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Systems Creation: Hand of Purpose, Root of Emergence

Yet I doubt not thro' the ages one increasing purpose runs
And the thoughts of men are widened with the process of the suns

Alfred, Lord Tennyson 1809–1892

The Hand of Purpose Flowing Through Human and Machine

Manmade systems are purposeful: the purpose they serve is that of their designers/makers/owners/operators/users. It is possible to follow the route from the mind of the owner/operator, through the whole system, to observe purposeful activity and to see the purpose achieved, so giving closure.

This simple circuit is perceptible at a number of levels: the first level is within the human individual. We are purposeful creatures — much of the time. We are also singularly unaware of how good we are at achieving our purposes. Consider, for instance the simple act of a man throwing a dart at a dartboard. First, it should be appreciated that man alone has the facility do such an everyday thing. Even our closest cousin the chimpanzee is poor at throwing and catching by comparison with quite young human children.

The would-be dart thrower steps up to the oche (throwing line), leans forward, regards the desired point of impact on the board, raises his or her arm and throws, seemingly in one smooth movement. However, analyzing the whole action indicates that there is a myriad of muscular actions that must take place in the right sequence and with the right degree of vigor. And, prior to the throw, there must have been a rather smart calculation to allow for the distance to the board, the gravitational drop, the weight and flight characteristics of the particular dart, etc.

Research suggests that we have the ability to establish mental 'templates,' sets of neurons that 'remember' the actions that we take, in sequence, and that can be called upon to repeat a complex series of actions, both in imagination and in reality, without having to 'go back to basics' each time. So, the dart player learns to throw the dart by trial and error, and then refines his or her performance with practice, until the neuron 'template' in the brain has stored a well-honed and dependable pattern relating to throwing darts. There must be many such patterns, relating to how we stand up,

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and manage to stay upright; how we walk and run; how we use a QWERTY keyboard without looking (touch-typing), and many, many more.

Humans become so adept at behaving purposefully that we can lose sight how we do it. You think not? Close you eyes and try to imagine yourself walking by operating the muscles in your back, arms and legs in the correct order needed to walk — not forgetting all the corrections necessary to retain balance. Give up? It's impossible. However, we may be able to work out what is going on in our brains and to use that understanding to help create purposeful social and sociotechnical systems, incorporating artifacts with which we can achieve our human purposes.

Figure 16.1 shows a notional model of purposeful behavior. The diagram might refer to an individual, with the functions being bodily functions, or it might be a complex sociotechnical system with some functions being performed by people and others by artifacts. Indeed, it might be repeated, creating two models one above the other: the upper one could refer to a human operator; the lower figure might refer to a complex artifact being controlled by the human operator. The two figures would be interlinked to show how the intent of the human operator activated and coordinated the various functions of the complex artifact.

Figure 16.2 develops this notion of the two models as one. At the top, the (human) mind perceives a situation, and determines upon some intent. According to psychologists (Klein, 1989), this intent is likely to engender a mental simulation of how we propose to achieve the intent that indicates whether our initial plan is credible. If not, we mentally change the plan and retry, until we find a plan that satisfices, i.e., one that is 'good enough.' All of this, it seems, is performed in the twinkling of an eye.

We then activate the plan, that is, orchestrate/perform the planned activities/functions, etc., all the while observing the developing situation. If things are not going according to plan, we may revisit the plan, perhaps more than once, homing in on an acceptable solution (satisficing). Finally, having realized our intent, we achieve mental closure: we have reached our goal, and achieved our purpose.

