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Complex solutions for complex problems

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Abstract. *Simple problems can often be remedied with simple solutions; however, complex problems need to be remedied in a different manner. This paper discusses the traditional problem solving approach and then applies holistic thinking to introduce a modified problem solving methodology for remedying complex problems. The paper uses urban traffic congestion as an example of a complex problem and explores the development of a mixture of partial solutions that remedy different contributors to the problem in an interdependent manner.*

Keywords. *Problem solving, complex problems.*

1. Introduction

Before applying systems engineering to solving problems it would be useful to have a classification of types of problems and ways to remedy them. This paper discusses the traditional problem solving approach and then applies holistic thinking to introduce a modified problem solving methodology for remedying complex problems. The literature abounds with descriptions of different varieties of the problem solving process often using the same words but with slightly different meanings. Consequently to assist the reader, Table 2 contains a glossary of common words with the meanings applied in this document.

Two of these problem solving processes are shown in Table 1. The Global Development Research Center (GDRC) version covers the problem-identification-solution-identification steps, while the Office of Vocational and Adult Education (OVAE) version goes beyond the GDRC version and contains steps that not only implement the solution but evaluate the solution to determine if the solution remedied the problem.

Table 2 Glossary (Dictionary.com[1])

Complex	Composed of many interconnected parts; compound; composite.
Complicated	Difficult to analyse, understand, explain, etc.
Problem	Any question or matter involving doubt, uncertainty, or difficulty.
Simple	Easy to understand, deal with, use, etc.
Situation	The state of affairs; combination of circumstances.
Solution	The act of solving a problem, question, etc. In mathematics, the answer is the solution.
Symptom	Any phenomenon or circumstance accompanying something and serving as evidence of it.

Note: 1 Accessed in November 2011

Table 1 Two versions of the problem solving process

GDRC, 2009	OVAE, 2005
1. Problem definition 2. Problem analysis. 3. Generating possible solutions. 4. Analyzing the solutions. 5. Selecting the best solution(s). 6. Planning the next course of action (next steps)	1. Identify and select the problem 2. analyze the problem 3. Generate potential solutions 4. Select and plan the solution 5. Implement the solution 6. Evaluate the solution

If all the tasks and activities performed in the various problem-identification-solution-provisioning process described in the literature were arranged in an N^2 chart the various descriptions in the literature may be considered as different groupings in the same N^2 chart where some of the tasks and activities may also have been omitted in that particular version. For example, steps 5 and 6 in OVAE's version are absent in the GDRC version.

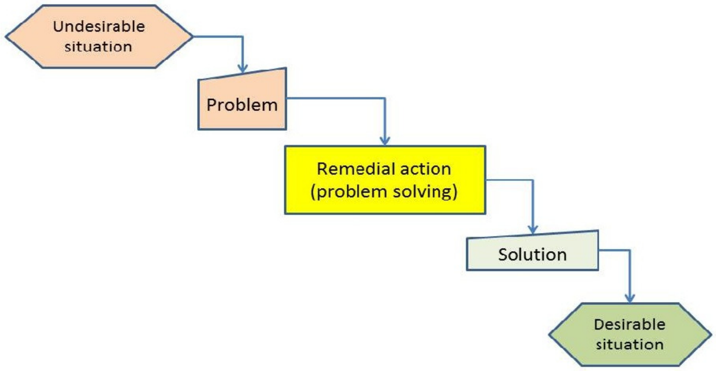

Figure 1 Problems and problem solving

Because "*problems do not present themselves as givens; they must be constructed by someone from problematic situations which are puzzling, troubling and uncertain*", the problem solving process must be considered in context as shown in Figure 1. Consequently, this process begins not with a problem, but with an undesirable situation. After some analysis of the symptoms the underlying problem is constructed. Then the problem solving process takes place to conceptualize and realize an optimal solution that should remedy the undesirable situation. Once the solution is realized the undesirable situation is changed into a desirable situation. This sequence may represent the classroom situation, but the real-world is somewhat different and more complicated for a number of reasons including:

1. After the solution has emerged transforming the undesirable situation into a desirable situation, a new undesirable situation may show up and the process has to iterate.
2. If solving the problem takes a long time, one or more undesirable situations may show up *while the undesirable situation is being remedied* and trigger a second problem solving process before the first one ends.
3. Errors made in each part of the process will produce undesirable outcomes. For example if the undesirable situation is converted to the wrong problem, not only will the solution not remedy the undesirable situation, the solution may make the situation even more undesirable. Similarly, if the correct problem is identified but the wrong solution conceptualized and realized then again the undesirable situation will not be remedied and may become even more undesirable. Even if the correct solution is conceptualized, errors in the realization process may produce an incorrect solution.
4. Even if the solution does remedy the original undesirable situation, it may not remedy the undesirable situation in existence at the time the solution is put into operation.

