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Systems Engineering in an Age of Complexity*

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ABSTRACT

This paper considers the creation of Complex Engineered Systems (CESs) and the Systems Engineering approach by which they are designed. The changing nature of the challenges facing Systems Engineering is discussed, with particular focus on the increasing complexity of modern systems. It is argued that modern complexity poses a major challenge to our ability to achieve successful systems and that this complexity must be understood, predicted and measured if we are to engineer systems confidently. We acknowledge previous work which concluded that, in complex systems, failures ("accidents") may be inevitable and unavoidable. To further explore potential tools for increasing our confidence in complex systems, we review research in the field of Complexity Theory to seek potentially useful approaches and measures and find ourselves particularly interested in the potential usefulness of relationships between the magnitudes of events and their frequency of occurrence. Complexity Theory is found to have characterized naturally occurring systems and to potentially be the source of profitable application to the systems engineering challenge, viz., the creation of complex engineered systems. We are left with the tentative conclusion that truly complex systems, with our present understanding of complex behavior, cannot be designed with a degree of confidence that is acceptable given our current expectations. We recommend that the discipline of systems engineering must investigate this issue as a matter of priority and urgency and seek to develop approaches to respond to the challenge. © 2003 Wiley Periodicals, Inc.[‡] Syst Eng 7: 25–34, 2004

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1. INTRODUCTION

Most people would agree that the world is becoming more "complex." Much of this is driven by two phenomena that have started to dominate our lives in recent years. First, we face an unprecedented level of integra-

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tion and are immersed in a "complex" web of interacting technologies and processes, dominated by the developments in information and communications technologies. Second, rapid change has become the norm with new technologies, practices, and organizations being introduced continuously into this highly integrated web.

The 21st Century has been described as "The Systems Century." The phenomena described above certainly reinforce the systemic nature of the world, and since this trend is man-made, we must ensure that we are "engineering" it in an appropriate and acceptable way. There are many dimensions to this, from the cultural and social aspects to the purely technical, and Systems Engineering (SE) as a discipline spans a major part of the center of this spectrum, using traditional and emerging technologies to achieve complex engineered systems (CESs) and introducing them, and their behaviors, into the real world.

SE must be able to create these CESs successfully and to do so with confidence, even in the face of increasing complexity. In order to do this, it is essential to understand the nature of the complexity and its implications, and characterizing the complexity would enable us to tailor our SE approach and deal with the challenge appropriately. In this paper we consider some of the key questions in "engineering design" and discuss their relationship with SE in the past and future. We then explore Complexity Theory, seeking a characterization of complexity that would be useful in creating CESs. Areas for further work in the complexity of modern CESs are identified.

2. THE DESIGN OF ENGINEERED SYSTEMS

Engineering design is a problem-solving process that produces an engineered product. Its effort is focused on achieving "objectives" in the real world. These objectives may take the form of seeking to solve a real world problem or of achieving a particular envisaged (useful) end product. "Design" is a broadly-applied word and any attempt at a comprehensive definition risks being general to the point of meaninglessness. Yet, there are common elements in most kinds of design.

Within projects for developing engineered products, we expect an essential part of good design to be "to plan"; we must identify and organize resources such as funding, skills, experience, knowledge, effort, and information, and we need a disciplined, systematic approach focused on achieving the identified design objectives. This planning implies a significant ability to analyze, identify, and predict key issues and form approaches for dealing with them.

But, of course, every design effort will also have constraints placed upon it, and these will need priorities to be established, and decisions to be made and reflected in the plans. Engineering programs are based on predictions leading to plans matched with these constraints. This emphasizes the importance of our ability to make confident engineering predictions. This is a recurrent theme in this paper.

The basics of an engineering design process have been described many times in publications, and they all illustrate a fundamental problem-solving process exposing the questions that the designer must tackle:

- What are our objectives?
- What must our solution do in order to achieve our objectives?
- What solution options may be appropriate?
- What option is best?

