AN INTRODUCTION TO
SYSTEMS THINKING
Derek Hitchins
What is “Systems Thinking?”

• Well, simply thinking about the world around us, about situations and problems, and “how things (might/could/should/do) work:”
  – As open, interacting systems, networks of systems and hierarchies of systems…
  – …of material or immaterial things

• Surprisingly revealing!

• Thinking about emergent properties, capabilities and behaviours, how they come about, what benefit they might be, what problems they might create…

• Unravelling the inner workings of complex systems… esp. non-linear—so, real world!
What about the “Systems” in Systems Thinking

• But, first, what is a system?
  – Many definitions, try:
    – A complex organized whole of interacting material or immaterial things...
      • complex—organized—whole—interacting
    – So, a script, car with driver, person, organization, solar system
    – Systems exist, function, behave, show emergent properties...
      • Properties of the whole that cannot be exclusively attributed to any of the parts
        – “the whole is greater than the sum of the parts, the part is greater than a fraction of the whole” Aristotle, Composition Laws
    • ...cornerstone of systems thinking!
What about the “Systems” in Systems Thinking

- There are different “aspects” of systems
  - Open/closed, hard/soft
  - Self-organized, man-made…

- Closed system has an impenetrable boundary—a theoretical concept used e.g. in thermodynamics

- A hard system is one made from material things, technology, whereas…
- “.. soft” implies human and immaterial, e.g. organizations, human activity systems (HASs), teams…
  - may not always do the same thing, perform the same way, as in “human…”

- ‘Self-organized’ implies naturally-occurring
  - Solar system, flora and fauna, ecosystems, you and me…
  - So, is an organization of people hard, soft or self-organizing?

- Is a car without a driver a system?
  - Or an artefact, a tool to serve a human’s purpose?

- Or is a car plus driver a system?
  - This combination is autonomous and purposeful, so…
  - .. could it be a sociotechnical system?
Levels of Organization

- Evident parallel between self-organizing, natural systems (left) and…
- Corresponding man-made systems at right

1. *Tissues* formed from emergent properties (EPs) of groups of *cells*.
2. *Organs* formed from EPs of groups of *tissues*
3. *Organ systems* formed from EPs of groups of *organs*
4. *Organism* formed from EPs of groups of *organ systems*…

- Manmade systems correspond…
- Suggests biological metaphor for systems engineering…

### Biology/Anatomy vs. Man-made Systems

<table>
<thead>
<tr>
<th>Biology/Anatomy</th>
<th>Man-made Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community</td>
<td>Company</td>
</tr>
<tr>
<td>Population</td>
<td>Group</td>
</tr>
<tr>
<td>Organ System</td>
<td>4 System</td>
</tr>
<tr>
<td>Organ</td>
<td>3 Subsystem</td>
</tr>
<tr>
<td>Tissue</td>
<td>2 Composite</td>
</tr>
<tr>
<td>Cell</td>
<td>1 Component</td>
</tr>
</tbody>
</table>

* Population - all the organisms that belong to the same species, in the same geographical area
** Community - a group of interacting living organisms sharing a populated environment
What about the “Systems” in Systems Thinking

- Systems are generally open, exchanging energy, information and substance with other, similarly open, systems
  - so, a continual flux through the system

- Systems adapt to the interchange…

- So, systems form networks of interacting systems—systems form hierarchies of systems within systems within systems…
  - .. and all dynamic, shifting, shimmering…
The Point/Value of Systems Thinking?

• Understand complex/complicated things/situations/problems:
  – Hence explain emergence, behaviour, resolve problematic situations

• Establish systems design requirements:
  – Cooperation, coordination, complementation, concinnity, control—of and between subsystems
  – Flux of energy, information, substance…

• Explain counter-intuitive behaviour, unintended consequences…
  – with a view to avoiding / exploiting!

• Get to the heart of the matter!

