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The process must fit the problem: Integrating root cause analysis with the system dynamics modeling process for difficult problems

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Supplementary Materials

Due to space limitations, these sections from the paper are here.

Current methods for finding a difficult large-scale social problem's root causes

What explicit method does the system dynamics literature offer to find a difficult large-scale social problem's root causes?

The leading textbook on system dynamics, *Business Dynamics* (Sterman, 2000), addresses the issue of finding causes by providing process step 2: "Formulating a dynamic hypothesis or theory about the causes of the problem" (p87). No method for doing this is provided, other than what works for client consulting, the most common use of system dynamics: "In practice, discussion of the problem and theories about the causes of the problem are jumbled together in conversation with client teams. Each member of a team likely has a different theory about the source of the problem; you need to acknowledge and capture them all" and from that "help the client develop an endogenous explanation for the problematic dynamics" (p95).

While this process can work for problems of a client consulting nature, it is not applicable to difficult large-scale social problems as historically intractable as environmental sustainability. In this class of problems there are no client teams. There is only a vast system of billions of selfish social agents (people, families, corporations, governments, politicians, etc.) engaged in an endless struggle for survival of the fittest. Sterman's claim (p85) that "the process, however, is similar for other contexts as well," including when the client is "the public at large," does not in our opinion hold for this class of problems.

The omission of an explicit method for finding a public interest problem's causes can be traced back to Forrester's (1971, p. 26) chapter in *The Systematic Basic of Policy Making in the 1990s*. There he stated that "The next frontier for

human endeavor is to pioneer a better understanding of environmental, economic, and social systems. The means are available." What are those means? He offered nothing more than system dynamics modeling: "It is now possible to take hypotheses about separate parts of a social system, combine them in a computer model, and learn the consequences."

How are those cause-and-effect hypotheses generated? The chapter did not say. But a later paper (Forrester, 1991) did: "The system dynamics process starts from a problem to be solved…. The first step is to tap the wealth of information that people possess in their heads. The mental data base is a rich source of information about the parts of a system, about the information available at different points in a system, and about the policies being followed in decision making." This mental data base is elicited in client interviews, as described above by Sterman in *Business Dynamics*.

That client interviews are seen as the only good source of dynamic hypothesis insights (other than from the model builder) was documented by the best practices of system dynamics study (Martinez-Moyano and Richardson, 2013). Of the nine "best-practice statements in system conceptualization," only one described an explicit method for generating cause-and-effect hypotheses: "Elicit clients' mental models to help develop the building blocks of the dynamic hypothesis."

We therefore conclude that present system dynamics modeling processes offer no effective method for finding a difficult problem's root causes.

How we found the root causes

Now that we have SIP, if we did the analysis again it would go an order of magnitude faster since we now have a standard structured problem-solving process for the problem type. Taken one at a time, each subproblem SFD looks so simple and obvious. What was hard the first time would now be straightforward, just as it is for mature industrial RCA-based processes.

The analysis was fraught with a long intricate series of hundreds of wrong ideas that had to be reworked. So much creativity, investigation, and iteration was required the project took seven years. Basically, we kept asking WHY does this occur and building tight causal chains until the analysis stabilized into the matrix of Figure 7, the SIP Summary of Analysis Results. The matrix was our guiding light. We kept adding and changing rows and columns and cell contents until the matrix said one thing loud and clear: This is the high-level essential causal structure of the problem. It all makes coherent sense and explains everything needing explanation.

Subproblem A. After defining the environmental sustainability problem, we asked WHY, after over thirty years of effort, has society failed to solve the problem? The answer was high change resistance to proposed solutions. This caused subproblem A to appear. Then we asked WHY is opposition to proposed solutions so high? That led to building The Dueling Loops of the Political Powerplace system dynamics model and the exciting insight that one loop, The Race to the Bottom

Among Politicians, had an inherent advantage over the other loop, The Race to the Top Among Politicians. This caused the Race to the Bottom to be the dominant loop most of the time, and was the main root cause of subproblem A.

Subproblem B. As we developed this model, it became apparent that politicians in the Race to the Top, because they appealed to voters on the basis of the truth about what's best for the common good (the basis of a healthy democracy), were essentially working for *Homo sapiens*, The People. Meanwhile, politicians in the Race to the Bottom were using political deception to support the goals of powerful special interests. By far the most powerful was *Corporatis profitis*, large for-profit corporations. This revealed subproblem B. Large for-profit corporations were dominating political decision making destructively. The root cause of this is mutually exclusive goals between the top two life forms in the biosphere, *Corporatis profitis* and *Homo sapiens*.

