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All problems arise from their root causes.

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Triggering Transition to the Sustainable Mode with Root Cause Analysis

Abstract

The core challenge of sustainability science is how to rapidly shift the world's socio-ecological system to a sustainable mode. To meet that challenge this paper proposes a cross-discipline infusion of knowledge. The powerful business tool of root cause analysis can be adapted to fit the sustainability problem. As engineers and business managers, the authors have some familiarity with the tool and its role as the foundation of process-driven problem solving. Root cause analysis, when properly wrapped in a process that fits the problem, enables efficient and correct identification of a problem's essential causal structure, regardless of problem type or difficulty. When such a process is applied to the sustainability problem, knowledge of causal structure allows a rigorous approach to solution by informed design of the system's critical structure, in a manner not unlike that of architecture, mechanical, and civil engineering.

Using standard business process procedures, we have taken a preliminary first pass at adapting root cause analysis and applying it to the sustainability problem. To demonstrate the tool's potential the paper presents the adapted tool and analysis results.

Introduction

Now that *Homo sapiens* has stumbled into the Anthropocene, one supreme puzzle confronts our presumptuous species. How exactly do we manage the biosphere sustainably?

That the global environmental sustainability problem, especially the climate change crisis, needs immediate solution has reached a crescendo of scientific consensus (Barnosky et al. 2015). But how to transition to a sustainable world has reached no consensus. Regulations haven't worked. Nor have market-based instruments, like carbon taxes or emissions trading. Nor has a long series of international summits. Problem difficulty is so extreme it has been classed as a wicked problem, "which are generally seen as complex, open-ended, and intractable (Head 2008)." For the climate change crisis some go one step further, classifying it as a super wicked problem with even greater intractability (Levin et al. 2012).

This presents an enormous challenge. How can sustainability scientists end the pattern of repeated solution failure and find solution strategies that will work?

From the beginning the field focused on finding the “appropriate methodologies” (Kates et al. 2001) necessary for “understanding the complex dynamics” of socio-ecological systems (Clark 2007). The emerging paradigm soon coalesced on the need to move “from slogans to specific tools and processes that help us understand complexity [and] design better policies” (Sterman 2012) and in particular, to “a comprehensive framework for answering” the question of how to achieve a sustainable future (Levin 2012).

Researchers responded with a wide range of frameworks, one of the most influential being Ostrom’s general socio-ecological system framework (e.g. Hinkel et al., 2014). Berg (2011) and Markard (2012) found six main types of transition frameworks: innovation systems, multi-level perspective, complex systems, evolutionary systems, transition management, and strategic niche management, with scores of lesser types. Generic frameworks being applied to the sustainability problem include comparative analysis (e.g. Diamond, 2005), scenario analysis (Swart et al. 2004), integrated world modeling (as in Table 1), and Bernstein’s (2015) meta-framework of transdisciplinary research. Moving from the general to the specific, The Natural Step framework (Robèrt 2008) is application ready, widely used, and has offices in some 25 countries. The United Nations Environmental Programme (UNEP 2012) used its “drivers, pressures, state, impact, and responses (DPSIR) analytical framework” as the basis for its latest Global Environmental Outlook.

However, these frameworks are ineffective. None have been able to halt the steady rise of the world’s ecological footprint, now at over 50% overshoot (Footprint 2015), or the rise of greenhouse gas emissions, which increased from a growth rate of 1.5%/year from 1980-2000 to an alarming 3%/year in 2000-2012 (Hansen et al. 2013). Bettencourt and Kaur (2011) found that despite explosive growth in the sustainability literature and unification of collaboration, there is “[no] direct evidence that sustainability science has created a new community of practice and a new synthesis in terms of concepts and methods. ...such unification is the hallmark of a true field of science.” The field struggles on in search of a methodology that works.

Sustainability science thus faces a critical knowledge gap. But where exactly is the gap? What “concepts and methods” are missing?

We conclude, based on the following research, that a single missing concept/method has the potential to explain lack of solution success. The concept is root causes. The method is root cause analysis.

None of the frameworks listed above seek to find and resolve the sustainability problem’s root causes using root cause analysis, except the UNEP’s DPSIR. That framework, however, does not use root cause analysis. It uses pseudo root cause analysis. While the UNEP’s latest report (UNEP, 2012, p483) stresses the need “to invest in solutions that will help tackle the root causes, not merely the symptoms,” most of the eight basic practices of root cause analysis (listed below) are missing. “Drivers,” used as a synonym for root causes, are not defined the way root causes need to be but as “overarching socio-economic forces.” The root causes found, population and economic growth, are in fact the PAT factors in the IPAT equation (Chertow 2001). These are not root causes but intermediate causes. For example, there are deeper causes of the P factor, over-population, like lack of a demographic transition, poverty, rising life expectancy, and mechanized agriculture. Still, it is heartening to hear the UNEP recognizes the need to “tackle the root causes.”

The closest we came to finding a case of all the basic practices of root cause analysis being followed was a World Wildlife Fund project completed in 2000. *The Root Causes of Biodiversity Loss* (Wood et al. 2000) presents a “framework for analyzing socioeconomic root causes of biodiversity loss....” (p11) The book uses the term “root cause” frequently, a good practice. However, it defines root cause incorrectly. It also searches for initial root cause hypotheses in the literature instead of tracing causal structure in the actual system. The root causes thus found, like population growth, poverty, immigration, and inequality, are broad intermediate causes rather than focused root causes. Still, the project is a strong step in the right direction.

These two examples reveal how far away current problem solving processes are from what’s needed. Problem solvers in two of the world’s most influential environmental organizations *thought* they were performing root cause analysis, but in fact were not. Study of the sustainability literature and environmental organizations found thousands of uses of terms like root causes, underlying causes, ultimate causes, and so on, but failed to find any cases of true root cause analysis, ones that would be recognized as such by the business world. Scholars and organizations are trying to move forward and practice root cause analysis, but a suitable method for doing that is nowhere to be found.

Accordingly, the objective of this paper is to demonstrate how the powerful business tool of root cause analysis can be adapted and applied to the sustainability problem. We deliberately refrain from any broader claims. Our scope is limited to the question of whether this adaptation could be productive.

The paper begins with an overview of root cause analysis as presently used in business, followed by description of a root cause analysis based framework designed specifically for analyzing the sustainability problem, and then analysis results.

Overview of root cause analysis

As a basic engineering practice, root cause analysis rests on several axiomatic principles: All problems arise from their root causes. If a problem’s root causes are unknown, the problem cannot be solved except by trial and error. Solution failure always indicates the solution did not resolve the root causes. Difficult problems tend to have multiple root causes. The root cause analysis process employed must be continuously improved, so that hard to find root causes may be found and *all* may be controlled over the life of the system. It is the process that solves problems, not the solutions.

For example, the root cause of infectious disease was eventually found to be germs. Once the root cause was known most infection problems were easily solved, either by prevention with hand washing, antiseptics, inoculation, and other techniques, or by treatment with antibiotics, etc. Later additional root causes were found, like a weakened immune system or infection control team practices. The latter, a social system problem rather than a technical problem, has been addressed by introduction of root cause analysis (Venier 2015).

A *root cause* is the deepest cause in a causal chain that can be resolved. A *causal chain* (aka causal structure) is a series of cause-and-effect relationships running from root causes to intermediate causes to problem symptoms.

Root cause analysis is the process of finding and resolving the root causes of a problem. This requires finding the essential causal structure of a problem, by starting at problem symptoms and following the causal chain (which may involve feedback loops) backwards until the root causes are found. As each cause-and-effect relationship is identified the causal structure is drawn and if necessary modeled. When done a cause-and-effect diagram exists. This diagram (and the model behind it) represents the simplest possible description of the knowledge needed to solve the problem. Everything else has been ignored because it doesn't matter. The signal has been separated from the noise.

This approach has long worked for business in the form of sophisticated processes based on root cause analysis (Horev 2010; Okes 2009; Andersen & Fagerhaug 2006). Modern quality control, on which entire industries like high tech electronics and auto manufacture are based, depends on root cause analysis to achieve consistent high quality by statistical control of the root causes of manufacturing defects (Wilson 1993; Black & Revere 2006). NASA could have never put a man on the moon or a rover on Mars without its Root Cause Analysis Tool (NASA Safety Center 2013). In 1998 the U.S. Joint Commission Accreditation of Healthcare Organizations began requiring use of root cause analysis for all adverse events (Anderson et al., 2010, p3). Root cause analysis has grown to be so critically important to business that 82% of Fortune 100 companies use Six Sigma, the most popular root cause analysis process (Antony 2004).

How standard root cause analysis works

The quality revolution, really the root cause revolution, began in Japan over a hundred years ago. Invention of root cause analysis is credited to Sakichi Toyoda (1867-1930), "king of Japanese inventors" and founder of Toyota. Toyoda's method came to be called

"The Five Whys." The method asks why five times or until the root cause(s) of a problem are found. "When a problem arises... we repeatedly ask why. This is the scientific basis of the Toyota system (Ohno, 1988, p18&77)."

