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

Jack Harich[1], Montserrat Koloffon Rosas[2]
[1]Thwink.og, Atlanta, USA. jack@thwink.org. Corresponding author.
[2]Vrije Universiteit Amsterdam, Amsterdam, Netherlands.

Abstract

System dynamics has the theoretical potential to productively model any dynamic problem where entity flow can be aggregated without significant loss of information and to offer practical solution strategies based on the model. However, in practice, as Jay Forrester observed, the field is presently stagnated "on a rather aimless plateau… there is very little penetration into the big issues." We argue the central reason is that for the more difficult problems, the present modeling process does not fit the problem because it lacks root cause analysis. This too often results in models that omit a problem's root causes and therefore the correct high leverage points. The paper begins the conversation for filling this gap by presenting an educational example of a comprehensive process for integrating root cause analysis into the system dynamics modeling process.

A series of increasingly more focused questions

As a tool for modeling and solving problems of a dynamic nature, system dynamics offers enormous potential. Models with "aggregated human actions" as well as other aggregated behaviors "are at least potentially better representations that any others" for solving social system problems (Meadows, 1980, p. 26).

However, this potential has not been realized in society's largest problems, those of such scale and public interest they must be addressed by governments. Fifty years after the birth of system dynamics, Forrester (2007) observed that while there are many applications of system dynamics in government, "there is very little penetration into the big issues" and stated the research question this paper attempts to answer: "Why is there so little impact of system dynamics in the most important social questions?"

In particular, society has been unable to solve the global environmental sustainability problem, epitomized by the looming climate change crisis. A long series of increasingly sophisticated integrated system models beginning with the iconic World2 and World3 models (Forrester, 1971; Meadows et al., 1972) , and continued with efforts like the Triple Value Model (Fiksel, 2012), Threshold21 (Barney, 2002), DICE (Nordhaus, 2018), and iSDG and IFs (Pedercini et al., 2020), as well as global models focused on climate change like C-Roads (Sterman et al., 2012), have not yet led to successful solution. The latest IPCC report states bluntly that time is running out. "Global warming of 1.5C and 2C will be exceeded during the 21st century unless deep reductions in CO2 and other greenhouse gas emissions occur in the coming decades" (Masson-Delmotte et al., 2021).

What is missing in these models, as well as any model that attempts to solve a difficult problem and fails? Probing the depths of that question begins with examination of the problem type.

Scholars have long noted the notorious difficulty of many large-scale public interest problems. Labeled "wicked problems," this class of problems was found by Rittel and Webber (1973) to be "inherently different from the problems that scientists and some classes of engineers normally deal with. … Social problems are never solved. At best they are only re-solved—over and over again." Ten characteristics of wicked problems were expounded. The general hypothesis was that wicked problems are intractable due to their extreme complexity and social nature, which places them in a class of problems far more difficult than "tame" problems that are successfully solved.

Yet the long steady march of science should eventually turn wicked problems into tame ones. How can that be done? How can public interest wicked problems be turned into tame ones?

Introduction to a deeper point of view

Our research offers surprisingly good news here. It's already been done by industry for its own top wicked problem: How to consistently produce products of very high quality and low cost. Solving this problem had proved impossible since the beginning of the Industrial Revolution around 1760 in England. As discussed below it was solved around 1950 starting in Japan.

Industry's solution to its top wicked problem was continuous improvement of root cause analysis (RCA) based processes of all kinds, such as product design, manufacturing, and customer service. RCA provides the foundation of industry's most advanced large-scale problem-solving processes, which has led to entirely new industries, such as personal computers, smart phones, the internet, the virtual workplace, and mass airline travel, all of which are low cost and reliable. Highly challenging business problems are now solved routinely, like how to put a man on the moon in ten years or how to create a covid19 vaccine in less than 12 months.[1]

[1] To achieve a high mission success rate, NASA created its own Root Cause Analysis Tool (NASA Safety Center, 2013). Six Sigma, the leading RCA-based quality control process, is

A root cause is the deepest cause in a causal chain (or the most basic cause in a feedback loop structure) that can be resolved. RCA is the systematic practice of finding, resolving, and preventing recurrence of the root causes of causal problems (Andersen and Fagerhaug, 2006, p. 12; Doggett, 2004; Okes, 2019, p. 5).

