Systems Engineering: Open Systems

Open Systems

A system is a 'whole:' or, at least that was one, early definition. We recognize different systems when we encounter them: an aeroplane, a washing machine, a gambling system, an integrated transport system, a political system, an economy/ecology, an enterprise, an industry, a tree; a conveyer; an oven; a submarine; and, so on. We recognize that all systems are 'wholes;' completeness and closure are fundamental to the concept of 'system.' Nature creates wholes: whole atoms, cells, animals, plants, etc; whence holism, and the observation that the whole may be greater than the sum of the parts…

Some systems (wholes) are viewed as effectively closed, i.e., they receive no inflows and emit no outflows; this is a traditional engineer's view of systems. However, some systems are viewed as open… An open system is one that exchanges information, material and energy with its environment: which of those systems listed in the first paragraph is open; which closed? (Clue: if a system were truly closed, would we be aware of its existence?)

Viewing a system as open is consistent with the Systems Approach, which proposes that a system interacts with, and adapts to, other systems existing within some wider or greater system and environment. The Systems Approach thus requires that an open system be considered *in context*; since the context influences the way an open system will act/react/behave.

Dynamics & Structure

A system that is open to inflows and outflows of material, information and energy is not stable in the way that a closed system may be stable. An increase in inflow may result in more information, material and/or energy within the system, unless there is a comparable increase in outflow. Inflow/outflow parity can lead to a potential 'relatively stable equilibrium,' or homeostasis, between opposing and balancing influences. Without parity, the system may either increase, or lose, internal content…

Stability and control within open systems, then, is likely to be achieved by balance of forces, influences, flows, gradients, rates, etc., which is indicative of potential non-linear behaviour. Stability, otherwise dynamic equilibrium, occurs at relatively high levels of energy within open systems.

A conceptual 'open system,' then, has physical and functional connections: to exchange information, material and energy with its environment, it will have internal coupled processes from inflow to outflow, with some material structure or substrate to support that information, material and energy flow-through and exchange.

Internal Management

This internal organization is evident in natural systems: flora and fauna; all natural systems are open. We humans, for instance, have our alimentary canals… When it comes to designing man-made open systems, however, there is a natural tendency to emphasize the purpose of the system, and the functions of which it must be capable to pursue its mission, to achieve its objectives: these might be called 'mission functions.'

Less obvious, but equally important, are the features of the open system that will manage its internal flow of information, material and energy; it is these internal features which will activate, coordinate and co-operate its various 'mission' functions which it must activate/deploy/coordinate to achieve its goal.

Mission and Resource Management

For an open system, it follows that there will be internal 'Mission Management,' to manage information exchange—and activate/coordinate mission functions—and 'Resource Management' to manage material and energy exchange:

	Mission Management	Resource Management
1.	Collect Information	Acquire resources
2.	Set/reset objectives	Store resources
3.	Strategize & plan	Distribute resources
4.	Execute plan	Convert and utilize
5.	Cooperate with others	Discard excess/waste

The two columns form minimal lists: while there could be more 'things to do,' the two activity lists are fundamental if an open system is to exist, persist and 'perform.' Both imply some external environment: an operational environment from which information may be collected, and into which missions may be mounted; and a resource environment from which resources may be acquired and into which excesses and waste may be discarded/ejected, etc; these may, but need not be, the same environment.

Mission Management concerns itself with the *purpose* of the open system; it may be subjected to all kinds of information, but may recognize and utilize only that which concerns its purpose and continued existence. A worm-as-an-open-system may sense food, set an objective of reaching that food, may plan to cross an open space to reach the food, may worm (!) its way across the space, avoiding dry patches en route (strategy?) and goes over/under other worms *en route,* perhaps. An airliner-as-an-open-system collects information about weather, traffic, etc., sets its objective as flying safely to its destination airport, (flight) plans the trip, choosing an altitude to avoid the bad weather forecast on one of the legs, flies in accordance with the flight plan, and cooperates with other aircraft, air traffic management, etc., throughout. Worm and airliner continue to collect/receive information throughout their respective missions, and may revise their objectives and plans accordingly: the processes are continual.

