Holistic Thinking and How It Can Produce Innovative Solutions to Difficult Problems

Joseph Kasser D.Sc, CM, CMALT
Visiting Associate Professor
Temasek Defence Systems Institute
National University of Singapore
Block E1, #05-05
1 Engineering Drive 2, Singapore 117576
Email: joseph.kasser@incose.org

Abstract: Systems thinking and innovation are deemed as required characteristic of systems engineers. This paper is written as the latest in a series of readings on systems thinking and innovation for postgraduate courses teaching systems engineering. The first part of the paper refers to earlier work in systems thinking and shows a difference between systems thinking and critical thinking, defines holistic thinking as a combination of analysis, systems thinking and critical thinking and shows that causal loops are tools used in critical thinking rather than elements of systems thinking. The second part of the paper provides examples of how holistic thinking resulted in innovative solutions to difficult problems in very different situations. The contribution of the paper is the definition of holistic thinking and the examples of how holistic thinking produced innovative solutions to difficult problems.

Holistic thinking

Providing the best solutions to complicated problems is the underpinning principle of systems engineering. This may be why the world turned to systems engineering to help manage the problems of complexity (Shinner, 1976). A critical competency of systems engineers is the ability to identify the underlying problem (Wymore, 1993), and determine the best solution, either by solving, resolving, dissolving or absolving the problem (Ackoff, 1991) page 195). The tool used by systems engineers to identify and tackle problems is holistic thinking. Consider the definitions of the words "holistic" and "thinking" (Merriam-Webster 2008):

- **Holistic** - relating to or concerned with wholes or with complete systems rather than with the analysis of, treatment of, or dissection into parts.
- **Thinking** - using one's mind to produce thoughts.

"Holistic" precludes analysis which is generally performed in a reductionist manner but is required for developing a complete understanding. Hitchins provides a solution to this paradox with the concept of elaboration (Hitchins, 2007) pages 93-95) – which examines the parts in increasing detail *without losing track of the part's relationship to the overall system*.

Holistic thinking is defined as the combination of analysis (in the form of elaboration), systems thinking and critical thinking.

Recognizing that the tight coupling between analysis, systems thinking and critical thinking has resulted in a number of [overlapping] definitions of systems thinking and critical thinking, this paper defines holistic thinking (the system) as the combination of analysis, systems thinking and critical thinking (the subsystems) with the relationship between systems thinking and critical thinking shown in Figure 1.

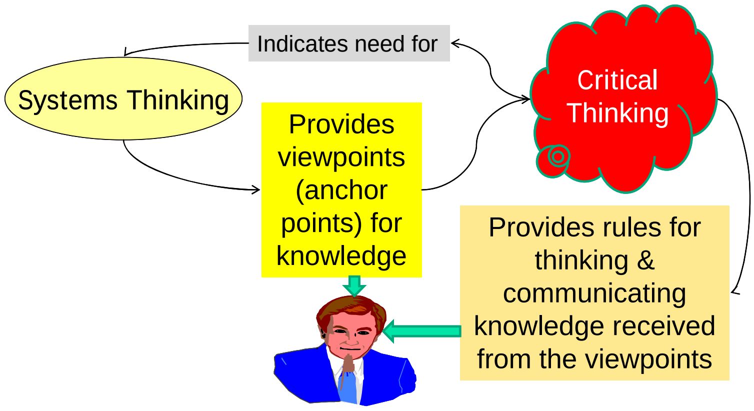

Figure 1 Relationship between systems thinking and critical thinking

Holistic thinking shall incorporate an analysis of the parts of the system in context (elaboration (Hitchins, 2007), rather than reduction) in the set of thoughts relating to the complete system as well as thinking about the system in its context; hence holistic thinking seems to be a way to develop an understanding of a system in accordance with (Hitchins, 1992) page 14).

Analysis

Analysis shown in Table 1, has three steps (Ackoff, 1991) and can be performed as 'reductionism' or 'decomposition' – reducing the parts to ever decreasing components *in isolation*. However, it can also be performed (and should be) by the systems engineer as 'elaboration' (Hitchins, 2003) pages 93-95) – which examines the parts in increasing detail *without losing track of the part's relationship to the overall system*.

Table 1 Analysis and Systems Thinking

Analysis (Machine Age)	**Systems Thinking (Systems Age)**
1. Take apart the thing to be understood	1. A thing to be understood is conceptualized as a part of one or more larger wholes, not as a whole to be taken apart;
2. Try to understand how these parts worked	2. An understanding of the larger system is sought;
3. Assemble an understanding of the parts into an understanding of the whole.	3. The system to be understood is explained in terms of its role or function in the containing system.

Systems thinking

Systems thinking shown in Table 1, also has three steps (Ackoff, 1991) but they are slightly different. Comparing analysis and systems thinking in the manner shown in Table 1, one can see that the focus of analysis is to look inwards while the focus of systems thinking is to look outwards. Both analysis (in the form of 'elaboration') and systems thinking have their place in the activities performed in developing an understanding of a system (Hitchins, 1992) page 14).