For difficult problems, study of leading business root cause analysis processes (Anderson et al. 2010; Horev 2010; Liker 2004; May 2007; NASA Safety Center 2013; Okes 2009; Pande et al. 2000; Pyzdek 2003) leads us to conclude that a minimum of *eight basic practices* are required:

1. Frequent use of the term "root cause" or an equivalent.
2. Definition of the term as the deepest cause in a causal chain that can be resolved, plus additional criteria as needed for the problem type.
3. Strict adherence to the principle that problems can be solved only by controlling their root causes.
4. Following causal flow by starting at problem symptoms and working backward to the root causes.
5. Written description of the causal structure found.
6. Design of solutions to resolve specific root causes.
7. Continuous improvement of the process.
8. Detailed written description of the entire process.

If any practices are missing from a process it is pseudo root cause analysis and will usually fail on difficult problems. The more practices missing, the more likely the process will fail.

Adapting root cause analysis to fit the problem

Problems vary, so to apply root cause analysis to a particular class of problems a custom process is required. The business world has developed and evolved a number of custom processes, called wrappers. A *wrapper* packages something to make it more transportable, cohesive, and useful. Root cause analysis has achieved extensive success in business using process wrappers like Six Sigma (Pande et al. 2000; Antony 2004), Lean Production (Womack et al. 1990), Kaizen (Imai 1986), the ISO 9000 family of standards, Intel's Manufacturing Quality Process (Intel 2013), The Toyota Production System (Ohno 1988), and NASA's Root Cause Analysis Tool (NASA Safety Center 2013). The first four are generic. The last three are particularly fine examples of creating a custom process wrapper for a unique type of problem. For instance:

> "After extensive review, NASA found that none of the commercially available tools and methods would support a comprehensive root cause analysis of all the unique problems and environments NASA faces on the Earth, in the ocean, in the air, in space, and on moons and planetary bodies. Existing tools were designed for a specific domain (e.g., aviation), a specific type of activity, a specific type of human error (e.g., errors of omission) or had a limited set of cause codes. The NASA RCAT, a paper-based tool with companion software (now available free to government Agencies and contractors), was designed to address the shortcomings identified in existing tools.
>
> The NASA RCAT was designed with the whole system in mind, so that all potential types of activities and all potential causes of accidents, whether they be initiated by hardware, software, humans, the environment, weather, natural phenomenon, or external events, could be incorporated into the timeline, fault tree, and event and causal factor tree. The RCAT aids users by providing a step-by-step guide, intuitive logic diagramming capability, standard terminology, standard definitions and standard symbols."

Social problems like sustainability differ substantially from business problems. Business problems typically consist of excessively high rates of defects or incidents. Difficult large-scale social problems (like sustainability, war, endemic poverty, and large recessions) consist of a large part or all of a social system being in the wrong mode, such as being unsustainable or being at war. This very different class of problems requires a very different process. As a result it has been impossible to apply off-the-shelf forms of root cause analysis to the sustainability problem.

To fill this gap the authors created the System Improvement Process. The process is generic and was designed to solve any difficult large-scale social problem whose solution would benefit the common good. The process was iteratively developed and applied to the sustainability problem until the process was mature enough to generate a comprehensive analysis of the problem that could demonstrate the power of the tool.

How the System Improvement Process (SIP) works

Social force diagrams

SIP is a problem solving framework. The one big problem is first decomposed into smaller subproblems, each of which becomes much easier to analyze. Each subproblem then undergoes root cause analysis using a modified form of cause-and-effect diagrams (Ishikawa 1986), called a social force diagram (Figure 1). Each social force diagram captures the high level essential causal structure of a subproblem.

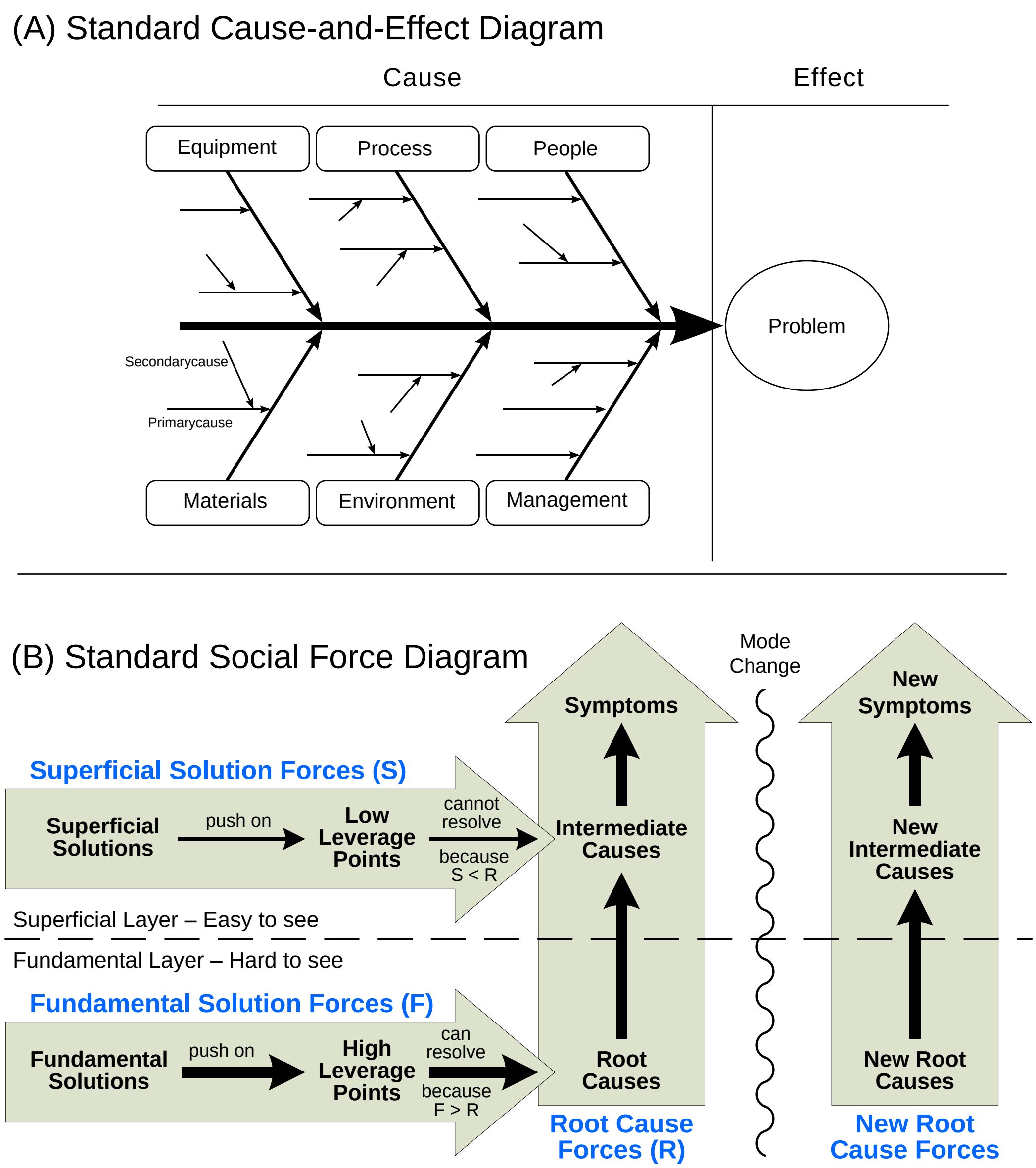

Figure 1. Standard cause-and-effect and social force diagrams. (A) Cause-and-effect diagrams show the causal tree leading to a problem. The six standard industrial subproblems are shown. Image source: https://en.wikipedia.org/wiki/Ishikawa_diagram. (B) Social force diagrams rearrange the causal tree of cause-and-effect diagrams into a format emphasizing the superficial and fundamental layers of the problem, the three main forces that must be understood to solve the problem, and the mode change that occurs when a problem is solved.

Like cause-and-effect diagrams (aka fishbone or Ishikawa diagrams), social force diagrams offer a structured method for analyzing a problem. In Figure 1B the eight line arrows represent cause-and-effect forces. The large box arrows represent the three main forces. Difference in force strength is illustrated by line arrow thickness. Correct application of fundamental solution forces causes a system mode change (aka regime shift), resulting in the new mode on the far right.

Social force diagrams simplify difficult social problems to their three main forces. The first is the *root cause forces* causing the problem. In difficult problems this systemic force is so strong it causes mode lock-in and inherently high change resistance. In this paper *systemic* means "originating from the system in such a manner as to affect the behavior of most or all social agents of certain types, as opposed to originating from individual agents (Harich 2010)." Lock-in to the wrong mode as the core of the sustainability problem has long been noted: "Each man is locked into a system that compels him to increase his herd without limit—in a world that is limited (Hardin 1968)."

Working backward from the symptoms, problem solvers identify what they believe are the causes and develop solutions based on that assumption. If it's a difficult problem the solutions fail at first because they are *superficial solution forces* attempting to resolve intermediate causes. This is the second type of force.

Usually all that problems solvers can see in the initial phase of solving a difficult problem is the superficial layer. But with application of root cause analysis problem solvers can penetrate to the fundamental layer and see the complete problem. There they will find the root causes. Once the root cause forces are known the third type of force can be employed. *Fundamental solution forces*, if properly designed, resolve the root cause by changing the feedback loop structure of the system such that a new homeostasis (aka dynamic equilibrium) becomes more attractive. Lock-in to the present mode ends, causing the system to quickly transition to the new mode. The system stays locked into the new mode due to the *new root cause forces* introduced by the fundamental solution forces. If the analysis (including testing) is sufficiently rigorous the solution force will solve the problem rapidly, efficiently, and permanently. Here *permanent* means no change in mode status is expected until another large problem appears. In particular, the system will not backslide to the prior mode.

