

# A Theory of Enterprise Command and Control

Jay S. Bayne

*jay.bayne@metacomsys.com*

**Abstract** – The theory of Enterprise Command and Control (EC2) concerns application of systems science (esp. cybernetics) to the real-time, network-mediated, adaptive and collaborative processes of command (decision) and control. EC2 provides a logical and technical framework for integrating concepts and requirements for network-centric operations within and among commercial enterprises as well as the departments and agencies of the U.S. Federal Government, especially its Departments of Defense and Homeland Security. The term “command and control” refers to governance of tactical and operational activities (e.g. logistics) in military force projection and in civilian domains “decision and control” of enterprise operational (e.g. supply chain) activities. The theory presented here defines and employs the term *enterprise C2* (EC2) to management activities in both domains. The theory is concerned with real-time enterprise governance and its requirements for a service-oriented C2 architecture (C2/SOA) capable of improving interoperability between and among interdependent enterprises, business units, departments and agencies, especially within the U.S. Defense Department, the Military Services and allied agencies (governmental and non-governmental, foreign and domestic). Improved interoperability, aided by GIG-mediated net-centric EC2 services, derives from improvements in institutional efficiencies, defined capabilities, speed and agility, collaborative (joint) planning, synchronized execution, shared resource management, group policy compliance, shared situational awareness, improved predictability of effects and scale economics.

**Index Terms:** Command and Control, Cybernetics, Enterprise Systems, Federated Systems, Network-Centric Operations, Real-time Systems, Unified Command

## I. INTRODUCTION

Our theory of *Enterprise Command and Control* (EC2)<sup>1</sup> is concerned with effective governance systems supporting *value production* in distributed *intelligent enterprises*<sup>2</sup>, about increased

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Dr. Bayne (SM IEEE, SM ACM) is President of Meta Command Systems, Inc (formerly Echelon 4 Corporation), 1045 W. Glen Oaks Lane, Suite 202, Mequon, WI 53092-3477 USA  
+1.262.240.2956; www.metacomsys.com

<sup>1</sup> The paper summarizes elements of a general theory described in the author’s to be published text *Theory of Enterprise Command and Control*, completed in October of 2005 [1].

institutional awareness and its ability to facilitate more effective, responsive and sustainable unilateral and multilateral action. Additionally, EC2 is about improved integration of human prerogatives and distributed computational systems that, acting in concert, are competent to establish and maintain viability<sup>3</sup> of large-scale, dynamic and increasingly complex enterprise systems. The theory maintains that intelligent enterprises are not possible without a formal EC2 infrastructure, one based on a *unified command and control framework*. Such an infrastructure necessarily sits above, yet intimately depends upon, underlying information services such as *Enterprise Resource Planning* (ERP), the *Global Information Grid* (GIG) and its attendant *Network-Centric Enterprise Services* (NCES). To this end, the theory of EC2 offers a framework for enabling collaborative, distributed and time-critical *service-centric operations*.

Our thesis is that definition, development and deployment of interoperable service-centric EC2 systems requires a more formal degree of standardization. In response, we define an EC2 framework comprising six key elements: i) a coherent enterprise model, ii) command (actor) interfaces, iii) command services, iv) control services, v) performance measurement services and vi) interfaces to legacy operational systems. In this restricted paper we introduce the enterprise model (i) and its attendant command (iii) and control (iv) elements.

Standardization necessarily requires a more comprehensive theory of C2 than provided by more *ad hoc* models present in traditional and typically social institutions of governance. Our theory postulates that without higher and more robust forms of enterprise automation and control, current institutions of government, commerce and society will be progressively challenged (constrained) in their individual and collective actions<sup>4</sup>, especially in an increasingly complex, interdependent and interactive world. The goal of a successful theory of EC2 is to move the frontier of enterprise systems conception, design, deployment and operation from its current communications (net-centric) and information sharing (*data-centric*) orientations forward to a theory predicated on coordinated (*service-centric*) operations.

Today the DOD emphasizes communications (i.e., GIG Transport) and data centrality (e.g., information repositories) as cornerstones of its integration efforts. The ability to interconnect arbitrarily large numbers of distributed and diverse

<sup>2</sup> The term *enterprise* refers herein to an arbitrary unit of organization accountable for production of a quantifiable measure of value.