The holistic approach to the application of systems thinking was developed from (Richmond, 1993). Further research based on Richmond's work produced a set of nine viewpoints called System Thinking Perspectives (STP) (Kasser and Mackley, 2008) which have been used in teaching holistic systems thinking in postgraduate classes and workshops in Japan, Singapore, Taiwan and the UK. The systems thinking element of holistic thinking is a systemic and systematic way of viewing a system from each of the following nine viewpoints.

1. Big picture
2. Operational
3. Functional
4. Structural
5. Generic
6. Continuum
7. Temporal
8. Quantitative
9. Scientific

The first eight perspectives are descriptive, while the scientific perspective is prescriptive. Consider each perspective in turn.

Big picture perspective. The big picture perspective allows the systems engineer to understand the whole system and provides a view of the forest rather than the trees. The perspective is from the meta-level in the hierarchy of systems containing the system and views the system within the context of its containing system – its environment, the closely coupled adjacent systems with which it interacts and any loosely coupled more distant systems. Thus the perspective contains information about the external boundary of the system and the assumptions behind the location of the boundary.

Operational perspective. The operational perspective allows systems engineers to understand the operation of systems without getting bogged down in details. The perspective is the manner in which the system operates or will operate in the case of a new system. The system is viewed as a black box. The perspective shows the inputs and outputs and their relationships. This corresponds to the traditional 'open system' view. The black box perspective abstracts out (filters) the details of the internal nature of the system providing a view of the forest rather than the individual trees. The perspective is documented in the form of Use Cases, concepts of operations, and other appropriate formats and produces operational requirements.

Functional perspective. The functional perspective allows systems engineers to understand the functions performed by a system. The perspective describes the functions or activities performed by the system without reference to which of the elements of the system perform those functions. This corresponds to the traditional 'closed system' view of the cause and effect feedback loops. The system is viewed as a white box. Depending on the level of system decomposition, this can be a view of what is being done or how it is being done. System dynamics is but one application of this perspective.

Structural perspective. The structural perspective provides an understanding of the interconnections between elements and subsystems. The perspective views the systems' architecture and the internal subsystem partition boundaries and any effects on the system due to its internal structure. This perspective incorporates the traditional physical, technical and architectural framework views.

Generic perspective. The generic perspective looks for similarities between the system and other systems in the same or other domains, in the present or in the past. This perspective leads to the:

- Understanding of analogies/parallelism between systems.
- Tolerance for ambiguity.
- Inheritance of domain requirements from similar systems.

- Adoption of lessons learned from other projects and determination if those lessons are applicable to current project.
- Adoption of innovative design approaches in the system domain using approaches from other domains. One application of generic thinking is the Theory of Inventive Problem Solving (TRIZ)[1], a problem solving process that has evolved over the last 50 years whose underlying concept is "*Somebody someplace has already solved this problem (or one very similar to it.) Creativity is now finding that solution and adapting it to this particular problem"* (Barry, et al., 2007) namely incorporating lessons learned from other people into the problem solving process by definition.

Other applications of the generic perspective include pattern matching, and benchmarking.

Continuum perspective. The continuum perspective recognizes that:

- Things are not necessarily 'either-or', there may be states in between. This leads to concepts such as 'fail soft' in operation and the replacement of 'either-or' questions such as "is systems engineering an undergraduate or a postgraduate subject?" by questions in the form of "*to what degree is systems engineering a postgraduate subject?*" or "*what is the knowledge needed by a systems engineering engineer and how much of it can be taught as an undergraduate subject*?" This is a very different perspective to the traditional 'either-or' 'one right way' perspective.
- There may be more than one correct solution to a problem.
- Changing conditions may cause movement along the continuum. This leads to the insight that systems can exhibit different types of behaviour in different situations rather than always behave in the same way and that the transition conditions causing that change in behaviour may not be known. In the case of human systems, the continuum perspective points out that:

  1. Maslow's hierarchy (Maslow, 1970) may not be so much as a pyramid, but a pie, and motivating people becomes a matter of figuring out which slices of the pie to offer them (Kasser, 1995).
  2. Theory X and Theory Y (McGregor, 1960) behaviour may be two ends of a situational continuum of behaviour rather than two opposing behaviour patterns.

An aspect of the continuum STP can be illustrated from Maslow's observation of human behaviour which was "*I suppose it is tempting, if the only tool you have is a hammer, to treat everything as if it were a nail*" (Maslow, 1966) pages 15 and 16). Applying the continuum STP a systems engineer would note that:

1. nails are the solution to one class of problems,
2. nails might be a solution to other classes of problems (although not necessarily optimal), and
3. the other classes of problems should be monitored while the systems engineer gets the correct tool to tackle those classes of problems.

The continuum STP also makes note that there may be times when the need to do something about the problem is so urgent, and in the absence of any other alternative, that nails are the only available solution. As an example, if you need to cut a plank in half, it can be done by hammering a series of nails along the line to be cut, extracting the nails and then scoring the line of holes until the plank breaks. However, it will be better to get and use a saw to do the job unless you need that plank cut before someone can get the saw.

