A SYSTEMATIC APPROACH TO DESIGN

BY

INSTRUCTOR COMMANDER M. MORELAND, R.N., M.A., A.I.W.S.P.,
AND W. J. BLIGHT, A.M.I.E.E., R.N.E.S.

FOREWORD

BY

CAPTAIN S. F. BARTON, R.N., A.M.I.MECH.E., M.I.MAR.E., M.B.I.M.
*(Director of Fleet Work Study and Management Services,
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Some months ago, Fleet Work Study was invited to contribute to this *Journal*. As many readers will know, the activities of the Fleet Work Study teams in the Fleet and ashore have covered a wide variety of subjects, many of which have been tackled using conventional work study techniques. It is thought that the following article would be of interest to readers of this *Journal* as it explains a recent development of the work study approach.

A major trend has developed during the last six years, namely the increased application of Fleet Work Study to design problems, such as to site development plans of shore establishments and in the Ship Department, where a Fleet Work Study team formed by naval and professional officers from the Ship Department has completed over thirty studies concerning various aspects of ship design. During this period, Fleet Work Study has been steadily adapting existing techniques or developing new ones to meet this trend.

It is of interest that there is currently in industry a growing realization of the importance of the process of design. It is claimed today that it is not enough to teach engineering technology on its own to the engineer who will be engaged in design. He requires to have an understanding of the logical processes involved—in short, he requires a design method.

Design method as such is in its early days. Mr. E. Matchett of Engineers' House, Bristol, has been a pioneer in this field. It was as a result of attending courses conducted by Mr. Matchett that Fleet Work Study Team No. 18 applied itself to developing a design method to meet the particular needs of the

Ship Department. The techniques resulting are called MAUD and PAM—Methodical Analysis for Use in Design, and the Provide A Means diagram. Training in the use of these techniques has started in the Ship Department with the active support of its Director-General, Sir Alfred Sims. The article which follows is taken from the pamphlet, written by Instructor Commander M. Moreland and Mr. W. J. Blight, which is used as a reference by those who have received this training.

The procedures involved will not appear strange as they are in fact the natural processes involved in problem solving. MAUD and PAM are intended to stimulate these natural processes, thereby ensuring a full understanding of the problem, a logical and systematic evolution of the solution, and a record of this evolution.

Although these techniques were developed for use in the Ship Department, they undoubtedly have application elsewhere and should be of interest to all engineer officers confronted with design problems.

* * *

THE DESIGN SITUATION

The Definition of Good Design

In defence projects the problem is to design to obtain the maximum reliability commensurate with achieving the Staff Targets on purpose and performance.

The choice has often to be made between providing simple and highly reliable items which do not exactly meet all requirements, and highly sophisticated and complex items which meet, and maybe more than adequately meet the need, although they are potentially fraught with unreliability. In warship design there are items in each group, the 'domestic' systems fall mainly into the first group, whereas the 'weapon' systems fall into the second group. The choice is dependent on the overall needs and circumstances of usage.

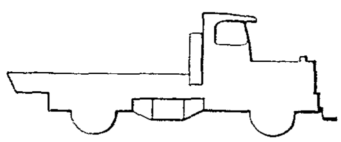
The task resolves itself into producing good design to meet the true needs of the service with the simplest and most reliable equipment; in short, the task is to produce 'good design' in accordance with the definition that it is 'the optimum solution to the sum of the true needs of a particular set of circumstances'.

Reliability

Complexity of modern equipment is the major contributing cause of unreliability. Because there is more to go wrong, the reliability of each component must be greater than its counterpart of some years ago—even if the target is only to maintain the overall reliability of that time.

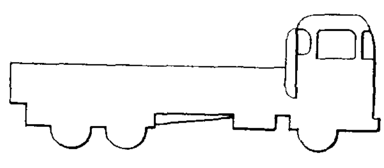
An example of this increase in complexity and its effect on reliability is the lorry.

1928



With 238 critical parts each having a reliability of 99·95 per cent, the vehicle reliability would be 90 per cent.

1964



With 696 critical parts, if each part was of the 1928 reliability, the overall vehicle reliability would be only 73·75 per cent. To achieve a vehicle reliability of 90 per cent, the individual part reliability has to be increased to approximately 99·98 per cent.

TABLE I

Individual Component Reliability (percentage)	*System Reliability (percentage)*				
	No. of Components				
	10	60	100	250	500
99·99	99·9	99·4	99·1	97·5	95·1
99·90	99·0	94·2	90·5	77·9	60·7
99·00	90·4	54·8	36·6	8·1	0·7
98·00	81·7	29·8	13·3	0·6	0·0

It should be noted that the definition of 'reliability' approved by the National Council for Quality and Reliability is: 'The measure of the ability of a product to function successfully, when required, in the specified environment. It is expressed as a probability'.

TABLE I indicates the theoretical effect of critical component reliability on system reliability. This table is calculated to one place of decimals on a binomial distribution of probability.

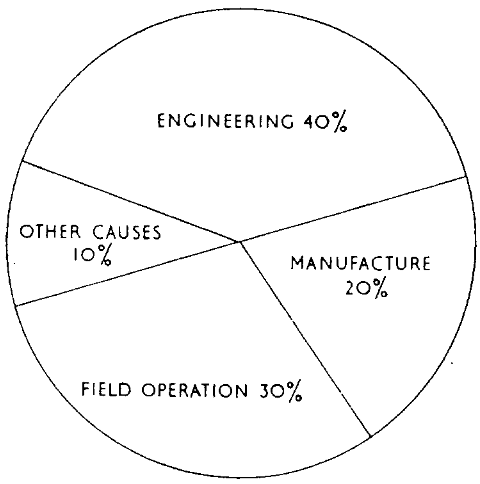


FIG. 1

Sources of Unreliability

Studies have been made in America to determine the source of trouble in equipment supplied by Government contractors. While the number of troubles varied from product to product, studies of different kinds of products showed similar distribution of troubles, and the percentages shown in FIG. 1 are representative of a large number of cases. The engineering troubles are attributed to shortcomings in the design—in other words, poor design.

Categories of Design Problems

Design problems can be divided into four categories:—

(*i*) *Enclosures*—such as ships or compartments in ships which provide a framework in which people and systems can operate in detail.

(*ii*) *Flow systems*—a set of separate components which together perform a well-defined function, e.g., a missile direction system, an air-conditioning system, a power supply system. Flow system design includes the specification and positioning of components to perform a function, but does not include the design of the components.

(*iii*) *Products or mechanical systems*—a single unit of closely integrated parts which together perform a set of functions. It may be a component in a flow system or in an enclosure or it may be used independently, e.g., a watertight door, a gland, a lighting fitting.

(*iv*) *Parts*—These are single pieces of material from which products are assembled.

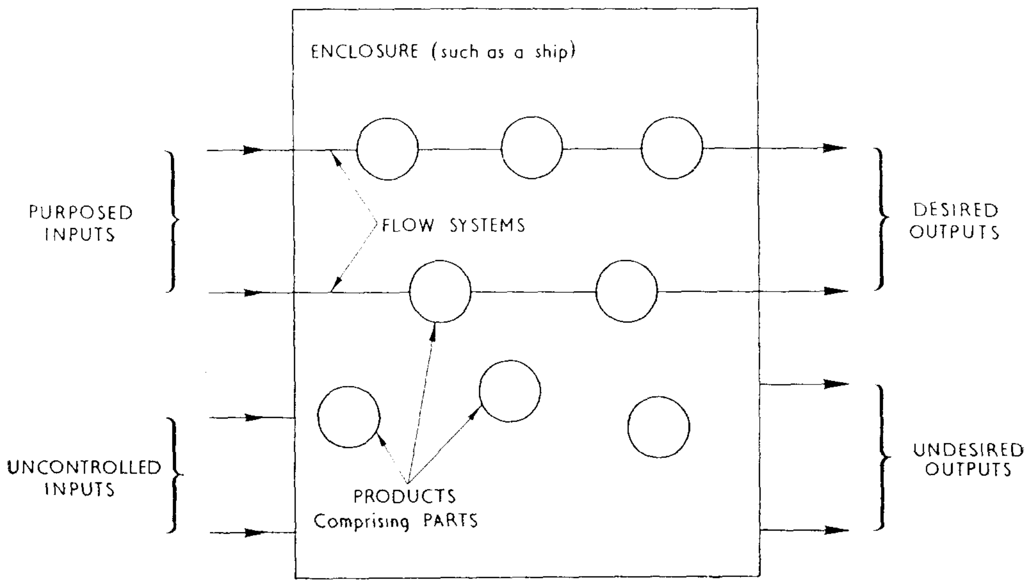


FIG. 2

These categories can be represented in a model as shown in FIG. 2.

