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# Imminent Return of Systems Science?

## Resuming Pursuit of the Optimum

Someone kindly reminded me recently of an old article, written back in August, 1998…It was in a management journal, so I laid it out with plenty of mathematics and diagrams. Well, you did, back then…

Anyhoo, the article. It was on the subject of Systems Engineering (SE), and I had presented the preferred wisdom of the day, that Systems Engineering disappeared and reappeared on a 25 year cycle. Moreover, it had done since inception……Ref A

Back in 1998, systems engineering was at one of its periodic zeniths. Very soon after, it disappeared again, in all but name: that soubriquet had been hi-jacked once again by the classic engineering fraternity, so that systems engineering *appeared* to be still around, but devoid of systems science, of course. Systems science-based SE had once again been put into hibernation, kept barely alive by a few remaining, faithful-but-ageing devotees, books and professional papers that few read, even fewer understood, and engineers appear to have been studiously avoiding.

But—and you have surely been counting—25 years on from 1998 would be, calculator please, 2023 Which is soon. Should we prepare for the return?

So, what was this Original Systems Engineering (OSE) like, I hear you cry. Well, it was founded in Systems Science, of course, which is anathema to many engineers, who conveniently overlook that is *why* it is called *Systems* Engineering (i.e. "applied Systems Science"). And it had a number of basic definitions, also systems theoretic.

First, and apparently most difficult today, what is—or should I say *was*—a system?

## SYSTEM

*'An open set of complementary, interacting parts with properties, capabilities and behaviours (PCBs) emerging both from the parts and from their interactions…to form…a complex, organized, unified whole of material or immaterial things.'*

- *Open*: potentially exchanging energy, information and material with other open systems in its environment, and adapting to that exchange
- *Complementary:* combining in such a way as to enhance or emphasise the qualities of each other or another
- *Interacting:* act in such a way as to have an effect on each other
- *Complex*: consisting of many different and connected parts
- *Organized:* arranged, structured, or configured in a systematic way

Of course, such a definition, clearly founded in systems science and theory, would be (and is) unacceptable to classic engineering folks. It speaks directly to emergence, dynamics and the fluidity of a system. Which might imply to any self-respecting engineer that it could not be constructed from fixed components in a straightforward manner; moreover, that a customer could not specify in detail what they required. Classic engineering seeks to provide the customer with what they *want*. Precisely. And very properly so. Oh! And not forgetting stakeholders, who - although not exactly customers - are to be

provided with what they want, too, thereby placing a veritable straitjacket around innovation…

Systems engineering, OSE, on the other hand, sought to give the customer what they *needed!* Which can be quite different. Needs go much deeper, and require investigation. So the definition of Systems Engineering/OSE, back in the day, was:

**SYSTEMS ENGINEERING**

"The art and science of creating whole solutions to complex problems."

By posing the need as a problem to be investigated and solved, Systems Engineering was obliged to investigate, find the roots of the problem, and come up with in-depth, innovative, comprehensive and lasting solutions. In which, systems thinking had a prominent place…

Just for a moment, think about international architects. Customers don't employ such architects and specify in detail what they want, where they want it, how big, what shape, etc. No, they employ an architect because of his/her reputation and expertise, flair and innovation, ability to create marvels seemingly out of thin air. Like the Sydney Opera House, the Louvre Pyramids…or, historically, Salisbury Cathedral—so much admired by those latter-day Russian spy-assassins…

It was much the same with Original Systems Engineering (OSE). Customers presented their problems, looking for answers that they could not envisage for themselves. Or, sometimes, they had envisaged an answer, but were less than happy with it. Or, the problem was too complex, or too daunting. And sometimes they were so close to the problem, they could not see it…or even, occasionally, the problem was of global proportions, requiring rational investigation free of political or economic pressure—so no avowed

customer, but an overwhelming issue to be addressed, explored and, perhaps, resolved…?

One other important thing about OSE, 'Systems Engineering that was:' it was very much about creating *the optimal solution,* that is the best solution in the situation and context. And finding - and maintaining - the optimum invoked systems science. The optimum configuration of a systems' functional parts—it turns out—coincides with minimum entropy, where entropy is the degree of disorder.

There are many measures of entropy, most of them mathematical. A useful and simple one for our purposes is as follows:

**ENTROPY**

The measure of a system's energy that is unavailable for work.

