SYSTEM THINKING

Key Takeaways

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Table of Contents

1.FOUNDATION OF SYSTEM THINKING

1.1. INTRODUCTION

- Systems have interrelated entities and deliver new function.
- System thinking is thinking of things as systems.
- Systems are becoming more complex as we ask more from them.
- System thinking helps make complex things appear simple.
- System thinking expands the scope of thinking and avoids stovepipes.

1.2. EMERGENCE

- Emergence of function—the system does something that was never done before.
- Emergence of performance—the system does something better than before.
- Emergence is of the ilities or non-functional attributes—for example the system has more reliability.
- Emergence of an emergency that we don't want to happen.

1.3. FUNCTION

- Function is what a system does.
- It is how systems create benefit.
- It consists of an operand that is changed, and a process that brings about the change.
- Emergence occurs in the functional domain.

1.4. FORM

- Form is the physical or informational embodiment of the system—what it **is**.
- Form is the instrument of function—what the system **does**.
- Value is benefit at cost, benefit derives from function, cost is dependent on form.
- Abstractions help make systems appear simple by hiding un-needed details.

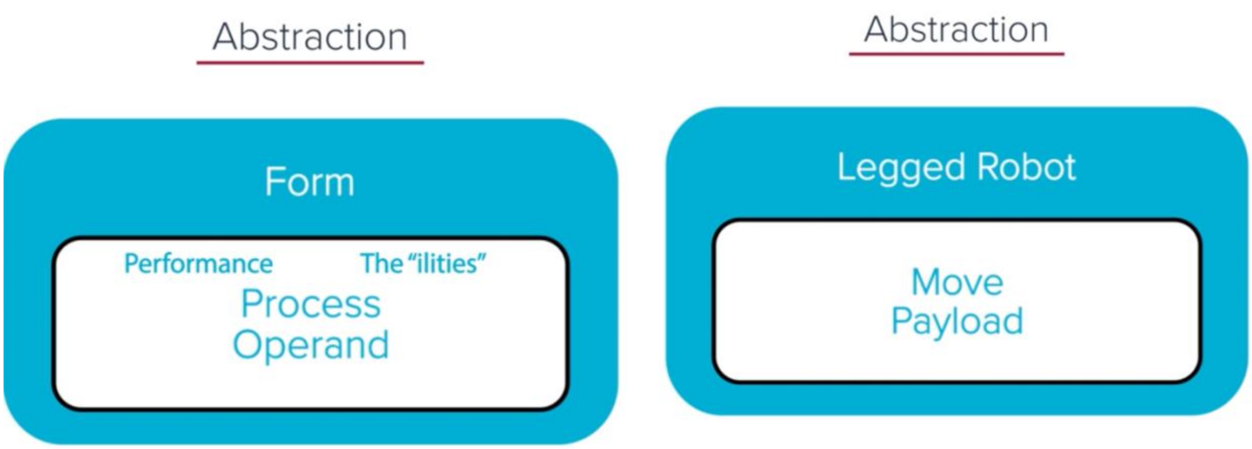

Figure 1 Form, process, and operand

1.5. IDENTIFYING ENTITIES

- A system can be decomposed into entities, and entities can be composed into a system.
- This decomposition and composition is one of our most powerful tools in managing complex systems.
- Every system is part of a larger system and can be decomposed into smaller systems.
- Every system and entity can be thought of as an abstraction with form and function.
- Systems and entities can be placed in a hierarchy.

