# Part II
# Systems Methodology

*Systems Engineering: A 21st Century Systems Methodology* Derek K. Hitchins
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# 6
# Overview of the Systems Methodology

*Though this be madness, yet there is method in't.*

William Shakespeare, 1564–1616, *Hamlet*

## What is the Systems Methodology?

A methodology is a system of methods, or a body of methods, rules and postulates used by a discipline. So, a systems methodology is a body of methods, rules and postulates used by systems practitioners to investigate, understand and address systems, their issues, problems, behaviors and contexts, and — where appropriate — to moderate, modify, or otherwise address and solve, resolve or dissolve issues and problems.

Essentially, a systems methodology is the 'how' of systems engineering; but that explains very little. The systems methodology incorporates methods, tools, procedures, processes, practices, and the skills and experience of practitioners who may be formed into teams, with leaders and managers; the whole then becomes the systems methodology.

Arthur D Hall III saw it as follows: 'what is envisioned is a new synthesis, a unified, efficient systems methodology: a multi-phase, multi-level, multi-paradigmatic, creative problem-solving process for use by individuals, by small groups, by large multi-disciplinary teams, or by teams of teams.' (Hall, 1989)

Hall went on:

> applied systems methodologists have been around for 40 years; they are called systems engineers, operations researchers, management scientists, systems analysts, policy researchers, value engineers, ecologists, and cyberneticians. They include . . . those from all the applied sciences, even if not usually associated with the systems movement. . . .
>
> A methodological umbrella big enough to cover systems sciences and the applied sciences practically mandates the development of a process that is context free. This makes a high level of awareness of process necessary for good systems work. . . .

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## The Social and Economic Potential of the Systems Methodology

Our world is a complex, dynamic place in which the tempo of life and conflict seem to increase inexorably. Our social systems become progressively more complex as we diversify our activities: create new organizations, businesses and industries; bring new technologies on line, enjoy our freedom to innovate, become ever-more materialistic; as our populations continue to increase, as our hunger for power and energy continues to grow; and as the waste products of our lifestyles accumulate to pollute our biosphere and prejudice the biodiversity of the planet. Small wonder, then, that some see this profligate lifestyle as counterproductive, even dangerous, and hanker after a simpler, more spiritual way of life: disagreement between holders of such divergent viewpoints is inevitable.

Our world has been made smaller by enhanced communications, by ease and speed of travel, by improved infrastructures, etc. This has had the effect of coupling many open systems that were previously only in the loosest of indirect contact. Close coupling increases the rate of interchange between systems, causing their behavior to become more dynamic, even chaotic. Technology has not only enhanced communications and travel, but has materially affected our ability to make war, so that the 'footprint' for our weapons is ever increasing, delivery vehicles go further and faster, and so on. After some 100 000 years of *Homo sapiens*, we are still not wise enough to manage human affairs without resorting to conflict and war.

Not surprisingly, as our many complex systems dynamically interact, change and evolve, issues and problems arise. Many of these are familiar to us, even if there seems to be no way of addressing them: meeting the global demand for energy; preventing the biosphere becoming even more polluted; stemming the observed diminution of species diversity; accommodating the burgeoning human population of the planet; and so on.

Many problems and issues are familiar to us, too, at a more local level, in the organizations where we work, perhaps: concern about an organization's morale; mixed sets of management objectives, disagreement and a need for a unified plan; a high-level briefing required urgently to rebut parliamentary criticism of a project; a partnership at risk of breaking up owing to lack of shared vision; differing views of causes for lack of performance, effectiveness and/or efficiency; a complex technological equipment repeatedly presenting inconsistent fault symptoms in high-altitude operations; concern over both research and teaching quality and the need to improve quality management in a university; how to resolve inventory problems in a large, diverse, defense engineering company, leading to inefficient logistics, poor response times, and customer dissatisfaction.

Then, of course, there are the major national and international projects, notably in defense, civil engineering, nuclear energy, aerospace, infrastructure, etc. These are seemingly always late and over budget, with continual wrangling between those who buy and those who build. Not to mention (but of course, I shall) software intensive projects, national information technology projects for national insurance, immigration, health, law, police and judiciary, etc., which in many countries have risen to the level of national jokes. . . . Large, software intensive projects appear to be either beyond the wit of man to control, or are they, perhaps, beyond the wit of man to realize that they cannot be controlled — ever.

What if . . . there was a way of addressing all of these problems, indeed of addressing virtually any complex problem? What if there was a way of solving, resolving or dissolving any complex problem, so that even problems that have no solution might still be 'dealt with,' or at least understood . . . ?

# Systems Methodology — a Paradigm

The systems methodology, then, is postulated as a generic, or universal, problem solver. Can there be such a thing? The short answer is probably ‘no;’ there must be issues and problems that are so intractable that solution is not possible.

However, it might be possible to create a systems methodology that addresses a wide variety of problem types, magnitudes, contexts/environments, complexities, etc. For the systems methodology to have such wide applicability necessitates that the systems methodology, *per se*, must be independent of problem type, context, etc. Instead, it has to fall into the category of ‘a way of doing things’ — a paradigm, or pattern that forms the basis of the systems methodology.

# Aspects of the Systems Methodology

## The scientific dimension

‘Systems’ can be just about anything that fits the definition: i.e., ‘an opens set of complementary, interacting parts, with properties, capabilities and behaviors emerging both from the parts and from their interactions to synthesize a unified whole.’ The definition is system-type, -scale and -context independent, and it evinces scientific roots in the terms ‘open,’ ‘emerging,’ ‘synthesize,’ and ‘unified whole.’ These are terms from the systems approach, of open systems, and of systems science, the science of wholes.

The systems methodology is necessarily founded in systems science, in that its operation recognizes systems, works with systems, configures and reconfigures systems, recognizes dysfunction in systems, and finds provable ways to ‘repair’ those dysfunctions. Provability is key: unless there is an established scientific underpinning to the systems methodology, any results or prognostications emanating from the systems methodology will lack credibility.

To be credible, the systems methodology ‘adopts’ the scientific method, i.e., the scientific method is ‘built in.’ The systems methodology incorporates the four steps of the scientific method, which are generally presented as:

1. Observe and describe a phenomenon or group of phenomena.
2. Formulate one or more hypotheses to explain the phenomena.
3. Use of the hypotheses to predict the existence of other phenomena, or to predict quantitatively the results of new observations
4. Perform experimental tests of the predictions by several independent experimenters and properly performed experiments

For the systems methodology, modifications may be necessary to the text, but not the principles, of the scientific method. So, the ‘systems scientific method’ becomes:

1. Explore the problem space: observe and understand the causes of dysfunction and disorder, i.e., the nature and behavior of the problem within its dynamic context. (This is the systems approach: understand and explore the system as an open, interactive part of some whole, where the part adapts to the whole, and vice versa)

2. Conceive one or more potential solutions, resolutions and/or dissolutions (remedies) to the problem that, if introduced into the context, would remedy the whole problem. (These are the hypotheses.)
3. Represent (visualize, model, prototype. . . ) the potential remedies interacting with other systems in the solution space, such that both the potential remedy and the other interacting systems may mutually adapt. Modify/enhance the representation(s) to render the best, whole 'answer' to the whole problem in the circumstances — as constrained by the solution space. (This is, or can be, quantitative prediction, together with optimization.)
4. Test/prove the modified representation(s) in a variety of relevant contexts. (This is testing the robustness of the remedy.)

