17

SoS Engineering Principles and Practices

> *'Wilkes,' said Lord Sandwich, 'you will die either on the gallows, or of the pox.' 'That,' replied Wilkes blandly, 'must depend on whether I embrace your Lordship's principles or your mistress.*
>
> John Wilkes, 1727—1797

Creating, Developing and Evolving a SoS

We have already met the concept 'system of systems' (SoS): see System of Systems on page 94. (In this chapter, the abbreviation SoS indicates system of systems: in earlier chapters, SoS indicated solution system as an outcome of the systems methodology. The different contexts should hopefully prevent any confusion . . . .) While there is much confusion about the term, with various pundits expounding contradictory views, it seems that the term refers in general to some new whole, which is formed by bringing together a number of complementary, extant, operational systems. The reference gives an example of an integrated, city-wide, transport system formed from extant transport systems such as underground/metro, rail, bus, taxi and other services.

Other examples would include:

- A volume supply system formed by bringing together existing businesses for making parts, designing, assembly plants, marketing, etc, each of which may be a viable business in its own right.
- An air defense system formed by integrating separate operational elements: ground radar system; surface to air missile systems; fighter interceptor aircraft; dispersed airfield support systems; airborne radar system; early warning sensor system; etc.
- A university formed by bringing together a number of existing colleges, choosing the disciplines of said colleges to be both complementary and contributing to a distinct discipline for the whole university, e.g., humanities, social sciences, physical sciences, etc.
- An army, formed from various operational units of infantry, cavalry, artillery, signals, intelligence, engineers/sappers, etc., to address a particular situation.

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In each example, the new whole is relatively large, and tends to be comprised of enterprises, i.e., of social or sociotechnical systems, which were viable systems before becoming part of the new whole, and may remain so after. A viable system is one that is able to exist, survive and operate in a suitable environment, acquiring its own resources, performing its functions and, as an open system, maintaining dynamic equilibrium.

When a number of extant systems is brought together, it is unlikely that the various parts will be fully complementary, nor will they cooperate and coordinate their actions in an ideal manner: after all, prior to being brought under one central umbrella, each of them had its on purpose, its own CONOPS, its own 'way of doing things,' or culture. Once brought together, there may be a need to harmonize their operations, to make the various parts 'more complementary,' to enhance cooperation and coordination between them — or not.

It may be impractical to render radical changes if they interrupt the operations of the various parts. Besides, how much change is needed? Are bridges and interfaces to be established/enhanced between the enterprises? And, in establishing such interfaces, is there likely to be resistance? It is as well, too, to bear in mind that these are open, nonlinear systems interacting in an open, often fluid, environment. It would seem to be essential to employ the systems approach to exploring the possibilities and limitations in this 'joining together' process.

Limitations in SE for SoS

The conception of any new system is, or perhaps should be, in response to a perceived problem. In this respect, a system of systems should be no different. Joining systems into an SoS triggers questions:

- What is the purpose of the 'bringing together? What is the purpose of the new created whole? What problem or shortcoming is it designed to preclude or overcome?
- Why join together these particular extant operational systems? What makes them suitable?
- What is to be gained in the process?
- What might be lost?
- How is the composite system of systems expected to operate:
    - will there be a central control and coordination bureaucracy, or. . .
    - will each part continue to 'do its own thing,' and ignore the need to cooperate and coordinate?
    - will there be functions and departments to be created 'at the new center? What will they be for? Are they an unforeseen cost? Can they be justified?
- How is the integration to be achieved — what degree of intervention is appropriate/too little/too much?
- And, most importantly, will the anticipated integration solve the problem, and at what cost?

These, and many more, are the kinds of questions and issues that the systems methodology is designed to address. So, should the systems methodology, with its seven steps (Chapter 6 *et seq.*), be applied to SoS as to any other problem?

In principle, yes — but with provisos. The systems comprising the whole are extant and operational. Whatever changes might be proposed are unlikely to be appreciated if they seriously interrupt operations — unless the value of any such disruption can be shown to outweigh the cost.

Importantly, too, the new whole should have a singular, distinct, high level purpose, to which the composite parts can contribute severally and together.

It may be an objective of classic systems engineering to create an optimum solution to a problem, but it is unlikely that bringing existing operational parts together will constitute an optimum SoS solution. Inevitably, there are going to be imbalances: capability and capacity mismatches, incompatible process rates, etc. For the extant operational systems, there may be limits to any changes and to the rate of such changes that should not sensibly be exceeded. Effectively, this suggests that it may not be possible to configure the parts into an optimum solution system of systems . . . .