Resources to be managed come under two categories: those 'external' resources that will be processed within the open system, and which constitute 'flow-through' from inflow to outflow; and those resources which comprise the processing facilities, and which need replacement, evolution, etc. For the worm as an animal, the flow through of resources may be soil, while the structures within the worm that process food are constructed from nutrients in the earth flow-through. In this particular, animals are distinct from man-made systems: people are not yet smart enough to design such self-constructing systems. The airliner has passenger, baggage and freight as its flow-through, while the airliner, incorporating its crew, is maintained using separately supplied spares and consumables: fuels, lubricants, oxygen, foods, etc.

Similarly, the sequence of resource management activities is variable: ‘store’ might come after, or both before *and* after, ‘distribute’ for example. And a variety of different material resources may be acquired at various times, in series and in parallel… so, also continual processes.

Behaviour Management

Open systems may exhibit ‘response to stimulus,’ generally termed behaviour. Behaviour may be reflex, conditioned reflex (e.g., Pavlov’s dogs), or considered, suggestive of thought or intelligence. Considered behaviour may be observed in enterprises, societal systems, aircraft, armies, individuals, animals (notably cetaceans, some crows and primates), teams, and so on.

Is it possible to conceive, design and realize a system with the ability to manage its behaviour? In some senses, the answer has to be yes: we can build systems that operate in different ways or modes, according to situation; but that is nearer to reflex than to considered behaviour.

Where the system includes the human decision-maker, the behaviour of the whole may be determined by the behaviour of a person or persons—provided that they are provided with the information to understand the situation, detect the threat, etc., and the means to act accordingly.

Working along these lines suggests that a for a system to exhibit considered response to stimulus requires at least:

Cognition – the ability to detect and *recognize* the stimulus

Interpretation – the ability to appreciate what the stimulus means in context

Behaviour selection – the ability to choose a response that is most appropriate in the circumstances, considering what has gone before, what is happening now and what is likely to happen as a result of a chosen response.

Excitation – activating the selected behavioural response

Behaviour Management in open systems, where it exists, is allied in some respects to Mission Management. Behaviour Management may require internal processes, and possibly structures too, over and above those needed for Mission and Resource Management. It suggests an ability to be aware of, and assess situation; to detect and interpret threats and opportunities; to consider, even, perhaps to simulate, likely outcomes of optional responses… and to choose between options.

Open System Viability

There is a concept of open systems, that they be viable: *capable* of prosecuting some mission. That is not to say that they *are* prosecuting a mission, but that they are *capable* of it. I learned the difference from a USAF discourse on a new fighter, where its various functions had been categorized under three headings: mission, resources and platform. Mission and resources have been discussed above: so, what was ‘platform?’ Platform functions/features were all those that were required to keep the fighter aircraft airborne and operating, but which were not specific to a particular mission.

So, a fighter might be fitted with navigation, fuel pumps and self-defence missiles – these would be categorized as platform functions, since their purpose is to maintain the integrity of the platform/aircraft. It might also be fitted with laser-guided bombs; these would be specific-to-mission and would be categorized as mission functions. On a different mission, the same fighter might be armed with, say, bunker-penetrating bombs, while the navigation, fuel pumps and self-defence missiles would remain the same, regardless of mission, continuing to ensure fighter capability.

Suspecting that the term 'platform' might be generalized, I called it 'viability;' a viable system is one that is capable of working successfully, regardless of particular mission. Viability features emerge as follows:

	Title	Description
1.	Synergy	Complementation, cooperation and coordination of/between the parts
2.	Maintenance	Detection, location, excision, replacement, disposal of faulty parts
3.	Evolution	Adaptation to changing environment
4.	Survivability	Withstanding/absorbing external threats: avoidance of detection; self defence; damage tolerance; damage repair
5.	Homeostasis	Maintenance of internal environment

Each of the factors applies to the whole system, i.e., is systemic. But, is the list complete?