<sup>3</sup> An enterprise is *viable* to the degree it maintains its value propositions (its capabilities) over time and within the federated contexts in which it operates.

<sup>4</sup> Witness, for example, difficulties encountered in collective responses to natural (e.g., Katrina Hurricane) and terrorist (e.g., 9/11) disasters.

information sources is a critical and logical necessity, but as a basis for unified command, it is insufficient. Large quantities of volatile context-sensitive information streaming in (whether pushed or pulled) from various geographically distributed sources are as likely to confuse a commander's assessment of a given situation as to clarify it, clouding his/her ability to act.

In addition, there are important collateral issues of information pedigree, timeliness, precision, semantics (ontology) and a host of other matters that connectivity and data access cannot resolve. These issues properly belong to the domain of the EC2 *processes* (i.e., net-centric services) that ultimately consume, interpret and utilize the data in support of human actors. These issues define the *context* in which EC2 processes unfold in time and space and the missions of the organizations that rely on results they provide.

In short, we believe that communications networks and their ability to support an abundance of data publishers and subscribers have a critical but supporting role in enabling effective and collaborative enterprise C2. This view motivates the next developmental phases of institutional (e.g., military enterprise) governance systems. It argues that the focus needs to be on the *assimilation* and effective *utilization* of information within and among communities of allied enterprises. This is the domain of distributed governance, of institutional and collective awareness, and the essential *processes* of enterprise C2. It is the domain addressed by our general theory of EC2.

## II. OBJECTIVE

The principal objective of this paper is to outline key elements of a broadly applicable (i.e., domain neutral, logical and scalable) *unified theory of enterprise command and control* consistent with DOD's *network centric warfare* (NCW) and *force transformation* and DHS's *Homeland Defense* objectives. This document introduces key elements of the theory. We assert that in its entirety it is capable of serving as formal guidance to subsequent GIG-compliant architectural specifications leading to the design, development, acquisition and deployment of individual C2 applications (services) that, once in operation, are able to contribute individually and in ensemble to a *unified command structure* (UCS). Unified C2 systems must be suitable for sustained *network-centric operations* (NCO) that provide *core C2 services* to DOD and DHS agencies.

## III. REAL-TIME GOVERNANCE

The fundamental requirement motivating our C2 reference model involves the *collaborative real-time governance* of an enterprise. A *real-time enterprise* is one whose essential EC2 activities, within probabilistic bounds, achieve specific completion-time requirements for its own internal (unilateral) and collaborative external (multilateral) activities. This feature motivates and distinguishes our approach from more traditional non-real-time (i.e. *ad hoc*) C2 systems. More specifically, a core requirement for what follows is the management of end-to-end timeliness of decision and control actions, especially in

situations where collaboration and synchronized action are critical.

## IV. ENTERPRISE – THE OBJECT OF C2

The theory defines enterprise command and control, be it military or civilian, governmental or commercial, public or private, as *governance of the processes of value production*<sup>5</sup>. The mechanisms of value production, and therefore the object of EC2's attention, includes operation of an enterprise, an abstract or virtual machine<sup>6</sup> referred to herein as a *value production unit* (VPU). A VPU represents an object (service) encapsulating a well-defined and manageable *capability*<sup>7</sup>.

As diagrammed in Fig. 1, a VPU is a *mesosynchronous*<sup>8</sup>, system functioning continuously at the intersection of a vertical *command axis* (accountability, superior-subordinate network, or asset chain) and horizontal *production axis* (effects, peer-peer, production network, or supply chain). This two-dimensional environment defines the domain, or operating context, of enterprise governance and its supporting EC2 services. The flow of information defining orders, resources, events, situations, policies, plans and effects on each axis intersect at the central *management core*<sup>9</sup> of a VPU, requiring competent information fusion, analysis, proactive and reactive planning, risk assessment, compromise and decision among time dependent and often conflicting demands. This is the essence of command, where value production emerges from the process of decision and control. Table 1 summarizes the primary function of each interface on the two primary axes of a VPU.

