Statistical Thinking Tools for System Dynamics[1]

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ABSTRACT

Statistical thinking is a well-established approach that involves the application of the scientific method to solving real-world organizational problems. The premise behind statistical thinking is that a disciplined approach to gathering facts can be used to identify the root causes that act as a barrier to successful performance. Once these root causes are identified, corrective action can be planned, and implemented, in order to change the underlying system. At a practical level, the Six Sigma methodology is the most widely known statistical thinking approach. Its structure involves a multi-stage methodology that starts at problem definition, and ends at implementation and consolidation of change. Throughout the stages of Six Sigma a number of practical tools – both qualitative and quantitative – are used to help formulate the problem, create a shared understanding of the problem amongst the different stakeholders, and identify policy levers that can improve system performance. This paper highlights the main parallels and differences between statistical and systems thinking, and illustrates how a number of tools from statistical thinking can also be used throughout a systems thinking consulting intervention. The paper concludes with a case study.

1. Introduction

Statistical thinking is defined as a philosophy of learning and action based on three fundamental principles (Hoerl and Snee 2002):

- All work occurs in a system of interconnected processes.
- Variation exists in all processes.
- Understanding and reducing variation are the keys to success.

There are a number of interesting points about this definition. It shows that the statistical thinking approach has a systems perspective, where human activity is viewed as occurring in a *system of interconnected processes*. This emphasis encourages problem solvers to think about the "bigger picture" and to ask questions relating to the connections between different organizational processes. It also reveals perhaps the core principle of statistical thinking, which relates to the idea of variation. *Variation exists in all processes,* in that differences in quality of output is pervasive in service and manufacturing industries. Think of a simple process such as ordering an espresso at your favourite coffee shop, and what is important to you as a customer. On a Monday morning, you might get served a perfect drink in five minutes. On Tuesday afternoon, the same drink might not taste as good, and could take ten minutes to prepare. This variation in quality is important to you, as a customer. Ideally, your requirement is to have a perfectly prepared espresso within five minutes of ordering it. If there is too much variation, if you cannot be sure in advance of the level of service you will receive, you may consider an alternative venue. Therefore, the success of many organizations is predicated on *understanding and reducing variation* in order to maximise customer satisfaction.

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This most prominent contemporary statistical thinking methodology is Six Sigma, which evolved out of Total Quality Management (TQM). The goal of TQM is to increase customer service, improve the quality of goods and services, and involve people in their work (Flood and Jackson 1991). Within TQM there are two interlinked objectives: to improve the quality of processes, and to develop the philosophy that individuals have individual responsibility for quality. Six Sigma can be viewed as an evolution of TQM, with a greater emphasis on the rigourous statistical tools in order to identify and eliminate sources of variability (Stamatis 2004, Buthmann 2008). An advantage of the Six Sigma approach is that its simple message can engage all employees, from chief executive level down to the front line, around a set of common measurable objectives centering on quality improvement, cost reduction, cycle time reduction and improved delivery performance. A disadvantage is the amount of organizational investment required, in terms of basic and advanced training, and also the consideration that the implicit goal of 3.4 defects per million opportunities may not be realistic for many organizations, and even trying to achieve such "perfection" may well lead to cognitive dissonance (Sterman 2000), and ultimately disillusionment and goal erosion.

In addition to a concrete goal (3.4 defects per million opportunities), Six Sigma provides and overall structured approach to problem solving. At a basic level, this methodology involves (Stamatis 2004):

- *Defining the problem.* Agreeing the problem to be solved, and its bottom-line business benefit. Producing a project charter, including team members, stakeholder analysis and a clear business case. Understanding the process ("as-is"), and the performing a detailed analysis of customer expectations ("voice of the customer").

- *Diagnosing the problem.* Formulating theories of causes, based on contributions from a range of process experts. The basic model is to represent causes and effect as Y = F(X), where Y is measurable, and linked to the earlier defined voice of the customer. The factors that influence Y (i.e. the Xs), are then explored, usually with the aid of a fishbone diagram, and using participative techniques such as multi-voting to initially identify what is known as the "vital few." This is followed by data gathering, and exploring sources of variation using techniques such as control charts. Further detailed statistical analysis such as design of experiments is then employed to "prove" – beyond a reasonable statistical doubt – that some Xs have a greater cause then others, and these will subsequently become the focus of taking action.

- *Remedying the problem.* For the causes identified, potential solutions are designed. Implementation issues are planned for, such as overcoming resistance, investment in newer technologies, and mapping out new work procedures.

- *Holding the gains.* Monitoring the new system performance over time, with particular reference to the key performance indicators (KPI) – often the Ys – that would have been identified when the problem was originally defined.

Typically, this problem solving methodology is iterative over time, and the classic Deming's Cycle of Plan – Do – Check – Act is used to continually evolve organization performance over time. [For an accessible selection of case studies relating to the statistical thinking approach, ranging from performance improvement for a high-school soccer team to a study of resolving customer complaints for a consumer product, the reader is referred to Hoerl and Snee (2002).]