Wicked problems, as well as many less difficult problems, are causal problems. A causal problem occurs when problem symptoms have causes, such as illness or a car that won't start. Examples of non-causal problems are math problems, scientific discovery problems, information search problems like criminal investigation or system optimization, card games like poker and bridge, multiple choice problems, and puzzle solving.

All causal problems arise from their root causes. Thus, RCA is the basic process all of us follow when we solve causal problems, whether we use RCA terminology or not. RCA employs hundreds of supporting tools and techniques (George et al., 2004, 100 tools; Pyzdek, 2003, over 100 tools; Tague, 2005, 136 tools). RCA is generic and for difficult problems must be wrapped in a process tailored to the problem class.

Formal RCA originated with the "King of Japanese Inventors," Sakichi Toyoda (1876-1930), in the early twentieth century when he formalized how he applied RCA with the now ubiquitous Five Whys method (Imai, 1986, p. 50). Use of RCA in Japan spread and began to mature, and received an enormous boost with arrival of W. Edwards Deming in 1947, who introduced a comprehensive process (the Plan/Do/Check/Act cycle, aka the Deming Cycle) for combining RCA with statistical quality control (Gabor, 1990, p. 20 and 74). This was the process that solved industry's wicked problem of how to consistently produce products of very high quality and low cost.

The process was received so well by Japanese industry that soon the Deming Prize (an annual award for quality beginning in 1951) was a national competitive event and came to be as prestigious in Japan as the Nobel Prize was in the West (p73). The prize was so difficult to win that most contestants first spent 3 to 5 years honing their operations to peak process maturity (p95). Almost instantly the emphasis on RCA-based continuous process improvement served as a potent component of the Japanese post-war economic miracle in the 1950s and 1960s, when Japan rose from devastation in the war to become the second-largest economy in the world, largely due to the unmatched high quality and low cost of exported products.

Finally in 1983 Deming's "philosophy" migrated to the west, when Ford Motor Company invited Deming for training. The reason? American auto manufacturers had lost so much market share to Japan they faced financial disaster. Ford learned and implemented Deming's teachings so well that Ford went from the brink of

---

used by used by 100% of aerospace, motor vehicle, electronics, and pharmaceutical companies (including vaccine development and manufacture) in the Fortune 500 (Marx, 2007).

bankruptcy in 1980 to the most profitable auto manufacturer in America. For six straight years its cars were rated highest in quality of all US manufacturers (Aquayo, 1991, pp. 2–3). The paradigm of RCA-based processes for all important processes and continuous process improvement has since spread to all large-scale industries, in the form of Total Quality Management, Lean Production, ISO 9000, Six Sigma, and more. For a cohesive review of these mega-tools see (Tague, 2005, pp. 13–34).

The foundation of RCA is the root cause point of view. While perceptions vary, we see the principles below as the core of that viewpoint and modern RCA-based processes. All the principles arise from the first, which states the essence of the viewpoint:

1. All causal problems arise from their root causes.
2. A causal problem can only be solved by finding and resolving its root causes.
3. The more difficult the problem, the more mature the process used to solve it must be.
4. Continuous process improvement is required to achieve and maintain high process maturity.

The third and fourth principles encapsulate the philosophy of Kaizen, "the single most important concept in Japanese management—the key to Japanese competitive success. Kaizen means improvement, …ongoing improvement involving everyone: top management, mangers, and workers" (Imai, 1986, p. xxix). The key is to cultivate an organizational culture that is "process-oriented" rather than "innovation and results-oriented." Continuous process improvement is a form of institutionalized organizational learning, seen by some as *the* key requirement for long-term organization success (Senge, 1990).

By now the answer to the question of "How can public interest wicked problems be turned into tame ones?" should be apparent. Those working on *public* wicked problems must adopt the same foundation as those working on *private* wicked problems. That foundation is the root cause point of view.