The Design Processes

Design is the process of selectively applying the spectrum of science and technology to the attainment of an end result which serves a valuable purpose. The responsibility of the designer is to use the maximum powers of creativity, judgement, technical perception, economic awareness and analytical logic to devise uniquely useful devices and systems. His function is usually not to originate the basic scientific building blocks but rather to utilize them so that the result is a useful creation.

The design process may be represented by the model shown in FIG. 3.

The whole of the evolution can be regarded as a recurrent and regenerative process of:—

Analysis—of knowledge, needs and circumstances

Synthesis—of applying the knowledge to satisfy needs and circumstances

Evaluation—of the feasibility of the concept and effectiveness of the design.

It is not possible to advance in design without feeding in new inputs, or taking a decision that is not fully supported by evidence of suitability in the context for which it is to be used.

In satisfying a given design situation, designers sometimes have the choice between the gradual improvement of an existing item and the sudden introduction of a new design—an innovative design. The simplicity of an existing item has often led to a gross underestimation of the complexity of the needs actually satisfied.

Design Difficulties

The formidable difficulties that have to be overcome in deliberate innovation —the creations of a new design—are:—

Firstly, in assessing the needs which have not hitherto existed or been fully met;

Secondly, in exploring simultaneously a sufficient number of alternative solutions to ensure a high probability of 'instant' operational success for the version which is chosen for the very costly process of detailed development and production;

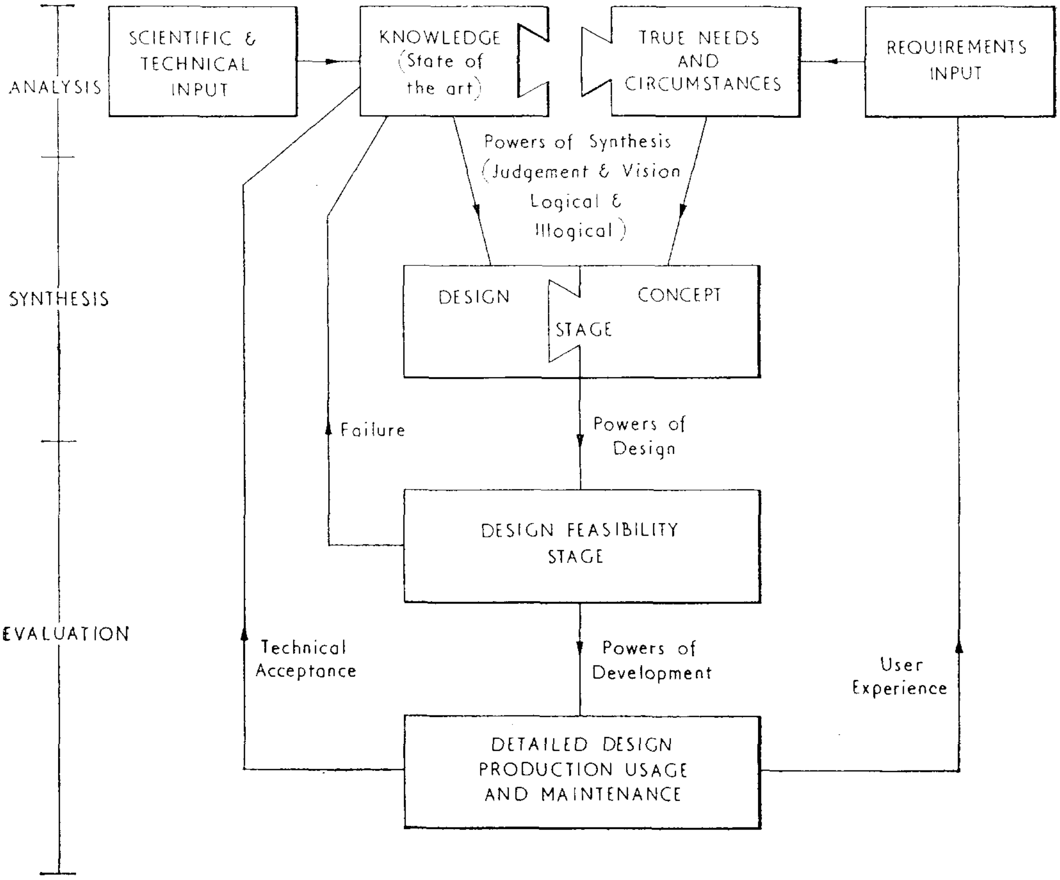


FIG. 3

Thirdly, the difficulty of foreseeing novel and disconcerting weaknesses or side effects which did not occur in the less complex device which the new design will replace.

There are limitations which are common to many kinds of designing. There is rarely time to collect and assimilate more than a part of the relevant information or to perform more than an incomplete or even simplified analysis. There is the difficulty of spotting errors before the design is well advanced. There is the high cost of altering or abandoning design upon which much time has been spent. The design team has to optimize the design, optimize the design time, and optimize the design cost. Rapidity is vital, but must not be bought at the expense of performance.

Design Strategy

The pattern of the engineering designer's work is long periods of routine analysis relieved by creative peaks. The burst of inspiration offering a solution is by no means accidental, but is consciously induced by the undertaking of long periods of immersion in detail of the problem.

The designer's mental structure plays the main part in designing, that of simulating the products and employing its properties in the imagination aided by calculations and sketches and informed experience.

Experience, however, is a double-edged weapon; it saves time and it saves thinking. The greater one's experience the more difficult it becomes to restructure one's thoughts to match the structure of a new design situation, new solutions and new sources. We all fall victims of personal pet aversions and hobby horses, and tend to develop these to satisfy needs and circumstances which did not exist in the original problem.

In general the mistakes which lead to disastrous failures in design occur at the stages when decision regarding needs, concept selection and feasibility are made.

The strategy should be to spend as much time as possible on analysis and evaluation, both of which are cumulative and convergent, and to minimize time spent on the synthesis of a single solution which may turn out to be a dud. Several alternative solutions should be developed in parallel, but not in detail, until clear evidence of the convergence of one acceptable solution is obtained.

Design Method

The common feature of all design methods is to formalize and make public the designer's thinking in the early stages. Thus more design effort can be applied at the beginning when it is more helpful and less towards the end when it can be wasted.

The aim of a design method is to increase the chance of adopting a strategy to make it less necessary to develop bad designs in order to learn how to develop good ones.

The object is to represent outside the brain the major part of the design process so that it becomes visible as a whole, not piece by piece as it is in trial and error. This externalized designing is no longer tied to the experience of one person. Greater leaps forward in design are possible because there is unlimited opportunity to restructure and test the relevant information patterns before finalizing the design. This systematic restructuring of thought enables the designer to explore more widely and to test more precisely with reference to experience that is not necessarily his own. Systematic methods of designing permit a widening of the area of search for interpretation of the problem and for solutions to it.

Previously it has been stated that designing can be regarded as a recurrent and regenerative process of analysis, synthesis and evaluation.

The MAUD—Methodical *Analysis* for Use in Design—procedure has been developed to assist in the uncovering of the true needs and particular set of circumstances that are required of a design. It assists in the formulation of the specification to be satisfied.

The PAM—Provide A Means—diagram has been developed as an aid to stimulate the *synthesis* of knowledge and needs and circumstances, and in the *evaluation* of the feasibility of design concepts.

THE MAUD PROCEDURE

Analysis

The model of the design process (FIG. 3) indicates that the initial task is the gathering and analysis of information; on the one hand this task is concerned with the spectrum of knowledge, and on the other with the establishment of the true needs and circumstances of the particular design problem.