2. The System Dynamics Methodology

Roberts (1977) identifies the usual sequencing of activities in a model-building project as: problem identification, model development (including data gathering) and exercising, recommendations and implementation. He recommends that "our overall criterion of model effectiveness must be dependent on implemented change, implemented improvement." He distils many years of consulting experience in system dynamics into a number of conclusions. For example, in relation to project selection, he recommends that the problem (or opportunity) must be important to the client, and that the stated objectives must be credible. With regard to the modeling process, this must have maximum in-house involvement, should expedite initial model development (i.e. use an iterative approach to development), and model detail should be sufficient for persuasiveness (i.e. to convince the client that you have properly taken into account their issues, questions and concerns). Furthermore, validity testing should be geared to assure management, and the measures of effectiveness designed into the model must be consistent with real-world measures. As the project moves from analysis of policy options towards implementing change, Roberts recommends that the consultant must take into account the ability of the organization to absorb change, and to carefully consider the impact of change on other systems. With regard to implementation, in his recent article (Roberts 2007) entitled "Making System Dynamics Useful" he reminds readers to:

> "Seek implementation in all you do. Modeling doesn't stop at comprehensive analysis and reporting. Those are merely midway points towards the objective of impact."

Many of these ideas are also infused into modern process improvement methodologies, such as Six Sigma, which are primarily concerned with the *objective of impact*. Best practice involves having a clear problem definition, and measurable objectives, ideally related to improving customer satisfaction and "delighting the customer." Successful projects usually have extensive involvement between client and consultant, where opportunities for shared learning are enhanced, and projects tend to iterate through model development in order to maximise client confidence. Problem solving relies on a scientific approach, where data is used to guide understanding, and mathematical and computational tools (simulation, hypothesis testing, decision analysis, optimization) are employed to identify targeted actions.

There is a strong awareness of barriers to successful change, when an improvement project produces "more sizzle than steak" because management have committed one or more of the "seven deadly sins", which include (Rummler and Brache 1995): (1) not linking the change to the strategic issues the business faces; (2) not involving the right people (especially top management) in the right way; (3) not producing a clear charter with accountability for success and failure; (4) thinking that for successful change to occur, old processes must be obliterated; (5) not considering how the changes will affect those in the organisation's front-line; (6) focusing too much on redesign, rather than implementation; (7) failing to leave behind a measurement system and other infrastructure elements necessary for continuous process improvement.

Sterman (2000) emphasizes the importance of the end-goal for modeling, where "the purpose is to solve a problem, not only to gain insight (although insight into the problem is required to design effective policies)," and the fact that "modeling does not take place in splendid isolation… it is embedded in an organizational and social context." He observes that modeling is a feedback process, not a linear sequence of steps, and that models go through "constant iteration, continual questioning, testing and refinement." The modeling process is summarised as a number of steps:

1. **Problem Articulation**. This involves identifying the problem, and exploring why it is a problem. Key variables are selected, and the problem boundary considered. The time horizon is considered, for example, how far back in the organisation's past are the possible root causes of the problem, and how far into the future should be considered. The timeline could be anything from weeks to years – for example Forrester (2007a) comments that, when discussing the world dynamics model, "the interesting behaviour in the computer simulations lay 50 years in the future and presumably beyond the time horizon of interest to most people." Reference models of key variables and concepts are considered (historical data and future projections).

2. **Formulation of Dynamic Hypothesis.** Here, a dynamic hypothesis is proposed in terms of what combination of feedback structures can best explain the problematic behaviour. The problem is mapped based on key variables, reference modes, and available data using tools such as causal loop diagrams, stock and flow maps, policy structure diagrams, and other appropriate facilitation tools.

3. **Formulation of a Simulation Model.** Based on the earlier analysis, a specification of the model structure is produced, along with key decision rules. Parameters are estimated, and initial tests performed.

4. **Testing.** The model behaviour is compared to the known reference models, and its robustness is tested under extreme conditions. Sensitivity testing can be used to evaluate the impact of uncertainly in model parameters on overall outcomes.

5. **Policy Design and Evaluation.** Explore the new decision rules, strategies and structures that could be tried in the real-world. Capture these in the model, and perform "what-if" analysis to observe the potential impact of policies. Test to see if different policies interact, in terms of reinforcing or diluting change. Utilise sensitivity techniques to determine impact of uncertainty.

Taken at a high level, these five stages in the modeling process map well to the first three stages (mentioned earlier) of the Six Sigma problem solving methodology, namely from the point of problem definition to the identification of possible solution (or policy) alternatives. At the early stages of problem analysis, both approaches can make use of their own set of qualitative models, such as process maps, SIPOC (Supplier – Input – Process – Output – Customer) diagrams, Fishbone Diagrams, Voice of the Customer (VOC) for Six Sigma, and Causal Loop Diagrams, and behaviour over time graphs for system dynamics. These are valuable tools, particularly from a group model building perspective, and they play a crucial part in defining and scoping the problem, prior to the undertaking of more thorough, mathematical-based, analysis.

