Re-evaluating Systems Engineering Concepts Using Systems Thinking

A. Terry Bahill, *Fellow, IEEE*, and Bruce Gissing

***Abstract*—Humans (individually, on teams, and in organizations) can follow simple processes to increase their probability of success. Many authors, both technical and nontechnical, have described processes for doing various things like designing a system, attaining business excellence, and solving personal and professional problems. The amazing similarities in these diverse processes suggest that there is a general process that might be closely related to human thinking. This general process was abstracted into the SIMILAR Process. This paper shows how the SIMILAR Process was used to help redescribe the Requirements Discovery Process and System Design Process.**

***Index Terms*—Design methodology, human thinking, modeling, problem solving, process description, requirements, standards, systems engineering.**

I. Many Disciplines Use a SIMILAR Process

SYSTEMS engineering is a grand unified theory for making things work better. Systems engineering has been in the domain of the technical community. But now we see nontechnical practitioners using systems thinking. According to Senge [21], "systems thinking is a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, for seeing patterns of change rather than static 'snapshots'." In essence, what we see is structured steps that give the individual the ability to walk a path toward a vision, whether it be the design of a Boeing 777 commercial airplane or the ability by Lands End to fill orders in 24 h. The path is not straight, nor is it absent of obstacles. The beauty of systems thinking is that it forces the individual to gather all possible processes and interrelationships into an organized structure. Where did the root of systems thinking come from? Or, have we always been doing it, using different names?

Two decades ago Wymore [25] said systems engineers should use interdisciplinary teams to state the problem, identify the system's functions and requirements, define performance and cost figures of merit, investigate alternative designs, and test the system. He said this process is recursive, iterative, and much of it is done in parallel. He, in essence, reinvented the Shewhart Cycle [22]: Plan-Do-Check-Act.

In the 1950's, Deming [9] used the Shewhart Cycle to revolutionize Japanese manufacturing. Welch reengineered General Electric using a similar process [24]. In 1993, Arizona passed a law that said all state agencies had to use such a process. This systems thinking is the Fifth Discipline according to Senge *et al.* [20]. Covey's *7 Habits of Highly Effective People* [10] applies this process to individual people, and Katzenbach and Smith [16] apply it to teams.

Evidently this process is such a natural endeavor that it is being reinvented over and over again in many different fields. The purposes might be different (e.g., design a system, reengineer business processes, explain why teams outperform individuals, manage a learning organization, do strategic planning, discover system requirements, or discover new knowledge), but the process seems to be the same. Bahill and Gissing [6] compared several of these processes and extracted the similarities in them. They called their abstraction the SIMILAR Process. The basis of the SIMILAR Process is presented in the Appendix. It explains over a dozen well-known processes from diverse fields of human endeavor and shows that they can be mapped to the SIMILAR Process. This mapping works well because the SIMILAR Process describes a logically consistent and effective means of planning and problem solving. The fact that so many authors describe the process suggests that humans have a tendency to act in a disorganized way and need to be continually reminded about effective reasoning.

This paper first explains the SIMILAR Process. Then, in the Appendix, it shows the development of the SIMILAR Process. Next, it uses the SIMILAR Process to improve the description of the Requirements Discovery Process and then the System Design Process. Finally, it shows how to customize the System Design Process so that it can be used in different phases of the system life cycle.

II. SIMILAR Process

Humans (individually, on teams, and in organizations) employ simple processes to increase their probability of success. Many authors, both technical and nontechnical, have described these processes, and their descriptions are similar. There is a common root that can be generalized as **S**tate the problem, **I**nvestigate alternatives, **M**odel the system, **I**ntegrate, **L**aunch the system, **A**ssess performance, and **R**e-evaluate. These seven functions can be summarized with the acronym SIMILAR: **S**tate, **I**nvestigate, **M**odel, **I**ntegrate, **L**aunch, **A**ssess, and **R**e-evaluate.

State the Problem. In an engineering environment, the problem statement starts with a description of the top-level function that the system must perform or the deficiency that

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must be ameliorated. This problem statement must include all of the requirements that the system must satisfy. The problem statement should be in terms of *what* must be done, not *how* to do it. It might be composed in words or as a model. Inputs come from end users, operators, bill payers, owners, regulatory agencies, victims, sponsors, marketing, manufacturing, etc.

In a modern business environment, the problem statement starts with a reason for change followed by vision and mission statements for the company. In subsequent phases, goals are written to ensure that the vision/mission will be accomplished. Strategies are developed for each of the goals. Finally, key initiatives are identified to implement the strategies.

Investigate Alternatives. In an engineering environment, alternative designs are evaluated based on performance and cost figures of merit. No design is likely to be best on all figures of merit, so multicriteria decision-aiding techniques should be used to reveal the preferred alternatives. This analysis should be redone whenever more data are available. For example, figures of merit should be computed initially based on estimates by the design engineers. Then models should be constructed and evaluated. Next simulation data should be derived. Subsequently, prototypes should be measured and finally tests should be run on the real system. For the design of complex systems, alternative designs reduce project risk. Investigating bizarre alternatives helps clarify the problem statement.

Sometimes investigating alternatives means evaluating many alternatives in parallel and choosing the best. And sometimes it means successively revising various aspects of one plan of action until it satisfies the need.

In the business environment, alternatives are considered when we run models, acquire data, check perception, and analyze the *what is*. At the same time, strategies are brainstormed to determine the optimum route to the goal state.

Model the System. In an engineering environment, models will be developed for most alternative designs. The model for the preferred alternative will be expanded and used to help manage the system throughout its entire lifecycle. Many types of system models are used, such as physical analogs, analytic equations, state machines, block diagrams, flow diagrams, object-oriented models, mental models, and computer simulations. Running these models clarifies requirements, reveals bottlenecks and fragmented activities, reduces cost, and exposes duplication of efforts.

In the business environment, models and simulations are run to analyze the process and find the *as is* and, through analysis, determine the *to be*.

Integrate. No man is an island. Systems, businesses, and people must be integrated so that they interact with one another. Integration means bringing things together so they work as a whole. Interfaces between subsystems must be designed. Subsystems should be defined along natural boundaries. Subsystems should be defined to minimize the amount of information to be exchanged between the subsystems. Well-designed subsystems send finished products to other subsystems. Feedback loops around individual subsystems are easier to manage than feedback loops around interconnected subsystems.