Systems science pervades the systems methodology: it is built-in to the methods and tools such that practitioners using such methods and tools observe the principles of systems science/applied science as a matter of course. Practitioners may be expert in the context of the problem space and/or the solution space so will bring their own scientific knowledge to bear, together with their experience and practices.

## The logic and epistemological dimensions

The systems methodology is necessarily logical and rational where both terms indicate, *inter alia*, an absence of cultural bias. The knowledge upon which the systems methodology is founded must be sound; epistemology is important; else, the results from the systems methodology may be invalid, yet the practitioners applying the methodology would believe them valid: as Will Rogers, the lariat-twirling vaudeville raconteur, famously said: 'It's not what you don't know that's the problem — its what you know that ain't so!' Part I of this book hopefully enables readers to appreciate the systems theoretic bases of the systems methodology.

In particular, the generic reference model (GRM) has been presented earlier (and will appear again in the systems methodology): it represents a system as having three aspects; being, doing and thinking, relating to form, function and behavior respectively. The thinking/behavior aspect is of concern, epistemologically — the 'do you know what you think you know,' and 'how do you know what you know' considerations Many engineers are uncomfortable with 'softer' issues such as personality, psychology, social anthropology, etc., none of which is addressed in many engineers' education and training. Moreover, psychologists, anthropologists and others are not in total agreement themselves about human behavior, mores, psyche, etc.

That which applies to the remedial system in the way of psychology, anthropology, and other soft factors, applies equally to the systems methodology in operation, where it is an undoubted complex system in its own right. The systems methodology is comprised of methods, tools and processes being used and conducted by individuals, teams and teams of teams, all with behavioral characteristics, all operating in a dynamic, interactive, creative cauldron. A vitally important contribution of science, the scientific method and epistemology within the systems methodology, is to ensure that the cultural, political and other biases, which might be present within individuals and team members, do not find expression in the application of methods, in the selection of information, in the choice and acceptance of strategies and options, in the identification and neutralizing of threats, etc.

Within such a minefield, to talk of logic is, perhaps, tantamount to treading on a mine. The approach taken in the systems methodology, however, has been to limit the extent of the methodology such that its content is logical. For instance, we may not fully understand how different behaviors arise in different people in response to different stimuli; but it is logical, rational and reasonable to deduce and state that behavior is response to stimulus, without necessarily knowing which behavior responds to which stimulus. So, it is logical to perceive and anticipate causality.

In many situations, it is logical, rational and reasonable to limit the range of possible behaviors that might result from a particular cause. When an army commander finds that his army is surrounded, that he is running out of provisions, water and ammunition, there are no reinforcements, etc., many emotions may be running through his mind, but only three stark options facing him: fight to the death; surrender; try to break out. Of course, he could always attempt a bluff. . . .

By operating in this manner, the systems methodology may prove logical, rational and reasonable even when dealing with soft and wooly issues.

## The time dimension

The systems methodology contains processes and tasks at its heart; some processes necessarily involve sequence. Without knowing the problem first, for instance, it is not sensible to predicate a remedy. So, for some aspects there is a natural, inescapable, logical sequence, which will take time to perform.

Complexity appears to emanate from at least three aspects: connectivity, variety and 'tangling,' or the degree of interweaving of strands and parts of any system. (Hitchins, 2000) The greater the complexity of an issue, the more time may be needed to unravel the knot, to identify and characterize the various open systems, and to understand how their various ramifications interact and interdepend.

The time dimension, then, relates to the time taken to 'apply the systems methodology;' in the affairs of man, the kinds of processes, tasks and methods that are at the heart of the systems methodology will generally be subject to 'management.' Timescales for completion of some project may be set and predetermined, perhaps with less than due regard to the nature of the problem to be solved, the degree of complexity to be unraveled, etc., and also — importantly — without due regard to the dynamics of the problem space. So, setting too short a period may allow insufficient time to apply the systems methodology. Set too long a time, on the other hand, and the original problem may have morphed by the time the systems methodology has been applied, such that the final remedy is applicable to a patient who has recently died, or at least to one with a new, and different, problem.

Having said that, the very existence of a systems methodology, and of a group of practitioners practiced in its application, offers the best hope for a sound remedy to any undefined problem in the shortest practicable time. Moreover, knowing that the problem may morph during the conduct of some process places upon the systems methodology the responsibility for remedying, not the original problem, but the continually morphing problem.

The time dimension relates also to the remedial system (i.e., the solution to, the resolution of, or the dissolution of, the problem): its dynamics, its 'metabolic rate,' if you will. Many problems are cyclic in nature — for example, many businesses have an annual cycle, while some social systems have a 'generation' cycle, affecting the cyclic reappearance of fashions in music, clothing and in crime, for instance, and the periodic swings between cultures of 'freedom of expression' and 'repression of expression,' which can be seen in education. Remedial solutions have to be applied at the appropriate stage in a cycle, else they may make matters worse rather than better, and have to be able to adapt dynamically at least as fast as the problem they are addressing.

## The cultural/political/behavioral dimensions

Culture has no place in hard science. However, culture does have a place within systems science and hence within the systems methodology. This arises for a variety of reasons, perhaps best demonstrated by example: solutions to problems have to be culturally acceptable to those who need the problem solved. Similarly, predictions of (particularly) human systems behavior are necessarily culturally colored. This is not to permit cultural bias within the systems methodology per se, but to recognize cultural aspects in both the problem and the solution spaces.

Politics is generally an issue with complex systems, too; those holding political views cannot be appealed to, in general, by logic, for instance. Political bias causes an observer to emphasize and accept information that jibes with his or her own affiliation, while at the same time de-emphasizing and rubbishing information that is discordant with his or her own beliefs: for many people, it seems, political beliefs color their viewpoints, their Weltanschauungen; epistemology is not a consideration. For such people, the logical, rational, reasonable remedy to a problem may be quite unacceptable; hence, the problem cannot be solved, at least, not in their eyes. In such cases, dissolving the problem may be the only way forward, i.e., moving the goalposts in such a manner that the politically biased, of whatever persuasion, have no grounds for complaint. Sometimes, however, moving the goalposts may herald a whole new raft of problems. . . .