This in turn suggests that a high degree of judgment may be called for, to determine how far and how fast to go towards full integration. The situation is unlike engineering integration — with SoS, the constituents are largely people systems (HASs) and people-managed sociotechnical system, both of which exhibit such human characteristics as:

- *Motivation* — inclinations to conform to social norms (achievement motivation and compliance motivation)
- *Dominance/submission* — tendency to lead or be led
- *Territorial imperative* — strong sense of territory ownership
- *Territorial marking* — visible signs/symbols of ownership
- *Personal space* — ego-centered space, physical and emotional
- *Family loyalties* — unquestioning adherence to relationship
- *Tribal loyalties* — unquestioning adherence to relationship
- *Dyadic reciprocity* — interactions between communicants
- *Natural predisposition* — inherited tendency to respond
- *Cultural predisposition* — learned tendency to respond
- *Group polarization* — tendency for group discussions/decisions to move to the extremes— 'risky shift'

Consider just one of these factors, tribal loyalties, in the contexts of the four examples bulleted at the start of the chapter, and the reader may start to realize that this integration task may not be straightforward. Each of the extant operational systems is likely to have developed its own culture, making the people who work there members of the 'tribe.' Such people will not readily become part of the much larger tribe, the SoS tribe of tribes: they do not know the other people, and have little in common with them. So, there will be mutual suspicion, even open hostility at being 'taken over,' and at the very least, barriers to bring down, as well as interfaces to build up. One key to success is motivation.

Of all the human characteristics on the list, perhaps this is the most significant and 'helpful.' It may prove vitally important to motivate the members of the extant operational constituents to be active, willing achievers in the new whole. After all, with a much wider whole, there should be greater prospects for advancement, a higher promotion ladder, enhanced prospects for training, etc., etc.

Strategy for SoS Engineering

Systems engineering for Systems of Systems (SoSs) is operational systems engineering, i.e., conceiving, designing, redesigning and reconfiguring 'on the go:' it is not static, 'green field' systems engineering — See Working Up the System — Operational Systems Engineering on page 234 for a perspective on operational systems engineering.

‘Spinning plates’

Operational systems engineering is constantly adapting the system to improve effectiveness and performance, increase efficiency, etc, and to keep pace with changes in the environment and in other, interacting systems. In the example referenced in the previous paragraph, the strategy adopted for operational systems engineering was one of ‘spinning plates.’ (The spinning plate analogy refers to the jugglers who spin a number of plates balanced on the tips of canes: to keep them all spinning the juggler has to constantly attend every plate in turn, spinning-up those that start to wobble.)

This is certainly one approach, and it has been adopted in the automobile industry. (Womack and Jones, 1990) In one notable example, the ‘plates’ turned out to be queues of parts forming at particular machines in an assembly plant waiting to be assembled. Queuing indicated that the work rate for the machine was too low, or conversely that two or more machines were needed in parallel to increase the mean rate. Each time actions were taken to reduce one queue of parts (which constitute work in progress (WIP), cost money, and reflect in the cost of the end product), another queue would appear in front of a different machine, and then another. However, by continually addressing queues in this way, the overall amount of WIP gradually reduced, and along with it down went unit production costs (UPCs).

Continual redesign

For complex, nonlinear, social and sociotechnical systems, an alternative to keeping up with this constant change is continual redesign. Continual redesign continually addresses the problem space, detecting and addressing changes in situation, and seeking revised and better conceptual remedies. It goes on to conceive and design remedial solutions, CONOPS, etc., to identify risks, threats and opportunities, and to include strategies and functions in the developing design to address them. A functional architecture emerges as part of the design process, which can be compared with the design of the existing system of systems. When differences between the redesigned functional architecture and the extant functional architecture exceed some threshold, it is time to act — to change the extant system to be more like the redesigned version.

Continual redesign ideally employs systems thinking in the form of behavior models — dynamic simulations of open interacting systems. It is one basis for evolving intelligent systems, where such systems are deemed intelligent when they can constantly adapt to changes in their environment, performing, remaining effective, avoiding or neutralizing threats and, ultimately, surviving in the process.

A sensible, practical approach to systems thinking and therefore to continual redesign is to employ so-called learning laboratories (see Systems thinking on page 17, Systems thinking and the scientific method on page 73 and the Battle of Britain Simulation on page 238.) The learning laboratories allow the analyst to experiment with system design solutions dynamically, in context, and while they are in operation — just what is needed for SoS continual redesign. Learning laboratories can be made simple to use and to experiments with, even if the models of dynamic opens systems and their nonlinear interactions may be complex.

With such simplicity of use comes the opportunity for managers, CEOs, VPs, commanders, and the like to explore possibilities themselves, rather than delegate to others, to share concepts, ideas, strategies and plans with staff at all levels and to focus motivation: if a SoS is to be successful, it seems likely that it will be because the workforce is motivated to cooperate and contribute in harmony towards a common goal, to understand and accept the need for change, to embrace it, and to effect that change swiftly and cleanly.

All of which depends on developing sound and effective behavior models for the open SoS, with its constituent open, interacting parts, open to its environment, and interacting with and adapting to other systems in that environment.

SoS Architectures

SoS pipeline architecture

The architecture of a SoS may be suggested in the title — a system of systems. There may be rather more to it, however. Figure 17.1 shows a notional architecture for a 'pipeline' SoS; see System of Systems on page 94. Pipeline architectures pass material and information through a series of systems, each system processing and transforming the throughput in sequence before passing it on. Lean volume supply systems are pipeline systems, where the throughput is material for manufacturing, processing and/or assembly; so, too, are policing systems, where the throughput is offenders and lawbreakers.