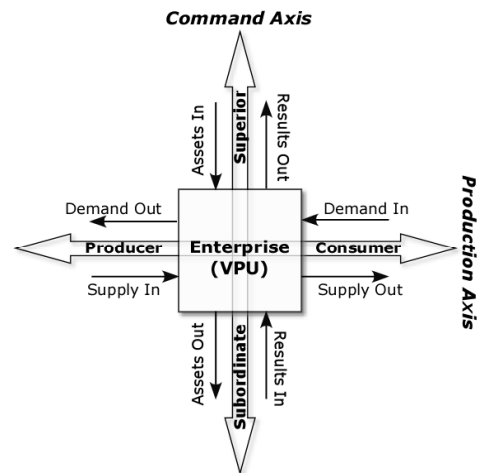


Fig. 1 – Enterprise Value Production Unit

<sup>5</sup> Value is defined in terms of specific *value propositions* associated with enterprise missions, goals and objectives.

<sup>6</sup> A *virtual machine* is any non-physical construct that functions (operates) within the confines of another real (physical) or virtual machine

<sup>7</sup> A *capability* is a quantifiable means of accomplishing a specific task.

<sup>8</sup> A *mesosynchronous* system operates in the middle ground between purely synchronous and purely asynchronous timing considerations.

<sup>9</sup> The *management core* is represented physically by a "C2 enclave" or "C2 bridge" where commander and officers gather to govern an enterprise and its mission(s). By analogy, an enterprise is a *ship*, the command staff is the *flight crew* and the C2 enclave is the *flight deck*.

Fig. 2 diagrams an enterprise VPU along with its immediate command and production axis neighbors. It also introduces a naming (indexing) scheme that supports the requirement that each enterprise be uniquely identifiable. The focus of the figure is the central enterprise designated  $VPU_{j,k,l}$ . Index “j” identifies the operational domain (i.e., federation, or community of interest), “k” denotes the horizontal position in the federation’s production network and “l” represents the location in its vertical command network. The enterprise VPU has a single superior designated as  $VPU_{j,k,l+1}$  and potentially many suppliers designated as  $VPU_{j,k-1,l}$ , customers designated as  $VPU_{j,k+1,l}$  and subordinates designated as  $VPU_{j,k,l-1}$ . Notice in the figure that each supplier, customer and subordinate VPU may actually represent (i.e., be a proxy for) multiple active neighbors. This detail is important technically, but we will not labor on its relevance further.

Table 1 - Enterprise VPU Interfaces

Axes	Port Name	Port Function
Command Axis	Assets In	Acceptance and assimilation, according to service-level agreements (SLA), of allocated assets and tasking orders from superior VPUs
	Returns Out	Production of returns on value produced by previously allocated assets or issued commands; requests for allocation of additional assets; clarification requests on issued tasking orders
	Assets Out	Issuance of assets and tasking orders to subordinate VPUs with expectations for a time-bound returns of value produced
	Returns In	Acceptance and assimilation of returns and receipt and evaluation of requests for new asset allocations or readiness for new commands from subordinate VPUs
Production Axis	Demand In	Acceptance and assimilation, according to SLA, of demand orders for goods or services from upstream consumer (client) VPUs
	Supply Out	Fulfillment of previously received demand orders to downstream consumer (client) VPUs
	Demand Out	Issuance of demand orders for goods or services to upstream producer (server) VPUs
	Supply In	Receipt and acceptance of fulfillment related to previously issued demand orders for goods or services from upstream stream producer (server) VPUs

## V. FEDERATED “COMMUNITIES OF INTEREST”

Enterprises generally participate in more than one *federation, context or community of interest* (COI). Federations are alliances formed by members striving to develop and exploit, for individual and mutual benefit, higher-order<sup>10</sup> value propositions. The role of VPU governance in balancing these

<sup>10</sup> A higher-order value proposition is one that benefits but transcends any given member’s objectives, requiring capabilities formed from member collaboration.

self- and community-serving value propositions is critical to the viability of both individual enterprises and the federations in which they operate.