A *leverage point* is the exact place in a social system structure a solution pushes on. SIP advocates modeling difficult problems, so the point is a node in the model corresponding to factors in the real world. A *low leverage point* is connected to an intermediate cause (aka false root cause or proximate cause) in such a manner that pushing on the low leverage point will reduce, but not resolve, the intermediate cause. *Superficial solutions* (aka symptomatic solutions) push on low leverage points. A *high leverage point* is connected to a root cause such that pushing on the point with *fundamental solutions* will resolve the root cause.

We can now explain an important phenomenon. Figure 1B offers a clear explanation of the historic pattern of repeated solution failure described in the Introduction. If sustainability solutions were designed to resolve specific root causes, solution success would be evident by now. Solutions are failing because they unknowingly attempt to resolve the intuitively attractive easy to find intermediate causes, rather than the much harder to find counterintuitive root causes. The root causes are buried so deep in the complexity of the system that they have not yet been discovered. Current sustainability solutions are unable to tip the system into a sustainable mode, no matter how well promoted or managed, and no matter how many clever and “better” variations are tried, because they are superficial solutions pushing on low leverage points.

Solution designers have thus fallen into the *Superficial Solutions Trap*. This occurs when people assume intermediate causes are root causes. It’s an easy trap to fall into because root causes can be deceptively hard to identify, as the sage of system dynamics, Jay Forrester, describes: (Forrester, 1971, p95, italics added)

> “The intuitively obvious ‘solutions’ to social problems are apt to fall into one of several traps set by the character of complex systems. ...people are often led to intervene at points in a system where *little leverage exists* and where effort and money have but slight effect.
>
> “...social systems are inherently insensitive to most policy changes that people select in an effort to alter behavior. In fact, a social system draws attention to the very points at which an attempt to intervene will fail. Human experience, which has been developed from contact with simple systems, leads us to look close to the symptoms of trouble for a cause. But when we look, we are misled because the social system presents us with an *apparent cause* that is plausible according to the lessons we have learned from simple systems, although this apparent cause is usually a coincident occurrence that, like the trouble symptom itself, is being produced by *the feedback loop dynamics of a larger system*.”

Forrester’s “apparent cause” is the social force diagram’s intermediate cause. “Little leverage exists” if people assume the apparent cause is the root cause because that leads to pushing on low leverage points.

The key to grasping how SIP works lies in understanding how the three fundamental forces interact. Superficial solutions fail on difficult problems because they cannot exert a greater force on intermediate causes than the root causes can, which explains why fundamental solutions are required.

Suppose sustainability scientists employed a process like SIP. Intervention policy could switch to fundamental solutions pushing on high leverage points. A long-awaited change would then occur, as Figure 2 explains.

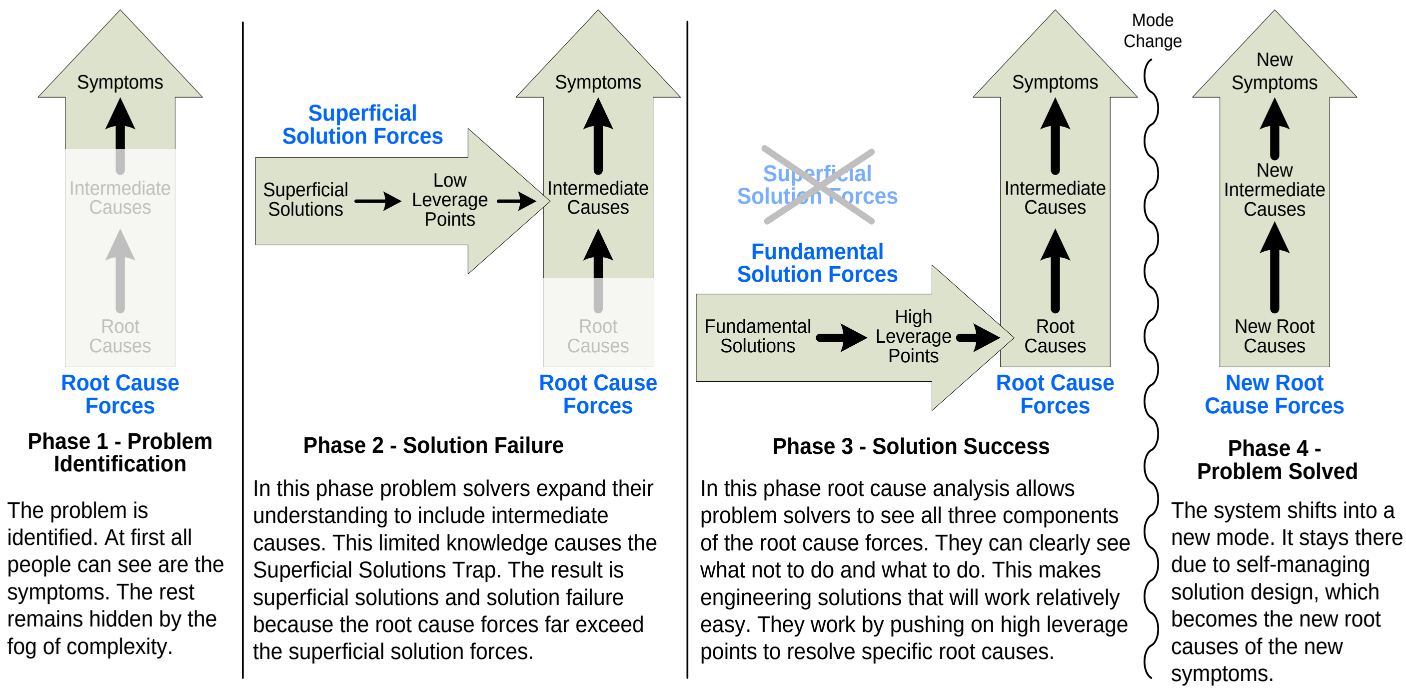

Figure 2. The four phase model of social problem solving. These are the steps difficult large-scale social problems pass through on the way to eventual solution. Typically a long delay occurs in phase 2 due to the One Subproblem and Superficial Solutions Traps. Unsolved problems stay in phase two indefinitely.

Over time, a difficult large-scale social problem goes through as many as four phases. A different force characterizes each phase. In phase 1 the *root cause forces* cause the undesired symptoms and lock the system into that mode. In phase 2, *superficial solution forces* lead to repeated solution failure. In phase 3, root cause analysis allows application of *fundamental solution forces*. These forces cause the system to transition to the new mode of phase 4, where the *new root cause forces* cause the desired symptoms and lock the system into the new mode.

The challenge facing sustainability scientists is how to trigger the transition needed to move the human system from phase 2 to phase 4. SIP provides the engineering framework needed to meet that challenge.

Definition of root cause

To make finding root causes more efficient and reliable SIP uses the following definition: A *root cause* is the deepest cause in a causal chain that can be resolved. *Resolved* means a system's feedback loop structure is changed such that a root cause force no longer exists or is acceptably low. To be more exact, a root cause is that portion of a system's feedback loop structure that, using the checklist below, explains why the system's behavior produces the problem symptoms. The five requirements of a root cause are:

1. It is clearly a (or the) major cause of the symptoms.
2. It has no worthwhile deeper cause. This halts the asking of "Why did this occur? What is its cause?" at an appropriate point in root cause analysis.
3. It can be resolved. Sometimes it's useful to emphasize unchangeable root causes in a model for greater understanding and to avoid trying to resolve them without realizing it.
4. Its resolution will not create other equal or bigger problems. Side effects must be considered.
5. There is no better root cause. All alternatives have been considered.

This checklist allows numerous unproductive or pseudo root causes to be quickly eliminated.

The System Improvement Process matrix

How SIP works is summarized in Figure 3. The matrix rearranges the structure of Figure 1B, the standard social forces diagram, into columns so that multiple subproblems and their relationships may be more easily conceptualized. Although the process steps are presented below in waterfall fashion, heavy iteration is the norm as analysis converges on the right subproblems, root causes, high leverage points, and solution elements.