Knowledge

Knowledge and the ability to apply it, are the keys to design achievement, and without an expanding knowledge it is unlikely that design will advance—it is only an accidental situation where practical progress is not based on sound theory. In engineering design the knowledge aspects are essentially in the scientific and technical fields and involve theory, working constraints, and materials and manufacturing technology. More often than not, the requirement is for an element in a man/machine complex where the effectiveness of the material project is how well it works in conjunction with the operator; it is essential therefore, that the designer has an awareness of human behaviour, skills, capabilities and aesthetics. The great increase in the amount of technical and scientific literature in recent years has led to a realization that progress is being retarded and research is being wasted and duplicated because knowledge cannot always be located when needed.

Basically there are two problems: how to analyse information to put it in a reproducible form and how to select relevant information accurately on demand. Much research is being carried out in this field. It is sufficient to state here that a design method cannot function without knowledge. It is the aim of design method to make the best use of the knowledge that can be made available from every conceivable source.

Needs and Circumstances

A full analysis of the user requirements is necessary to determine the true needs, and these are not necessarily what the user says he requires but the reasons why he says he requires them.

Similarly it is necessary to clearly understand the circumstances under which these needs arise; a design to meet needs in one set of circumstances may be completely unsuitable for the same needs in a different set of circumstances.

Primary Functional Need

Among the needs that have to be satisfied by the creation of a design there is usually one need which is paramount to all others. This need is termed the Primary Functional Need, PFN, and is defined as that need, which if not properly satisfied, makes fulfilment of all the other needs pointless.

In any type of design situation it is desirable at the onset to define, as well as one can, the PFN. It may be that as other needs and circumstances are revealed the PFN becomes more clearly defined, or it may emerge as a different need from that originally specified. The principle objective of the design must be to best satisfy this PFN, and this objective must be firmly realized by all concerned. All other needs become secondary and of relative importance to this PFN. The satisfaction of other needs will at times influence the solution to the PFN but at no time should the proposals to satisfy a secondary need be to the unacceptable detriment of the solution that could be pursued to satisfy the PFN.

The definition of the Primary Functional Need is the first step in the MAUD procedure.

The Procedural Steps

The MAUD procedure—the analysis of the true needs and particular set of circumstances—of a design, resolves into a number of steps:—

Step 1 —Define the PFN as well as one can

Step 2 —Marshal and record all known facts and intentions concerning the design

Step 3 —Consider the influences and life stages of the design to uncover additional needs and limitations

Step 4 —Critically examine (CUBE) the PFN and other needs which might affect the design, in apparent order of priority, and *challenge* the limitations in order to build up a true specification for the design.

Marshalling of Facts and Intentions

This step is in the form of a preliminary survey to sketch the broad picture of the concealed requirements. The information is best gathered by direct contact with those concerned in the conception of the requirement.

The recording should include the opinions and fancies as well as the hard facts, and should seek out intentions of use and their relationships in the broader issue.

In this way the designer can quickly assess the magnitude of the problem.

Influences and Life Stages

The object of the third step in the MAUD procedure is to channel thought in a systematic way so that needs and limitations (some regard these as negative needs), which have not already been stated or are not obvious, are uncovered.

If the name MAUD is mentioned, the average person might imagine an elderly lady. Thinking of life in this concept, her life may have gone through a series of stages, some well defined, others not clearly defined. These in broad terms might have been as follows:—

Prenatal
Infancy
Childhood
Adolescence
Motherhood
Old age

During these stages, her behaviour—her functioning—has been affected by many influences. These could be classified as:—

Inborne
Parental
External Influences

These influences to a less or greater degree have manifested themselves during each life stage in her functioning and her state or condition. For instance, during her infancy, although her life may well be influenced by national and international events, the greatest effects on her behaviour are due to inborne and parental influences. In the later stages of her life, these influences may be felt less and she may be much more dependent on the State for her well-being. It would be extremely difficult to write a specification for a MAUD whose functioning, dimensions and condition had to be quantitatively and qualitatively detailed in this labyrinth of life. Each and every need and limitation would have to be stated. In order to do this comprehensively, each influence acting on each life stage would have to be considered in the endeavour to see that no point was omitted. It might mean disaster if it was not specified that growth must cease at the age of twenty or that her appearance should alter with age!

For a material design, the life stages and influences will differ according to circumstances. For work in the Navy Department, the following influences are suggested with life stages which might apply to any industry:—

Influences due to:		*Life stages:*
Functional needs and limitations Associated parts Naval practices and procedures External conditions, practices and procedures	acting on	Drawings Prototype Production Assembly Test Packaging Distribution Installation Usage Maintenance

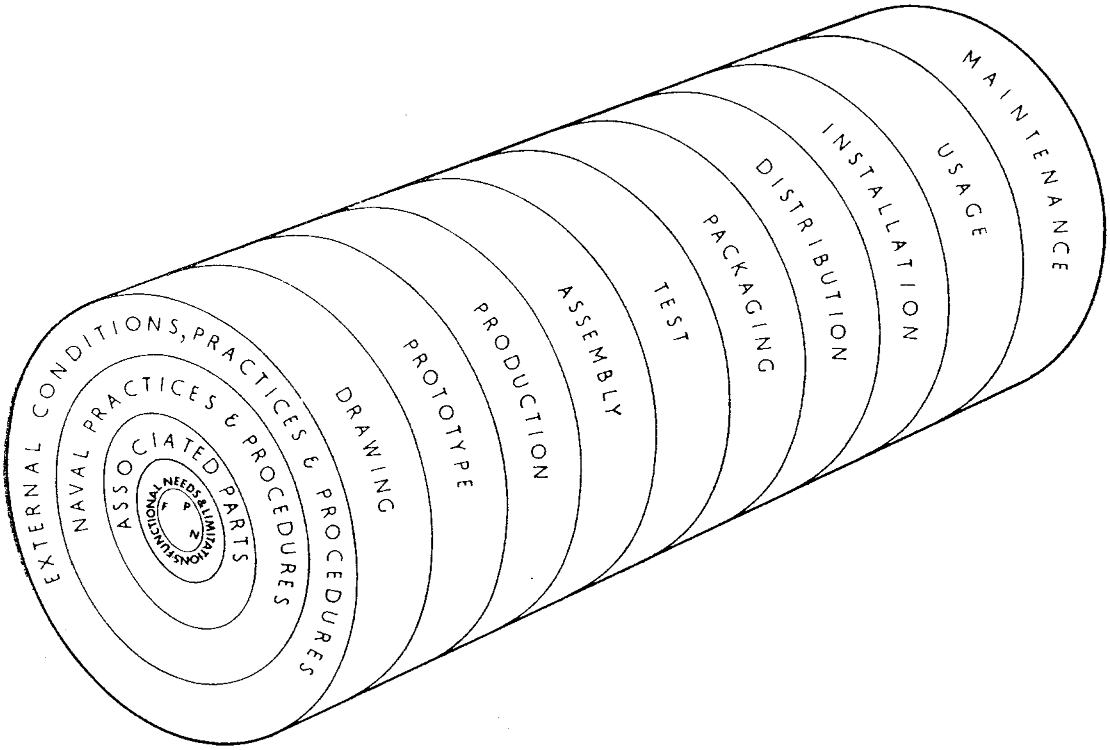


FIG. 4

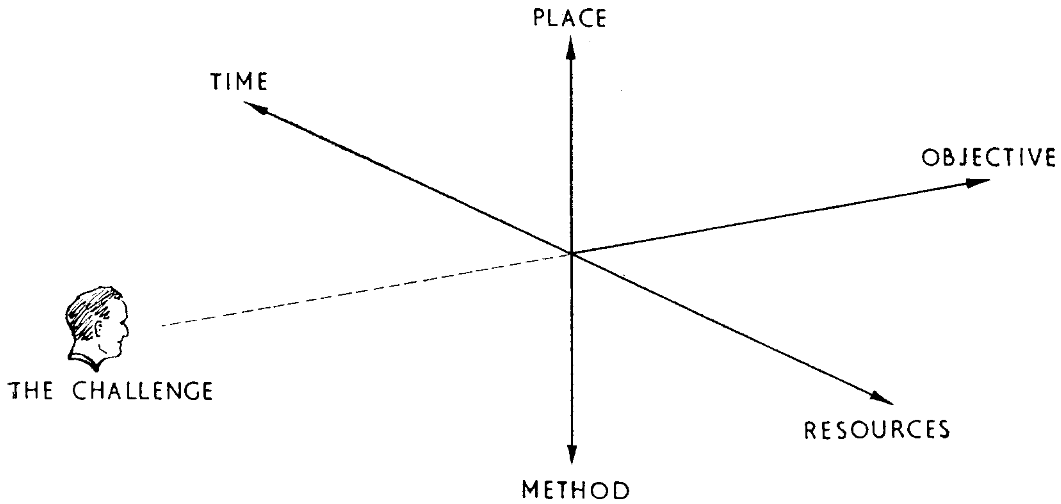


FIG. 5

These can be represented by a three-dimensional model like a concentrically ringed Swissroll as shown in FIG. 4.