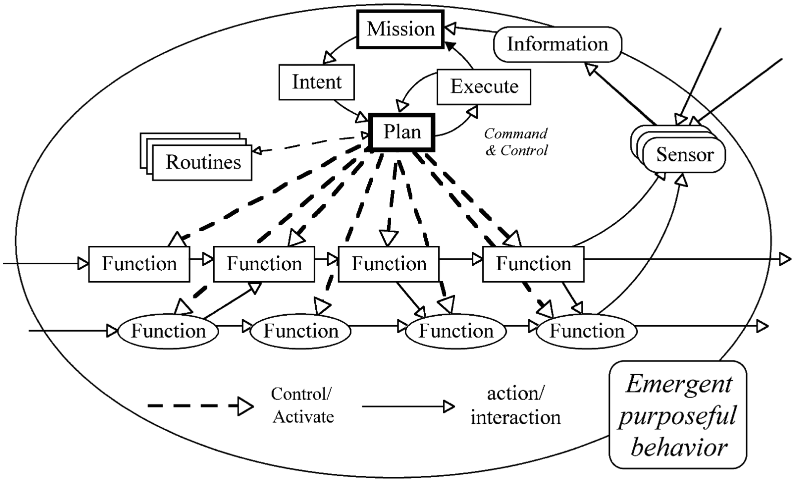

Figure 16.1 Orchestrating functional synergies to create emergent, purposeful behavior. Intent gives rise to a plan, comprised largely of practiced, rehearsed routines that may be adapted in real time. The plan is executed by activating functions/processes according to the routines in the plan, giving rise to synergistic functional activity in pursuit of the Intent; i.e., emergent purposeful behavior.

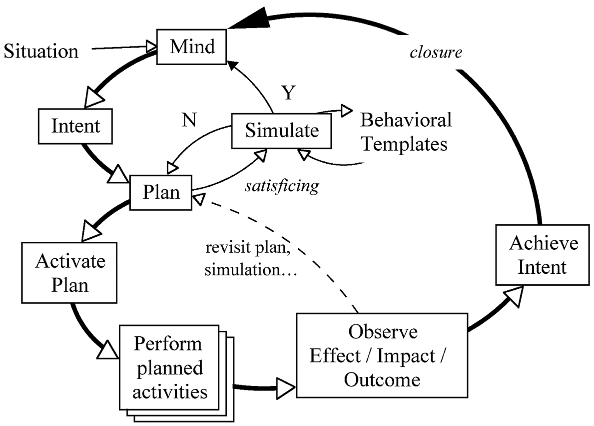

Figure 16.2 Notional model of dynamic control in achieving intent, i.e., purposeful behavior.

Figure 16.2 could refer to something as simple as a golfer at the driving range, practicing his or her swing. It could refer to an aerobatic display, with the pilot controlling stick and throttle as he/she undertakes a series of preplanned maneuvers, making corrections for crosswind, buffeting, etc., as the display progresses. In this case, the model could refer to just one stick movement, an aerobatic maneuver, or to a complete sequence of maneuvers. . . .

Yet again, the figure could refer to a concert pianist playing a concerto, listening to the orchestra, observing the conductor, and initiating all the various routines in sequence that constitute the piano score. . . .

In each case, the figure shows 'the hand of purpose,' i.e., the closed loop that leads from intent to closure when intent is satisfied. It incorporates both function and control of function. . . . And, to a significant extent, the creative phases of the systems methodology and of systems engineering are about identifying, establishing and maintaining this 'hand of purpose' as it goes from human intent, through human and artifact in such a way as to create requisite emergent purposeful behavior, and hence closure.

Which ought to be easy. . . but which, as following sections will show, may not be, as the loop representing the hand of purpose may be come tangled, obscured and confused with other loops and features attendant upon any complex system.

Preserving Interfunctional Connections in Functional-to-physical Mapping

Figure 16.3 shows the notion of functional-to-physical mapping. In the upper diagram, a set of functions is shown, with inter-function flow and function control: this is part, only, of a model such as Figure 16.1, with the elements of purpose, intent and planning omitted for clarity.

The lower diagram of Figure 16.3 shows the functional architecture compartmentalized to create structure, but with all the interflows and controls maintained exactly as in the upper part. This is simple functional to physical mapping, resulting — in this instance — in three compartments: these