Richardson (2011) argues persuasively that the foundation of system dynamics is "the endogenous point of view," and states this point of view is the *sine qua non* of both system dynamics and systems thinking. This foundation has proven to work on many problems. But it is insufficient for wicked problems.

Figure 1 illustrates how the root cause point of view serves as the foundation of modern causal problem solving. Because system dynamics is a tool for solving causal problems, it is one of many tools used by RCA practitioners. Therefore, below the foundation of system dynamics rests the larger and more critical foundation of the root cause point of view. *If system dynamics modelers wish to solve wicked problems, or any problem type more difficult than they can routinely solve today, then they must do what industry has done. Modelers must expand their paradigm to include the root cause point of view and drive model construction with RCA.* That is the message of this paper.

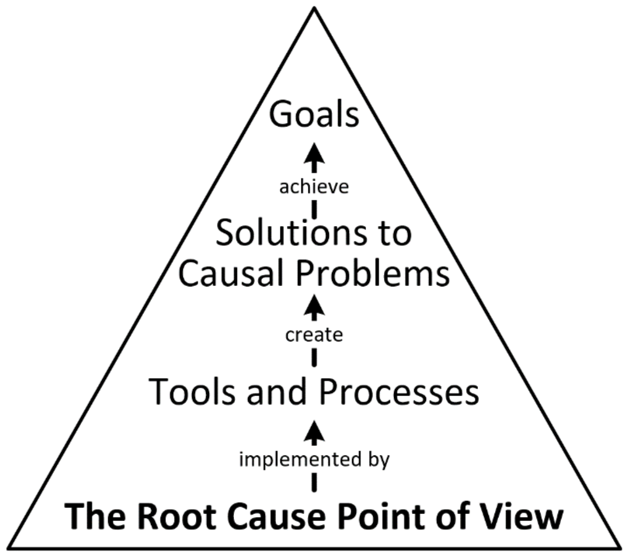

Figure 1. The Pyramid of Causal Problem Solving, showing how the root cause point of view serves as the foundation of modern causal problem solving. System dynamics is one of many tools used to implement the root cause point of view.

Doctors use RCA to diagnose and treat patient illness without ever using the term root cause or root cause analysis. Countless professions do the same, since causal problems can only be solved by resolving their root causes.

System dynamics modelers are thus already performing RCA. However, because there is no explicit root cause point of view and no RCA-based process that fits the problem, for difficult problems their models tend to not include the root causes. Instead, the models contain intermediate (proximate) causes, which leads to superficial solutions that have less than the desired effect.

This process gap can be filled. The paper presents a tool, the System Improvement Process (SIP), for integrating RCA into the system dynamics modeling process. The tool is presented not as *the* correct RCA-based process, but as an educational example of how to begin this transition.

The potential of this transition is immense. Once the business world began formal use of RCA and changed entire corporate philosophies to the root cause point of view, it was able to solve previously insolvable highly difficult problems. We see no reason why system dynamics modelers cannot expect to do the same.

Finding causal chains with the Five Whys method

RCA uses many tools to find root causes. All are variations of the core method of the Five Whys. Imai (1986, p. 50) describes the method:

> In the factory, problem solvers are told to ask "why" not once but five times [or as many times as necessary]. Often the first answer to the problem is not the root cause. Asking why several times will dig out several causes, one of which is usually the root cause. [For example:]
>
> 1. Why did the machine stop?
>   Because the fuse blew due to an overload.
> 2. Why was there an overload?
>   Because the bearing lubrication was inadequate.
> 3. Why was the lubrication inadequate?
>   Because the lubrication pump was not functioning right.
> 4. Why wasn't the lubrication pump working right?
>   Because the pump axle was worn out.
> 5. Why was it worn out?
>   Because sludge got in.
>
> By repeating "why" five times, it was possible to identify the real cause and hence the real solution: attaching a strainer to the lubricating pump. If the workers had not gone through such repetitive questions, they might have settled with an intermediate countermeasure, such as replacing the fuse.