The Point/Value of Systems Thinking?
Academic viewpoint…

1. Systems Thinking
   - when used in
   - which promotes

2. Other Disciplines
   - when formalised
   - leads to
   - which promotes

3. Real-World Applications
   - helps promote management effectiveness

4. Problem Management
   - improves the effectiveness of
   - which promotes

Promotes which promotes when used in which promotes

Other Disciplines

Systems Theory

Real-World Applications

Problem Management

Academic viewpoint…
The First System Principle and its Corollary

• First Principle of Systems:—

  – The properties, capabilities and behaviours of a system derive both from its parts and from the interactions between those parts.

• Corollary to the First Principle

  – Altering the properties or behaviour of any of the parts, or any of their interactions, affects other parts, the whole system and interacting systems.
How to go about systems thinking…
CAUSAL LOOP MODELLING

...key method for “systems thinking:”
formulating, sharing, improving,
completing!
Cause and Effect

Disjointed Viewpoint

Linear, Control Viewpoint

Causal-loop, Non-linear Feedback Viewpoint
Systems Thinking – *Resources*

```
<table>
<thead>
<tr>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Births { + }</td>
</tr>
<tr>
<td>Deaths { — }</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total Space</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available Space</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Available Food</th>
</tr>
</thead>
<tbody>
<tr>
<td>Disease</td>
</tr>
</tbody>
</table>

| Total Food Supply   |
```
CLM of Body Temperature Regulation

Exertion → Temperature

Dehydration → Temperature

Exertion → Illness

Fluid intake → Available Body fluids

Temperature → Perspiration

Perspiration → Sweat loss as droplets

Evaporation → Local Humidity

Sweat loss as droplets → Evaporation

Evaporation → Latent Heat of Evaporation

Latent Heat of Evaporation → Available Body fluids

Available Body fluids → Passing water

Passing water → Fluid intake

Dehydration → Temperature

Illness → Exertion
Darwin
Survival of the Fittest

Variable inheritance

Predator variation

Predator fitness

Variable inheritance

Elimination of weak prey

Prey fitness

Elimination of weak prey

Predator variation

{ + }

{ + }

{ + }

{ + }
Nature’s Co-evolution – Moths & Bats

Flying Insects evolve smart Bats!!

Bat Sonar evolves smart Moths!!

Insect Population

Moth Sonar Jamming

Bat Predation

Bat Sonar

Night-Flying Insects

Night-Flying Bats

Night Navigation

Competition for Insect Prey

Flying Insectivore Mammals
Truancy

- CLM developed to explore possible solution to school truancy.
- A model of “how it might work…”
Desire for increased Efficiency

Establish Efficiency Targets

Perceived Efficiency shortfall

Develop Strategy to Achieve Targets

Create Plan to achieve Strategy

Provide Resources for Plan

Implement Plan

Measure Efficiency against Targets

CLM for Organization & Method
Belief systems

Interpretation of everyday events, situations

Reducing psychological uncertainty

{ + }

Straightforward believer's World Model

Personal Beliefs

Reward/punishment concepts

Role models of "good" and "bad" behaviour

Icon establishment

{ + }

Co-operative social behaviour

Social Group Beliefs

Power structures

{ + }

Social cohesion

Indoctrination / education in belief system

Reduction of psychological uncertainty

{ + }

Belief system

Personal Beliefs

Social Group Beliefs

Belief Systems
Systems Thinking – *Queues*

- Simplified and generalized…
  - No mention of any technology…
  - No mention of who or what is queuing…

- Concerned only with:
  - What a queue *is*
  - Different ways in which queues can *behave*
  - *Outcome* from differing behaviours

- So, systems thinking about queues applicable to:
  - Supermarket checkout, Wimbledon…
  - Serial data highways, data links…
  - …anything where queues form…
Systems Thinking – Queues

• Traditionally used mathematics:
  – \( \lambda \) mean arrival rate of items in the queue
    • (exponential distribution)
  – \( \mu \) mean rate of items being serviced
    • (exponential distribution)
  – Mean channel utilization = \( \frac{\lambda}{\mu} = \rho \)

• Then, number in Q = \( \frac{\rho}{1-\rho} \)
  – E.g. if \( \rho = 0.5 \) then Q contains 1 item on average

• And, number in Q and being serviced is \( \frac{1}{1-\rho} \)
  – E.g. if \( \rho = 0.5 \) then = number in system is 2.