The most difficult problem in the business environment is assuring that all activities are totally integrated under a common direction or business plan that supports the vision/mission and goals. The business plan provides the resources (people, money, and facilities) to support the direction of the company. The natural result is that everyone is working together in the same direction. Business plans evolve iteratively using feedback, checks, and balances.

Launch the System. Launching the system means running the system and producing outputs. Engineers produce designs for the product and the process to make it. In a manufacturing environment, this might mean buying commercial off-the-shelf hardware or software or it might mean actually making things, e.g., bending metal. In the business environment, launching the systems means the business plan is decomposed into tasks and actions and is deployed throughout the company. Launching the system means doing what the system was intended to do.

Assess Performance. Figures of merit, technical performance measures, and metrics are all used to assess performance. Figures of merit (sometimes called measures of effectiveness) are used to quantify requirements. Technical performance measures are used to mitigate risk during design and manufacturing. Metrics are used to help manage a company's processes. Measurement is the key. If you cannot measure it, you cannot control it. If you cannot control it, you cannot improve it [18].

In the business environment, metrics or measures are a key element of the process. The measures tie back to the short- or long-term goals of the company. Each measure must be quantifiable. There are many methods of oversight to monitor progress.

Re-Evaluate. Re-evaluation is arguably the most important of these functions. For a century, engineers have used feedback to control systems and improve performance. It is one of the most fundamental engineering tools. Re-evaluation should be a continual process with many parallel loops.

In the business environment, people step back and re-evaluate the performance achieved. Several options are considered: continue as is, make minor modifications, rework the entire project, or discontinue the project.

Re-evaluate means observing outputs and using this information to modify the system input, the product, or the process.

Fig. 1 summarizes the SIMILAR Process. This figure clearly shows the distributed nature of the re-evaluate function in the feedback loops. However, all of these loops will not always be used. The loops that are used depend on the particular situation. The reader may want to read all or parts of the Appendix at this time.

III. Application of the SIMILAR Process

We suggest that someone describing a process should try to map his or her description to the SIMILAR Process. As an example, let us apply the SIMILAR Process first to the Requirements Discovery Process and then to the System Design Process.

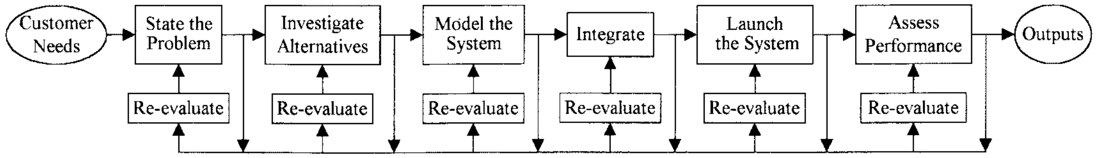

Fig. 1. SIMILAR Process.

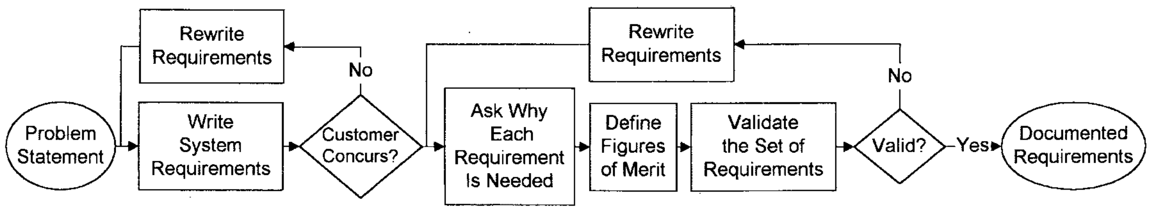

Fig. 2. New Requirements Discovery Process.

TABLE I

The SIMILAR Process	The Old Requirements Discovery Process (Bahill and Dean, 1997)
State the Problem	Identify Customers and Stakeholders, Understand the Customer's Needs, Define and State the Problem
Investigate Alternatives	Ask Why
Model the System	Define Figures of Merit
Integrate	Validate System Requirements
Launch the System	Write System Requirements
Assess Performance	Review Requirements with Customer, Review System Requirements
	Describe Verification Process, Define Technical Performance Measures, Mitigate Risk
Re-evaluate	

No two systems are exactly alike in their requirements. However, there is a uniform and identifiable process for logically discovering the system requirements, regardless of system purpose, size, or complexity. Bahill and Dean [5] have described this Requirements Discovery Process. This description evolved over a three-year period, with contributions from hundreds of systems engineers. Table I shows how this Requirements Discovery Process maps to the SIMILAR Process. The right column contains the major section headings of this paper.

Validating system requirements means bringing all requirements together to see if they are consistent and complete. So it rightfully maps to integration. The *ask why* section exhorts engineers to ask why each requirement is needed. The purpose is to help eliminate unneeded requirements and reveal the true requirements. Thus, it is a step in evaluating alternative requirements. Therefore, it is mapped to the investigate alternatives function of the SIMILAR Process.

However, this mapping shows fragmented, missing, and extraneous functions. The functions *Identify Customers and Stakeholders, Understand the Customer's Needs,* and *Define and State the Problem* are fragmented (or decomposed). They should be combined into one function, *State the Problem*. The two sections dealing with reviews should be combined into one. The *Re-evaluate* function is missing in Table I. This function was in the original document [5], but it was buried. The functions *Describe Verification, Define Technical Performance Measures*, and *Mitigate Risk* certainly are related to requirements, but they are extraneous to the Requirements Discovery Process. The Requirements Discovery Process is supposed to be a box that fits into the System Design Process of Fig. 3; these extraneous functions do not fit into that figure. Part of the problem with Table I was that the process being described was not explicitly stated. Most of the functions in Table I concerned discovering requirements. But the extraneous functions involved *using* (not discovering) requirements.

Using these results, a New Requirements Discovery Process was derived from the original paper, omitting extraneous functions and extracting functions that were obscured in the original. This new process is shown in Fig. 2. To help with validation, this New Requirements Discovery Process will be mapped to the SIMILAR Process, as shown in Table II.

We think the New Requirements Discovery Process of Fig. 2 and Table II is more understandable than the old one. Applying the SIMILAR Process has added value.

The System Design Process shown in Fig. 3 represents a consensus of dozens of senior systems engineers developed over a three-year period [3]. Table III maps this System Design Process to the SIMILAR Process.

Mapping this Old System Design Process to the SIMILAR Process points out that it had fragmented functions and missing functions. The functions *State the Problem, Discover Requirements,* and *Write Behavioral Scenarios* should be combined into one function called *Discover Requirements*. The *Integrate* and *Re-evaluate* functions seem to be missing. Let us now try to ameliorate these deficiencies.

