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INNOVATION THROUGH DESIGN

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Abstract: The paper discusses the central role of design in technology. It considers the social and economic drivers of innovation and design as well as trends in technology. It views the role of ethics. The life-cycle of products is discussed in relation to design. The definition of requirements, as the starting point of design, is considered. An outline is presented of the design process, and developments in the process considered. A view is given of the way forward and the of the tasks of measurement and instrumentation science in support of design.
Keywords: innovation, product life-cycle, design

1 INTRODUCTION

The task of science is to describe and understand the world. The task of technology is to change it.

Technology changes the world by the generation of products to meet human requirements. It advances by innovation.The principal tool by which this is accomplished is design. This is the process of transforming a specification of a requirement into a specification of an artifact, or system, which will meet that requirement, in such a way that the product can be made or implemented.

Our material culture has been built through design from the dawn of humanity. The explosively rapid technical advances of our times, and profound social and economic changes mean that the nature of design itself is changing, as demands upon products and systems develop and as the tools for design advance.

It is therefore imperative, as we review the state and advances of our technology, that we also examine the processes by which it is applied, that is the process of design.

2 NOT INVENTION BUT INNOVATION

In looking at design it is essential to start by distinguishing between novelty and innovation. The task of science is novelty, the discovery of new facts and new understanding. The task of technology is innovation, that is the finding satisfactory solutions to practical problems and applying them successfully.

To put it simplistically, the task of scientists is to be clever, the task of engineers is to be successful.

3 SOCIAL AND ECONOMIC DRIVERS

Technology is an activity driven by social and economic forces. The nature and methods of design are determined by them.

It is arguable that the rapid changes in economic and social conditions in the world influence technology in general, and design in particular, more that scientific and technical advances.

In the world in which technology is developing, design must meet first of all stringent economic criteria. It must result in products which generate more resources for the maker and user, than have been consumed in their production or acquisition. In general the economic benefit must be specific and determinate. A vague and general benefit is not in general a valid consideration. There must be recognition that the acquisition of technical knowledge and the activity of design represent significant costs.

In general the costs and benefits of products are measured in terms of money. This is appropriate in most applications, there are significant areas of technology such as the delivery of health care, the provision of public goods, and, for that matter, the technology of weapons of war, where money is an inappropriate measure. It is especially important in such applications that soundly based methods of cost-benefit analysis are used.

All innovation involves risk. A proper estimation and management risk is an essential part of design considerations.

Design is determined by a market for products. The customers in the market determine what they want, and what they are prepared to pay for what they want. Producers must design and provide products which customers want, at a price the customers are willing to pay.

To a substantial extent, markets are global and there is a free flow of technology and capital. Design, particularly in high technology, must thus generally meet the demands of a global market, and generate products that are globally competitive.

These economic forces involve a paradox. Advances in technology require an expanding knowledge base. Expansion of the knowledge base requires basic research and the free communication of scientific and technical information. The modern economic paradigm works against the funding of the acquisition basic knowledge, which is often costly, and where the economic benefits are uncertain, lie in the indeterminate future and where further more the benefits do not flow exclusively to those who provided the resources to acquire the knowledge. Therein lies a major danger.

Social forces drive design as much as economic ones. It is possible to discern some major social impacts on design.

Firstly, as affluence increases, there is an increased demand for quality of products, and for this quality to be transparently assured.

Secondly, society increasingly demands that products are safe, and that they do not injure health. Again society increasingly demands that these aspects are transparently assured.

Thirdly, as our increasing population and high impact technology affects our limited planet, society presses for technological solutions which are environmentally and ecologically friendly.

Finally it must be recognised that there is a widespread public distrust of science, technology, and the changes they bring. The social and environmental risks in innovation are feared. They must be met by openness of scientific knowledge and transparency in technical decisions, notably in design.

With globalisation the social demands, and public fears must increasingly be met by agreed international action.

4 TECHNICAL DRIVERS

This presentation is not intended to review the state and progress of technology, not even in the more restricted field of measurement and instrumentation. It is nevertheless imperative to recognise that design is substantially driven by technology and thus, in looking at design, it is necessary to discern general technical trends.

Firstly, it must be recognised that technology is increasingly based on fundamental scientific knowledge, rather than mere practical experience. Science provides new solutions for technical problems, allows the optimisation of established solutions, and is the basis for more objective and transparent technical decisions.

Secondly, we must take account of the rapid, and rapidly accelerating, change of technology. Designs tend to be technically obsolete almost as soon as they are implemented. At the same time it is essential to remember that new technology always involves uncertainty and is accompanied by risk, It is necessary to balance the advantages of new technology against that risk.