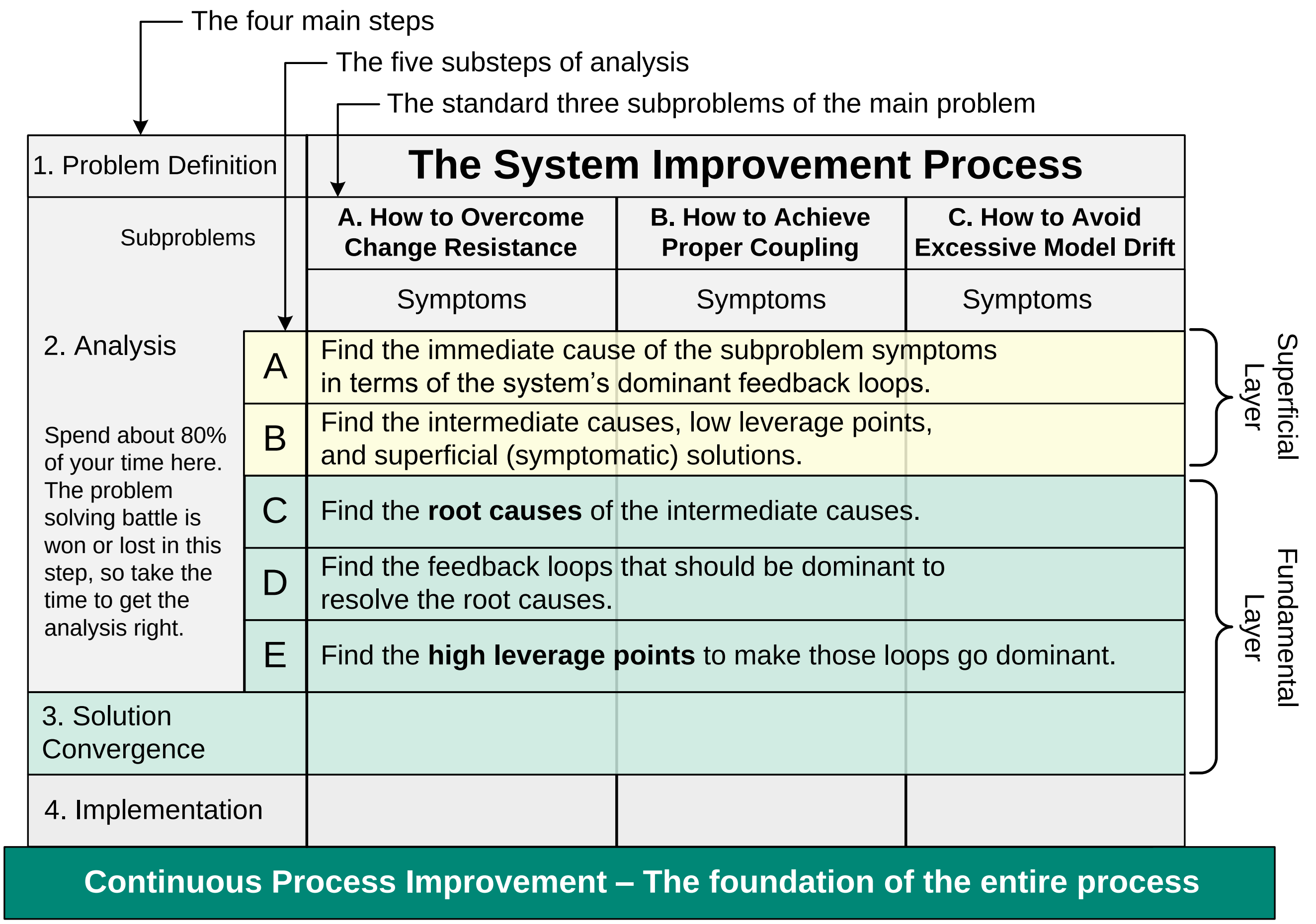

Figure 3. The System Improvement Process matrix. SIP is a fill-in-the-blanks matrix style framework. Each column summarizes one social force diagram. The standard three subproblems are shown. More subproblems are added as necessary.

Main Step 1 – Problem Definition

SIP defines a problem using a standard format: *Move system A under constraints B from present state C to goal state D by deadline E with confidence level F*. C and D are present and desired symptoms (system state). D, E, and F are the solution goal, the most important part. Constraints B include human resources, budget, conflicting goals, uncertainty, authority limitations, and so on. The format is flexible and may be changed.

An example of defining a problem using this format is "Given you are down-town and have lost your wallet and car keys, get home by 6:00 PM today with a 90% probability." Here system A is implied. It's the normal world you live in.

Main Step 2 – Analysis

Once the problem is defined analysis begins. The first step decomposes the one big problem into smaller subproblems. What these are makes or breaks the entire analysis.

During our work we found that without the right decomposition the sustainability problem was impossible to analyze. We expect this holds for all difficult large-scale social problems. Studying the ones we are familiar with, environmental sustainability, over population, recurring wars, recurring large recessions like those of 1929 and 2008, endemic corruption, excessive wealth inequality, and the class of difficult large-scale social problems itself, we concluded that all had a common set of three subproblems plus additional subproblems as needed. To leverage this potent pattern SIP suggests beginning with the standard three subproblems found in all difficult large-scale social problems and adding more as necessary. Exceptions to starting with three subproblems would be problems not of this class, such as small-scale problems, new problems where solution failure has not yet occurred, problems with low change resistance, etc.

Standard processes routinely use standard subproblems. Examples are the 4 Ps of marketing (McCarthy 1960), since extended to the 8 Ps of services marketing (Lovelock & Wirtz 2014), the 6 Ms of lean manufacturing (George et al., 2005, p147), the 9 Ms of quality control (Feigenbaum, 1991, p59), and the six standard manufacturing subproblems of cause-and-effect diagrams (Fig. 1A).

If a difficult large-scale social problem is not decomposed into multiple subproblems, analysts have fallen into the *One Subproblem Trap*. This occurs when problem solvers assume a single subproblem is the only one to solve, which makes the problem impossible to solve because it remains too complex to analyze correctly. The standard subproblems listed in the previous paragraph are examples of how mature processes avoid the deadly effect of the One Subproblem Trap.

The standard three subproblems are:

Subproblem 1: How to overcome change resistance

Change resistance is the tendency for something to resist change even when a surprisingly large amount of force is applied. Change resistance (aka policy resistance or organizational momentum) is present in all social problems that have long defied attempts to solve them. Change resistance is the most important subproblem to solve and must be solved first, before the original problem will yield to solution (Harich 2010).

Subproblem 2: How to achieve proper coupling

Proper coupling occurs when the behavior of one system affects the behavior of other systems properly, using the appropriate feedback loops, so the systems work together in harmony in accordance with design objectives. For example, if you never felt hungry you would starve to death. You would be improperly coupled to the world around you.

The original problem to solve is usually a proper coupling subproblem. This is the case in our analysis of the sustainability problem, where the original problem is the *environmental proper coupling subproblem.* The human system is improperly coupled to the larger system is lives within, the environment, because the right feedback loops are missing.

Environmentalism has fallen into the *One Subproblem Trap* by assuming that the only significant subproblem to solve (and hence to formally analyze) is the environmental proper coupling problem. This is a fatal error because it omits the other two standard subproblems or possible additional subproblems.

Subproblem 3: How to avoid excessive model drift

Problem solutions are based on models of understanding of a system's behavior. *Model drift* occurs when a political system's solution model (a solution policy and the understanding behind it) fails to evolve as needed to solve new problems or to prevent old problems from recurring. The solution model drifts away from what's needed. Model drift is short for solution model drift.

Excessive model drift is the same as low resilience. "System resilience [is] the capacity of a system to be subjected to disturbances without shifting into a new regime (Norberg and Cumming, 2008, pxiv)." From a management perspective resilience is the ability of a social-ecological system to successfully adapt to problems of any kind. The larger and more complex a system becomes, the slower and more poorly it tends to adapt to major problems, and thus the stronger and more proactive its resilience must be.

In the short term, how to overcome change resistance is the most important subproblem to solve and must be solved first. In the long term, how to avoid excessive model drift is the most important subproblem because once it is solved the system is permanently resilient.

The five substeps of analysis

Once a problem is decomposed into subproblems, each subproblem undergoes the five substeps of analysis. The goal is to engineer the feedback loop structure needed for resolution of the root cause.

Analysis Substep A – Find the immediate cause of the subproblem symptoms in terms of the system's dominant feedback loops

This substep begins construction of a feedback loop model of the subproblem. The feedback loops immediately causing subproblem symptoms are modeled. Examples of this step for the environmental proper coupling subproblem are listed in Table 1. Integrated models like these are extremely useful for general initial understanding of problem dynamics.

Table 1. Examples of immediate cause models

Simulation Model	**Immediate Cause Feedback Loops**
World3-03 of *Limits to Growth* (Meadows et al. 2004)	Industrial capital and population growth (p142)
Threshold 21 Model (Millennium Institute 2013)	Pollution and natural resource consumption
Triple Value Model (Fiksel 2012)	Ecosystem services use and pollution flow
2052 Forecast Model (Randers 2012)	Production growth (p57)

Analysis Substep B – Find the intermediate causes, low leverage points, and superficial (symptomatic) solutions

This takes the immediate cause loops as a starting point and identifies the intermediate causes of those loops, the low leverage points for resolving those causes, and the superficial solutions that have been pushing on those points. These are enlightening (and often humbling) insights because they tell problem solvers what they have been doing wrong for so long, as well as why.

Superficial solutions push on low leverage points. Examples are carbon taxes, renewable energy, the Kyoto Protocol treaty, and conservation. Solutions like these are encouraged by models like those listed in Table 1 because solution scenarios can show the problem is solved. But when the same solutions are attempted in the real world the problem is *not* solved, which offers considerable proof these models are incomplete. The root causes are not in the models. Only the intermediate causes are.

Thus the models in Table 1 are superficial layer models. A *superficial layer model* is present when pushing on one or more leverage points in the model solves the problem, but attempting to push on the same points in the real world does not. The Table 1 models focus on the superficial layer of the problem, so they can do no more than test if a solution will resolve intermediate causes. However, that's not a valid test because there are root causes influencing the intermediate causes. Superficial layer models have thus fallen into the Superficial Solutions Trap by assuming there is nothing deeper than the intermediate causes. These models generally include only the environmental proper coupling subproblem, so they have also fallen into the One Subproblem Trap.