A further common characteristic of system dynamics and statistical thinking is that, after the initial problem definition phase, scientific thinking plays a large part in the problem solving process. In system dynamics, the goal is to produce a simulation model, based on Calculus, that can enhance our understanding of, and insights into, complex systems. The importance of simulation is highlighted by Forrester (2007b), when he states that "only by going the full road to extensive computer simulations is one prepared for the depth of understanding required in real-world situations." In statistical thinking, the goal is to reduce policy analysis of cause and effects to a Y=F(X) scenario, whereby using statistical theory (e.g. hypotheses testing, control charts, etc.), the best alternative can be selected based on an objective, scientific approach.

However, there are also significant differences between the two approaches. In statistical thinking, feedback is not considered. So while tools such as the fishbone diagram explore cause and effect, they stop after "the five whys", and do not assess the impact of circular causality. Also, the core elements of the system dynamics approach such as non-linearity, delays, and stocks and flows, are not part of statistical thinking. Because statistical thinking is largely based on the analysis of data, the availability of accurate, statistically valid data, is essential. Furthermore, it could be argued that this primary focus on data means that less attention is given to the underlying structures that generate that data, and so longer term dynamics and behaviour may not be captured.

In summary, a number of observations can be made. While acknowledging their divergent properties, the common features of systems dynamics and statistical thinking are that they both:

- Focus on the "objective of impact" and the improvement of organizational performance.
- Utilise a structured problem solving approach.
- Are client-centred and make use of group-based modeling.
- Make use of both qualitative and quantitative tools and methods.

The remaining elements of this paper will highlight specific tools from statistical thinking that could be used as part of a system dynamic's based intervention into organizational improvement.

3. Statistical Thinking Tools for System Dynamics

Within system dynamics, there are two categories of tools: qualitative and quantitative. The same classification can be applied to statistical thinking tools (see table 1) which can be applied during the system dynamics modeling process, and these will now be summarised.

Statistical Thinking Qualitative Tools	Statistical Thinking Quantitative Tools
SIPOC and Process Map	Regression
Voice of the Customer	Control Charts
Fishbone Diagram	Statistical Inference Tools

Table 1: Applicable tools from Statistical Thinking

1. Supplier – Input – Process – Output – Customer (SIPOC) and Process Map

The SIPOC allows problem solvers to construct an end-to-end view of a given process, where the focus is on the external entities that interact with a given process. Normally, the SIPOC documents a process at a relatively high level (guidelines are that no more than eight steps should be documented). A benefit of building a SIPOC is that it encourages a system-wide view of the process, as people from different functions work together in a collaborative way to understand the customer, and how individual functions add value to the end customer. In some cases (for example, an order fulfillment process), the supplier and the customer could be the same entity. An example of a SIPOC for an order fulfillment process is shown in table 3. This also highlights the internal customers for a process, which is valuable as it clarifies the "links in the chain" for a given process.

Supplier	Input	Process	Output	Customer
Consumer	Order	1. Validate Order	Valid Order	Planning
Sales	Valid Order	2. Create Build Plan	Build Plan	Production
Planning	Build Plan	3. Build Computer	Computer	Quality
Production	Computer	4. Test Computer	Tested Computer	Shipping
Shipping	Tested Computer	5. Ship Computer	Computer	Consumer

Table 2: Sample SIPOC for an order fulfillment process

The process map is closely related to the SIPOC, but it is designed to show more of the "wiring" for a process, in terms of decision points, main flows, alternate flows and exceptions. Normally, a "swimlane" approach is used, which visualizes the different functions that must interact in order to successfully generate value for the customer. A detailed example of a process map is documented in the case study section.

2. Voice of the Customer (VOC)

The goal of any process – manufacturing or service – is to deliver value to the customer, and the VOC is a method for capturing the customer's "voice", and translating that into a set of measurable targets. These targets are called critical to quality (CTQs). The VOC can be captured in a number of different ways, for example, surveys, customer focus groups, analysis of complaint logs, observations of behaviour, etc. Effective use of the VOC method can obtain a baseline assessment of customer satisfaction, and also identify the important drivers of customer satisfaction. These drivers, once expressed in a measurable way, provide the stimulus to making informed design choices for the organisation's processes. Starting with the list of customers that appear on the SIPOC, each group of customers would be asked "what is important to you as an output from our process?" Going back to our earlier example of the coffee shop experience, sample answers from a range of customers could include:

- "I want a reliable service"
- "The staff must be welcoming and friendly"
- "I want my coffee brewed to perfection"
- "I want the cost to be reasonable."

Given this set of customer requirements, the challenge is to translate these into measurable characteristics. The normal approach used is to continue the dialogue with the customer, until they can commit to something that is quantifiable. For example, consider this hypothetical scenario:

- Analyst: "What is important to you when you visit our coffee shop?"
- Customer: "I want a reliable service."
- Analyst: "How would you measure reliability?"
- Customer: "That's easy. I want my order taken within five minutes of entering, and I want my order on the table within ten minutes of ordering."