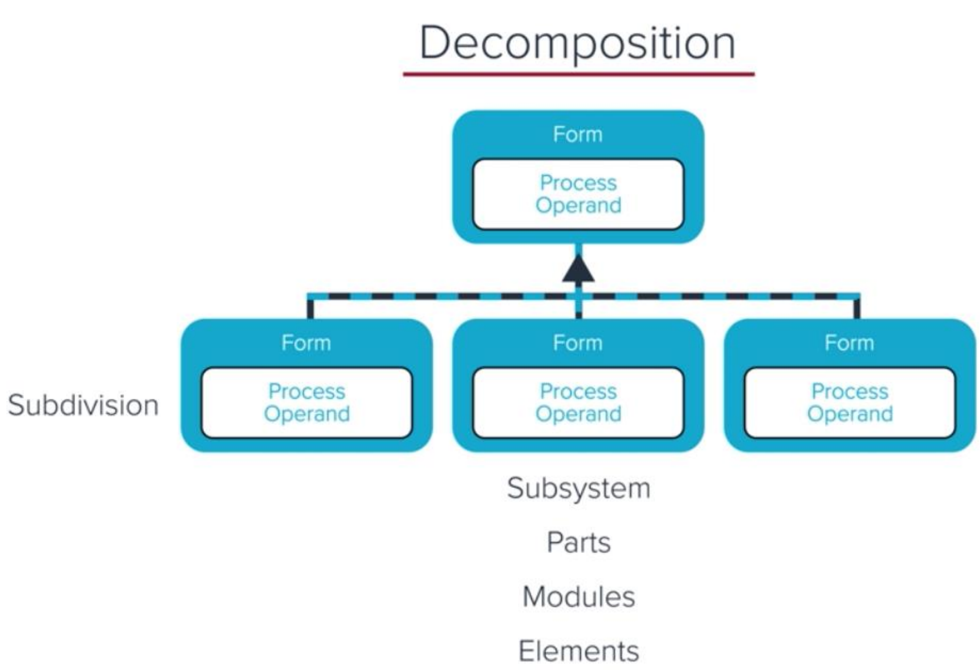

Figure 2 Composition and Decomposition

1.6. SYSTEM BOUNDARIES

- Identify the entities by decomposition or composition.
- Try to limit the number of entities to 7 +/- 2.

- Use holistic thinking to identify all reasonable entities of a system.
- Focus on the minimum set of essential entities.
- Draw a boundary that divides the system from its context.