## The moral and ethical dimensions

The systems methodology must exhibit integrity, in both senses of the word, i.e., must adhere to high moral principles and professional standards, and must remain complete, undivided, sound and undamaged.

Can a systems methodology be moral? It can be moral in the sense that the methodology has a duty to be open, honest, unbiased and complete. It can also exhibit a moral responsibility in proving that solutions to problems are valid, optimum and complete, as well as culturally acceptable.

A key attribute of the systems methodology, then, is integrity. Traditionally, systems architects and systems engineers have jealously guarded their integrity, choosing always to tell the truth even when it may be unpalatable. In industry, telling the truth may, at times, be prejudicial to continued employment; sometimes the systems engineer may have to be sparing with the truth, but a true systems engineer never lies.

Is there an ethical dimension to the systems methodology? Yes, there has to be, in the sense that the systems methodology can be employed to address problems and issues of all kinds, including those that are politically, economically, environmentally, socially and even security sensitive. The systems methodology is ethically bound to be objective, impartial, unbiased and culturally aware, yet culturally unbiased, too.

The systems methodology operates within a global environment where waste and pollution are of growing concern. As in the medical profession, there is an ethic for the systems methodology that solutions to problems ‘should do no harm’ to the biosphere and to the environment.

## The social dimension

The systems methodology incorporates individuals, teams and perhaps teams of teams, all with their various skills, capabilities, cultures, tastes, etc. These practitioners form into social groups both informally, and formally, perhaps as part of some organizational structure. The applied systems methodology operates within a societal environment where there may be problems, those who want the problems addressed, and those who have an interest in the social impact of solutions to problems. The systems methodology therefore has a substantial social dimension, with various social systems acting, interacting and counteracting.

Despite this, tensions between the various social groups, and the various cultures that might influence activities, judgments and choices within and without the systems methodology should have no effect on the integrity of the product from the systems methodology. This necessitates that absolute, objective measures of the conceptual solution system be applied at key points in any procedure; relative measures, those that might compare one conceptual solution with another, may be useful, but will prove insufficient to ensure integrity and freedom from social influence and cultural bias.

## The organizational dimension

To perceive and comprehend the systems methodology in operation, then, envisage it as part of a wider whole, i.e., adopt the systems approach. The systems methodology is not a fixed entity, but — as a system open to its environment — adapts to its environment, yet remains viable, with all that implies: synergy, maintenance, evolution, survivability and homeostasis (S-MESH).

Nonetheless, there has to be within the systems methodology an identifiable, characteristic 'way of doing things,' a paradigm that transcends any adaptation, in that its identity, principles, integrity and values remain unchanged. The methods, tools and practices used for a particular application may be selected from a range of suitable candidates, as a surgeon selects the right scalpel, or a craftsman selects the tool appropriate to the job in hand: so long as the methods, tools and practices are context free.

There is, in all of this, evidence of the need for organization within the systems methodology: organizing data into information; practitioners into teams; teams into roles, such as problem exploration, conceptualizing, architecting, designing, assessing threats and risks, proving, etc. It is in the nature of people that some are more adept at starting and innovating, while others are more at ease with managing and coordinating, while yet others are more at home with finishing. It is pragmatic to recognize these predilections and to organize the systems methodology into corresponding structures and phases.

## The economic dimension

It has become the practice in systems engineering circles to be concerned about the business aspects of potential solutions to problems, about the cost to customers, and about the importance of stakeholders. This might seem to be both natural and reasonable, but it may also inhibit the discovery and creation of the optimum solution. If, for instance, there is some premature decision about how much a solution is to cost, then options and alternatives will be reduced, the resultant solution is unlikely to be optimal, and may be less than effective. (Conversely, less expensive ways of achieving the solution system may be overlooked, or the simpler solution 'over-egged,' or 'gold-plated.')

In such cases, the systems methodology may be viewed as operating in the 'satisficing context,' i.e., resolving the problem by producing a resolution that is 'good enough.' Although this is not 'solving the problem,' it may prove both pragmatic and useful in the short term. Satisficing may result in a succession of resolutions, producing first one resolution to the problem, then a second, and perhaps a third; each resolution learns from the operation of its predecessor, such that the whole problem may eventually be solved, and the goal eventually achieved (*cf* Apollo). While clearly slow and probably expensive, such approaches have the merit of generally being quicker and more affordable at the start, even if prolonged and expensive overall. By biting off just a piece of the cherry each time, the overall process may also prove less risky, as each step forward is founded on prior experience, and is made with better knowledge of the risks. . . .

Undue emphasis on the cost of things early in the problem solving process may also be quite inappropriate for reasons that are more fundamental. Even the most cursory look at the history of man's achievements will show that the greatest and most memorable are rarely the result of financial caution. Apollo would not have happened if the budget had been constrained from the start. The Channel Tunnel joining England and France would not have been started had the financiers been aware of the overall cost at the start. The Scottish Parliament building in Edinburgh, a masterpiece of civil engineering, was many times over budget. Look around the world at the great achievements, and this same picture emerges on all fronts — the greater the achievement, the more likely it is to have been financially unconstrained.

This observation can, of course, be seen from different viewpoints. One view might be that the goal, the problem to be solved, is so important that cost is not a sensible consideration: that was the view at the time of Apollo, and it is often the view during periods of intense warfare, where survival is paramount. Another view is that people are incredibly poor at estimating the cost of solving complex problems, and underestimate through lack of understanding of the complexity and complication in creating a solution.

A third view might be held by those who have a good idea of the overall cost of solving some problem, but are also aware that customers, buyers and backers would be deterred if they knew the real cost; instead, the end cost is concealed, and those concerned with cost are subject to 'mushroom management:' kept in the dark and fed horse manure.

There is, too, an important economic dimension to the systems methodology in the sense that the applying or conducting the systems methodology requires time, skill, energy and money. To judge whether or not the systems methodology offers 'value for money' in any situation, it would be prudent to consider the cost of not using the systems methodology. If the systems methodology can solve complex problems that cannot be solved in other ways, then the alternatives to the systems methodology would seem to be guesswork coupled with trial and error; how costly might that prove, and how long might it take?

In reality, the cost of applying the systems methodology is directly related to the nature of the problem or issue, the threats contained within the environment, and the constraints imposed by the solution space. In some instances, an individual will have the necessary skills to apply the systems methodology on his or her own. Such an individual would find that observing the paradigm, applying the methods, tools and practices, encouraged objectivity, creativity, innovation and risk management. The individual would create an audit trail as proof of the bases for design, of solution optimality, etc., and would if required be able to prove that the solution system solved, resolved or dissolved the original problem as appropriate.