So, if we can minimise the entropy/disorder—which is equivalent to creating a tight, functionally-bound configuration—then we can create an optimal system, one that has the maximum amount of energy available for work. Or, in military terms, will give "more bangs per buck." Now, that's a useful notion—'an optimized system gives better value for money!' Which begs three fundamental questions:

> **A.** *How do you "optimize a system;"* **B.** *How do you* prove *that you have optimized a system; and,* **C.** *How do you maintain that optimum condition through life?*

Last question first. As the tempo of life, commerce, competition and and conflict increase inexorably, the environment changes, the problem space morphs, and the solution system's optimum point

inevitably shifts. Solution? Continual re-optimization. So, the plan was for Systems Engineering to continually re-optimize during design, development and – particularly – operation. This was known, unsurprisingly, as Continual Re-Design. Carried out assiduously, particularly throughout the operational lifecycle, it would continually enhance both the effectiveness, and the efficiency, of a system, and extend its life. To a point, perhaps, where there need be no practical limit to the lifecycle (sic).

And the Uber-plan was, hopefully, to build this continual redesign capability into an operational system such that it could continually re-optimize itself, and so sense-and-adapt to perhaps unforeseen situations, environments and changing conditions. Invaluable for unattended systems such as planetary explorers, nuclear installations, orbiting satellites, and some military applications.

Meanwhile back at the remaining two questions… *How do you optimize a system, and How do you prove you've done it?*

You won't be surprised to learn that we used models of our intended solution systems. Not static models of technology architecture, but dynamic ones, in keeping with the definition of any system as having complementary and interacting parts. [This should be no surprise. E.g., an F35 Lightning 2 is a useless, leaky artefact, unless and until it is piloted and powered. Then its parts become complementary and interactive—it becomes a viable, autonomous system (q.v.)….]

Back in 1998, systems dynamics applications were becoming available on PCs. Using these applications it was, and is, possible to create dynamic systems models of the potential solution to some problem.

From there it is a short step to adjusting the design of the system being modelled, to find the configuration which gives the best

performance *in vitro*. Using genetic algorithms within the application could help in finding the dynamic optimum of the more complex of system designs, interacting with their similarly dynamic operational environments……Ref B

So, you can find - and track - the optimum configurations/ conditions for some designed operational system interacting with, and adapting to, its operating environment. In dynamic simulation. But would that translate into the real world?

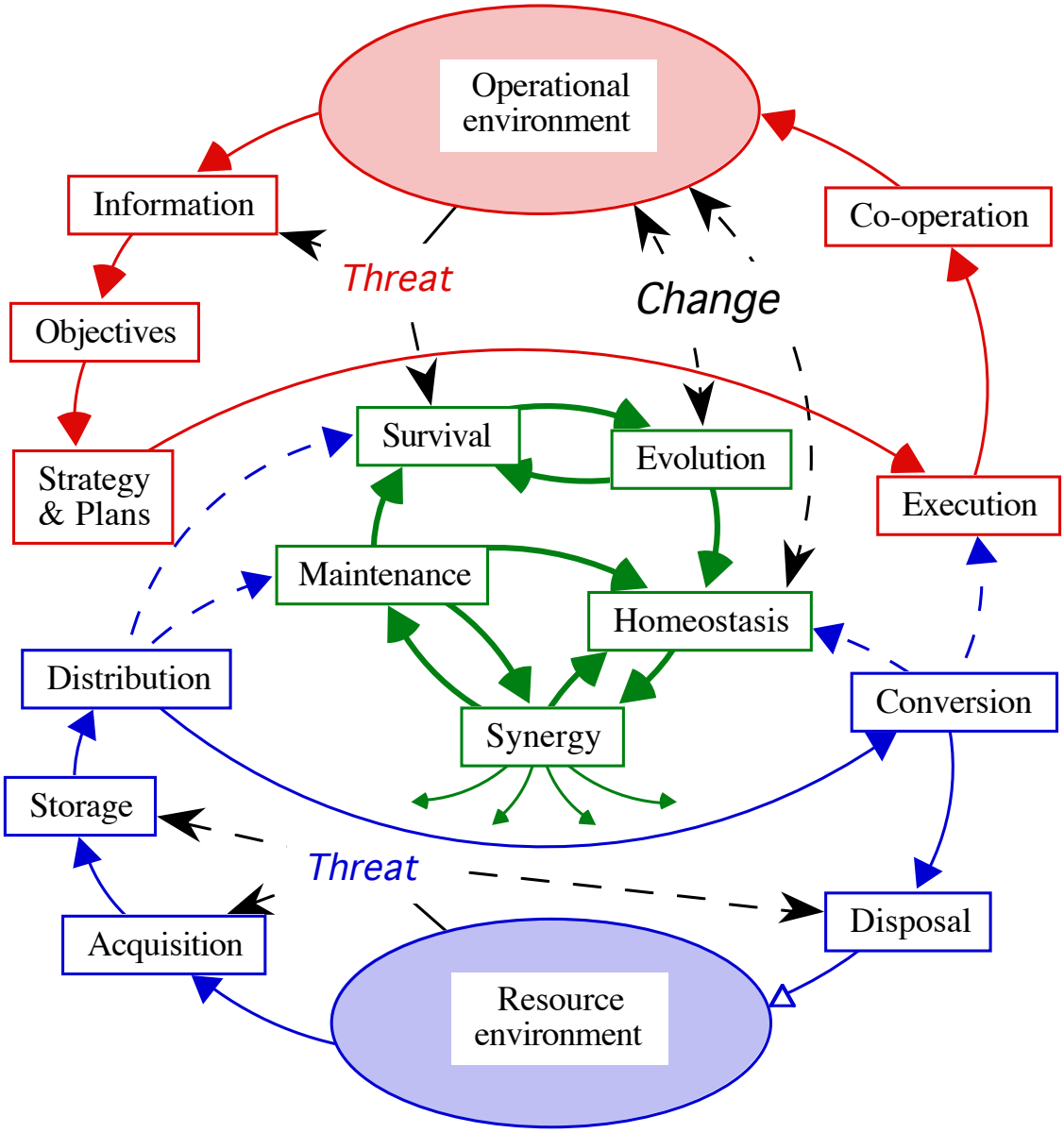
Depends. On the quality of the modelling. If the modelling is good enough to represent the dynamics of the actual system-in-operation, *and* to represent the ever-changing environment with which it will interact, *and* the interaction and adaptation that will inevitably arise between the two, then potentially, yes.