To be fair, the 2052 Forecast Model is not designed for testing solution strategies but for forecasting how one scenario, business as usual, will play out. However, it may be used "to clarify what new policies [will work]." (p2)

Analysis Substep C – Find the root causes of the intermediate causes

This substep is the key to a correct analysis. Once the superficial layer is thoroughly understood, the analysis penetrates to the fundamental layer to find the root causes. This is easier than one might expect because the process is not asking a hopelessly broad question, like "What are the root causes of the sustainability problem?" Instead the process focuses with "What are the root causes of the intermediate causes of a single subproblem?" This is a decidedly easier problem to solve.

Analysis Substep D – Find the feedback loops that should be dominant to resolve the root causes

This substep finds the feedback loops that need to become dominant (over other loops) to resolve the root causes. All feedback loops emit amplification or balancing forces that affect the rest of the system. It is these forces that can act upon root causes to reduce their effects to acceptable levels.

Analysis Substep E – Find the high leverage points to make those loops go dominant

Finally this substep finds the high leverage points to make the loops in substep D go dominant. A *high leverage point* is a specific place in a system's feedback loop structure that solution elements push on in order to efficiently resolve the connected root cause. A high leverage point is thus a high level solution strategy.

Main Step 3 – Solution Convergence

This step narrows down the many possible solutions to the realistic few. Fundamental solutions push on high leverage points. Given Analysis results, only a few solutions make sense. These become solution element candidates and like all important hypotheses require testing. Iteration with the Analysis step is frequent.

Main Step 4 – Implementation

Finally the process arrives at implementation of solution elements. What is today the hardest step of them all (due to superficial solutions that don't work no matter how hard people try) now becomes the easiest, because policy managers have a clear understanding of how the system will respond to being pushed on at high leverage points. While this may sound like an extraordinary claim for a difficult social problem, it happens daily in the business world for companies and industries using mature forms of root cause analysis.

Continuous process improvement

This is the step that's taken SIP and the analysis of the sustainability problem to where they are today. Continuous process improvement is *the* key component of any highly productive process. The strategy is that if the initial process (seed process) is sufficiently well designed and continuous process improvement is properly done, over time process maturity is guaranteed to grow until it's good enough to solve the problem. This follows from the principle that *"The right process will produce the right results,"* as documented by Liker (Liker 2004, pp.85–168) for the largest, most successful, and most copied large-scale production process in the world, the Toyota Production System (Womack et al. 1990, p.49).

The twelve practices

SIP adds four additional practices to the eight basic practices of root cause analysis:

1. The five requirements definition of a root cause.
2. Use of social force diagrams to avoid the Superficial Solutions Trap and so that root causes resolution causes the system mode change required to solve the problem.
3. Subproblem decomposition, using the standard three subproblems and more as necessary, to avoid the One Subproblem Trap.
4. Use of the five substeps of analysis and the Solution Convergence step to build a social force diagram for each subproblem.

The eight practices have grown to twelve, and changed from generic practices to a concrete detailed method for a specific class of problems. These twelve practices form the initial vision of a tool that could help trigger transition to a sustainable world.

Next we present results of applying SIP to the sustainability problem.

Drilling down to find the main root cause

Figure 4 summarizes analysis results. To our knowledge, this is the first comprehensive root cause analysis of the environmental sustainability problem as a global whole.

"Drilling down" refers to Toyota's famous *Five Whys of Kaizen* (Ohno, 1988, p17), where you ask WHY is this happening until you arrive at the root cause. Starting with problem symptoms in the upper right, the analysis drills down through a chain of four subproblems to find the main root cause. The outstanding feature of the analysis is decomposition of the sustainability problem into four smaller and hence easier to solve subproblems.

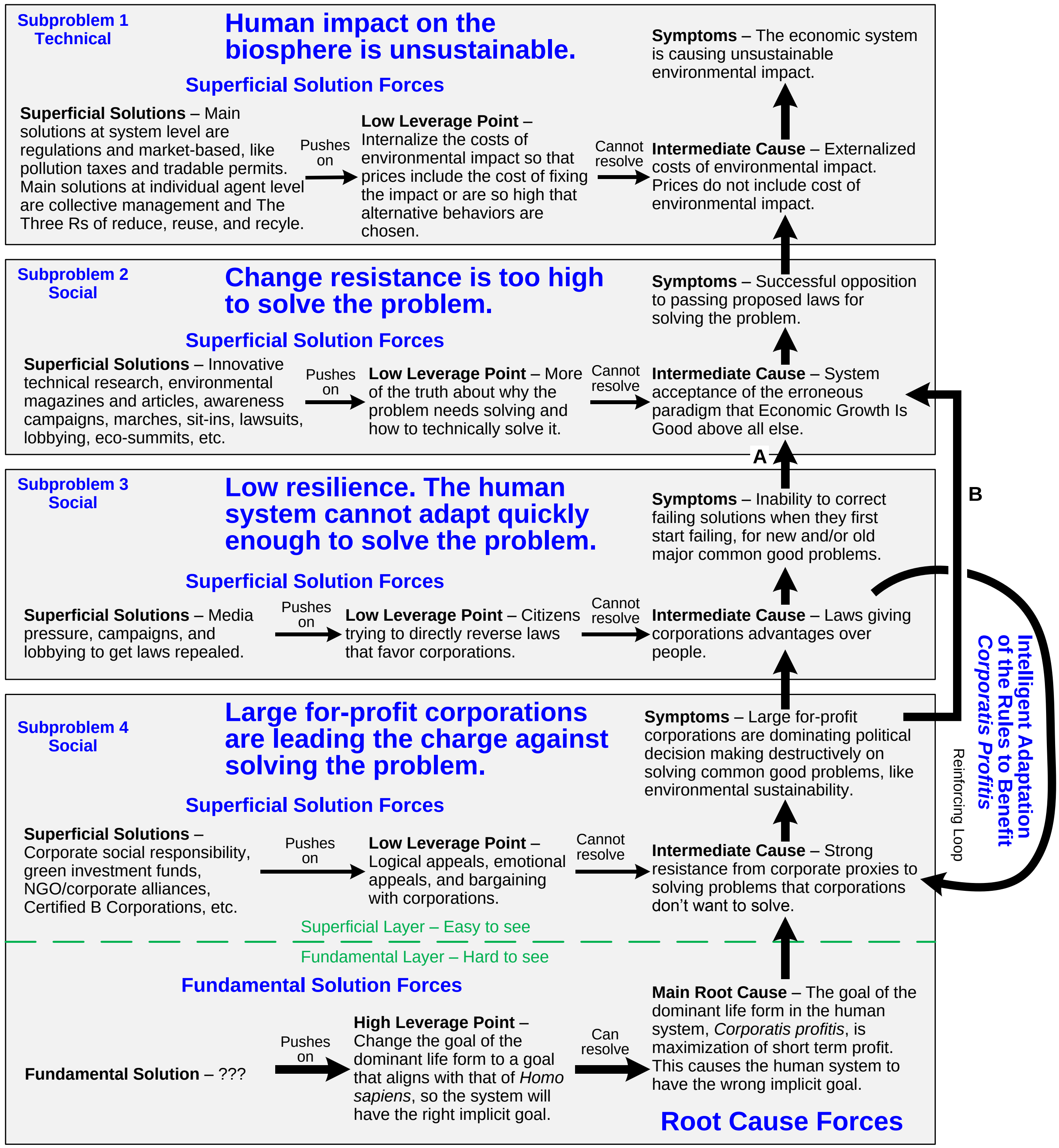

Figure 4. Root cause analysis of the environmental sustainability problem, unsustainable mode. None of the superficial solutions work as well as needed due to the unresolved main root cause. The backbone of the causal structure is the thick arrows. These are the problem's causal chain and its dominant forces.

Subproblem 1 – Human impact on the biosphere is unsustainable.

The symptoms of this subproblem are the economic system is causing unsustainable environmental impact. WHY is this?

While the immediate physical cause is the PAT factors in the IPAT equation, the deeper system level cause is widely assumed to be externalized costs of environmental impact (Daly and Farley, 2011, p222; Stern, 2006, p27). The leverage point follows. The costs must be internalized. At the system level, this led first to regulations and later market-based instruments. In addition, many "going green" voluntary solutions have been promoted at the individual agent level. These solutions are not working, indicating they are superficial solutions.

A subproblem is primarily technical or social. Subproblem 1 one is technical as determined by its symptoms, which are undesirable changes in physical aspects of the biosphere, and by its solutions, which involve mostly more sustainable technology.

Subproblem 2 – Change resistance is too high to solve the problem.

Drilling down again, our next question is WHY are so many costs externalized? Because solutions to internalize costs are being rejected by the system. Change resistance is too high to solve the problem, giving subproblem 2. Its symptoms are successful opposition to passing proposed laws for solving the problem. The symptoms are social, since they deal with people and organization behavior.

The analysis has now moved to the social side of the problem, where the real opportunities for solution breakthrough lie. The next question is WHY is there so much successful opposition to passing proposed laws for solving the problem? What is the cause of high change resistance?

Our analysis found the main intermediate cause is system acceptance of the erroneous paradigm that Economic Growth Is Good above all else. The worst thing that can happen to a nation (short of war) is a recession or even worse, a depression. The worst global events of the twentieth century, other that the two World Wars, were the Great Depression of 1929 and the Great Recession of 2008.