2. Classification of problems

As mentioned above, the various descriptions of the problem solving process in the literature, describe different sets of activities performed to remedy an undesirable situation. The descriptions also differ due to the type or classification of problem being remedied. There are several ways of classifying problems including:

- Level of difficulty of the problem.
- Structure of the problem.
- Complexity of the problem.

2.1. Level of difficulty of the problem

Ford introduced four categories of increasing order of difficulty for [well-structured] mathematics and science problems: easy, medium, ugly, and hard . These categories may be generalized and defined as follows:

- *Easy problems* are problems that can be solved in a short time with very little thought.
- *Medium problems* can be solved after some thought, may take a few more steps to solve than an easy problem and can probably be solved without too much difficulty, perhaps after some practice.
- *Ugly problems* are ones that will take a while to solve. Solving them involves a lot of thought, many steps and may require the use of several different concepts.

- *Hard problems* usually involve dealing with one or more unknowns. Solving them involves a lot of thought and some research and may also require iteration through the problem solving process as learning takes place (knowledge that was previously unknown becomes known).

Classifying problems by level of difficulty is difficult in itself because difficulty is subjective since one person's easy problem may be another person's medium, ugly or hard problem.

2.2. Structure of the problem

Problems lie on a continuum which ranges from 'well-structured' to 'ill-structured' problems where:

- **Well-structured problems** are problems where the existing undesired situation and the desired future situation are clearly identified. These problems may have a single solution or sometimes more than one correct solution. Examples of well-structured problems with single correct solutions are:
  - Mathematics and other problems posed by teachers to students in the classroom. For example 1 + 1 = 2 every time.
  - Finding the cheapest air fare between Singapore and Jacksonville, Florida (if there is only one cheapest fare.

  Examples of well-structured problems with several correct but different solutions are:

  - What brand of coffee to purchase? Although the solution may depend on price taste and other selection criteria, there may be more than one brand (solution) that meets all the criteria.
  - Which automated coffee maker to purchase?
  - What type of transportation capability to acquire?
  - Finding the cheapest air fare between Singapore and Jacksonville, Florida (if two airlines charge the same fare).

  When there are one or more solutions, selection criteria are developed to select the desired option. For example, if there are several tickets at the identical lowest price, then other criteria such as departure time, or length of journey including transit times at intermediate steps are used to choose between the solutions.

- **Ill-structured problems,** sometimes called 'ill-defined' problems or 'messy'[1] problems are problems where either or both the existing undesired situation and the desired future situation are unclear . Examples of ill-structured complex problems are:
  - The initial feeling (something is wrong and needs to be changed) that triggers the problem solving process.
  - Where to dispose of nuclear waste safely? This is where the desired future situation is unclear.
  - How to combat international terrorism? This is where different stakeholders perceive different causes of the situation and different solutions

2.3. Complexity of the problem

The complexity the problem is determined by the number of issues, functions, or variables involved in the problem; the degree of connectivity among those variables; the type of functional relationships among those properties; and the stability among the properties of the problem over time . Complex problems also contain interconnected variables where changes in one variable change the state of the other variables.

2.4. A problem classification matrix

The complexity and level of difficulty of problems are combined in matrix form in Figure 2 where the terminology is in accordance with the definitions in Table 2. The vertical dimension, complexity, ranges from non-complex through well-structured problems, ill-structured problems and Wicked Problems. The horizontal dimension covers the level of difficulty ranging from easy to hard; where simple problems are easy and medium while complicated problems are those that are ugly and hard. Different people may position a particular problem in different places in the matrix since knowledge gained from research, education and experience allows a person to reclassify the subjective difficulty of problem from 'hard' down the continuum towards 'easy'.

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[1] When complex.

