The study of what systems are and how they work can help us understand much in the world of complex engineering enterprises

Systems in engineering

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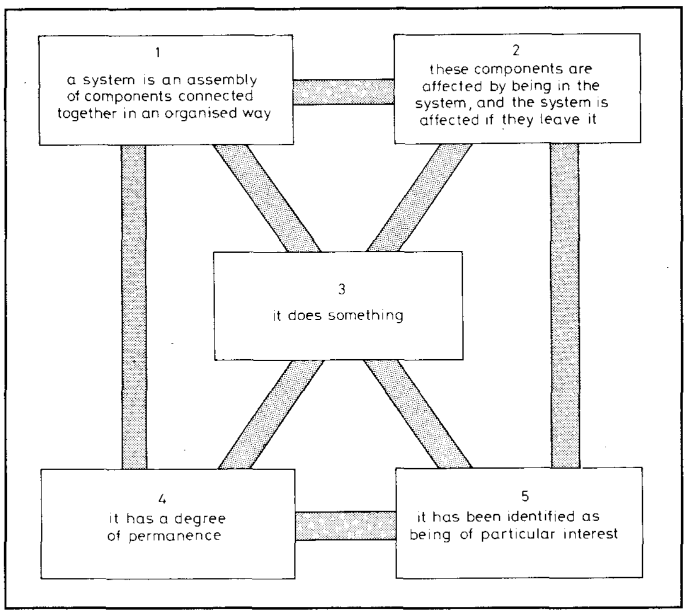
Systems, as a word, means different things to different people. Used loosely, it may describe something complex, artificial and having a specific purpose. As such, it is a useful general-purpose word which saves having to think whether the thing in question is a collection, an assembly or an arrangement of such things.

A system, as defined in a dictionary, is more specific, typically a 'group of parts working together in a regular relation'. Now some useful properties are emerging, from which we can learn things applicable to systems that we may come across in the future. First, and fundamentally, a system consists of a set of interrelated components.

The interdependence of these components is what differentiates a system from a mere scheme or network. Thus a system is fundamentally altered if a component joins or leaves it. This is an important property, which, when applied to designing, using or working on a system, differentiates it from non-systems. Thus a wheel is very much a part of a vehicle system, quite unlike the relationship that a lamp-post has to a street-lighting scheme or a telephone to a network. It is the special influence which the component and the system have upon each other that differentiates a system from a scheme. It gives each component a vital degree of notability, helping ensure it does not get overlooked, however small. And it gives each system an individual characteristic which differentiates it from others.

A system is not an edifice to be admired; a system does something; it has a purpose. This cardinal sense of purposeful activity is central to the concept of a system. There is always a singularity of purpose, even if subobjectives exist which are involved in achieving the main objective. Thus a water-supply system might include filtration and chlorination activities vital to supply water of adequate quality, but it is the supplying itself that is the key activity. When dealing with complex systems, it is important not to lose sight of the main activity among the plethora of subobjectives of actions.

Many of the needs and the activities that people pursue to achieve their ends change with time, but life goes on. The successful system is that which endures beyond the mere passing purpose of the moment; a system sustains a degree of permanence. A successful system is one which may grow and develop, as if organically, to meet the changing needs of its owner. Thus a



1 The five key characteristics of a system

list of names and addresses in a diary that has to be started again each year may not be much of a system; but an alphabetical card index, listing all those to whom you send Christmas cards, with dates to facilitate the weeding out of obsolete entries, may well be described as a system.

Even with all the above attributes of a system defined, there may still be a lingering doubt as to just what constitutes a system and what does not. Take, for example, the cases of a building's hot and cold water facility and its central heating. If the former is just a standard installation, with little regard as to just what the hourly flow rate demands are likely to be, and with little need to plan for how many extra taps may later be connected to it, it hardly constitutes a system, and many of the special properties to be discussed below will not apply. However, if a central-heating provision is designed to achieve a certain interior temperature for a given room usage, wall insulation and outdoor climate, then clearly it may be most sensitive to the addition of another wing to the building.

On the other hand, if the central heating were merely a series of room storage heaters, an extra wing may have negligible effect, and this would not be treated as a system. Or again, if the hot and cold water supply was fed from header tanks and if outlet pressures were critical and sensitive to the addition of an extra wing, then the former example may well be worth considering in systems terms. It thus becomes apparent that a system is something that has been identified as of particular interest.

