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# IMPLICATIONS OF SCALE FOR SYSTEM DESIGN

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ABSTRACT

Prevailing practice in large-scale system design implies the acceptance of certain unreasonable beliefs. These include: (a) practices that are useful in ordinary-scale designs readily extrapolate to large-system designs, (b) what is important in design is professional territory, and (c) design practice does not need to reflect any human mental limitations such as bounded rationality stemming from a modest span of immediate recall.

Nevertheless there is abundant evidence that these beliefs are invalid, and must be replaced entirely by a new set of beliefs that is responsive to both experience and scientific knowledge.

Specifically, large-scale system design typically involves sociotechnical systems, not just technical systems; the economics, the consequences of failure, the cognitive burden, the role of science, and the ethical basis are all different.

The increasing and highly-publicized series of financial and casualty-producing incidents involving large-scale systems should be teaching us that we must begin at once to develop standards for large-scale system design, to test these over time against experience, and ultimately to strive for world-wide legislation to promote responsible design and protect humanity against the evils of prevailing practice.

Scholars and professionals must work together with political leadership to develop these standards so they meet the test of reason and provide severe sanctions for those who continue to abuse humanity by their failure to apply the standards in large-scale system design.

# FUNDAMENTALS

Large-scale systems in the world of today are sociotechnical systems. Such systems involve the invasive merger of subsystems consisting of social systems and technical systems.

We may say that any two elements S and T are proionic in a context C if, in that context, through invasive merger, they comprise a new element V that does not preserve the individual identity of either of the original elements. For example, when oxygen and hydrogen unite to form water, the resulting element is almost opposite in properties from the constituents.

A social system is a collection of interacting actors. A social system model is a collection of roles together with a scenario that accounts for role interactions. Design of a social system consists of developing the scenario and the roles, whereby actors can comprehend not only the roles but also how each role relates with the total system. Social systems are fundamentally proionic, because people perform differently in groups than they do as individuals, hence the merger of individuals into social systems leads to new identities all around.

A technical system is a collection of interacting artifacts. Technical systems may or may not have proionic elements. Prominent engineers have urged that technical systems be designed so that each component is independent of all of the other components, in the interests of understanding, production, testing, diagnosing, and maintenance.

A sociotechnical system arises by invasive merger of a social system S with a technical system T to produce the sociotechnical system V. Since any social system is proionic, and since any system that contains a proionic subsystem is proionic, every sociotechnical system is proionic.

For any system U designed from k distinctive parts, there will be always $2^k$ combinations (the set of all subsets, including the null set), which should be considered for proionic combination. As a result, if the designer mind can handle k pieces of information, the only kind of system that mind can work with will be a non-proionic system, since this is the only system formed from these elements that will not involve more than k units to interpret.

The study of limits on immediate recall has suggested previously that the human mind can only recall at any given time between 5 and 9 elements. In his original paper on "the magical number", Miller [1] suggested the range just mentioned. But later Simon [2] suggested that the estimate of 5 for the magical number was likely to be the best. Subsequently Warfield [3] indicated that the number is precisely 3 if the elements involved are proionic, since a set of 3 distinctive elements will involve 7 non-trivial entities in its power set.

The scale of a system design is clearly a factor in determining cognitive burden on the designer. Thus the larger the scale, the more likely the designer will be unable to match cognitive effort with cognitive limitations, and the more likely the design will be defective.

It is also fundamental to technical design, as pointed out by many including Vickers [4] and Conant [5], that historically technology leads science. The initial design or invention of most technological artifacts has been done with only marginal benefit from science. The value of science to technology has been greatest in the stage where the technology is being highly refined and perfected.

Since science does not provide the basis for most design, one may readily conclude that experience is what most designers rely on. Thus the ubiquitous radio has been steadily improved over time as designers get more and more experienced, and it is only in recent times that science has led (through the invention of the transistor, rooted in quantum theory) to highly reliable and inexpensive radios.

It is also fundamental to design and invention that design evolves through repeated fabrication of trial units, and that manufacturing evolves through pilot plants and through pilot production.

The economics of design dictate that many throw-away versions be built, or that much trial-and-error occur, as the designer gradually gets educated.