- Synergy is essential for all parts to work together, to cooperate, to coordinate, to complement each other, to afford requisite variety, etc.
    - without synergy there is no system, no capability…
- Maintenance addresses internal threats to capability
- Survivability addresses external threats to capability
- Evolution adapts, to sustain capability in a changing environment
- Homeostasis establishes and maintains the conditions for present capability.

So, the list *appears* complete: it addresses the internal and the external threats to capability; dynamic equilibrium to ensure continuing existence and capability; longer-term adaptation to environment to ensure future capability; hence, continuing capability, now and in the future…

Open System Function & Behaviour Management

In deducing the internal functional features that must exist within any open system, we should not forget that all the functions, including the mission functions, are interconnected and interactive. It is, after all, one of the roles of function management to coordinate and orchestrate mission functions to implement strategies, to achieve objectives, and so to fulfil purpose.

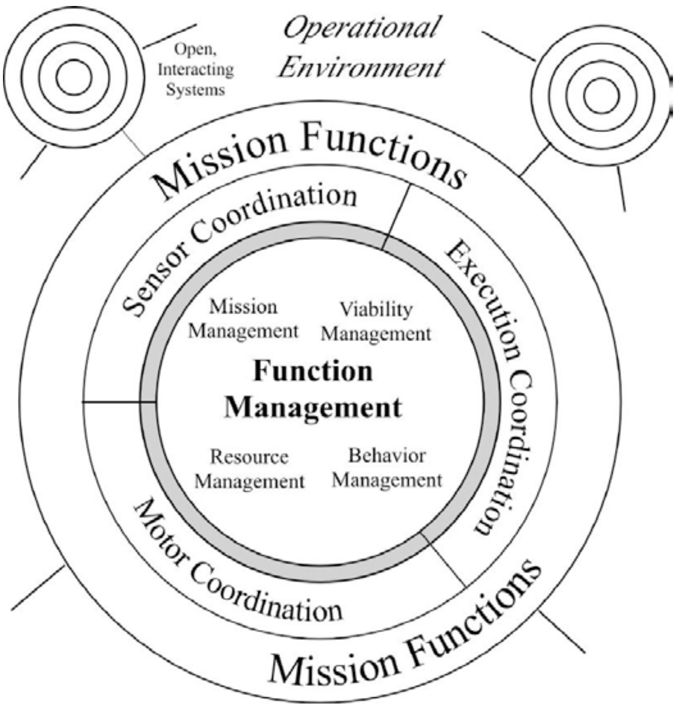

Figure 1. Open System: Mission Functions and Function Management. A view of an open system, interacting with other open systems, highlighting the discernable aspects of an open system – those that interact directly with other systems in the environment. Mission Functions are those engaged in pursuing the mission. Many mission functions may be active at any time, and these may be coordinated by sensor, motor and execution coordination, part of Function Management, as shown. Less apparent from the exterior, but nonetheless organizing, arranging, managing, etc., is internal Function Management, sustaining the continual exchange of material, energy and information with the environment, and actively pursuing missions. For some open systems, there may be Behaviour Management, indicative of thoughtful, considered, even intelligent actions and responses to stimuli.

Figure 1 illustrates this relationship conceptually. In the figure, an open system is seen in context, interacting with, and adapting to, other open systems in some environment. Mission functions are likely to evince activity in pursuit of mission, of purpose, and of striving to attain goals. Less in evidence, but nonetheless real, must be the 'internal functions which organize and coordinate the mission functions. Perhaps even less in evidence from the outside of the open system are the many functions which maintain the system in a viable state — the basis, foundation or substrate on which the various functions and processes – internal and mission – act.

Figure 2 illustrates mission management activating and coordinating mission functions, to create emergent purposeful behaviour, i.e., behaviour of the whole as it acts, interacts with, and adapts to, other systems in the environment – so interchanging information, energy and material with its environment.

Conceptually, both figures could apply to any open system, including natural systems such as a person, and manmade systems such as a plane, a ship, an enterprise, an industry, an economy, etc.