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[1] Altshuller named it Teoriya Resheniya Izobreatatelskikh Zadatch which has been translated into English as the Theory of Solving Inventive Problems or TRIZ to maintain the sound of the acronym.

The 'fail soft' perspective leads to an analysis of failure modes for the system and each of its components. The analysis may influence the structural and functional perspectives in the design of the system. The perspective also leads to a risk analysis of the probability and effect of internal and externally induced failures and ways to mitigate the failures. Internal failures are failures of components due to aging and normal wear and tear (Moubray, 2005), external failures are those inflicted from without, such as natural disasters, sabotage and enemy action.

Application of the continuum perspective also leads to a tolerance for ambiguity.

Temporal perspective. The temporal perspective looks at how the system behaves over time. If the system exists, past patterns of behaviour are examined and future patterns are predicted using this perspective. Insights from this perspective include:

- Understanding the implications of a proposed change.
- The consideration of availability, maintenance, logistics, obsolescence, etc.
- The concept of prevention.
- The need to consider the effects due to aging, the need for upgrades and replacement and the effect of diminishing manufacturing sources and material shortages (DMSMS) and the technology to be used in the system.
- Lessons to be learned from the system implementation and improvements for future iterations of the system.
- An understanding that even if the implemented solution works it may introduce further problems that only show up after some period of time. Temporal cause and effect loops are considered and the reflection on the past provides lessons learned from the system. This perspective also alerts analysts that past performance may not be a useful predictor of future performance unless the factors contributing to the past performance are understood.

Quantitative perspective. The quantitative perspective relates to the big picture and to the operational and functional perspectives to develop the performance requirements. According to (Richmond, 1993), the quantitative perspective however is not about the need to measure everything, "*it is more the recognition that numbers must be useful, not necessarily perfect and need not be absolute*". Sometimes relative comparisons are more useful. This perspective is about quantification rather than measurement, and helps to understand relationships and leads to the mathematical relationships in (functional) models and simulations. An example of quantification is the Likert scale, named after its originator Rensis Likert (1903-1981). The Likert scale offers a means of determining attitudes across a continuum of choices, such as "strongly agree," "agree", "don't care", "disagree" and "strongly disagree." A numerical value can then be allocated to each statement for further analysis. The numerical values may not necessarily be in a linear relationship, namely they may be weighted.

Scientific perspective. Whereas the other descriptive perspectives are used to examine (and document) a system, problem or situation, this prescriptive perspective covers the formulation and testing of hypothetical candidate representations of the solution system to meet the need that will be constructed in the design and implementation phases of the system development life cycle (SDLC), and the construction of the tests used to validate the representation by the Test and Evaluation (T&E) function of systems engineering.

Combinations of perspectives. Since the boundaries of the STPs are artificial for the benefit of applying systems thinking, the understanding gained from one of the STPs might generate a scientific perspective (hypothesis or solution) documented in a different STP or even a combination. For example, the HKM Framework (Kasser, 2007a, b) is a hypothesis (scientific STP) which presents the concept using a two dimensional table (structural STP), yet the insight to postulate it came from the big picture STP (vertical axis) and the temporal STP (horizontal axis).

Table 2 Apparent relationship between SSM's CATWOE and the STPs

CATWOE	Systems Thinking Perspective
Client/customer	Big picture
Actor	Operational
Transformation	Functional and Quantitative
Weltanschauung	Big Picture
Owner	Big Picture
Environment	Big Picture

The Soft Systems Methodology (SSM) (Checkland and Scholes, 1990) came out of the Operations Research field and incorporates some systems thinking. Its "root definition" describes the purpose of the system while the CATWOE template seems to align as shown in Table 2[2]. The grouping of elements is a process of functional allocation, namely design. Thus SSM is not "systems thinking" *per-se*; rather it is a useful tool which incorporates some systems thinking concepts. It should be given recognition for introducing an early application of systems thinking into systems engineering. In addition, from the generic perspective, the meaning of "Weltanschauung" seems to be the same as that of "paradigm" (Kuhn, 1970; Churchman, 1979) page 105).

Generating ideas

Brainstorming is a technique for generating ideas that has a number of variations. However all the variations suffer from a number of defects which include:

- Being a generally passive approach because they are based on waiting for the ideas to be generated before writing them on the whiteboard[3].
- Being prone to capture by the most opinionated person in the brainstorming session.
- Being unstructured, while allowing free range of ideas, tends to fail to focus of issues pertinent to the session.
- Being less productive of ideas when performed in a team than when performed by an individual, while providing a social setting.

