Systems creativity

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Abstract: The paper identifies the important area of creativity in the design process as least amenable to definition, being comprised of seminal ideas which must fall into a fertile ground of expert domain knowledge coupled with a progressive management environment. Creativity is presented as an essential element in design which can be taught and encouraged, however, and the paper presents creative design 'seeds' for decision-based systems, flow-line manufacture and maintenance processes and management information systems. Concept evolution techniques are presented as a structured decomposition methodology. The first example of creative design presented in the paper is of the design of a notional systems engineering company which is unusual to most readers in that it contains no manufacturing or production, and preconceived ideas of company organisation are likely, therefore, to be misleading. The application of state-variable analysis to the cash flow of a start-up defence company follows, and the application of systems dynamic to intercompany competition is presented. Creativity is not restricted to initial design; flow-line analysis using queuing theory for intensive flying of training aircraft is demonstrated as a means of resequencing activities to reduce mean throughput times. And finite state/transition analysis is used on the grand scale to examine the potential for European conflict. Finally, the author presents the principles of creativity and suggests that, far from being peculiar to engineering, one finds parallels in music, composition and the arts.

Introduction

The spark which represents a creative idea or concept often passes unnoticed, and dies unrecognised. Industry needs such ideas; they need to be encouraged, nurtured and used as the seeds of our future products, services, structures, organisations and capabilities. Among engineers, however, the idea of creativity might conjure up some artistic concepts which they would consider alien to their craft.

Systems creativity seeks to present the process of conceiving, designing, developing and implementing creatively in an engineering environment. Identifying and nurturing the spark necessitates the right organisation, techniques, tools and tenets, the principal elements of which are presented by example. This paper is the sequel to Reference 1.

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1 Ingredients of creativity

Creativity is a blend of many things: youth and experience, discipline and freedom, knowledge and serendipity. These elements, coupled with energy and ability, and set in the right environment, are the basic ingredients of creativity. Luck? Luck is opportunity meeting preparation.

Creativity is a difficult concept with which to grapple, especially in an engineering environment. Certain ingredients are often seen in retrospect to have combined to result in a seminal idea, design or solution to a problem. Fig. 1 shows these ingredients, and, while some may appear to be in conflict, in practice they go together as follows:

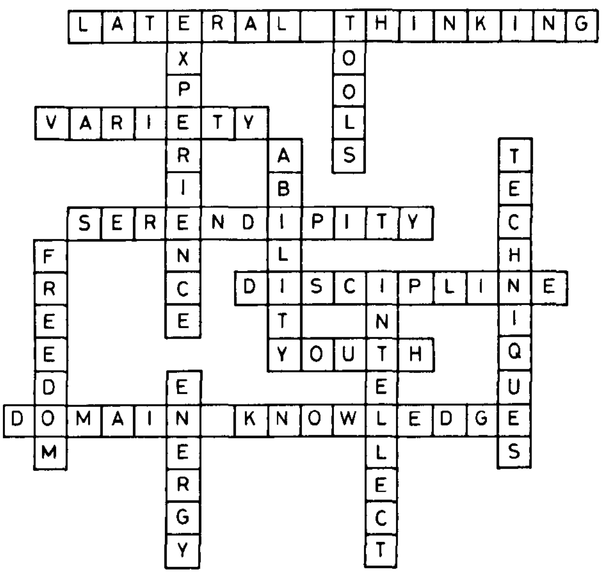


Fig. 1 *Ingredients of creativity*
Creativity requires a blend of many constituents, set in a disciplined framework

(*a*) *Experience and youth:* A blend of youthful energy and ideas is a valuable basis for generating creative solutions, provided it is tempered by sound experience. Experience alone will rarely be innovative. Mixed teams give the best results.

(*b*) *Discipline and freedom:* There is a time for both; freedom of thought and expression, positively encouraged and set in a formally disciplined procedure, will identify and find solutions to problems quickly. Brainstorming is a form of disciplined freedom.

(*c*) *Domain knowledge and serendipity:* Domain knowledge implies a good understanding of the sphere of endeavour in which the solution to a requirement must be created. Serendipity implies chance or luck. And both have a valuable role to play. The good fortune which stumbles across an idea must recognise the idea and view it in the context of its own domain.

The remaining ingredients of the nonexhaustive list are also important. Ability coupled with intellect is essential. Some are creators, some are improvers, some are critics; all have their role. But the creators will invariably be able and energetic. To be effective in a sophisticated engineering environment, these creators need force multipliers; tools and techniques allow creators to be more productive and co-operative.

2 In pursuit of creativity

Creativity can be incorporated into a systematic procedural framework, the so-called top-down systems approach. Optimising the preferred solution is often left out of this otherwise well-established process.

Fig. 2 shows an almost classic, systematic approach to finding a solution to the problem at hand. A top-down approach requires a complete understanding of the requirement and the objectives. So often this solution-transparent requirement analysis is ruined by premature assumptions: 'we'll use our standard product . . .', 'what we did last time was . . .', 'sell the hardware first, we will sort out maintenance later . . .'.

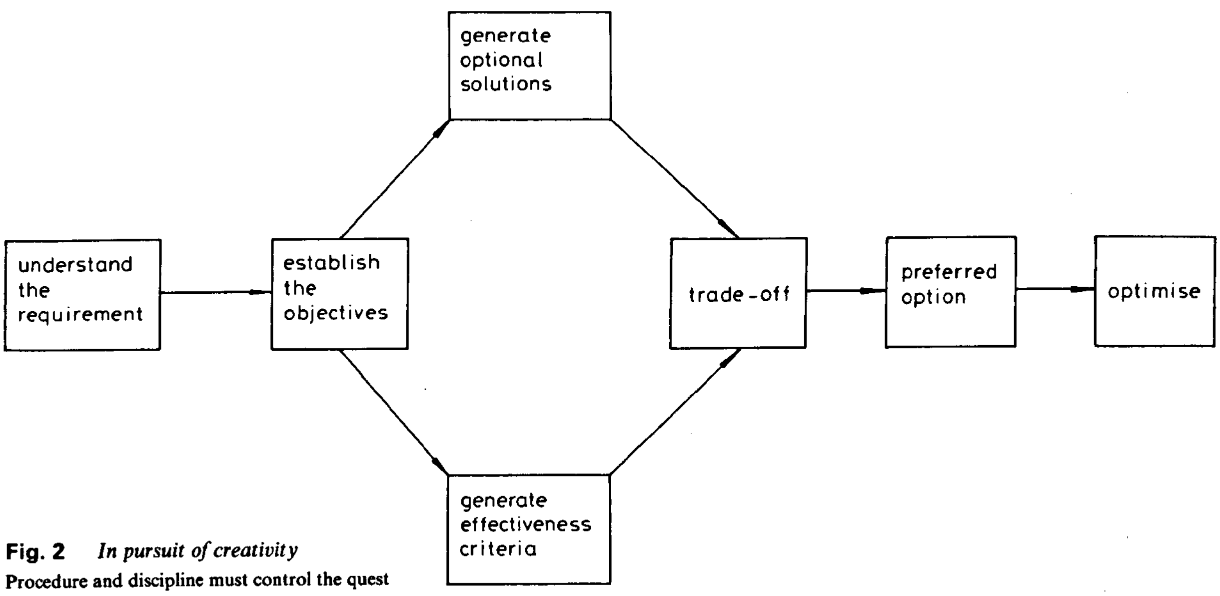


Fig. 2 *In pursuit of creativity*
Procedure and discipline must control the quest

The generation of optional solutions to the requirement should occur ideally in isolation from the generation of effectiveness criteria, and strict discipline is needed during trade-off to avoid 'massaging' effectiveness criteria to suit preconceived notions about the best answer. Preconceptions are the enemy of creative innovation. Trade-off techniques have already been presented in Reference 1.

The final box in the Figure is the one most often overlooked. It would be rare indeed for the preferred option to excell against all criteria; indeed, such a result implies either that the problem was trivial or that the optional solutions were inadequate. Following topics will show by example how this systematic problem-solving approach is applied in practice and how optimisation is achieved.

3 Creative seeds

Most creative ideas in engineering require a seed or kernel of an idea to form effectively. The decision cycle and the flow line are two common kernels for structure and organisation systems.

Real solutions in engineering can very often be formed about a conceptual seed or kernel. The two most common, the decision cycle and the flow line, are shown in Fig. 3A.