One of the first and most important steps in applying the SIMILAR Process is identifying precisely the process to be described. In this example, we want to describe the System Design Process specifically for the preliminary design phase. The resulting New System Design Process is shown in Fig. 4. We think the New System Design Process of Fig. 4 is easier to explain and understand than the old one in Fig. 3.

Some people, particularly those raised with MIL-STD-499A, think the first job of systems engineering is stating the functions that the system must perform to satisfy its purpose. Other people, particularly those with extensive

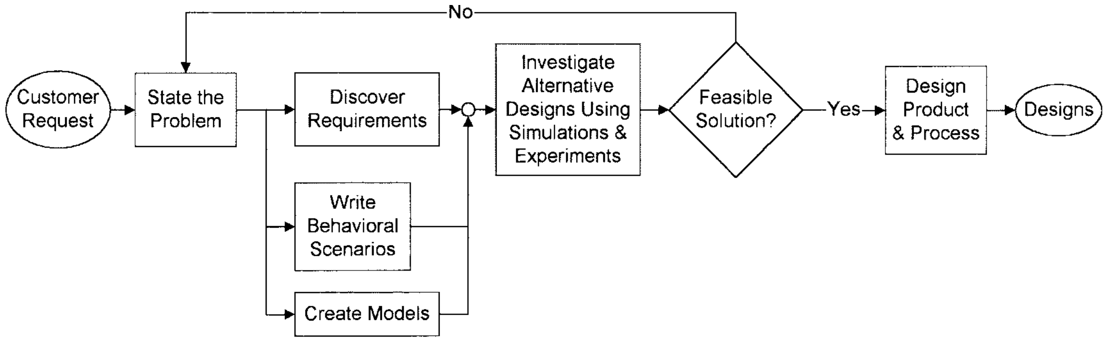

Fig. 3. System Design Process from [3].

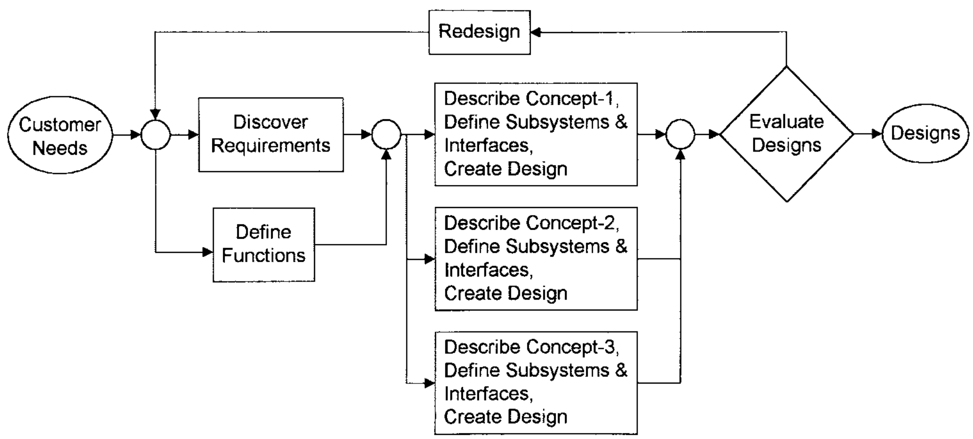

Fig. 4. New System Design Process tailored for the preliminary design phase.

TABLE II

The SIMILAR Process	The New Requirements Discovery Process
State the Problem	Define and State the Problem
Investigate Alternatives	Ask Why Each Requirement is Needed
Model the System	Define Figures of Merit
Integrate	Validate the Set of System Requirements
Launch the System	Write System Requirements
Assess Performance	Check Validity of Requirements, Review Requirements with customer
Re-evaluate	Rewrite requirements

TABLE III

The SIMILAR Process	The Old System Design Process (Bahill, Bentz and Dean)
State the Problem	State the Problem, Discover Requirements, Write Behavioral Scenarios,
Investigate Alternatives	Investigate Alternative Designs Using Simulations & Experiments
Model the System	Create Models
Integrate	
Launch the System	Design Product & Process
Assess Performance	Question Feasible Solution
Re-evaluate	

management or business experience, think the requirements must be discovered first; then the functions can be stated. Fig. 4 shows it as a parallel and iterative process. First look at system requirements, then at system functions. Then reexamine the requirements and functions. Then reassess the requirements, functions, etc. Finding the system's functions helps identify the system's requirements. Investigating alternatives also helps requirements discovery. Of course, more than three alternatives will usually be investigated. Fig. 4 shows three alternatives to emphasize that alternative concepts can be investigated in parallel. To help validate this New System Design Process let us map it to the SIMILAR Process, as shown in Table IV.

TABLE IV

The SIMILAR Process	The New System Design Process
State the Problem	Discover Requirements
Investigate Alternatives	Describe Alternative Concepts
Model the System	Define Functions
Integrate	Define Subsystems & Interfaces
Launch the System	Create Designs
Assess Performance	Evaluate Designs
Re-evaluate	Redesign

It is important to note that processes mapped to the SIMILAR Process will not maintain their temporal sequencing. The right columns of these tables do not have time running from top to bottom. Time sequencing varies for different processes. Indeed, although Fig. 1 implies a serial process, in most cases, many functions will be done in parallel.

After Bahill, who was the principle architect of the Requirements Discovery Process of Table I and of the System Design Process of Fig. 3, completed his work, he initiated further study in the processes that comprise the design phase. Based on study and the development of the SIMILAR Process, Figs. 2 and 4 were produced, which provides vast improvements.