• But, when \( \lambda = \mu \), then \( \rho = 1 \), and Q = \( \infty \)

• Maths for multiple Qs can get tricky…
Systems Thinking with STELLA™ – Queues

• Simple FIFO Queue, but with “leakage” from “conveyor:”
  – E.g. discard faulty part…

• Poisson distribution to represent arrivals distributed around mean arrival rate, \( \lambda \)

• Control panel at right:
  • Vary \( \lambda \) and Mean Leakage Rate
  ➔ Mean Service Rate, \( \mu \)
  • Graphs for Service & Leakage Sums
    • Graph for Mean Time end-to-end.
    • Graph for number in conveyer
  • Experiment with various queuing parameters and many runs.
  • Hence build models of serial / parallel queues for more complex applications…
System Dynamics…

- …using STELLA™
  - Systems Thinking
  - Environment and Learning Laboratory Approach
  - …says it all!

- Broke! …got a job!
- 12 equal end-of-monthly payments,
- Fixed monthly outgoings.
- Broke again(!) in 18 months!
Mass Hysteria

Undamped "thrashing"

Tight social coupling

Simultaneous, widespread high-density concentration on (non-)news

Seizure on any news item

Insufficient "real" news

Increase in media news coverage

Media Competition

Spread of high impact TV medium

Projected onset of Social Chaos…and Collapse!

Ill-educated Population—isolated individuals, not societies—no Beliefs, faith to fall back on. All fed same news, repeated and repeated *ad nauseam* Reaches wide, dense population of individuals all at the same time. Result—shock to system already "on edge of chaos". Shoal/herd behaviour.

Self-Induced Media Feeding Frenzy

Each impulse increments prior turbulence, until final impulse cause total instability

Non-linear, stable, on the edge of chaos

Chaotic decay

Chaotic decay

System A

System B

System C

Ramer

A to B

C to A

B to C

Coupling

1: System A

Graph 1: Page 2

Graph 2
Interpretive Structural Modelling: Railways–Stakeholder Analysis!

Legend
"…helps to achieve…"

Passengers
Signal and Rail Staff
Drivers & Guards
Drivers & Guards + Station Staff
Business
Station Staff

Job security
Satisfied passengers
Less crowded trains
More leisure trains
More frequent trains
More trains
Reliable trains
Robust systems
Trains on time
Less track maintenance
Greater profit
Fuller trains
Fewer trains
More pay

- Dichotomy—business objectives widely incompatible with those of passengers and staff
- Is this really a private, commercial business, or should it remain a public infrastructure service?
• Public drunkenness
• Breaches of the Peace
• Rowdy behaviour
• Winos and Druggos
• Noisy neighbours
• Youth congregations
• Drug dealing
• Living/sleeping rough
• Tramps
• Beggars

Disordered Proportion, \( p = \frac{\text{Disordered Society}}{\text{Ordered Society} + \text{Disordered Society}} \)
N2 Chart Interface Patterns...

- Leading diagonal shows *internal* functions/subsystems of one system...
- Circles represent interfaces; border represents permeable boundary
- Whole represents functional architecture of system-in-context
- Overview of whole system of interacting (sub)systems... shows “how it works as a whole, how they work together, cooperate...to create secure family home.”
### Unclustered N2 Chart