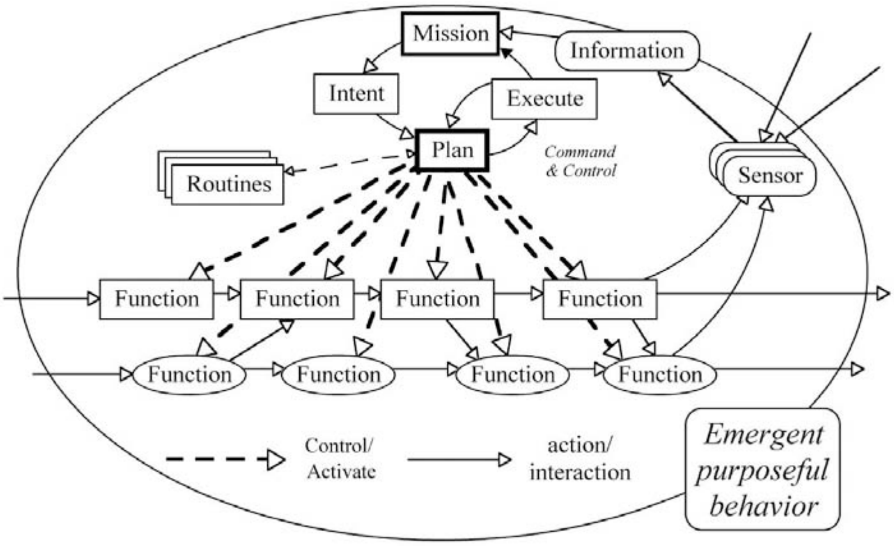

Figure 2. Open Systems: Orchestrating Mission Functions.

Generic Reference Models for Open Systems

The deductions made above can be brought together into a so-called reference model – in this instance, part of a Generic Reference Model (GRM) – which identifies functions that must exist and act within any open system.

Function Management

Figure 3 shows the Generic Reference Function Model, which represents:

- **Mission Management** at the top, interacting with an external operation environment, from which information is collected to inform a decision-making process which determines impending and ongoing mission activities
- **Resource Management** at the bottom, interacting with an external resource environment, distributing necessary resources to support internal processes and functions, and progressing the flow-through of materials, from inflow to outflow
- **Viability Management** in the centre, which supports the continuing capability of the open system, whether or not it is actively engaged in some mission, or missions.

Although not shown in this figure, there are interactions between the three functional aspects: Synergy, for instance, an aspect of Viability Management, identifies with interconnecting all the processes within both Mission and Resource Management, and indicates that the various internal parts of the system have complementary variety, such that they can cooperate and coordinate their activities.

Homeostasis, or dynamic equilibrium maintained through a balance between inflows and outflows, may refer to a wide range of materials, sources of energy, and even, perhaps, categories of information. For instance, in a factory-as-an-open-system, it could refer to the maintenance of necessary skill levels, as personnel leave and new staff are recruited, inducted and, perhaps trained 'on the job'… or the continuing inwards supply of parts to be assembled into complete products constituting the corresponding outflow…

Figure 3. GR Function Management Model

Survival features relate to the open system *per se* and to the 'external' threats within its operating environment. Survival essentially involves either avoiding threats or dealing with them 'head on.' Survival features and functions are seen in context – a benign environment might require none; a hostile environment might require camouflage, defensive weapons, armour, damage repair facilities, etc., as in the case of, say, a naval destroyer operating in hostile waters. The survival features that appear in a particular open system design will relate to the environmental threat on the one hand, and the intent of the design to survive that threat on the other…

Maintenance interacts with the other functions. For instance, the processes that constitute Mission and Resource Management would be subject to failure, and would necessitate maintenance. So, too, would the interconnections that facilitate synergy…

Behaviour Management

A reference model of Behaviour Management is more problematic. The ability to manage behaviour is generally regarded as thoughtful, and indicative of intelligence. Descriptions of thought processes and of intelligence are, at best, arguable. Even the experts, iconic researchers such as Freud and Jung, could not agree how the human mind – or any other mammalian brain – 'worked' – if that is even the right work.