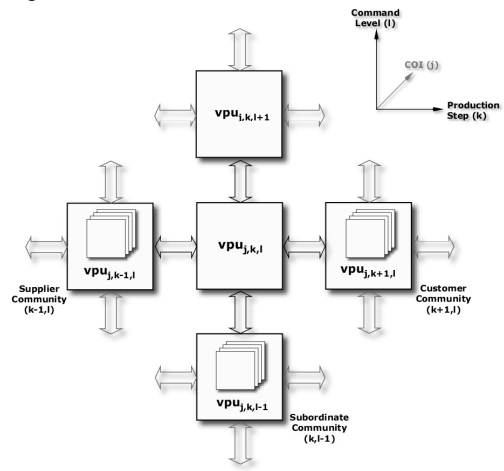


Fig. 2 – Enterprise (VPU) Structure

According to Jeffersonian principles, the so-called axioms of free society<sup>11</sup>, federation members are semi-autonomous and self-regulating. Their designs are required to allow them to be 1) viable and uniquely identifiable members of one or more federations, 2) governed by federation laws (policies), and 3) to provide their individual contributions (capabilities) to the coherent ensemble behaviors that characterize missions, goals and objectives of the federated enterprise as a whole.

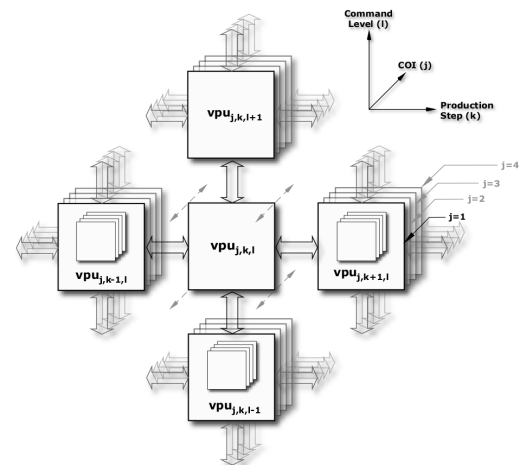


Fig. 3 – Enterprise C2 Space

Membership in multiple federations effectively adds a third (z-axis) dimension to the VPU model shown in Fig. 2. Fig. 3 expands the model, defining a VPU’s operating context, referred to as “enterprise C2 space.” The central enterprise is uniquely identified as  $VPU_{j,k,l}$ . As depicted, it holds membership in four COI, numbered  $j=1$  through  $j=4$ . In order for the central VPU’s

<sup>11</sup> <http://www.lewrockwell.com/vance/vance17.html>



The lateral flow of information through the SAS stage passes through three primary functions. A *filter process* searches information (e.g., subscriptions)  $\{i\}$  for occurrence of significant events  $\{e\}$ . A *triage process* subsequently correlates these event lists in order to recognize new or changes in situations  $\{s\}$ . Finally, an *analysis process* converts new or evolving situations into candidate responses in the form of courses of action (COA)  $\{c\}$ .

### PLAN GENERATION SERVICES

Two functions define plan generation; they are responsible for policy compliance and resource allocation to proposed courses of action, respectively. COA enter the plan generation stage where they are analyzed by a *policy process* (*pp*) that, utilizing context- (federation- or COI-) specific *policy*<sup>13</sup> database, produces zero or more policy-compliant plans of action (POA)  $\{a\}$ . Then, utilizing a *resource*<sup>14</sup> database containing the status of available resources, the *resource process* (*rp*) converts the POA into zero or more (e.g., a primary and back up) executable plans of record (POR)  $\{p\}$ .

Courses of proposed action  $\{c\}$  arrive at PGS in an “unqualified” state. They are generalized recipes for action based on the sequences of events unfolding in the VPU’s environment. COA have yet to be qualified by the context of current operating policies (e.g., rules of engagement) and they have yet to be assigned the necessary resources required for action. PGS is responsible for policy compliance and resource allocation.

### PLAN EXECUTION SERVICES

Plan execution services (PES) of a VPU include two primary processes. Policy-validated and resource-allocated plans of record  $\{p\}$  enter at the left in Fig. 4, arriving first at the *command process* (*cp*). Here they are reviewed, scheduled and authorized by the VPU commander, emerging as formal *tasking orders*  $\{t\}$ . Tasking orders are given to the *execution process* (*ep*) for assignment, activation, execution, synchronization and monitoring.

## VII. COMMAND PROCESSING SERVICES

The enterprise command structure, diagrammed in Fig. 5 and enumerated in Table 2, derives from four decades of cybernetics [8, 9], systems theory [10], operational research [11] and theories of human consciousness and neuroanatomy [12]. Its role in modeling consciousness and adaptive behavior is documented in [13]. The figure diagrams relationships among the principal VPU actors responsible for the conduct of enterprise operations.