Each slice of the 'Swiss roll' corresponds to a life stage—the substance of the cake is formed by the needs generated by the influences acting during the life stages. We must in turn analyse each slice of the cake, and each ring of each slice, if we are to search systematically for all the possible needs and limitations of a design.

In Navy Department problems, the usage and maintenance life stages are liable to generate the majority of needs as opposed to a manufacturing enterprise when other life stages may have greater effect. However in neither case should the search through all the life stages be neglected.

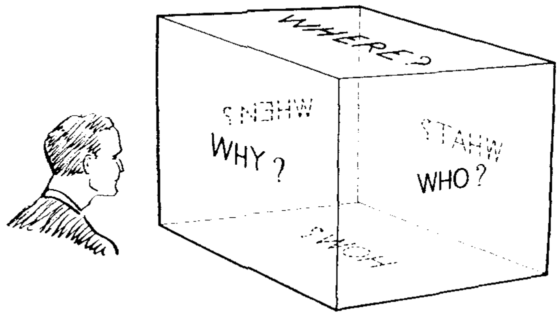


FIG. 6

The CUBE Process

When a need is investigated, one is looking at an objective in the design. This objective may not be well qualified and may not have been challenged. In order to qualify it, dimensions of time, place, resources and method should be considered with a challenging and sceptical attitude (FIG. 5).

These aspects correspond to the standard method study questions—What? When? Where? Who? How? with the challenge of Why?

The challenge can be thought of as looking into a crystal cube (FIG 6), each side of which has a set of pertinent questions which cause systematic analysis of the need in order that it may be fully qualified.

To lay down a set of questions that can be used for every design circumstance is no easy task but it is suggested that those below are used as a basis, with the proviso that every question should be asked and answered in every interpretation possible and should be elaborated if necessary in order to draw out detail. The essence is a systematic but flexible approach in the endeavour to obtain as much information as possible.

CUBE Questioning Sequence

(*i*) *Objective*
(*a*) What is the need?
(*b*) What is its form?
(*c*) What is its magnitude?
(*d*) What is its standard?
(*e*) What is the cause of having to satisfy this need?

(*ii*) *Time*
(*a*) On what occasion will the need arise?
(*b*) What is the sequence of which this need forms part?
(*c*) How often will the need arise?
(*d*) How long will the need endure?

(*iii*) *Place*
(*a*) Where will the need arise?
(*b*) What are the positional needs?
(*c*) What are the relationship needs?
(*d*) What are the environmental needs?

(*iv*) *Resources*
Are there any needs or limitations in:—
(*a*) Men?
(*b*) Machines?
(*c*) Materials?
(*d*) Money?

(*v*) *Method*
What basic principles and procedures is it intended to use?

(*vi*) *Challenge*
What would be the consequences of not satisfying this need? This is the fundamental challenge—but every other answer must be challenged as it arises—Why that?—Why then?—Why there? etc., and the questions What else?—When else? etc., applied in order that good reason is found for every qualifying detail of the need.

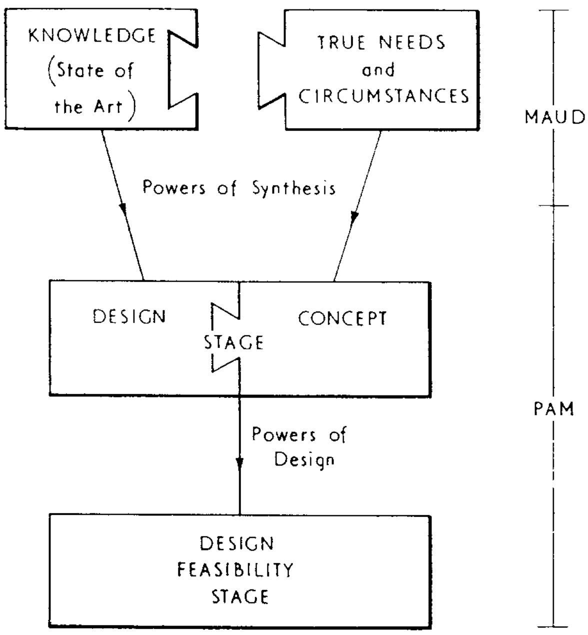


FIG. 7

Recording the Needs

Each need must be recorded as it arises during the search and recorded in such a way that during the development of the design reference can be made to the needs so that they are satisfied or at least given due consideration during the design. It will be important also to obtain decisions on the relative importance of satisfying these needs and to investigate the penaltties of not satisfying them. Depending on the problem, it may be desirable to group and arrange the list of needs and limitations in an order of priority.

This record of needs with all qualifying detail obtained by the MAUD procedure constitutes a statement of requirements on which the synthesis of the design can proceed by the use of PAM.

THE PAM DIAGRAM

Synthesis and Evaluation

The next step in the design process is to apply knowledge, either directly or as modified by judgement and vision, to the true needs of the particular situation so as to formulate (or synthesize) design concepts which can be assessed to determine their feasibility for development into satisfactory solutions to the problem (FIG. 7).

The PAM Diagram

To assist in this step of the design process the PAM diagram has been developed.

The purpose of the PAM diagram is to:—

(1) Display the problem to be solved

(2) Display every conceivable means that could be developed to solve that problem

(3) Permit qualitative and quantitative assessment of the feasibility of each proposal in terms of the advantages and disadvantages with regard to how nearly it satisfies the needs and circumstances

(4) Enable a decision to be made as to the concept, which, if developed would best satisfy the needs of the particular set of circumstances.

Process Chart

The first step in the construction of a PAM diagram is to draw a process chart which defines the need as an activity and makes reference to the states before and after the activity.

Thus, if the problem to be solved was the replenishment of victualling stores to a ship at sea, the process chart would take the form shown in FIG. 8.