It is also true, naturally enough, that the individual would take time to become used to the methods and tools, and proficient in their application and interpretation — there is a learning curve. Once this curve has been climbed, the individual would not only create comprehensive solutions to complex problems with the highest integrity, but would also do so in short order. It is in the nature of a methodology that it contains the underlying process as an integral part of the paradigm, and that this process constitutes the critical path from whole problem to whole solution.

Similarly, teams and teams of teams operating as an integral part of the systems methodology benefit from its inherent order, structure and strategy. It is also true that teams of people will go through a learning curve in applying the various methods, tools and practices; additionally, they will take time to develop person-to-person relationships and understanding, so that a team will take longer to become practiced than an individual. On the other hand, of course, the team will be comprised of many complementary skills and capabilities, such that the team would be expected to prove more capable and more proficient than the individual.

## The technological dimension

The systems methodology employs/applies context-free methods and tools; none of these need be technology-based or supported. However, vast amounts of information may be generated in many applications, and information technology may prove invaluable in handling this information.

The essence of 'system' being order, there will be occasion to assess or evaluate entropy, and to reconfigure systems to minimize configuration entropy, e.g., to reveal intrinsic architectures. Again, this may be accomplished without technology, but suitable tools may both ease and speed up the processes, to the point that some complex issues — although they could be addressed by hand — would be best addressed using some kind of information manipulation tool.

It is, too, in the nature of open system problem solving, particularly on the grand scale, that the dynamics of the problem, the situation, the environment and the solution become of paramount importance. While it may be possible for those of superior brainpower to conduct the necessary mental gymnastics, for most of us it is likely that we will resort to dynamic open systems modeling. Such modeling has the benefits that it allows many different aspects of the open-system problem, its potential solution and its environment, to be simulated, to interact, and to find their resultant balance points in ways that even the brightest person might find difficult to match. Moreover, dynamic simulations provide experimental learning laboratories, permit the application of the 'scientific method,' demonstrate solution validity — or otherwise — to practitioners and customers, and serve as a cornerstone of proof.

The technological dimension may arise as a part, or occasionally the whole, of the solution to some problem. In the general case, the solution system is likely to be socio-economic, sociopolitical, sociotechnical, or any combination of the three. Some systems engineering practitioners recognize systems engineering as concerned only with technology; they emphasize 'engineering,' to the virtual exclusion of 'system.' On the other hand, some systems engineering practitioners concern themselves with social systems, particularly businesses and enterprises, and they emphasize (soft) 'systems,' to the virtual exclusion of 'engineering' — except in the sense of 'to create, to cause to happen.' As so often in such cases, the truth lies somewhere in the middle: systems engineering is best viewed, perhaps, as a portmanteau word, i.e., a singular expression with singular meaning, rather than two words with separate (divergent?) meanings.

Systems engineering, then, is creating optimum solutions to complex problems: it is neither systems, nor engineering alone; it is both systems and engineering at the same time. In the technology context, solutions to complex problems may be sociotechnical. For instance, long-range ground radar is (part of) a sociotechnical system: the whole radar-as-a-system includes operators, supervisors, controllers, maintainers, etc. It is also an open system, so interacts with the corporate system (air traffic management, perhaps), which adapts to the radar, just as the radar adapts to the air traffic system/whole.

This is generally the case: purposeful solutions to problems are highly unlikely to be exclusively technological, although some may contain a technological element which others may chose to see in strictly reductionist terms as a discrete, closed, artifact-to-be-engineered. Such situations may occur, for instance in defense procurement where, for contracting simplicity and tight managerial control, a technological artifact may be considered, designed and procured as an isolated entity: this is intended to concentrate development effort, and to prevent post design change, which can bedevil development and manufacture. Such practices do not bode well, however, for the operational performance of such entities when subsequently introduced to a complex sociotechnical system of which they will form an inflexible (and possible obsolescent) part.

# Systems Methodology: Conceptual Model

The systems methodology is, essentially, a problem-solving methodology, and as such is formed around a problem-solving paradigm. One such is shown in Figure 6.1, which shows a problem-solving process in diagrammatic form. It starts at the top with 'Issue' — a topic of concern. The issue is presumed to stem from intrinsic problems, which can be used to model an Ideal World, i.e., a world in which the problems would not exist, and therefore the Issue would not arise.

Having generated an Ideal World model, it is compared with the Real World, so that the difference between the two can highlighted and used as an agenda for change, to move from the present Real World towards a future Ideal World, in some undefined way. However, the figure shows that any future improvements can be judged by their ability, or otherwise, to address the original problems.

This is one version of the General Problem Solving Paradigm (GPSP); it is simple in concept, yet can be powerful in application, especially when incorporated into the systems approach. The systems approach adds strength to the GPSP by allowing that changes may cause adaptations, both

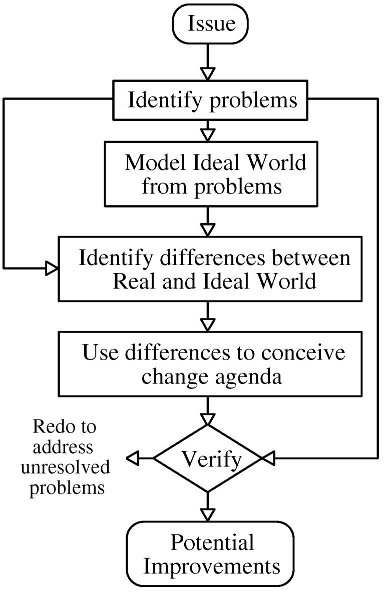


**Figure 6.1** General problem-solving paradigm.

of the 'issue systems,' and of the corporate whole of which they form part. In this way, the 'agenda for change' takes account of the dynamics of open systems interactions, and the 'acid test' — does the changed world solve the original problems — can act as a backstop, or safeguard against any errors, misapprehensions or misconceptions along the way.

Using the GPSP in association with the systems approach addresses the dynamics that are so often overlooked in trying to address problems, where the solution causes further, often counterintuitive problems, which may on occasion prove more severe than the original problem that was to be solved.

The GPSP is not the only problem-solving paradigm. There is another in wide use — the systems engineering paradigm. One version of this approach is shown diagrammatically in Figure 6.2. It starts by defining, or circumscribing, some problem space. There follow two independent activities: conceive solution options; and, independently, identify ideal solution criteria. Then, tradeoff between options and criteria to find the optimum solution and, finally, formulate strategies and plans to implement. Although this forms the nucleus of many systems engineering processes, it is much more widely applicable and is used by engineers, managers, financial advisers, and police. . . in fact, most people seem to have used this approach to finding the best answer.