Problem symptoms were the machine stopped. Answers to the first four questions are intermediate causes. The answer to the fifth question is the root cause. Application of the Five Whys has identified the problem's causal chain. Causal chains follow this basic form:

Root cause → Intermediate Cause(s) → Problem Symptoms

Causal chains can branch, as when a problem has multiple root causes. They can also encounter feedback loops. High level causal chain diagrams can treat loops or groups of loops as single nodes. This allows a complex causal structure to be clearly summarized. Unlike causal loop diagrams or system dynamics models, where emphasis is on feedback loop structure, emphasis in causal chain diagrams is on linear chains of cause and effect.

Why the root cause point of view is required for difficult problems

(➔NOTE: This is the section we have the most qualms about. What have we gotten wrong here? Where is it weak or confusing?

Earlier we concluded that "If system dynamics modelers wish to solve wicked problems, or any problem type more difficult than they can routinely solve today, then they must expand their paradigm to include the root cause point of view and drive model construction with RCA."

System dynamics experts may object and counter they are already finding what can be called root causes. If a model endogenously generates the "right output behavior for the right reasons" (Barlas, 1996), then it must contain the root causes of the problem. The right reasons occur "if the model has an internal structure that adequately represents those aspects of the system which are relevant to the problem behavior at hand."

However, Barlas found that "judging the validity of the internal structure of a model is very problematic" because "there are no established formal tests (such as statistical hypothesis tests) that one can use in deciding if the structure of a given model is close enough to the 'real' structure."

We argue that judging model validity is problematic because the model lacks explicit root causes and may not even contain the root causes. Lack of explicit root causes results in validating the entire model structure (a "very problematic" diffuse task), instead of just the causal chains or root causes, a much easier precise task and one that can be specified by diagramming the causal chains to be validated, or validating just the root causes. The last is the most efficient.

Here we are speaking of causal problems with a small number of root causes rather than system optimization problems, where the entire model structure requires validation to confirm that reference mode behavior arises for the right reasons, because any node or loop may require change to support optimization. Optimization problems are information search problems rather than causal problems, since to optimize the system, every model node must be considered.

"Most of the critical assumptions in any model, mental or formal, are the implicit ones, the ones buried so deep that the modelers themselves are unaware of them" (Sterman, 2002). The endogenous point of view embodies a critical assumption that dominates system dynamics modeling: If a model can endogenously replicate reference mode behavior and is built "for the right reasons," then it must contain the root causes of the problem. Let's call this the *Principle of Endogenous Causes*. Homer and Oliva (2001) summarize the principle: (italics added, references preserved)

> The *dynamic hypothesis* is a cornerstone of good system dynamics modeling practice. It "explains the dynamics as *endogenous consequences* of the feedback structure" (Sterman, 2000), and explicitly states how structure and decision policies generate behavior (Richardson and Pugh, 1981). Moreover, "The inclusion of basic mechanisms from the outset forces the modeler to address a meaningful whole at all stages of model development" (Randers, 1973). That is, a *dynamic hypothesis* is the key to ensuring that the analysis is focused on diagnosing problematic behavior and not on enumerating the unlimited details of a "system."

Because the model's behavior arises endogenously, it must include the root causes of the problem. These are identified to diagnose the problem.

Sterman (2000, p. 95, italics added) states the principle this way: "A dynamic hypothesis is a working theory of how the problem arose. … In practice, discussion of the problem and theories about the *causes* of the problem are jumbled together in conversation with client teams. … Your goal is to help the client develop an *endogenous explanation* for the problematic dynamics."

The Principle of Endogenous Causes holds for relatively easy problems, such as the many client problems system dynamics has been applied to. But the principle fails for difficult problems, those where high system complexity (often combined with problem novelty) hides the root causes from traditional problem-solving methods. How this failure occurs can be explained with two (imperfect) examples:

Problem 1. *A patient has a fever. The intermediate cause is infection. The root cause is a damaged immune system, which has failed to prevent the infection.*

A system dynamics model of the fever and infection could easily be constructed. It would endogenously show how once the infection entered the body it replicated, causing the patient's temperature to rise to the point of a fever.

But if this was a case where there was a deeper root cause, such as a damaged immune system, then the model boundary would be inadequate and the model would omit the root cause, just as many doctors have done, when due to a faulty diagnosis they treated only the infection because they failed to spot its deeper cause. If the doctor had asked "Why did this patient get infected, when most people don't?" then she probably would have found the root cause.