With this information, two measurable characteristics (CTQs) have been identified. The first is the length of time the customer waits before their order is taken. The second is the amount of time the customer waits before their order is delivered to the table. The VOC and corresponding CTQs are then given a priority (high, medium or low), as well as a target value, and often the format used is similar to that shown in table 2.

Voice of the Customer	CTQ	Target	Priority
"I want a reliable service"	Customer Wait Time (Service) Customer Wait Time (Order)	5 10	H H
"The staff must be welcoming and friendly"	Customer survey results (Likert item 1)	4.2	M
"I want my coffee brewed to perfection"	Customer survey results (Likert item 2)	4.8	H
"I want the cost to be reasonable."	Customer survey results (Likert item 3)	3.8	M

Table 2: Sample VOC/CTQ for a coffee shop example

3. <u>Fishbone Diagram</u>

The fishbone diagram (or Ishikawa diagram, is named after Kaoru Ishikawa who was a quality management practitioner in the Kawasaki shipyards) is a collaborative tool that can be used to identify the root causes that drive a given effect. Normally, the effect is based on specific CTQs identified using the VOC process. For example, “Long Waiting Time” is an example of an effect for our earlier coffee shop example, so this would be represented at the head of the diagram. It is a group-based brainstorming process, and a facilitator will often use the “5 whys” as a technique to arrive at a root cause. For example, consider the following dialogue:

- “Why do our customers have to wait a long time for service?”
    - “Because our waiting staff are run off their feet.”
- “Why are our waiting staff run off their feet?”
    - “Because its difficult to keep staff levels at the required level.”
- “Why is it difficult to keep staff levels high?”
    - “Because once they are trained, they all leave for other coffee shops.”
- “Why to they leave for other coffee shops?”
    - “Because they think we don’t pay them high enough wages.”

In this case, “4 whys” reveal a possible root cause for the problem identified. In reality, there will be a range of root causes, and these can be classified by the group, or a standard classification such as the 6Ms for manufacturing (Method, Machine, Man, Mother Nature, Material, Measurements), and the 4Ps for services (Policies, Procedures, People, Plant/Technology).

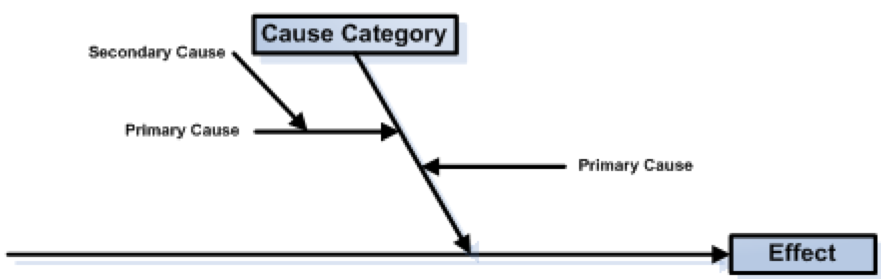

Figure 1: Overall structure of a fishbone diagram

In order to prioritise causes, multi-voting can be used to gather views on which causes are the most likely to influence the outcome. Each participant can be given a quota of votes, and these can be allocated to the different causes. A simple tally of votes will give an indication on what root causes – if addressed – are likely to achieve improvements on the outcome. Data can then be collected and analyses in order to confirm the impact of these influences, and in a Six Sigma project, this data collection would be followed by detailed statistical analysis in order to gain a thorough understanding of the Y=F(X) relationships.

4. <u>Statistical Thinking – Quantitative Tools</u>

A detailed discussion of statistical inference tools is outside the scope of this paper. However, the application of statistical techniques to system dynamics modeling is not in any way a new concept, as techniques such as least squares are often used for testing and calibrating models. The key point to be made here is that, depending on the quality of data available, the use of statistical inference can assist the model building process. For example, if you wanted to verify that the yield differences (e.g. proportion of defects generated per worker) between different cohorts of workers were statistically significant, discrete data tests such as the 2-proportions test or the Chi-squared test could be used to verify this. If the hypothesis failed (i.e. there were significant differences between cohorts of workers), this would provide an empirical basis for disaggregating the stock of workers into a number of separate stocks, and it would also provide a justification to the client for making such a decision.

This section has given an indication of the statistical thinking tools – both qualitative and quantitative – that can be used by system dynamics practitioners throughout the model building process. As of yet, there is no empirical evidence to show the practical benefit of using these tools. The basic premise is that in certain situations these tools could well have an impact in terms of consultant-client interaction, and in terms of group facilitated discussion. Perhaps the tool that needs most thought beforehand is the fishbone diagram, as its shares a cause and effect focus with the causal loop diagram. The major difference is the absence of feedback. A possible solution would be for the practitioner to create the diagrams in parallel, and by using common variable names, link across from the causal loop diagram to the fishbone. The key objective is that the practitioner would use these tools to (1) gain insights into the problem and (2) maximise the client's confidence in the model. In summary, the statistical tools that could be deployed - alongside causal mapping and stock and flow diagrams - as part of a system dynamics intervention are:

- SIPOC, so that the end-to-end model can be constructed in a participative way, and that both internal and external customers can be identified.
- Voice of the customer, in order to discover measures that are critical to quality;
- Fishbone diagram, and associated multi-voting method, in order to help identify root causes to problems. With no little skill from the consultant, these diagrams could be aligned and developed iteratively with the causal loop diagrams to identify of feedbacks can enhance our understanding of how systems behave over time.
- Finally, the use of formal statistics techniques can assist in the identification of causal relationships, and in model validation and testing.