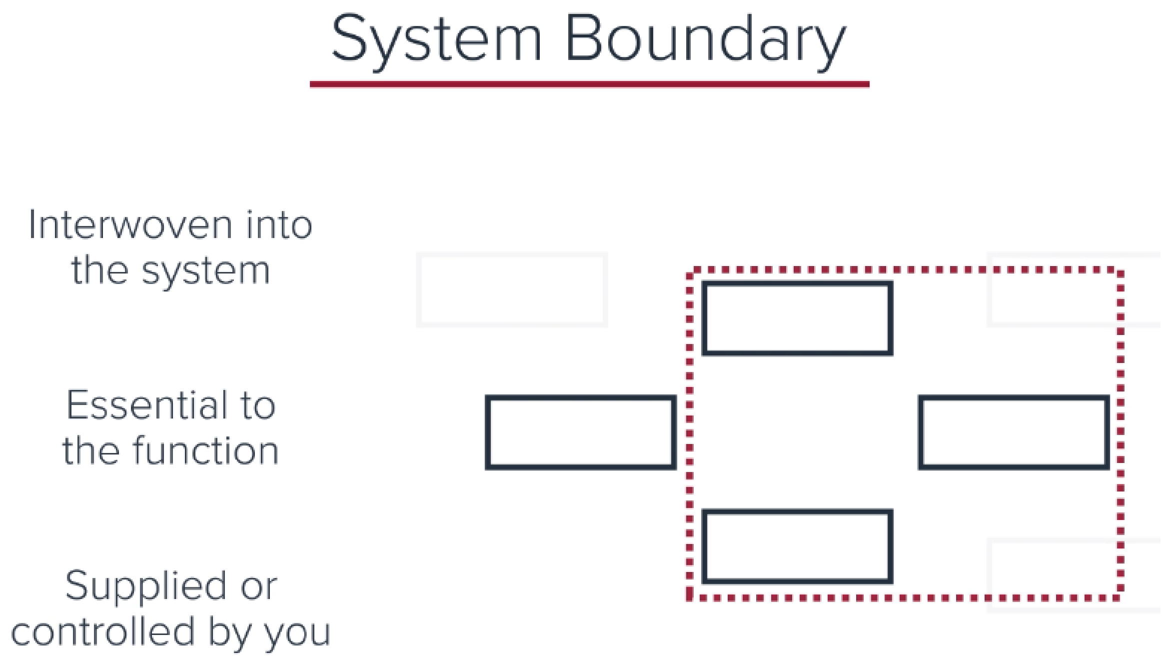

Figure 3 System Boundary

1.7. FUNCTION RELATIONSHIPS

- A group of entities become a system when there are relationships.
- Relationships have form and function—emergence happens as a direct result of functional relationships.
- Functional relationships are interactions—one entity affects another. An operand is passed, or an operand is shared.
- Functional relationships can be among the entities within the system, or with entities outside the system in the context.

1.8. FORMAL RELATIONSHIPS

- Where there is a functional relationship (an interaction) there is usually a formal relationship (the structure).
- The functional interaction is usually enabled by a formal relationship.
- Structure can include all kinds of connections, as well as location and sequence.
- When structure and interaction cross a system boundary, careful system thinking is required.

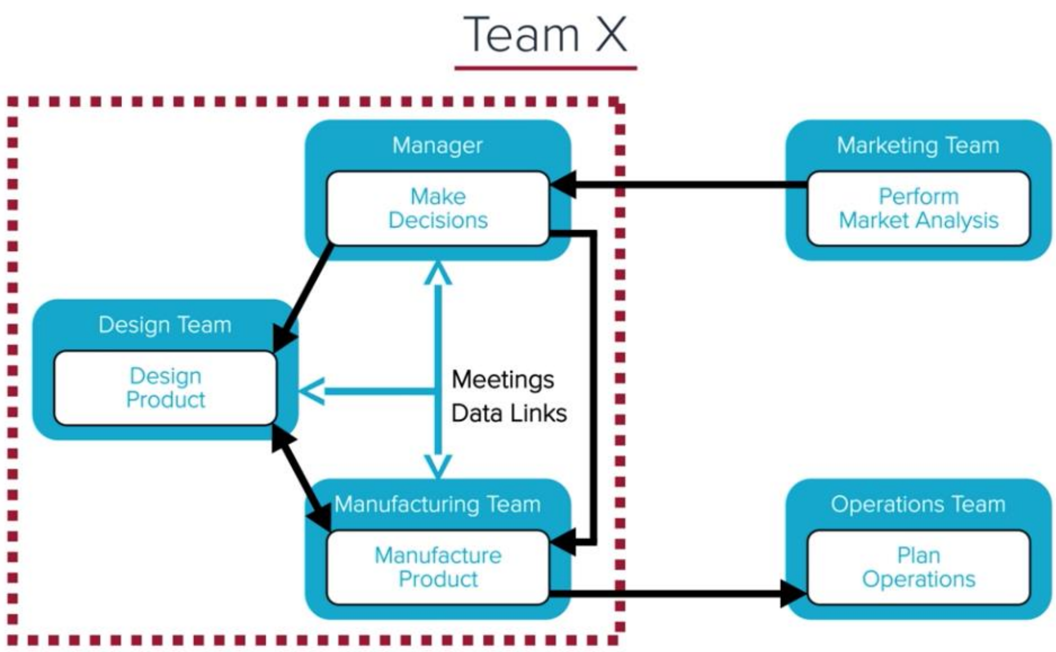

Figure 4 Team X (functional relationships in black, form relationships in blue)

2. EMERGENCE AND SYSTEM SUCCESS

2.1. PREDICTING EMERGENCE

- Emergence occurs when the functions of entities interact through the functional relationships.
- Emergence is enabled by the form of entities (the instrument of the function) and the form of the relationships (the instrument of interaction).
- When emergence actually is tested, the possible results are that the expected emergence occurs, it fails to emerge, or an unexpected emergence occurs.
- When a piece of a system is altered, that change can propagate far throughout the system.