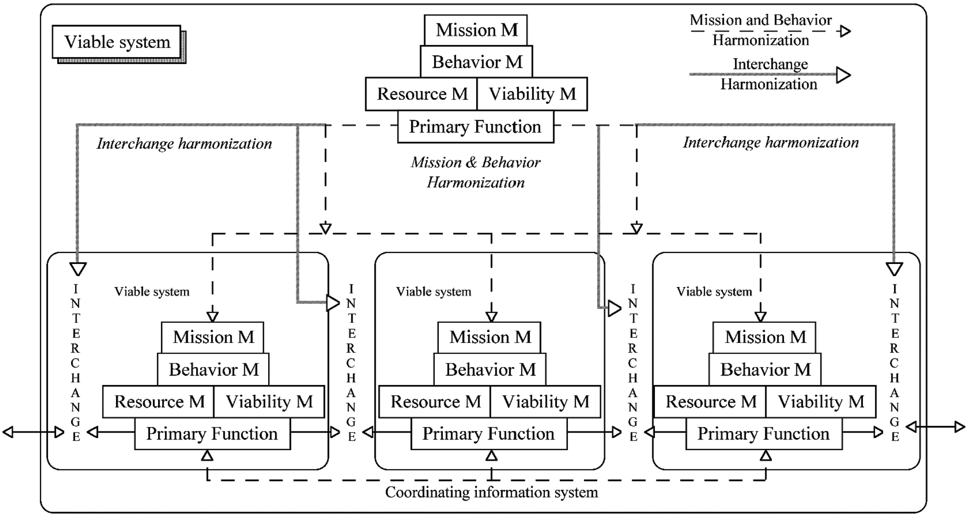

Figure 17.1 System of systems (SoS) 'pipeline' architecture. Each of the contained (sub) systems is a viable system. The three subsystems exchange material and information. Activity initiations, rates of operation, activity coordination are effected with the aid of a (primary function) coordinating information system. Primary functions of the whole system, shown at the top of the figure, include mission and behavior harmonization of the subsystems, and interchange harmonization to enhance cooperation, coordination, compatibility and synergy.

Figure 17.1 shows three elements in a pipeline; the three contained, viable systems at the bottom of the figure. The three are formed into a pipeline via an interchange, which transfers/transforms the output from one into the input to its successor. Acquiring input, processing throughput and providing output (input–process–output) are the primary function(s) of each viable system.

In the figure, each of the three systems is a viable system: each has its own mission management, behavior management, resource management and, of course, viability management. Each system organization could, in principle, operate on its own. However, for the three systems to behave as a unified whole, i.e., as a system of systems, without prejudicing their viability, some degree of harmonization will be needed:

- *Mission harmonization*. The mission of the whole system will 'guide' the missions of the three viable subsystems. Directors of each viable subsystem will pursue a mission, or missions, consistent with, and possibly approved by, the director of the whole. They may be free to pursue their separate missions without supervision, in a manner of their choosing, but are likely to be held to account should they fail.
- *Behavior harmonization*. The containing system may seek to impose 'ways of doing things,' including a 'corporate image,' and a doctrine, or company procedure, on the three viable subsystems, such that they all separately and together appear and behave as a single, unified whole. An integrated transport system may see the various operatives from their various viable subsystems all wearing the same uniform, for example. Publicity and public relations may be provided only for the new SoS, and no longer for individual contained systems — see Behavior Management on page 130 and The GRM and the Systems Approach on page 135
- *Interchange harmonization*. The smooth flow of e.g., people, materials and information through the whole system, and therefore through the three subsystems in the example, requires, inter alia, that the interchanges between the viable subsystems – which may be miles, or even oceans, apart — should be swift and effective. In a lean volume supply systems, parts and subassemblies flow from part suppliers through subassembly manufacturers, and on to final assembly, before going out to the market. Any parts, subassemblies or assemblies in the system represent a cost, including any waiting for, or transit between, factories. In some situations, interchange may involve some transformation of the throughput, e.g., information may be reformatted, separate parts configured into sets, etc.
- *Primary function coordination*. It can be shown that the minimum amount of WIP in a lean volume supply pipeline is consistent with a steady manufacture and assembly rate, rather than one that works in batches, or where demand rises and falls. Similarly, transfer between sites (viable subsystems) should be of individual units, rather than batches. Primary function coordination seeks to initiate and regulate activity such that outputs are available from one unit just in time to be used as an input to the next unit, allowing for transit time. This primary function coordination may benefit from a dedicated information system, as shown in Figure 17.1.

Harmonizing and coordinating the various flows and interchanges between the subsystem is not unlike 'spinning the plates,' except that it is potentially able to address all the 'plates' at once and in parallel. The objective is to promote synergy, improve responsiveness and hence increase overall effectiveness for less effort. In the process, the various viable subsystems may change; they may also resist change, as people systems are wont to do. Achieving harmonization turns out, in practice, to be a management and leadership task, and may either take time, or invoke a 'bloodbath,' with transfers, redundancies, strikes, etc. Much depends on the suitability of the original viable systems that were selected to form the SoS . . . .