- Channel Tunnel N2 Chart for notional Crisis Management System (1988)
- Direct readout from CADRAT© Tool

| Damage Ctrl | 1 | N | 6 | 6 |
| Interpol   | 2 | D | 3 | 9 | 3 | 3 |
| Activ Sens | 3 | H | 8 | 8 | 8 | 9 |
| Env. Sens  | 4 | G | 8 | 9 |
| Customs    | 5 | 3 | B | 3 | 7 | 1 | 3 |
| Bag. Insp  | 6 | 6 | C |
| Safety Ctrl| 7 | I | 2 |
| Rail Ops   | 8 | 9 | 0 | 9 |
| Intel      | 9 | J | 9 | 8 |
| Logistics  | 10| 2 | L | 2 | 6 |
| Immgrtn    | 11| 6 | 1 | 7 | A | 6 |
| Local Pol  | 12| 6 | 2 | 9 | 2 | E | 1 | 4 |
| Emgy Svcs  | 13|   | F | 4 |
| Security   | 14| 1 | 7 | 7 | 3 | M | 8 |
| Operations | 15| 9 | 1 | 2 | 9 | 7 | 5 | 4 | 4 | 9 | K |

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Clustered N2 Chart

- Minimized configuration entropy – reveals functionally bound blocks (candidate subsystems) and Operational Node at Operations, 10-K

| Bag.Insp | 1 | C | 6 |
| Customs | 2 | B | 1 | 3 | 3 | 7 |
| Immgrtn | 3 | A | 6 | 6 | 7 |
| Interpol | 4 | 3 | D | 3 | 9 |
| Local Pol | 5 | 2 | 2 | 6 | E | 9 | 1 | 4 |
| Intel | 6 | J | 9 | 8 |
| Emgy Svs | 7 | F | 4 |
| Activ Sens | 8 | 8 | H | 8 | 9 | 8 |
| Security | 9 | 3 | 7 | 1 | M | 8 | 7 |
| Operations | 10 | 4 | 5 | 4 | 1 | 9 | K | 7 | 9 | 2 | 9 |
| Rail Ops | 11 | 9 | 0 | 9 |
| Safety Cntl | 12 | 2 | I |
| Envir. Sens | 13 | 9 | 8 | G |
| Dmge Cntl | 14 | 6 | N | 6 |
| Logistics | 15 | 2 | 6 | 2 | L |

Clustering method employed genetic algorithm to “tease out” optimum configuration, revealing architecture
A few of a wide variety of...

**METHODOLOGIES...**
Checkland’s SSM

- SSM: built around seven-stage model. Analyst addresses problem situation from two perspectives: what is actually happening in the situation being analyzed (the Real World); and what could/would/should be happening in an Ideal World.

- Picture of the problem situation—precursor to possible purposes for a system: can either be a new system designed to alleviate the problem or a redefinition of an existing system.

- 3. A root definition is developed for each system that describes six key aspects of that system, CATWOE:

  ‘Customers’ of the system – victims or beneficiaries of transformation that system carries out.

  ‘Actors’ within the system – those who carry out the transformation.

  ‘Transformation process’ carried out by the system – in converting input to output.

  Weltanschauung – worldview that makes transformation meaningful in context of the system.

  ‘Owners’ of the system – those with the authority to stop the transformation process.

  ‘Environmental constraints’ – elements outside the system that it takes as given.

- 4. Each root definition elaborated to produce conceptual activity model: includes core activities to service needs of root definition.

  Elaboration: results of systems thinking rather than of explicit reference to existing organizations and processes; exposes only those activities that are logically necessary.

- 5, 6, 7 Feasible actions to improve situation…based on differences between Real & Ideal
Hitchins’ Rigorous Soft Methodology
RSM—Seven Steps to…

Step 1. Appreciate broad area of concern

Step 2. Find the symptoms causing concern

Step 3. Find suspect *implicit* systems (c.f. organ systems)

Step 4. Group suspect *implicit* systems into sets

Step 5. Highlight set deficiencies compared with ideal

Step 6. Propose remedy

Step 7. Check remedy eliminates *all* symptoms

“THE GP APPROACH”
1 Nominate Issue and Issue Domain

2 Identify Symptoms and Factors

3 Generate implicit systems

5 Understand Containing Systems, interactions, imbalances

6 Propose Containing Systems Imbalance Resolution

7 Verify proposals against original symptoms

4 Group into Containing Systems

Resolution

Y/N

Requirements

Rigorous Soft Method — Graphic

Systems Engineering: A 21st Century Systems Methodology
Derek Hitchins, 2007
RSM as a Behaviour Diagram (another approach to systems thinking)

- Horizontally, a sequence of IPO (Input-Process-Output) figures
- Vertically, a column of functions/activities forming a central process
- Input column shows data, tools and methods
- Output column shows Deliverables
- Whole may be elaborated, with each level forming a new Behaviour Diagram…
- Altogether exceedingly powerful method of thinking, and expressing!