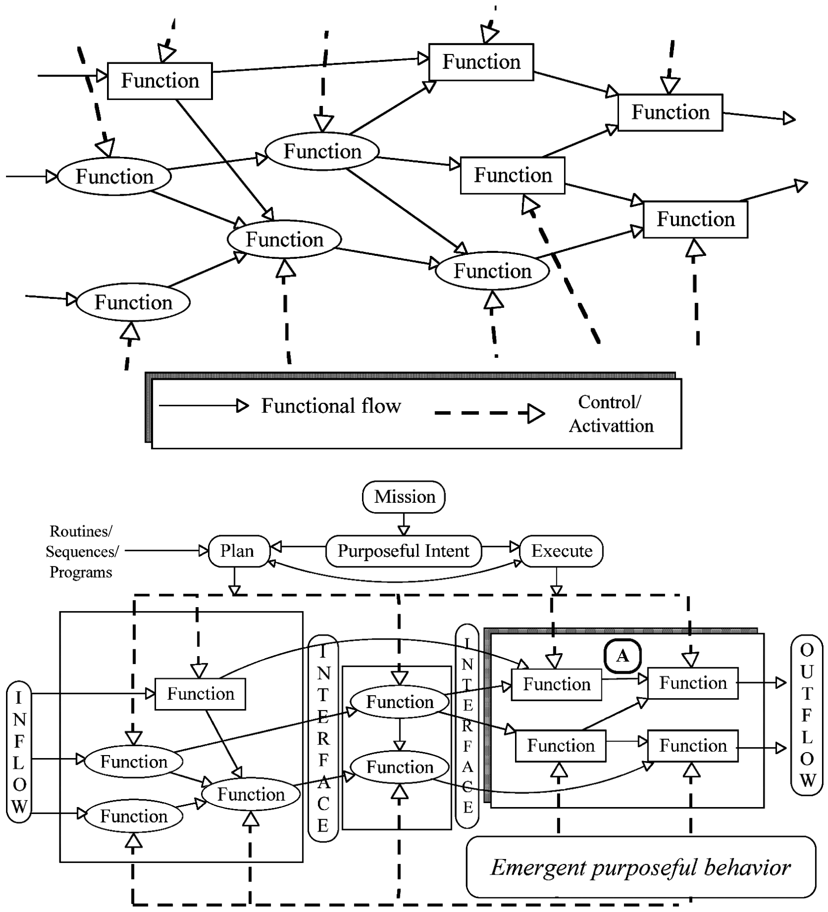

Figure 16.3 Preserving functional architecture in functional-to-physical mapping. The upper figure shows a notional (prime mission) functional architecture, with functional interactions/functional flow. Also shown dotted, are the control/activation lines that coordinate functional activity, and which give rise to synergy. In the lower figure, the elements of the upper figure have been partitioned into a simple physical structure, carefully preserving both the functional features and the control/activation features, without which requisite behavior will not emerge. The right hand block, A, is shown as a closely coupled subsystem of the whole, but will be reconsidered as a viable subsystem in Figure 16.4, below.

might be candidate subsystems, subassemblies, etc. Compartmentalizing creates internal boundaries, necessitating interfaces or accesses to traverse the boundaries.

Figure 16.3, lower diagram, restores the missing Mission, Purposeful Intent, Plan and Execution elements. Note, too, that the control 'lines' have been organized: these are analogous to the central nervous system, providing sequences of controlling signals to the muscles and organs of the body. The whole is beginning to look more like the model of some manmade device.

The right-hand compartment in Figure 16.3 has been marked 'A.' As shown, it is part of the whole, which whole may be presumed to incorporate overall function management, i.e., mission