The predominant technical advance in measurement and instrumentation is the development of information technology. The process of measurement is one of the acquisition, processing and effectuation of information. Measuring instrumentation must thus increasingly be viewed as information machines and systems, and its functions realised in software. To a significant extent the use of distributed information processes and the internet must impact upon design.

The general technical recognition of the central significance of information technology in measurement and instrumentation must not deflect our attention from the fact that in the design of measuring systems, the system under measurement, the sensors and the output devices, must be considered and designed in terms of their physical embodiment. Significant progress is being made in the technology of new sensors and sensing processes. Deficiencies in that physical embodiment design can only partially be eliminated by information processing. Instrumentation systems must be designed to meet ever more challenging environmental conditions and reliability requirements requiring attention to physical embodiment design. Significant technical progress is being made in the science underpinning such design and the tools for its implementation.

Technology drives instrumentation towards increasing complexity. Instruments have become instrumentation systems. Design processes have become cooperative, with design activities becoming distributed and concurrent. This leads to the need for more systematic, formal, rational and documented methods.

5 ETHICS

Design is action. Therefore ethics, the consideration of what the objectives of human action should be and what proper constraints on human action should apply, must be a basic consideration of design. Design is generally a collective activity. Design decisions are taken in organisations and subject to the pressures and constraints of society. Nevertheless there are significant moral duties that are incumbent on the individual designer. Notably they are to acquire and to maintain the highest level of knowledge and skill applicable to his or her activity. Secondly to recognise that they are the most competent expert on their own work and that they should be objective, transparent and open in their decisions, and be prepared to be accountable for them.

6 LIFE-CYCLE OF PRODUCTS

Design must consider the life-cycle of the product to be designed.

The life-cycle of an individual artifact or system can best be illustrated by Figure 1, which illustrates, the sequence of all the stages through which a device, equipment or system goes from its initiation to ultimate disposal.

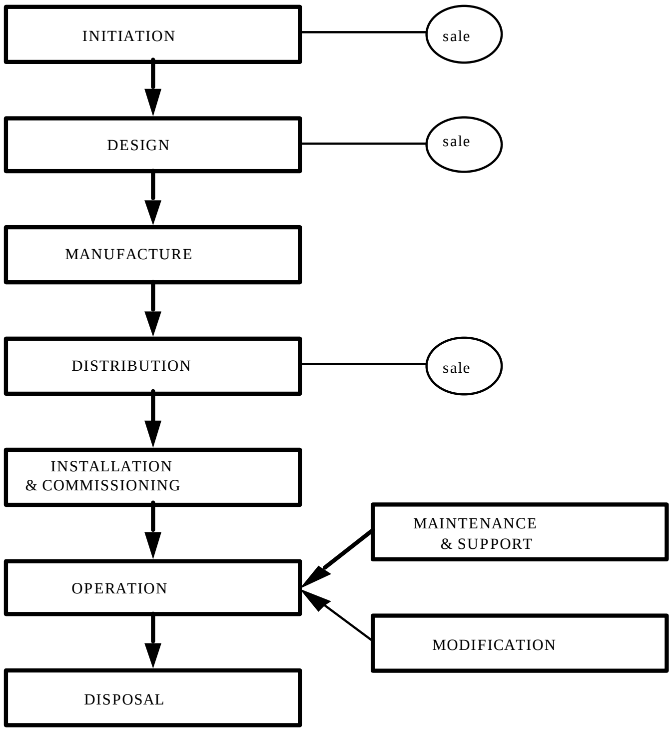

Figure 1. life-cycle of product item

The product initiation stage is the set of all the activities concerned with identifying a want, a possibility of satisfying it, and the commitment to do so. Design is the process which takes the statement of want originating from the product initiation stage and translates it into a specification of a device, equipment or system to satisfy the want, such that it can be made or implemented. The manufacture stage takes the above specification from the design stage and makes or implements the product. The manufacture of the product involves its testing.The distribution of the product involves the transport of the product from the site of manufacture to the site of use including any storage. The processes of installation and commissioning are concerned with the bringing of the product into operation including its incorporation into any larger system. Operation is the basic process of use of the product. In parallel with the operation of the product there are the processes of maintenance and logistic support. The former is concerned with keeping the product in an operational state the latter with providing the supplies required to do so. Also in parallel with the process of operation there is in general a process of modification. It is useful to recognise the distinctions between corrective modification, which is concerned with remedying faults of design or manufacture; adaptive modification, which is concerned with adapting (or tailoring) the product to new uses and enhancement modification, which is concerned with enhancing the performance of the product, say by retrofitting of new technology. Finally, there is the disposal of the product at the end of its useful life. It takes place when either the product has ceased to function or more generally when its disposal is cost effective. Disposal involves decommissioning and waste disposal. The product may, of course be transferred to another user in which case it begins its life again from the distribution stage. The diagram of the life-cycle shows the points of the lie cycle at which the item may be sold.