In order illustrate the practical use of these tools, a case study is now presented.

4. Sample Case Study

The case study is informed by a real-world example, which involved the implementation of an information technology solution to support a repairs process. The perceived problem that drove the solution was that a call centre manager was concerned at the average length of time that call centre operators were spending on calls. The manager, a firm believer in the power of incentives, championed a solution that set a target call time for operators, monitored individual call times, and notified operators when they approached the system-wide target. When operators met their target, they were given a financial bonus. Not surprisingly, the average call time went down, and so management anticipated the average end-to-end repair time would also drop.

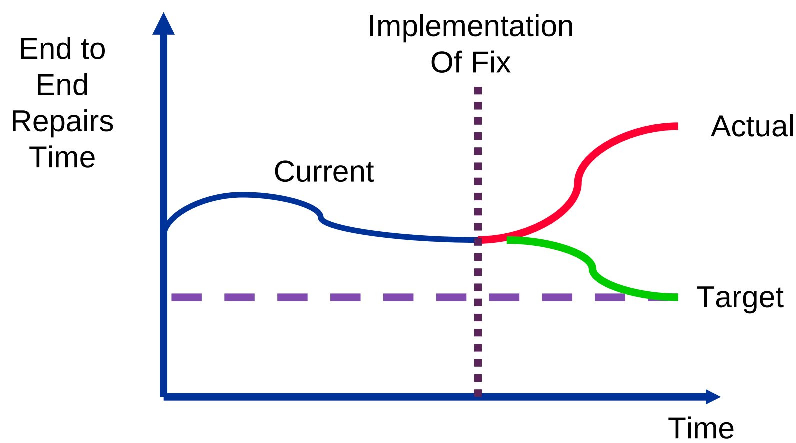

Figure 2: Unexpected outcome of system implementation

However, figure 2 illustrates the actual outcome of this intervention. Rather than following the expected line of success – highlighted in green, the system responded in an unexpected manner and followed the red line trajectory. Therefore the behaviour over time would indicate the some unexpected side effect influenced the outcome. At first glance, the systems archetype "fixes that fail" would be a good starting point for articulating a dynamic hypothesis, but before that is examined in more detail, a number of statistical thinking models are presented. These are:

- The voice of the customer
- The SIPOC / process map
- The fishbone diagram

Voice of the Customer

Here we speculate on what might be important to the customer, and translate these voices into measurable characteristics (see table 3).

Voice of the Customer	CTQ	Target	Priority
"I want my call answered right away"	Number of calls that ring out	2%	H
"I only want to give information once"	Number of times a customer is called for clarification	0	H
"I want my problem fixed promptly"	End to end repair time	1 day	H

Table 3: Voice of the customer for the repairs process

SIPOC/Process Map

The process map for the repairs process is shown in figure 3. This clearly shows the different functions involved in the process, and how they interact. Also, closer inspection of the flow chart often indicates where time is consumed unnecessarily. The interaction between the repairs function and the customer is effectively rework, as there may be situations where sufficient information is not available for the repair person to complete the task successfully.