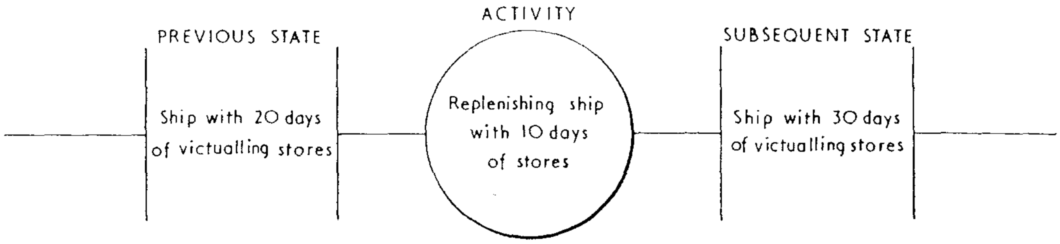


FIG. 8

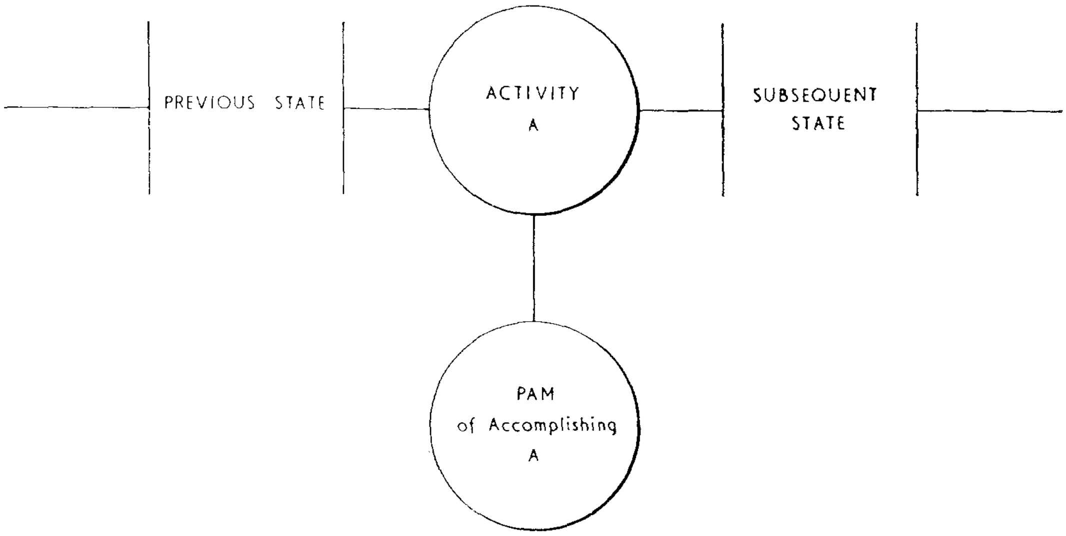


FIG. 9

This chart is included to define the upper limits of the diagram; it indicates at what level of decision the problem is accepted. In the example the decisions that the ship requires to be replenished with 10 days of stores when it has 20 days' on board has already been taken. The MAUD procedure would have critically examined this need and established without any shadow of doubt that this was the problem to be accepted. Any doubts as to the validity of the need should have been exposed, and the requirement to replenish the ship with 10 days of victualling stores at sea would have emerged as the true need and the Primary Functional Need—PFN.

The design problem that has, therefore, to be solved is to Provide-A-Means to replenish a ship at sea with 10 days of victualling stores, and this PAM requirement is recorded below the activity; in the general case as in FIG. 9.

Decision Chain

The PAM diagram is developed as a decision chain emanating from this problem of Providing-A-Means to satisfy the PFN. In symbols the decision chain is depicted in FIG. 10.

An essential requirement of the PAM diagram is that the problem description as written in the circle must be in concise fundamental terms clearly defining the problem but giving no hint as to the method or means of achieving it. (Qualifying detail will of course be in the record of needs.)

It can be readily appreciated that in setting down a PAM diagram on paper, the circle and the diamond can be drawn of sufficient size to contain a precise description of the problem and decision. The square to the same scale is by no means large enough to contain the argument. For this reason the square is retained on the diagram but the detail involved is moved to the side of the diagram (FIG. 11) and assumes whatever form is best suitable for the assessment.

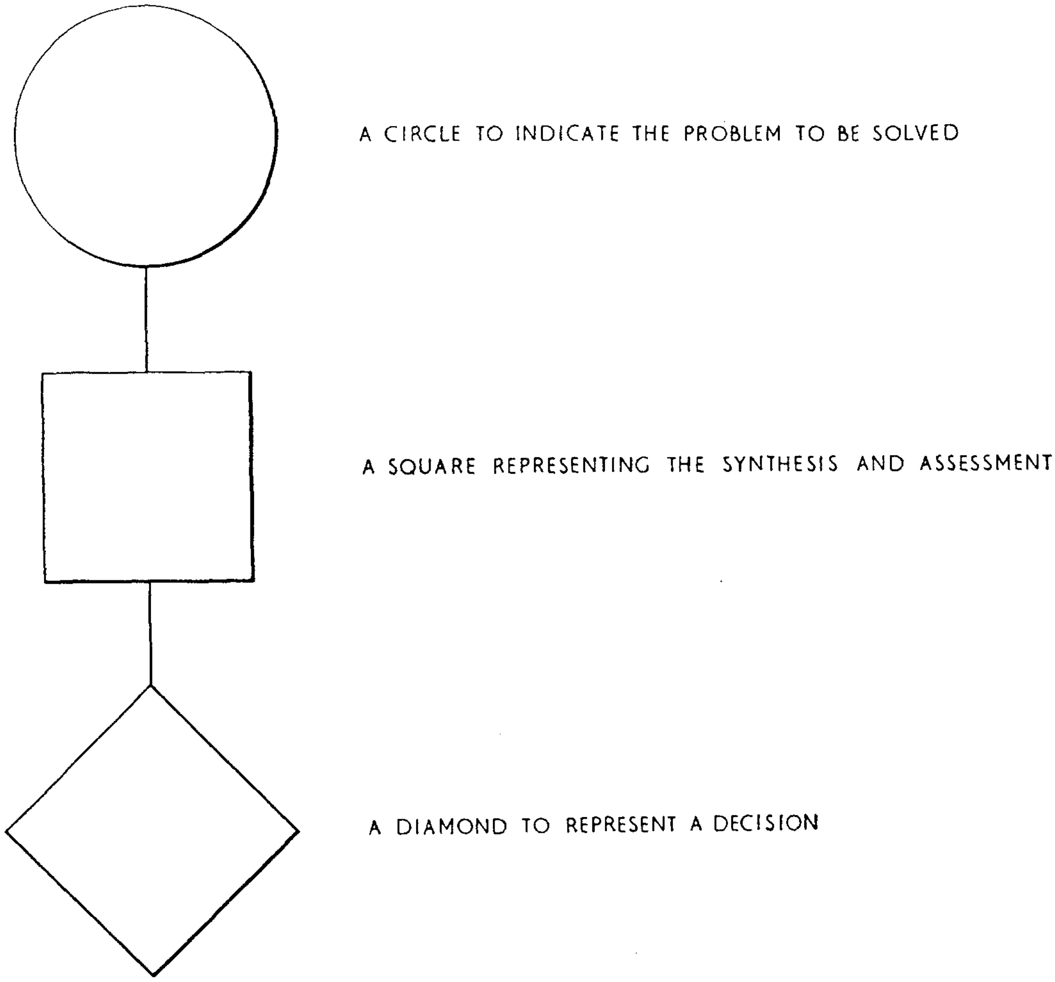


FIG. 10

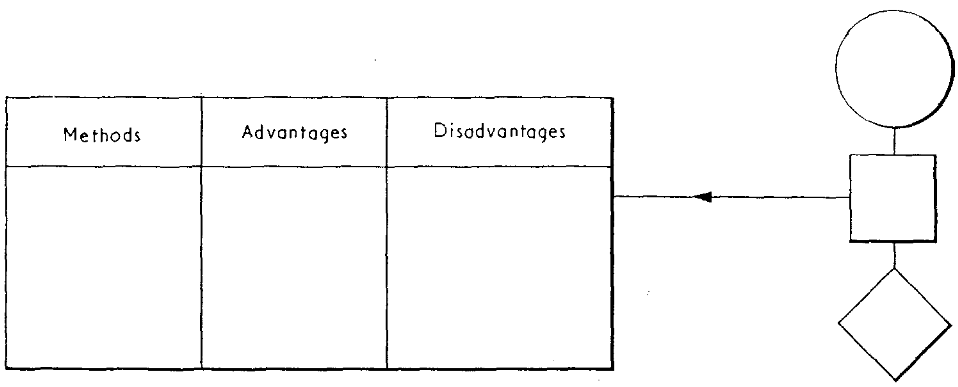


FIG. 11

Conception

It is of the utmost importance when considering means of achieving an objective that the mind is permitted to run free and bring out all manner of proposals no matter how wild or unpalatable they may appear at first sight. It is, at times, the random and out-of-this-world proposal which has the germ of an idea which when developed provides the most suitable concept.

Many techniques have been developed to stimulate the brain to release ideas—logical or illogical application of knowledge. The simplest is to pose such questions as 'How would my wife/mother-in-law/son etc., do it?' More elaborate techniques are brainstorming and synectics (see Appendix 1).

