SYSTEMS ENGINEERING
AND THE BUSINESS
by
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First, let’s look at Systems

What is a system?
Two Schools of Thought

• Break things into parts
  – separate parts easier to understand on their own
  – assemble complex things from these simpler parts
  – systematic

• Treat things as part of a Whole
  – parts behaviour influenced by other parts to which they are connected—connections vital
  – maintain interactions to understand behaviour—connections make things complex/complementary
  – assembly whole things from these complementary parts
  – systems
What is a System?

• A set of complementary, interacting parts which exhibits properties of the whole set which are not exclusively attributable to any of the parts.
Persil’s Washing System

• The Emergent Property? The whitest, brightest washing!

• If you bring together
  – the **right washing powder**
  – in the **right machine** with the **right soaking, washing and rinsing** actions
  – using the **right water** at the…
  – …**right temperature**, then you will get

• …the whitest, brightest washing

The definition *works*—only complementary parts give properties of the whole system, and none on its own

(I am not underwriting Persil!)
Whole System Principles

• Based on a sound, but simple truth: —
  – The properties and behaviour of a system derive both from its parts and from the interactions between those parts. Altering the properties or behaviour of any of the parts, or any of their interactions, affects other parts and the whole system.
7 Ages of *System*

| Conception | Design | Creation | Transition to Use | Use | Senility | Replacement |

**Whole *Life* Principles**

- Each Age is the Product of Previous Ages.
- Success depends fundamentally on proper Conception and Design for all Successive Ages
- (N.B. It is now EU Law to provide for the disposal of systems as part of their conception)
Open Systems

• Whether or not to treat each part separately in the first instance turns out to be crucially important—ask any doctor

• Isolating each part suggests ‘closed’ systems
  – scientific method based on closed systems

• Real world systems are open to inflows and outflows: people, airports, machines, companies…
  – if a system were truly closed, how would you know it was there at all?
A general view of any system

Inflow
- Energy
- Resources
- Information

Outflow
- Residue
- Waste
- Product
- Dissipation
- Information

System
- Physical Properties
- Capacity
- Order
- Structure
- Information

Internal Relationship

Contained Systems

Environment
Stability in Open Systems

• Quite unlike stability in closed systems
• Open systems stabilize at high energy levels
Open systems can oscillate without feedback

- Constant inflow to (initially) empty Reservoir
- Outflow proportional to Reservoir contents, but…
- …delay by a fixed amount
- Sink outflows often oscillate—“gurgling”
Babushka Russian Dolls

• Systems exist within systems exist within systems…*ad infinitum*

• Babushka Russian Dolls fit one inside one inside one…

• In general, systems fit several related subsystems inside one system
Given we know what a *system* is, then what is Systems Engineering?
Systems Engineering

The Art and Science of Creating Systems
First, why should we be interested in Systems Engineering—1?

- Fashions sweep through the UK
  - diversification, consolidation, core business, Outsourcing, Market Testing, Total Quality Management, simultaneous/concurrent engineering, Business Process Re-engineering, PFI…
  - can’t all be right, mutually interfere, and look only at parts of overall system as though separate
  - each new fad heralded as the silver bullet—we really must stop!

- Systems engineering looks at the whole system, does not isolate the parts, is a continuing lifetime process, gets it right!
Why should we be interested in Systems Engineering—2?

• Grouping many parts into fewer systems allows us to get a grip on complex issues
• The more parts, the better the grip
• So, systems engineering comes into its own just when conventional “break’ em apart” ideas fail
What Systems Engineering Isn’t

- **Isn’t Piecemeal Development.** Optimizing part of any system de-optimizes the rest
  - piecemeal development—UK’s norm, government promoted

- **Isn’t Systematic Engineering.** Break processes into sub-processes, activities. Fit parts into plan. Follow plan.
  - Standard method for PM and BPR
  - Insidiously plausible, *but* ignores relationship between parts, ignores changing circumstances
  - Better than piecemeal, but…
  - …far short of *True Systems Engineering*
TSE—Blazing the Trail

Optimum Route to any Goal is *not* some pre-determined, fixed path. Changes with Time, Threat and unfolding Situation.

- True Systems Engineering creates a broad strategy to reach a Goal, using the best information available at the time.

- Makes intelligent choices—*impossible* to know everything in advance.
- Continually re-evaluates, especially when situations change, unforeseen circumstances arise. Within broad strategy, route to Goal is re-evaluated. If necessary, TSE will back-up and go around, or circumnavigate.

*TSE continually seeks the most efficient and effective route to the Goal*
Manages Complexity and Uncertainty

- A careful, thoughtful approach to creating and operating complex systems, keeping the parts in balance with each other and with the whole system for its whole life

Pharos Lighthouse, Alexandria, 270 BC, 400 feet high

Thames Barrier from Control Tower, 1994
Good Systems Engineering

- Apollo\textit{Homo Sapiens} Sapiens
  - Balanced ecologies
  - Defensive architectures
Poor Systems Engineering

- Hubble Mirror
- NIMROD AEW
- Autonomous robots: —
  - Separate, intensive development of parts
  - Realization that optimal parts won't fit together
- "An Optimal System is Comprised of Sub-optimal Parts"  (Hitchins 6th Law)
The 5-Layer Systems Engineering Model

| Industry System Engineering       | National Wealth Creation, the Nation’s Engine. (Japan operates at this level) |
| Business System Engineering       | Industrial Wealth Creation. Many Businesses make an industry |
| Project System Engineering        | Corporate Wealth Creation. (West operates at this level.) |
| Product/sub-system Engineering    | Artefacts. To some the only “real” systems engineering. Many Products (can) make a system |
How Does True Systems Engineering Work?