This reflects a general decision process from problem definition through to evaluation and selection of a solution. However, there are other implied questions that are of equal importance:

- What constraints apply, either in the nature and scope of our design effort (time, cost, funding, and other resources) or in the nature (size, cost, weight, etc.) of our solution?
- What priorities are appropriate?
- How will we know when we are "done"? (That is, how will we know when our design effort has produced a solution which will satisfy the objectives within the constraints?)
- How confident are we? [That is, how do we know, to an acceptable level of confidence, that our engineering judgments are correct, both in our predictions and plans for the design process (effort, time, etc.) and in the predicted behavior of the resulting product when introduced into the real world?]

There are, of course, many other questions necessary within the process of design, but the above subset is used in this paper to illustrate the changing impact of complexity and its implications on the approach needed to create successful CESs within constraints of time and cost. These questions are equally applicable to the design of a simple "artifact" and to the "engineering of systems." Clearly the former is inherently "less complex" than the latter, but the real implications of this are not well established in most systems engineering texts.

3. THE NATURE OF COMPLEXITY

3.1. Complexity of Early Systems

If a "system" is defined as a set of interacting elements exhibiting an overall behavior beyond those of its individual parts, then engineers have been designing systems for many years, although the scope of such engineered systems has changed dramatically. Early systems were viewed very much as engineered products—a natural extension of the simpler machines that preceded them. These systems were often based on a well-understood architecture that had evolved over the years coupled with some new technology resulting in the next evolution of the system (e.g., the horse-drawn carriage and the internal combustion engine gives us the horseless carriage). Even when the system architecture was new (e.g., first airplane—although there had, of course, been gliders) the relationships between the interacting parts were clear and easily defined and their functions were easily segregated for thought and analysis. The design concept and the associated effort could be partitioned easily, and this could be done with some confidence at a system level since effects across partition boundaries were dominated by primarily mechanical interfaces that were well defined and understood. Such a system structure is illustrated in Figure 1a.

Consider how these kinds of weakly-integrated engineered systems and their engineering approach relate to the questions raised earlier (see Table I). These questions are relatively manageable for these kinds of systems. The systems engineering design decisions have a strong foundation in prior experience, precedented architecture, and previous evolution and, since the interrelationships between the parts are relatively clear, many of the systems-level decisions can be related directly to similar questions for the contributing subsystem technologies.

These types of systems problems clearly have a degree of complexity, but the systemic influences are relatively weak. Senge [1990] called this Detail Complexity. We have developed systems engineering processes and organizations for dealing with it, including techniques such as requirements decomposition and allocation and Failure Mode Effects and Criticality Analysis. The characteristics of Detail Complexity systems are:

- Hierarchical relationships dominate lateral influences.
- Cause and effect are relatively obvious and direct.
- The implications of design decisions are relatively predictable.
- Risks are dominated by the local risks in achieving the contributing parts.
- Influences on, and implications of, decisions tend to follow the local partitioning of the solution elements.

These characteristics of Detail Complexity relate directly to our ability to answer the fundamental questions raised earlier. In particular, the predictability of systems exhibiting Detail Complexity enables us, in theory, to identify important issues, plan our approach, evaluate options and assess risks and be relatively confident that we are making progress towards a successful achievement of our objectives. Clearly, past failures show that this is an oversimplification. Engineering such systems is not a trivial task, and there are, of course, still risks within such system projects. These problems, though, tend to arise because of failings in our understanding of the local, often very novel, tech-

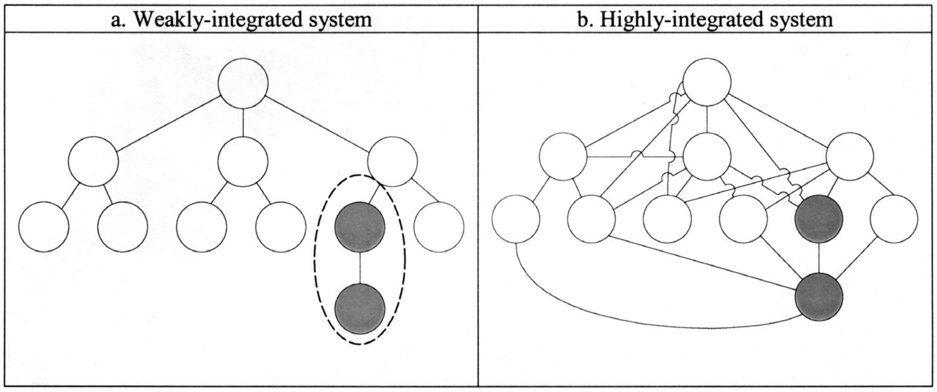

Figure 1. The impact of design decisions on components of highly integrated systems can be system-wide.