But, there is more to any solution system that the configuration of dynamic functions: indeed, to pretty well any man-made system - including humankind, itself. The operational system-in-design may be envisioned as undertaking a mission, such that it encounters changing environmental situations and conditions *en route* to some objective, which may also morph.

The mission could be almost anything:

- going to the post office to post a birthday card;
- intercepting a rogue satellite in near-earth orbit;
- endeavouring to increase market share;
- improving examination results;
- engaging a cloaked target;
- neutralising an aggressor
- integrating city transport systems
- preventing further global temperature rises
- etc., etc., etc.

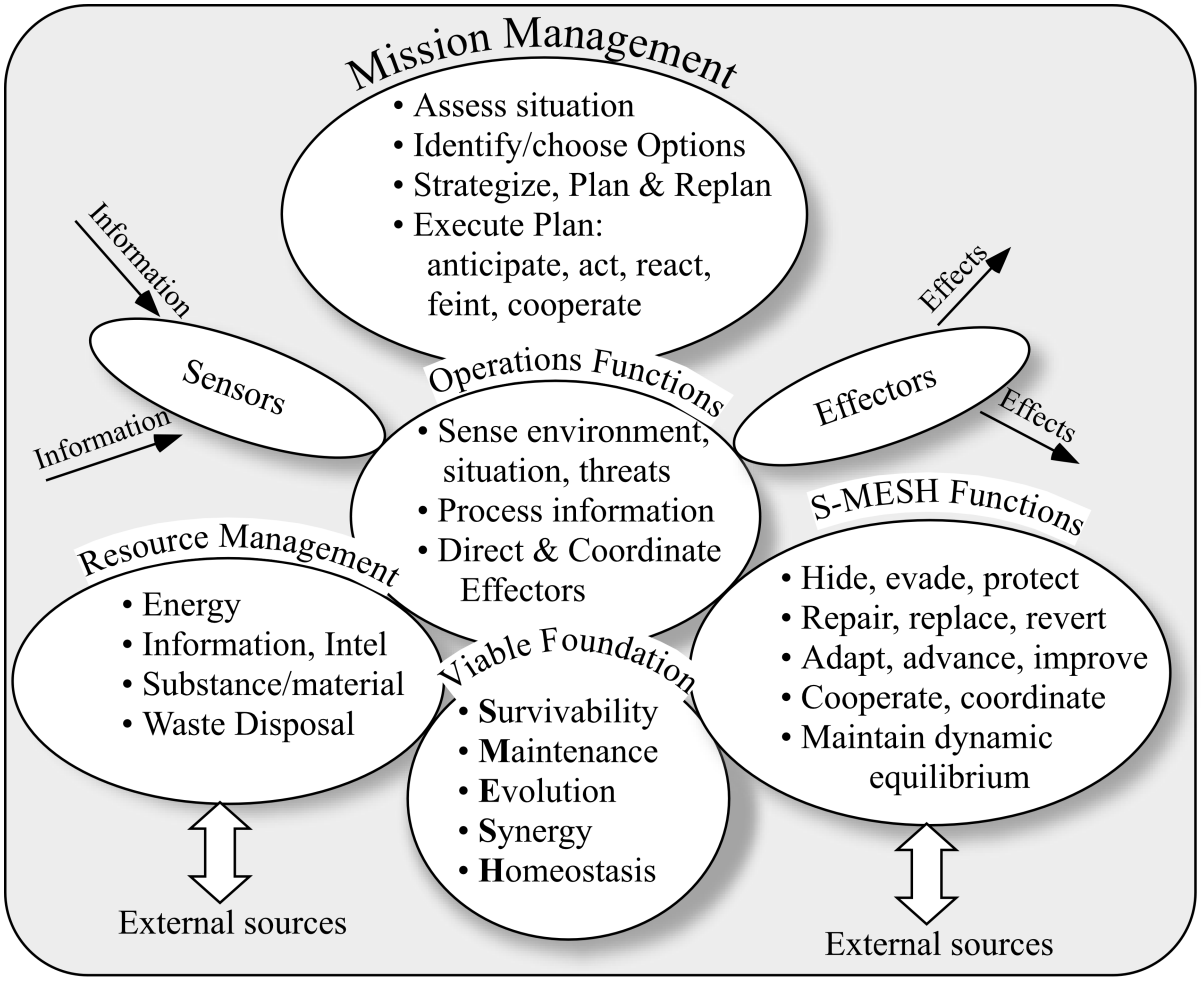
So, firstly, the solution system will need some way of 'managing the mission' as it plays out over time. Second, since conducting the mission will expend energy and resources, there will be a means of managing those resources throughout the mission. Third, since there may be threats, risks and continual change, the solution system will need means of maintaining its integrity /viability throughout the mission…