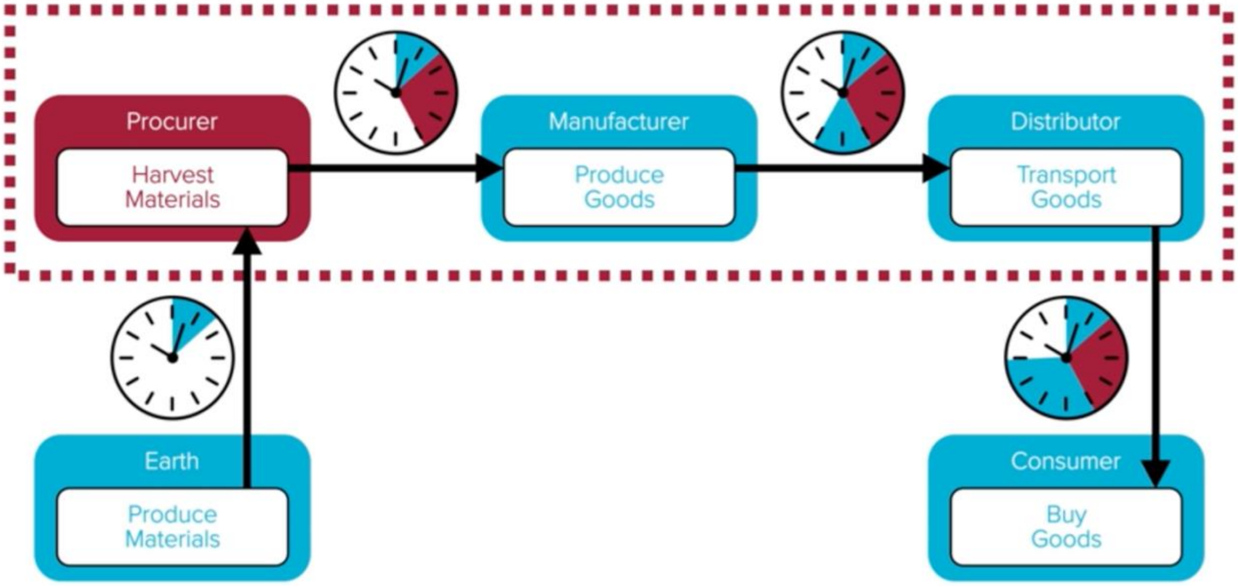

Figure 5 The emergence of this system is the transformation of raw materials (harvest materials) to goods in the hands of the consumer

2.2. UNDERSTANDING EMERGENCE

- It's hard, but essential, as emergence is why we deal with systems.
- Emergence can be understood and predicted by human reasoning, supported by precedent, experimentation and modeling.
- For unprecedented systems, where modeling and experimentation are not easy, only human reasoning is available to predict emergence.
- This is the real goal, and the real art in System Thinking.

2.3. SYSTEM'S SUCCESS AND FAILURES

- For systems to succeed, all the entities and all of the relationships have to be functioning.
- A system can fail if one entity or one relationship—the weak link in the chain—fails to function.
- But a system can also fail as a system even though all the entities and all the relationships function well.

2.4. USING SYSTEM THINKING

- System thinking is thinking of things as systems: Entities and relationships, form & function, emergence & value.

3. SYSTEM DYNAMICS: TOOLS FOR LEARNING IN A COMPLEX WORLD

3.1. SYSTEM DYNAMICS METHOD FOR SYSTEM THINKING

- Policy resistance is the phenomenon where when well intentioned people receive sufficient support and implement the policies that they believe are best suited to address the pressing challenges that they face, it doesn't work, or more commonly and more insidiously, it works locally right now, but then the problem comes back often worse later.
- “There is no such thing as a side effect - there are just effects: you make decisions, your decisions have multiple effects. You're not the only player in the system, there are other actors and other agents with their own goals and those goals are typically different from your goals. But we all share the same world. So, whenever you take action that pulls the status system closer to your goals. You're almost certainly pulling it farther away from the goals of those other actors. And they're not just gonna sit there and take it, they're gonna respond.” - Professor John Sterman**.**