Subproblem C. Discovery of this subproblem, How to avoid excessive solution model drift, occurred when we asked WHY didn't governments solve the environmental sustainability when it was small and keep it solved as it grew large? Millions of small local pollution problems, water shortage problems, topsoil loss problems, and so on had been solved all over the world for thousands of years. But as the PAT factors in the IPAT equation grew and total impact began reaching its Limits to Growth, governments had been unable to keep up. Their sustainability solutions deteriorated. WHY was this? The ultimate answer was the root cause: a high rate of defects in the political decision-making process.

Subproblem D. The original problem to solve became subproblem D. There we asked WHY is the economic system causing unsustainable environmental impact? Because of externalized costs of environmental impact. To correct that, popular solutions have long focused on internalizing those costs. But these solutions have not worked, so they must be superficial and externalized costs of environmental impact must be an intermediate cause. WHY do so many externalized costs occur? What is the deeper cause? Eventually we asked WHY are externalized costs so much higher for common property than private property? This led to the root cause: High transaction costs for managing common property, like the air we breathe, the water we drink, the oceans we share, the topsoil we grow food on, and critical non-renewable natural resources we depend on to "never" run out.

How we developed SIP

This was done simultaneously while applying it. As the matrix evolved, we continually reviewed our research and identified these reusable concepts:

1. In difficult large-scale social problems like sustainability, the next task after *problem definition* must be *problem decomposition* into smaller and easier to analyze subproblems. You have to figure out what the columns should be.

2. Each column can be arranged into a visual diagram that contains additional information on the mode change required to resolve the powerful root cause

forces causing lock-in to the present undesired mode. This became *social force diagrams*.

3. Subproblems A and C, plus the original proper coupling problem, are the *standard three subproblems* found in all difficult large-scale social problem, such as those listed in Figure 9.
4. We had created a checklist procedure for finding and validating (at a high level) the feedback loop structure of the superficial and fundamental layers of each subproblem. We were using the same systematic series of steps in each column. This became the *five substeps of analysis*.

These concepts became the main components of SIP: a tight minimalistic problem definition to focus your work, problem decomposition, social force diagrams, the standard three subproblems, and the five substeps of analysis.

Integrated Process Step 6B. Empirical testing of solution elements

This section examines an important benefit of the integrated process.

This process step runs laboratory experiments, field experiments, and pilot projects (a type of experiment) as necessary. "However, in many settings, particularly in the human and social systems where system dynamics is often used, RCTs, [randomized controlled trials] and experiments are often prohibitively expensive, time consuming, unethical or simply impossible (Sterman, 2018)." These barriers to experimentation arise because it is usually superficial solutions that are being tested, like those listed in Summary of Analysis Results (Figure 7), the row for superficial solutions.

Analysis results show it is not superficial solutions but fundamental solutions that need testing. These tests are usually much faster and less expensive to run because of the higher leverage involved. The higher the leverage, the more a solution (and hence solution tests) focuses on a smaller and more easily changed portion of the social system's structure. Let's explain this with an example.

Earlier in the Conclusion 5 section we wrote "Because political truth literacy is low, corporate deception works and has become the cornerstone strategy for achieving the interests of Corporatis profitis." The superficial solution strategy to counter this deception is misinformation correction, using fact checks, articles, social media posts, news, and so on to point out the truth. For this to work, most misinformation has to be corrected and most citizens have to see most corrections. This fails. For example, "We almost never observe respondents reading a fact-check of a specific claim in a fake news article that they read" (Guess et al., 2018). Misinformation can seldom be corrected if people seldom read the correction, which explains why "more of the truth" is a low leverage point strategy.

Conclusion 5 explained how the main root cause of subproblem A is low political truth literacy. The high leverage point for resolving this root cause is raise

political truth literacy from low to high. To test this high leverage point we designed the Truth Literacy Training solution element and ran an experiment on 93 US subjects randomly assigned to three groups. An online Prolific panel and our own training/testing website and software was used. Group 1 (the control group) received training on a neutral topic. Group 2 received training on logical truth literacy, the ability to tell if a political claim is true or false. This works by training on how to spot the pattern of fallacies found to be common in deceptive political claims, like cherry picking, ad hominem attack, appeal to emotion, etc.

Group 3 received the same training as group 2 plus training on how to vote correctly given the perceived level of truth in a political claim, which is political truth literacy. Training and testing averaged 87 minutes. Results show that political truth literacy is low, under 10% (group 1). This confirmed the analysis hypothesis that presently political truth literacy is low. Results also showed it can be raised to high, about 67% (group 3). A follow up study 26 days later found the group 3 effect persisted and had fallen only seven percentage points. Thirty minutes of refresh training restored the effect. Group 3's behavior confirmed the high leverage point is potentially valid, i.e., its root cause can be resolved.