Enterprise governance structures exist throughout a federated system [14]. Each VPU contains a command structure

<sup>13</sup> A *policy* is a set of constraints that govern action with a given federation (*policy domain*).

<sup>14</sup> A *resource* is any consumable or serially reusable asset (men and material) that may be used in “resourcing” pending plans of action.

capable of self-governance. Command structures, typically collocated in mobile or fixed command “enclaves,” are actor teams that operate semi-independently with a high degree of autonomy.

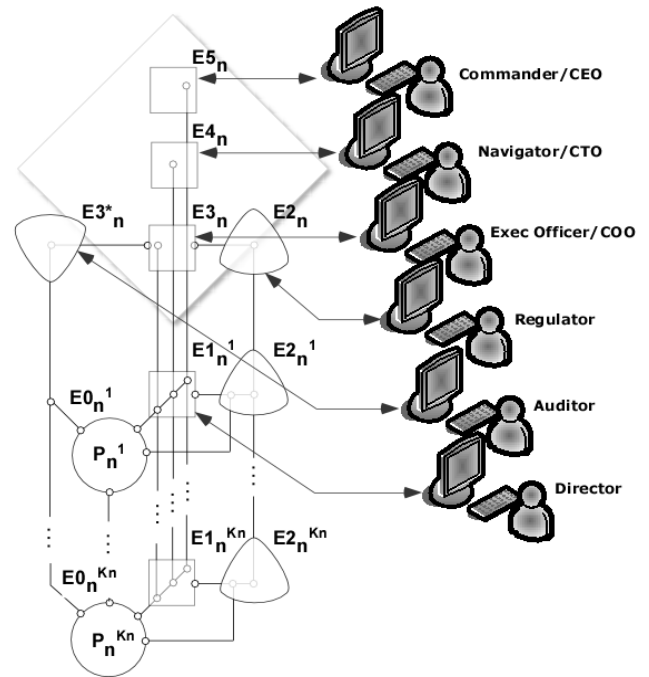


Fig. 5 – EC2 Command Structure

These per-VPU actors include:

- A single commander or command staff (aka, supervisor, director, or manager denoted as echelon five, E5) representing the highest authority within the VPU
- A single navigator or planning staff (aka, planner-analyst, denoted as echelon four, E4) responsible for modeling, planning and analysis functions (e.g., adaptation and change management)
- A single operator or operations staff (aka, operations executive, denoted as echelon three, E3) responsible for the execution of authorized plans of record

Fig. 6 shows a sequence of embedded commands, each governing a successively lower level of the enterprise. At each level, the three primary actors (E5, E4 and E3) are contained in a rectangle (rotated 45°) to emphasize both their leadership role and the nested or recursive nature of their position within the ECS structure.

The figure shows the Level “n” organizational unit at the left. The central figure shows the Level “n” subordinate enterprises at Level “n-1” (i.e., P<sub>n</sub><sup>1</sup> through P<sub>n</sub><sup>K<sub>n</sub></sup>), with each symmetrically defined and rotated 45°, as are their respective Level “n-2” structures diagrammed at the right. This sequential nesting is a key feature of the ECS model within our theory of C2. Command concepts are coherent, structured and uniformly