SoS complementary architecture

An alternative architecture, SoS complementary architecture, is shown at Figure 17.2. Three viable subsystems are shown: the actual number would depend on situation, but there should be sufficient to complete the complement. For a naval task force, for instance, there would be various ships and aircraft to provide air defense, surface defense and subsurface defense: the three defensive arenas are complementary since, given those three, there should be no more. In a distributed enterprise, there might be separate viable facilities for research & development, design, manufacture, marketing and sales; these four might constitute a complementary set.

The name of the departments in the President's cabinet are indicative of a complementary set: State, Treasury, Defense, Justice, Interior, Agriculture, Commerce, Labor, Health and Human Services, Housing and Urban Development, Transportation, Energy and Education. The test of complementarity is to consider which of the set could be left out without leaving an evident gap, one that would result in an incomplete and probably dysfunctional system.

The human body can be viewed as a complementary set of subsystems, although none of the subsystems is viable: instead, they are all mutually dependant. There are subsystems for ingesting

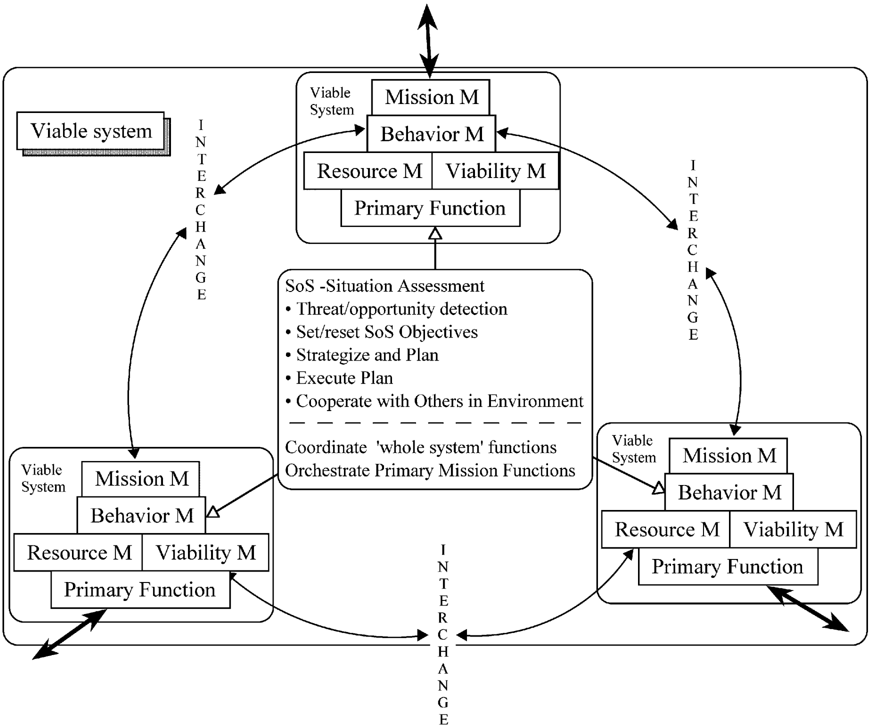

Figure 17.2 SoS complementary architecture. A requisite variety of complementary systems (hence primary mission functions) are brought together: their behaviors are cooperative, coordinated and complementary, encouraging synergy. Additionally, whole system functions may be established, perhaps with functional parts distributed amongst the viable subsystems — see text. Potentially, the central focus may be vestigial, or even conceptual only . . . .

food and energy, breathing and exhaling, circulating blood, sensing, moving, thinking. . . the list goes on. With such a complementary set, the question becomes — which of these could we do without and still remain viable? (Our answers may change with advancing years!)

In a not unrelated vein (sorry!), the twelve cranial nerves form a complementary set of nerves emerging from the human brain. As trainee doctors will have learned, using various mnemonics, the nerves are: olfactory, optic, oculomotor, trochlear, trigeminal, abducens, facial, acoustic, glossopharyngeal, vagus, accessory and hypoglossal; these nerves comprise a complementary set. It would be apparent if any one of these were missing or inoperative. All would be needed for a fully operative system . . . .

In the general case of Figure 17.2, it may not be simple to establish when the set of different, complementary viable subsystem is complete. For the naval task force, might there be a space-borne threat? And to a significant degree, variety in complementary system sets is driven by risk and threat — see Threats and Strategies, part of SM3, on page 226.

Bringing together a complementary set of subsystems to form a SoS whole may provide the opportunity to develop and introduce whole system functions, i.e., functions of the SoS that cannot be exclusively attributed to any of the viable subsystems.

For an integrated transport system as an SoS, a whole system function might be dynamic capacity management, in which the capacity for travel on particular routes is adjusted by putting on more, or larger, vehicles as routes start to get crowded, at the same time as reducing the capacity on routes that are not so busy. This would be a complex arrangement to execute ‘on the fly,’ involving traffic flow sensors, dynamic resource allocation, rerouting, etc., etc. But, with an integrated transport system, it may be both feasible and beneficial — especially during rush hour times.

For an integrated air defense system, with complementary systems including ground radar and airborne early warning radar, fighter interceptors, surface to air missiles, etc., a subset of viable subsystems, perhaps the airborne radar and a fleet of interceptor fighters, might suffice. Suppose they were all fitted with track-while-scan radars — see Case F: Fighter Avionics System Design — and could automatically exchange target track information via some data link. Then each aircraft could display a set of all identified targets being tracked on a map. This would be a dynamic map, one that moved with the fleet, and would operate even when the fleet moved out of ground radar range; indeed, it might improve as the fleet moved towards the target area. The formation of this so-called recognized air picture (RAP) would be a whole SoS (fleet?) function.