Note, too, that it proposes finding the optimum solution — this is solving the problem, Ackoff-style, and is suggestive of some evaluative process. Interestingly, there are arguments even amongst seasoned systems engineers about optimization, some declaring that it is not a necessary part of systems engineering yet, at the same time, insisting that trading between options is a central tenet of the discipline and practice. As Figure 6.2 shows, tradeoffs are about finding the optimum. . . although often by non-mathematical, or quasi-mathematical means.

Comparing the two paradigms, it is evident that they are significantly different. Figure 6.1 emphasizes the problem, but has little to say about the solution, while Figure 6.2 emphasizes the solution, and how to get it, but with little to offer with respect to the problem, per se. It is possible, then, to combine the two paradigms into one.

Figure 6.3 shows the two problem-solving paradigms combined into one. Together, they form the basis for one strand within the systems methodology — the strand concerned with solving complex problems. There are two other strands that must also be addressed: one concerned with resolving

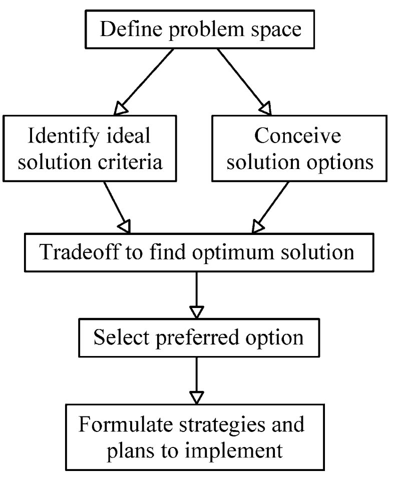


**Figure 6.2** The systems engineering problem-solving paradigm.

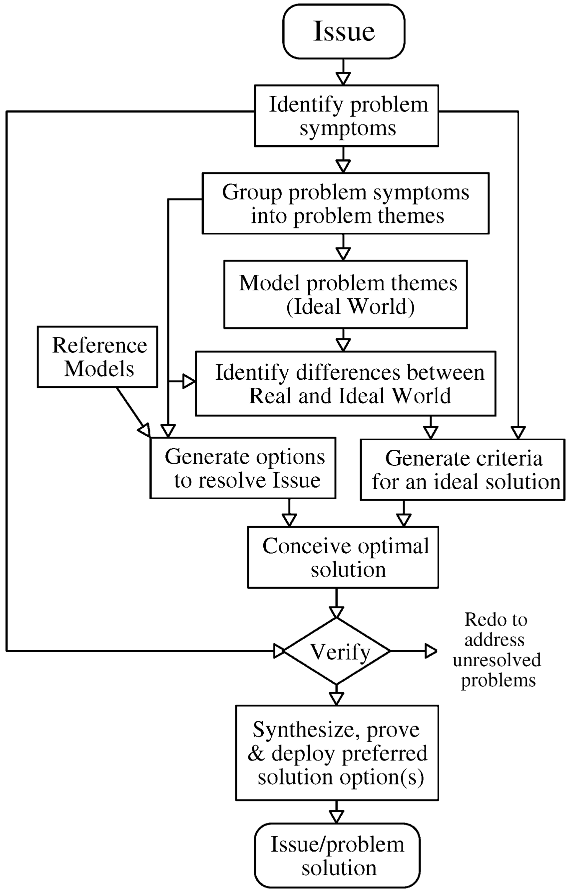


**Figure 6.3** Combined general problem-solving paradigm and systems engineering problem-solving paradigm. The combined paradigm aims to solve problems, rather than resolve, or dissolve them — see text.

problems, i.e., satisficing, or finding an answer that is 'good enough'; and another concerned with dissolving problems, or 'moving the goal posts' such that the issue or problem effectively disappears. Having said that, the figure does represent the strand in the systems methodology that many engineers would regard as systems engineering. . . .

Notice in Figure 6.3 the appearance of Reference Models. These are models such as the Generic Reference Model – see page 124 *et seq*. Reference Models are invaluable when generating options, to promote completeness of each option, such that like is compared with like, including emergent properties, capabilities and behaviors.

A conceptual model of the systems methodology is shown in Figure 6.4; it starts with an Issue or Problem (the terms are interchangeable in this context). The problem is evident owing to problem symptoms, perceptible in the problem space. These symptoms may be instrumental in directing exploration of the problem space, in the same way that a patient's symptoms may direct a doctor towards a diagnosis. The 'diagnosis' promotes a conceptual remedial solution, or remedy, one that

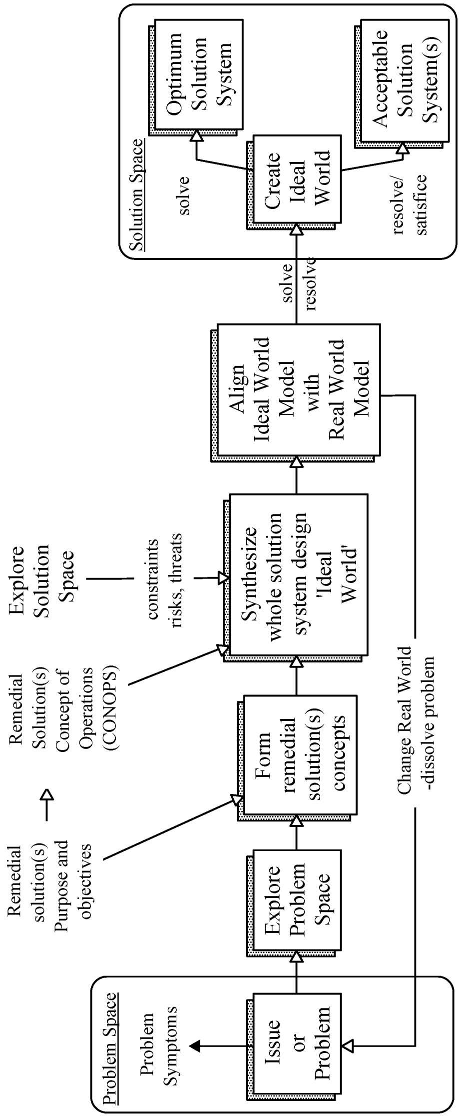


**Figure 6.4** A conceptual model of the systems methodology.

if it were applied might reasonably be expected to neutralize all of the symptoms – this is the acid, or decisive, test of any posited solution at any stage in the overall process. A conceptual remedial solution is defined by its purpose, and by its emergent properties, capabilities and behaviors: that is, what it is intended to do, how it will work, and what effects it is meant to have; there may be little about structure, content, or viability at this early stage.