Large-scale technical systems do not lend themselves to such practices. The so-called "waste" in military procurement is better interpreted as the cost of education of large-scale systems designers. Regrettably the designs cannot go through repeated and evolutionary development in many cases, because it is not economical to do this. Thus high-quality systems are not to be expected.

## CULTURAL CANALS

Alfred North Whitehead [6] inspired the term "cultural canal" to describe a kind of groupthink that allows bad practice and bad thought to continue to hold sway for long periods of time. He stated that:

> "modern scholarship and modern science... canalize thought and observation within predetermined limits, based upon inadequate metaphysical assumptions dogmatically assumed."

He spoke of the "intimate timidity of professionalized scholarship". Nowhere are such tendencies and descriptions more appropriate than in the arena of large-scale system design.

In this region, people allow design to be ego-driven, to be expansive, to expend vast sums of other people's resources on projects that these people have not been able to conceive, all in the absence of any disciplining science or methodology that offers any assurance of sound design [Warfield,[7]].

Meanwhile the relevant professional associations and learned societies sit in relative quiescience, allowing all this to go on without providing the essence of any quality-evoking activity: informed and detailed criticism and correction founded in responsible science.

Because of this, we observe extensive failures on large scales at great cost in time and human casualties.

Some who observe this situation believe that it is inevitable that large system failures will occur, and one scholar, Perrow [8] has even described them as normal.

Scholarship that assesses quality in any field must look beyond the incidences of malfunction or failure, and observe the quality of knowledge that is available to provide corrective influence. In the case of large system designs, we already have generic design concepts from scholars that demonstrably can reduce significantly the incidence of bad large-scale system design.
And there is ample evidence that large-scale system designers are ignorant of this knowledge, and not much interested in learning of its existence. Moreover the division of responsibility and authority between the designer and the supervisor or manager or administrator allows all actors to escape responsibility, given the absence of any disciplining science at work.

## PRESCRIPTIONS

Three laws of design, as a minimum, must begin to play a role in large-scale system design:

(1) Variety. Variety in establishing design requirements, in developing options, in defining alternatives, and in making choices must drive out ego. There are too many examples of bad large-scale system design that stem from undisciplined ego to avoid drawing this conclusion.

Thus the Law of Requisite Variety must become something more than a hallway conversation piece at society meetings.

(2) Parsimony. The requirement to limit the information that the mind must be able to deal with at any given time means that the design process must be itself designed so that the information rate the designer must deal with is conservatively controlled.

This implies a stringently sequenced design process, rather than the expansive type encouraged by big promoters. There is no substitute for disciplining the rate of information flow that people must manage.

Thus the Law of Requisite Parsimony must underlie all design methodology for large-scale systems.

(3) Saliency. The inability of people to interpret the relative saliency of design factors demands that the design process must itself incorporate the means of leading the designer(s) through an assessment of saliency of the factors. The same process must exert strong discipline on managers of design, who have to understand that undisciplined design is a recipe for failure.

Thus the Law of Requisite Saliency must underlie all design methodology for large-scale systems.

Professionals have unwittingly contributed to the spate of large-scale system design failures. By assigning undue saliency to freedom and creativity in the design process, as reflected in their indiscriminate promotion of a wide variety of methodologies that have not been tested against adequate criteria, professionals share the blame for large system design failures.

**The time is now at hand when professional societies must exit their cultural canals. They must join together to establish a set of standards for large scale system design. These standards must be weighed against strict criteria. They should be formulated with guidance from the spate of large-scale system failures that have occurred in the past decade.**

**Once agreement is reached on their technical content, these standards must be publicized and tested around the world, and modified to correct any weaknesses or any unclear interpretations.**

After a suitable period of testing, it will be necessary either (a) to get voluntary compliance from the large organizations that engage in large-scale system design or, failing that, (b) to enact into law measures that provide severe punishment for individuals who are responsible for large-system design failures.

In order to avoid punishment when it is unwarranted, evidence of responsibility can be defined as failure to use well-defined processes to carry out the design, wherever those processes are linked to solid theory, be it from systems science or other sciences.

The world will be better off for this intervention.

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