(*a*) *The decision cycle:* Decisions follow a natural progression in many real situations, starting with an assessment of the situation at the top of Fig. 3A. The ubiquitous decision cycle is at the heart of management, command and control, driving a car, running a football team, structuring an expert system etc. A company board, for example, shares the decision cycle elements; economic threats are identified by the financial director, while constraints may be presented by the operations director, and so on. Thus, structured decision-making can be constructed around the decision cycle. The decision cycle can also be straightened out, in which case it becomes a flow line.

(*b*) *The flow line:* In process control of information flow, products or concept evolution, a central line of flow is invariably present. Fig. 3A shows the central line in a computer integrated manufacturing (CIM) flow line (after an idea from DEC), in which components are bought, received, inspected, assembled, stocked, distributed and sold. All elements not on the central path have as their purpose the maintenance and enhancement of flow. In the example, sales information is used to plan future production, and marketing identifies the need for new products. By working outwards from the flow line it is possible to organise commercial, personnel, accounting and all other company functions in support of the central theme, so providing unity of effort.

The vigour of these simple, even simplistic, concepts can be remarkable and this is due, in no small part, to the ease with which everyone in a group can relate to the decision cycle or the flow line. Retention of simplicity is more difficult (but a valuable goal) as the experts and

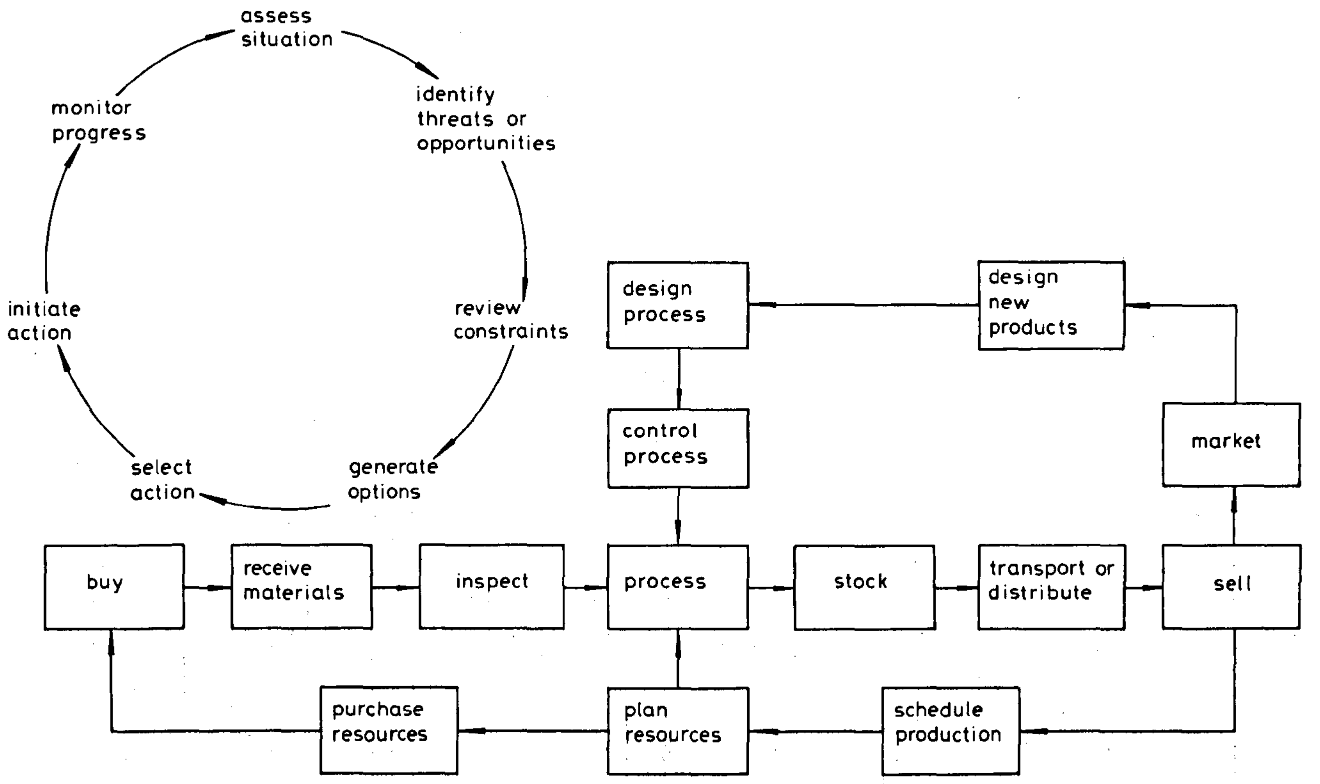


Fig. 3A *Creative seeds*

Decisions and the flow of activities and processes are inherent in all creations, be they artefacts or organisations

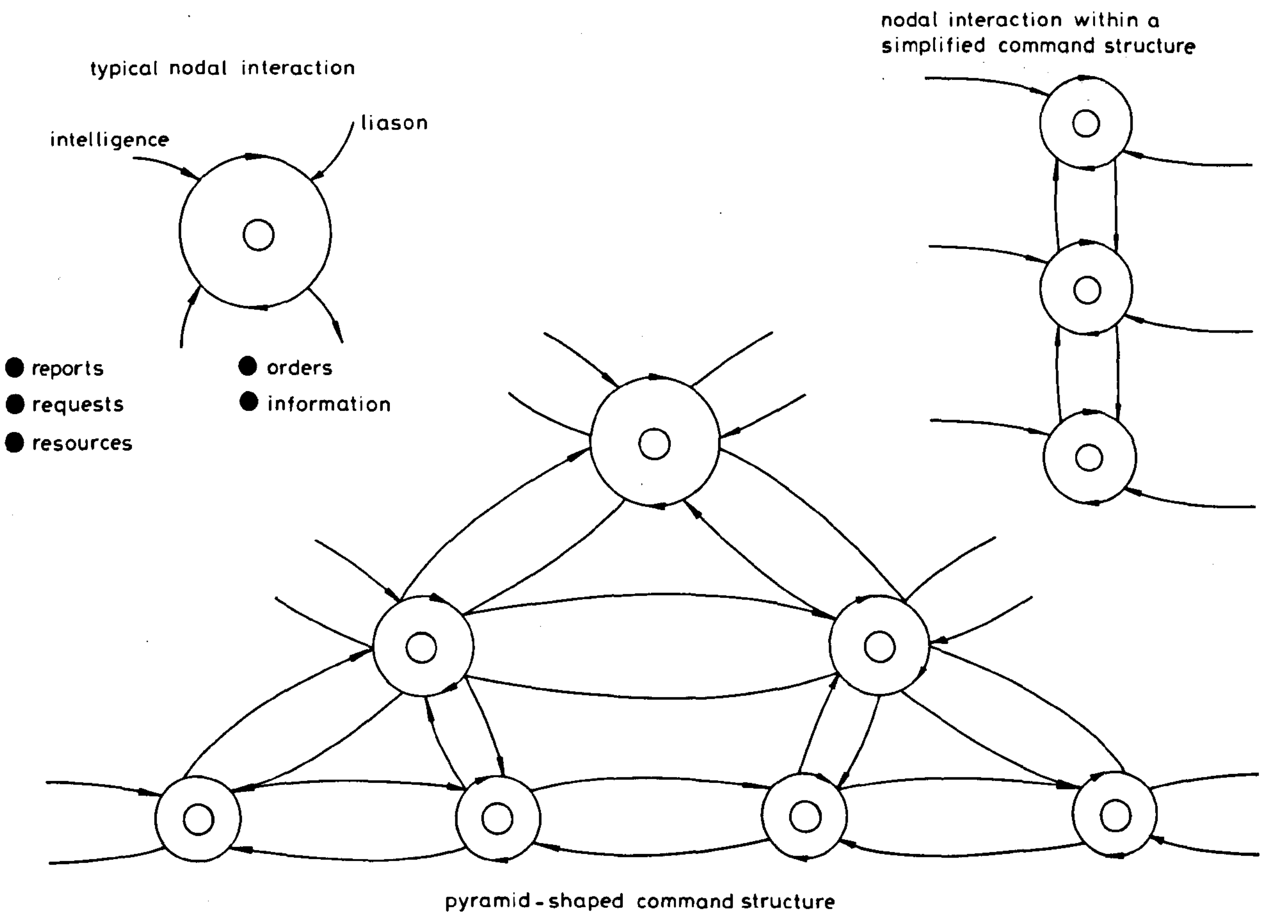


Fig. 3B *Linked decision cycles*

Decision cycles from discrete elements within an organisation can be linked into networks. The representational technique is better replaced by an N^2 chart

	a	b	c	d	e	f	g
1	joint operations centre	• orders • information		• orders • information		• orders • information	
2	• reports • requests • resources	land operations centre	• orders • information	• liaison • co-ord.		• liaison • co-ord.	
3		• reports • requests • resources	mobile land HQs				
4	• reports • requests • resources	• liaison • co-ord.		naval operations centre	• orders • information	• liaison • co-ord.	
5				• reports • requests • resources	naval task groups		
6	• reports • requests • resources	• liaison • co-ord.		• liaison • co-ord.		air operations centre	• orders • information
7						• reports • requests • resources	air bases / radars

outputs →

inputs ↓

typical sub-cell structure

Fig. 3C *N^2 network*

Representing linked decision cycles in an N^2 chart allows a high level of abstraction to be maintained, while providing a powerful tool for architectural analysis

specialists start to fill in detail and suggest alternatives. Obscuration of the fundamental concept will defeat the creative concept.