Table I. Design Questions Related to Weakly Integrated Systems

Question	How well understood?
1. What are our objectives?	Relatively clear, based largely on achieving a clear "product"
2. What must our solution do?	Relatively clear, based largely on previous architectures
3. What solution options may be appropriate?	Relatively clear, based on a small number of available technologies
4. What option is best?	Relatively clear evaluation, based largely on previous experience, clear objectives and simple relationships between parts
5. What constraints apply?	Relatively clear, based largely on immediate measures of time, cost and technology limitations
6. What priorities are appropriate?	Relatively clear, based largely on clear relationships between the elements and clear trade-offs
7. How will we know when we are done"?	Relatively clear, based largely on previous experience and on knowledge of the contributing technologies
8. How confident are we?	Relatively clear, based largely on previous experience and on knowledge of the contributing technologies

nologies that are being used within the system, rather than at the system level itself.

It is important to note that Detail Complexity is not related to the scale of the system. The nature of Detail Complexity shows us that large systems of this type can be partitioned (reduced) into smaller, relatively independent groupings, and the apparent complexity disappears once the pattern of (local) interrelationships is exposed.

The systems engineering method has evolved over the years largely to cope with this type of complexity. During that time, systems have become larger but many have still fundamentally exhibited Detail Complexity and so we have become used to being able to address questions such as those raised above and, in particular, aspire to achieving increasing confidence in our plans and solutions.

However, the nature of modern system complexity is now fundamentally changing (at least partly because of the pervasiveness of information technology and software, addressed below), and we must question whether we can achieve the level of confidence we demand, and whether previously well-established systems engineering approaches are still appropriate.

3.2. Modern Systems Complexity

In recent years there has been unprecedented progress in information and communications technologies, fundamentally changing the nature of the systems we engineer. Today things are very different from the complexity exhibited in early systems (see previous section). Information Technology developments and other sources of complexity, allow us to engineer very highly integrated systems (see Fig. 1b) that change the nature of the interactions between contributing parts; i.e., they offer developments at the system architecture level. Highly integrated systems exhibit more complex interactions across the system than earlier, simpler systems. In the highly integrated system, the designer must consider effects on all parts of the system. We are therefore engineering at the systems level more fundamentally than ever, as opposed to introducing subsystems into an evolved, well-precedented system structure.

Now the lateral influences and interactions are very strong and dominate the system behavior. This has been called "Dynamic Complexity" [Senge, 1990], and such systems have very different characteristics from Detail Complexity systems:

- Lateral influences dominate hierarchical relationships.
- Cause and effect are not obvious and direct.
- Small causes can have large effects.
- The implications of design decisions are much less predictable.
- Risks are dominated by system risks, with unforeseen emergent properties.
- Influences on, and implications of, decisions are much more difficult to bound and to establish.

In such a system, a change at almost any level may, because of the complexity of the integrated architecture, have system-wide impacts. As in the case of Detail Complexity described above, these characteristics of Dynamic Complexity relate directly to our ability to deal with the questions set out earlier (see Table II).

3.3. Complexity and "Normal Accidents"

In 1984 (and 1999) Charles Perrow reported on his analyses of the vulnerability of complex systems to what he termed "accidents" [Perrow, 1999]. In his work, which approached the problem from an organizational behavior perspective, Perrow (a sociologist and researcher in organizational behavior) categorized systems with respect to the nature of their interactions (from linear to "complex") and the nature of their coupling (from loose to tight). He concluded that systems which are tightly coupled and complex are inherently vulnerable to failure and that most attempts to make them safer or more reliable will, at best, fail to improve the situation and, at worst, make things even worse. We will continue to use the terminology we have described above, with Perrow's loosely coupled, linear systems being equivalent to what we have described as Detail Complexity and his tightly coupled, complex system being our Dynamic Complexity system.