These general systems properties are illustrated in Fig.1.

From these five fundamental properties of systems, a number of other characteristics emerge. For instance, there is no reason why the components which go to make up a system cannot themselves have all the properties of a system. Components can be subsystems in their own right, having all the same properties as their parent system. It follows that the facility originally defined as the main system could itself also be a subsystem of some grander system, and this is nearly always the case. This is illustrated in Fig.2.

Putting a system into context like this helps dispel key misconceptions. Without a systems approach, a project manager can readily be forgiven for imagining that the world rotates about one project. But this systems approach explains that that project is merely a component, or subsystem, in someone else's wider project.

These tiers are not always too obvious to everyone. Take the case of the recent building of the Saltash Bypass Control System Project. Buried in this one title were indeed at least three projects. First there was the Department of Transport's project. Its definition of 'it does something' may well have been 'to increase the Government's popularity' and this could have influenced the project's timing with respect to elections.

Second, there was the engineer's project, a key aim of which may have been 'to provide a professionally impressive facility of use to the travelling public'. Third, there would have been the contractor's project, which may have seen the objective as 'building a sound structure in a stated time for a given price'.

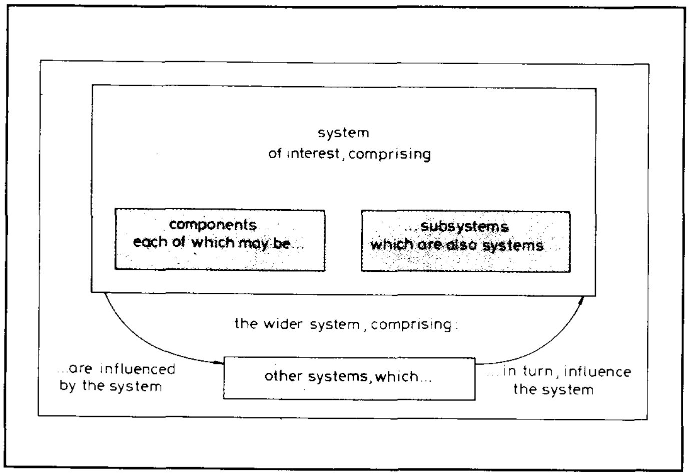
These three aims do not necessarily conflict, and, indeed, a systems approach that makes them more explicit helps identify potential conflicts early and facilitates their early resolution. In this particular case, we even coped with the three identically titled projects having, at one time, project managers whose names were A. Pickett, A. Pidduck and A. Puddock.

One problem here is that sometimes semantic imprecisions cause confusion regarding just which system is being discussed as the main one. Supposing an electrical and mechanical engineering firm undertakes E&M services for its civil-engineering parent company, as well as undertaking work in its own right. To simplify departmental areas of responsibility, it might be accepted that railways work will generally be the prime concern of the civils, and much E&M work that this embraces will be passed on to the E&M department. Thus, chasing after railways business now becomes defined, in systems terms, as something of particular interest to the civils. As such, the civils will perform well to the extent that the work required by the client is civil work.