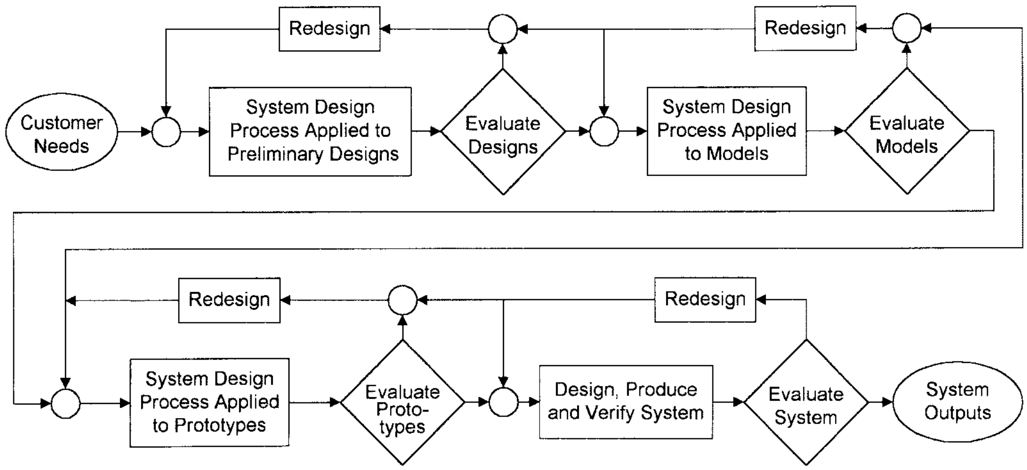

Fig. 5. Design portion of the Systems Engineering Process.

Now that we have a System Design Process, we will have to customize it to apply it in the various phases of the system lifecycle.

The Systems Engineering Process has a vertical hierarchy. It is applied at levels of greater and greater detail: it is applied to the system, then to the subsystems, then to the components, etc. It is applied to the system being designed and to the enterprise in which the system will operate. It is also applied horizontally. It is applied to alternative-1, then to alternative-2, then to alternative-3, etc. It is applied to component-1, component-2, component-3, etc. This process is hierarchical, repetitive, recursive, iterative, and much of it is done in parallel.

The fact that the Requirements Discovery Process (Fig. 2) is a subprocess in the System Design Process (Fig. 4) and that the System Design Process is a subprocess in the Systems Engineering Process of Fig. 5 illustrates the hierarchical nature of system engineering (see also [7]). We will now try to explain the repetitive aspect of the System Engineering Process. In Fig. 5, the System Design Process is applied to preliminary designs, models, prototypes and to the real system. However, this process is not serial. Each of the loops will be executed many times. Execution of the redesign loop in the upper left is very inexpensive and should be exercised often. Execution of the redesign loop in the lower right is expensive, but should be exercised when necessary. Whereas, execution of the redesign loop from the lower right all the way back to the upper left is *very* expensive and should seldom be exercised. This just restates the principle of concurrent engineering and integrated product development teams: doing a through job early in the design process reduces the amount of change in the production phase, which improves cost and quality.

Fig. 5, of course, only shows a part of the Systems Engineering Process. It omits purchasing, manufacturing, logistics, maintenance, risk management, reliability, project management, documentation, etc. [4]. Fig. 5 also omits the important feedback loop from system outputs back to the customer needs. And we all know that educating the customer is a very important task of systems engineering.

Although it seems that the Systems Design Process has been applied like a cookie cutter to preliminary designs, models, prototypes, and the real system, the emphasis should be different in each application. In the preliminary design phase, the emphasis should be on discovering requirements and defining functions, with some effort devoted to alternatives and interfaces. In the modeling phase, the emphasis should be on alternatives, interfaces, and designs, with some effort devoted to rewriting requirements and redefining functions. In the prototype phase, the emphasis should be on evaluating the prototypes. Finally, when applied to the real system, the emphasis should be on evaluation. Fig. 6 shows where each function is emphasized.

IV. Assessment and Re-Evaluation

This paper has made three major contributions. First, there is something about human reasoning that has caused many authors, both technical and nontechnical, to propose processes that have strong fundamental similarities. These similarities have been encapsulated with the SIMILAR Process of Fig. 1. Second, using the SIMILAR Process can help eliminate redundant or extraneous functions and help ensure inclusion of necessary functions, as can be seen by comparing the Old Requirements Discovery Process (Table I) to the New Requirements Discovery Process (Fig. 2 and Table II) and the Old System Design Process (Fig. 3 and Table III) to the New System Design Process (Fig. 4 and Table IV). Third, there is a process for doing systems engineering. It is repetitive, there are multiple feedback loops, and many things are done in parallel, as is suggested in Figs. 2, 4, and 5. For two years this paper was continually re-evaluated and improved. The processes it was applied to (e.g., the Requirements Discovery Process and the System Design Process) were re-evaluated many times. This re-evaluation is a very natural function.

Appendix
Alternatives to the Similar Process

In order to test or verify the SIMILAR Process, we will now map it to many other engineering, business, and personal

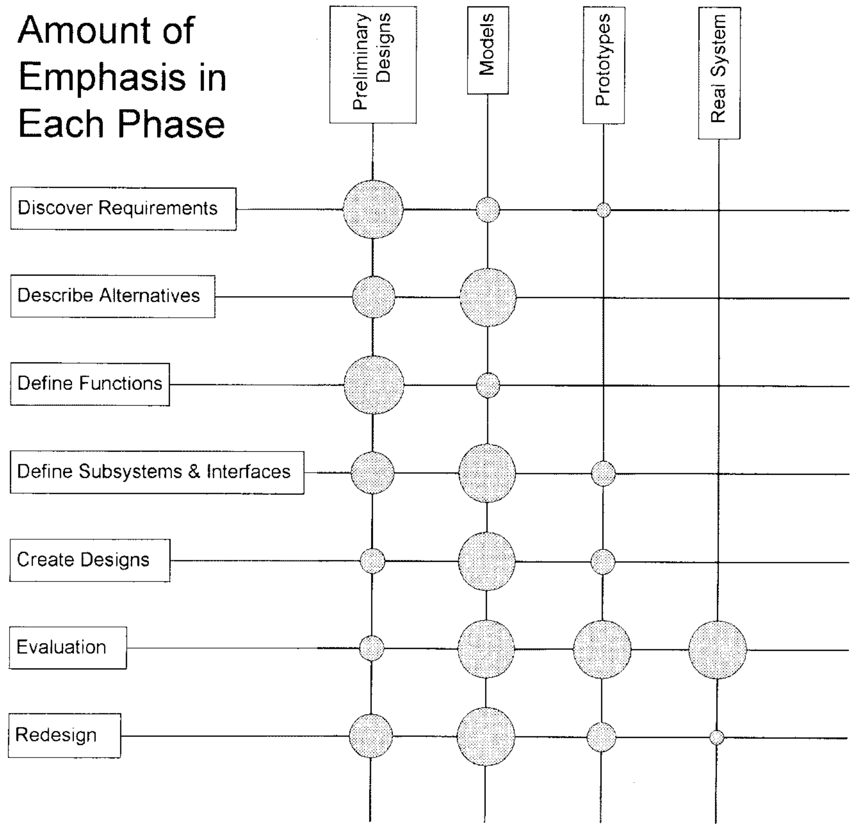

Fig. 6. Functions of the System Design Process in the phases of the system lifecycle. The size of the circle suggests the level of effort.

processes. We drew examples from many fields of endeavor to show the broad applicability of the SIMILAR Process. In these mappings, we used the words and format used in the original books and papers. Sometimes these words made the mappings obvious. However, at other times, these words made the mappings difficult because different people use words differently. In all cases, our mappings were based on our interpretation of the original authors' intentions.

