elements are shown in Figure 3.1. (These will be considered in some detail in following sections.) Remember that they are the primary triggers from which the PDS will evolve; the information on which they are based will have come (or should have) from the preceding user need definition stage. In preparing a PDS, do *not* cut out any of the elements, even though the information they generate starts to overlap and integrate. The PDS sets the design in context, representing as it does a comprehensive set of constraints which are always in a unique combination.

As with the previous market/user need stage, the full spectrum of this stage of the total design activity has been revealed – the design boundary encompassing the major elements. Notwithstanding this fact, the previous arguments in respect of rigour still apply.

In a first design project, it is preferable to cover the full spectrum of elements, albeit to a superficial level. As a course proceeds, a more professional thoroughness should be expected, but within the limitations of the knowledge and experience of the participant to that point in time.

Most courses will provide coursework and exercises pertaining to an engineering discipline; these will sometimes be called 'design', but in relation to total design they may be considered as 'partial', as stated

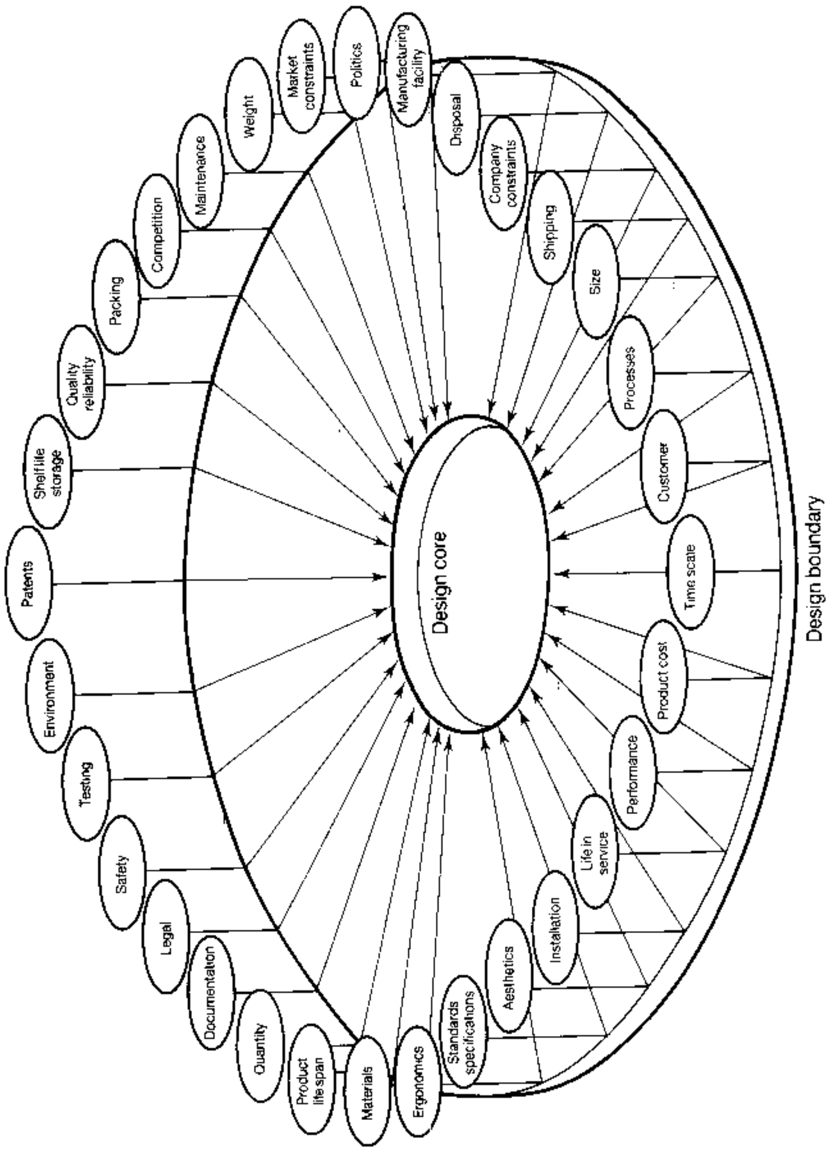


Figure 3.1 Elements of the PDS.

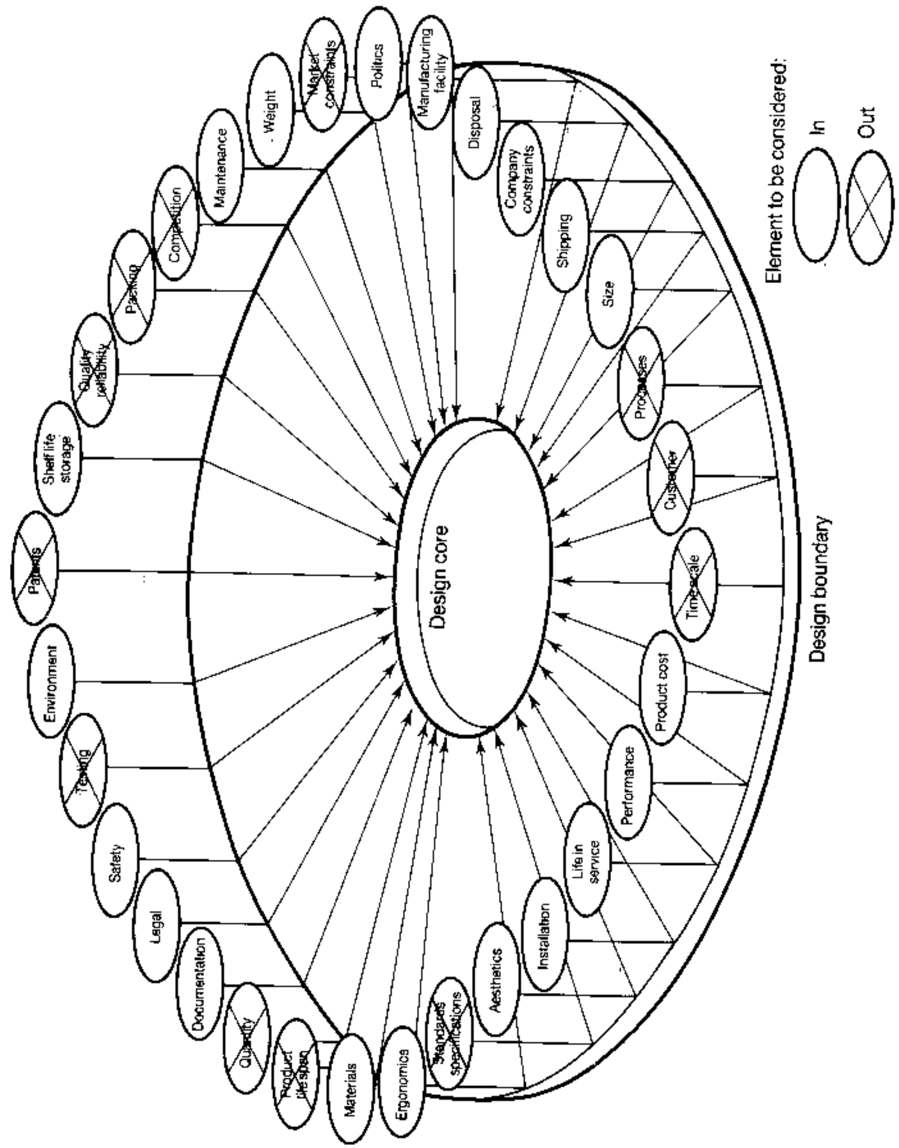


Figure 3.2 Elements of the partial PDS.

in Chapter 1. Since it is recognized that, particularly in a first degree course, full comprehensive coverage can rarely be achieved with design, you will be given partial PDSs appropriate to the exercises at the time. If you consider that a task is partial but does not match the PDS, you should clarify this with your tutor or your immediate superior as appropriate (Figure 3.2).