Active brainstorming (Kasser, 2009) is one way of increasing the number of ideas produced in brainstorming. Active brainstorming is used after the initial flow of ideas from regular brainstorming dries up. Active brainstorming produces additional ideas relating to the problem or issue in a systemic and systematic manner. Table 3 contains data from a postgraduate

Table 3 Improvement in numbers of ideas generated

Team	Total number of ideas after Brainstorming	Total number of ideas after Active Brainstorming	Improvement (percent)
	(After Exercise 1)	(After Exercise 2)	
1	20	40	100
2	9	89	889
3	22	66	200
4	31	64	106
5	39	79	103
6	28	89	218
7	20	"Too many to count"	Large

[2] The boundaries do not align directly because the decomposition of systems thinking is different.
[3] There are variations which trigger ideas using 'what' and 'why' questions.

classroom exercise showing the increase in the number of ideas. Active brainstorming achieves these increases in the number of ideas generated by examining the issue from each of the STPs and triggering ideas by asking the questions "who, what, where, when, why and how" (Kipling, 1912) in a systemic and systematic manner. However, since the boundaries of the STPs are artificial for the benefit of applying systems thinking, the understanding gained from one of the STPs might generate a scientific perspective (hypothesis or solution) documented in a different STP or even a mixture of them.

Critical thinking

Critical thinking is "a unique kind of purposeful thinking in which the thinker systemically and habitually imposes criteria and intellectual standards upon the thinking, taking charge of the construction of thinking; [continually] guiding the construction of the thinking according to standards; [deliberately] assessing the effectiveness of the thinking according to the purpose, the criteria and the standards (Paul and Willsen, 1995) page 21).

Causal loops are concept maps used in systems thinking to describe operational, functional, temporal and other relationships. However, as causal loops describe relationships they are a reasoning tool and hence should be a part of critical thinking as defined in Figure 1.

"*System dynamics is the study of processes through the use of systems and how they can be modeled, explored and explained"* (Clark, 1998). A process consists of activities or functions. Hence in holistic thinking, systems dynamics is a [critical thinking] tool with which to analyse the **functional and operational** behaviour of a system **over time**.

Using holistic thinking

(Hitchins, 1998) states "[systems engineering] is a philosophy and a way of life". A way of life can be interpreted as the continuous application of holistic thinking and provides a bridge between the activity known as systems engineering defined in (Kasser and Hitchins, 2009) and the different roles of the systems engineer. Systems engineers use holistic thinking when researching the issue, situation or problem in the manner of (Hall, 1962):

- To view the issue, situation or problem from the STPs using thinking tools such as brainstorming and active brainstorming to create the initial list of pertinent factors.
- To reason about the pertinent factors and their relationships using analysis and critical thinking tools such as causal loops[4].

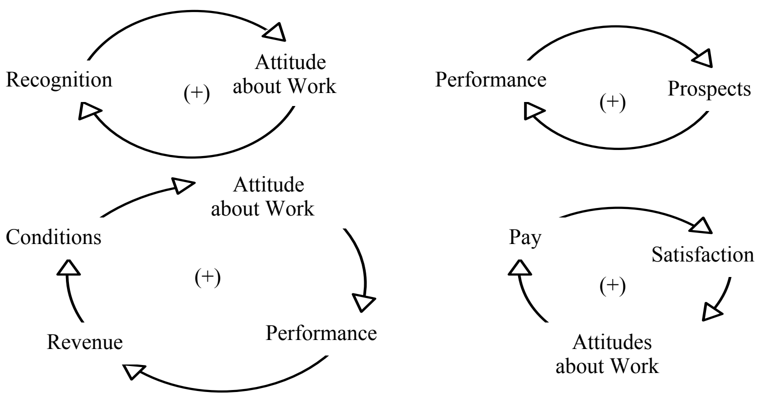

Figure 2 Elementary relationships

[4] This might occur when considering responses to the 'how' question in active brainstorming.

Consider the following example[5] of using holistic thinking to examine the factors that affect and are affected by morale in an organisation. The first step is to use brainstorming and active brainstorming develop a list of such factors from the STPs. This list would include:

- Low pay.
- Poor [working] conditions.
- Lack of recognition [of performance].
- Poor prospects [of promotion or reward].

The relationships between the factors are drawn in form of the concept maps or causal loops shown in Figure 2. These loops show how each element affects another element. The individual loops are then combined into a single loop as shown in Figure 3. The single loop can be converted into a model by adding numeric values from the quantitative STP.