The conceptual systems methodology shows next the synthesis of a system design, such that the design, if implemented would neutralize all symptoms, creating in the process the so-called ideal world; i.e., the best world in the circumstances. Note that the ideal world design is not necessarily some completely new system — at this stage, it is simply the design of an ideal system that, if realized, would in operation, while interacting with and adapting to, other open systems:

- generate none of the symptoms of the problem;
- exhibit requisite purpose, emergent properties, capabilities and behaviors;
- be viable in the solution space.

The next stage is to align the ideal world model with the real world model, i.e., to see where they match, and where they do not match, and to understand the relevance of the differences. This is a decision-point. Potentially, the issue can be addressed, i.e., the symptoms eradicated, by solving, resolving or dissolving:

- 'solving' implies creating the ideal world:
  - by altering (modifying, reconfiguring, connecting/disconnecting, enhancing/diminishing/balancing, etc., etc.) that which exists already, or. . .
  - by creating and introducing a new system to interact with those already in existence;
- 'resolving' also implies creating the ideal world indirectly, by satisficing, i.e., finding an answer that is 'good enough' or, a series of answers that home-in on the ideal world solution, perhaps, over time.
- Finally, dissolving the problem is seen, in the figure, as effectively addressing the problem space in such a way that the problem effectively disappears (see The Systems Approach on page 16.).

A choice will be made, generally by exploring each avenue and its implications, and comparing their relative merits in terms of feasibility, practicability, timescale, effectiveness, reactions and knock-on effects, cultural acceptability, likely costs, etc., etc. and, it may be that the ideal solution is to be found in some solving, some resolving and some dissolving all at the same time. . . .

Note in Figure 16.4 that:

- the remedial solution has purpose and objectives, which will include neutralizing the problem symptoms;
- a concept of operations (CONOPS) is developed for the remedial solution system, to show how it is intended to operate; there may be several competing CONOPS associated with any remedial solution, and indeed several competing remedial solution systems;
- exploration of the solution space is necessary to identify constraints, limitations, risks and threats that might prejudice the synthesis and manifestation of an ideal world design and solution system(s);
- according to situation, it may include functional-to-physical mapping, i.e. partitioning the overall design into physical compartments, with interconnections and interfaces.

An applied version of the systems methodology is shown in Figure 6.5 as a behavior diagram. The diagram shows functions or processes in the center panel, with essential inputs to each function or process at left, and outputs from each function or process at right. Inputs and outputs form logical patterns, too, such that the whole behavior diagram is self-checking, both vertically and horizontally. Note that the behavior diagram presumes that the objective is to create an optimized solution to the problem, rather than to resolve or dissolve the problem; moreover, some particular

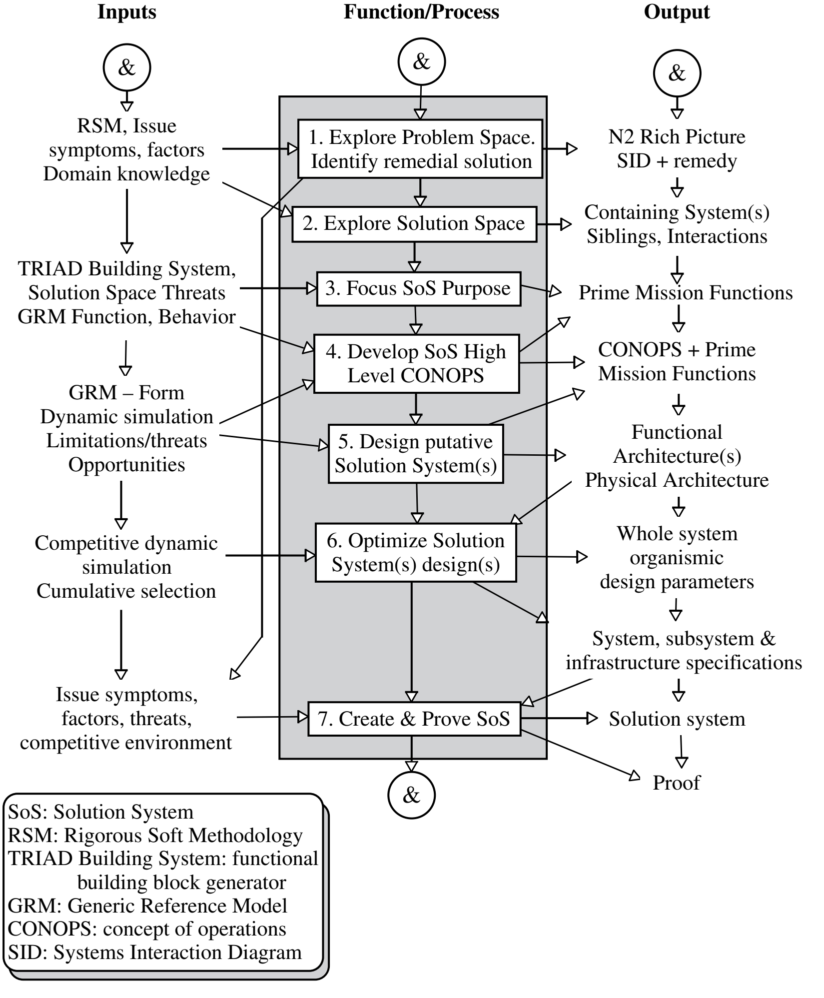


**Figure 6.5** The systems methodology as a high-level behavior diagram. In this example, particular tools and methods have been shown. In the general case, tools and methods may be selected from a suitable range, according to the nature, magnitude and extent of the issue or problem. The behavior diagram shows both inputs to, at left, and outputs from, at right, any central function/process. Using the GRM underpins solution system emergent properties, capabilities and behaviors. Cumulative selection enables optimization. Note the built-in acid test, that the solution must solve the problem.

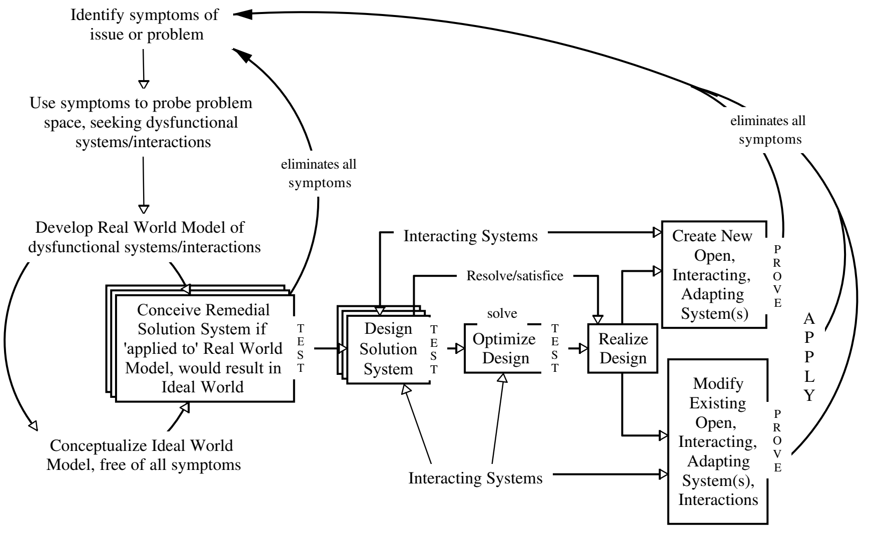


**Figure 6.6** Organismic view of the systems methodology, showing solving and resolving, and alternatives in design realization. Note the continual test/prove theme, requiring the developing designs to demonstrate their ability to eliminate all of the original symptoms.

tools have been nominated. Typical tools and methods will be presented later: subsequent chapters will expand on the seven steps/stages/processes shown in Figure 6.5.