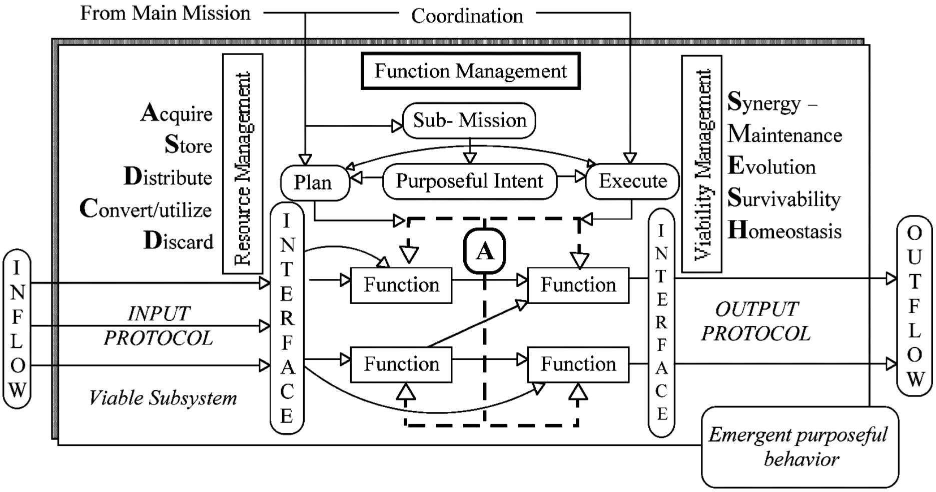

Figure 16.4 A viable subsystem structure model, showing at lower center the functional block, A, as also shown in Figure 16.3. The viable subsystem is able to exist, maintain itself, resource itself, and function on its own. However, when transparently connected to the other subsystems of the whole, as in Figure 16.3, it will be functionally identical with block A in that figure, and will contribute equally to the emergent purposeful behavior of that whole. Note that viable independence has greatly increased the complexity of the whole, and has introduced the need for communications and interchange protocols and interfaces. However, viable independence may also have reduced the vulnerability of the whole, allowed the whole to change form more freely, and presented opportunity for specialization and independent evolution. . . .

management, resource management and viability management, for all three compartments. . . . Suppose, however, that compartment A was to be created, not as an intimately coupled subsystem, but as a discrete, separate, viable subsystem, i.e., able to exist on its own. . . .

Compartment A is revisited in Figure 16.4, this time as a viable subsystem The functions of compartment A are shown, marked ‘A,’ center bottom of the figure: note that the interflow lines and control lines are all unchanged. However, being a viable system, ‘A’ now possesses its own, discrete mission management, resource management and viability management, also shown in the figure. This viable system still forms part of the original whole, but it is no longer closely coupled. It sets up its own missions — as ‘sub-missions’ of the whole systems’ mission(s). It executes its own plans, although these are coordinated with the plans and execution of the whole. It manages its own resources. It manifests its own viability. And, because it may be physically separate from other parts of the whole, it may need interflow/intercommunication protocols to allow it to operate remotely, yet at the same time be part of the whole.

Viable subsystems are common. They may be divisions in a business, brigades in an Army, fighter aircraft, ground radars or command and control in an air defense system, navigation systems in a commercial airliner’s avionics suite, vehicles in an Apollo mission, etc. Viable subsystems have the characteristics of systems: being subsystems, additionally, they also complement other subsystems in contributing to the whole. (Viable subsystems may undertake missions and pursue purposes in addition to those inherent in being part of the whole: such additional features will not be examined here.)

Emphasizing the Process View

Looking at Figure 16.4, it may become clearer how it is that the 'hand of purpose,' if not overlooked, may at least be played down, during the processes of creating, particularly, viable subsystems of some greater whole. It is a linchpin of systems engineering that this hand of purpose is *not* played down, but is kept visibly to the fore during detailed design, development, engineering, integration and test. It is particularly evident during integration and test, and when fault finding, where the procedure is generally to follow the 'hand of purpose' through the system, finding where it has either not been connected, or has come adrift. Such misfortunes are common during development, and may appear as timing errors, buffer overloads, absence or distortion of signal, loss of control, excessive control, overpowering, under powering, etc., etc. They are also common during operation, with failures, damage, etc., interrupting the 'hand of purpose,' which then has to be reconstituted by repair, replacement, reprogramming, retraining, etc., as appropriate.

Figure 16.5 shows an alternative view of Figure 16.4, emphasizing the systems approach. The viable subsystem, or SOI (system of interest), is shown as an open system in its environment, to