Suppose further that each aircraft could see potential targets on the map display that were within the capability of that aircraft to intercept. The aircraft, under crew control, could transmit details of their preferred targets to other interceptors. These others may also have seen targets, and some may prefer the same target(s) as the first interceptor, so there would follow an automatic negotiation in which particular targets were automatically allocated between interceptors in the way most likely to achieve some objective: maximum interceptions in a set period; maximum interceptions before the targets crossed some boundary line; etc., (Hitchins, 1987.) This would be automatic target allocation: it would be a second whole SoS function.

Complementary architectures of SoS, then, may exhibit emergent properties, capabilities and behaviors, even without a central coordinating capability. Indeed, the point of bringing a set of complementary systems under a single SoS umbrella may be to generate synergy, and, in so doing to generate emergent properties, capabilities and behaviors of the whole SoS, i.e., not exclusively attributable to the separate parts. In some instances, as in the air defense example, survivability of the whole may be enhanced by the elimination of a vulnerable node, such as a central, coordinating focus.

SoS — Unified Whole, or Dissociated Set?

From the foregoing SoS models, it seems that there may be 'degrees of system-ness;' i.e., there may be SoSs, with viable interacting (sub) systems where the mission and behavior management of each subsystem is less than, or entirely, congruent with that of the whole.

For full congruency, the SoS could be represented by an instantiation of the layered generic reference model as shown in Figure 17.3 — (see The GRM and the Systems Approach on page 135.) The figure is a standard version of the layered GRM, with the Form layer highlighting the viable subsystems. Each subsystem is shown as having discrete resource management and viability management, as well as performing primary functions of the SoS as a whole. The mission management and behavior management elements of each viable subsystem have been subsumed into the two upper layers of the diagram, indicating either that:

- the management of the subsystems is entirely congruent with that of the SoS as a whole, or that
- there is no discrete management of the whole: management of the viable subsystems is by, and of, the subsystems — by mutual agreement, by negotiation, etc. This would be consistent with Figure 17.2, and air defense example above, where whole system functions had been set up, enabling cooperation, coordination, and negotiation to take place between the parties, without the need for a central, nodal figurehead, commander, CEO, chairman, president, etc . . . .

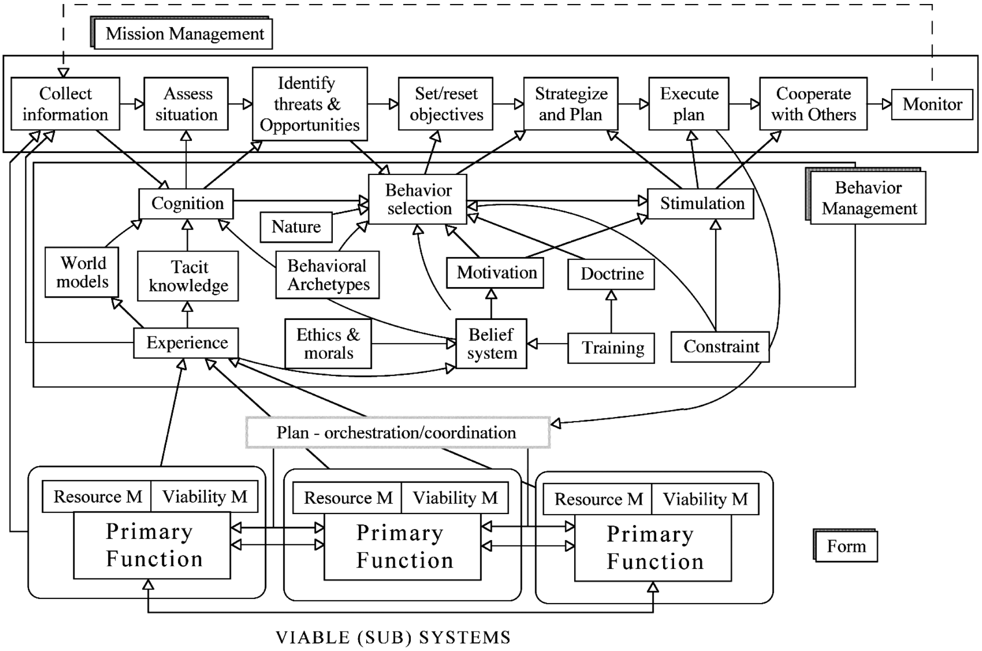

Figure 17.3 Layered generic reference model for a system of systems — see text.