Perrow [1999] concludes that systems exhibiting Dynamic Complexity will unavoidably fail when some, possibly totally unimagined set of circumstances arise. He suggests that we must get accustomed to the accompanying lack of confidence (hence the title of his book, *Normal Accidents*). As designers, we do not wish to accept this and ask: "Are there tools which might help us out of this impasse? Can we find some means of predicting and understanding this complexity and its implications and behavior so that we can achieve our current expectations of confidence?" These questions led the authors to consider the applicability of Complexity Science to the design of complex engineered systems.

Table II. Design Questions Related to Highly Integrated Systems

Question	How well understood?
1. What are our objectives?	Dynamic Complexity in itself does not make this more difficult, although the rapid development of technologies is encouraging other trends, such as the aspiration to produce "capability" rather than just "equipment" and these make the systems problem much more open-ended and difficult to establish and bound
2. What must our solution do?	as for question 1
3. What solution options may be appropriate?	There are now many more solution options available, not only because of technological developments in each individual engineering domain, but also, of particular importance at a system level, because these integrating IT and communications technologies enable a wide range of novel architectural options to be envisaged
4. What option is best?	This evaluation is much more difficult to conduct since the behaviors of the multitude of options are much less predictable and emerge from the systemic interactions both within the solution and between the solution and the wider environment
5. What constraints apply?	The range of potential constraints is much broader and varied given the multitude of options and hence they are more difficult to establish
6. What priorities are appropriate?	Priority judgments must be made with knowledge of the implications of decisions and these are much more difficult to establish in Dynamic Complexity systems
7. How will we know when we are done?	This too is much more difficult to establish since there is a much greater risk of un-envisaged emergent behaviors arising from the strong lateral interactions
8. How confident are we?	as for question 7, this is much more difficult to establish.

4. IMPLICATIONS FOR SYSTEMS ENGINEERING

The importance of system complexity and its implications on our ability to tackle the fundamental questions of engineering design for systems raises additional crucial questions for systems engineering, such as the following:

> When faced with increasing Dynamic Complexity how can we…

- Develop an acceptable level of confidence in the quality of our system?
- Achieve sufficient predictability in developing the system so as to enable meaningful costed and time-bounded, resourced plans to be formed?

The approach of "Traditional SE" works for Detail Complexity but is focused on a systematic approach rather than an understanding of the nature of systems themselves. What approach will permit us to deal with the kind of unpredictable emergent behaviors that Dynamic Complexity can introduce? Given the critical importance of complexity to the fundamental issues of SE, we need to be able to recognize, characterize, and ideally quantify the nature of the complexity applicable when we set out to tackle any given systems problem; i.e., we need to deal with such complexity in a predictable way.

We need to be able to know…

- When a systems problem, and/or its solution, is complex.
- How complex it is (in relation to other systems, as a minimum).
- How to manage the complexity to permit us to answer earlier questions, such as: When have we done enough? Is our confidence at an acceptable level?

Being able to characterize and manage the complexity in this way would enable us to ensure that our SE approach is appropriate to the situation in hand, presuming that we can establish an approach that confidently copes with Dynamic Complexity. In the extreme, if we cannot achieve an acceptable level of confidence, then the objectives of our SE program and the strategies employed within it may need to be made more conservative until an acceptable level of confidence is achievable.

5. UNDERSTANDING COMPLEXITY THEORY MORE FULLY

Going beyond the qualitative description of Detail and Dynamic Complexity as we have used them so far, we seek a quantitative approach to dealing with complexity. Recently, much has been discovered concerning Complexity Science or Complexity Theory, which attempts to understand the behavior of complex systems. If this can offer the quantified approach we seek, then it may permit us to better understand the nature of man-made complex engineered systems (CES) and give us tools for managing their design better. For an introductory overview of complexity science application to Systems Engineering, see Beckerman [2000].

In complex systems we cannot confidently predict the emergent behavior by examining the individual parts—behaviors occur which were not apparent from the analysis of the component parts and their summations. When Dynamic Complexity is present, cause and effect are not clearly related; failures can occur from unforeseen (and, perhaps, unforeseeable) causes. So, can we find some tools or insights from complexity science that will aid us in understanding complex engineered systems that exhibit Dynamic Complexity?