However, Jung's pioneering work in particular has given some ideas that might contribute to a model of *choosing* response to stimulus. Jung, in particular, considered the behaviour of groups of people, as well as of individuals, which suggests that his models and insights may contribute to a more generic approach. Fortunately, a Behaviour Management Model does not have to represent thinking, or behaviour as such, but instead addresses the features that would reasonably be expected to occur in any system capable of *controlling*, or *managing*, its behaviour.

Figure 4 is a simple GR Behaviour Management Model: it does not represent behaviour, *per se*, but instead the *management* of behaviour. Even then, it may at first glance appear complicated. A stimulus enters at left, to the area labelled Cognition. Here the stimulus is 'recognized' and interpreted in context. This implies that there may be some record, register, or memory of stimuli, against which a particular stimulus can be compared. If a stimulus is recognized, then its source, meaning, and implications may be recalled from memory.

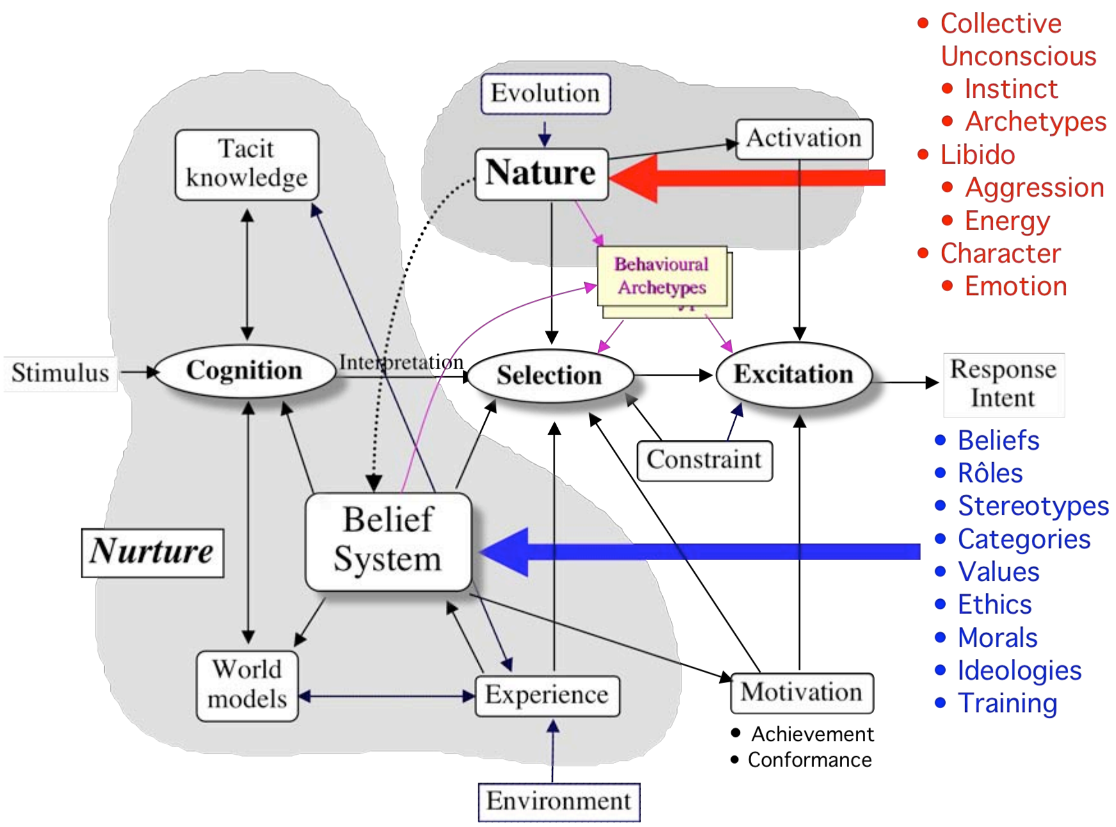

Figure 4. GR Behaviour Management Model

Cognition is 'fed' by Tacit Knowledge, World Models and Belief System, all shown as being nurtured, i.e., learned:

- Tacit Knowledge is 'low-level' knowledge, knowledge of simple, everyday things: grass is green, iron is heavy, this is food; that is *not* food – and so on. (A human's tacit knowledge is vast, much of it having been learned by the age of five.)