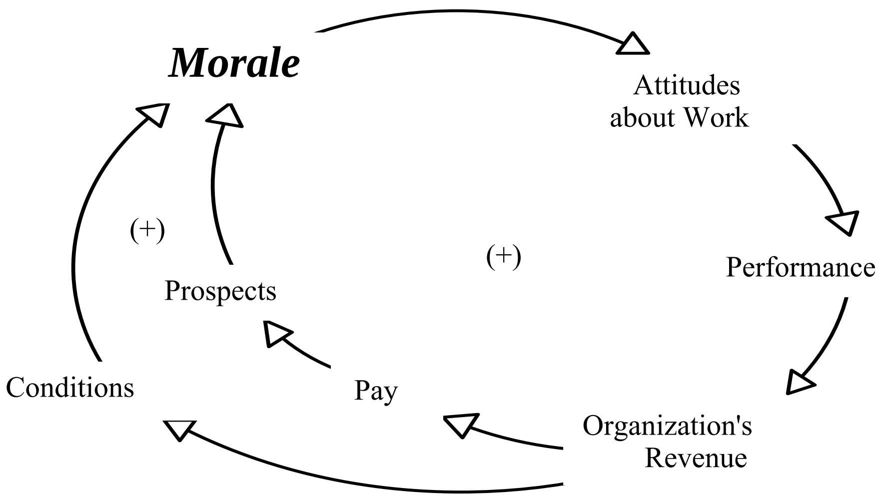

Figure 3 Combined Relationships

Examples of innovative solutions from Holistic Thinking

(Hitchins, 1998) states "[systems engineering] is a philosophy and a way of life". This statement can be interpreted as the continuous application of holistic thinking in a systemic and systematic manner to think about parts and their interactions as a whole as viewed from various perspectives. Holistic thinking allows the thinker to use analysis, systems thinking and critical thinking

- To see [missing] connections where others don't,
- To develop an understanding of a situation,
- To identify the real problem,
- To resolve and dissolve problems with innovative approaches,
- To predict probable futures, risks and their mitigation,

Holistic thinking leads to innovation when the key question that changes the perspective on the problem is identified as shown in the following examples. In these instances the problems were dissolved or resolved rather than solved.

- LuZ SEGS-1 Control and Control System.

[5] My thanks to Prof Derek Hitchins for the graphics in Figure 2 and Figure 3.

- NASA Goddard Space Flight Center (GSFC) Pacor Panic Attack.
- An investigation into the lack of teaming by Small and Disadvantaged Businesses in certain types of government contracts.
- Determination of a set of risk-indicators to predict project failure.

LuZ SEGS-1 Command and Control System

The LuZ Group, a start-up joint Israel-American venture defined, designed, developed, installed and operated the world's first commercial solar electrical power generating system (SEGS-1) in 1981-1983 (Kasser, 2008). At the design time, as the first of its kind, SEGS-1 initially only existed as a vague concept and met (Donaldson and Siegel, 1997)'s definition of a (very) high risk project. SEGS-1 was installed in the Mojave Desert in California and the Research and Development was in performed in Jerusalem. SEGS-1 was intended to generate electrical power from the sun by focussing the sun's rays on about 600 parabolic mirror trough reflector collectors each about 40 meters long. The operation of each parabolic trough reflector would be monitored and controlled by a microprocessor based local controller (LOC). Each LOC would control a motor that would position the parabolic mirror, receive information about the angle of elevation of the mirror and the temperature of the oil in the pipe positioned at the focus of the trough. Oil would be pumped through the piping, and as long as the LOC would keep the reflector pointed at the sun within an accuracy of ±0.2 degrees, the oil would be heated. The hot oil would be pumped around the field and into a heat exchanger to generate steam. The steam would then drive a turbine that generated up to 15 Megawatts of electrical power. Although it would be a complicated system, it would still have a conversion efficiency of about 40%, greater than any alternative method of harnessing solar energy at the time. A partial photograph of the system is show in Figure 4.

Figure 4 Part of the LuZ SEGS-1 Solar Array

The difficult problems

The early stage engineering had developed a conceptual design based on a Central Station minicomputer containing all the intelligence in the system and dumb LOCs interfacing the minicomputer to the mirror assembly. Communications would be by the then new high speed technology known as Ethernet. This concept created some difficult problems including:

- **Lack of experience.** There was minimal experience in using minicomputers and Ethernet on the team. This put the minicomputer solution in the high-risk category.
- **Cost.** Minicomputers were expensive. One system would cost at least $300,000 for the basic hardware and software. At least two Central Station systems would be required, an operational unit and a software maintenance development unit. LuZ was a start-up company and cash-strapped.
- **Mirror control.** The Central Station would have to perform a loop repeating the command and control algorithm for each mirror; monitoring the position of the mirror and temperature of the oil in the pipes, and moving the mirror to keep the sun in the focus position. This would be complicated, and the design would have to be validated by estimating the software cycle time for each LOC control loop based on an estimate of the number of instructions. The complete loop plus all the other computations associated with the loop (such as communications) would have to be performed in less time than it would take the sun to move 0.1 degrees.

The key questions. There were two key questions.

The first key question came from the generic STP and was "*what is this system similar to?*" The answer came from the scientific STP and was 'a constellation of low earth orbiting satellites!' The similarity was based on the structural STP; the "architecture" being similar to a central command station handling a network of remote satellite units via command and control links. Each remote unit would perform its own onboard station keeping (positioning and telemetry generation).

The insight gained from the key question resulted in an object-oriented approach using a self-regulating or homeostatic LOC. The intelligence was shared between the Central Station and the LOC such that:

- The Central station computed the mirror pointing angle.
- The Central station commanded the LOCs to deploy their mirrors to just below the calculated sun angle.
- The LOC deployed their mirrors, acquired and tracked the sun.
- The LOC sent back status information to the Central Station.
- The Central Station performed the operator interface functions.
- The Central Station software was designed to be implemented in sequential releases using the cataract approach (Kasser, 2002), where the first release contained the architecture, operator interface and manual control functions. Successive releases then added automation.