Since a system made up of "simple" pieces can exhibit complex behavior as an emergent property, we would like to understand what makes for complexity. A number of workers in Complexity Science, seeking to characterize complexity, have developed lists of features, of which at least some would be possessed by a complex system:

- Elements (and their number)
- Interactions (and their strength)
- Formation/Operation (and their time scales) Diversity; Variability
- Environment (and its demands)
- Activity(ies) [and its (their) objective(s)].

When observing natural systems, complexity theorists can identify, to some degree, which systems have these features. To apply Complexity Theory to engineered systems that we have not yet designed, can we predict these features within acceptable accuracy ranges? It is very important that we are able to make such predictions since what we want to do is to be able to plan our performance of the system design and development as well as to design with confidence in the ultimate performance of the system. Our whole approach to the project management and contractual environment in which systems are developed expects such confident predictions to be made (consider, for example, the placing of fixed price, fixed time system development contracts). Let us look at these features of complexity with engineered systems in mind.

Elements and their number. Estimating the number of elements in a system should be relatively straightforward for systems evolving within known architectures. This, of course, becomes much more challenging to predict with any confidence if the nature of the system architecture is unprecedented and has yet to be determined.

Interactions and their strength. Predicting the degree to which the interactions within the system under design will contribute to its complexity is a major impediment when the system may be expected to exhibit Dynamic Complexity. We should remember that a feature of Dynamic Complexity is that cause and effect relationships are not obvious, meaning, of course, that there are interactions present whose existence (much less their strength) we may be unable to identify. Identifying these effects in any predictive way is extremely difficult, and, in fact, as systems become more complex, it becomes increasingly difficult even in a retrospective way (i.e., by testing the end system) to judge the degree of confidence that we have achieved in a system's behavior. For example, how much testing is necessary in order to expose all the potential failure modes and situations of highly integrated complex systems?

Formation/Operation (and their time scales). This feature refers to the way the system is formed and operates and the scale of interest; e.g., are we interested in complexity "at the level of atoms or of cells or of organs"? (Note the biological system flavor.) At first it may appear that for the engineered systems of interest to us we can probably appropriately identify this feature. However, this remains problematic because in the presence of Dynamic Complexity critical interactions do not follow the system hierarchy. In other words, in an increasingly joined up world it becomes increasingly difficult to establish the influences on our systems engineering decisions. Further, how much confidence should SE claim that such decisions are robust (e.g., that we have not forgotten something critical)?

Diversity/Variability. As to Diversity/Variability, most of the complex systems observed by Complexity Theorists tend to have limited diversity and variability across the system (e.g., birds in a flock, grains of sand in a pile, or trees in a forest). We cannot say this for most CESs, where the nature of system components can vary greatly through the system and where the diversity of kinds of components can be very large. This diversity is increasing in modern systems as more technology options are developed and offer design choices to be incorporated into systems and, as we integrate even more widely, producing systems of systems.

Environment (and its demands). Trends in the environment affecting the design of complex engineered systems are increasing the range and complexity of influences that must be addressed in our systems engineering decisions, if we are to meet the expectations of stakeholders. These expectations are becoming broader and more stringent and form such an integrated "open ended" problem that this area, too, may be difficult to understand with a degree of confidence that can be quantified. Some of the changes in the environment causing this are: the reasonable increasing desire for the success of our engineered systems to be judged on the "benefits" they deliver in the real world, rather than the "features" they contain; the increasing focus on through-life costs; and the growing need for systems under design to fit well with other systems into "systems of systems."

Activity(ies) [and its (their) objective(s)]. The complexity of our design task is significantly affected by the nature of the objectives for the systems to be designed. Is the task intricate, or difficult? Highly constrained or not? Modern systems are often designed to (and sometimes expected to, without having been explicitly designed to) function in multiple roles, involving multiple activities. This adaptability and versatility becomes increasingly desirable in a situation where the rate of change is accelerating.

This discussion causes us to conclude that, in the development of CESs, understanding these six characteristics of complex systems is likely to be present us with a major challenge and, further, is significantly more difficult for modern CESs than it was in the past for less complex, precedented, engineered systems. Also, engineering a complex system with confidence is in many ways even more challenging than observing the complexity of natural systems.