- World Models are representations (*Weltanschauungen*) of how particular 'worlds' work. For example, a helicopter hovers with the rotor uppermost – if a helicopter were seen hovering inverted, it would jar with World Model… suggesting a misperception, conflict or issue.
- Tacit knowledge 'informs' World Models, such that together they create abstract models of complex and complicated situations and scenarios to serve as perceived context and rationale for interpreting stimuli, and for confirming the rationality of beliefs.

A Belief System is an individual, or group, view of 'how the world works,' how things ought to work, perhaps. Beliefs can provide simple explanations of complex situations, issues or problems that may be invalid, but which nonetheless satisfy the believer. If experience supports the believer's interpretation, then the belief will be reinforced.

The Mayans may have believed that the Sun would rise only if they sacrificed a living human heart to their god. Every time they sacrificed, the Sun did indeed rise; so reinforcing the belief to the point that *not* to sacrifice may have become unthinkable.

A stimulus, then, is interpreted in *perceived* context, and on the basis of belief, and is passed to a process in the model labelled Selection (of behaviour). 'Selection' focuses Nature, Belief, Experience, Constraints and Motivation, to select a particular behavioural response from among a range of Behavioural Archetypes. 'Nature' might be thought of as the 'base creature' that, in this context, reacts quickly to stimulus as reflex, or knee-jerk; speed of response may be a survival feature. Motivation, Belief, Experience and Constraint come together to consider the advisability, and likely impact, of different behavioural responses in the light of perceived current situation and experience, to choose a particular behaviour; which may then override and suppress the immediate knee-jerk response before it happens.

The last process in the central sequence is Excitation, which identifies the various mission functions corresponding to the chosen behaviour, so constituting the behaviour response. Behaviour Management may thus redirect Mission Management; may modify or redefine Objectives, Strategy and Mission.

The GR Behaviour Management Model purports to identify features and functions that will appear in any open system that may be seen as 'thoughtful,' and which can produce 'considered responses' and 'intelligent behaviour.' How is all this realized in real, man-made systems? Sociotechnical systems may have an individual, or group, at the focus that incorporates all these features. A military command & control system might be organized into individuals and groups which:

- develop situation awareness
- assess situation
- identify threats & opportunities
- identify resource constraints
- set objectives
- strategize to achieve objectives

- plan missions
- initiate & manage operations
- etc.,

On the other hand, a corporate management group might perform similar activities under quite different headings, while individuals may perform some of these activities subliminally – or take situations for granted, omit some steps, plan 'on the fly,' and so on…

The GR Behaviour Management Model does not, then, represent any *de facto* organization for behaviour management. Instead, it indicates the purposeful, underlying processes that are likely to be occurring. It is for a systems designer, perhaps, to instantiate these underlying processes in organization, function, interaction and structure…

Bringing the GR Model Aspects Together

In discussing the GR Mission, Resource, Viability and Behaviour Management Models, it may be tempting to think of them as separate. They are, however, contemporaneous aspects of the one entity – the open system – and cannot sensibly be viewed in mutual isolation, either from each other or from their environment. It is sensible, therefore, to view them as one. Figure 5 shows such a view, in layered form, partially instantiated, with the centre panels showing Function, Behaviour and Form Management Models from top to bottom, with Resource and Viability Management Models at left and right. The Form Model concerns itself with the internal structure and tangible systems that, *inter alia*, give substance to the mission functions, that will be managed by the other layers. Form is also concerned with configuration: open system architecture, redundancy, boundary, mass, volume, shape, storage, communications, memory, sensors and displays, effectors and controls, etc., etc.