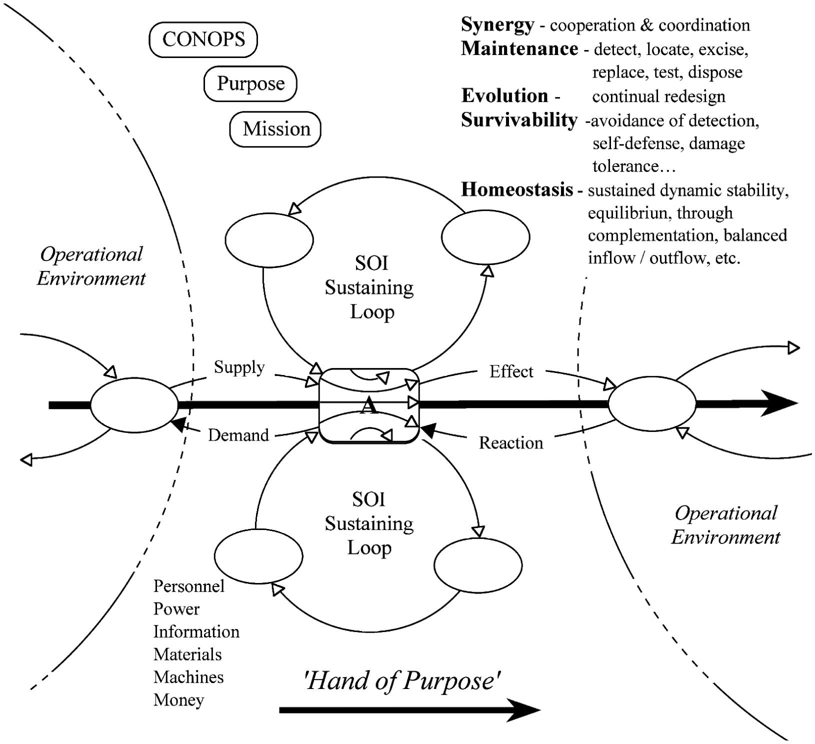

Figure 16.5 A viable subsystem process model. The systems approach regards the viable subsystem of Figure 16.4 as an open system in context, with resource management and viability management sustaining the 'hand of purpose,' i.e., purposeful processes. The viable system will have its own CONOPS, derived from, and contributing to, the CONOPS for the whole of which this viable subsystem is a part. The 'hand of purpose' will pass through all of the prime mission subsystems. . . . N.B. Functional Block A from Figure 16.4 presents, center, as a series/parallel arrangement of processes, A, which together 'perform' the requisite functions.

which it may adapt. The ‘hand of purpose’ passes from left to right through the subsystem: this is the operational aspect of the system, the prime mission function, processes and behavior. The functional block, shown as ‘A’ in Figure 16.4, is seen in Figure 16.5 as a series/parallel arrangement of coupled processes, which achieve the functions. For example, in a volume supply system, the function ‘assemble’ would present as a series of assembly processes in which various parts were offered up to a chassis or substrate, or to each other, in sequence until the assembly was complete. The function view is relatively static: the process view is more dynamic. (Coordination of processes might be necessary, invoking an information system to activate the relevant sequence of coupled processes at the appropriate time.)

Similarly, a function ‘track target’ would become a series of processes: a function ‘strategize,’ or ‘plan,’ would present as two different series of processes; and so on. In general, any function can be presented as a dynamic set of interacting processes — see Understanding Open System Behavior on page 12.

Sustaining loops in Figure 16.6 ‘enable,’ or resource, the prime mission functions with manpower, materials, money, information and power. They also sustain the viable subsystem *per se*, establishing a dynamic stability or equilibrium at high energy levels, and maintaining order (negative entropy) by ensuring connectivity, cooperation and coordination, neutralizing threats from inside and outside of the viable subsystem, and by progressively and continually redesigning the viable subsystem as the need and opportunity arise — see Organismic Control Concepts on page 20. In this Weltanschauung, training systems, simulators, design systems, maintenance systems, financing systems, etc., are part of the viable subsystem, are designed as part of it, created as part of it, and — if appropriate — delivered and operated as part of it.