Reference mode data would be a graph showing the rise in the patient's temperature. The model would be able to reproduce reference mode behavior. However, as the example shows, this is not enough to ensure the model contains the root cause.

Problem 2. *The classic Five Whys problem of "Why did the machine stop?"* As explained earlier, the first four answers were intermediate causes, while the fifth answer was the root cause.

It would not be hard to build a system dynamics model for each depth of analysis. The first would endogenously model the first intermediate cause. The second would model the first and second intermediate causes, and so on, as each model enlarged its boundary. Only the fifth model would have a correct boundary and include the root cause. All the models could replicate reference mode behavior, which is a graph showing the machine running and then stopping.

(➔NOTE: Can anyone think of an actual case where a completed SD model was later discovered to not include the root cause(s)?

These two examples should illustrate how revolutionary Sakichi Toyoda's invention of the Five Whys was. It offered an easy formal method for applying RCA to causal problems of any type or level of difficulty, and became the foundational method of formal RCA.

The examples should also illustrate why the root cause point of view is required for applying system dynamics to difficult problems. All the example models could replicate reference mode behavior endogenously. But that did not guarantee the models contained the root causes.

Model validity is "usefulness with respect to some purpose" (Barlas, 1996). If that usefulness includes explaining how a causal chain works dynamically and the chain is incomplete, no validity test of the model will reveal missing root causes. Only testing of solutions on the problem or closer study of the problem itself could do that, which is why in the Five Whys method "problem solvers are told to ask 'why' not once but five times." This suggests it is time to retire the Principle of Endogenous Causes and replace it with something else, when modeling potentially difficult problems.

(➔NOTE: The rest of the paper is only outlined in detail. What are your impressions so far? Are you convinced the general direction of the paper has merit or not? Why? This is valuable feedback for making it a stronger, more useful paper.

(Please note we will be following up on this paper with two more. Both are examples of applying SIP. One is for the environmental sustainability problem and how to add a change resistance layer to integrated system models, using World3 as an example. The other is for the rise of authoritarianism problem.

A similar process: The Toyota Production System (TPS)

Before describing SIP, we examine a similar tool.

(Briefly discuss lessons from two process diagrams from *The Toyota Way*. The diagrams describe the most mature RCA-based process in the world, the TPS. The first diagram is the 4P Model on p6 and 13. Large problems require a team of analysts, similar to a small company. Add two quotes on p12 on inability of companies to implement lean, discuss how SD modelers can avoid that fate. The second diagram is the problem-solving process on p256. This comes the closest to SIP. It's tailored to Toyota's class of problems. SIP is tailored to WP.

(A hard part is adapting RCA for a particular problem type. Cover this. Also cover how most attempts to adopt Lean fail.

The System Improvement Process (SIP)

This section describes SIP, an example of a tool that can integrate RCA with system dynamics modeling.

Overview of SIP

(Begin description of SIP. Present the grid and summarize the process. The other subsections cover various components of SIP. Open with "The question not asked cannot be answered" from *The Art of Problem Solving*, p33. SIP provides a series of questions that guides the analyst to the most productive RCA route. Once SIP is understood, analysts can modify and improve the process as they see fit.

(Steps 3 and 4 are not needed since we are integrating into the SD process. But we do need to describe Solution Convergence.

SIP Step 1. Problem definition

(Use present material. Try to add citations.

(Include WP characteristic of no definitive formulation. SIP solves this problem with the standard problem definition template. Give example. Now find a WP in the literature and see if we can give it a definitive formulation using template. Will be an interesting test.

SIP Step 2. Analysis

(Summarize this step, then transition to the other sections for the details.

The need for standardized subproblems

(Here we first review RCA literature on standard subproblems: Why they are needed, image examples from industry. This is problem decomposition.

The three subproblems present in all difficult large-scale social problems

(Present these. Focus the all-important change resistance subproblem, how it differs from policy resistance.