The second key question came from the quantitative STP and was *"how fast do things happen?"* The answer was not very fast. The massive mirrors deployed slowly, the oil heated slowly, so there was no requirement for high speed command and control links between the Central Station and the LOCs. This insight eliminated the need for the risky Ethernet and allowed the use of a low cost 1200 Baud ASCII asynchronous polled communications protocol using shielded twisted pair cables.

The innovative approach reduced the development risk considerably and allowed the Central Station to be downsized to a $2,000 Z-80 based 8-bit S-100 bus microcomputer. As a consequence, the control system for the solar field was installed on schedule.

NASA GSFC Pacor Panic Attack

In the mid 1990's the Code 560 Packet Processor Data Capture Facility (Pacor) at the National Aeronautical and Atmospheric Administration's (NASA) Goddard Space Flight Center (GSFC) was in the middle of a facility upgrade. Pacor's mission was collection and storage of data received from spacecraft in near Earth orbit. Pacor's architecture was in transition from a minicomputer based system to a client server open architecture network system.

Minicomputer based Pacor 1 was the operational system containing two systems, Pacor A and Pacor B, where Pacor A was the operational system and Pacor B was the spare and used for software maintenance. Pacor 2 was the new open architecture network based system under development. The plan for support of spacecraft on orbit was:

- Current spacecraft to be supported by Pacor's 1 and 2
- Future spacecraft to be supported by Pacor 2.

The difficult problem

One day Pacor's personnel identified a risk that Pacor might not be able to support operational spacecraft before transition would be completed. The risk had to do with aging minicomputer hardware in Pacor 1. The reliability data projected a statistical probability of a permanent failure of Pacor 1 within 12-18 months, while Pacor 2 was not scheduled for completion for at least another 24 months. Moreover, the manufacturer had discontinued the production of the minicomputers several months earlier so spares were unobtainable. Pacor's manager was thus faced with an estimated probability of a temporal window of 6 - 12 months in which Pacor would fail to meet its spacecraft support requirements.

The non-holistic thinking approach produced two options.

1. Absolve the problem or do nothing. The prediction that Pacor 1 might fail to meet its spacecraft support requirements if enough system hardware fails was based on statistics and there was a probability that the hardware would in fact not fail. However, if nothing was done and Pacor 1 failed, the principal investigators would lose their experimental data and become exceedingly unhappy with dire consequences for the Pacor manager.
2. Begin crash development of a Pacor 1 temporary replacement. This would be costly, estimated at about $2,000,000, would be a temporary solution. It was also risky as it might not be completed in time and since it would compete with resources for the Pacor 2 development, it would delay the Pacor 2 development.

The holistic thinking approach considered the problem in context with adjacent systems and produced the following key questions

- *"What is the expected lifetime of the spacecraft currently supported?"* (Temporal STP)
- *"What external sources of spares are there for Pacor 1?"* (Big Picture STP)

The answers provided the insight for the innovative solution. It was found that the orbit of the spacecraft supported by Pacor 1 would decay within 12 months to the point where the spacecraft re-entered the Earth's atmosphere. The orbital physics were such that the 12 months was a maximum value and excessive solar activity would shorten the lifetimes. It was also determined that there were a number of minicomputers available in the secondary (pre-owned) computer market suppliers. These findings meant that there was no need to panic. Since the current spacecraft would no longer be on orbit within 12 months there was no need to support them in Pacor 2. This finding reduced the Pacor 2 software development effort.

The recommended innovative solution was to purchase a previously owned computer (Pacor C) for about $500,000. Pacor C would be used as an operational spare and for maintenance software development. The availability of Pacor C would also relax the mean time to repair the minicomputer in Pacor 1 in event of a hardware failure in Pacor A or Pacor B and provide support in the unlikely situation that the current spacecraft operational lifetime would stretch beyond the predicted maximum of 12 months. This recommendation produced an estimated cost saving of $1,500,000 in hardware costs alone.

An investigation into the lack of teaming by Small and Disadvantaged Businesses in certain types of government contracts

Systems Engineering and Technical Assistance (SETA), Business Process Reengineering (BPR), software and hardware engineering, and other consulting, advisory and assistance types of contracts are low-capital-cost knowledge-intensive types of work. In the early 1990's the United States (US) government tended to award these contracts under the terms of full and open competition to large businesses. Many Small and Small Disadvantaged Businesses (SDBs) had the capability to perform these activities and could have formed strategic alliances to compete for these low-capital-cost knowledge-intensive awards against the large contractors. Such alliances could provide lower cost products coupled with the socioeconomic benefits of the Set-Aside programs. However, as these strategic alliances were not being formed at the time, the research question investigated was *why weren't they teaming?* (Kasser, 1997). The literature review and preliminary research identified 13 hypotheses (answers) to the research question, so there would have to be 14 questions on the survey asking if the responded agreed (supported) or disagreed (refuted) the statement (hypothesis)[6]. In addition the survey would be two-pages since the SDBs were parameterized in the following categories:

1. Size in several ranges
2. Revenues in several ranges
3. Age of company in several ranges
4. 8(a) or non 8(a) where 8(a) = federally-certified minority and woman-owned businesses.
5. Woman or non-woman owned.
6. Prior or no prior government contracting experience.
7. Member of the Armed Forces Communications and Electronics Association (AFCEA).