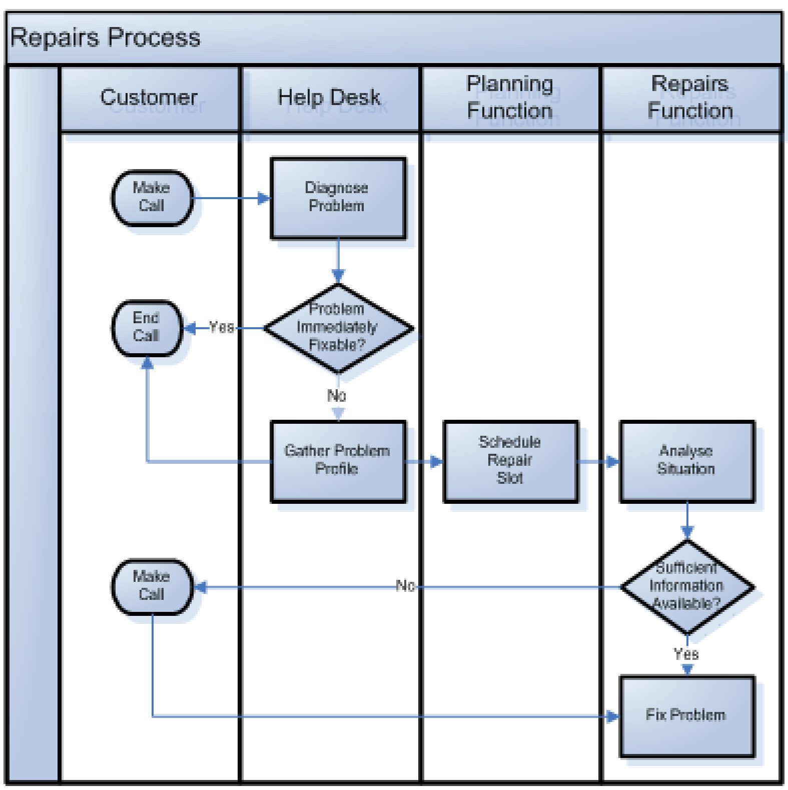

Figure 3: Process map for the repairs process

Fishbone Diagram

As problem solvers collaborate to build an end-to-end process map, and also take time to consider what is important to the customer, a fishbone diagram (see figure 4) can be constructed for the important CTQs identified earlier.

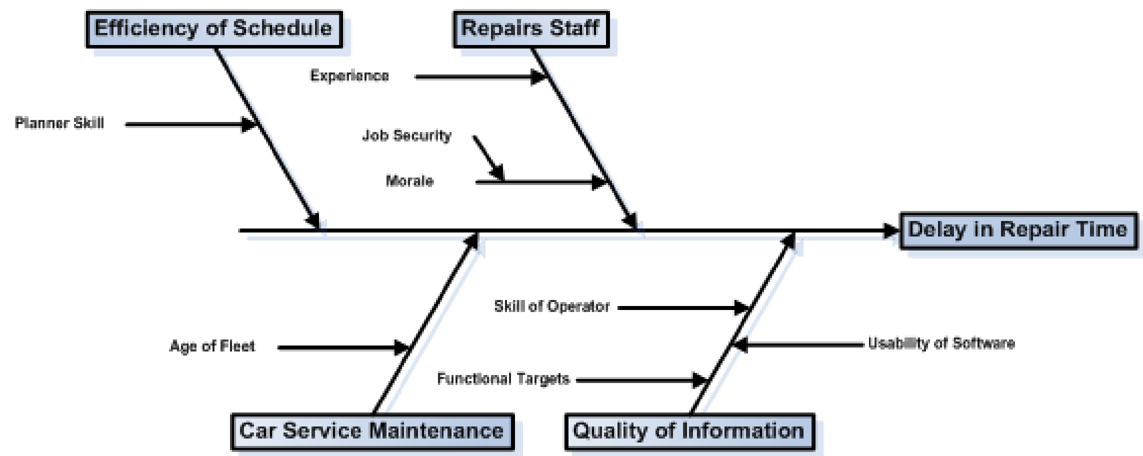

Figure 4: Fishbone diagram for CTQ Repair time

In exploring the possible causes, issues such as schedule efficiency, staff experience and morale, equipment quality, and the quality of information are regarded the main effects that influence the cause. One of those identified in quality of information is functional targets, whereby targets relevant to one part of the system (the help desk) reduce the quality of information, and lead to an increased delay in the repair time. This delay is caused by a rework cycle where the repair technician does not have enough information to fix the problem, and so must contact the customer. This information problem was the root cause of the poorer performance, and the overall dynamic can be captured within the archetype "fixes that fail", as shown in figure 5.

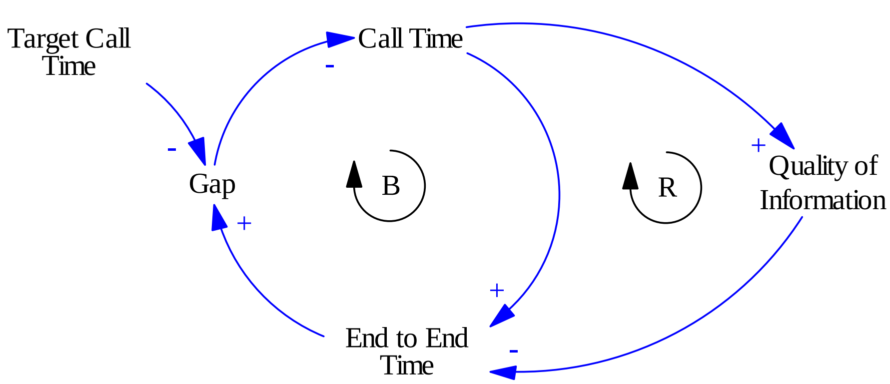

Figure 5: Quality of information as a cause of unintended consequences

An early iteration of a simulation model is now constructed, and this focuses on the link between the quality of the initial diagnosis and customer satisfaction, and ultimately, their likelihood of defection. This is a longer term impact of poorer quality, a "slow burner" that might not show up as an issue if the problem solving time horizon was relatively short.