Figure 6.6 shows an organismic view of the systems methodology, as a closed-loop system, one seeking closure. Note that there are two distinct systems approaches to addressing the issue or problem:

- create some new, additional, or replacement system or systems that has to be realized and introduced as one or more entities; or. . .
- modify that which already exists in the problem and solution spaces, by reconnecting, by reconfiguring, by (re)balancing, but essentially not by introducing new systems, entities and/or artifacts.

Engineers may recognize the first of these as systems engineering. Systems practitioners may recognize the second of these as reorganization, proactive management, or as systems engineering, too. Both groups are correct, although neither may be too happy to concede the others' territorial claims to 'ownership' of systems engineering.

# Create a (Better) Systems Methodology?

The systems methodology is a paradigm: an archetype, pattern or model, forming the basis of a disciplined basis to solving complex problems and issues. There may be other paradigms, other ways of creating solution systems. If there is such a thing as a 'best solution,' then competing paradigms would necessarily have in common that, in starting from the same problem space, they would end up with the same 'best solution:' they need not have followed the same route, however, suggesting that competing paradigms would differ principally in the demands they imposed on skills and resources, and the time and cost that they incurred in the process.

On the other hand, the systems methodology presented above, this particular paradigm, has a degree of flexibility built in, since the various activities shown, for instance, in Figure 6.5 can be undertaken in different ways, using either manual techniques or with the support and aid of tools-supported methods, according to the nature of the problem, the volumes of information being handled, the experience and proclivities of the practitioner, and so on. The key to such a methodology is to so design, organize and arrange each process/function/method that the output from the previous activity is exactly the input required by the current activity, and that the output from the current activity is exactly the input required by the following activity. Each process, then, may be seen as a transformation, and set of processes as an 'information transmission matrix,' in the sense that disorganized information about the problem space, the situation and the solution space enters at the start, undergoes a series of transformations, and emerges as highly organized, specific information about an optimum solution system. The end-to-end process is one of progressively reducing entropy, to such a degree that a specific solution can be realized, all within the context of the systems approach.

The systems methodology presented at high level above, and to be presented in more detail later, is, then, capable of improvement, in that different and better methods and tools can undoubtedly be conceived than those currently available. If newer, better methods are substituted individually, then the paradigm remains constant. If, on the other hand, all of the processes, methods and tools are changed together, then that might constitute a paradigm shift: the paradigm is in the pattern of skills, processes, practices, tools and methods.

## Create an Intelligent, Auto-adaptive, Evolving Solution System?

If it is possible to conceive, design and realize an optimum solution to a complex problem, and if that problem is continually changing, then it should also be possible to continually conceive, design and realize; that is, to continually reconfigure the system so as to maintain its ability to solve the continually morphing problem.

Figure 6.7 shows a notional approach to designing such an auto-adaptive system. The design envisages that the system contains a model, a dynamic simulation of itself, operating in its simulated environment and interacting with other simulated systems in that environment. So, the system is presumed to exist in some hostile environment, which it is able to sense, and to which it presents its emergent properties, capabilities and behaviors, indicating that it is open and interactive. The system is presumed to be 'designed' using so-called genetic methods, i.e., there are 'genes' coding for different elements and configurations of elements that go to make up the system.

The problem-solving process operates by simulating the environment, and by injecting into that simulation a representation of the system as open and interacting with others, in which state it is supposedly achieving its goals optimally. The problem to be solved is one of determining whether or not the current configuration is, indeed, optimal, and if not, what should be done about it. . . . Offspring from the current configuration are generated for the simulation, such that each offspring differs from the current configuration in some respects and in some small degree. Should a simulation using one of the offspring show a significantly better performance than the run using the (model of the) current configuration, then the current configuration will be rearranged to match

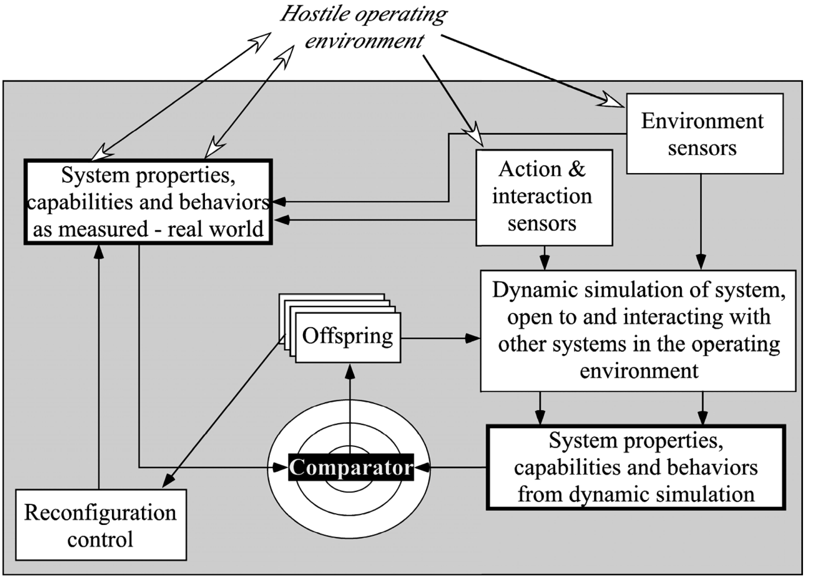


**Figure 6.7** An auto-adaptive system reconfiguring to maintain its balance with other systems in the environment. See text.

that of the most suitable offspring. At that point, the selector will activate the reconfiguration control, reconfiguring the (real) whole system to match that of the preferred offspring model. In reconfiguring, the system's open, interactive and adaptive emergent properties, capabilities and behaviors are restored to optimum for the contemporary situation.