3.2 THE CONTENTS OF A PRODUCT DESIGN SPECIFICATION

In discussing the preparation of specifications, most engineers think primarily in terms of performance, since performance achievement forms a major part of their design activity. We will therefore commence our discussion with performance.

3.2.1 Performance

The performance demanded or likely to be demanded should be fully defined; how fast, how slow, how often – continuously or discontinuously, loadings likely – electrical, hydraulic or pneumatic, tolerance of speed, rate of working, etc. Remember that the more complex the product, the more likelihood there is of ambiguities and conflict between the performance figures specified – for example, the specification of an electrical cable to carry 20 kVA to an underwater vehicle when the sum of the vehicle power requirements amounted to 50 kVA?

Is the performance demanded attainable in an economic manner? A common failing in specifying performance is to ask for the ultimate, rather than that which is obtainable. Research evidence shows that successful design teams pay great attention to establishing objectives that can be attained.

In the tropospheric aerial example given in Chapter 10, the allowable physical variations to the specified true parabola dictated the approach to the design. In fact, the decision to design the dish in 36 sectors was based primarily on the stated tolerances from microwave experts. In the event, it was shown that these tolerances could have been significantly relaxed in this instance.

It is extremely easy to tighten up a performance specification to such an extent that if one designed to meet that performance, the customer would not be willing or able to afford it, even if the company could possibly afford to make it in the first place. Sales departments and clients never cease to be amazed that the product emerging from their specification costs so much. It takes little effort or thought to specify ± zero for any parameter, which in reality means infinite cost.

While the practice of over-specifying (belt and braces) sometimes occurs in mass production industries, it is more likely to occur with specialist equipment, particularly in the large, one-off field where the client does not really know the adequate level of performance needed to suit his requirements. Beware therefore of 'over-specification' of performance, and also remember that performance is but one component of the PDS.

It is not uncommon, say, with hydraulic pumps, for manufacturers to specify performance parameters that are not attainable *coincidentally*, but independently with reductions in the other parameters – for example, pressure and flow for variable delivery pumps. In other words, maxima do not always occur together.

3.2.2 Environment

All aspects of the product's likely environment should be considered and investigated:

- temperature range
- pressure range (altitude)
- humidity
- shock loading (gravity forces)
- dirty or dusty – how dirty? – how clean?
- corrosion from fluids – type of fluid or chemical
- noise levels
- insects
- vibration
- type of labour or persons who will use the equipment – likely degree of abuse?
- any unforeseen hazards to customer, user or the environment – for example, inclusion of CFCs?

All manufactured items experience a number of these environmental changes in any or all of the areas before being called on to function for the user. These may occur at the following stages:

- During manufacture – exposure to cutting fluids, solvents, fluxes (flow soldering), acids (plating and cleaning), etc.
- During storage – in the plant.
- During assembly – assembly forces, contamination from sweating hands?

- During packaging.
- During transportation.
- During storage – at a wholesaler's warehouse.
- During display.
- During use.

These environmental subsets must be considered at the outset, otherwise the essential performance required during usage may never be achieved, or at best may be somewhat less than the user expectation.

3.2.3 Life in service (performance)

Should service life be short or long and against which criteria should this be applied? Against which part of the PDS is (or should) the product life be assessed? One year on full performance, 24 hours a day, seven days a week, or what?

3.2.4 Maintenance

Is regular maintenance available or desirable? Will designing for maintenance-free operation prejudice the design to such an extent that the product will become too expensive to buy in the first place? Does the company, or indeed the market into which the product will ultimately go, have a definitive maintenance policy? Is the market used to maintaining equipment once it is purchased? The following points are relevant:

- Specify ease of access to the parts that are likely to require maintenance. It is no good calling for regular maintenance if it takes 10 days to reach the part.
- What is the maintenance and spares philosophy of the company and market?
- What is the likely need and desirability of special tools for maintenance?

In the design of the hydraulic power pack discussed in Chapter 7, the first production models had the oil filler cap on one side of the pump/motor bracket (Figure 3.3). In practice, the packs were placed close together alongside rock walls and in many instances it was extremely difficult to top up the tank. The design shown has provision for mounting the filler on either side of the base tank.

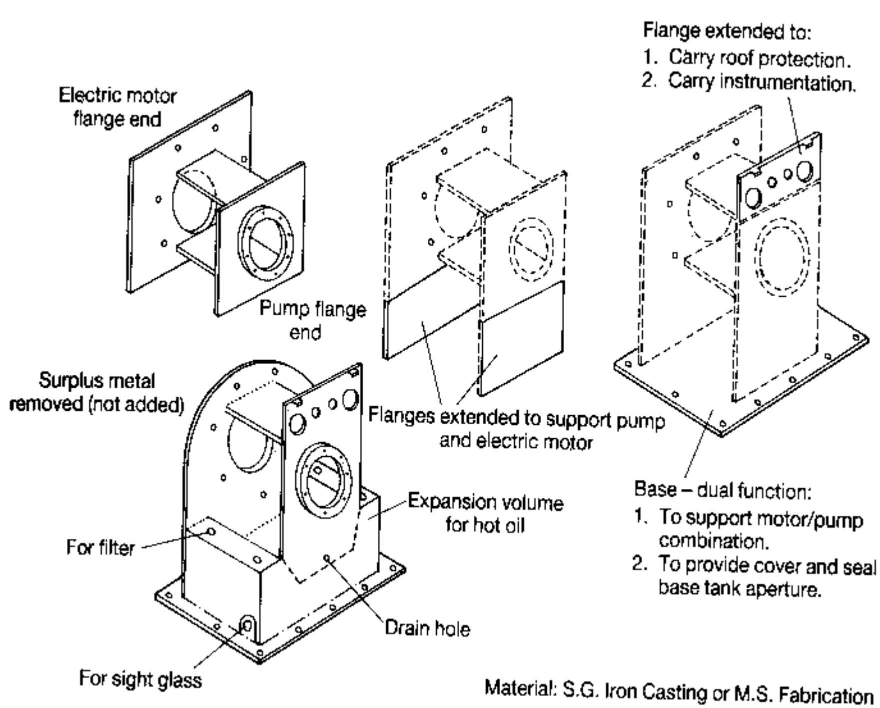


Figure 3.3 Evolution of pump/motor support bracket.

3.2.5 Target product cost

Target production costs should be established from the outset and checked against existing or like products. Invariably, all target costs are on the low side, and in many cases they are unattainable within the constraints of the PDS.

Care should be taken at this stage to ascertain whether the target cost is compatible with competitors' products and, most importantly, with the manufacturing facility available to make the product. Cost patterns should be established and studied in detail before setting the target cost.

If a whole-life costing attitude is being adopted by the company or market area into which you are entering, then this should be considered, with particular reference to maintenance trade-off and down time.