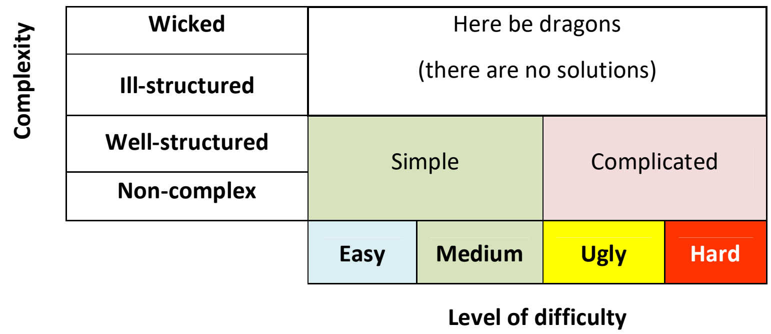

Figure 2 Problem classification matrix

Well-structured complex problems may be considered as a number of interconnected well-structured non-complex problems.

Ill-structured complex problems are posed in situations when the problem is unclear or poorly structured.

Wicked problems are extremely ill-structured complex problems first stated in the context of social policy planning . Wicked Problems :

- cannot be easily defined so that all stakeholders agree on the problem to solve;
- require complex judgements about the level of abstraction at which to define the problem;
- have no clear stopping rules (since there is no definitive 'problem', there is also no definitive 'solution' and the problem solving process ends when the resources, such as time, money, or energy, are consumed, not when some solution emerges);
- have better or worse solutions, not right and wrong ones;
- have no objective measure of success;
- require iteration-every trial counts;
- have no given alternative solutions-these must be discovered;
- often have strong moral, political or professional dimensions.

3. Solving the problem

Non-complex problems. In general:

- Easy well-structured problems are simple problems and require little if any research before creating the solution.
- Medium well-structured problems are less simple and require some research before creating the solution.
- Ugly well-structured problems are complicated yet require little if any research before creating the solution.
- Hard well-structured non-complex problems are complicated and require research before creating the solution.

Complex problems. Consider the three types of complex problems:

Well-structured complex problems consist of a set of interconnected well-structured non-complex problems and since the remedy to one may affect another, these problems cannot be solved in one pass thorough the problem solving process. Hence undesirable well-structured complex situations must remedied by evolving a solution using multiple passes of the problem solving process where each iteration produces a better (less undesirable) situation. Moreover, to make it more complicated, one party's remedy may be another party's undesirable situation and foster further change. For example the tank was developed to remedy the undesirable well-structured situation that machine guns were slaughtering attacking infantry attempting to cross the no man's land between the trenches in World War I. So, while tanks remedied an undesirable situation for the attacking forces, tanks created a new undesirable situation for the defending forces who then developed anti-tank weapons, which led in turn to further changes in military doctrine and technology, and so on

Ill-structured complex problems. These problems cannot be solved. They need to be converted to well-structured problems before attempting to provide solutions. However, different people convert ill-structured problems into different and sometimes contradictory well-structured problems and which would generate different and sometimes contradictory solutions.

Wicked Problems. The fundamental paradox with respect to Wicked Problems is that there are no problems; since while the stakeholders may agree that the situation is undesirable, they cannot agree on “the problem”, hence the attributes of Wicked Problems listed above . Since paradoxes may be dissolved by changing the paradigm, change the way Wicked Problems are conceptualized. Describe Wicked Problems, not as problems but as Wicked Situations in which,

1. There is an undesirable situation where different stakeholders perceive different symptoms, problems and solutions.
2. The stakeholders often lack an understanding of the point of view or concerns of other stakeholders.

Wicked Situations may manifest themselves in the first step of the scientific method problem solving process even if nobody is consciously using the scientific method to address the problem. That is, the current situation is under observation, but a working hypothesis to explain the causes of the observations (desirable and undesirable) has yet to be developed. For example, the state of the art of chemistry before the development of the periodic table of the elements could have been considered as a Wicked Situation, as could the state of electrical engineering before the development of Ohm’s Law.

3.1. The complex problem solving process

As mentioned earlier, there are many aggregations of the activities performed in the problem solving process, consider the activities as being aggregated into the following phases:

1. The current situation analysis phase.
2. The conceptual solution design phase.
3. The solution selection phase.
4. The solution realization planning phase.
5. The solution realization phase.
6. The test and evaluation phase.
7. The in-service phase.