Figs. 3B and 3C show how decision cycles may be linked to represent a decision hierarchy, and how that hierarchy can be better represented using an N^2 chart. The example chosen shows a joint command and control information system can be constructed from linked decision cycles, each representing an individual command post or HQ.

4 Concept evolution

There are certain fundamental techniques used to evolve concepts which experience shows to provide the most effective results. In practice, it is very difficult to adhere to these tenets in the face of pragmatic short-term solutions.

System design is based on certain fundamental tenets which give the approach its strength. Five of the most important tenets are shown in Fig. 4.

(*a*) *Highest level of abstraction:* It is vital to avoid being confused by irrelevant detail at the early stage in concept formulation. A car is, at the highest level, a means of transporting people by road. In the same vein, what is a tank?

(*b*) *Functional before physical:* Functional decomposition requires the most careful selection of functions. To partition a human (sic!) into senses, nerves and brain is to employ physical, not functional partitioning. To iden-

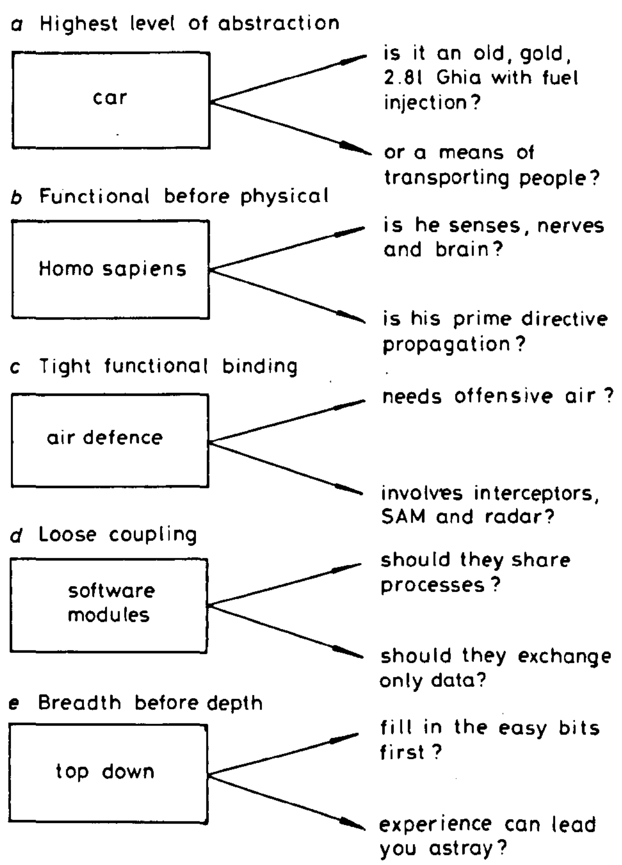


Fig. 4 *Concept evolution*

A methodology is essential to the evolution of concepts if we are to be creative, not repetitive tify human functions as propagation, survival, communication and co-operation is to provide a basis for understanding why we have such types of sensor, nerves and brain. To partition a distributed information system (DIS) into sources, communications, processing and sinks is to overlook its purpose; it is not incorrect, simply unhelpful.

(*c*) *Tight functional binding:* It is valuable to group together people, resources, features and skills which have the same objectives and many mutual interfaces. This concentrates effort, clarifies, simplifies and economises.

(*d*) *Loose coupling:* Conversely disparate groups of people, resources, features and skills with different objectives should be coupled loosely (separated), generally by the exchange of carefully defined data. They should not share functions.

(*e*) *Breadth before depth:* This tenet is linked with the first — high level of abstraction. It is vital to span the 'complete' problem at the higher level, before moving to the next level of detail. So often, it is all too easy to dive into that part of the problem we believe we understand, emerging after much (nugatory?) effort to find that we have been pursuing the wrong path. Worse, we may have invested so much effort that there is no going back, mentally or practically.

5 Creating the creative framework

This and the three following topics illustrate the systems creativity approach by postulating the requirement for, and producing a resulting design of, a systems company. Familiarity with organisation is seen as the major obstacle to a good solution.

If the system approach is sound and general purpose, it should be applicable over a wide range of endeavours, from the Severn barrage to a PCB design, from exploring the solar system to photo-microlithography. As a simple example, we can turn the systems approach in upon itself (Gödel's incompleteness theorem undoubtedly applies) and use it to design a systems company's divisional structure. This approach to creating a creative framework inside which creative ideas may be nurtured is outlined in Fig. 5. The trap to be avoided is overfamiliarity with conventional organisation: we know the solution to similar problems too well.

Familiarity can present real difficulties. For example, how do we functionally divide a house? If we choose, say, bathroom, bedrooms, lounge, dining room and kitchen as the obvious partitions, then subdivision in each room will contain much the same elements, e.g. lighting, plumbing, power, central heating etc. Thus, the 'obvious' divisions for a house which are physical, not functional, are unhelpful, because they have resulted in tight coupling and loose binding, the opposite of our objective. Our familiarity with the problem has led us astray. In essence, we did not divide the house by *its* functions; we divided the house by its *occupants'* functions — and that is a common trap. The same hurdle has to be overcome with divisions in a company. The following Section will continue with this 'case study' by generating four archetypal divisional organisations.

- *Create a creative organisation*
- *Design a systems company* (no manufacturing)
- *Objectives*
  - growth
  - synergy between divisions
  - concentrated skills
  - market led
- *Pitfalls*
  - familiarity with conventional organisation
- *Approach*
  - treat as any other system

Fig. 5 *Creating the creative framework*
Because the framework/organisation has to be created, that process is a good basis for a case study

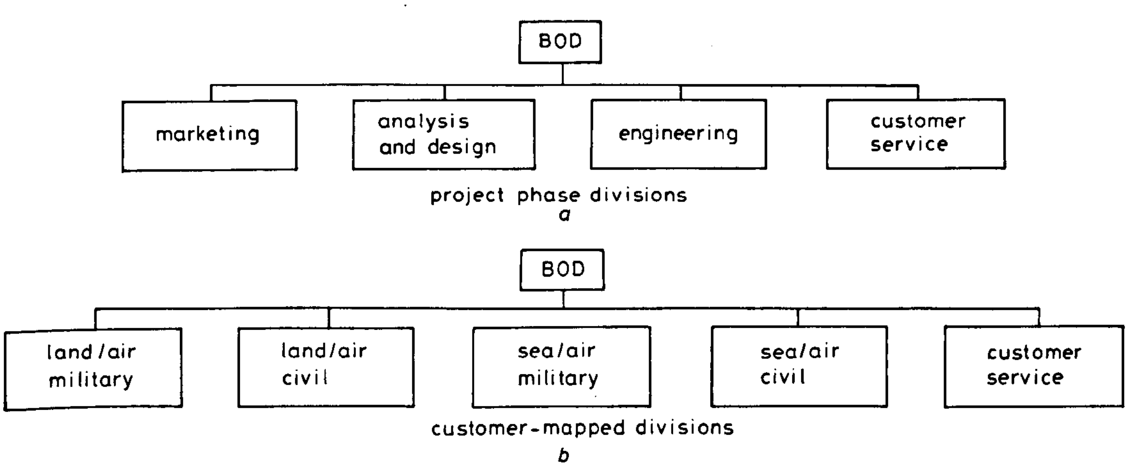
6 Systems company structure options

The four archetypal divisional organisations are outlined at the highest level of abstraction. None of these options is seen as preferred at this stage.

The four archetypal divisional organisations shown in Fig. 6 and are as follows:

(*a*) *Project phase divisions:* This structure is used by most production companies, principally because of the high tooling, stock and WIP investment required for production, which dictates maximum utilisation and inventory turns. A systems company has no large-scale production, however, and so the usual pressure does not apply.