3.2.6 Competition

A thorough analysis of competition must be carried out, including a comprehensive literature search, patents and product literature search relating not only to the proposed product area, but also to analogous product areas. These must be analysed. The nature and extent of existing and likely competition is probably the most important aspect of a PDS, at least from a comparative viewpoint. If, for example, the evolving specification shows serious mismatches or deficiencies when compared with what already exists, then the reasons for such departures must be fully understood. Therefore, it is essential that a full parametric analysis be carried out. Chapter 2 demonstrates this more fully.

Typical magnitudes of such searches are:

- Useful papers: 300–600
- Relevant patents: 10–100
- Competing products: 2–80
- Useful parametric graphs: 5–30 (from a selection of, say, 100).

In order to stay in business, more and more companies are carrying out these sort of searches very thoroughly indeed, and are looking for world-class parameters.

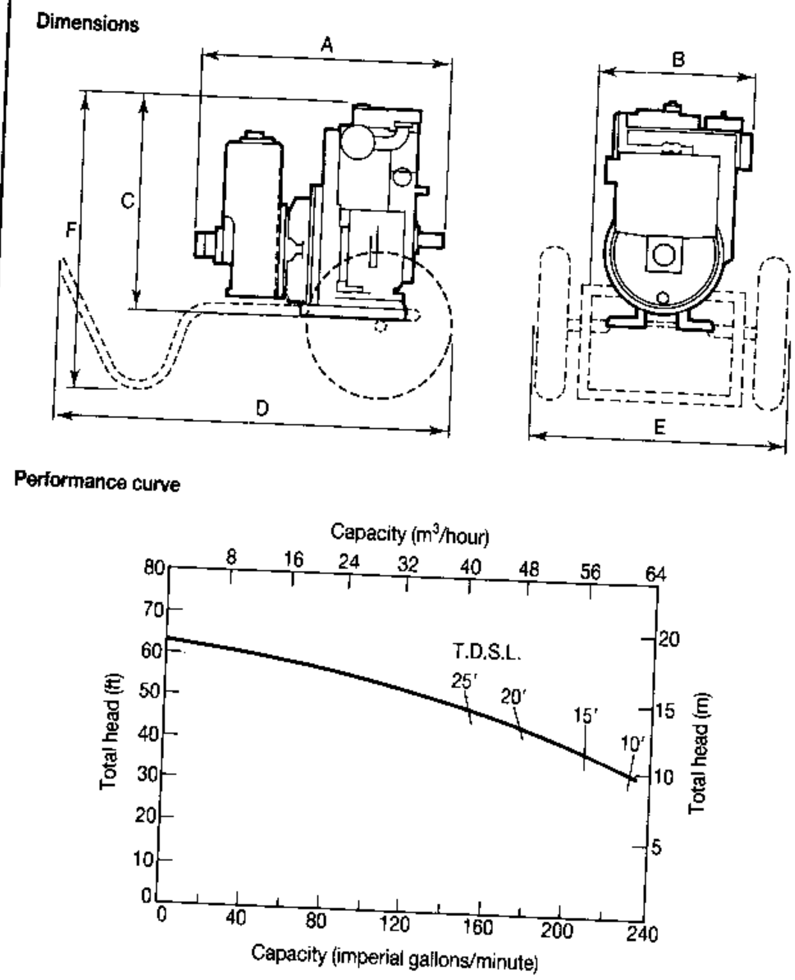
3.2.7 Shipping

It is necessary to determine how the product is to be delivered:

- By land, sea or air – home or overseas; what type and size of truck, pallet container (ISO) or type of aircraft used for the type of product under consideration. It is not unknown for equipment not to be able to pass through cargo hatches of aircraft or ships, or to be expensive in terms of shipping volume. This can affect the subassembly breakdown of the product.

- A product may be competitive in the UK but by the time it is shipped overseas it may have become too expensive. For example, a pump designed for land irrigation and sold mainly overseas became non-competitive because it was made portable (a good idea) by putting it on a trolley. The consequent doubling of shipping volume rendered it uncompetitive even though the increase in basic prime cost of the pump itself was very small (Figure 3.4).

- Lifting capability, provision of lifting points. A product may be competitive in the UK but by the time it is shipped overseas it may have become too expensive.



All dimensions subject to confirmation

Pump set		On base			On trolley	
Nett weight		430 lb	195 kg		490 lb	222 kg
Length	(A)	32½ in	825 mm	(D)	37 in	940 mm
Width	(B)	18¾ in	476 mm	(E)	27 in	686 mm
Height	(C)	28 in	711 mm	(F)	37 in	940 mm
Shipping weight		560 lb	254 kg		627 lb	284 kg
Cubic contents		13.9 ft³	0.393 m³		27.9 ft³	0.789 m³

Figure 3.4 Pump dimensions and shipping information.

3.2.8 Packing

Depending on the type of product being designed, some form of packaging may be necessary for transport, storage, etc. The cost of packing will add to the product cost and volume. Should the packaging protect against the environmental effects of shipping such as salt water, corrosion, shock-loading, etc?

3.2.9 Quantity

Likely numbers to be run off – the size of the run – will affect all aspects of a product's design. A one-off may require very little tooling, although there are exceptions, such as the Channel Tunnel. Moderate numbers may require cheap temporary tooling, while large numbers may require permanent, expensive tooling. This has a considerable effect on the supportive investment required and the plant already existing in-house.

3.2.10 Manufacturing facility

Are we designing to fill an existing plant or is the plant and machinery involved a constraint to our design? What are the plans for new plant and machinery? It is no good designing for a one-plant set-up to find a new one in existence by the time the production phase arrives. See Chapter 8 where simultaneous engineering is discussed.

Make-in or buy-out policy: is the product constrained to techniques with which the company is familiar?

Is our proposed flexible manufacturing system the ultimate in inflexibility? More and more companies are resorting to subcontract manufacture which will make them less capital intensive and reduce their fixed costs. It also allows them the ultimate in flexibility in terms of manufacturing processes and technologies.

3.2.11 Size

Are there any restrictions on the size of the product? Size constraints should be specified initially. So many designs 'grow' like Topsy, with the result that the equipment will not fit into the space provided, and even though it may do so ultimately, access for maintenance could be difficult. Does the product size and shape make it difficult to handle?

3.2.12 Weight

What is the desirable weight? (Remember that, for a given technology, weight is frequently directly related to cost.) Allied to size, weight is important when it comes to handling the product on the shop floor during manufacture, in transit, during installation or in the user situation with the customer. Should the design be modular to assist in the size/weight area? Should lifting points be provided.

3.2.13 Aesthetics, appearance and finish

The appearance of a product is a difficult thing to specify and therefore, in many instances, it is left to the designer: the complaints come afterwards.

Colour, shape, form and texture of finish should always be considered from the outset. Advice and opinion should always be sought either from within the company or without. Sales, marketing, production and others will always criticize a design once it exists. Therefore, efforts should be made to obtain these opinions before the design commences, and certainly as it progresses. Every person is a design critic, accomplished or otherwise. So often the final appearance of a product 'just happens' and then strenuous efforts are made to make it look better, which usually prejudices the design in all aspects.

Never forget, whatever the product, that the customer *sees* it first, before he buys it – the physical performance comes later. The visual performance is always first.

3.2.14 Materials

The choice of materials for a particular product design is invariably left to the design team. Usually, this is not a bad thing. However, if special materials are necessary, they should be specified, preferably by quoting the appropriate standard. The converse is also true. If it is known that certain materials, such as lead-based paint for consumer products, must not be used, they should not be specified. Aluminium or its alloys on exposed surfaces for underground coal-mining equipment is forbidden in the UK but not in the USA.