The difficult problems

When scoping the effort to provide an answer to the question, the difficult problems identified included the following.

1. How to get responses from US Government and contractors (Large, Small and Medium Enterprises?
2. How to get sufficient responses from the survey?
3. How to deal with small sample sizes due to few responses?

Consider each of them.

How to get responses from US Government and contractors (Large, Small and Medium Enterprises? The personnel were busy and could be expected to ignore doctoral students. This was a potential show-stopper because if the cognizant personnel would not respond to questions, the research could not take place.

The key question came from the generic STP and was "*Who do contracting officers and*

[6] The option for 'other' to be filled in by the recipient made up the 14th question.

contractors speak with?" The answer was 'Small Businesses'. The way to tackle the problem was to become a Small Business. So the researcher formed a Delaware Corporation electing Subchapter C of the Internal Revenue Service Code. The approach allowed the researcher to receive the Commerce Business Daily (CBD), request copies of government issued Requests for Proposals (RFP) and bid as an individual and as part of a team in response to RFPs in SDB set aside opportunities.

How to get sufficient responses from the survey? A normal response was estimated as being <=3%.

The key question came from the generic STP and was "*what communications media is viewed as important (responded to)?*" being 1996, the answers were facsimile (FAX) and face to face personal contact. These answers resulted in[7]:

- **Fax:** 391 sent, 81 received for 21.5% response rate. Some faxed responses were received within 24 hours, the first one within 2 hours.
- **Personal contact:** 45 handed out at association meetings, 30 received for 66% response rate.
- **Serendipity:** cost savings. The cost to Fax a two-page questionnaire was significantly less than the cost of paper, envelopes, postage stamps and self addressed stamped envelopes for return post.

How to deal with small sample sizes due to few responses? Normal statistics are not valid for small sample sizes.

The key questions came from the Quantitative perspective were:

1. *"Do the 13 hypotheses need to be ranked?"* The answer was negative because of the way the research was framed (boundary). Framing the research to avoid ranking the hypothesis simplified the survey by eliminating the need for the respondent to do pair-wise comparisons or other ranking approaches.
2. *"What is the required level of confidence in the data?"* Research into statistics indicated that the answer was 0.95 for standard statistics (Downie and Heath, 1959).
3. *"What is the relationship between sample size and level of confidence?"* This question provided the key to the innovation. Research into statistics indicated that the relationship is expressed in the following equation (Downie and Heath, 1959).

$$n = \frac{z^2 * \sigma^2}{H^2}$$

where:

n = sample size
z = level of confidence factor (for a 95% level of confidence, z = 1.96)
σ = estimated standard deviation (square root of the variance) of the data
H = accuracy of the estimate (+/-)

The equation was rearranged to provide a zone of ambiguity (+/- accuracy) on the median

$$H = \sqrt{(z^2 * \sigma^2 / n)}$$

Since the sample size is the number of responses to the questionnaire, the equation could provide three results for each hypothesis.

- **Supported.** If value of the Median is positive and the zone of ambiguity does not overlap

[7] Without follow up reminders to non-responders.

the zero line, i.e., (Median > 0) and (Median - H) > 0.

- **Refuted.** If value of the Median is negative and the zone of ambiguity does not overlap the zero line, i.e., (Median < 0) and (Median + H) < 0.
- **No clear result (ambiguous).** If the value of the Median is zero or the zone of ambiguity overlaps the zero line when overlaid on the median, i.e., (Median = 0) or (Abs (Median) < H)

For example, if, for a given sample size H = 2. Then if the Median of the responses is more positive than +2 the hypothesis is supported. If the Median of the responses is more negative than -2 the hypothesis is refuted. If the Median of the responses is between -2 and +2 then there is no clear result.

The results showed trends in the data even though there were no clear results in some parameters. Typical results are shown in Figure 5 and Figure 6. Support (S) and Refute (R) can be clearly seen for some of the hypotheses (questions) and subsets of the SDBs while the grey areas show no clear results. Even then, changes in the responses as a function of the subsets can be clearly seen in some instances. For example, the response to Q1 in Figure 5 changes from support for new companies to refute for companies that have been in business for more than 15 years. Since Q1 was 'Government regulations are too complex', the findings reflect that a learning curve may be in operation. Other results such as the response to Q4 in Figure 5 Q8 in Figure 6 need further data. In the event that such further information had been needed about a question or subset of the SDBs, a follow up survey could have been performed.