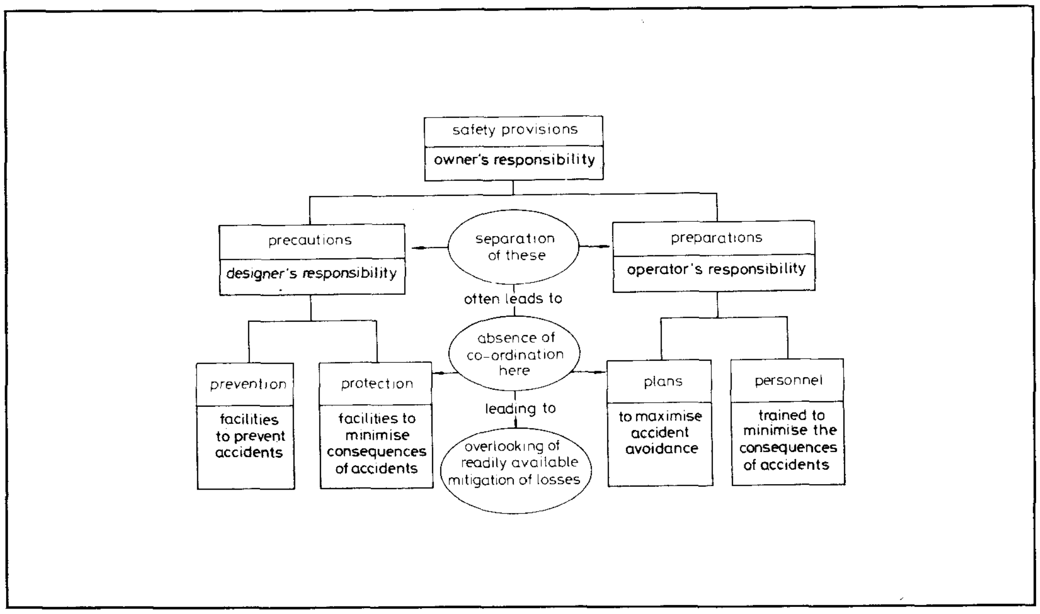
This runs the risk of misplaced objectives, a most serious matter. Consider two cases. First, take the above-mentioned Saltash Bypass Control System. As it happened, using a systems approach, the project was implemented on time, to budget, with a list of two snags rectified in a fortnight. A little earlier, two similar projects, not using the systems approach, ran 34 and 45 months late and incurred extra costs totalling £1 million and £2 million, respectively.[1]

Second, the architect or civil engineer may subconsciously guide the client towards ensuring that the project is given an undue bias towards the civil aspects. Civil aspects may be the major, the initial and/or the capital-intensive aspects. But they may not be the only key aspects. Making it work safely, reliably and efficiently may be key E&M aspects. A classic example, the Sydney Opera House, has been described by Holgate.[2]

Often, the client's instructions are necessarily brief, perhaps even formulated in civil-engineering terms, and may, to all intents and purposes,



2 Systems are parts of wider systems



3 Getting safety right first time

appear to be entirely limited to civil matters. This will undoubtedly be true where the instructions themselves are prepared in nonsystems terms, such as 'what are we going to build here?'. That tends to be answered in terms of what it will look like, and could result in an impressive monument. In systems terms, there is a greater emphasis on 'what is it supposed to do?'. This is more likely to lead to something that works well, although one needs to be careful to avoid the risk of it not looking so nice.

A second field, where the systems approach has led to a different conclusion to the traditional method, has been in the area of safety design. Naturally, in every major project handling large numbers of members of the public, safety considerations play a central role. But the traditional approach has been one of asking 'what safety features are available for consideration in the design of this project?'.

The systems approach would rather look at it from the umbrella question of 'what is the project's purpose?'. (Remember, in the definition, a system does something.) The reply 'to handle people safely, efficiently and economically' leads directly to the supplementary questions 'what safety facilities are available, and are these adequate? And if not, what more needs to be done to rectify this?'.

In nearly every project so undertaken, this has led to new features or facilities being added which might otherwise have been left out. They may have otherwise been left out either because they weren't considered necessary for the previous (similar but not quite the same) scheme, or because the standards expected by the public have risen since then.

Examples of such recent instances include effective tunnel telephones for road tunnels, automatic train protection for mainline railways and a series of safety studies for a new railway extension. In the latter case, where normally one study would have sufficed, already four have been commissioned, with two more on the drawing board to follow when appropriate. Each of these has lead to further engineering developments, the important feature being that these are being implemented as a result of a systems study rather than as a result of an accident investigation. This could similarly have been described as a pro-active approach rather than a reactive one.

But there were clearly other forces at work too. These included the recognition that safety was of key importance,[3] that there are hierarchies of safety systems to be considered, and there are many safety aspects whose very interconnectedness is a key feature.

Such systems thinking leads to a new approach to project safety engineering encapsulated in Fig.3. Hitherto the left-hand aspects of this diagram tended to be considered pretty separately from the right-hand aspects, with the result that the latter were all too often given the Cinderella treatment.[4]

A systems approach to engineering design can therefore be described as one of understanding the main and the emerging characteristics of systems (defined in a concise manner); of identifying such systems features in one's current tasks; and of applying the systems characteristics to such tasks in order to arrive at better solutions in less time.

This article has attempted an introduction to the nature of systems, and the relationship between theory and practice. It has only scratched the surface of the many emerging properties that derive from some of the foundation stones outlined here.

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