3.2.15 Product life span

Some indication of the life of a product as a marketable entity should be sought. Is it likely to remain in production for two years or 20 years?

The answer is crucial as it can affect the design approach and interacts with the market and competition, tooling policy, manufacturing facility and the like. Product life spans are reducing rapidly – for example, Sharp calculators change their designs approximately every six months.

3.2.16 Standards and specifications

Is the product to be designed to current international and/or British standards? If so, then these should be specified and copies obtained. Cross-correlation of such standards should be carried out prior to commencement of the design. It is difficult, costly, time consuming and inefficient to attempt retrospective matching of designs already finalized to such standards. Also bear in mind that while standards are extremely useful and essential in many areas, they generally represent an industry or technology and a consensus at a particular point in time. They must not be allowed to freeze innovation.

3.2.17 Ergonomics

All products have, to some degree, a man–machine interface, certainly during manufacture and if not directly during usage, again at the time when maintenance is required. It is therefore necessary to elucidate the likely nature of the interaction of the product with man. What height, reach, forces and operating torques are acceptable to the user. Postures and lighting should be considered; the devices must be a delight to use – potential users must be consulted.

3.2.18 Customer

It is essential to obtain first-hand information on customer likes, dislikes, preferences and prejudices. Eyeball-to-eyeball discussion, question and answer, and examination of competitors' trends and specifications are all useful inputs to the specification.

To a great extent, such input will depend on whether there are product line precedents already on the market or whether it is a product breaking new ground. Customer input is, nevertheless, essential to success. The degree of difficulty with which this input is obtained varies enormously from the large one-off turnkey type of project where the designer will interface directly with the customer, to the mass-produced product where he will not – this point is considered in more detail in Chapter 7.

3.2.19 Quality and reliability

The laying down of levels of quality and reliability necessary to ensure product success and acceptability in a particular market is a cause for increasing concern. They are the most difficult aspects to quantify in absolute terms, although statistical data from company product precedents are helpful here. In electronics, mean time before failure (MTBF) and mean time to repair (MTTR) are familiar expressions, although it must be remembered that by comparison with mechanical, hydraulic, pneumatic and even electrical components, electronic components experience a relatively controlled, sheltered life. Nonetheless, some quantitative expression must be made in respect of quality and reliability at the specification stage. Reference should be made to:

- BS 5750, *Quality Systems* in five parts. Part I (1987). *Specification for Design, Development, Production, Installation and Servicing.*
- *Guide to Use of BS 5750*, Part 1, *Specification for Design, Development, Production, Installation and Servicing.*
- BS 5760, *Reliability of Systems, Equipment and Components* in three parts. Part 3. *Guide to Reliability Practices: Examples.*

A company must ensure adequate feedback of any failure analysis to the design team.

3.2.20 Shelf life (storage)

A factor often overlooked in specifications is that of 'shelf life' (applied to units) or storage on site (as applied to complete plant). With respect to units, shelf life must be specified at the outset and the means to combat decay considered (see 'Environment', Section 3.2.2), otherwise rusty gearboxes, perished rubber components, seized bearings, defective linings, corrosion and general decay will occur.

The designers of a complex plant should also be aware of these problems, since equipment designed on the assumption of immediate installation and commissioning may lie around on site for months on end without adequate protection and storage.

3.2.21 Processes

In-house process specifications, as opposed to manufacturing techniques, are vitally important. If special processes are to be used during manufacture, they should be defined – for example, plating specifications, wiring specifications. Alternatively, the relevant standards – British, foreign, in-house, etc. – should be called upon.

3.2.22 Time-scales

What is the time-scale for the project as a whole, in parts or phases? Is there a need to fit in with the time-scales of others concerned with the project? Lead times allowed for design activity are frequently inadequate, but they determine the time-scale for the whole project up to manufacture and product launch. Design time must be adequate to ensure that the product is designed effectively and efficiently – in other words, professionally. Lack of adequate time spent at the beginning of a design project will be made up for later and to other people's time-scales due to defective products, market mismatches, overwhelming competition and the like. There is no alternative to adequate design time.

3.2.23 Testing

Most products require some form of testing after manufacture, either in the factory, on site or both. Products for the consumer or engineering markets usually require a factory test to verify the quality of the product and its compliance with the PDS. Curiously, this usually relates to the performance aspects which, although essential, represent a narrow view of the whole question of product evolution.

Do we sample test one in ten, one in a hundred, or what? Do we need a new test facility? How can we be sure that the product is designed to have rapid engagement with and detachment from the test rig? Data collection and product history are needed to answer these questions. An initial test specification should be written at this stage. It is too late after the design has been completed!

Process plants and projects of this nature usually have acceptance and witness tests, in addition to factory tests. As with all testing, these require careful planning and execution, not only to ensure compliance with the PDS, but also to limit the cost.

3.2.24 Safety

The safety aspects of the proposed design and its place in the market must be considered. Indeed, there may be legislation and standards covering this aspect, such as HASAWA, EEC legislation on product liability, and particular specifications relevant to particular product

areas, such as BS 5724, *Safety Requirements on Hospital Medical Electrical Equipment*. The following extract from the specification for the MICROM 160 (see Figure 1.15) is typical:

Electrical safety

(1) This aspect is comprehensively covered by Hospital Technical Memo No. 8, *Safety Code for Electro-Mechanical Apparatus*. The relevant paragraphs appear below. The specification then goes on to quote the actual paragraphs from the memorandum. (BS 5724 subsequently superseded this memo.)

(2) Sharp corners are to be avoided as far as possible to minimize the risk to personnel and the splitting of surgical drapes.

(3) As far as possible, any component should be 'fail safe' as in performance.

(4) Design of the manipulator must be such that horizontal arms just above eye level are avoided if at all possible.

(5) The manipulator should be designed so that parts liable to move relative to each other are unlikely to trap limbs, hair, clothing or drapes at their joints.

(6) No part of the manipulator should have unguarded projections where clothing, drapes or parts of the body are likely to be snagged or torn.

Labelling should give adequate warnings. Likely degrees of abuse, whether obvious or not, should also be considered; also likely misrepresentation of function of equipment. Definitive operating instructions must be prepared. See Section 3.2.31 – documentation.

3.2.25 Company constraints

The constraints of current company practice should be highlighted and discussed. Is the company constrained by its previous products? If so, it is as well to know about it at the specification stage. Possible manufacturing facility constraints, financial and investment constraints, and attitudes are very relevant.

Are there adequate in-house facilities for research, design, development, testing, etc., including quality of personnel.

3.2.26 Market constraints

Feedback from the market place should be considered. It is no good incorporating a certain firm's engines in equipment for some Middle East countries, if they will not accept them. The first rough terrain telescopic handler was designed to utilize a range of Ford engines. At that point in time, and for the foreseeable future, Ford products were unacceptable in the Middle East. Therefore, the design was changed to accommodate Perkins engines, as well as Ford engines. Knowledge of local conditions, particularly overseas, combined with a full knowledge of the market must be incorporated in the PDS at the beginning of the project and as the design evolves. Otherwise, if during the course of the project the market disappears, the whole activity may have proved to be a waste of time.