(*b*) *Customer-mapped divisions:* This structure maps directly on to the customer's domains of activity. While excellent in marketing terms, the structure distributes engineers and resources in every division with identical capabilities, and is hence not necessarily effective in implementation, because it requires much lateral flow of engineers between divisions.



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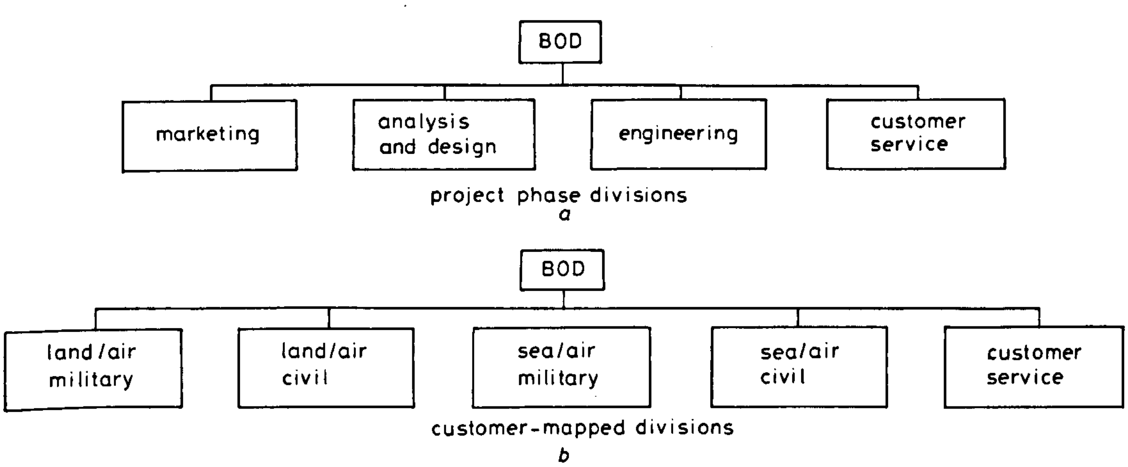

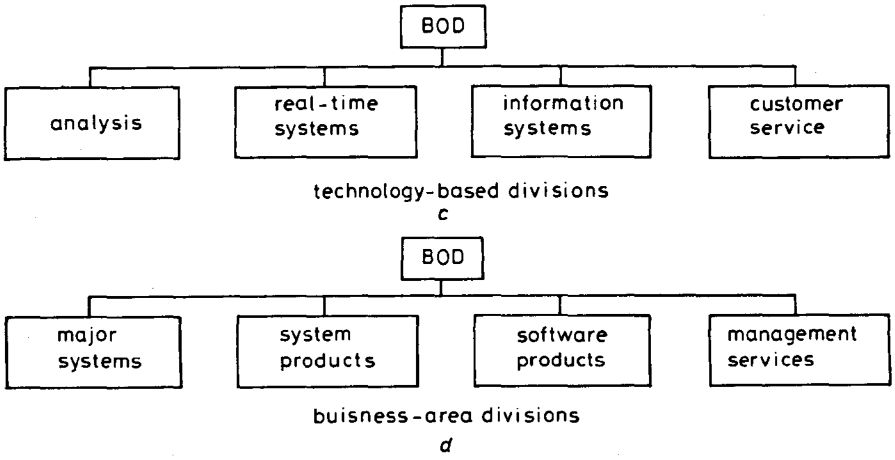

Fig. 6 *Structure options*
At the highest level of abstraction there are four archetypal divisional structures: hierarchical against matrix is not visible at this level. BOD = Board of Directors

(*c*) *Technology-based divisions:* This structure concentrates skills and resources, but discourages synergy between divisions, as they tend to operate in separate customer and business-areas.

(*d*) *Business-area divisions:* This structure maps on to complementary sectors in systems engineering markets, but is, of itself, nonexplicit in terms of marketing and implementation.

None of the organisations is immediately obvious as being the best solution to meet the objectives of growth, synergy, skill concentration and market lead. Further analysis of benefits is clearly needed, first by generating a solution-free set of criteria to judge and compare options.

7 Criteria for a good design

The choice of criteria is fundamental to reaching the best solution; the systems approach is no panacea and can be mishandled. Business-area divisions gave the best solution, but other options have their special merits too.

Choice of criteria is vitally important to drive out the 'right' design solution; as with any approach, it is possible to misapply the techniques. Fig. 7 shows, in a highly visible manner, the criteria and the rank order allocated against each archetypal design. Readers may disagree with both criteria and ranking: it is the objective of the presentation to encourage such results, which will lead to a more solid solution.

Principles of business have been predicated, based on the principles of war (which are not unrelated). Effectiveness criteria have been generated within the principles. Options have been ranked (i.e. 1 is first, 4 is fourth, in order of preference) and inability to differentiate has resulted in equal ranks. Row sums equal 10.

Column sums favour option 4, business-area divisions, with little to choose between customer-mapped and technology-based; project phase is a poor fourth. However, business-area divisions did not rank first against all criteria; first ranks appear in favour of:

(i) technology-based for work flow
(ii) customer-mapped for user/design contact

Principles of Business	Divisional organisation / Effectiveness criteria	Options (ranks) Project phase	Customer-mapped	Technology-based	Business-area
Flexibility	• adapts to new markets	4	2	2	2
	• encourages growth	4	2.5	2.5	1
	• simple, easily understood	3.5	1.5	3.5	1.5
Economy of effort	• non-overlapping business areas	2.5	2.5	2.5	2.5
	• accountable/visible profit and loss	4	3	1.5	1.5
Unity of effort	• synergy between divisions	3.5	1.5	3.5	1.5
	• concentrates resources	1	4	2.5	2.5
Market led	• promotes user/designer contact	4	1	2.5	2.5
	• profitable market potential	3	3	3	1
Resilience	• sufficient regular business	2.5	2.5	2.5	2.5
	• responsive to market	4	2	3	1
Maintenance of the aim	• promotes systems approach	4	2	2	2
	• promotes work flow	4	2.5	1	2.5
Rank sum		44	30	32	24
		fourth	second	third	first

Fig. 7 *Criteria for a good design*
The criteria must be chosen to support the design aim. In this example, the principles of war have been adapted as a basis for addressing business organisational options

(iii) project phase for concentration of (capital intensive) resources.

Optimisation at the next level of detail will incorporate these elements into a preferred solution, where practicable.

8 The preferred solution

The business-area solution is optimised by incorporating the best features from the other structures inside each division as appropriate.

The preferred solution, which best satisfies the requirements of growth, synergy, skill concentration and market lead, is shown in Fig. 8. Business-area divisional structure has been employed, with each division set up differently internally according to need:

Software: addresses software engineering, company-wide and external sales of software products, applications programs, small turnkey information systems and consultancy. Technology-based to promote work flow and concentrate scarce resources, including expensive software development tools. Sales account organised to promote directed growth.

System management services: customer-mapped and with skills concentrated into tightly functionally bound groups of specialists in customer domains and analytical techniques.

Overall, each division is internally bound tightly, while interdivisional synergy is promoted in two senses: there is no business-area overlap, and both system products and software divisions provide resources and products in support of the other divisions (synergy loops). Thus, loose coupling exists too in this structured design.