Consider now a product model, that is a set of product items manufactured to a particular design. The main processes of the product life-cycles as far as the manufacturer is concerned are: product policy and management, design, manufacture, promotion distribution and sale, and manufacturer support. Manufacturer product policy is the process of planning and decision as to which products are to be manufactured and supported. Design in the life of product model is a continuing process which takes in information from manufacture, sales, use and support to introduce product modifications. The process of manufacture has already been considered. Promotion and sales are self-explanatory concepts. They are closely coupled with distribution Together with product policy they constitute marketing, although all other aspects of the life of the product model are strictly involved in marketing. The manufacturer support process in the life of the product model consists of all the activities of the manufacturer undertaken following sale.

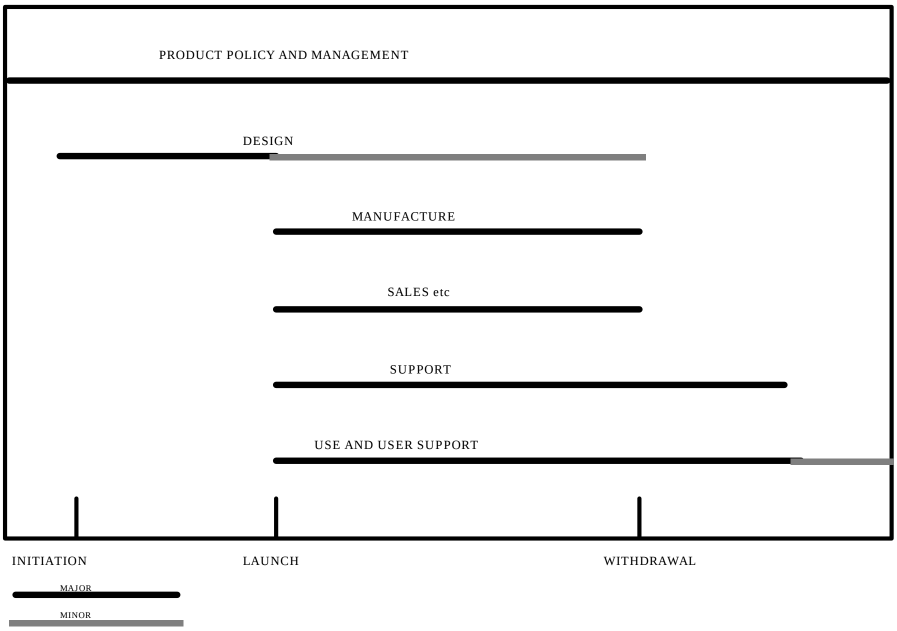

Figure 2. Operation of the processes in the product life-cycle over time

The operation of the processes in the product life-cycle over time is illustrated in Figure 2, which shows a maker perspective. The main time-reference points are the product initiation (the point at which the initiation activity, subsumed within product policy and management, ends), launch and withdrawal. Product policy and management extends from before initiation till beyond withdrawal. Design starts with initiation and continues after launch as a minor activity. Manufacture, sales etc. start effectively with product launch and continue to product withdrawal. Support starts with product launch and continues beyond product withdrawal to the point of support withdrawal.

It is useful to consider life-cycle of a product model in financial terms. These are generally important since they determine in general product initiation, launch and withdrawal. Consider an income flow for a product model from the perspective of the manufacturer. There is an initial negative income flow corresponding to the investment in design, preparation for manufacture and the like. After launch there is, in a successful product, a positive income flow. There is a growth to a peak as sales increase with market penetration. The flow then steadies with product maturity and market saturation, and then may begin to decline with competition from new products, changes of fashion and technological obsolescence. The product is in general withdrawn at or before that point.

It is important to recognise that there is a user perspective, as well as a maker perspective on the life-cycle of a product.

In the consideration of design and innovation, it is essential to take into account all stages of the life of a product, and not merely the operational one. Further it is important to take into account the user perspective as well as the maker perspective.It is also important to recognise the impact of the design process on the flow of income. Design is a significant expenditure. No income is derived from a product before design is completed, and hence the costs grow with time. In modern technology product life-cycles are short and growing shorter due to technology obsolescence and competition. It is also important to recognise that the design must be completed speedily. Further, although it is possible to modify a design after it is completed, the later in the life of a product modification is made, the more expensive it is. The rule of design must be, get it done quickly and get it right first time.

