The Systems Approach to Engineering Problems

I. Introduction

A. Attitude rather than plan

B. Complexity of present engineering projects

1. SAGE system

C. Two methods of attack in past

~~1. Good tools, but better organization of design task is needed~~

D. Need for systems engineering felt among defense systems designers

E. Question: Can a method be devised that will facilitate system design?

E. Outline of discussion
1. Definition of system
2. Comparison of scientific method applied to natural systems and to design of complex artificial systems.

II. Primary definition: "An assemblage of objects united by some form of regular interaction or interdependence; an organic or organized whole." Biological use, common purpose: "Those organs collectively which contribute toward one of the more important and complex vital functions; as, the alimentary or nervous system". Combination fits our requirements: " A system is an assemblage of objects united by some form of regular interaction or interdependence, which collectively contributes toward an important and complex function.

A. Size of system relative to observer and resources
1. Systems exceed resources in biological, psychological, social, and economic worlds.
2. Neurons - 10^{10}; artificial automata - 10^3 to 10^6.
3. Two kinds - natural and synthetic.

III. Task of the engineer--assemble new systems that have useful function
A. Process and control
B. Increase in information--more mechanical data processing
C. Human operator integral part of purposeful system.
D. Design is biomechanical problem.
E. Air-frame industry and man-machine system.

IV. Current practice
A. Improve old system to obtain new one--retain atavisms
B. Growth around new technique or equipment.
1. May compromise potential of new component or components used for construction in lab may not be operational.

V. The task of the scientist--understand natural world.
   A. Predicts outcome of new interactions.
   B. Constructs analagous system to demonstrate understanding, and account for a natural phenomenon.

VI. Similarity in tasks. Each step in scientific method has a counterpart in system design.

TWO.

I. The scientific method
   A. 1. Scientist's awareness and statement of problem
      2. Hypothesis
      3. Outcome demonstrates hypothesis
      4. If demonstrated often enough, without exception, it is a highly probable explanation.

   B. Each step in scientific method corresponds to an operation in system design.
      1. Someone must appreciate the need for a system.
      2. Requirement must be stated with clarity to designer.
      3. Designer formulates the system.
      4. Demonstrated only by putting it to practice and conducting a well controlled evaluation.

   C. Science recognizes three levels of abstraction
      1. Most concrete is comprised of measurable, or observable real world events.
      2. Empirical level--observations and measurements of real events.
      3. Theoretical level--uses surrogates for events and arranges in new interactions, leading to new unobserved events.
         a. Symbolic logic
         b. Fitting natural systems to formulas
         c. Some are known already for systems use--mechanical, chemical, electrical formulas.
         d. Biological systems and human behavior present difficulties.

      4. Empiricism uses careful observation and experiment.
         a. Original observation
         b. measurement of events
         c. Test by observation or experiment

THREE The Systems Approach

1. Interrelation of components and human operators is theoretical, as is reduction of model to blueprint stage.
2. The equipment and operators that match the blueprints are the events of the real world. Also personnel schedules.
3. Identification of technical and professional people.
   A. OR people usually first to realize need for new system.
   B. Theoretical work usually done by OR
   C. Results of OR theory are reduced to blueprints by engineers and draftsmen, or selection and training schedules by personnel men.

4. Evaluation of engineering, operations, and effectiveness.
   A. Engineering verifies that physical components meet specs.
   B. Operations test establishes that it will work in the field.
   C. Effectiveness determines whether or not the system meets the original requirement.

5. Useful System Theories.
   A. Search theory-optimum procedure for intercepting objects when time of arrival, number, speed, dispersion and other characteristics are not precisely known.
   B. Game theory prescribes the optimum strategies to be adopted by competing systems.
   C. Information theory is much more restricted in its usefulness than its popularity would suggest. It is confined to the design and use of communication channels.
   D. The theory of servomechanisms led to the development of control engineering. It is based on the principle that information about the actual output of a process can be fed back and compared with the ordered output, the result being used to regulate the process in the desired direction.

   E. Linear and dynamic programming are computational techniques for optimizing a multistage process or for maximizing or minimizing some characteristic of the output of the final stage. High-speed computers make the maximum use of these techniques.
   F. Decision theory is a method of choosing between alternatives when an acceptable risk level has been established.

6. Level of system analysis
   A. Some models are suited to description of very complex systems, while others deal more specifically with smaller systems or subsystems. Statistical models derived from probability theory are more appropriate to the description of large and complex systems capable of many states, while determinate analytical methods are more suited to smaller systems.

7. Theories described offer guides for the design of physical components in a man-machine system, optimum solutions according to formal theory.
   A. Cannot be used to represent human reactions since they do not necessarily represent the way in which human operators would intuitively accomplish the same tasks.
   B. Theories exist which attempt to describe the natural performance of the human operator. But they are only reliable for the simplest "reflex" kinds of behavior, and then only give average behavior to be expected.

8. Empirical aids to theoretical solutions. Computer simulation and gaming.
   A. Computers
   B. Under conditions not so simple or repetitive, human judgement cannot be averaged reliably. The decision-making function of the human must be part of the analysis. Gaming is accomplished by adding the human operator. War gaming has been used since the Prussians evolved the technique from military chess. Gaming can uncover weaknesses and

strengths of certain forces. It is most important in analysis when the problem involves complex decisions and human judgement. As an analytical device, gaming lies between the uncontrolled observations of actual operations and a rigorous mathematical analysis.

FOUR Experimental System Evaluation

A. After shop and field testing of components, the system must be evaluated against a criterion of operational effectiveness derived from the original system requirements. An attributeof the experimental method is that of objectivity. The evaluation should be based on the system's demonstrated merits, not solely on expert opinion.

B. Predicting front-line performance
   1. Should have operators who will be in the field.
   2. Candidates who do <u>not</u> qualify are engineers who designed the system.
   3. Not usually possible to anticipate all situations, so a representative sample must be constructed for problem.
   4. A statistical treatment must be made and data boiled down to a few useful numbers expressed in terms of the original performance criteria.

C. Laboratory systems Evaluation.

   1. Sometimes reliable evaluations are not easy to obtain in the field. True particularly for large defense systems. Cost may be too high. Pleasure craft in sub test area.
   2. One answer to these practical difficulties is to conduct the evaluation in the laboratory, using simulated inputs. It is much easier to exclude extraneous factors in the laboratory and to achieve some sort of statistical reliability.