Nevertheless, it would be extremely useful if we could gain insights from Complexity Theory that help us to understand the characteristics of the CESs that we deal with and, crucially, that we expect to be able to predict with confidence. In our continuing search for tools or insights from Complexity Theory, which may assist us in developing complex engineered systems, we recall that complexity science tells us (among other things) that:

- Systems made up of simple parts, following simple laws, can give rise to complex systems behavior, called emergent complexity. Parts governed by simple local laws can produce global complexity at the system level. Behavior of the system cannot be inferred from the behavior of the components [Bar-Yam, 1992].

- Much of complexity science has grown from the observation of natural systems such as earthquakes, avalanches, forest fires, and biological populations. For example, dropping grains of sand on a table, one grain at a time, will eventually produce a sand pile which exhibits complex behavior where the addition of a grain of sand causes an avalanche on one part of the pile. There is no "typical" size for avalanches—they range from a few grains to much of the pile [Buchanan, 2000].
- Plotting the sizes of avalanches (or earthquakes or forest fires) against their frequency of occurrence, produces a power-law distribution as in Figure 2. For instance, avalanches of size *X* might be 4 times as common as those of size 2*X*. While the power-law distribution appears in many kinds of natural systems, the actual power varies across kinds of systems.

All the systems mentioned in this discussion of complexity science are natural systems whose behavior has been observed, and observers of complexity employ a number of tools to further their understanding of these observed systems. Further study of complexity will reveal additional points, such as the existence of fine-scale and large-scale effects (fractal behavior), multiple steady states in complex systems, and others [Bar-Yam, 2000]. The question of interest to us as engineering designers is whether relationships seen in these natural systems apply to man-made engineered systems. If the relationships apply—if, for instance, occurrences such as failures in complex engineered systems obey a power-law distribution of some sort—can this knowledge assist us in understanding their behavior or in carrying out their design? The expectation that CESs might follow a power law, as observed natural systems do, would provide us with a powerful design insight. In the next section we shall use this Power Law feature as an example of the insight gained by complexity theorists as we pursue the potential for such work to help us with the engineering design challenge for modern, complex systems.

6. APPLICABILITY OF POWER-LAW RELATIONSHIPS TO ENGINEERED SYSTEMS?

While some useful conclusions have resulted from the observation of natural systems (power-law relationships; local simplicity leading to global complexity), can we expect this behavior to extend to CESs?

The engineered system, which we suspect is complex enough to cause us to concern ourselves with its complexity, will not, generally, exhibit uniformity of local behavior across the entire system. Some aspects of the CES will be dominated by mechanical interactions, others by electrical and others by human influences. The system is not likely to consist of a large number of elements each of which operates in local conditions that are similar to the local conditions of other elements. Hence, we are forced to conclude that a basic element of systems exhibiting the kind of complex behavior that has been observed in the natural systems mentioned above is absent in CESs. They do not exhibit uniformity of local laws of behavior across

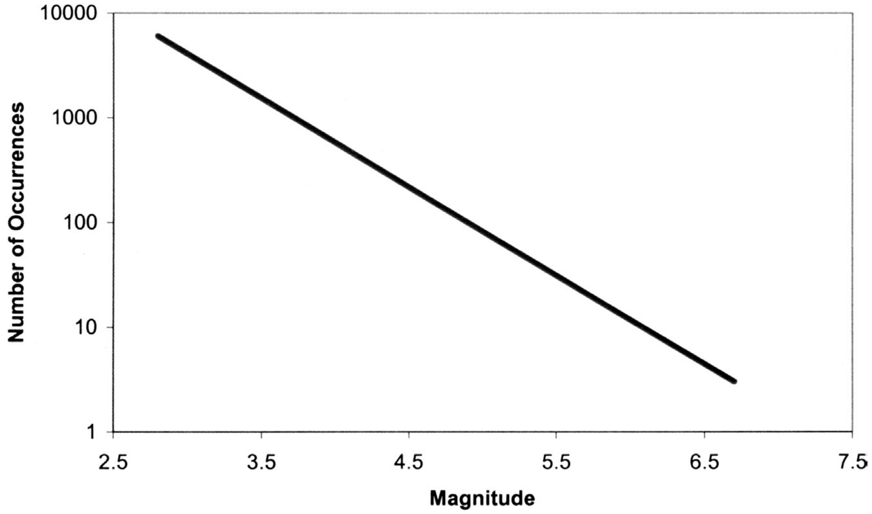

Figure 2. Earthquake magnitude vs. number of occurrences, southern California, 1987–1996 [Buchanan, 2000].

the system (at least not when viewed in traditional component engineering terms).