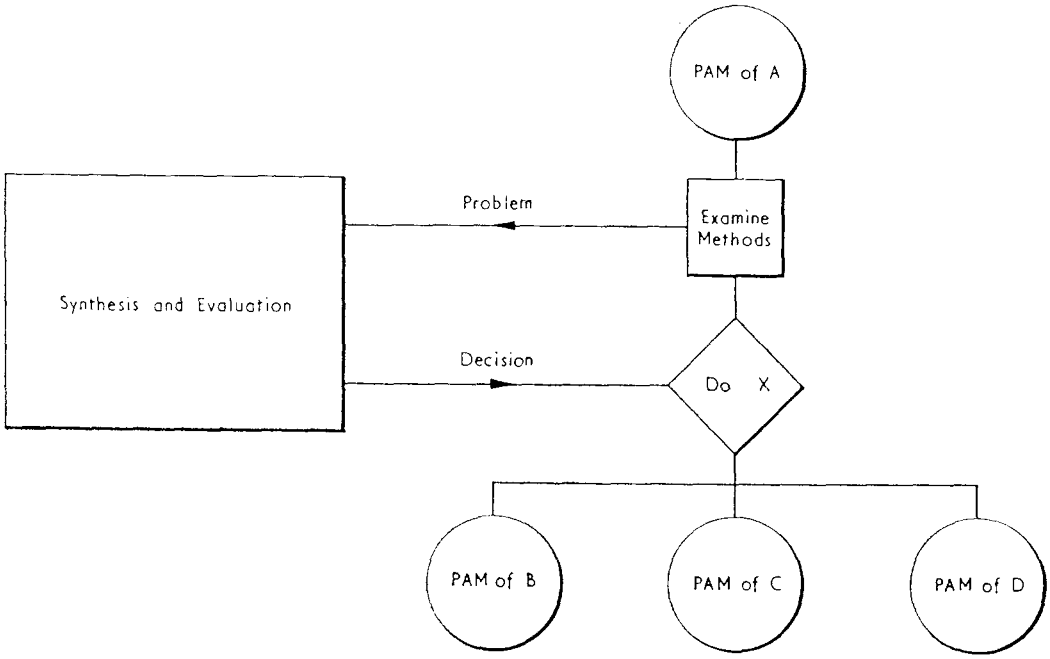


FIG. 12

Whatever release techniques are used the alternative methods are recorded as they arise without any attempt at the time to assess how well they satisfy the need; the only limitation imposed to a proposal is that it must offer a complete solution to the problem. For example:—

To the problem 'PAM to lower a load' methods could be: free fall, a lift, balloon, chute, men carry, etc.—*not* 'An electric motor'.

The electric motor is a means of providing power, the answer is out of scale with the problem being considered. The provision of power would arise if it were subsequently decided to provide a lift, but this decision had not been made at that time.

Evaluation

Faced with a host of methods to satisfy the need, each must now be considered in detail to evaluate how nearly it meets the PFN in the particular set of circumstances under consideration.

Here again the design engineer must use every device at his disposal to evaluate the solution. Such aids as acceptance matrices (see Appendix 2) and work-study techniques of process charting and analytical estimating can be used to advantage.

Decision

The state of the art contributes to the feasibility of proposals, and in instances where the PFN can be equally satisfied both quantitatively and qualitatively by a number of possible methods, then the effects of other needs must be fed into considerations so that a decision to pursue one, or a number of equally meritorious feasible concepts, can be made.

Each decision made is recorded in a diamond on the PAM diagram.

Breakdown

Armed with a decision on how to satisfy the initial PFN, this need, in the light of the decision, is broken down into a number of component needs, such that the sum total of the component needs exactly equals the initial need, as shown in FIG. 12. This breakdown has to be such that $B + C + D = A$.

In practice it is desirable that the breakdown should not exceed four components.

The initial problem now assumes a number of lesser problems at a lower scale. The PAM diagram is further developed by treating each and every one of these lesser problems as a PFN in its own right.

It must be remembered that total needs and particular set of circumstances as established for the initial PFN apply equally to the developed PFNs.

If any developed PFN is not fully understood it can be 'extracted' from the diagram and CUBED.

Roulettes

Throughout the construction of a PAM diagram there are two challenging procedures that must be carried out at every breakdown and evaluation stage.

These are termed Primary and Secondary Roulette.

The purpose of these roulettes is to clarify and justify each component need and put it in perspective with every other need with the overall objective of obtaining the simplest and most reliable design.

Primary Roulette

This challenge entails consideration of each component need with reference to itself and all other needs, pursuing the questions:—

How can I ELIMINATE?
How can I TRANSFER?
How can I COMBINE?
How can I SIMPLIFY?
How can I MODIFY?
How can I STANDARDIZE?

Secondary Roulette

This challenge entails consideration of each component need with reference to all other needs, pursuing the question:—

What EFFECTS/DEMANDS/RESTRICTIONS has A on B, A on C, B on A, etc? This is best explored on a co-relation chart as shown in FIG. 13.

The considerations of both these roulettes must be explored in the basic CUBE dimensions of TIME, PLACE, RESOURCES and METHOD.

Jumping Scale

Ideally the synthesis, evaluation and decision chains on a PAM diagram are dealt with in order of scale of importance so that decision is not taken at a level until decision has been taken at the scale above.

In practice, because of lack of knowledge, occasions will arise when it is necessary to investigate possible concepts at a low level in order to reach a decision at a scale above.

This procedure is represented on the PAM diagram by recording the decision to pursue more than one concept, and then the feasibility of solution at a lower level decides the concept to pursue (FIG. 14).

Parallel PAM Diagrams

It has been stated that good design is the optimum solution to the sum of the true needs of a particular set of circumstances, and that in the development of a design to satisfy the PFN then that design is influenced by all the other needs that have to be satisfied, but this influence must not be to the detriment of satisfying the PFN.

A	B	C	
Fill in the essential characteristics of A	Fill in the effects/demands/ restrictions of B on A	Fill in the effects/demands/ restrictions of C on A	A
A on B	Fill in the essential characteristics of B	C on B	B
A on C	B on C	Fill in the essential characteristics of C	C

FIG. 13—CO-RELATION CHART

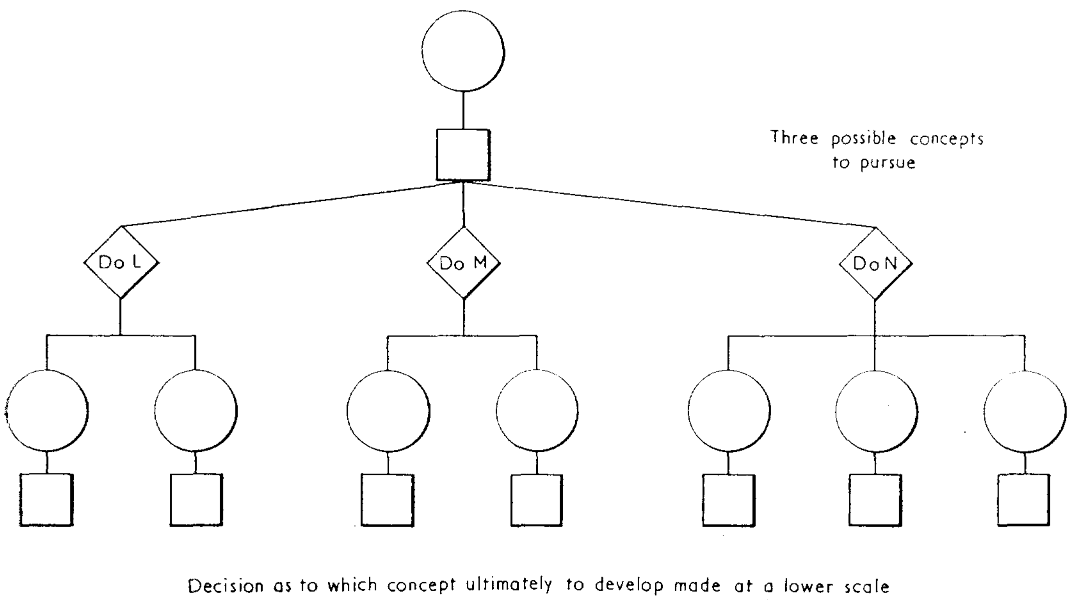


FIG. 14

In complex design situations, as those associated with 'enclosures', it is possible that the design pursued to achieve satisfaction of the PFN does not satisfy needs, or may not even have considered needs, of lower relative importance, but needs nevertheless which have to be satisfied. In such circumstances it would be necessary to develop a parallel PAM diagram commencing at the correct level of scale as the associated needs in the main diagram, so that all needs at the same scale are considered relative to one another at the same time.