A. Systems Engineering Consensus

Systems engineering is an interdisciplinary process that ensures that the customer's needs are satisfied throughout a system's entire lifecycle. Bahill and Dean [4] developed a consensus of hundreds of senior engineers about what systems engineering is. They summarized it with 22 subprocesses. We think these subprocesses are self-explanatory. Therefore, we will not repeat their explanations here: we merely list them in the right column of Table V, which maps the Systems Engineering Consensus to The SIMILAR Process.

For the last entry in this table, we used the words Improve Quality from the original paper, rather than their paragraph title of Total Quality Management, because we thought Improve Quality captured the intent of that paragraph better.

It is important to note that processes mapped to the SIMILAR Process will not maintain the temporal sequencing of their functions. The right column of Table V does not have time running from top to bottom. Time sequencing varies for different processes. Indeed, many functions will often be performed concurrently. We place this note after the Systems Engineering Consensus because it is so obvious here. However, the note applies to all processes that we map to the SIMILAR Process.

TABLE V

The SIMILAR Process	**The Systems Engineering Consensus** (Bahill and Dean, 1996)
State the Problem	Understanding customer needs, Stating the problem, Discovering system requirements, Validating requirements
Investigate Alternatives	Defining performance & cost figures of merit, Exploring alternative concepts, Sensitivity analyses
Model the System	Functional decomposition, System modeling, System design, Risk management, Reliability analysis
Integrate	Designing and managing interfaces, System integration
Launch the System	Configuration management, Project management, Documentation
Assess Performance	Prescribing tests, Conducting design reviews, Total system test
Re-evaluate	Improve quality

In the rest of this appendix, each mapping will have less description. We are trying to provide a gestalt that shows the great commonality of a large number of processes.

B. Design Process

One part of systems engineering is design. Table VI maps the Design Process of [7] to the SIMILAR Process.

TABLE VI

The SIMILAR Process	The Design Process (Braha and Maimon)
State the Problem	Need Assessment
Investigate Alternatives	Analysis
Model the System	Decomposition
Integrate	Synthesis
Launch the System	
Assess Performance	Testing, Evaluation
Re-evaluate	Design Adequacy, Design Improvement

TABLE VII

The SIMILAR Process	The System Life Cycle (Wymore, 1993)	Product Development Cycle (Braha and Maimon)
State the Problem	Discovering system requirements	Market Needs
Investigate Alternatives	Concept exploration	Conceptualization, Research and development
Model the System	Full-scale engineering design, Manufacturing	Design
Integrate	System integration and test	Marketing
Launch the System	Operation and maintenance	Manufacturing
Assess Performance		Testing
Re-evaluate	Retirement, disposal & replacement	Maintenance

They do not explicitly mention the function *Launch the System,* presumably because they think it is obvious that a design process should Produce Designs.

C. System Lifecycle

Wymore [25], [26] has a mathematical theory for systems engineering that helps prevent certain methodological mistakes. His theory is complex, but in Table VII, we map one simple part of it, the system lifecycle to the SIMILAR Process. In this table, we also map the Product Development Cycle of [7].

Assessing performance is not a phase in the system lifecycle because performance should be assessed continually throughout the system lifecycle. The mapping of Marketing to Integrate may seem odd. But Braha and Maimon did not place this marketing function up front to help with the problem statement. Temporally, they placed it after testing and before maintenance. It is as if they are integrating the manufactured product into society.

D. System Design at Boeing

The Systems Design Overview Course at Boeing [8] explains the process and products of a method for creating system designs. It is mapped to the SIMILAR Process in Table VIII.

We believe that they have subsequently added material to their course notes to cover assessment of performance and re-evaluation.

E. FRAT Model

Mar [17] has said that the essence of systems engineering can be captured with the acronym FRAT: functions, requirements, answers, and tests. The mapping between the FRAT model and the SIMILAR Process is shown in Table IX.

TABLE VIII

The SIMILAR Process	Boeing System Design Overview (Dahlberg and Lowe)
State the Problem	Define operational objectives, Define external interfaces, Define mission functions, Define measures of effectiveness
Investigate Alternatives	Propose design concepts, Select preferred concept
Model the System	Evaluate concept effectiveness
Integrate	Verify mission capability
Launch the System	Specify design criteria, Develop detailed design, Deploy system (Submit designs)
Assess Performance	
Re-evaluate	

TABLE IX

The SIMILAR Process	FRAT (Mar)
State the Problem	Requirements - describing how well the functions must be performed
Investigate Alternatives	Answers - describing what performs the functions
Model the System	Functions - describing the behavior of the system
Integrate	
Launch the System	
Assess Performance	Tests - describing how to evaluate if the answer performs the functions as required
Re-evaluate	

TABLE X

The SIMILAR Process	The Scientific Method (Webster)
State the Problem	recognition and formulation of a problem
Investigate Alternatives, Model the System	formulation of hypotheses
Integrate	
Launch the System	collection of data through observation and if possible experiment
Assess Performance	testing and confirmation of the hypotheses formulated
Re-evaluate	

F. Scientific Method

The following definition comes from *Webster's Third New International Dictionary*: "**scientific method** *n*: the principals and procedures used in the systemic pursuit of intersubjectively assessable knowledge and involving as necessary conditions the recognition and formulation of a problem, the collection of data through observation and if possible experiment, the formulation of hypotheses, and the testing and confirmation of the hypotheses formulated." Table X shows the mapping between this definition and the SIMILAR Process.

This seems to be a fairly standard definition of the scientific process. But if you are a scientist, think about how you conduct your analysis and development. You follow the above steps. But after you have done them, you probably sit back, consolidate your results, construct new hypotheses, design new experiments, and then cycle through the whole process all over again. Thus, you do re-evaluation. You also fit your new discovery into the existing body of knowledge, which is integration.

G. Fifth Discipline

Senge *et al.* [20] present strategies and tools for building and managing a learning organization. They summarize their five disciplines as follows.