Can we view a CES at a level where uniformity of local laws may emerge, permitting us to hope we might employ the power law and other complexity tools and insights? We propose further examination of this question. For instance, might the diverse components of a complex system, components that are mechanical, electronic, hydraulic, human, and so on, be abstracted to a higher level where, independent of their physical nature, all can be viewed as "actuators," "transmitters," "receptors," or other terminology? At this level, might the system have the "uniformity of local laws across the system," which is a hallmark of natural complex systems? If we can define and work at this level, further exploration of the applicabiltiy of complexity science insights to our engineered systems may be fruitful. In such a case, the power law, which has intrigued us as a potentially very useful insight, may well become applicable.

If that were to occur, though, could the power-law relationship seen in nature provide us with a design tool? Even in the study of natural systems, the power law does not have predictive power; we cannot say anything about the size of the *next* landslide. But we might gain a useful engineering design tool if we could determine that such a law, for instance, related the severity of a fault to its likelihood of occurrence—we could at least infer a gross characteristic of system behavior.

A further complication is the fact that in observed natural systems behaving in a complex way, the power-law relationship exists between the magnitude or size of a kind of event and the frequency of occurrence of events of that magnitude. In a CES it is not at all clear what would substitute for "magnitude." If, as assumed above, we tried to use "severity" of a fault as an indicator of "magnitude" and related it to frequency of a fault, how will we measure and compare "severity"? And can we compare faults arising from vastly different kinds of behaviors? (In natural systems, no matter the size of the forest fire, earthquake, or landslide, it will have resulted from the few simple local laws at work homogeneously across the system.) We find ourselves realizing, then, that even if we can successfully abstract CESs to the point where uniformity of local behavior may be expected to permit a power law to apply, we must still determine how the concepts of "magnitude" and "frequency" will apply to our human-designed system.

We note that complexity science has been used, with some success, in observing biological organisms which, like CESs, do not possess system-wide homogeneity of local laws (eyes are physically very different from fingers). A common approach used to achieve successful application of typical behavioral complexity is to consider only the cells of the nervous system as components of the system, on the reasonable assumption that the nervous system plays the predominant part in determining behavior [Bar-Yam, 1992: 771, 772]. There may be promise in exploring the idea that some CESs may possess a "nervous system analogy." It is interesting to speculate that in our CES this role might be played by software or IT systems; however, in a CES, we cannot assume the hardware to be reliable and a noncontributor to failure events of interest as we might do with bones in a biological organism.

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Modern systems challenge our ability to successfully design them with desired degrees of dependability and confidence in that dependability. Much has been learned in recent years in the fields of Complexity Science/Theory, and we consider application of this knowledge to systems engineering and engineering design to be a field ripe for further research.

We see a number of areas worthy of further study:

- It would be useful to have techniques which would allow us to develop quantifiable (at least in a relative sense) descriptions of the degree to which engineered systems reflect the features found in observed natural systems, as enumerated and discussed in Section 5, above.
- Can we describe complex engineered systems with a degree of abstraction which allows local laws to apply uniformly across the system, giving us the basis for applying additional tools and insights from complexity theory (such as fine and large scale similarity, description of system global complexity using automata, etc.)?
- If we can describe engineered systems in a way analogous to natural systems (global complexity emerging from local simplicity, for example), can we identify the parameters which obey the kind of power-law relationship we find in natural systems?
- What will take the place of "magnitude" in our attempts to discern a power-law relationship? Can "magnitude" be a surrogate for "severity" of a fault, with "frequency" then becoming the frequency of occurrence of faults of given magnitudes?
- And if such a relationship can be seen to emerge from our abstracted complex engineered system, how can we use it to assist us in improving our

confidence in the reliability and robustness of the systems we design?

The authors look forward to the investigation of these and other aspects of Complexity Theory as it may apply to the engineering design of complex systems.

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