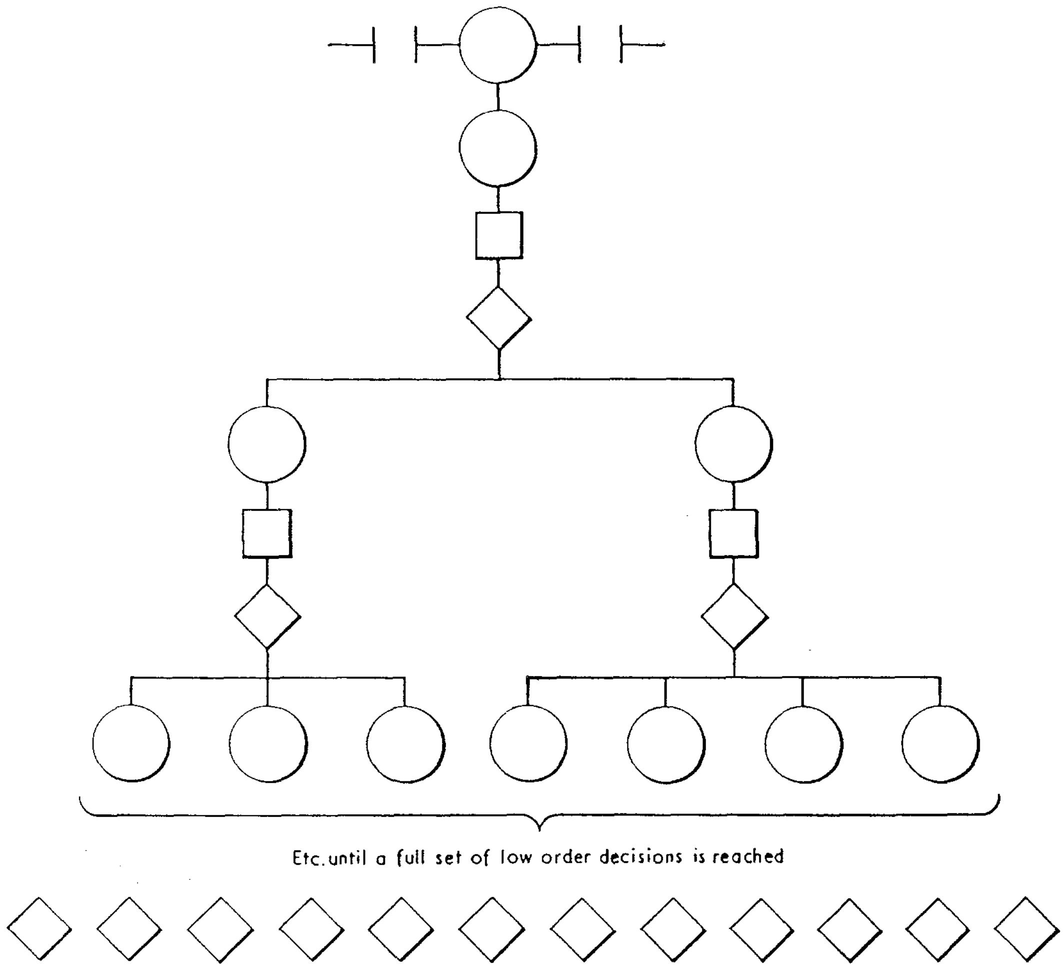


FIG. 15

PAM Development

Ideally the PAM diagram develops until a full set of low order decisions is reached (FIG. 15).

The sum total of these decisions provides the optimum solution to the sum of the true needs of a particular set of circumstances.

The PAM diagram would develop:—

From the PFN for an Enclosure into flow systems,

From the PFN for Flow systems into products, and

From the PFN for Products into parts.

Thus a PAM diagram can be constructed for any design situation. The procedure is the same in each case. The scale of concept, evaluation and decision is in keeping with the scale of the particular design situation.

CONCLUSION

Degree of Application

It would be wrong to suggest that good design, especially innovative design, can be achieved by one pass through the MAUD and PAM procedures. As indicated on the design process model the process is cyclic, lessons learnt during the feasibility, development, production and usage stages feed back to enhance the designer's knowledge and colour the needs and circumstances. Similarly the influence, life stage and cubing procedures as well as being applied at the onset can be applied whenever a problem is not fully understood.

On the other hand it can be argued that strict and absolute adherence to such a procedure in every design situation would entail such effort and produce so many conceptions that design realization would be hindered rather than advanced.

The degree of application of the techniques—the depth of the synthesis and evaluation procedures—very much depends on the state of the art appropriate to the particular design situation. It may be acceptable to proceed direct from a problem to a decision without the rigours of a full scale evaluation, but in such instances the designer must be absolutely confident of the decision and record this fact on the PAM diagram.

What MAUD and PAM Offer

The complete PAM diagram displays for all to see the logical breakdown of a problem into problems of lesser order, and in doing so explores and records the reasons and decisions of every step made. The PAM diagram also provides a lasting record of the evolution of a design, and, with the preparatory MAUD procedure, records the needs and set of circumstances current when the design was formulated.

On occasion enclosures, flow systems, products and parts are criticized in the light of needs and circumstances which were not present in the original problem. In fact far too often the needs and circumstances of a design situation are not precisely recorded. The designer loses sight of the original Primary Functional Need to such an extent that the ensuing design only offers a partial solution to the true needs, but offers bonuses in directions which are not essential in the particular set of circumstances.

MAUD and PAM will help to alleviate this situation.

Acknowledgements

A large part of 'The Design Situation' section of this article is derived from papers presented at the Design Method Symposium held at the University of Aston in Birmingham (Designate) in September, 1965.

The MAUD and PAM procedures are techniques developed by Fleet Work Study Team No. 18 from the teachings of Mr. E. Matchett of the Department of Work Study and Staff Training, Engineering Employers West of England Association, Engineers House, Bristol.

APPENDIX 1

BRAINSTORMING AND SYNECTICS

An extract from a paper "Creativity" by G. H. Broadbent of the University of Sheffield, presented at the Design Method Symposium, at the University of Aston in Birmingham, Sept. 21st-23rd, 1965.

Brainstorming

This is the brash, Madison Avenue technique *in excelsis.* It was devised by Alex Osborn, himself an advertising executive and the intention is that the members of a group shall vie with each other in generating a rapid succession of ideas. Osborn lays down four basic rules for brainstorming:—

(1) Criticism is ruled out
(2) 'Free-wheeling' is welcomed
(3) Quantity is wanted
(4) Combination and improvement are sought.

It is essential that group relationships be amiable and relaxed; for this reason, Osborn recommends that the session start over a good lunch. The leader states the problem in basic terms, focused on a single point and throughout the session, he is at pains to suppress the criticism of any idea, however crude and irrelevant it may seem. The aim, in fact, is to stimulate competition in ideas generation, by free association, the wilder the better.

Much of the success of brainstorming depends on leadership and difficulties may arise if a group is asked to rework old problems. If these are desperately familiar, the group will simply restate old attitudes. This is the chief defect of brainstorming but, conversely, a good group may generate so many ideas that evaluation becomes a major task. Osborn insists that all ideas be written down, and that afterthoughts are also added to the list. This is then submitted for scrutiny, preferably by assessors who took no part in the original brainstorming. The most promising ideas are then put forward for verification.