3.2.27 Patents, literature and product data

All areas of likely useful information should be investigated and researched, and in particular possible patent clashing should be known about as soon as possible. It is pointless designing something for sale in ignorance of someone else's patent. Figure 3.5 gives an example of a patent for the MICROM 160, described in Chapter 1.

3.2.28 Political and social implications

The likely effect of the product on the political and social structure of the market or country for which it is to be designed and manufactured should be considered. Typical factors include the effect of consumer movements, the stability of the market, and the avoidance of product features that can create social unrest and upset.

3.2.29 Legal

With the adoption by the EEC of product liability legislation, based in part on US experience, it is essential to consider the legal aspects of a design at the PDS stage. Such legislation considers 'product defect' as its primary basis. Many defects are designed into a product through lack of adequate consideration of all the constraints at the outset.

It is suggested that 'defect of specification' may account for many 'defects of design' and even for subsequent 'defects of manufacture'. In this respect, the following incident, relating to a product currently on the market, should prove of interest (Pugh, 1979a). During the formulation of the original PDS for the 'Giraffe' site placement vehicle (see Figure 1.9), it was decided to make it the safest vehicle on the market, from the viewpoint of stability. Since any handling device using forks relies on gravity to retain its load, the risk to life and limb increases with height and reach, both in terms of the operator and people in the vicinity of the vehicle. Being the first vehicle of this design in the field, it was decided to provide a system of operation

United States Patent [19]
Pugh et al.

[11] **Patent Number: 4,515,333**
[45] **Date of Patent: May 7, 1985**

[54] ADJUSTABLE SUPPORT FOR AN OPTICAL OR OTHER INSTRUMENT

[75] Inventors: **Stuart Pugh; Douglas G. Smith,** both of Loughborough, England; **Chee M. Lee,** Jurong Town, Singapore; **Leslie R. Parr,** Leicester; **John N. Birkett,** Aylesbury, both of England; **Richard G. Stibbs,** Glasgow, Scotland; **Tet C. Tai,** Petaling Jaya Selangor, Malaysia

[73] Assignee: **University of Technology,** Leicestershire, England

[21] Appl. No.: **333,870**

[22] PCT Filed: **Apr. 14, 1981**

[86] PCT No.: **PCT/GB81/00068**
§ 371 Date: **Dec. 14, 1981**
§ 102(e) Date: **Dec. 14, 1981**

[87] PCT Pub. No.: **WO81/03054**
PCT Pub. Date: **Oct. 29, 1981**

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[52] U.S. Cl. **248/122;** 248/123.1; 248/124
[58] **Field of Search** 248/122, 123.1, 124, 248/125, 127, 162.1, 132, 289.1, 282; 350/513, 514, 515, 522, 521

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Primary Examiner—William H. Schultz
Assistant Examiner—Ramon O. Ramirez
Attorney, Agent, or Firm—D. N. Halgren; V. A. White

[57] **ABSTRACT**

An adjustable support for an optical or other instrument (e.g. a binocular microscope for use by a surgeon in neurosurgery) which readily permits adjustment in the position of the instrument in a predetermined spatial envelope and/or adjustment of the orientation of the instrument at any given position within that envelope, and which is compact, relatively inexpensive to manufacture, easy to adjust, and incorporates a high degree of safety, comprises a rod-like carrier, supporting the instrument at one end and an adjustable counterweight at the other, mounted, by a ball joint arrangement on a linkage system rotatably supported on a column. The ball joint arrangement and the other joint arrangements in the linkage system are provided with clamping devices, normally urged to clamping position by springs but released by the application of air pressure under control of a switch device.

11 Claims, 12 Drawing Figures

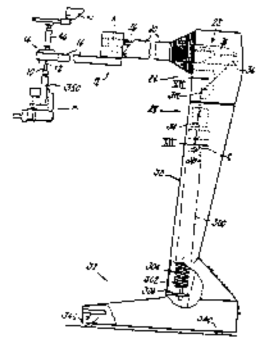

Figure 3.5 Patent for MICROM 160.

such that any increase in the extension of the boom at a fixed elevation or, alternatively, depression of the boom at a fixed extension beyond predetermined limits, would automatically override the operator, leaving him with two options – either let the load remain at a position in space, but still in safety, or shorten the boom and withdraw the load into the safe envelope.

A system was designed to perform in this manner and is fitted to every vehicle – and it works. The essential feature of the system is that ne manual lever-operated valves, which control the two motions escribed, automatically centralize when the danger zone is approached, verriding the operator's input.

Two examples where potential hazards might have arisen will rther illustrate the problem of classifying defects.

Firstly, a customer complained that the levers fitted to the control alves were not strong enough and indeed some had broken. ubsequent investigations revealed that when the safety system had ome into operation, with valves centralizing, lights flashing and uzzer sounding, the operator had attempted to extend the load range y the application of tubes to the levers. Naturally, long pieces of tube nd tremendous effort were required to overcome the system even artially, the net result being the bending and ultimate fracture of the evers, hence the request for stronger levers. If an accident had esulted from this practice, under which defect classification would it ave been considered?

- Defect of specification – should it have been foreseen at the outset that operators would attempt to override the safety system by the application of tubes to the valve-operating levers?
- Defect of design – if the control levers had snapped, injuring the operator, should they have been made strong enough to accept pipes of infinite length?
- Defect of manufacture – was the lever material not to specification?

econdly, a vehicle of similar design appeared on the market with a afety system that sounds a klaxon and flashes a light in the event of novement of the load outside the safe envelope of operation. If these re ignored, the danger zone can be entered and instability may result. hould an accident occur with this vehicle, it is interesting to speculate vhether it would be considered a defect of design or specification. As he Giraffe pre-empted this latter machine, would it give rise to uestions in the area of 'reasonable user expectation'?

.2.30 Installation

Many products must interface with other products or be assembled nto larger products (or buildings). Installation therefore must be onsidered in the PDS. This will include fixing holes and lugs, access, he volume available for the product, system compatibility, power ompatibility and the like.

In the case of the hydraulic power pack discussed earlier, the

problem of the initial filler position had ramifications for installation, but it was subsequently eased by the dual positioning of the filler/breather unit.

3.2.31 Documentation

Product documentation is always important in terms of instructions to the user, the maintainer or others. Even with consumer products, it is an important and vital task that must not be shirked (see 'Safety', Section 3.2.24, and 'Legal', Section 3.2.29). With large turnkey projects, the associated documentation can become a substantial part of the overall design task, say for a power station.

In the light of previous comments re legal requirements, it is imperative that full documentation is prepared for all projects – this should be done formally, not informally. I recently had to refer to detailed documentation for the wind tunnel referred to in Chapter 1, which is currently being refurbished some 30 years on from the design stage.

3.2.32 Disposal

Disposal has been included as a primary element as the effects of man's design of products impinge more and more on our environment.

With many products, it is not possible to 'forget' about the item after ownership has passed to the customer. If the product contains hazardous or toxic parts, or indeed parts worth reclaiming, these should be considered at the PDS stage. Should we, for instance, design for disassembly – for example, Magnox nuclear reactors? This is becoming an increasing problem with many products, and is not necessarily confined to time-expired nuclear reactors, chemical process plants and the like.

Non-biodegradable plastic packaging and items made from plastic present a problem of increasing magnitude – in fact the whole problem of waste disposal and recycling looms large indeed.