Limitations are evident in the conceptual design. The environment simulation is not the environment; unless the simulation is sufficiently representative, decisions based upon it may be invalid. Even if the simulation were adequate, there is a risk of continually reconfiguring in response to environmental perturbations; some threshold would be necessary, below which reconfiguration did not occur, implying that optimization, as such, may be impractical in a dynamic environment, since the current configuration is likely to trail behind the true optimum as the environment changes. Furthermore, highly dynamic environments may change at rates which the auto-adaptation cannot sustain — perhaps as the dinosaurs were unable to adapt to rapid climate change.

Nonetheless, the basic notion of including within the system the ability to continually solve the problem of its own re-optimization is conceptually interesting.

## Auto-adaptation and the intelligent enterprise

If a system such as an enterprise, a business, or industry contained within it the ability to address its own problems and create solution system designs to optimally solve those problems, then the whole system could be auto-adaptive in the manner of Figure 6.7. When problems are substantial, enterprises tend to employ external consultants using such methodologies, but it does not have to be that way. Using the systems methodology, an intelligent enterprise, for example, would continually scan the environment, assess the situation both externally and internally, and would continually rebalance, reconfigure, adapt itself so as to remain viable, and to survive in the longer term. (I choose 'survive' rather than 'make a profit' since an intelligent enterprise would realize that the enterprise that survives is the winner in socio-economic terms of wealth creation and wealth accumulation. Of course, it has to make a profit along the way, but it also has to be prepared to invest some of its revenues in remaining robust and viable, and in continually enhancing performance.)

## Summary

A systems methodology is feasible and practicable, and would afford a paradigmatic, archetypal, generic approach to realizing complete solutions to complex problems and issues. Such a systems methodology would, in effect, incorporate the 'how' of systems engineering, taking it out of the realm of sometimes-dubious practice, and into that of provable solutions of high integrity.

A wide range of issues, incorporating a wide variety of problems, environments, situations, technologies, cultures, societies, etc., can be addressed thoroughly and objectively using just the one paradigm, such that the solution systems are provably sound as well as culturally acceptable. Using the systems methodology, societies would have at their disposable an invaluable tool, not only for solving problems, but also for planning, estimating, managing, organizing, strategizing, optimizing, etc., etc. The systems methodology would allow the rational and logical analysis and solution of problematic issues such as national and global energy shortages, national and international disasters, disaster relief, diminishing species diversity, atmospheric pollution, and many, many more.

At the same time, the systems methodology would support the rational and logical analysis and solution of problematic local issues: policing and the rule of law in democratic societies; affordable national defense procurement; enterprise and industrial performance; national resource management; waste disposal; etc; etc. It is not possible to solve every problem; some are simply too intractable. However, a common systems methodology would allow diverse groups and cultures to work together within a rational, science-based framework, pooling knowledge and experience so as to develop provably sound solutions to a wide range of important problems.

The systems methodology is a composite of skills, domain knowledge and experience, tools, methods, practices and processes, together enabling an individual, a team, or a team of teams to explore a problem space and to realize a whole solution system to the whole problem, in some solution space. There are many aspects, or dimensions, of the systems methodology: scientific, logical, epistemological, temporal, cultural, political, behavioral, moral, ethical, social, organizational, economic, and technological have been mentioned — there are many more, building to an ontology.

The systems methodology progressively reduces entropy observable in the problem space to the point at which a real-world solution can be specified, in detail, and realized. Since the solution system need not be technological, realizing the solution system may involve (e.g.) recruiting and training teams of people, reconfiguring an organization or process, writing a new instruction manual, or even changing a culture, as well as creating a new or replacement sociotechnical system, or a technological artifact.

So, systems engineering is more, much more, than creating new technological systems. It is more, too than solving problems: additionally, it can include resolving and dissolving problems.

The systems methodology incorporates a range of tools and methods that may be selected, as a surgeon selects a scalpel, according to the job in hand. The various tools and methods can be viewed as transforms, in that they handle and organize data and information about the problem space, the solution space and the environment. Each transformation can be thought of as taking data as an input and providing information as an output, where 'information is to data' as 'more ordered is to less ordered.' Successive transformations treat the previous transform's output as their input, and so on, creating an 'information transmission matrix,' which takes the raw, disordered data from the problem space and provides well structure, ordered, specific information about the solution system as an output at the other.

The systems methodology is not some linear-predictive information machine, however: choices and decisions have to be made continually throughout the process, since much of the capability is derived from the skill and knowledge of the systems practitioners, as well as from the problem and solution domains. Different individuals, teams, or teams of teams would produce different solutions to the same problem: some may be better at exploring the problem space and extracting domain data, some may be more familiar with the solution space and the threats contained therein, some might generate — and design into the solution system — unique strategies for addressing such threats, and so on.

So, while different teams with different capabilities might all produce provable solution systems, nonetheless some solution designs may be richer than others, address a wider range of threats, employ more cogent strategies, contain greater diversity, employ different kinds of solution system (e.g., a human activity system solution as opposed, say, to a largely technological solution), and so on. It is important, too, to remember that solution systems have to be culturally acceptable; different cultures, in different situations, with different values, may see different solutions systems as the optimum solution to their problem. This is not to say that the systems methodology will operate in a culturally biased fashion: it should, however, recognize that solutions have to be culturally acceptable; else, those being handed a solution to their problems, may neither recognize it nor accept it. An optimum solution is, after all, one that is best in the circumstances of the problem space and the constraints imposed by the solution space.

The systems methodology may be viewed as a means of solving problems to be applied whenever a major issue arises; in such circumstances, it might 'be applied,' if that is an appropriate term, by some consultant external to the organization with the problem. However, the systems methodology can also be used 'in-house' as a way of ensuring that an organization (enterprise, business, industry, socioeconomy) is operating to its best advantage, i.e., optimally. In this guise, the systems methodology is set to continually sense symptoms of dysfunction, indicating an incipient problem either within the organization, or with its interactions with other systems. Once detected, these symptoms will indicate the source of dysfunction and identify the root problem, which can then be addressed and solved. In this manner, including the systems methodology within an organization renders it auto-adaptive, so that it may continually adapt, reconfigure, even redesign and reinvent itself as the problem morphs. Such auto-adaptive systems hold the promise of operational success and survival.

# Assignment

1. Justify the view that the systems methodology is a system in its own right. Identify a set of emergent properties, capabilities and behaviors that the systems methodology would evince in operation.
2. If the systems methodology is a system, as suggested in 1, then can it be conceived and created using the systems methodology? Would this flout Gödel's Incompleteness Theorem? Discuss.

3. Consider the systems methodology as an operational system in an environment, interacting with other systems. Specifying an environment of your choice, identify the threats you envisage to the systems methodology and to its continued operation.
4. The systems methodology embodies the systems approach. How, then, can the systems methodology, as an open system, interact with, and adapt to, other systems in its environment? Explain, with examples from Layer 3 of the five layer model – see The 5-layer systems model on page 113.