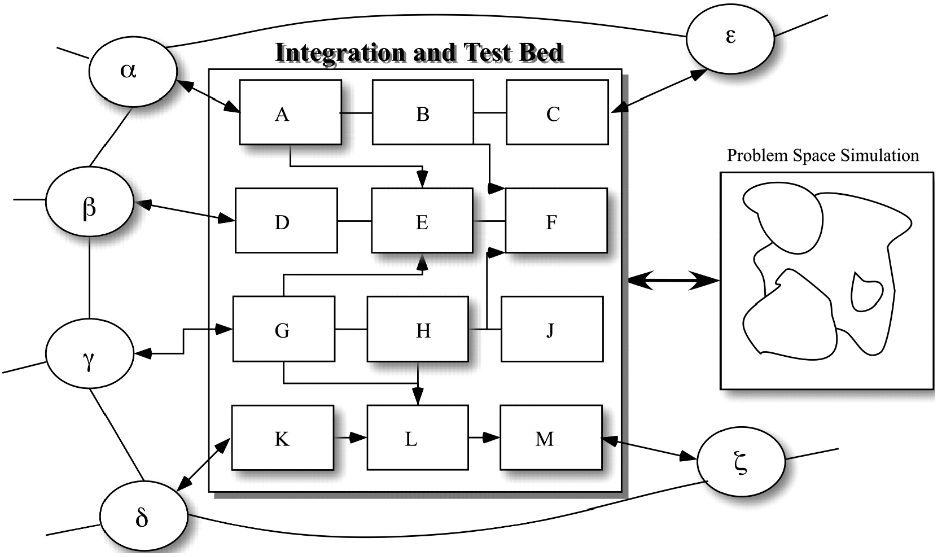

Figure 16.6 Integration and test bed. The whole starts as simulation. The central box contains the modules of a (viable?) subsystem, interconnected and interacting. The subsystem is one of many making up the whole system. The ovals (α–ζ) represent other interacting systems and subsystems that affect behavior of the subsystem, and of each other. The subsystem interacts with the problem space, in concert with other subsystems of the whole, to observe and measure the effectiveness of the whole. Progressive integration sees simulation modules (A – M) being replaced by engineered modules or parts, currently AEFHKM (shown shadowed), until the integration is complete . . . .

System design of the viable subsystem follows the Inner Loop of the Systems Methodology: see Outer Loop– Inner Loop Design on page 293, *et seq*. In so doing, both the structural view of Figure 16.4 and the process view of Figure 16.5 are relevant.

Elaborating the design of the viable subsystem will be facilitated by simulating it dynamically in its open systems context, interacting with other open subsystems as a complementary part of the whole, which is also interacting dynamically with other open systems in the environment. This is best achieved using the process view, since this lends itself more readily to dynamic simulation. Using the simulation approach, the effects on behavior of the whole can be envisaged/predicted by reconfiguring processes, selecting/substituting processes as situations develop, enabling processes not only to interact, but also to adapt/modify each other, reacting to outputs, improving complementarity, cooperation and coordination, responding to threats and failures, etc.

It is this process view, in which the so-called ‘hand of purpose’ runs through the various subsystems, integral and viable alike, that characterizes systems engineering. The interactions between these various functions and processes are the source of emergent capability and behavior — see Does the GRM Capture emergence? on page 141. This is why it is vitally important to maintain visibility of the lateral processes running through the various subsystems throughout the development, engineering, integration, and proving processes.

In proceeding from design to specification, to development, to engineering, to integration and test and into operation, the process view is, then, held to the fore. The various structures that are designed, developed, manufactured and maintained may be compared, albeit somewhat fancifully, with a trestle railway bridge, designed to support the train as it crosses a ravine, where the train, with its engines and carriages become the prime mission processes which can proceed only provided the trestle bridge is robust and enduring. The bridge creates and provides a supporting capability, which ‘enables’ the train to operate. In much the same way, the viability and resource management features of the viable subsystem provide an enabling capability, which the prime mission processes use to further the whole system purpose.

This conceptualization is consistent with a neat, insightful approach attributed to USAF scientists at Wright Patterson AFB during the 1980s. They regarded the systems within a fighter aircraft under three headings: mission, resource, and platform. Platform systems (equivalent to viability management systems in the context of this book) were subsystems concerned with establishing and maintaining the aircraft as a platform, i.e., abilities to take off, fly, land, maintain and defend itself. Resource systems were subsystems for acquiring various consumables such as fuels, lubricants, spares, etc., to maintain the platform, and acquiring and managing deliverables such as weapons. Mission systems were concerned with achieving specific missions, such as navigation, reconnaissance, targeting, jamming, weapon aiming, weapon delivery, evasion, recovery, etc. So, the platform and resource systems provided a capability, but without purpose; the mission systems, on the other hand, provided the crew-driven purpose that was supported and enabled by the other two.