(Quote Donella Meadows, *Elements of* book p37: “These [policy] recommendations are often politically unacceptable. The problem is intrinsic to the basic paradigm of system dynamics and the nature of public decision making, and will probably always be a factor hindering the practical use of system dynamics in the policy world.” – This is change resistance. This limitation is solved by use of problem decomposition and the standardized subproblem of change resistance. The need to model change resistance on WPs must be added to the SD paradigm. Huge insight here.

Social Force Diagrams (SFDs)

(Present Social Force Diagrams and how they work. Include “A model is a purposeful and often radical abstraction. It should contain only those elements of reality that are needed to solve the problem” from *The Search for Solutions*, p116. The nucleus of these elements is what SFDs find. The model provides the rest.

(The Figure in the CR Layer paper has a blank SFD and the Autocratic Ruler Problem.

(As another example of an SFD use Challenger Explosion from CR Layer paper, mention how it too shows why RCA is needed on difficult problems.

The five sub-steps of analysis

(This will be of great interest to SD modelers and adds a lot of meat.

SIP Step 3. Solution Convergence

(Describe this step very briefly.

SIP Step 4. Implementation

(Describe this step very briefly.

Integrating SIP into the system dynamics modeling process

(Show table of present and modified process, discuss it, emphasize this is an example of how to improve the present process using the RCA point of view.

(Below are the main ideas of the modified process. This will evolve as we writeup this section. Using RCA, the key change is to construct a Static Hypothesis before constructing the Dynamic Hypothesis. The Static Hypothesis is a high-level causal hypothesis. The Dynamic Hypothesis is at the medium level. The model is at the low level. All three are causal hypotheses.

1. **Problem Definition**, of the original subproblem using the standard SIP format.: Move system A under constraints B from present state C to goal state D by deadline E with confidence level F.
2. **Formulation of Static Hypothesis**, done with RCA, problem decomposition, and Social Force Diagrams. Here additional subproblems are identified. Further and more detailed reference mode data is collected as needed, which continues in steps 3 and 4. Step output is the Social Force Diagrams.
3. **Formulation of Dynamic Hypothesis**, done in the traditional manner with Causal Loop Diagrams. RCA is also used. Note the main input to this step is the Social Force Diagrams (the Static Hypothesis), which serve as a starting point for building the Dynamic Hypothesis.
4. **Formulation of a Simulation Model**. RCA is also used.

Later steps are unchanged.

Example: Applying SIP to the Environmental Sustainability Problem

(This will be very condensed but should illustrate how SIP can be applied. Present the analysis results table, some of the SFDs, one solution specification. Discuss how some of the SFDs have loops, how use of SIP has allowed discovery of RCs and HLPs that have eluded traditional methods. Contrast these results against the present SD process as possible.

Discussion

(Accumulate these and Further Research as we go.

(The definition of RC allows determining if a problem is insolvable. Many WCs will be. But by relaxing the problem definition a WP can be shaped into a less damaging problem, one we can easily live with. For example, the income inequality problem can’t be solved completely. But it’s extremes and effects can be reduced. Discuss how. Is this a good example?

(Address potential criticism that detailed processes like SIP are reductionist. See notes on call with Shayne.

Further research

(A very important section, since there is much further research to do. Accumulate what these issues should be as we write the rest of the paper.

(The field of system dynamics could benefit by doing what industry has done. It set up formal organizations to assist with training and continuous improvement of industrial RCA, via certifications and what else?

Acknowledgements

This paper benefited hugely from the input of Shayne Gary, in the Publication Assistance Workshop at the 2021 System Dynamics Society Conference.

(More to be added later.

Supplementary materials

(Refer reader to the book *Cutting Through Complexity* for further detail at Thwink.org. We will also be publishing additional papers illustrating application of SIP.

References

Andersen, B., Fagerhaug, T., 2006. Root Cause Analysis: Simplified Tools and Techniques, Second Edition. ASQ Quality Press.

Aquayo, R., 1991. Dr. Deming: The American Who Taught the Japanese About Quality. Fireside.