While the points discussed in the preceding sections represent the primary elements or 'triggers', thus enabling the preparation of a PDS, never forget that a specification will be, and should be, subject to amendment and alteration with the passage of time – as stated earlier, it is *evolutionary*. When a design has been completed, the evolved specification may be suitably embellished with detail. Almost by definition, it provides the basic material for handbooks, sales and technical literature. The PDS becomes the specification of the product itself, rather than the specification for its design. Therefore, it provides the basis for the user or producer to make his decisions in a comprehensive manner.

There are no alternatives to a meticulous and thorough approach to PDS preparation in a competitive world.

It is perhaps worthwhile reiterating that the PDS is defined as that which sets out in detail the requirements to be met to achieve a successful product or process. When the product has been designed, it is itself specified by the drawings, documentation, etc., which go to describe the product in great depth. This is known as the specification of the product – the product specification. Try to avoid the use of loose semantics where the one may be confused with the other.

There is a great deal of evidence to the effect that a poor PDS is a very common cause of unsuccessful designs (Cooper and Kleinschmidt, 1986).

3.3 THE PDS DOCUMENT

Guidelines for preparation:

(1) Remember that the PDS is a control document. It represents the specification of what you are trying to achieve – not of the achievement itself.

(2) Remember that it is a user document – for use by you and in industrial situations by others. It should therefore be written succinctly and clearly.

(3) Never write a PDS in essay form. Use short, sharp definitive statements under the headings provided in Figure 3.1. It is useful in practice to allow space for amendments and additions; therefore, do not crowd the page. Two headings to a page is usually adequate at the start; a professional PDS may ultimately have many pages to a heading. Figure 3.6 shows a typical approach. PDSs need to be user-friendly.

(4) From the beginning, try to quantify parameters in each area – for example, weight. Students and professional engineers frequently say they do not know the extent of such parameters: if in doubt, estimate a figure.

(5) Since a PDS is always unique in a new design situation, the relationship between the elements always varies. It is recommended that in preparing a PDS that you also vary your starting point – for example, you may start one with performance and another with environment or politics. Varying the starting point

Product ____________

Date: ____________ Issue: ____________

	Parameters			
Performance:	Competition best	Current model (ours)	This design (intent)	World class (target)
Description				
Safety: Description				

Figure 3.6 Format for a product design specification.

will aid the acquisition of the flexibility of thinking, which is required to prepare good PDSs.

(6) Always date the document and put an issue number on it.

(7) Clearly document amendments.

3.4 THE PARTIAL PDS

The term 'partial design' has been referred to and a case made for it earlier; the phrase 'partial PDS' has now been used and the two should be brought together.

All statements made so far in relation to the PDS have referred to the whole product – for example, the motor car or the electric shaver. But all products may be conveniently broken down from the whole (total system) to the subsystems and then to the component level. To take advantage of this breakdown, it is useful to refer to **subsystem design specifications (SSDSs)** and **component design specifications (CDSs)**.

For particular subsystems or components of a product, many of the facets of its 'specification' will be taken from the overall PDS, and will apply. However, some of the primary areas will not, in some instances, be relevant, while others will become more relevant; for example, a component of a machine will be very much subject to its interactions with its adjoining components, and therefore will be subject to its *local* environment within the envelope of the total PDS environment.

Students on engineering courses have to learn the fundamentals of engineering, and it is usual to acquire this through the mechanism of component and subsystem designs utilizing the appropriate technologies and analytic techniques; for example, the design of a shaft using finite element techniques; the design of a circuit using circuit analysis techniques. This is the way you acquire your engineering tool-kit – you do not acquire it initially by tackling the total diesel engine, video recorder, airplane, bridge or Concorde replacement.

So, in the context of total design as discussed so far, the constituents of the partial PDS need to be addressed. Both in teaching and in practice it should be quite clearly delineated to the 'doer' just what is required – judgement as to the quality of the design should not be left, as in many instances it is, to the opinions of the tutor, or, in industry, to your immediate superior. Such judgements will be made against the background of the different experiences and contexts of the arbitrator. If the differences between that experience and the current project are large (for example, judging the details of a bridge design where previous experience has been concerned with pressure vessel design), then the value of such judgements will be open to question.

Always try to establish the context of the subsystem or component in a partial PDS against which design alternatives might be measured. It could well be that the partial PDS for a shaft (or CDS) might only encompass some of the elements (see Figure 3.2).

As with the overall product, component designs should also be handled quite systematically, otherwise vital factors will be omitted, the product quality will suffer and competitive situations will deteriorate. Systematic design is essential at all levels.

4 Design Core: Conceptual Design

4.1 Introduction

The conceptual phase of the design core is primarily concerned with the generation of solutions to meet the stated need; in other words, it involves generating solutions to meet the PDS. In total design terms, design must *never* be started without a PDS – however, you will recall the earlier reference to partial design.

It is recognized that conceptual design as such can be applied at the total, subsystem or component level. Thus, it may not be possible to significantly change for the better the overall concept of a motor vehicle, although many opportunities for improvement may exist at the subsystem and component level. So, in effect, while we have so far referred to a process of total design, implying that it applies to a whole system, which it does, as a process continuum, it can and should be applied at any level. After all, a fuel pump is but a subsystem of a car; fuel pumps can be researched, specified and conceptualized following the procedure so far outlined – to the fuel pump manufacturer, it is his product. Equally, in considering alternative approaches to the fuel pump diaphragm, this also could be treated in the same way but at the appropriate level.

Nevertheless, it cannot be over-emphasized that in a total design sense, if you are asked to design something without a partial or total PDS, then you should:

- Seek clarification from your tutor or superior.
- Compile your own version of the PDS.

It is professionally impossible to give an opinion of any value about a design without knowing its origins – the PDS. Many engineers in