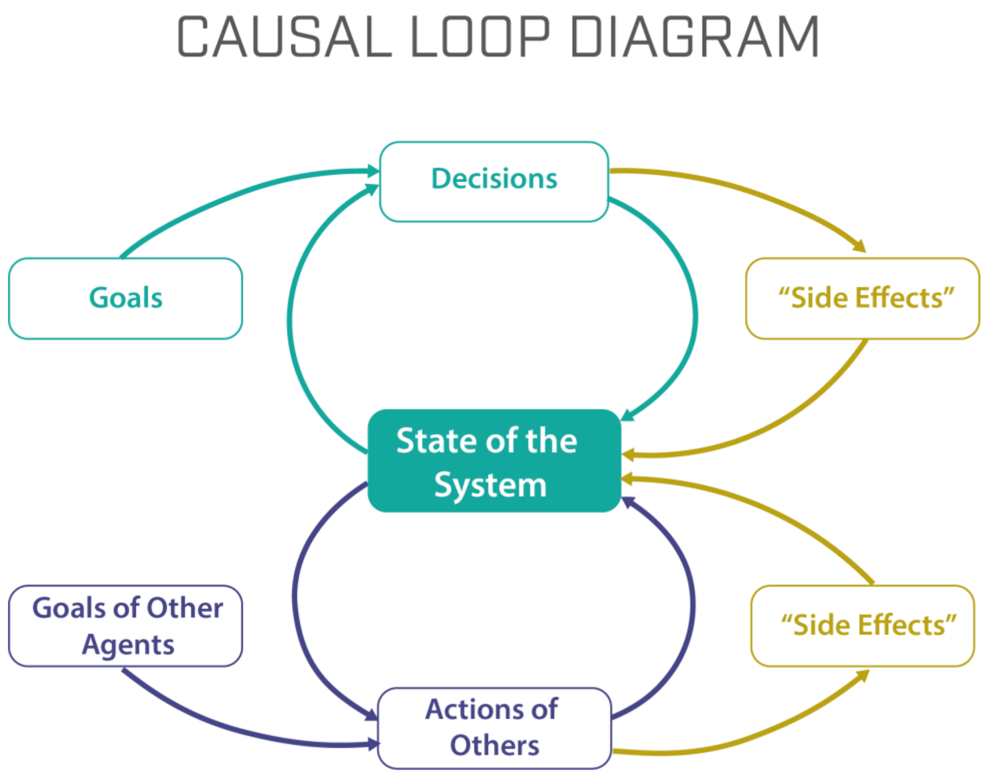

Figure 6 Casual Loop Diagram

3.2. SYSTEM DYNAMICS ON PROJECT MANAGEMENT

- Common problems of project management:
  - LEW (late, expensive/over budget, wrong/fail to meet customer requirements, low quality)
  - 90% syndrome
  - Corner cutting and quality erosion

  - Normalization of deviance
  - Liar's club
  - Firefighting
  - Blaming people for process and systems problems

4. SYSTEM DYNAMICS APPLICATION: MANAGING COMPLEX PROJECTS

4.1. PROJECT MANAGEMENT SIMULATOR: DEBRIEF

4.2. PROJECT MANAGEMENT: WRAP UP

- Liar's club: Concealing known rework requirements from managers and colleagues
- Self-confirming attribution error: Workers become reluctant to reveal problems, and managers overestimate the impact of their get-tough policy
- Lessons learned:
  - Start with more people than the plan, do not wait to hire at the end, hire upfront and hire more people than you think you're going to need;
  - Use overtime sparingly and only at the end of a project;
  - Never cut corners; and
  - Never cut testing.

5. SUPPLY CHAIN AND COMPUTATIONAL APPROACHES TO SYSTEM THINKING

5.1. SYSTEM THINKING IN SUPPLY CHAIN AND TRANSPORTATION

5.1.1. FORM, FUNCTION, AND PERFORMANCE

- We care about the performance of the systems, that is how well the system conducts its functions
- The performance of a system depends on its entities, their relationships, our knowledge of the system, and our ability to regulate it
- The performance of systems can vary because of differences in: the systems' form; the systems' entities; the entities' connectivity; the scale; the control of the entities; the knowledge of the system; or the behavior of the operands.
- Three scenarios:
  - When we know almost everything about the system and have the ability to regulate the operands and entity behavior - a very high level of performance can be obtained through optimization
  - When we know something about the system but have limited ability to regulate the system - Good performance can be obtained through control policies