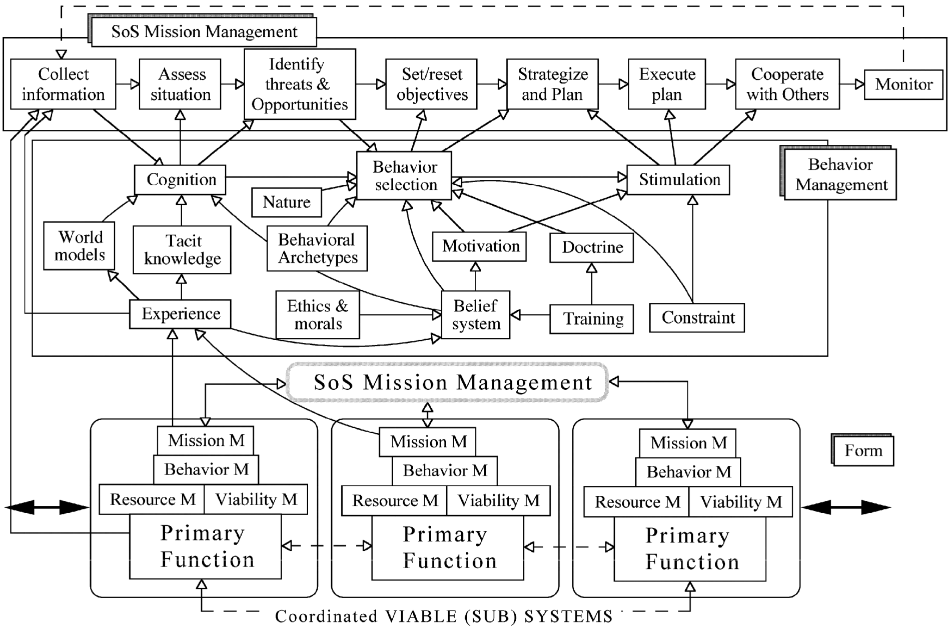

Figure 17.4 Layered generic reference model of a SoS, where each of the systems has discrete mission and behavior management. The GRM is presented in three layers as usual. SoS Mission Management is shown at the top, and is repeated in the center, in abbreviated form. See text.

On the other hand, some viable subsystems may have a ‘mind of their own;’ i.e., each of the viable subsystems has its independent approach to mission management and or, has its own culture, doctrine, and ‘way of doing things.’

An alternative instantiation is presented in Figure 17.4. This considers the situation where there is a central, containing system element, itself a system. As the figure shows, each of the viable (sub)systems has its discrete mission and behavior management, in addition to resource and viability management (resource and viability management for the central, directing element are omitted for clarity).

This might suggest that each system is independent and may retain, or create, its own culture, belief system, way of doing things, etc. However, that need not be the case. The three systems are shown ‘tied into’ the SoS Mission Management. That indicates that the ‘directors’ of each of the viable systems contribute to SoS Mission management, providing information, assessing situation, identifying threats and opportunities, setting and resetting objectives, strategizing and planning, etc. It also indicates that the mission of each of the viable systems is harmonized within the plan and that the viable systems coordinate and cooperate intelligently to prosecute the plan. As illustrated, the SoS is potentially capable of exhibiting intelligent behavior, particularly since it is using experience of what has gone before in assessing situations and formulating strategies. Note that Experience also feeds Belief System, such that Beliefs may be grounded in reality, and may evolve in consequence.

Managing Change in a SoS

Provided subsystems in a relatively dissociated SoS perform their primary functions in a coordinated, cooperative, complementary manner, it might be that there is no immediate issue — the SoS, in effect, is operating as it should. Looked at another way, an outside observer would not be aware that the parts of the whole were culturally and managerially independent. Some global volume supply systems appear to operate in this manner, with different organizations/enterprises in different countries forming links in supply and manufacturing chains. So long as the links continue to form strong, coordinated and cooperative connections, then so long will the SoS maintain the status quo.

However, few SoS are in a steady state for any appreciable duration — SoSs are open, interacting systems and, as such, are continually adapting to their environment and to their systems in that environment — or not, in which case they may soon become terminal. The ability and manner in which dissociated and fully integrated SoS accommodate change may differ: see Figure 17.5.