7 REQUIREMENTS AND MARKETING

A product is determined by the initial statement of the design requirements. This is the task of product policy and management. It must establish the requirements of the product user and the price the user would be willing to pay for their satisfaction. It must be balanced against the resource cost to the maker of satisfying the requirements and alternative opportunities that exist of employing those resources. Successful organisations employ a marketing perspective, determining correctly the requirements of the user and shaping products to meet them.

It is important to recognise that in addition to the effects of market pull, there is also the effect of technology push. New technology makes new products possible, for which a market requirement does not yet exist. The task is the creation of a new market.This is a risky way forward, but may be highly rewarding.

8 THE DESIGN PROCESS

In earlier stages of technology design was carried out by a single individual, who did not externalise and communicate the creative process involved, except, perhaps, to provide instructions for manufacture. This is no longer the case.

Technological designs are generally complex. There are many design agents, who work cooperatively. They carry out many of the design tasks concurrently. It is thus necessary to have a model of the design process as a basis for organising it. The design work must be formally documented at all stages, firstly as a basis of communication among design agents, secondly because designers are increasingly held accountable by customers and society, so that their process are increasingly required to be rational and transparent. There is a view that such a formal approach is a barrier to creativity. It is, however, inevitable. It is necessary to organise design work so as to eliminate, as far as possible, barriers to creativity.

There is a developing understanding of the nature of the design process, and of the methodologies that underlie it. This understanding has a variety of sources. Firstly there is systems engineering, which has developed concepts and methodologies to deal with large and complex systems. Secondly, there are the systematic methods in machine design. There are significant insights from studies of creativity. Finally, there are the rapid advances in machine intelligence and problem solving.

It is not appropriate, in this general presentation to discuss models of the design process, but it is nevertheless necessary to outline our present understanding of the design process as a basis of further discussion.

Design starts from a definition of design requirements. This should generally be in the form of an abstract functional model of the artifact or system to be designed. This definition should not imply a specific embodiment or form of embodiment. It should also involve a value model which expresses the design criteria.

The first step in design is generally a decomposition of the task into components to be separately designed. This decomposition involves the determination of abstract functional models of the components and the definition of interfaces. Each component may be further decomposed for the purposes of design, until primitive components of design are achieved.

The design of a primitive component starts with the abstract functional model which constitutes the component definition. A number of design concepts are then generated.

Such design concepts are then generally in the form of a model of embodiment. Since the requirement is for the performance of the specified component function, it is generally necessary to analyse the model of the concept to determine the function, that is the input-output relation, of the conceived component.

The functions of the various design concepts are then evaluated in terms of the value model of the design criteria.

One, or more, of the candidate design concepts are then selected for further development, or determined as the final design. This selection is a decision process. If none of the candidate design concepts satisfy the requirements, or if it is considered that it may be possible to improve on them, the process returns to the generation of further candidate design concepts.

The development of a design concept takes place, in general in several phases, starting from a general abstract description or model, and terminating in a detailed and concrete description. The phases generally recognised are: the conceptual phase in which the working principle of the object of design are determined, the embodiment phase in which the general geometrical and material form of the component are defined, and finally the dimensioning phase, in which the details of physical form and material are fixed. In modern instrumentation, when many functional components are realised in software, the software design phases proceed in similar phases, from general system concepts to the definition of implementation.

The design process is a process of knowledge acquisition and transformation. It is based on, knowledge bases. The knowledge is firstly procedural, being the set of design methods available to the designer. The other knowledge is declarative, consisting of knowledge about physical effects and laws, their models, developed design concepts, and the like. In traditional design methods, much of this knowledge was internal to the designer and not explicitly formalisable. It may have been supplemented by written standards and guides. Increasingly there is an emphasis on the organisation and management of such knowledge. With modern computation it is possible to store such knowledge in computers and to manipulate it, providing ever improving automatic tools for design.

A significant task before measurement and instrumentation science, in support of design, is the systematic organisation of basic knowledge, so that it can be effectively stored and retrieved. An essential component of this task is the development of methods of knowledge representation.