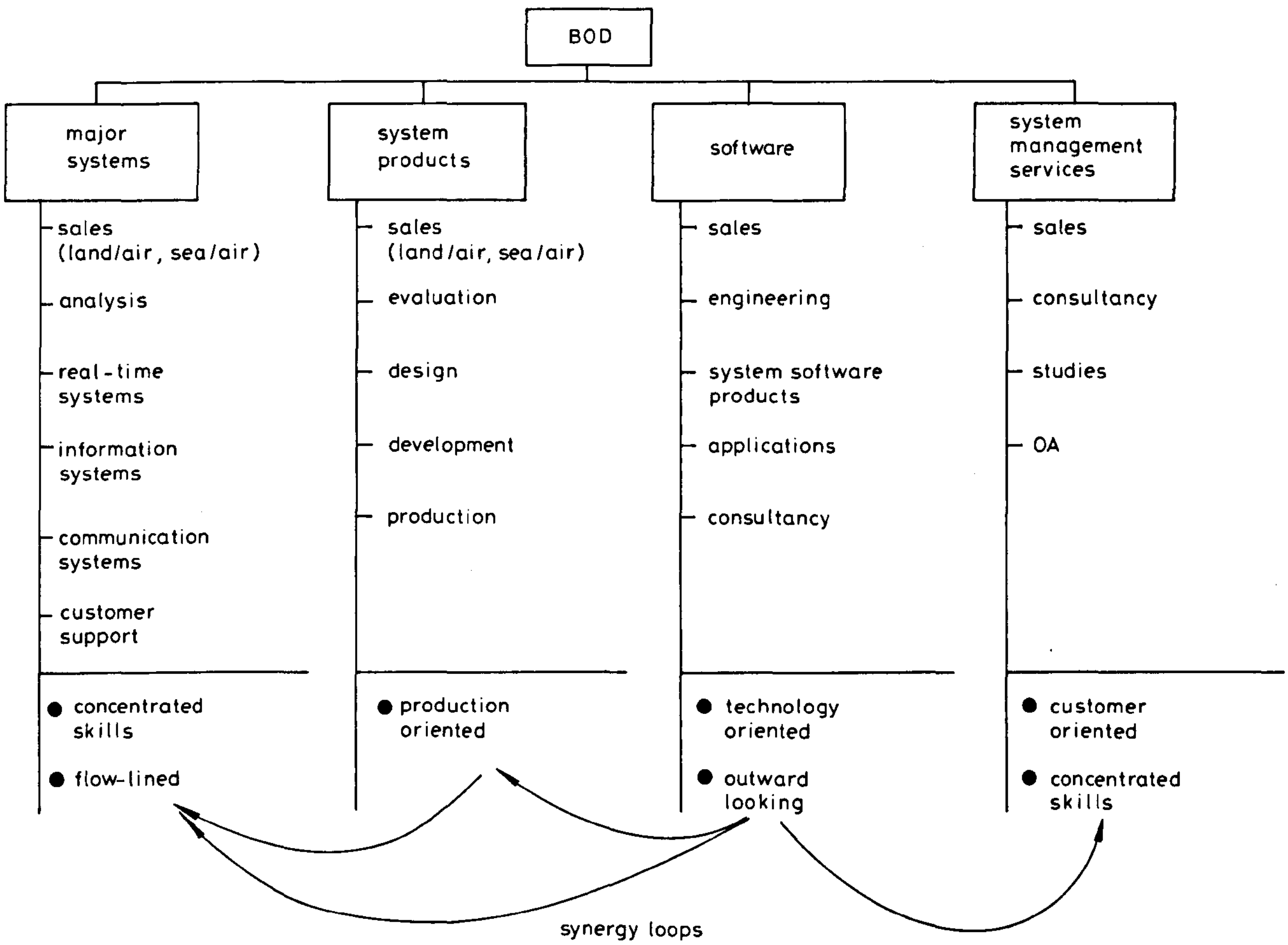

Fig. 8 *The preferred solution*

The structure is business-oriented at divisional level, purpose-oriented within divisions; it is tightly functionally bound within divisions and loosely coupled (via the synergy loops) between divisions. BOD = Board of Directors. OA = Operations Analysis

Major systems: addresses systems engineering projects. Sales organisation is customer-mapped. Resources are technology grouped, and hence skills are concentrated. Project teams are envisaged, dedicated to tasks, with most resources in the division for the complete project from analysis to implementation. The division would probably be matrix-organised internally.

System products: addresses system products — workstations, interfaces, communication switches etc. Production-oriented to meet the high-technology, low-volume throughput. Sales mapped on to customer's domains.

9 State-variable analysis

Company cash flow can be considered as a central problem and addressed using state-variable numerical methods. The results fit observed fact well for start-up companies in the defence business, and present opportunities for different approaches to creative management.

One technique for assessing the dynamics of a company organisation is shown in Fig. 9, in greatly simplified outline. The model, for a systems company, shows a manpower model encapsulated in a surrounding cash-flow model. The company is presumed to be starting from scratch, and capital purchases are considered separately. tually no income for the first 15 months, after which an upsurge is followed by violent and increasing oscillation, brought about by the long loop delays and the lack of

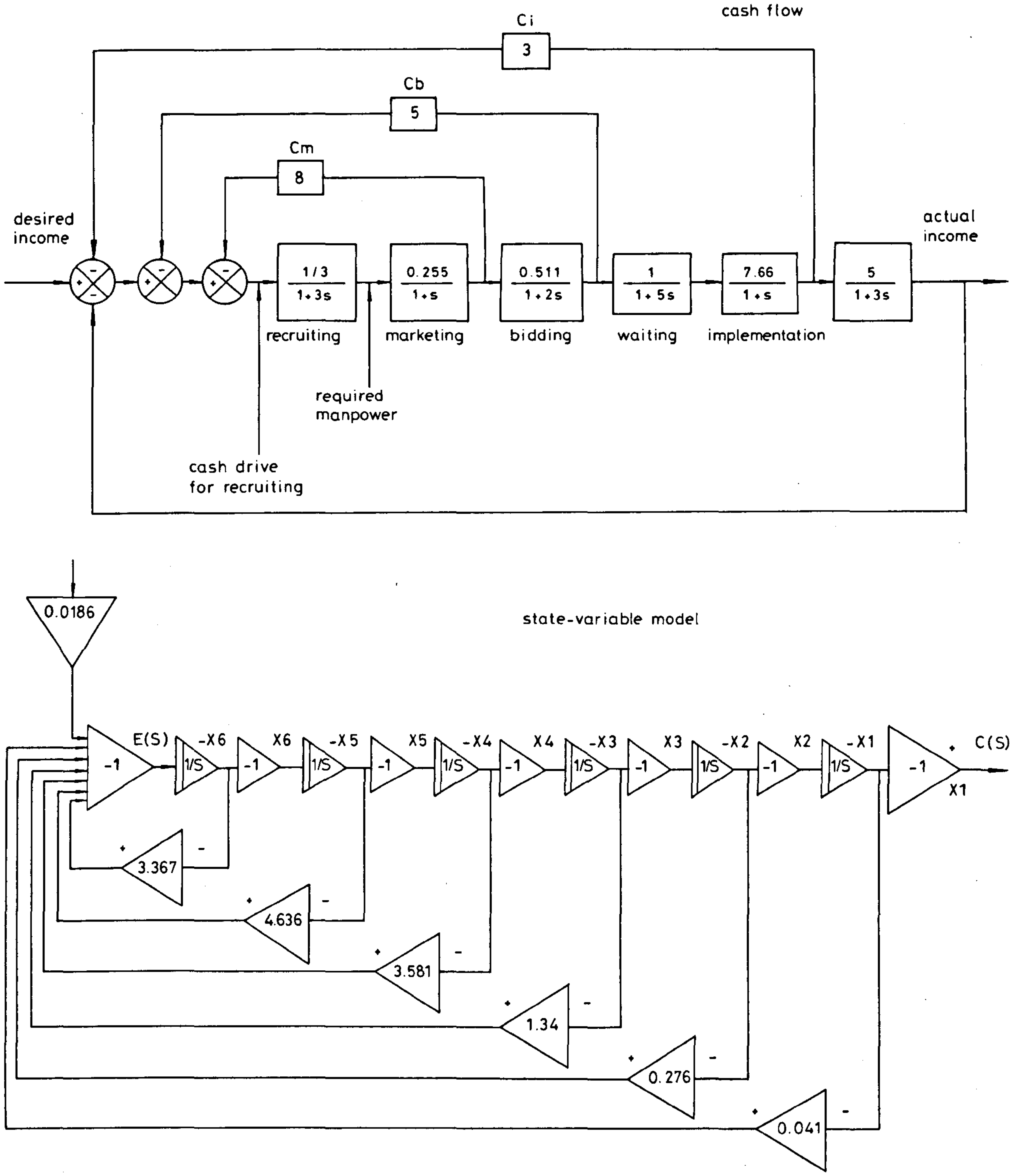

Fig. 9 *State-variable analysis*

The control-loop concept of company economic modelling can be addressed as a classic control-theory problem

Time delays are allowed for recruiting, marketing for opportunities, bidding, awaiting the outcome of the bid, implementation and receipt of first sales revenue. The costs of manpower are calculated and compared with this revenue. Analysis of the cash-flow model is greatly simplified by converting the resulting 6th-order differential equation into six 1st-order equations in the state-variable model.

The state-variable model is simply solved by computer, using recursive numerical methods; the result is nonetheless dramatic for being predictable. There is virtually no income for the first 15 months, after which an upsurge is followed by violent and increasing oscillation, brought about by the long loop delays and the lack of inertia. It is possible to sustain exponential growth, at least in the model, by the simple expedient of preventing $E(S)$, the error, from going negative. The meaning of this in management terms is obscure, but perhaps worthy of investigation.