Arndt (1978) found the ascendancy of the Economic Growth Is Good meme to be a recent phenomenon: "There is in fact hardly a trace of interest in economic growth as a policy objective in the official or professional literature of western countries before 1950. But it is possible to detect in the five post-war years changes in the climate of opinion which foreshadowed the ascent of growth to preeminence. (p30) By the end of the decade [the 1950s], economic growth had, as one commentator put it, been 'thrust to the top as apparently the supreme, overriding objective of policy.' (p41) …more rapid economic growth came to be regarded as a prophylactic or remedy for all the major current ailments of western economies." (p43)

Problem solvers have attempted to somehow overcome change resistance with a strategy of more of the truth about why the problem needs solving and how to technically solve it. This leverage point has been pushed on with innovative technical solution research, though most of this is already done as part of subproblem 1. But the major thrust has been social solutions, ones designed to get social agents to want to change their behavior, like environmental magazines and campaigns. Once again these solutions are not working.

Subproblem 4 – Large for-profit corporations are leading the charge against solving the problem.

The next question is WHY is change resistance so high? WHY has Economic Growth Is Good above all else become so universally accepted? The analysis found two causes, shown by arrows A and B. These lead from subproblems 3 and 4. Let's examine subproblem 4 first.

WHY has Economic Growth Is Good become so universally accepted? Who is promoting this environmentally destructive value? Whoever it is, they must be extremely powerful. Tracing the causal forces, we find compelling evidence of who this entity might be:

> "Towards the end of the 1970s we witnessed a turning point in history. The rise of Thatcherism in the UK and Reaganism in the US, as well as the conversion of labour and social democratic governments in countries such as Australia and New Zealand to free market policies, marked a shift in government priorities. Corporate interest began to take priority over national interests and the nation state began to fade as the pre-eminent organizing principle for human activities (Beder, 2006, p219)."
>
> "Capitalism as we know it today... includes ...the modern corporation as its principle mechanism.... Inherent in the dynamics of capitalism is a powerful drive to earn profits, invest them, innovate, and thus grow the economy.... The capitalist system, whatever its shortcomings, is very good at generating growth. These features of capitalism, as they are constituted today, work together to produce an economic and political reality that is highly destructive of the environment. ... The first tenet of globalization design is to give primary importance to the achievement of ever-more rapid, never-ending corporate economic growth—hypergrowth (Speth, 2008, pp7&172)."

Evidence like this strongly points to the main promoter of Economic Growth Is Good. It is the modern large for-profit corporation. While corporations provide many benefits, they are dominating political decision making destructively on solving common good problems, like environmental sustainability. This becomes subproblem 4.

WHY is subproblem 4 happening? The intermediate cause is strong resistance from corporate proxies to solving problems that corporations don't want to solve. Examples are the way "the US conservative movement... launched a war against environmentalism, both nationally and globally" (Lever-Tracy, 2010, p244) and a study showing 45 of the world's 100 largest companies are "obstructing climate change legislation" (Influence.org 2015). Beder's (2002, p275) exhaustive examination of "the corporate assault on environmentalism" concluded that "Surveys show that the majority of people in most countries are not only concerned about the environment: they think environmental protection should be regulated by governments and given priority over economic growth. Yet this widespread public concern is not translating into government action because of the activities of large corporations that are seeking to subvert or manipulate the popular will."

Confronted with change resistance from corporate proxies, solutions have tried to overcome that resistance by pushing on the low leverage point of appeals and bargaining, using solutions like corporate social responsibility and NGO/corporate alliances. But these solutions are not working. WHY is this? What is the deeper cause of strong resistance from corporate proxies?

That's a tough question to answer well. Let's begin with a key principle of ecology. The *Competitive Exclusion Principle* states that when two species compete in the same niche, the population of one species will come to dominate the niche due to competitive advantage differences, however slight they may be. The other species will be driven to extinction, or it will adapt and be driven to a different niche.

An *agent* is an independent entity with the ability to pursue a goal. A *social agent* is an agent in the human system, such as people, nations, organizations, cultures, and religions.

All social systems have goals because all social systems are composed of social agents and all social agents have goals. Understanding social system goals is indispensable when attempting to change the behavior of a social system:

> "To understand how an organism works we must understand its balancing processes—those that are explicit *and* implicit. ... Leaders who attempt organizational change often find themselves unwittingly caught in balancing processes. To the leaders, it looks as though their efforts are clashing with sudden resistance that seems to come from nowhere. In fact, as my friend found when he tried to reduce burnout, the resistance is a response by the system, trying to maintain *an implicit system goal*. *Until this goal is recognized, the change effort is doomed to failure.* ... Whenever there is '*resistance to change'* you can count on there being one or more 'hidden' balancing processes (Senge, 1990, pp86-88, italics added except for 'and')."

"Balancing processes" refers to balancing feedback loops, which contain goals. A balancing loop (aka goal seeking loop) causes all or part of a system to automatically pursue the loop's goal. If a balancing loop is the dominant balancing loop in a system, the system will pursue the loop's goal.

Like an ecological niche, a social system contains a single dominant agent due to competitive exclusion unless dominance is in transition. Building on this and Senge's advice to always consider implicit system goals, we arrive at a primary principle of social system behavior, the *Principle of Social System Goals*: Over time, the goal of the dominant agent in a social system becomes the goal of the system. Let's apply this principle.

An abundance of literature (Beder 2002; Beder 2006; Hartman 2002; Korten 2015; Nace 2003; Monbiot 2000; Carroll & Carson 2003), along with the obvious influence of industrialization (i.e. the spread of *Corporatis profitis* in the global niche) on the course of civilization, suggests *Corporatis profitis*, the modern large for-profit corporation, is now *the* dominant life form in the biosphere, as measured by influence on jobs, technology, economic growth, quality of life, ecosystem impact, and legislation. The corporate life form's goal is to maximize the short term (net present value) of profit. Applying the Principle of Social System Goals, the goal of the human system has aligned with and become the goal of *Corporatis profitis*.

The effect of this goal on the human system is so fundamentally systemic and has no deeper cause that we have not only found the cause of strong resistance from corporate proxies. We have at last drilled down to the main root cause of the problem. (The analysis also found three lesser root causes, not described here. These are automatically resolved when the main root cause is resolved.)

The main root cause is that the goal of the dominant life form in the human system, *Corporatis profitis*, is maximization of short term profit. This is the wrong goal because of its opposition to the goal of *Homo sapiens*: to optimize long term quality of life for those living and their descendants. These two goals are mutually exclusive and cannot be achieved in the same system. One goal is "right" and one is "wrong." Which is right or wrong to a particular person depends on whether they are a corporate proxy or not.

If the system has the wrong goal then the high leverage point follows logically: Change the goal of *Corporatis profitis* to a goal that aligns with that of *Homo sapiens*, so the system will have the right implicit goal. In their investigation of how to overcome "systemic roadblocks to sustainability," Beddoe (2009) reached a similar conclusion: "...creating a sustainable and desirable future will require an integrated, systems level redesign of our socio-ecological regime focused explicitly and directly on the goal of sustainable quality of life rather than the proxy of unlimited material growth."

Goals control systems. Systems thinker extraordinaire Donella Meadows (2008, pp111, 112, and 138), in a chapter on *System Traps and Opportunities*, describes how "some systems ...are perverse. These are the systems that are structured in ways that produce truly problematic behavior; they cause us great trouble." The chapter discusses eight common traps. Identification of the main root cause reveals that our good friend *Homo sapiens* has fallen into one of the biggest traps of them all: "Seeking the Wrong Goal ...one of the most powerful ways to influence the behavior of a system is through its purpose or goal. That's because the goal is the direction-setter of the system, the definer of discrepancies that require action, the indicator of compliance, failure, or success toward which balancing feedback loops work. If the goal is defined badly, if it doesn't measure what it's supposed to measure, if it doesn't reflect the real welfare of the system, the system can't possibly produce a desirable result."

If the human system has the wrong goal of maximization of short term profit, then it can't possibly produce a sustainable planet. "But," as Donella points out, "system traps can be escaped ...by altering the structure—by reformulating goals, by weakening, strengthening, or altering feedback loops, or by adding new feedback loops."

Subproblem 3 – Low resilience. The human system cannot adapt quickly enough to solve the problem.

We can now explain arrow A. WHY has the erroneous paradigm that Economic Growth Is Good above all else become so strongly accepted, when it is so obviously self-destructive? Thinking at the system level, WHY has the system allowed an intermediate cause this important to go unsolved for so long? This behavior reveals another distinct subproblem. The fact that the sustainability problem has gone unsolved for over forty years indicates excessive model drift, aka low resilience. This gives subproblem 3. Its symptoms are inability to correct failing solutions when they first start failing. Due to low resilience, the human system cannot adapt quickly enough to solve the problem, which prevents solution of the intermediate cause of subproblem 2.

WHY is resilience so low for the sustainability problem? The analysis found that the most productive answer, because it connects subproblem 3 to subproblem 4, is that *Corporatis profitis* has grown so powerful it has been able to consistently have laws passed giving corporations advantages over people. Those laws are the intermediate cause of subproblem 3. These laws bias the system toward solving problems that would benefit *Corporatis profitis*, such as the "problem" of infinite maximum economic growth. This bias neglects common good problems, leading to the symptoms of subproblem 3.