The layered model of Figure 5 is bare: it does not illustrate, for example, the route by which resources flow to support processes, the interconnections that enable synergy, cooperation and coordination, the needs of maintenance to detect defects and failures, the means of supplying replacement parts, how and where energy is stored, and so on. All of these are features that will be inserted by a systems designer, using the layered model as a reference, template or substrate, on which to superimpose the missing features, interconnections, functions, etc., to create a comprehensive systems design.

Such a full design can be simulated as a whole, acting and interacting with, and adapting to, other systems in their environment. Such simulations have the potential to reveal limitations in the design, to anticipate counterintuitive behaviour, and to improve design so that the real system, when created, has an improved prospect of operating, interacting and behaving as the designer intended, in the real operational environment.

How to go about conceiving systems solutions to complex problems and issues is another dilemma. However, the concepts and models of open systems offer the would-be systems designer/architect a reasoned target at which to aim, one that hints at the extent and content of the design challenge.

Derek Hitchins **August 2008**

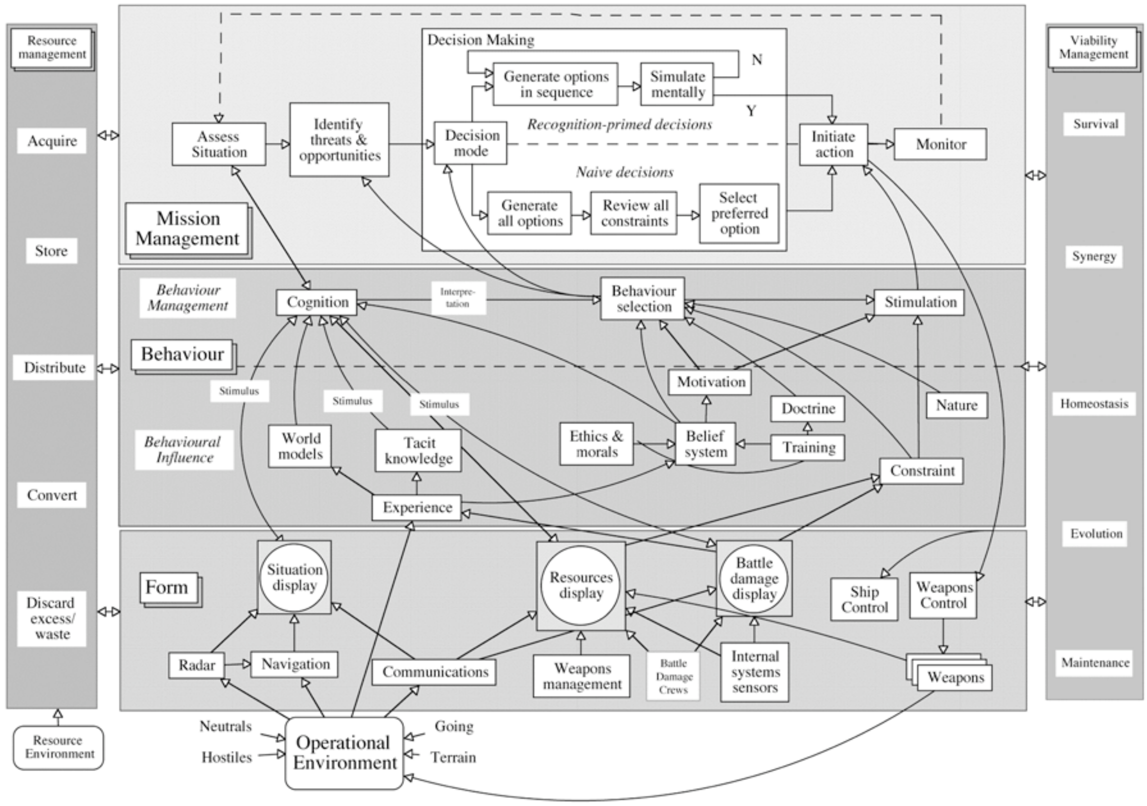

Figure 5 Layered GRM, partly instantiated, for an amphibious Naval Combat System…