State-variable analysis is potentially useful, then, in obliging the modeller to home-in on the basic cost and income elements in the company, and in providing a simpler numerical mechanism by which to observe their interplay. Feeding competition and external market forces into the model can also be achieved. The principal value, as the more conventional use of the technique would suggest, is the ability to analyse stability and the impact of discontinuities on system performance.

10 Systems dynamics and competition

Systems dynamics presents valuable insight into the coupling between widely separate influences. In so doing, it helps to define system boundaries at the highest level of abstraction.

Company dynamics can be viewed, qualitatively at least, using the so-called influence diagram of systems dynamics. Fig. 10 shows a company, at centre right, competing for a dwindling defence budget, at bottom left, and for engineers at top right. Systems dynamics influence diagrams are valuable in several senses:

(i) they encourage the highest level of abstraction
(ii) interactions (coupling) can be clearly seen between apparently remote elements in a system
(iv) system boundaries can be found.

This particular diagram suggests that reductions in education spending and increases in engineers leaving the industry can have just as serious an effect on defence business as reductions in the defence vote. Such analysis can (and should) influence companies to be as interested in retaining good staff as in bidding for new work.

Systems dynamics proceeds to a fuller modelling technique which is less simple to justify, owing to the need to quantify and describe in detail influences which may be hard to define mathematically. For example, it would be hard to define the precise relationship between competitors' contracts and the rate of consequent recruiting. Care must be exercised in the design of the model to avoid such parameters where practicable.

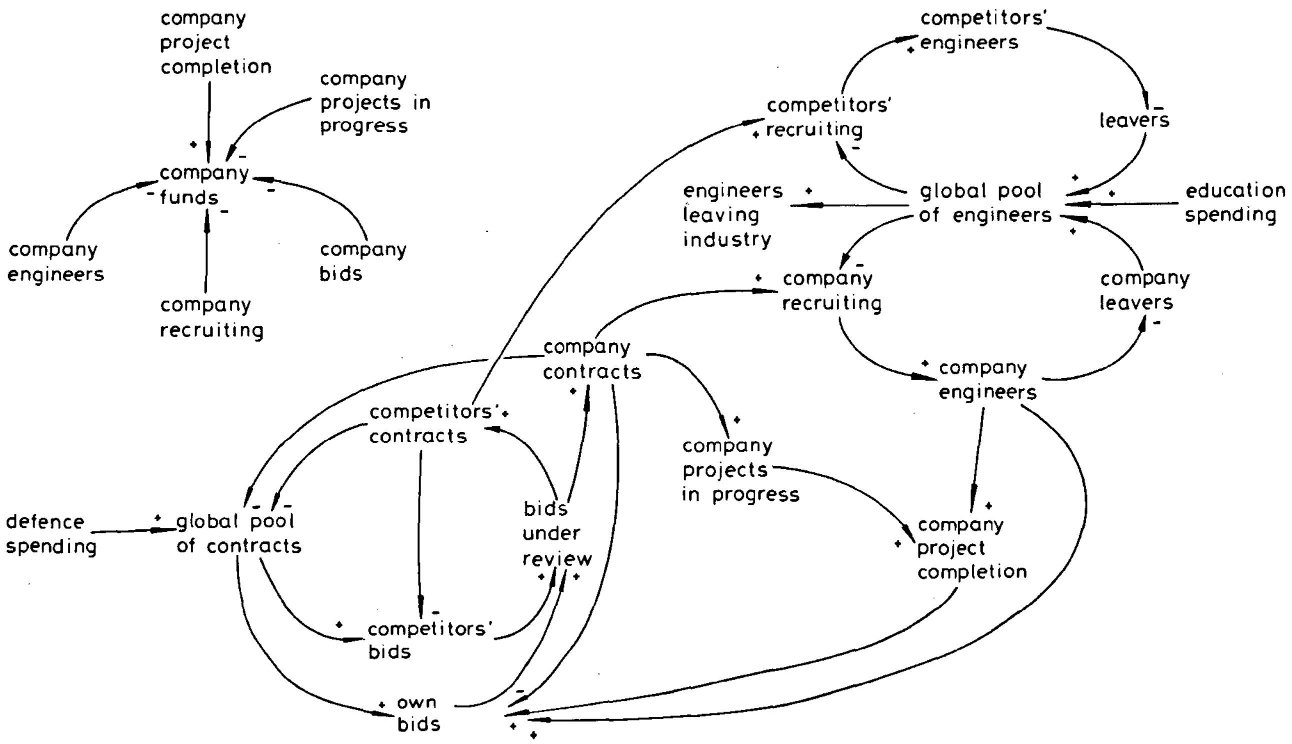

Fig. 10 *System dynamics and competition*
A system dynamics view shows competition to be for common pools of funding and of skills

11 Flow line for aircraft turnround

Flow line activity sequences may change materially at different throughputs. Modelling is a valuable tool in support of flow-line analysis.

Current interest in computer integrated manufacture (CIM) is revitalising flow-line analysis. Techniques and the experience in their use are few, however, and a simple analysis follows to show that the creation of flow lines is not obvious. The subject chosen is intensive flying of training aircraft which fly, in the example, at a fleet rate of 15 sorties per hour, and require to be replenished (turned round) between sorties.

The PERT network in Fig. 11A shows a single turnround. Rules are few and simple:

(i) The marshaller cannot check inside the cockpit until the pilot exits
(ii) Refuelling and re-oxygenation must not overlap, for risk of explosion.

The critical path (CP) for this single sortie is 12 min 41 s. But what happens when the sortie rate rises? Aircraft queue, principally, for the fuel bowser and the oxygen trolley. Fig. 11B is an activity timeline chart showing relationships, queueing times and activities. clearly refuelling is holding up the proceedings. And, moreover, the activity chart is not comprehensive; reoiling, for example, could occur much later than shown, and so float exists. Practical observation of the flow line showed an average turnround time of 19 min, rather than 12 min 41 s, and it was also noticeable that, as the sortie rate rose, a point came at which reoxygenation occurred before refuelling, not after.

Fig. 11C, the final PERT network, shows that, at 15 sorties per hour, the critical path has risen to 19 min, provided oxygen is replenished before fuel. The network therefore represented the fact and justified the