Company age	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
1991 - 1996	S	S	S		S	E	S	S	S	S	S		S
1986 - 1990			S	S	S	S	S	S	S				R
1981 - 1985		S	R	R	E	R	S		S	S		R	R
Pre 1981	R	S	E	S	R		S	R	R	S	R		R

Primary	
S	Support (>50%)
R	Refute (>50%)
	Ambiguous
Secondary	
E	Even [S=R] (±2%)
C	Complacent [0] (>50%)

Q1 Government regulations are too complex
Q2 The Government is not interested in dealing with a team of small businesses
Q7 Government "bundling of contracts" excludes Small and SDBs from competing, so why waste resources
Q11 My company can handle the whole contract Q12 The right opportunity has not come along
Q13 We never thought about it

Figure 5 Results by Company Age

Determination of a set of project failure indicators to predict project failure

All the measurements made during the System and software development lifecycle do not provide predictions of impending project failure. These measurements provide post facto information, namely they report on what has already happened. This causes management to be reactive instead of being proactive. (Kasser and Williams, 1998) describes the results of using holistic thinking to develop a set of 34 project failure prediction or risk-indicators and a methodology that applied the quantitative STP to develop an approach for ranking the top seven risk-indicators in the survey instead of using a pair-wise comparison method.

The traditional approach to evaluating the priority or ranking of a set of parameters is to use a pairwise comparison approach in which people are asked to compare each parameter against

Employee size	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13
1-10	S	S	S	S	S	S	S	S	S		R		R
11-25	S	S	S	S	R	R	S	S	S	S	R	R	R
26-50	E	S			S	S	S		S	S		E	R
51-100		S					S		E	R			R
101+	R	S	R	R	R	R	R				E	E	R

Q5 Teams of small businesses will not be perceived as being credible, so why bother
Q7 Government "bundling of contracts" excludes Small and SDBs from competing, so why waste resources
Q9 The time delay between submitting the proposal and the award date
Q10 Other Small and SDB owners are not easy to work with
Q11 My company can handle the whole contract
Q13 We never thought about it

Figure 6 Results by Company Size

all the others. However, the process is time consuming, and it was felt that the survery respondents would be detered from responding when faced with perfroming a pair-wise comparison on 34 parameters so the quantitative STP was used to reduce the number of parameters in consideration.

The survey first asked respondents to state if they agreed or disagreed that the risk-indicators were causes of project failure anfd then asked the respondents to rank their top seven risk-indicators as czauses of project failure in order of priority. The top seven (high priority) risk-indicators were identified using the following three approaches:

- **The Tally:** An "agree" was allocated a value of +1, a "disagree" a value of -1. The answers to each survey statement were then tallied.
- **Priorities:** The ranking of the top seven risk-indicators in order of priority.
- **Top Seven List:** Since the actual position in the ranking may be subjective, the number of times a risk-indicator showed up in the priority list was also tallied.

The results showed a high degree of consensus on these risk-indicators as causes of project failures. The (CHAOS, 1995) study served as a reference having identified some major reasons for project failure just a few years prior to this survey. The five risk-indicators in this study that were chosen as the most important causes for project failure also appear on the Chaos list of major reasons for project failure.

Part of the analysis of the survey results was to determine which risk-indicators received the most amounts of disagreement as causes of project failure. This was done by determining the:

- largest number of disagreements by the recipients;
- least number of agreements by the recipients.

In each method of analysis, the same six risk-indicators showed up in the group receiving the most amount of disagreement. The application of the quantitative STP increased the number of survey responses and provided useful information. The temporal STP can now be employed to use the risk-indicators as predictors of project failure should an audit take place to determine their presence.

Summary

The first part of this paper referred to earlier work in systems thinking and showed a difference between systems thinking and critical thinking, defined holistic thinking as a specific combination of systems thinking and critical thinking and showed that causal loops are tools used in critical thinking rather than elements of systems thinking. The second part of the paper provided examples of how holistic thinking resulted in innovative solutions to difficult problems. The contribution of the paper is the definition of holistic thinking and the examples of how holistic thinking produced innovative solutions to difficult problems.

Biography

Joseph Kasser combines knowledge of systems engineering, technology, management and educational pedagogy. Having been a practicing systems engineer and engineering manager since 1970 in the USA, Israel, and Australia he brought a wealth of experience and a unique perspective to academia in 1997. He has since become internationally recognised as one of the top systems engineering academics in the world. He is an INCOSE Fellow, the author of "A Framework for Understanding Systems Engineering", "Applying Total Quality Management to Systems Engineering" and many INCOSE symposia papers. He is a recipient of NASA's Manned Space Flight Awareness Award (Silver Snoopy) for quality and technical excellence for performing and directing systems engineering and the recipient of many other awards, plaques and letters of commendation and appreciation. He holds a Doctor of Science in Engineering Management from The George Washington University, is a Certified Manager and a certified member of the Association for Learning Technology. He gave up his positions as a Deputy Director and DSTO Associate Research Professor at the Systems Engineering and Evaluation Centre at the University of South Australia in early 2007 to move back to the UK to develop the world's first immersion course in systems engineering as a Leverhulme Visiting Professor at Cranfield University. He is an INCOSE Ambassador and also served as the initial president of INCOSE Australia and as a Region VI Representative to the INCOSE Member Board. He is currently a principal at the Right Requirement Ltd. in the UK and a Visiting Associate Professor at the National University of Singapore.

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