* SID – Systems Interaction Diagram

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January 23, 2015

Systems Engineering: A 21st Century Systems Methodology
Derek Hitchins, 2007
Beer’s Viable Systems Model
Beer’s VSM

- Beer developed a model of management control based on his understanding of the human nervous system: this is the Viable Systems Model (VSM), for an autonomous system. The model is recursive:

- The large circle represents **System 1** of the five systems.

- **System 2**, ‘Coordination,’ coordinates System 1 (Upward Arrow)

- **System 3** is about overall Cohesion.

- **System 3**\* is about monitoring. (Downward Arrow)

- **System 4** (Intelligence) is concerned with looking forward into some future environment (question mark in the figure).

- **System 5**’s (Policy) functions include setting context, establishing corporate identity and ‘providing closure to internal dialogues.’
Hitchins’ Generic Reference Model

• Reference Model of any system
• All systems Exist, have Being
  – Solar system
• Some systems also Do things, Function
  – Elevators, transport, clocks, generators…
• …and some systems Think and Behave…
  • respond to stimulus, Nature Vs. Nurture…
  – Humans, Elephants, Cetaceans, car-with-driver…
• Any system is a selection/combination of the three: Being, Doing and Thinking/Behaving
• Open Systems face continuing flux of energy, information and substance, yet maintain Viability
  • ability of a thing to maintain itself or recover its potentialities.
Generic Reference Model
Level 0

Behavior Management
• Cognition
• Belief System
• Selection
• Intent

Function Management
• Mission
• Viability
• Resources

Form Management
• Structure
• Potential
• Influence

System

Thinking

Doing

Stimulus

Being

Advanced Systems Thinking, Engineering & Management, Derek Hitchins, 2003
• 3 elements seen in respective “environments”
• Viability provides platform for Mission Management
• Resources provide energy & materials for Viability and (internal) operations
• Threats to Mission Management, Resource Management
• Change challenges Homeostasis (resist) and Evolution (adapt)
• Open System Flux of energy, information and substance “managed” in Mission and Resource Management
GRM Behaviour Model

After Carl Jung

- Collective Unconscious
  - Instinct
  - Archetypes
- Libido
  - Aggression
  - Energy
- Character
  - Emotion

Tacit knowledge

Nature

Evolution

Activation

Behavioural Archetypes

Response Intent

- Beliefs
- Rôles
- Stereotypes
- Categories
- Values
- Ethics
- Morals
- Ideologies
- Training

Nurture

Belief System

Cognition

Interpretation

Selection

Excitation

Stimulus

World models

Experience

Motivation

Environment

Constraint

Achievement

Conformance
Hitchins’ Generic Reference CLM in Conflict…

Blue Force GRM

- Behaviour
- Viability Management
- Resource Management
- Form
- Maintenance
- Logistics System
- Defense Suppliers
- Procurement System

Red Force GRM

- Resource Management
- Viability Management
- Form
- Behaviour
- Mission Management

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Conflict Simulation

- CLM Red and Blue Forces each represented by a full GRM in STELLA™, instantiated with appropriate values for combat
- Forces, one GRM each, then interconnected through a representative environment…
- …let (simulated) battle commence…
Conclusion

• Systems Thinking—vast subject
  – surface only scratched here
• Principal ideas and methods and methodologies shown, but…
• There are many more to be discovered, some rigorous, others less so…
  – challenge: to get to the heart of the matter
• However, a most rewarding and useful exercise…