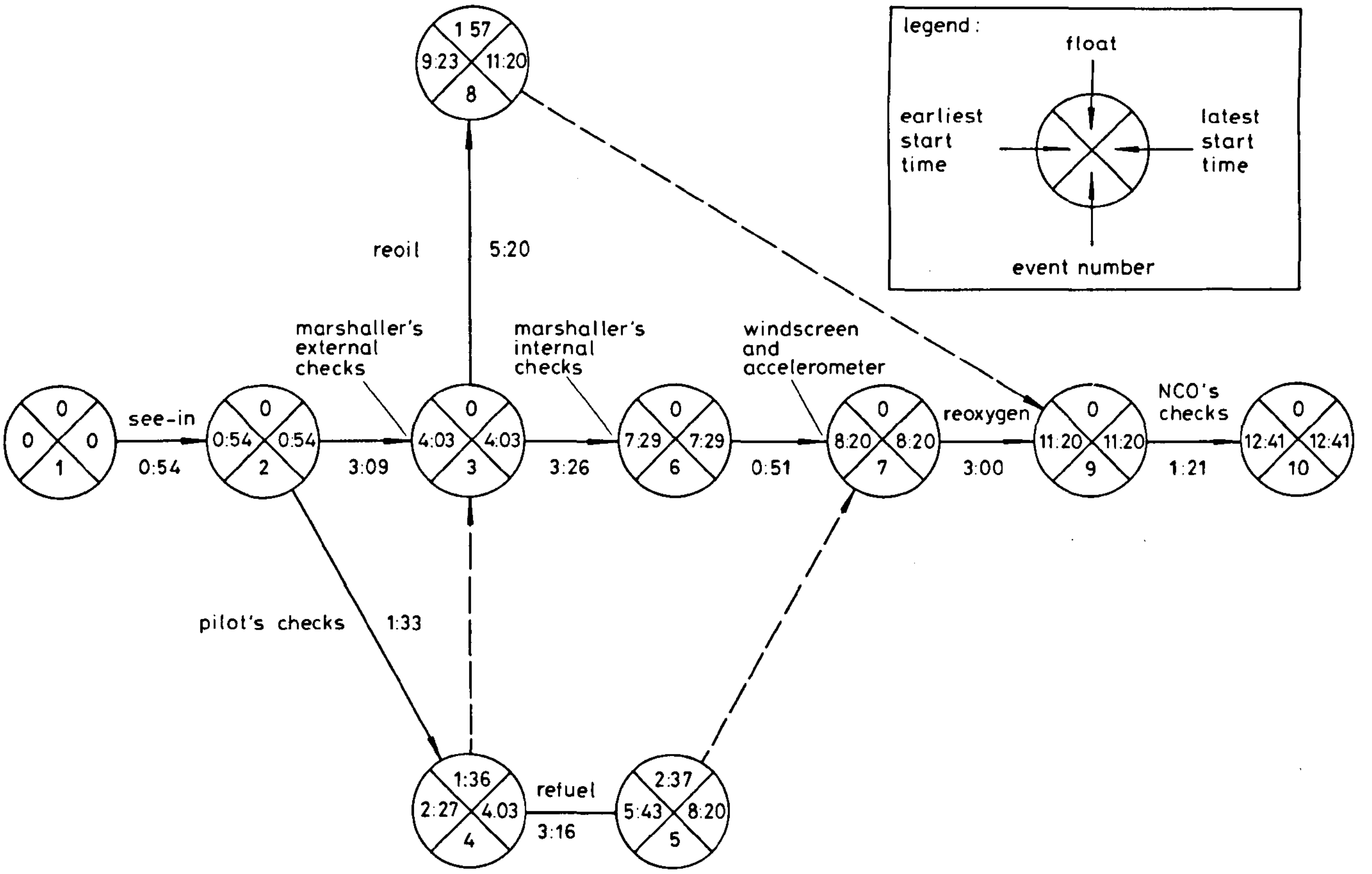

Fig. 11A *Aircraft turnround singleton PERT*

The Figure shows a network for one aircraft on turnround. Note refuelling before reoxygenation. Critical path for single sortie = 12 min 41 s. NCO = non-commissioned officer
Reoiling occurs 10 in 148 times, i.e. 0 : 06
Reoxygenation occurs 97 in 148 times, i.e. 0 : 65
Windscreen and accelerometer check occurs 41 in 148 times, i.e. 0 : 28

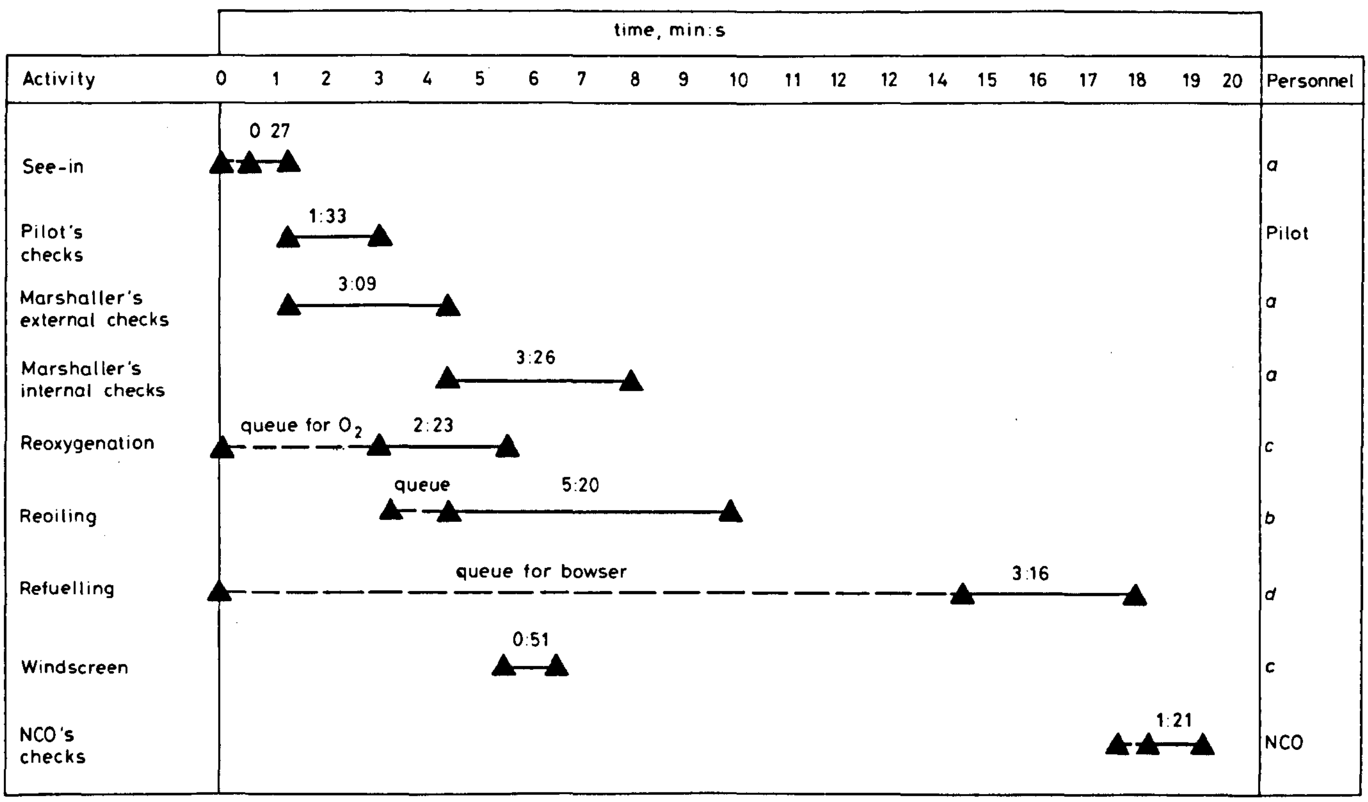

Fig. 11B *Activity timeline chart showing relationships, queuing times and activities*