Much further research and replication remains. However, we interpret these results to mean that in a democracy, political truth literacy training is as essential to a citizen's education as reading, writing, and math literacy. Given the very small amount of training required to achieve study results, this training would require much less expense than teaching the other forms of literacy. Similar results of inoculation against misinformation have been reported by others (Cook et al., 2017; Roozenbeek and van der Linden, 2019), though these studies did not focus on political truth literacy.

The Truth Literacy Training solution element inoculates citizens against common forms of deceptive claims found in the media. Truth literate citizens can spot fallacious arguments quickly by spotting fallacy patterns. This solution strategy is several orders of magnitude more efficient than misinformation correction strategy. This difference in efficiency makes testing of high leverage solutions more efficient.

For example, an experiment designed to test misinformation correction on common forms of political deception on common issues, would be highly complex and expensive. Suppose there are 10 common political fallacies, 10 common issues, and the average citizen sees 1 out of 100 misinformation corrections. The number of deceptive political claim cases is 10 x 10 x 100 = 10,000 cases. Each must be corrected with a fact check. Complete case coverage would require 10,000 claims in a questionnaire and some sort of mechanism that simulated (endogenously, of course) the percentage of corrected false claims (questions) a person would find along with the large amount of time the average person spends consuming information. This is probably so hard to do realistically that a field instead of a laboratory experiment would be required to host the 10,000 cases, and training and questionnaire time would run into many days or weeks for realism. In practice, experimental

designs test a statistically valid small sample of all cases. Still, this would be a major experiment.

By contrast, an inoculation against misinformation experiment only has to test 10 types of fallacies, because the issue is irrelevant and misinformation correction is not used. Only 10 cases are needed for complete coverage, using a short laboratory experiment as we have done. Our study used 17 questions in random order, of which 13 were fallacious.

This example demonstrates how an RCA approach can greatly reduce the barriers presently holding back policy testing, because testing is done on high leverage points instead of low leverage points. This assumes that high versus low leverage points exist in the problem, which we expect holds for all difficult large-scale social problems.

How long will it take system dynamics to accept the Deming philosophy?

We have one paramount concern. "Dr. W. Edwards Deming is widely credited as the management philosopher most influential in the economic recovery of post-war Japan as well as the 20th Century ascent of quality as a strategic approach toward organizational leadership and culture" (Polito et al., 2004). Deming had first tried to interest Americans in his approach. Yet he was largely ignored (May, 2007, p. 169). By contrast, after Deming arrived in Japan in 1950, "Japan soaked it up" (ibid, p170).

Years later, when Japanese exports began flooding into the United States due to consistently high quality and low cost, American industry took note but resisted the Deming paradigm. First, the theory said Japan was winning because of low labor cost. But when Japanese wages rose to equal those in the US, nothing changed. Then the theory was Japan's new factories and equipment was the advantage. After General Motors spent 70 billion dollars on new technology and still lost market share, the theory morphed again. It must be the soft yen, which allowed cheap exports. When the yen reached parity with the dollar, nothing changed. (Gabor, 1990, p. 4)

Ultimately a few insightful senior managers realized the Japanese advantage must be due to something more fundamental. In 1981 Ford engaged Deming. Because of Ford's success, Demings's philosophy of RCA-based continuous quality improvement immediately began spreading across Western industry. But it had taken the West thirty years to accept what Japanese managers had accepted in a single series of a dozen lectures given by Deming in 1950 (ibid, p80).

Industrial RCA revolves around the concepts of defects and root causes. RCA is used to maximize the quality of solutions to customer's problems by minimizing average defects per solution. Anything that displeases the customer is a defect. Defects arise from root causes. Six Sigma, an RCA-based process for radical improvement of core business processes, routinely cuts defect rates by an astonishing three

orders of magnitude, from roughly 6,210 defects per million transactions to 3.4, as process maturity in an established company rises from a typical initial level of Sigma 4 to a final level of 6 (Pyzdek, 2003, pp. 5 & 60). While this data applies to manufacturing and service industries, the concept applies to all industries.

Our field has a quality problem. On difficult problems, the present modeling process produces low quality solutions due to a high rate of defects per solution. Solutions, not models, are our product.

How long will it take our own field to accept the Deming philosophy?

"We need to start making some tough choices about who we are and who we are not, or else we will just keep wandering along the aimless plateau" (Homer, 2013).

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