Future Vision = Future System in Future Environment, interacting dynamically with Other Future Systems
Impact of Product on Process System of Interest

Containing Objectives

Sibling System

Creating System

Environment

System

Sibling System

System of Interest

"Hidden" Container(s)

System Concepts

Design

System Implementation

System Proving

System Delivery

Operation & Support
Conventional Traps

• Project Management Computer Tools ask for…
  – activities, durations, earliest and latest start times, dependencies, etc.

• Based on a *fundamental flaw*
  – treats each activity as time and content independent—yet we *know*…

• Activity times depend on:—
  – upstream activities—completed, errors made, undetected, under/overrun?
  – culture, skill, training, motivation, etc.—human factors

• BPR uses PM method
What *should* a Plan Look Like?

Inflow at Time Zero, only

Task 4 Activity

Rework

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Evidently, Systems exhibit *Behaviour*

How can we examine System Behaviour?
Systems Lifecycle Behaviour

• Some features are common to all kinds of system—man-made, human activity, natural…

• All systems have a lifecycle
  – conceived, born, live, decay and die

• All systems have complementary parts—variety
  – Too little and they break up. Too much and they also break up. Just right, and they can adapt to change…

• These abstract notions form a convincing lifecycle model, predicting order from chaos, causes of decay, strategies for its prevention…

(Vehicle Speciation, Yellowstone Park)
N.B. The tendency to Stability may invoke non-linear, unpredictable, catastrophic or chaotic system behaviour.
Systems—Organizing the Parts in Different Ways

(Architecture)
Systems Engineering Architectures

• Layered
  – a series of successive layers to either progress or resist something passing through, so increasing effectiveness

• Clustered
  – like parts grouped together to reduce overall interchange time, so improving efficiency
Layered Architectures

Maiden Castle, Dorset—
1500BC—450AD
Image processed to enhance layer visibility

- Counting earth ramparts, Maiden Castle had 5 layers of defence.
- Counting ditches between ramparts too, there were 11/12.
- Note at left and right ends, the additional earthworks guarding the entrances—always a weak point.
BMD Layering

System Management

- Sensor Management
- Configuration Management
- Alert State ROE Management
- Resource Management
- Performance Management
- Reserves / Refors Management

Layer 1

**Surveillance**
- Acquire,
- Track,
- Ident,
- Tell

**Situation Assessment**
- Threats
- Opportunities

**Option Generation**
- Phases
- Sensors
- Weapons
- Tactics

**Option Constraints**
- ROE
- Policy
- Resources

**Option Selection**

**Weapon Assignment**

**Initiation & Monitor**

Layer 2

**Option Constraints**
- ROE
- Policy
- Resources

**Option Selection**

**Weapon Assignment**

**Initiation & Monitor**

Pass to Next Layer

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Layered Models in ATM

• Safety
  – primary communications, reversionary communications, emergency comms., impaired comms procedures, non-comms procedures, etc.

• Throughput Processing
  – en-route, approach, landing, taxiing, terminal access, controls, baggage, departure transport

• Modelling
  – layered models—straightforward to simulate
  – results can save real time and money
  – why guess when it’s easier to work it out?
Clustered Architectures
Layout Example—before

- Figure shows rectangular room with 12 “positions”, A—L, and arrows showing principal workflow paths.

- Matrix represents path-lengths between Positions A—L. Numbers represent path utilization e.g. 1 = low, 2 = moderate, 3 = heavy.

- Work index $= \sum_i (\text{Path-length}_i \times \text{Utilization}_i)$ for $i = 1$ to 12.

- Work index from matrix = 160.
Layout Example—after

- Figure shows Positions rearranged to maintain original work-flow logic, but reduce overall work Index
- Paths form “waterfall”

- Matrix rearranged to reduce overall value of Work Index from 160 to 56, a real reduction of 65% in the work of interchanging material between positions
- Some separations increased, e.g. A to B, but overall path-length reduced from 79 to 36, i.e. by 54%
- Matrix score = f(Entropy)
Systems Ideas
to challenge
Pre-conceptions
Maximum speed, 50% Efficiency!
Dangers of Piecemeal Optimization

- Change the efficiency of the centre process only
- Result—impairs the effectiveness of the two untouched systems
- Result—impaired efficiency and effectiveness of the overall process-as-a-system
STELLA™ Cost Model

Requirements → Design Effort → Specification → Development Effort → Build Rate → Integration & Test → Commissioning Rate

Design Error Rate → Design Effort → Specification

Spec Effort → Development Effort → Build Rate

Dev Error Rate → Dev Error Detection → I&T Error Rate

I&T Error Detection → I&T Error Rate

Overall cost

Cost rate

Build Rate → Commissioning Rate

Time to Clear → Design Error Detection

Dev I&T Balance

Design Error Detection

Overall cost

Cost rate

Build Rate → Commissioning Rate

Time to Clear → Design Error Detection

Dev I&T Balance
Commissioning Effort Vs. Early Fault Detection

1. 70% defects found early
2. 80% defects found early
3. 90% defects found early
4. 100% defects found early

Increasing initial error detection
Systems Engineering Cost Model

Total Cost

Increasing Initial Error Detection

100%

Time

Graph 1: Page 2

Total Cost

Increasing Initial Error Detection

60%

100%
We haven’t Scratched the Surface…

- Behaviour, individually and socially
- Identifying your good systems people
- Measuring systems
- Evolving better systems
- Training, tools, techniques, methods…
- Architectonics, emergence, organization, regulation and control…
Conclusions

- Local optimization can *seriously damage* performance and profit
- Systems engineering looks at *whole systems* and at *all management levels*
- Not some short-term, quick-fix “silver bullet”
- A philosophy. A way of thinking. A way of Life, of Performance through Continual Improvement.
- Major business advantage accrues from strategic systems thinking