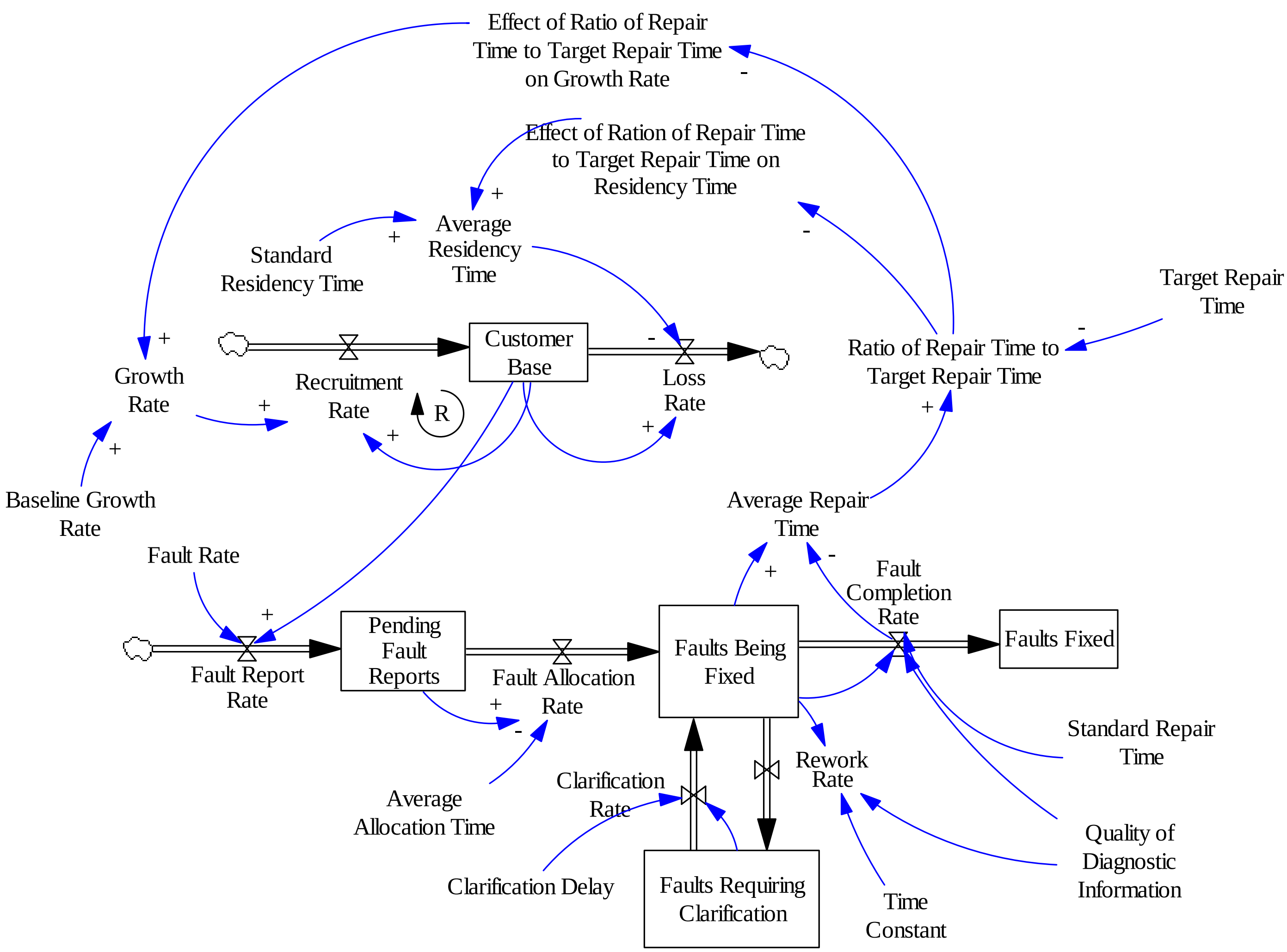

Figure 6: Initial stock and flow model to highlight link between quality of diagnostic information and customer growth

The idea behind this initial model is to communicate a longer term dynamic to the client, where the consequences of a myopic system change could lead to the erosion of their customer base. This hypothesis can be supported through the use of sensitivity analysis, whereby the constant *quality of diagnostic information* can be varied between the values [0.2 to 1.0]. The results of this initial simulation is shown in figure 7, and the full set of equations are listed in table 4.