The core of the design process is the generation of design concepts, that is working principles and embodiments. It needs to be recognised that the basis of practical technical design is often the appropriate use of established design concepts. This confirms the need for well organised knowledge bases and effective methods of their searching. An established design concept may be the starting point of a convergent, or vertical, development, in which the initial candidate concept is developed, by systematic variation, until a final design is arrived at. Divergent, or lateral, concept generation arrives at innovative solutions by creative jumps or the use of analogies. methods have been developed for motoring creativity in both convergent and divergent concept generation. Computer based tools for design concept generation hold out promise, but are only at an early stage of development.

The analysis of the candidate design concepts, which determines function from a model of embodiment, is based on mathematical models. The analysis of a candidate design involves the formulation of a model, and the determination from it of the relations between the design criteria, that is those variables which determine what is required of the design, and the design variables which the designer can determine. There has been extensive development of the mathematical tools for the representation of models, and also for the formulation and analysis of their computer representation, Methods for the dynamic analysis of signals and systems are particularly. powerful. The development of finite element techniques have provided means for the analysis of complex physical designs. These capabilities mean that analysis using models implemented in computers are the basis of modern technical design.

Evaluation of a candidate design follows analysis. Modern approaches to design put emphasis on the appropriate formulation of the value model which expresses the design requirements and on the explicit, systematic and documented performance of the design evaluation. The appropriate representation in the model of qualitative design criteria, and the appropriate integration of the values of criteria having multiple attributes, are significant problems.

As with evaluation, modern approaches to design are based on the application of formal methods. They involve making decisions on explicit evaluations and incorporating uncertainty and risk considerations in the decisions.

Decisions in design normally involve the consideration of competitive candidates, and commonly result in a decision to generate further candidates, generally by a systematic variation of key design variables, resulting finally, after further evaluation in the decision to accept one or more candidate concepts for further development. Modern methods of optimisation, such as numerical optimisation and genetic algorithms are powerful tools for this process.

It was stated at the outset that a design of any, but the simplest, system starts with a decomposition of the design into components. It accordingly terminates with an integration of the component designs into a total system.

The description of the design given above is one of top-down process, which starts with a determination of the design requirements and proceeds systematically to a design. This is appropriate to innovative design. Such top-down design promises optimal solution, but involves the risk that it may not prove entirely feasible, or meet time and cost criteria. In practice design very frequently starts with an established concept, or a set of established component concepts, and proceeds by incremental development. Such bottom-up, or middle-out design reduces risk, but may result in design solutions which do not optimally meet.the requirements of product policy.

9 THE WAY FORWARD

Design, like the whole of technology, will continue to change very rapidly. The way forward can be discerned in general outlines, though the unforeseen is the most likely to happen.

Design will be driven forward by increasingly stringent economic, social and environmental demands and by the requirement for high and assured quality.

Technological drive in measurement and instrumentation technology will come firstly from information technology, particularly the use of machine intelligence, distributed processing and innovative sensing mechanisms.

Design will need to become more rapid and accurate, to accommodate ever shorter product life-cycles, It will be aided in meeting these demands by developments in design methodology including systems engineering, and by the development of computer aided design tools and environments.

10 THE TASKS OF MEASUREMENT AND INSTRUMENTATION SCIENCE

The future of design in measurement and instrumentation technology places significant tasks before measurement and instrumentation science.

Firstly it is imperative to recognise that design is at core of measurement and instrumentation science and that the science and education in it must become design orientated.

The basis of design is the effective and efficient storage and retrieval of knowledge, which in turn requires its systematic organisation. It is a central task of measurement and instrumentation science to continue to develop a systematic organisation of knowledge in the field. Appropriate languages for knowledge description are needed

Modern design is based extensively on modelling and simulation. Models are being rapidly developed in the field of information systems. In measurement and instrumentation science there is a need for better methods for physical modelling of sensors and actuators.

The application of machine intelligence and knowledge engineering methods to the design of measurement and instrumentation equipment offers exciting prospects.

10 LITERATURE

This paper is an overview of a very wide field. The field has an extensive literature. The paper, however, is not intended as a critical review of this literature. The views presented above are based on work of the author which has been previously published. To help those who wish to study the basis of these views reference will be made here to publication, mainly of the author, which give extensive bibliographies and discuss it critically.

Design methodologies and the design process are reviewed in [1] and applications to instrumentation in [2]. The systematic organisation of knowledge in measurement and instrumentation science and technology and the place of design in the science is reviewed in [3]. Advances in models of the design process are discussed in a paper elsewhere in these Proceedings [4]. The life-cycle of products is discussed in detail in [5]. An analytical review of models of instruments and instrument systems is given in [6]. Automation of the design process is discussed in [2] and some earlier thoughts in [7].

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