Laws giving corporations advantages over people include limited liability, unlimited lifespan, ability to own other corporations, lower effective income tax rates (e.g. 12% for corporations versus 37% for families in the U.S. (Hartman, 2002, p175)), ability to incorporate wherever they want (in order to minimize taxes and/or regulation), international trade laws (where trade law trumps state law), general preferential treatment in "pork barrel" or company/industry specific legislation, and personhood rights (Kelly 2001; Hartman 2002; Beder 2006).

If too many laws giving corporations advantages over people exist, then the leverage point is citizens must directly reverse those laws. This has been attempted through media pressure (articles, books, talk show appearances, etc.), campaigns, and lobbying to get these laws repealed. These solutions have not worked.

The power and incentive to pass laws advantageous to corporations creates the Intelligent Adaptation of the Rules to Benefit *Corporatis profitis* feedback loop. This reinforcing loop, which has been operating for centuries, has tremendous impact. The loop works this way: The stronger the laws giving corporations advantages over people become, the stronger resistance from corporate proxies to solving problems that corporations don't want to solve becomes. The stronger that becomes, the greater the destructive effect of large for-profit corporate domination on solving common good problems. As that dominance grows, even more laws are passed giving corporations advantages over people, and the loop starts over again.

This feedback loop is particularly troublesome because it causes systemic lock-in to the status quo of *Corporatis profitis* dominance. Until the power of this feedback loop is eliminated, the human system will remain locked into its present mode of unsustainability.

Triggering transition to the sustainable mode

A variety of solutions could push on the high leverage point. Let's assume the general solution is Corporation 2.0. This replaces Corporation 1.0, *Corporatis profitis,* with *Corporatis publicus,* a trusted servant whose goal is the long term optimization of quality life. It does this by providing its master, *Homo sapiens,* with needed goods and services. The new goal returns corporate design to where it began. "As an 1832 treatise on corporate law put it, 'The design of the corporation is to provide for some good that is useful to the public.' (Kelly, 2001, p129)"

If properly designed, fundamental solutions would introduce the right balancing feedback loops, causing transition from the present unsustainable mode to a sustainable mode to occur quickly. The social force diagram of Figure 4 would shift to that of Figure 5, where the old *unfavorable* main root cause has been replaced by a new *favorable* main root cause. The fundamental causal chain (the thick arrows) has changed radically. It now includes the technical solutions environmentalists have long promoted but were blocked from implementing. Due to the new root cause forces these solutions would now be rapidly implemented because that's in the best interests of the dominant life form in the human system, *Corporatis publicus*.

Since the system now follows the right implicit goal, change resistance has largely vanished. The system is trying as hard to solve the problem as it tried to *not* solve it before. Thus the superficial solutions for subproblem 2 are no longer needed. Neither are the superficial solutions for subproblem 3, since corporations no longer want laws favoring themselves over people. And neither are the superficial solutions of subproblem 4, since corporations now want to do the same things people want to do.

The feedback loop that was previously driving the system to ruin has changed to a beneficial loop: Intelligent Adaptation of the Rules to Benefit *Homo sapiens*. This loop causes a key node, strong preference from corporate proxies to solve problems that would benefit the common good, to grow stronger and stronger. The stronger this node becomes the more the entire human system focuses its effort on solving common good problems. At the top of the list sits the global environmental sustainability problem. It is a pleasant thought experiment to imagine how fast that problem would now be solved.

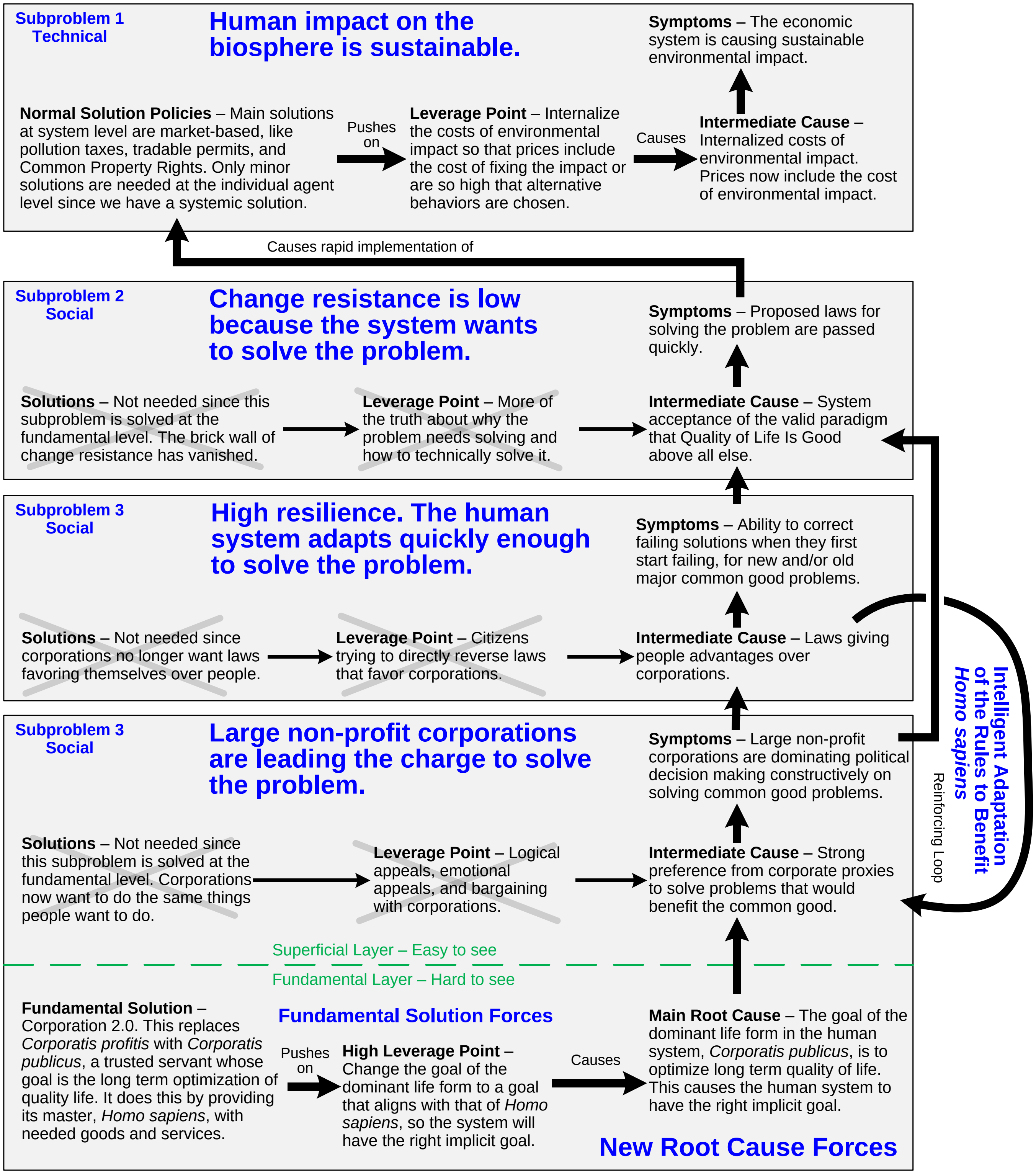

Figure 5. Root cause analysis of the environmental sustainability problem, sustainable mode. Resolution of the old *unfavorable* main root cause has led to a new *favorable* main root cause, causing solution of all four subproblems.

Making the *inherent* Overshoot Correction loop appear

Suppose the broad brushstrokes of the analysis are sound. This leads to interesting implications.

The key insight in the analysis is a high leverage point may exist that has never been pushed on before in a focused large-scale manner. The high leverage point is "Change the goal of the dominant life form to a goal that aligns with that of *Homo sapiens*, so the system will have the right implicit goal." How well pushing on this leverage point with a fundamental solution will work depends on understanding the key feedback loops involved, the ones governing ecological footprint growth at the system level. Figure 6 shows how the loops work.