Design, Integration and Test

The continuing emphasis on the dynamic aspects of the system-to-be-created presents both needs and opportunities for dynamic simulation. Figure 16.6 shows one approach, which offers significant advantage in maintaining the ‘hand of purpose’ and of developing requisite emergence.

Investigation of the problem space may have employed dynamic simulation to understand the problem, and to locate the sources of the various symptoms that characterize the problem. Design of the whole system will have employed dynamic simulation to address the interactions that take place within the whole, and between the whole and its environment, with other systems in that environment, etc. These simulations may be brought together to create an overall simulation after the style of Figure 16.6, with the problem, the solution system, and the environment all interacting. In the figure, the large central box may represent the whole solution system, or one of several subsystems that together represent the whole.

Within the box, the simulation modules A – M correspond to the physical tangible modules of the solution system, A – M. Initially, the whole is run in simulation, although it may be possible to connect the solution system simulation to extant, real world sources and sinks (α, β, γ, δ, ε and ζ, shown shadowed in the diagram). In this state, the (simulated) solution system should 'solve the problem,' i.e., should eradicate the problem symptoms, ideally without creating counterintuitive and adverse 'side effects.'

Creating correspondence between the modules of the simulation and the modules to be engineered into the final solution facilitates the development of specifications of behavior for both: this in turn emphasizes the process view, and maintains the flow of purposeful behavior through the solution system.

Designed and specified modules are engineered and/or trained as appropriate — there is nothing in Figure 16.6 that requires a module to be technological — any module could be an individual performing a function, a person operating a machine to perform a function, or a machine performing a function.

As modules, however composed, become available, they are introduced into the test bed in place of their simulated version, interconnections for inflow, outflow and coordination are made, and the whole is run to test the effectiveness of the composite arrangement. If all has gone according to plan, there will be no discernible difference between the behavior of the simulated module and the behavior of the real-world, engineered/trained module. Where differences arise, it may be possible to restore order by including adjustment facilities in the module design. . . otherwise, investigation will be necessary to sort out which is wrong — the simulated or the real-world module. It may also be possible to accommodate deviations from expected behavior within other modules. . . but, if all else fails, it may be back to the drawing board for whoever simulated, specified, engineered and/or trained the offending module.

Introducing tangible modules one at a time is prudent, if time consuming. The alternative, replacing many of the simulation modules with their real world counterparts simultaneously, is fraught with risk. If the resulting whole does not operate according to expectations, it may prove difficult to find the source of the problem, if only because of the complex of actions and interactions between the many parts as they react and adapt to each other.

Summary

Manmade systems have the user's/operator's intent coursing through them; this has been dubbed 'the hand of purpose.' It is the unifying theme that runs through systems and subsystems as they cooperate, coordinate and interact to create emergent properties, capabilities and behaviors of the whole system: it is also their instigator, activating and orchestrating those whole system emergent properties, capabilities and behaviors.

Systems designs may be viewed either from a structural perspective, or from a process perspective, where coupled serial/parallel process sequences constitute functions and functional behavior. Both views are important during the creation phases of detailed design, specification, development, engineering, integration, proving and operation.

Systems engineering emphasizes the process perspective, creating, elaborating and continually testing the design using dynamic simulation of the system or subsystem as an open system in its environment, part of a containing system whole, interacting with, and adapting to, other systems and subsystems. This is the systems approach, and is fundamental to systems engineering.

Assignment

You work at senior level within a dynamic business. The business presently operates from a single site, so that the five operating divisions of the company, each with about 500 employees, share all the common services, etc. You are tasked by the CEO with drawing up plans to relocate one of the five divisions to a separate site some 45 miles distant, where there is significant room for expansion. As a start, the CEO, who sees the move as a systems problem, wants to see a notional site plan showing the division, with its three 'contained' groups, and all of the supporting facilities it will require to exist as a viable operating unit, remote from the main site, but still firmly linked to it.

For the transferred division to remain viable, it will have to address homeostasis, dynamic equilibrium, in terms of revenue, manpower, energy, resources, facilities, security, etc. The move will clearly disturb manpower in the short term, if only because some employees will be reluctant to travel the extra 90 miles per day to reach the new site. Consider homeostasis for the transferred division, and for the four divisions remaining at the main site, and present your considerations in no more than five PowerPoint slides to the CEO