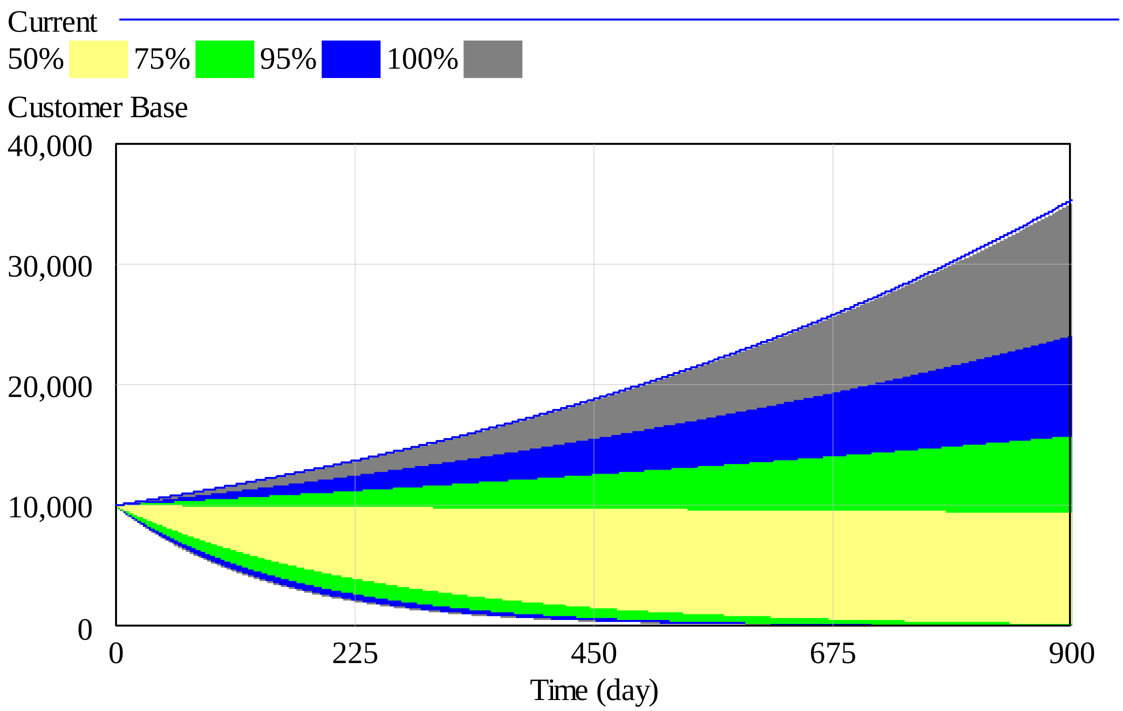

Figure 7: Sensitivity runs for impact of quality of information on customer base

(1)	Average Allocation Time = 1
(2)	Average Repair Time = XIDZ (Faults Being Fixed , Fault Completion Rate , 1)
(3)	Average Residency Time = Standard Residency Time * Effect of Ration of Repair Time to Target Repair Time on Residency Time
(4)	Baseline Growth Rate = 0.2 / 100
(5)	Clarification Delay = 1
(6)	Clarification Rate = Faults Requiring Clarification / Clarification Delay
(7)	Customer Base = INTEG(Recruitment Rate - Loss Rate , 10000)
(8)	Effect of Ratio of Repair Time to Target Repair Time on Growth Rate = WITH LOOKUP(Ratio of Repair Time to Target Repair Time , ([*see model for data points*]))
(9)	Effect of Ration of Repair Time to Target Repair Time on Residency Time = WITH LOOKUP(Ratio of Repair Time to Target Repair Time , ([*see model for data points]*)
(10)	Fault Allocation Rate = Pending Fault Reports / Average Allocation Time
(11)	Fault Completion Rate = Quality of Diagnostic Information * Faults Being Fixed / Standard Repair Time
(12)	Fault Rate = 1 / 30
(13)	Fault Report Rate = Fault Rate * Customer Base
(14)	Faults Being Fixed = INTEG(Clarification Rate + Fault Allocation Rate - Fault Completion Rate - Rework Rate , 1000)
(15)	Faults Fixed = INTEG(Fault Completion Rate , 0)
(16)	Faults Requiring Clarification = INTEG(Rework Rate - Clarification Rate, 0)
(17)	Growth Rate = Baseline Growth Rate * Effect of Ratio of Repair Time to Target Repair Time on Growth Rate

(18)	Loss Rate = Customer Base / Average Residency Time
(19)	Pending Fault Reports = INTEG(Fault Report Rate - Fault Allocation Rate, 1000)
(20)	Quality of Diagnostic Information = [0..1] varied on the sensitivity analysis run
(21)	Ratio of Repair Time to Target Repair Time = Average Repair Time / Target Repair Time
(22)	Recruitment Rate = Customer Base * Growth Rate
(23)	Rework Rate = (1 - Quality of Diagnostic Information) * Faults Being Fixed / Time Constant
(24)	Standard Repair Time = 1
(25)	Standard Residency Time = 1000
(26)	Target Repair Time = 1
(27)	Time Constant = 1

Table 4: Equations for the initial stock and flow model

Clearly, the model shown is at an early stage, and additional factors such as employee skill levels, motivation, and productivity could also be considered. Furthermore, a system approach would focus on trying to reduce equation (12) – the fault rate, as reducing that would take pressure of the repairs process, and in an ideal organization that produced high-quality products, there would be less of a need for a repairs process.

5. Conclusion

The aim of this paper is to highlight the similarities – and differences – between system dynamics and statistical thinking, and in doing so, identify opportunities for statistical thinking tools can be used as part of the system dynamics modeling process. Future work will focus on gathering empirical data on how the use of these tools might work in practice, and whether they can enhance the process of generating a shared understanding of the problem, contribute to increasing the client's confidence in a model, and contribute to the goal of successful implementations of system dynamics.

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