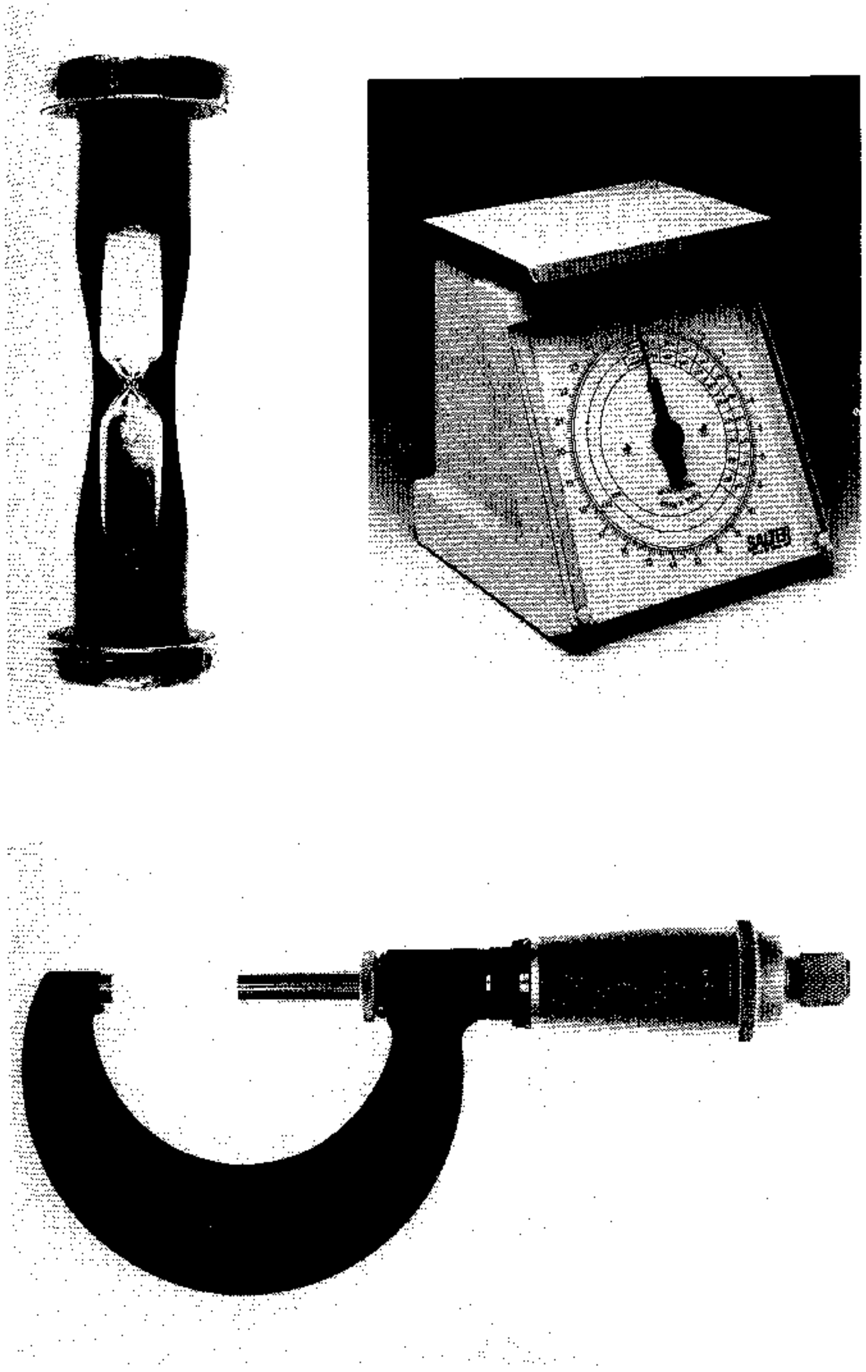

Figure B.6

C Domestic Door Security Device – Total Design Task

This report contains the PDS for a domestic door security device. The intention is to produce a product that will be competitive with those already available on the market while producing a solution to the problems encountered with such designs.

A multi-disciplinary team of four people, mechanical, electrical and production engineers, nominally of 17 years of age, responded to the total design task. The PDS has not been corrected in any way by staff so that it is representative of what can be produced with the total design approach.

Performance

1.1 To fit any domestic exterior door (left-hand or right-hand).
1.2 Must be able to withstand an attempted forced entry, up to a force of 3000 lb (see BS 3621).
1.3 To allow visual contact with caller.
1.4 To allow communication with caller.
1.5 Must be easy to operate – it is expected that the user age group will range from children to senior citizens (see 'Customer').
1.6 The device should be strong enough to resist wire cutters.
1.7 The normal opening/closing of the door must not be affected by the presence of the device.
1.8 The strength of the door is not to be unduly impaired by the presence of the device.
1.9 When the device is in use, the door must not be able to open more than 6 cm.
1.10 Operating conditions (see 'Environment').

Environment

2.1 Normal use: Device will be fitted to an entrance door or the immediate area of the door, in a dwelling house.
2.2 Resistance to adverse weather: If the device is exposed or partially exposed on the outside of the door, then it must be able to withstand all extreme weather conditions (heat or cold).
2.3 Temperature: The unit should perform and not be damaged by temperatures in the range of −20°C to 70°C.
2.4 Pressure range: The unit should perform and not be damaged by air pressures between 0 Nm^2 and 10 000 Nm^2 (to enable air transport to be possible).
2.5 Corrosion resistance: The unit should be resistant to corrosion from salt water or any other household liquids.
2.6 Shock loading: If the door is restricted from fully opening by the device, then the device must be able to withstand a shock load of 3000 lb. However, the unit should not be regarded as an alternative to existing locks and bolts on the door.
2.7 Abuse: The device must be able to withstand vandalism.
2.8 Dust and dirt: Any lenses or polished parts or components that would be inhibited from operation by dust or dirt should be protected or at least be easily cleaned.

Life in service

A minimum of 10 years is required, but, if economically viable, a 20 year life in service would be preferred.

Maintenance

The general policy of the competitors tends towards maintenance-free products. To keep within the targeted production cost and equal the competitors' maintenance policy at this end of the market, the design should comply with the following:

4.1 Be completely maintenance free with the exception of light lubrication if and when required. Therefore, no spare parts will be manufactured.
4.2 Where screws, bolts and washers are used, British standards must be complied with (see 'Standards and specifications').
4.3 Any parts that do require lubrication should be accessible within one minute, without the need for special tools or equipment.
4.4 The device should be removable but only by the occupant(s) of the dwelling or by a person designated by the occupant(s), this only being necessary in the event of a new door being fitted or when the occupant(s) wishes to move house.

Target product cost

Our aim at AEI is to produce an effective security device that will fall into the lower price range. The average retail cost of present devices is £10.28. Allowing for overheads and the possibility of unforeseen events, the target cost for manufacture should be between £3 and £5 per completed and packaged device.

Competition

6.1 Polycell: Polycell manufacture a wide range of door security devices. However, only two such devices should prove to be in direct competition (see market research document for further details).
6.2 J. E. Reynolds & Company Ltd: J. E. Reynolds & Co. Ltd market four security devices, which will be in direct competition to the device to be manufactured (see market research document for further details).
6.3 J. Legge & Co. Ltd: Legge UK ranks as one of the leading lock manufacturers in Europe, selling high-volume quality products in more than 50 countries. However, they do not manufacture a door security device that allows communication or visual contact with the visitor.
6.4 Welpac: (see market research document for further details).
6.5 Chubb: Chubb manufacture a wide range of locks and safes which have, for many years, enjoyed an enviable reputation in providing reliable security for banks, Government departments, prisons, hotels, post offices and many other institutions throughout the world (see market research document for further details).
6.6 Yale: (see market research document for further details).
6.7 Ingersoll: (see market research document for further details).

Packing

At present, materials to be used for the device have not been specifically chosen, nor has the actual size, but some, if not all, of the following should be considered for the final packaging of the device (see 'Materials' and 'Size').

7.1 Size must be kept to a minimum.
7.2 Cost must be kept to a minimum.
7.3 The package presented to the customer must be physically attractive (shape and colours used).
7.4 Weight must be kept to a minimum.
7.5 Should prevent corrosion if applicable.
7.6 Must be waterproof.
7.7 Should prevent damage by shock loading, the level of which will be dependent on the material used for the device.
7.8 Must be easily removed by the customer.
7.9 Assembly and fitting instructions should accompany the package.
7.10 Company logo must be shown on the package.

Shipping/transport

8.1 Packages will be stored for transport in boxes with at least 10 per box.
8.2 ISO containers will be used to carry the boxes.
8.3 Transport will be by road or rail within the home market.
8.4 Transport will be by sea then road or rail within the overseas market.

Quantity

Market analysis indicates that a large percentage of households do not have a door security device of any description. Those households that do have such devices consider them to be inadequate. Therefore, it would be reasonable to expect the market to grow over the next five years, considering the rising crime rate.

9.1 10 000 units per annum to be initially produced, with production increase to meet demand once the product is established on the market.
9.2 Long production run envisaged, extending relative to market demand.
9.3 Permanent new tooling should be installed if required, but full use of existing tooling and equipment must be achieved.