TABLE XI

The SIMILAR Process	*The Fifth Discipline Fieldbook* (Senge et al.)
State the Problem	Shared Vision
Investigate Alternatives	
Model the System	Mental Models
Integrate	Team Learning
Launch the System	Personal Mastery
Assess Performance, Re-evaluate	Systems Thinking

Personal Mastery means learning to expand personal capacities to create results we most desire and creating an organized environment that encourages all its members to develop themselves toward the goals and purposes they choose.

Mental Models means reflecting upon, continually clarifying and improving our internal pictures of the actions and decisions, and seeing how they shape our world.

Shared Vision means building a sense of commitment in a group by developing shared images of the future we seek to create and the principles and guiding practices by which we hope to get there.

Team Learning means transforming conversational and collective thinking skills so that groups of people can reliably develop intelligence and ability greater than the sum of individual member talents.

Systems Thinking means understanding and describing the forces and interrelationships that shape the behavior of the systems. This discipline helps us see how to change the systems more effectively and to act more in tune with the larger processes of the natural and economic world. Senge *et al.* make extensive use of feedback in their models, but they do not use the mathematical techniques of systems theory [23]. Their techniques are all qualitative: graphs and sketches. Why? Because they want everyone to be able to understand the models. If the feedback system models are not understood by all, it will be difficult to get everyone to buy in. This is also the philosophy of Quality Function Deployment (QFD). It is a very simple tool. There are more sophisticated tools that can do a better job. However, they are not as popular because QFD is so simple everyone can understand it. Senge *et al.* and QFD offer two examples of engineering tools being simplified for use without mathematics. Table XI shows how Senge's disciplines map to the SIMILAR Process.

The idea of investigating alternative designs is not explicitly in this fieldbook. We think it should be. However, this is a difficult mapping because Senge *et al.*'s disciplines are distinct unto themselves, but also applicable to all the functions of SIMILAR. In particular, systems thinking applies to all the functions of SIMILAR.

H. Shewhart Cycle

One of the oldest similar processes that we have found is the Shewhart Cycle [22]. Plan-Do-Check-Act, which was popularized in the 1950's by Deming [9], is illustrated in Fig. 7 and is mapped to the SIMILAR Process in Table XII.

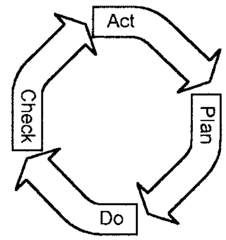

Fig. 7. Shewhart cycle [22].

TABLE XII

The SIMILAR Process	The Shewhart Cycle
State the Problem, Investigate Alternatives	Plan
Model the System, Integrate, Launch the System	Do
Assess Performance	Check
Re-evaluate	Act

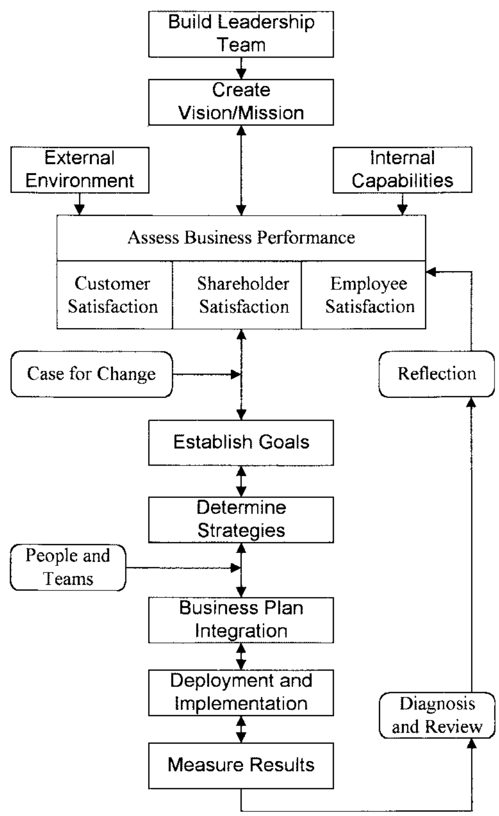

Fig. 8. Road map to business excellence from [12].

I. Road Map to Business Excellence

Many companies have good people, superior technology, and are committed to improving shareholder, customer, and employee satisfaction. But unfortunately their efforts to improve are muddled because the organization has not followed a focused process to align the knowledge and initiative of the company to the true business needs.

The Road Map to Business Excellence, shown in Fig. 8, was developed by Gissing [12] to provide business leadership

TABLE XIII

The SIMILAR Process	Road Map to Business Excellence (Gissing)
State the Problem	Create Vision/Mission
Investigate Alternatives	Establish Goals, Determine Strategies
Model the System	Assess Business Performance
Integrate	Business Plan Integration
Launch the System	Deployment and Implementation
Assess Performance	Measure Results
Re-evaluate	Diagnosis and Review, Reflection

TABLE XIV

The SIMILAR Process	*Reengineering the Corporation* (Hammer & Champy)
State the Problem	Fundamental rethinking
Investigate Alternatives	Hunt for reengineering opportunities
Model the System	Model the business processes
Integrate	Relocate work across organizational boundaries
Launch the System	Radical redesign
Assess Performance	Achieve dramatic improvements
Re-evaluate	

a structured path to attaining business excellence. The results of the process are clear goals and strategies, which are then broken into deployable tasks ready for empowered employees to perform. Each step in the process is not new, but the key to success is the integration of all steps into a usable and highly effective process. The process has been applied to several companies in the last years with notable success. The Road Map is an iterative process, thus the double arrows in Fig. 8. Table XIII shows how the Road Map to Business Excellence maps to the SIMILAR Process.

In this table, we have mapped Assess Business Performance to Model the System. This is appropriate because in the business environment, models and simulations are run to analyze the business performance and find the as is and, through analysis, determine the *to be*.

J. Reengineering the Corporation

Hammer and Champy [14] define reengineering as "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service, and speed" [14, p. 32]. They emphasize that we must focus on business processes, not on tasks, jobs, people, or structures [14, p. 35]. Thus, they are telling us to model the business in terms of processes. They say that when we relocate work across organizational boundaries [14, p. 61] work units change from functional departments to process teams [14, p. 65]. This is the integration process. Their chapter "The Hunt For Reengineering Opportunities" illustrates how companies identify their business processes and suggests techniques for selecting the processes that should be reengineered. Table XIV shows how Hammer and Champy's book can be mapped to the SIMILAR Process.