The figure presents a so-called Viable Systems Model (VSM). A Viable Systems Model is a scientific model of the organization of a *viable* or *autonomous* system.....Ref C

Viability is the ability of a thing (a living organism, an artificial system, an idea, etc.) to maintain itself or recover its potentialities.

The centre of the VSM presents interconnected aspects of Viability in green. Mission Management is presented at the top in red, acting into and out from the Operational Environment: Resource Management is at the bottom in blue, acting in and out of the Resource Environment. And, there is a flux of energy, information and material running vertically through the VSM…




Here the same VSM is shown partly expanded. Any purposeful system can be represented by instantiating the many, various appropriate aspects of the VSM, be that purposeful system a child going to the post office; an interceptor launching a missile towards an orbiting satellite; a business looking to increase its market share; a

teacher trying to help pupils do better, a naval destroyer engaging a cloaked target in the Gulf of…or whatever…

All of which is, was or should be part of Systems Design. Back in 1998, it *was*. Now? So-called systems engineering appears largely disinterested in Systems Design, although how you can have one without the other is puzzling…

*  *  *  *

So, what happens now? Will the avowed SE cycle continue, will OSE reappear? There are green shoots… Systems Design is in revival. Mind, it never really went away, but the classic engineering fraternity tried to replace it with a hotchpotch they call Requirements Analysis, or Requirements Capture. (Beware 'Capture'—it smacks of a hunting expedition for an elusive quarry. Oh! And Analysis–any analysis–is Cartesian Reduction, so incompatible with "systems," and never provably complete.)

Recent conferences have shown that Systems Design is alive and well, and is ready to retake its place as the cornerstone of Systems Engineering proper. Similarly, conference presentations have shown that OSE is still widely practiced, in particular its problem solving aspects. OSE's optimality criterion, less so.

The stage is set, then, but not for OSE. It was of its time. We must look forward to a *new systems engineering* (NSE). One which omits the deficiencies of OSE, such as functional decomposition—which was much practiced but which, like analysis, is Cartesian Reduction, and does not lead to an optimal system solution. And, yes, NSE should aim for optimal system solutions, where practicable.

There is a tradeoff—while optimal solutions will be more efficient and effective in operation ("more bangs per buck!"), they may take longer, and so cost more in systems design and

implementation. Perhaps lifecycle costs should be the order of the new day…?

And then there are those problems where the cost of solving is immaterial. Like:

- global warming, where we may already be too late—but there could be a way out, and escape route…
- human population expansion, the fundamental cause of global warming. Or is it?
- global warfare, which might obviate the need to limit population, but could also render the planet non-viable?

Perhaps New Systems Engineering will enable us to find answers before it is too late. Not too long to wait, now! Fingers crossed…

Derek Hitchins March 2021

References

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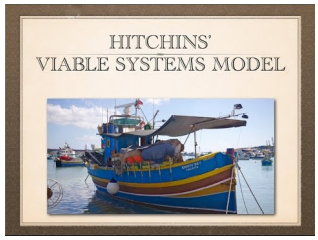
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