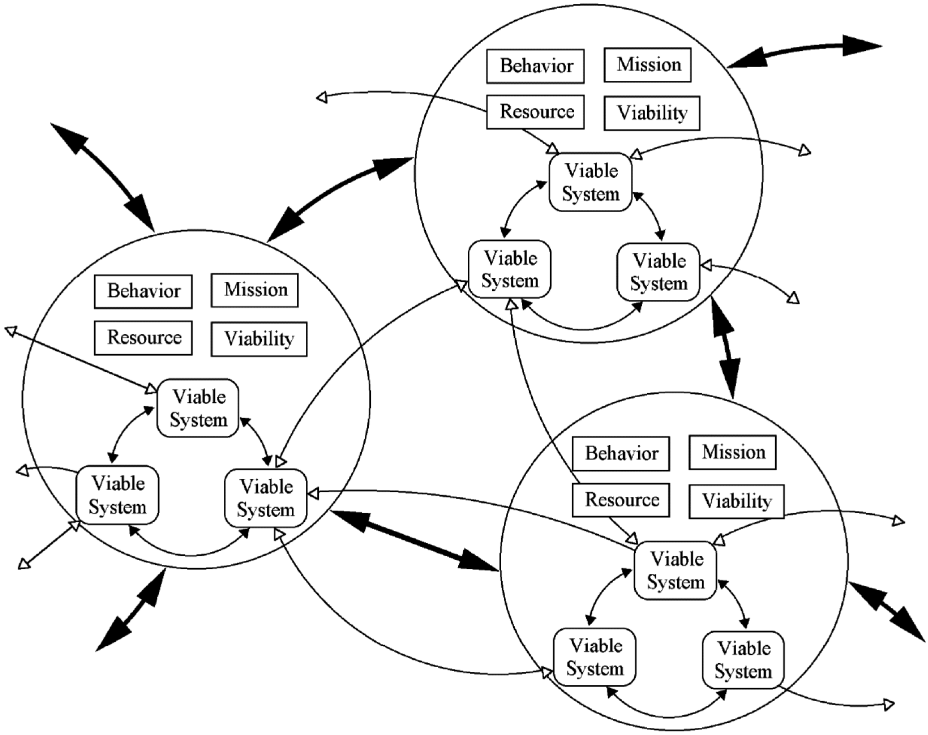

Figure 17.5 A SoS, left, containing three viable systems, interacting with other SoS at SoS level and at system level. The environment for any SoS is constantly changing, perhaps even weakly chaotic. From a contained system perspective, it appears to be a node within an ever-changing network of changeable systems. To survive and flourish, and SoS will need to adapt and evolve. For a unified SoS, adaptation may invoke change within and between the integrated systems composing the SoS. For a more dissociated SoS, adaptation may invoke discarding some contained systems and replacing them with others.

For the dissociated SoS, rapid environmental change may present problems: the state of dissociation militates against the SoS as a whole being able to adapt quickly and in a coordinated manner, without losing what little coherence exists in the process. Instead, one way of accommodating change would be to replace one or more viable subsystems with others: effectively, to reconfigure the SoS. This approach may seem attractive and quick, but a settling down period will follow as new cultures adapt, cooperation develops, and coordination synchronizes.

For the fully integrated system, speed of adaptation to changing circumstances may conceptually be greater; provided, that is, that the viable subsystems — either HASs or sociotechnical systems — are themselves able to change. It is possible for a large, integrated SoS to become a monolith. Alternatively, an SoS might be comprised of large numbers of small units, each able to form and reform in response to e.g., market change, new opportunities, availability of new technology, etc., etc. Essentially, speed of adaptation in this context can be looked upon as an architectural characteristic. Architecture with few, monumental blocks, is potentially slower out of the starting blocks than architecture of many small, relatively independent parts.

By analogy, the rate at which an organism adapts and evolves to changes in its environment is also dependent on size and structure. A large dinosaur may have taken 25–30 years to grow to maturity and have offspring, which it may then need to nurture for 10–15 years or more. A small mammal, by comparison, may mature in perhaps two years and may have offspring in even less time. The mammal can create many more generations within, say 100 years than can the dinosaur, giving the mammal much more opportunity to adapt and mutate in ways that improve its prospects. A rapidly changing environment, then, favors the survival of a species that has a relatively short lifespan and which can generate variety in its offspring.

What is true in ecology may also be true in economics. It is not always the large, monolithic company that survives and overcomes the opposition. IBM, Big Blue, found that out to their cost, and had to regroup, reorganize and reconfigure such that they could adapt to changes in the market that had previously passed them by.

System of Systems Engineering

Is system of systems engineering (SoSE) any different from conventional systems engineering? Opinion on that score will rather depend on where one is coming from. For those steeped in ideas of systems engineering as being concerned with creating artifacts, SoSE will seem alien: systems engineering as propagated by some defense agencies does not overly concern itself with systems in general, but almost exclusively with engineered artifacts, and their continuing support. However, those for whom ‘system’ includes organizations, teams of people, sociotechnical systems, enterprises, industries, economies, etc., there will be little or no distance to travel. To them, SoS engineering will be virtually indistinguishable from classic systems engineering — which has not been confined to artifacts.

For SoSE — if indeed there is such a discrete subject — the best approach would seem to be to employ the systems methodology as it stands, since it is designed to address systems of all kinds, remembering that within the systems methodology, the Generic Reference Model serves as a keystone for bridging from problem to the solution. In addressing SoS, then, the key will be to instantiate the layered GRM in the form of the SoS, and to set the resulting whole in the context of a dynamic, interactive network of systems as in Figure 17.5.

Instead, however, of trying to establish a variety of different functional/physical partitions, (see SM5: Architecting/Designing System Solutions on page 253) it may be appropriate to accept the inherent partition formed by the choice of viable systems that are to be brought together. Coupled with Continual Redesign, the whole SoS will then be harmonized, adapted and evolved as it seeks to flourish and survive in its dynamic environment.

Summary

Systems of systems (SoS) may be formed by bringing together extant, complementary, viable systems under a single umbrella. The systems in question are human activity systems (HASs) and sociotechnical systems. SoS fields of endeavor include Levels 3, 4 and 5: see the The 5-layer systems model on on page 113, i.e., enterprise/business, industry, economy; they do not appear to include artifacts-comprised-of-artifacts (AoA?), such as an avionics system, a tank, or a racing car, although the term SoS is so inadequately defined that it is not possible to be definite. Another term, family of systems, for example, does not appear to mean the same as 'SoS,' since the latter must sensibly exhibit the characteristics of a system. 'Association of systems,' on the other hand, is unclear — it could, but need not, refer to a SoS.