Hammer and Champy's reengineering process seems to lack the function *Re-evaluate*. We think people who have reengineered a system should look back and evaluate whether they made the system better or worse. It should be a standard part of the reengineering process.

K. Jack Welch at General Electric

Tichy and Sherman [24] analyze the steps that Jack Welch, the Chief Executive Officer (CEO) of General Electric (GE), took to transform the company. They trace actions that Welch took to move a successful company to a new and higher plateau of performance. The financial performance from the beginning, in 1981 to today has certainly delighted the shareholders.

It would be the envy of the systems engineers if the steps and paths of Welch complied with the rigor and discipline of systems engineering. But unfortunately, Welch's path was erratic, involving successful and unsuccessful initiatives. When he started the transformation, Welch knew he had to change GE, but he was not sure what would and would not work. The leadership that he displayed and the vision that described the future state of GE were the foundation of his quest.

Looking back, we can develop a structure of what occurred. Welch's transformation went through three acts: Awakening, Vision, and Revolution as a Way of Life. From a systems viewpoint, each act was a discovery, instead of a planned stage. The SIMILAR Process describes the process that a company should go through to transform the organization, but Welch danced through the process learning and experimenting as he progressed. Designing a hydraulic actuator versus designing an organization, which is totally aligned and focused on a common set of goals, is very different. The big difference is people. This was Welch's biggest challenge. Welch used the steps of the SIMILAR Process in each of the "Acts." The "Acts" were self-contained, but as progress slowed, Welch redeveloped his thinking with new concepts and processes.

L. Covey's 7 Habits

Covey's [10] *7 Habits of Highly Effective People* presents principles that are designed to help individual people solve their personal and professional problems. These principles can help people adapt to change and take advantage of opportunities that change creates. These are his seven habits.

Habit 1) Be Proactive: This means that we are responsible for our own lives. We can and should do things to change our lives. Our behavior is a function of our decisions, not our conditions. We must change the things that we can change and accept the things that we cannot.

Habit 2) Begin with the End in Mind: The most effective way to begin with the end in mind is to develop a personal mission statement focusing on what you want to be and want to do. Your mission statement is the solid expression of your vision and values. Rewriting your mission statement forces you to think through your priorities and align your behavior with your beliefs.

Habit 3) Put First Things First: This habit encourages you to investigate your daily activities and give priority to important, but not urgent activities, like building relationships and planning. It suggests that you identify and prioritize your

TABLE XV

The SIMILAR Process	***7 Habits of Highly Effective People*** (Covey)
State the Problem	Begin with the End in Mind
Investigate Alternatives	Put First Things First
Model the System	Think Win/Win
Integrate	Synergize
Launch the System	Be Proactive
Assess Performance	Seek First to Understand, Then to Be Understood
Re-evaluate	Sharpen the Saw

key roles. Select two or three goals for each role. And then schedule time to work on each goal.

Habit 4) Think Win/Win: This principle encourages you to understand (or make mental models of) human interactions and suggests ways of working with people to produce mutually beneficial outcomes.

Habit 5) Seek First to Understand, Then to Be Understood: Diagnose before you prescribe. Understand system performance before you try to change it. Listening with the intent to understand is called empathic listening. "Empathic listening is so powerful because it gives you accurate data to work with" [10, p. 241].

Habit 6) Synergize: The whole is greater than the sum of its parts. The interactions between people add value to the organization.

Habit 7) Sharpen the Saw: We should continually evaluate progress and strive to improve our physical, social/emotional, spiritual, and mental dimensions.

Table XV shows how Covey's seven habits can be mapped to the SIMILAR Process.

There are people who think that Seek First to Understand, Then to Be Understood means you should first try to figure out how the other person thinks, and therefore, this habit should map to Investigate Alternatives.

In our development tables, we have deliberately listed each function only once in a column. Sometimes this restriction caused difficulties, but we think it makes the mappings more meaningful. Haimes and Schneiter [13] did not do this. For example, they mapped habit 5, Seek First to Understand, Then to Be Understood, onto their systems engineering tasks of 1) determine objectives, goals, performance criteria, and purpose and 2) communicate the solution to the client. They also mapped their systems engineering task, determine objectives, goals, performance criteria, and purpose, onto Covey's Habits 1) Begin with the End in Mind, 2) Think Win/Win, and 3) Seek First to Understand, Then to Be Understood. They used a different method because they had a different purpose. They were merely showing similarities, whereas we are trying to create a universal template.

M. The Wisdom of Teams

Katzenbach and Smith [16] wanted to explain why teams outperform individuals, show what is necessary to make real teams, and state what high-performance teams do. They have a succinct definition of a team, as follows. "A team is a small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable. Teams need to develop a common approach" [16, p. 45], which means that they should investigate alternative economic, administrative, and social ways of working together. Individuals must be integrated into teams. Holding themselves mutually accountable, which means being evaluated as a team, instead of as individuals, enhances this integration. Also, teams must be integrated into the organization. Katzenbach and Smith's [16, Part Three] *Exploiting the Potential* begins with "teams will be the primary building blocks of company performance in the organization of the future.... Such organizations will not promote teams for their own sake. Rather, the performance ethic of the company—that is, the focus on balanced results that benefit customers, employees, shareholder, and other key constituencies—will generate the challenges that give rise to teams.... The primary role of top management is to focus on performance and the teams that deliver it." Finally, they give an uncommon statement of common sense: to be successful teams must "do real work" [16, p. 144]. Table XVI shows how *The Wisdom of Teams* maps to the SIMILAR Process.

TABLE XVI

The SIMILAR Process	***The Wisdom of Teams*** (Katzenbach and Smith)
State the Problem	Common purpose and performance goals
Investigate Alternatives	Common approach
Model the System	Balanced performance ethic
Integrate	Hold themselves mutually accountable, Exploit the potential of teams
Launch the System	Do real work
Assess Performance	Focus on performance
Re-evaluate	

It seems that this book does not recommend re-evaluation of the problem the team was to solve. We think they should. This was a difficult mapping because the SIMILAR Process and The Wisdom of Teams work toward different ends.

N. Arizona Budget Reform Act

Arizona's Strategic Planning Advisory Committee evaluated the strategic plans of 34 state agencies [2]. They found that few were developed with any consideration of customer needs or employee participation. Virtually none had links to performance measures. Many agencies had strategic plans and total quality management, but the strategic plans had no relationship to the quality plans. Therefore, the committee developed guidelines to help state agencies do strategic planning. Their processes are shown in Table XVII.