Barlas, Y., 1996. Formal aspects of model validity and validation in system dynamics. Syst. Dyn. Rev. 12, 183–210. https://doi.org/10.1002/(sici)1099-1727(199623)12:3<183::aid-sdr103>3.3.co;2-w

Barney, G.O., 2002. The Global 2000 Report to the President and the Threshold 21 model: influences of Dana Meadows and system dynamics. Syst. Dyn. Rev. 18, 123–136. https://doi.org/10.1002/sdr.233

Doggett, A.M., 2004. A statistical comparison of three root cause analysis tools. J. Ind. Technol. 20, 20. https://doi.org/10.1074/JBC.274.42.30033.(51)

Fiksel, J., 2012. A systems view of sustainability: The triple value model. Environ. Dev. 2, 138–141.

Forrester, J.W., 2007. System dynamics—the next fifty years. Syst. Dyn. Rev. 23, 359–370. https://doi.org/10.1002/sdr.381

Forrester, J.W., 1971. World Dynamics. Wright-Allen Press.

Gabor, A., 1990. The Man Who Invented Quality: How W. Edwards Deming Brought the Quality Revolution to America. Penguin Books.

George, M., Maxey, J., Rowlands, D., Price, M., 2004. The Lean Six Sigma Pocket Toolkit: A quick reference guide to 100 tools form improving quality and speed. McGraw Hill.

Homer, J., Oliva, R., 2001. Maps and models in system dynamics: a response to Coyle. Syst. Dyn. Rev. 17, 347–355. https://doi.org/10.1002/sdr.224

Imai, M., 1986. Kaizen: The Key to Japan’s Competitive Sucess. McGraw Hill.

Marx, M., 2007. Six Sigma Saves a Fortune. Six Sigma Mag. 3.

Masson-Delmotte, V., Zhai, P., Pirani, A., 2021. Summary for Policymakers: Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Meadows, D., 1980. The Unavoidable A Priori, in: Elements of the System Dynamics Method. Productivity Press.

Meadows, Donella, Meadows, Dennis, Randers, J., Behrens, W., 1972. The Limits to Growth. Universe Books.

NASA Safety Center, 2013. NASA Root Cause Analysis Tool [WWW Document]. URL https://software.nasa.gov/software/LEW-19737-1 (accessed 2.16.16).

Nordhaus, W., 2018. Evolution of modeling of the economics of global warming: changes in the DICE model, 1992–2017. Clim. Change. https://doi.org/https://doi.org/10.1007/s10584-018-2218-y
Okes, D., 2019. Root Cause Analysis: The Core of Problem Solving and Corrective Action. ASQ Quality Press.
Pedercini, M., Arquitt, S., Chan, D., 2020. Integrated simulation for the 2030 agenda. Syst. Dyn. Rev. 36, 333–357. https://doi.org/10.1002/sdr.1665
Pyzdek, T., 2003. The Six Sigma Handbook: A Complete Guide for Green Belts, Black Belts, and Managers at All Levels. McGraw Hill.
Randers, J., 1973. Conceptualizing dynamics models of social systems: lessons from a study of social change. PhD dissertration, MIT Sloan School of Management.
Richardson, G.P., 2011. Reflections on the foundations of system dynamics. Syst. Dyn. Rev. 27, 219–243. https://doi.org/10.1002/sdr.462
Richardson, G.P., Pugh, A., 1981. Introduction to System Dynamics Modeling. MIT Press.
Rittel, H.W.J., Webber, M.M., 1973. Dilemmas in a general theory of planning. Policy Sci. 4, 155–169. https://doi.org/10.1007/BF01405730
Senge, P., 1990. The Fifth Discipline: The Art and Practice of the Learning Organization. Currency Doubleday.
Sterman, J., 2002. All models are wrong: reflections on becoming a systems scientist. Syst. Dyn. Rev. 18, 501–531. https://doi.org/10.1002/sdr.261
Sterman, J., 2000. Business Dynamics: Systems Thinking and Modeling for a Complex World. McGraw Hill, Boston.
Sterman, J., Fiddaman, T., Franck, T., Jones, A., 2012. Climate interactive: the C-ROADS climate policy model. Syst. Dyn. Rev. 28, 295–305. https://doi.org/10.1002/sdr
Tague, N., 2005. The Quality Toolbox. Quality Press.