Synectics

In contrast to brainstorming, synectics in the whole is a quiet, contemplative activity, in which ideas are generated in a purposeful way, with evaluation, as far as possible, during the session itself. Synectics was devised by the Invention Research Group at Harvard University, under the leadership of William J. J. Gordon. It has some features in common with brainstorming—it is primarily a group activity in which, during a session, personal criticism is ruled out. It can also act as a great stimulus in the individual creative act because, more than any other method, it is designed to draw on the resources of the whole personality. Synectics is a complete design method, including analysis, which is called: 'Making the Strange Familiar', and creative synthesis: 'Making the Familiar Strange', in other words, seeing the familiar problem in a new light. This is achieved by a system of analogy-generation, which is the most striking feature of Synectics. Three types of analogy are identified, which are:—

(1) Personal analogy
(2) Direct analogy
(3) Symbolic analogy.

Between them, these analogy-types are capable of tapping the entire range of human experience, which is why they are different in kind from each other—personal, concrete and abstract.

Personal analogy —The designer identifies himself with the object in design: 'If I were this beam, how should I feel? What are the stresses acting on me? What is my attitude to the supports?' etc.

Direct analogy —The problem is compared with known facts in another branch of art, science of technology. Synectics quotes the example of Brunel who, faced with the problem of building underwater constructions, observed a shipworm forming a tube for itself as it bored into timber. From this, Brunel conceived the idea for the caisson.

Symbolic analogy —The designer tries to penetrate to the essence of special meaning which he attaches to the problem by means of some personal symbol. This may be verbal, visual or conceivably could take some other form. In one synectics session, the group was concerned with detecting the presence of an unwanted flame in some complex piece of hardware. They asked the question: 'What is the essence of flameness?' and eventually, thought of it as a 'ghostly wall', which opened up a new range of feasible solutions.

In practice, a synectic session is conducted systematically by a chairman, who introduces the problem, which is then analysed and discussed. At the key stage, there is a 'purge of immediate solutions', after which attention is narrowed down onto one particular aspect of the problem. The chairman then asks an 'evocative question' which will force answers in terms of one of the analogy types; once a fruitful analogy has been generated, its implications are examined in detail. Like all creative acts, a synectics session is cyclic. If no viewpoint can be established from the chosen analogy, the chairman will guide the discussion back to an earlier phase, and try a different approach.

Synectics draws on the whole creative capacity of the brain. It is concerned with far more than mere ingenuity, because analogy generation is a very personal thing, depending on the stored associations which have been built up in the brain over the years. The brain may very well make apparently irrational connections which lead to supremely rational solutions because, however curious they may seem at the time, they have been subjected to the censoring mechanisms which control the input of ideas into the brain, their associations and subsequent output. The strength of synectics, which is shared to some extent by the other methods, lies in the fact that it taps precisely those thought processes which are inaccessible to the computer. At one level, the computer might be programmed to 'brainstorm' itself; it could throw up an enormous range of random associations, but the problem of evaluation would be greater even than with a human brainstorming session. Certainly, it could not be programmed to draw meaningful analogies in the manner of synectics.

APPENDIX 2

ACCEPTANCE MATRIX

At the design concept stage a number of basic solutions may have materialized and it is necessary to choose the most acceptable solution for development, detailing and production. This choice will have to be made as objectively and impartially as possible, and a useful method to assist in this analysis is to construct an acceptance matrix.

The comparison procedure takes the form of a scoring for each essential characteristic of the candidate concepts and arranging the score in the form of a matrix. The matrix is so designed that the overall or lumped acceptance of each candidate concept can be readily calculable and also so that the respective advantages and disadvantages can be perceived.

In such a comparison it is as well to define the threshold of acceptance—at which the design is only just acceptable—and to define the ideal concept which would be the ultimate realistic design on all counts and would be a challenge to innovative design.

Table II illustrates an acceptance matrix for an existing design, and two concepts of power supply systems. The effectiveness is judged by assigning a number, 1 through to 10, for each characteristic. An effectiveness number of 1 means that the system performs at the threshold of acceptance, whereas 10 indicates ideal performance. The product of the value index and the effectiveness rating gives a score for the acceptance of each characteristic, and the total indicates the degree of overall acceptance.

Note that the total of the Value Indices is 10 so that the overall acceptance is given as a percentage.

TABLE II

Characteristic	Limits		Value Index	Effectiveness / Acceptance		
	Threshold	Ideal		EXISTING DESIGN	CONCEPT A	CONCEPT B
Performance	80%	99%	2	4 / 8	6 / 12	10 / 20
Reliability	90%	99%	4	7 / 28	9 / 36	5 / 20
Size	10 cu ft	3 cu ft	1	4 / 4	6 / 6	9 / 9
Weight	1000 lb	250 lb	1	4 / 4	8 / 8	6 / 6
Cost	£1000	£250	2	8 / 16	5 / 10	1 / 2
Overall Acceptance				60	72	57

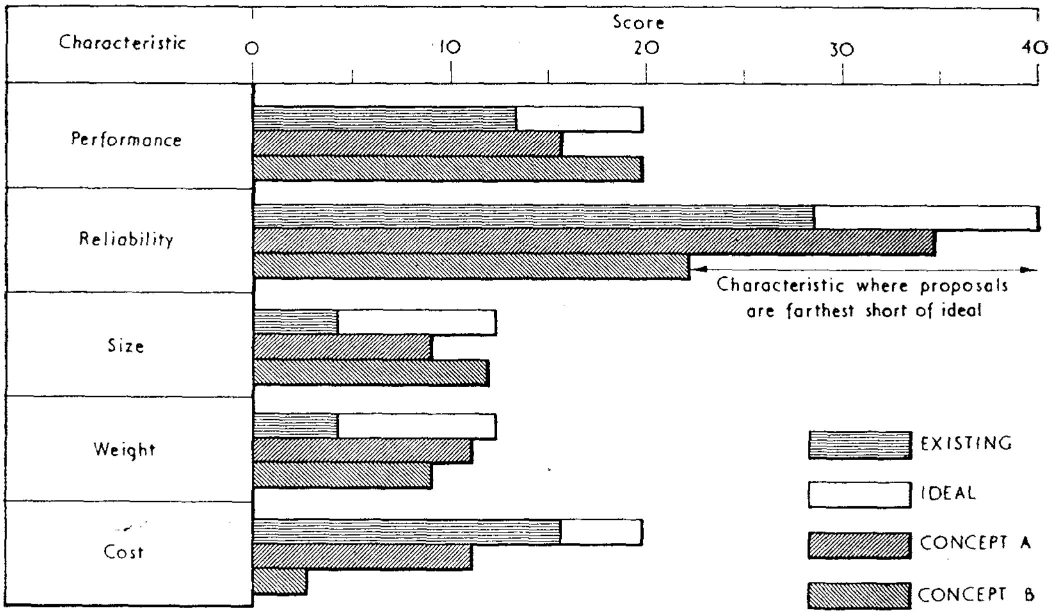


FIG. 16—A BAR CHART

The results can be displayed on a bar chart as shown in FIG. 16. It can be appreciated from this assessment that Concept A which is a possible development of the existing system resulting in increased performance and greater reliability, is a far more acceptable system than the sophisticated, high performance but smaller and less reliable system than the innovative design proposed in Concept B.

The bar chart clearly shows the degree by which each characteristic falls short of ideal and indicates where technical effort should be directed to effect the most worthwhile improvement.

TABLE III

Characteristic	Limits		Value Index	Effectiveness / Acceptance		
	Threshold	Ideal		EXISTING DESIGN	CONCEPT A	CONCEPT B
Performance	80%	99%	5	4 / 20	6 / 30	10 / 50
Reliability	90%	99%	2	7 / 14	9 / 18	5 / 10
Size	10 cu ft	3 cu ft	1	4 / 4	6 / 6	9 / 9
Weight	1000 lb	250 lb	1	4 / 4	8 / 8	6 / 6
Cost	£1000	£250	1	8 / 8	5 / 5	1 / 1
Overall Acceptance				50	67	76

If, however, the power supply system proposals were for a service where the performance was deemed to be by far the most essential characteristic and give a rating value of 5, with reliability 2 and size, weight and cost of equal importance of 1, then the matrix would be as shown in TABLE III which indicates that for this particular service Concept B will best satisfy the requirements.