Manufacturing facility

10.1 There are no constraints whatsoever on manufacturing facility.

Size

11.1 Length not to be greater than 200 mm.
11.2 Breadth not to be greater than 140 mm.
11.3 Depth not to be greater than 80 mm.

Weight

12.1 The weight of the device should be kept to a minimum; however, strength must be the principal factor if the device is a restrainer.
12.2 The total weight of the device, including fittings, should be no greater than 3 kg.

Aesthetics

13.1 Robust image must be projected to the customer.
13.2 Attractive appearance, should be colour co-ordinated with other door fitments and attachments.

13.3 When mounted, BS 6100 number must be visible.
13.4 AEI company logo must be visible in bold lettering (5 mm high).

Materials

14.1 The use of existing materials for manufacture is preferable; it is not envisaged that a new material will have to be developed.
14.2 The materials chosen will be easily used in production.
14.3 The chosen material must withstand the necessary environmental conditions (see 'Environment').
14.4 The materials chosen must not oxidize in any way.
14.5 The materials should be lightweight, within the designated limitations (see 'Weight'). However, strength must not be sacrificed for weight reduction.
14.6 The chosen materials should be resistant to wear and tear.
14.7 The surface finish should not react with skin, wood, paint, varnish or any other household materials.
14.8 The materials should not be poisonous to humans or household pets.
14.9 The materials should resist cutting by wire cutters.

Product life span

This should be as long as possible so that the initial investment may be recovered. Each market (home and overseas) will be analysed separately, and production will continue until the 'product life cycle curve' levels out. Thus, the product life span will also be dependent on a favourable market reception.

Standards/specifications

BS 8220 Part 1 (refer to enclosed document at end of PDS).
BS 5872 Security for locks and latches on doors (in buildings).
BS 6100 Parts 1, 2 and 3 refer to security systems in buildings.
BS 6800 Specifications for home and personal security devices.
BS 4737 Intruder alarm systems.
BS 6707 Specifications for intruder alarm systems for consumer installations.
BS 6799 Code of practice for wire-free intruder alarm systems.
BS 4190 Bolts and screws, ISO metric black hexagon.
BS 3692 ISO metric threads, screws and bolts.
BS 6105 Screws and bolts, stainless steel, corrosion resistant.
BS 4464 Spring washers, metric units.
BS 5750 Part 1 refers to specifications for design, manufacture and installation.
BS 5760 Reliability of systems, equipment and components.
BS 3456 Safety standards.

Ergonomics

17.1 Hand-operated controls must be able to be positioned at any height suitable to the user.
17.2 Hand-operated controls must not require a force of more than 3 Nm.
17.3 The design should be based on one-hand operation, if hand control is to be used.
17.4 No sharp edges will be exposed to comply with British safety standards (see 'Safety').
17.5 Preferable if controls were distinguished by colour and/or shape, to allow operation in low lighting conditions.
17.6 Allowance should be made for operation when the user is sitting, such as in the case of the disabled.
17.7 Considering OAPS with co-ordination problems, the following dimensions must be complied with (if applicable to the design):
- (a) Control buttons must have a diameter greater than 25 mm.
- (b) Control levers must be longer than 100 mm.
- (c) Control knobs must have a diameter greater than 25 mm and a protruding length longer than 30 mm.

Customer

The customer will be a householder, ranging from children to senior citizens and the disabled. A questionnaire was prepared and issued to householders. From the questionnaire, the following conclusions can be drawn:

18.1 32% of the people surveyed felt insecure when answering their doors.
18.2 44% of the people surveyed only had a lock fitted on their doors.
18.3 40% thought that their doors were inadequately protected.
18.4 People thought that strength and being able to see the visitor were the most important factors. Some also required to be able to communicate with the visitor.
18.5 28% of the people surveyed were willing to spend over £20 on a security device.
18.6 16% would install the device by themselves.

From the questionnaire, it can be seen that there is space on the market for a new security device, as 44% of the people surveyed had only a lock fitted to their doors. The device should be aimed at all ages of the community, but special efforts must be made to capture the market of the senior citizens.

Quality and reliability

As AEI work to BS 5750, this product will also be designed to comply with this standard.

19.1 To enhance the company's reputation, and to remain competitive, a three-year guarantee will be offered.

Shelf life storage

20.1 Warehouse storage: Devices will be stored in their individual packaging. Depending on the size of the final device, they will be stored in boxes, at a minimum of 10 per box.
20.2 At retail outlets, the devices will be displayed within their individual packages.
20.3 There are no limitations on shelf life, since the device will be of a non-organic nature (non-perishable).

Processes

21.1 There are no limitations to the manufacturing processes as there are no constraints on the manufacturing facility.

Time-scale

22.1 Specification formulation – 24th February 1989.
22.2 Concept evaluation – 10th March 1989.
22.3 Evaluation of concepts – 10th March 1989.
22.4 Design process complete – 21st April 1989.
22.5 Process setting complete – 1st July 1989.
22.6 Commence manufacturing – 1st August 1989.

Testing

23.1 In the case of parts being purchased from an outside company, visual inspection of 1 in 40 items will be carried out.
23.2 Due to the expected high volume of production, batch inspection will be used for the final product.
23.3 Typically, a batch test of 1 in 1000 will be carried out.
23.4 In the case of a restrainer or chain, the device will be fixed to a standard domestic door and destructively tested to BS 3621.

Safety

Device must comply with all of the relevant parts of BS 3456 and the Home Safety Act of 1961.

Company constraints

25.1 The company is already well suited to manufacturing security products, and as there are no manufacturing constraints, no company constraints should be envisaged.

25.2 Depending on the market reception of the device, excess labour may have to be employed.

25.3 If new manufacturing processes are required, allowances should be made for the retraining of personnel.

Market constraints

The device will be marketed on a trial basis within the UK and, if successful, will be marketed worldwide.

Patents

The following are patents (from GB) that should not be breached.

1520429 Chain catch for doors.
2114206 Improvements in door security devices.
4079973 Adjustable chain door guard.
4106800 Chain latch for door.
1507281 Observation port.
2036841 Security communication device.
1604627 Door viewing device.
1574813 Door fitting, allowing a visitor and his credentials to be inspected before the door is opened.

Political and social implications

All parts of the device are to be obtained from British companies. Consideration should be made to the naming of the product when exported to non-English-speaking countries. The product shall not be exported to any country where current trade embargoes exist.

Extract from BS 8220: 1986

Part 1, Section 3.4.2.16 – door viewers, door limiters and door chains.

The fitting of the above is recommended for any door through which a stranger might be admitted to a dwelling – that is, front entrance doors and rear/side doors as appropriate.

Door viewers permit the inspection of callers to be made with the door locked and bolted. For maximum clarity, a viewer should have a wide angle of view (minimum of 160°), a glass lens, and be mounted at a height to suit adult occupants including the elderly and the disabled. Spaces outside doors should be illuminated to permit identification of callers.

Door limiters are suitable only for wooden doors; security chains can be fitted to wooden and metal doors. Limiters or chains, which only provide limited security against forced entry when doors are opened partially, should not be regarded as an alternative to security locks and bolts. They should be robust and should be securely fixed with screws of at least 30 mm in length, in such a way that they cannot be dislodged from outside a dwelling by manipulation or by force. Safety chains should be made from brass or steel, and should have welded or forged links.