NB Refuelling and reoxygenation must not coincide

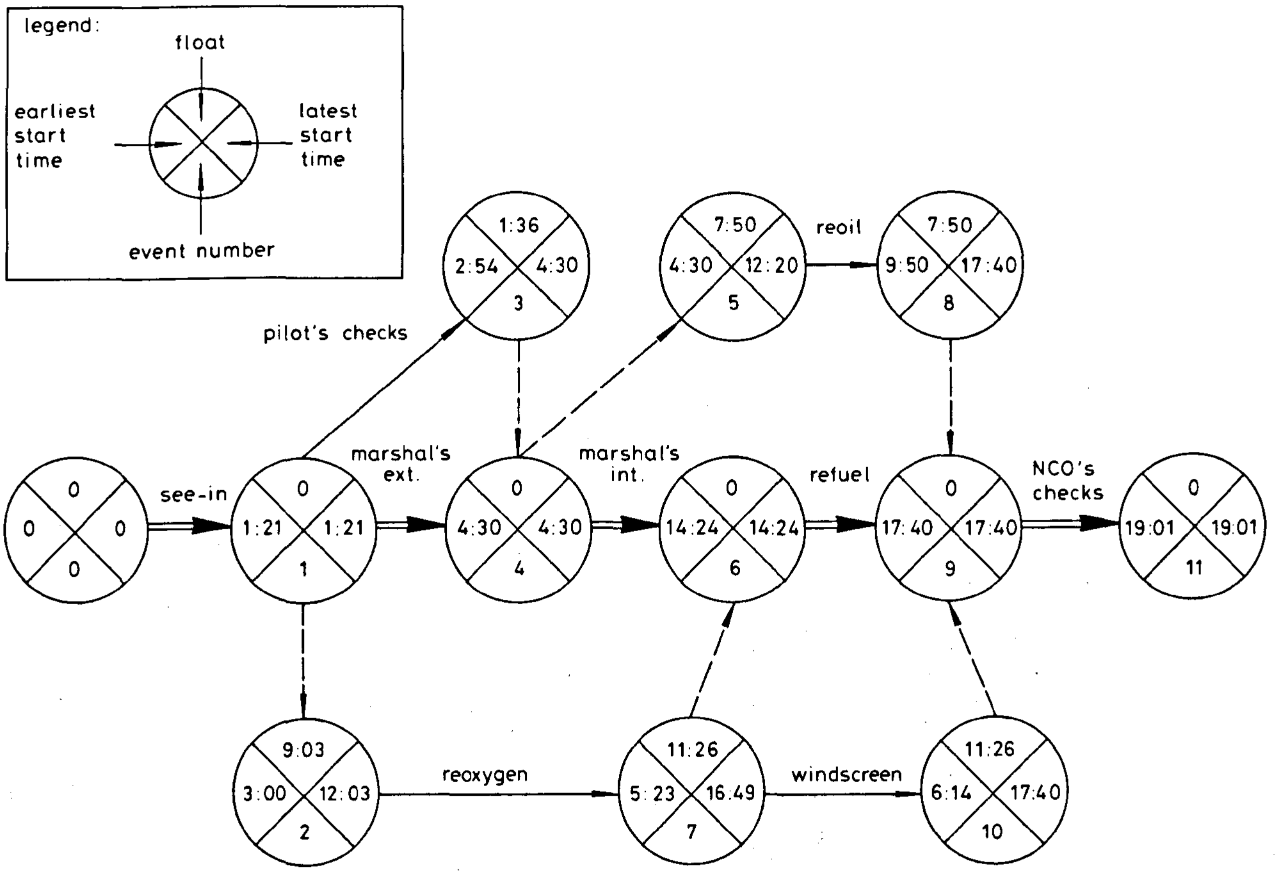

Fig. 11C *Flow-line simulation*

In flow lines, queuing effects introduce delays which vary with the flow rate and can change the preferred sequence of activities. In this real-life example, oxygen would be replenished after fuel when turning round a solitary aircraft. At 15 sorties per hour, the reverse sequence is shorter overall. CP = 19 min 01 s

(unauthorised) change in replenishment sequence which had been observed in practice.

We can conclude, in this case, and generally, that the one-off process does not multiply linearly to the many-off inflow, that the sequences employed to promote flow line throughput may change with rate, and that modelling of flow line process is feasible, practical and highly valuable.

12 Finite state/transition

The technique concentrates on critical factors causing a system to change from one state to another, and gives a valuable insight into design stability and thresholds.

So far we have considered continuous processes, evolution and growth. Life is not always like that.

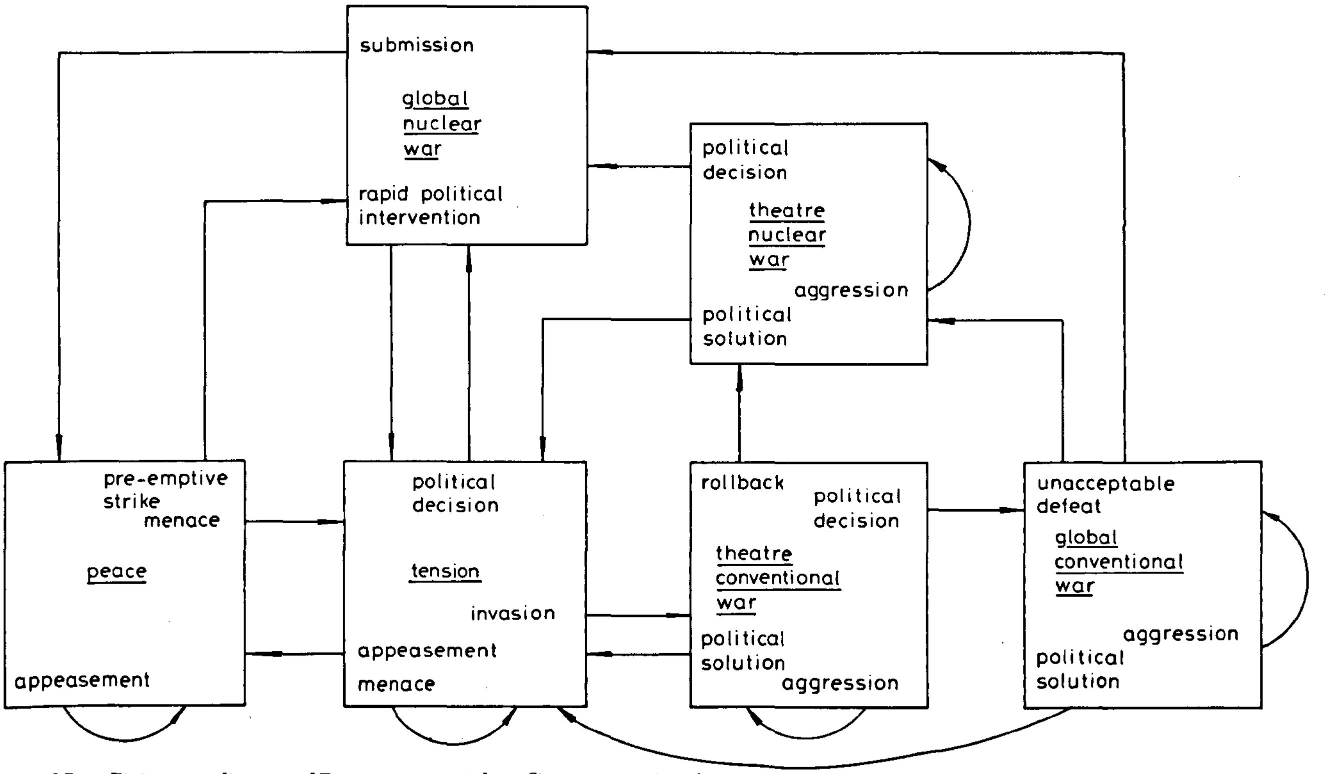

Fig. 12 *Finite state diagram of European potential conflict transition/resolution*

This analytical technique forces highest level of abstraction and the identification of critical factors causing change
NB Political solution generally implies victory or defeat

Catastrophe theory seeks to study the theory regenerative situations, and can prove quite complex. A simpler, but effective, approach is finite state/transition analysis.

Fig. 12 shows one such example for a major system, conflict in Europe. Six states are shown, and Europe is considered to be in only one at any time. It is the cause of transition that is of principal interest. Menace causes tension where peace reigned. Invasion causes theatre conventional war; and so on.

This valuable technique forces the highest level of abstraction and identification of critical factors; it is a valuable adjunct to any creative designer's toolkit, and, as shown here, can give clarity of insight into a generally intractable problem. In practice, most systems have a number of mutually exclusive states. A business, for example, can be static, expanding, or shrinking. A flow line can be smooth, irregular or stepped etc. It is useful, and can help in the creative process, to deliberately identify as many unique system states and their transition factors as possible.

13 Principles of creativity

The principles presented in Fig. 13, for engineering systems creation, are hopefully applicable across a wide sphere of activities.

The principles of creativity proposed in Fig. 13 are general and simple in concept; they require discipline to observe. It is the hope and intention that they have applicability beyond engineering systems creativity, as shown in the Figure.

- *Highest level of abstraction*
- *Breadth before depth*
- *Disciplined anarchy*
- *Functional before physical*
- *Decomposition before integration*
- *Level at a time*
- *Tight functional binding*
- *Loose functional coupling*
- *Functional migrates to physical*

Fig. 13 *Principles of creativity*

The principles apply to many endeavours including engineering, product design, man-machine interface, organisation and management, software engineering and even, perhaps, art.

Highest level of abstraction, breadth before depth, functional before physical, level at a time, binding and *coupling* have all been presented.

Disciplined anarchy implies that creative freedom must not only be permitted but positively required, within a constructive framework.

Decomposition before integration is necessary to understand the problem properly, and provide a sound, considered solution.

Functional migrates to physical is observed in design generally. Functionally, a computer input is quite different from its output. Physically, computer I/O is often one unit, driven by the physical similarities of the two functions. So it is with organisations; functionally discrete groups will aggregate for economy, communication, identity and many other reasons. But well defined functional responsibilities will ensure that performance is maintained throughout the migration.

Having presented the principles of creativity in an engineering environment, it is instructive to consider their wider applicability. At least two noted areas of creativity, oil painting and orchestral composition, have similar underlying principles, although they use different terminology. The artist in oils, for example, first sketches in charcoal and gradually works from a broad background towards a refined foreground, holding the whole eventual composition in his mind's eye. The composer seems to follow a similar line. So, too, does the system designer. Perhaps creativity does have common characteristics in all walks of life.

References

1 HITCHINS, D.K.: 'Managing system creation', *IEE Proc. A*, 1986, 133, (6), pp. 343–354
2 HOFSTADLER, D.R.: 'Gödel, Escher, Bach: An eternal golden braid' (Penguin Books, 1980)
3 SHINNERS, S.M.: 'Modern control systems theory and application' (Addison-Wesley, 1979)
4 ROBERTS, N.: 'Introduction to computer simulation' (Addison-Wesley, 1983)
5 RUIZ-PALA, E.: 'Waiting line models' (Van Nostrand Reinhold Co. Ltd., 1967)