- When we have limited knowledge of the system but not about the operand behavior - Improvement in performance can be obtained through implementing methods to collect information to increase knowledge about the system

5.1.2. COUNTERINTUITIVE EMERGENCE

- The Price of Anarchy is a concept in economics and game theory in which the performance of a system degrades due to its agents (operands) acting in their own self-interest and doing what's best for them (selfish behavior)

5.1.3. QUEUING SYSTEMS

- Queuing systems - Little's Law ($L = \lambda W$) is a powerful concept to help us analyze simple or complex systems
- Networks - Cascading Failures are an emergent property of network systems
- The bullwhip effect is a result of trade-off between uncertainty and the efficiency of the system. Improving information sharing and the ability to regulate the system can mitigate the bullwhip effect.

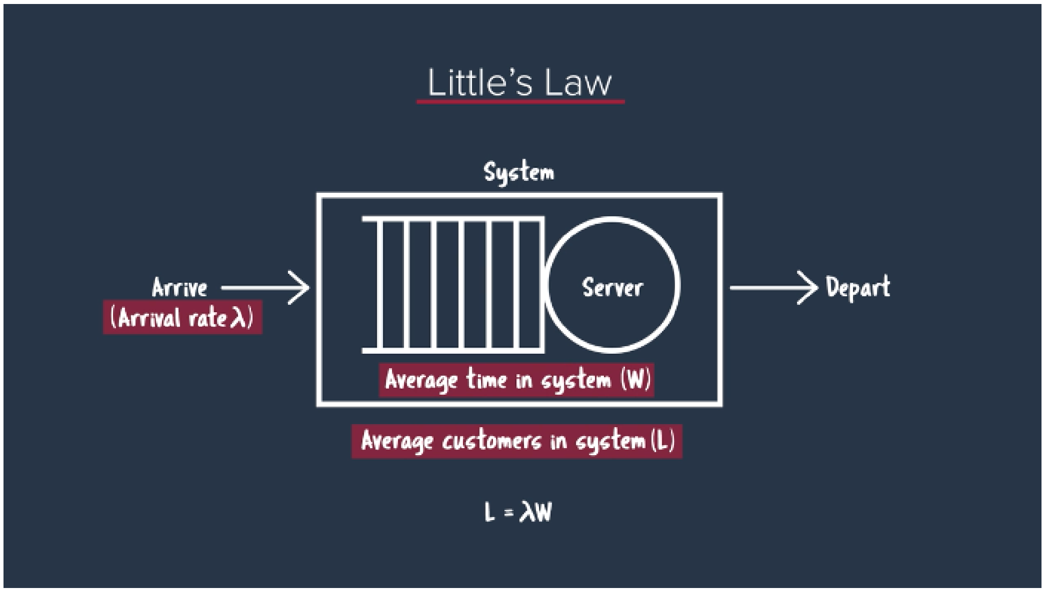

Figure 7 Little's Law

5.1.4. MODERN LOGISTICS AND TRANSPORTATION

- Modern technologies such as AI and ML enable us to go from data to models to decision and insights
- We should be mindful about trade-offs between efficiency obtained from sharing information and security and privacy concerns

5.2. SYSTEM THINKING IN COMPUTATION

5.2.1. SYSTEM THINKING: THE COMPUTATIONAL APPROACH

- A system is an entity with interrelated and interdependent parts. It is defined by its modules, by the boundaries between the modules, and by their interaction
- Computational systems thinking design process: database -> choose modules -> compose modules -> simulate and verify -> fabricate

5.2.2. CASE STUDY: THE LEGGED ROBOT

- Computational approach to systems thinking is data driven. Data driven approach relies on a database that is seeded with low level designs, and some higher-level designs created by experts
- “The gap between symbolic reasoning and concrete, precise specifications is filled through computational approaches.” - Professor Daniela Rus

5.2.3. COMPUTATIONAL DESIGN

- Computational approach to systems thinking is enabled by 3 important concepts: data driven specification, hierarchical composition, and simulation and verification.