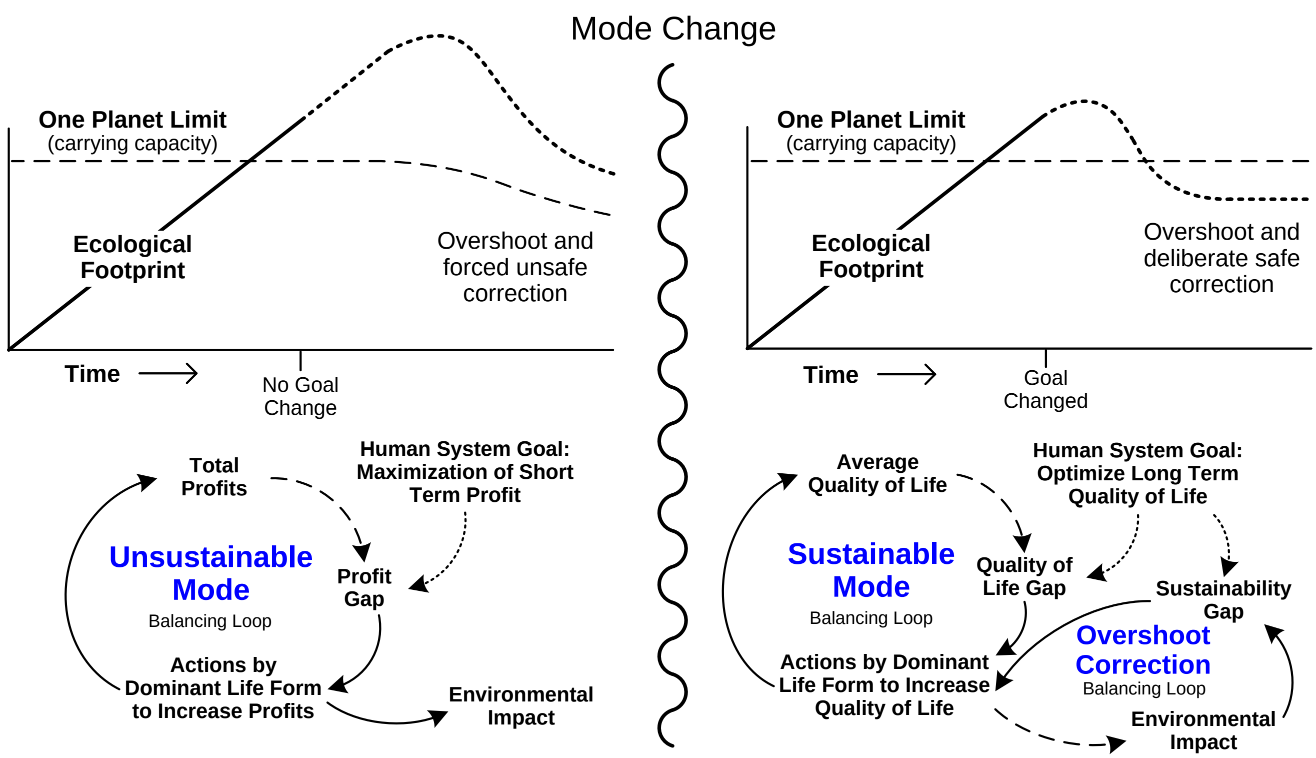

Figure 6. Balancing loops for unsustainable and sustainable modes and their behavior. The fundamental solution causes a mode change by changing the implicit goal of the human system. This causes footprint growth to change from that on the left to that on the right, as the Unsustainable Mode loop's dominance transitions to the Sustainable Mode loop's dominance. The key difference is the left system lacks the *inherent* Overshoot Correction loop of the right system. Legend: Solid arrows are direct relationships. Dashed arrows are inverse relationships. Dotted arrows are constants.

Present behavior of the world's ecological footprint is controlled by the Unsustainable Mode loop on the left. The loop has the wrong goal, so as Peter Senge cautioned earlier, "Until this goal is recognized, the change effort is doomed to failure." Conventional change efforts have failed for over forty years. Until the implicit goal of the human system is recognized and changed, prolonged overshoot will lead to environmental collapse, causing population and economic collapse, which in turn causes footprint collapse.

The dotted portion of the curve on the left shows how no goal change would approximately play out. The footprint continues to rise for too long, collapses, and then enters a long decline as population and industrial production do, as the result of continued unsustainable behavior. It's a forced correction, due to overly prolonged overshoot. It's an unsafe correction because the footprint stays above the One Planet Limit, causing carrying capacity degradation.

An infinitely more pleasant future occurs when the system goal is changed to the one on the right. The Sustainable Mode loop immediately appears. This creates the Overshoot Correction loop, because the "optimize long term quality of life" goal requires sustainability. Presence of the Overshoot Correction loop causes footprint growth to begin falling much sooner. It continues to fall until well below the One Planet Limit, where it levels off with no carrying capacity degradation.

Present sustainability solutions attempt the equivalent of laboriously tacking an Overshoot Correction loop onto the system on the left. This has proven to be inefficient and ineffective because it conflicts with the goal of the system. Far more efficient and effective is the *inherent* Overshoot Correction loop in the system on the right. Problem solvers do not have to create this loop. It appears automatically due to the right human system goal.

Thus the entire solution depends on making the right human system goal appear. There may be several ways to make that happen, not just the one presented here. But once it does happen, the puzzle of how to manage the biosphere sustainably is solved. *Homo sapiens* can switch from stumbling through the Anthropocene to soaring through it, because the right system goal doesn't solve just the environmental sustainability problem. It solves all three pillars of the sustainability problem. Environmental, economic, and social sustainability are all required to optimize long term quality of life. *Complete* sustainability is essential, because weakness in any one pillar spreads to them all.

This completes description of analysis results. What we have presented here is an abbreviated version. For the complete version, with four root causes, the feedback loop simulation model behind the analysis, sample solution elements, and further description of the process used, please see (Harich 2016), available in book or PDF form at Thwink.org.

Discussion

This paper has argued that the sustainability problem is too complex to solve without root cause analysis. No suitable root cause analysis wrappers for doing this appear to exist. To begin filling the process gap we described the System Improvement Process (SIP) and demonstrated how it can be applied to the problem.

The significance of this work lies in its ability to help establish a line of research leading to successful application of root cause analysis to the sustainability problem. From our perspective as system (Harich) and process (Bangerter) engineers, filling the process gap requires only two steps:

1. Commitment to the practice of root cause analysis as the core of the problem solving paradigm.
2. A seed process to apply and continuously improve until it's mature enough to solve your central problems.

This is exactly where the Ford Motor Company started in 1981, once it committed to Deming's form of quality management. At that point U.S. automakers were bleeding market share to Japanese imports due to superior Japanese quality and design. Ford started with Deming's total system of quality control, now known as the Fourteen Points. Less than ten years later "Ford would be hailed as a model of American management. ...Ford's success would help turn Deming into the most sought-after quality expert in America, his ideas serving as an inspiration to hundreds of companies (Gabor, 1990, p4)."

Quality control uses root cause analysis to eliminate defects by finding and resolving the root causes of defects (aka incidents). The pattern of repeated solution failure discussed in the Introduction is a quality control problem because solution failure occurs due to defects. Defective solutions contain assumptions (defects) that are false, due to not taking root causes into account. Low quality solutions fail. High quality solutions work. The more difficult the problem, the more defect free its solutions must be. This explains why the most popular root cause analysis process, Six Sigma, defines the highest level of quality as 99.9997% defect free, i.e. only 3.4 defects per million opportunities (Pande et al., 2000, p29).

That we have been able to map the causal structure of the sustainability problem down to its main root cause, in a manner that compellingly agrees with observed system behavior, suggests the sustainability problem is not so wicked after all. It too will yield to the power of root cause analysis, *if the process fits the problem*. Therefore it is realistically possible for sustainability scholars, activists, NGOs, and agencies to follow the lead of industry and quickly learn how to apply root cause analysis to the many aspects of the sustainability problem. This is a path traveled before. It will not be easy due to the extreme novelty, complexity, and urgency of the problem. Fortunately, however, there is no need to build a new analytical approach from scratch. Analysts can build upon the large body of root cause analysis literature and expertise that has accumulated, and confidently begin applying that knowledge to the problem. The key to unlocking and applying that vast storehouse of knowledge is the right seed process.

A prime research question thus emerges: What would be a suitable starting process? Thinking broadly, is it possible to design the process so that it can be jointly used by the global sustainability community on all aspects of the problem? This might require a central core with optional modules. Are there applications of true root cause analysis to the sustainability problem that we are unaware of? What can be learned from them? Are there applications of root cause analysis to business problems with similarities to the sustainability problem that we can learn from? Is SIP a suitable starting point, so that we can start with something now and address these questions later?

Suppose SIP is used as one of several competing seed processes. Are the four additional practices that SIP adds to standard root cause analysis proper and sufficient? In particular, are the standard three subproblems correct? Do the five substeps of analysis need improvement?

Turning to the output of SIP, how sound is the main root cause? If it is sound, can the sustainability problem be solved by resolving only the main root cause presented here, or would it be better to pursue resolution of all four root causes? This would include three additional root causes not presented in this paper. These are the root causes of subproblems 1, 2, and 3. We suspect the preferred strategy would tackle all four root causes, due to anticipation of exceptionally high change resistance from *Corporatis profitis* to changing its goal.

Several further questions remain. How easy would it be to extend existing integrated world models, like the four listed in Table 1, to include the root causes? Could these models be improved by application of SIP's five substeps of analysis, which are feedback loop and model oriented? Finally, how can a global root cause analysis project, one involving many different countries, organizations, and individuals, best be initiated and managed?

We foresee a host of such questions as this research continues, along a path traveled before.

Conclusion

This paper has demonstrated how root cause analysis can be adapted to fit the sustainability problem, with the goal of learning how to trigger transition to the sustainable mode. That appears eminently possible, due to identification of a high leverage point that's never been utilized and its ability to make the inherent Overshoot Correction loop appear. While the authors have not experimentally tested the strength of this hypothesis, the theoretical existence of such a potent leverage point suggests that further research would be productive. We found no issues of any kind preventing root cause analysis from working as well on the sustainability problem as it has on business problems. Some time and process innovation will be required, but once a suitable version of root cause analysis is applied to the sustainability problem, we expect that present difficulties will melt away and solution will follow. Like their business counterparts, sustainability scientists will find all sorts of previously unknown nuggets of knowledge as they turn the telescope of root cause analysis not to the structure of the heavens, but here on earth to the structure of the *complete* sustainability problem.

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