Instead, SoS appears to refer to commercial enterprises or military systems formed by bringing together other, complementary commercial enterprises or military systems. The whole will also be a system, and will become, more or less, a unified whole.

Why 'more or less'? Because the enterprises/systems composing a SoS were viable systems prior to 'incorporation,' they will have had their own purpose, concept of operations, etc. In bringing several such, previously independent, systems together, it would be fortuitous if they fitted together perfectly. Instead, it is likely that there will be a need to harmonize their previously independent missions and behaviors; similarly, interchanges between the viable systems may need to be made easier, swifter and more transparent. The functions performed by each viable system will now become (some of) the primary (mission) functions of the whole SoS, harmonized to be cooperative and coordinated, such that the SoS can develop synergy between its constituent parts.

Harmonization may prove less than straightforward: the systems to be harmonized are HASs and sociotechnical systems (which may exhibit the behavioral aspects of their human elements), and as such are nonlinear. There are different strategies that might be adopted to bring about a degree of harmonization within a complex of non-linear systems. One strategy is the so-called spinning plates approach, where imbalances, dysfunctions and disharmonies are tackled one at a time and resolved before moving on to the next.

An alternative harmonization strategy is Continual Redesign, which seeks to balance the whole nonlinear structure. Using the systems approach and the systems methodology, or some other way, the problem space is continually explored to detect shifts and changes in the problem. Remedial solution concepts are generated, purpose is focused, etc., and a functional design for the whole is developed, taking into account threats, risks and strategies to address them. A functional design and architecture are developed, and mapped on to the existing partitions formed by the extant viable systems. The resulting functional/physical design is compared with the real world: if the difference between the two exceeds a sensible threshold, then further harmonization, reconfiguration, etc., are required. The method adopts the systems approach with dynamic simulation using open systems models to address nonlinearity, environment, adaptation, evolution, survival, etc.

SoS physical architectures, comprised of contained systems, may vary: two archetypes are presented; the pipeline architecture and the complementary systems architecture. Additionally, a SoS may be hierarchically organized, with some central system serving as overall mission and behavior management. This might be the case where a company had a number of subsidiaries.

On the other hand, it is both feasible and practicable to form SoS architecture from complementary systems, but without central focus or coordination — not unlike a committee without a chairman.

For such a SoS to function and behave as a whole, there must exist a basis for the systems to cooperate and coordinate, implying a means of negotiation that will operate successfully without independent arbitration. Modern digital communication systems are making such SoS practicable, as in military nodeless, network centric operations. Invariably, such nodeless SoS, like the committee without a chairman, will need methods for negotiating agreements and deriving corporate decisions. These methods and capabilities are ‘functions of the whole,’ i.e., of the SoS, and are not attributable exclusively to any of its logically separable parts: essentially, they are emergent capabilities.

A variety of Layered Generic Reference Models (LGRMs) is presented for differing SoS configurations. They suggest that the ability of a SoS to adapt swiftly and effectively to changing environments may depend in part on the degree of integration/dissociation of and between the various viable systems comprising the whole.

Dissociated viable subsystems are those that, although performing the appropriate primary functions, say, in a pipeline SoS, may retain their original culture prior to incorporation, and still possess their own, independent mission and behavior management. Changes in the environment for the SoS as a whole may see such dissociated systems either unwilling or unable to adapt; instead, the SoS may adapt by replacing the system. In effect, some SoSs may comprise a ‘floating population’ of largely dissociated, viable subsystems.

Integrated viable subsystems of a SoS are those that participate in and share the same, overall mission and behavior management, although perhaps retaining discrete resource and viability management. As is more general in HASs, integration involves less control, more leadership and influence. In particular, fully integrated subsystems would tend to share a common Belief System.

For those steeped in the more recent defense version of systems engineering, which restricts itself to creating and supporting linear technological artifacts, SoSE may seem to be novel. However, SoSE appears from the assessment and analysis above to be in the mold of classic systems engineering, i.e., appropriate for application of the system methodology presented in this book. It should be noted, however, that the prospects for optimizing a SoS may be limited: potential synergies and emergence may be similarly limited by the original choice of systems to be brought together, and by the degree to which they can be harmonized and coordinated. With SoS, it may be more a case of satisficing than of solving the original problem — see The Systems Approach on page 16.

Assignment

You are the Business Development executive for a large manufacturing company in the automobile industry. The company is seeking to introduce a new product, unlike those currently manufactured. The company will need to form a supply chain of parts from which to assemble the new product. You have identified five companies that supply similar parts to the industry.

Your initial idea is that your manufacturing company should purchase these supply companies so that they may be incorporated and dedicated to supplying parts exclusively for the new product. On second thoughts, you realize that buying these potential suppliers may not be the best plan.

Develop a conceptual strategy for setting up and establishing the supply chain for the new product that does not involve buying the supply companies, but which, instead, seduces them to supply high-quality parts predominantly to your company. You should consider harmonization and interchange factors, and how requisite quality can not only be achieved, but also improved upon. You should also consider how supply of parts might be guaranteed . . . .