TABLE XVII

The SIMILAR Process	***Arizona Budget Reform Act***
State the Problem	Mission and principles, Vision
Investigate Alternatives	Goals & objectives
Model the System	
Integrate	
Launch the System	Action plans
Assess Performance	Use performance measures, Do internal/external assessment, Conduct monitoring & tracking
Re-evaluate	

TABLE XVIII

The SIMILAR Process	The Manufacturing Process
State the Problem	Receive program plan, Discover requirements, Develop preliminary manufacturing plan
Investigate Alternatives	Analyze various manufacturing plans, Determine tooling and facility plan, Determine optimum make or buy plan, Conduct tradeoff studies
Model the System	Simulate the manufacturing process, Finalize the manufacturing plan
Integrate	Negotiate design release dates, Assure manufacturing plan supports program plan
Launch the System	Release program plan, Release production schedules, Initiate detailed production planning, Initiate tool design, Release orders to production, Release purchase orders, Acquire facilities and machines
Assess Performance	Monitor performance to program metrics, Conduct quality assurance tests
Re-evaluate	Improve manufacturing plan

This legislation [1] was written by politicians. They read about modern management practices, but did not read relevant engineering publications. Consequently, they missed the important modeling, integrating, and re-evaluating functions.

O. Manufacturing Systems

The manufacturing process is the result of numerous inputs that eventually come together in the delivery of a finished product to the customer. It starts with the development of requirements, whether they are customer inspired or internally generated. Next, manufacturing specialists are brought into the process to help determine the best way to transform the requirements into a finished product. The main effort, in the initial phases of the program, is spent by the engineers who design the concept and details of the product. Manufacturing's task is to determine if the design can be manufactured and provide input to the designers that make the product affordable, producible, and satisfy the requirements. The process does not operate in series but takes place concurrently with the participation of many disciplines. The manufacturing organization pulls together the program plan, design, schedule, and cost requirements and starts to develop the optimum manufacturing plan. However, the manufacturing plan is not produced in a vacuum. There is a continuous interface and dialogue with the designers and other involved disciplines. The manufacturing process can be mapped to the SIMILAR process, as is shown in Table XVIII.

P. Emerging Standards

We tried to map the SIMILAR Process to the two emerging standards for systems engineering, namely, IEEE 1220 [15] and EIA 632 [11]. The heart of IEEE 1220 is Section 6 that describes the Systems Engineering Process, whose purpose is to transform a customer's needs into a system solution. Table XIX shows the mapping of this section to the SIMILAR Process.

Although the Integrate function is missing at the high level, it is considered at lower levels for requirements (6.1.7), functions (6.3.1.2), physical interfaces (6.5.7), and the final design (6.5.15). We think these integration functions should be combined and mentioned at a higher level. Similarly, we think the three Re-evaluate functions should be combined.

TABLE XIX

The SIMILAR Process	IEEE 1220 Systems Engineering Process
State the Problem	Requirements Analysis (6.1)
Investigate Alternatives	Synthesis (6.5) Systems Analysis (6.7)
Model the System	Functional Analysis (6.3)
Integrate	
Launch the System	Synthesis (6.5)
Assess Performance	Control (6.8)
Re-evaluate	Requirements Baseline Validation (6.2) Functional Verification (6.4) Physical Verification (6.6)

TABLE XX

The SIMILAR Process	EIA 632 System Design Process (4.3)
State the Problem	Requirements Definition Process (4.3.1)
Investigate Alternatives	Solution Definition Process (4.3.2) Reqs. 17 a & b, 18 c & d, 22 and 23
Model the System	Logical Solution Representations (Req. 17)
Integrate	Identify and define interfaces (Req. 17b2)
Launch the System	Product Realization (4.4)
Assess Performance	Product Verification Process (4.5.3)
Re-evaluate	Many tasks are highly iterative (4.3 note 5)

The high-level section headings of EIA 632 produced poor mappings. There were many extraneous functions and many functions were missing. For example, it ignores feedback of the Re-evaluate function. This document contains lots of good stuff, but this good stuff is not organized. Furthermore, it is not a good description of a system or of a process for producing a system. Nevertheless, some subsections could be mapped to the SIMILAR Process, as is shown in Table XX.

The System Design Process (4.3) seems to constitute a consistent process whose purpose is to define requirements and transform them into a set of design solutions. However, this process lacks clarity. The level of detail varies from whole sections to single notes. For documents describing a process or system, the section headings should map to the SIMILAR Process. Furthermore, successive versions of a document should follow an evolutionary not a revolutionary process.

Q. Generalizations

This appendix has tried to show that within both technical and nontechnical methodologies there are many similarities with the concepts of systems engineering: Structure, Interrelationships, Tests, Feedback, Analysis, etc. are all part of Covey, Senge *et al.*, and Wymore's work [10], [20], [21], [25], [26]. The concepts are different, but they should be, because they design to different parameters and have different payoff times. The key root is the application of systems thinking. Because of the similarities of the processes from such diverse fields, we think that there is something in the SIMILAR Process that maps closely to human thinking.

On the other hand, the SIMILAR Process may map well to such disparate processes because it describes a logically consistent and effective means of problem solving. The fact that so many authors continue to describe the process suggests that humans have a tendency to think in a disorganized way and need to be continually reminded about systems thinking.

What makes the SIMILAR Process so generic? It has seven functions, which matches human information capacity [19]. The process follows the thinking process that takes a thought or an idea from conception state (State the Problem) through analysis, development, and production of an output that then has to be assessed to assure that the performance equals the fundamentals of the thought or idea. When the cycle is complete, we sit back and determine if we are satisfied with the result. The process pushes us to think differently, not only in a structured disciplined manner, but also to open up our minds to a new paradigm. The SIMILAR Process seems to have the functions that are necessary to explain how to do something. For particular tasks, some of these functions might be combined or omitted. However, no additional functions are commonly performed.

The SIMILAR Process is dynamic. It evolves with time. In dealing with complex systems, people start with a simple process and embellish it as they learn more about the system. The SIMILAR Process is hierarchical. It is applied at levels of greater and greater detail. It is applied to the system, then to the subsystems, components, etc. It is also applied horizontally and to alternative-1, then to alternative-2, alternative-3, etc. The SIMILAR Process is dynamic, hierarchical, recursive, iterative, and much of it is done in parallel. Because of the analogy to pictures that are created with fractal algorithms, we say that the SIMILAR Process is a fractal process.

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