The current situation analysis phase. This stage of the complex problem solving process bypasses trying to convert the ill-structured problem to a well-structured problem and focuses instead on gaining consensus on the nature of the feasible conceptual future desired situation (FCFDS). The FCFDS can be described in a number of scenarios. For example, consider the undesirable situation that result from traffic congestion in a large city. The mayor, feeling under pressure to do something about the growing traffic congestion in her city, provides the trigger to initiate the process which begins with the ill-structured problem of how to remedy the effects of traffic congestion.

The solution depends on the vision of the FCFDS. If the vision is of traffic moving purposely at a reasonable speed from suburbs to CBD, efforts to realize that solution will depend on the meanings associated with ‘a reasonable speed’. If, on the other hand, the vision is stated as the city allows people to fulfill the purpose of their journey with a minimum amount of commuter traffic. The meaning of ‘minimum’ in this case is what the mayor wishes to assign to the term.

The stakeholders produce a number of FCFDS that include:

- Tolls or charges on the main routes into the CBD to try to persuade commuters to leave their vehicles at home and ride public transport.
- University extensions being located in the suburbs to localize student travel. These extensions might contain traditional classrooms or be linked via two-way teleconferencing technology to classrooms in the CBD campus.
- Offices (government and non-government) being located outside the CBD.
- Vehicular road traffic being moved in the most efficient manner using a computer controlled traffic system.
- New high-speed roadways with limited entrances and exits to move vehicles in and out of the CBD. These may be bidirectional the entire day, or allow traffic in different directions in the mornings, evenings and weekends.
- New light rail services.
- Additional buses and bus routes.
- A tax on ownership of private vehicles discouraging same.
- A ban on deliveries and delivery vehicles in the CBD during commuting hours.

- A ban on deliveries and delivery vehicles in the CBD during daylight hours.

The traditional approach in the current paradigm is to consider these solutions as different single and possibly conflicting problems. Stakeholders talk about the problem posed by the traffic congestion (undesirable situation) as being the realization of their specific FCFDS. The systems approach however, considers each FCFDS as a potential partial remedy to the whole undesirable situation. Thus the ill-structured problem posed by remedying the effects of traffic congestion has been transformed into a number of well-structured problems, namely how to realize each FCFDS listed above.

The conceptual solution design phase is the same as in the traditional process. Each FCFDS is designed to the point where the feasibility, risks, costs, realization schedule, etc. are determined.

The solution selection phase begins with the process for solving non-complex problems, namely developing selection criteria, and evaluating each FCFDS against the selection criteria which might include:

- *Cost*. The city has a limited budget.
- *Schedule.* How soon the FCFDS will be needed, when certain undesirable aspects of the current situation will become unbearable, etc.
- *Political*. The need to award development contracts to certain contractors for a variety of reasons.
- *Performance.* The degree that the FCFDS changes the current situation for the better.
- *Resiliency and robustness.* The ability of the FCFDS to recover from a disaster, natural or man-made.

Selection of several partial solutions. The problem solving process for non-complex problems ends when a single FCFDS is chosen. In the problem solving process for complex problems several FCFDS can be chosen depending on the situation. For example:

- The budget may cover more than one partial solution.
- It will take a number of partial solutions to provide the desired decease in congestion.
- Some partial solutions can be implemented quickly to provide short-term relief.

The solution realization planning, solution realization and test and evaluation phases for the partial solutions are almost the same as the current phases for single solutions. The planning for each partial solution realization effort has to not only realize its solution but also integrate with the other partial solutions as and when they are realized.

The in-service phase begins with an evaluation of how much of a remedy is provided by the partial solution in the then current undesirable situation. The degree of undesirability of the changed situation drives the next iteration of the process.

4. Summary

This paper discussed the traditional problem solving approach and then applied holistic thinking to introduce a modified problem solving methodology for remedying complex problems. The paper used urban traffic congestion as an example of a complex problem and explored the development of a mixture of partial solutions that remedied different contributors to the complex problem in an interdependent manner.

5. Conclusion

Complex problems can be remedied, but not by a single simple solution. The complex problem solving process iterates evolving partial solutions until an undesirable situation no longer exists, namely:

1. Convert the ill-structured complex problem to a well-structured problem.
2. Convert the well-structured complex problem to a set of well-structured non-complex problems that provide partial solutions to the complex problem.
3. Realize a partial solution to the complex problem by remedying one or more of the non-complex problems.
4. Reexamine the undesirability of the changed situation.
5. Go back to step 1.

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