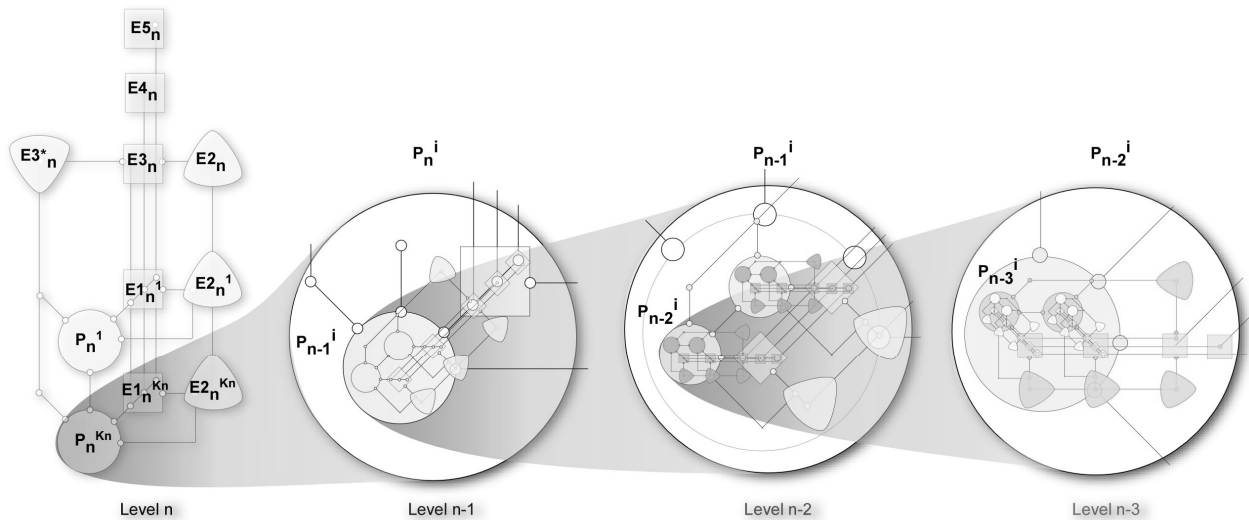


Fig. 6 – Command Axis Recursion (Accountability Hierarchy)

applicable throughout the enterprise accountability hierarchy. This recursive property is the foundation for accountability and the collaboration framework necessary to reinforce it.

As noted in Fig. 5 and Fig. 6, a given VPU may contain “ $K_n$ ” subordinate processes within its authority at Level “ $n$ ,” labeled  $P_n^1$  through  $P_n^{K_n}$ . In the EC2 model outlined here, the minimum number of such processes is two ( $K_n=2$ ), one for value production along the command axis and one governing value production along the production axis.

Table 2 - Principle EC2 Actors

Label	Services	Roles & Responsibilities
E5	Command	Mission Goals & Objectives, Policy & Command Authority
E4	Analysis/Planning	Modeling, Situation Assessment & Plan Generation
E3	Operations	Plan Execution & Capability Management
E3*	Audit	Program & Process Performance Assessment
E2	Regulation	Plan (Task) & Resource Synchronization
E1	Direction	Plan (Task) Execution Management
E0/P	Process	Embedded [Value] Production Process

In addition to, and in direct support of, the three principal EC2 actors, there are:

- Two or more subordinate directors (denoted as echelon one, E1) of the internal functional capabilities (embedded VPUs, at least one for the asset chain, and one for the supply chain)
- Regulators (denoted as echelon two, E2) responsible for the synchronization of subordinate VPUs in their execution of coordinated tasks that must rendezvous in

time or synchronize on shared serially-reusable resources (providing “excitatory” or stimulus controls)

- An auditor (denoted as echelon three star, E3\*) responsible to E3 for continuously measuring and reporting on the performance of subordinate VPUs (providing “inhibitory” or damping controls)
- Two or more embedded value production processes (denoted as echelon zero, E0 or  $P_n$ ) are managed by their respective E1 actors

The ECS loop defined on the right side of Fig. 5, labeled E3-E2-E1-E3, provides the “excitation pathway”<sup>15</sup> responsible for initiation and amplification of activities in subordinated processes. The loop on the left side, labeled E3-E3\*-E0-E1-E3, is the “inhibition pathway”<sup>16</sup> responsible for restraining or attenuating activities in subordinated entities.

This approach to defining EC2 capabilities offers several benefits. First, the recursion creates a structure whereby applications (software-based C2 services) designed for one level of command can, in principle, be deployed at levels above and below it in the command hierarchy. Second, a commander trained to use EC2 services a one level can ascend (descend) to the next level of command and be at home with the concepts and mechanisms of C2 at that level. Third, EC2 systems whose implementations are validated at a given level of command are in principle valid at other levels. Fourth, documentation and training prepared for a given level are relevant at other levels with minor adjustments.

### VIII. GUIDING EC2 INFORMATION FLOW

Information flows through the three control processing stages (seven processes) under the guidance of command actors and their respective EC2 applications (net-centric services).

<sup>15</sup> Aka, the *sympathetic* loop, as defined in neuro-anatomical systems

<sup>16</sup> Aka, the *parasympathetic* loop, as defined in neuro-anatomical systems

Table 3 summarizes the end-users (command) and the application services required for this interactive guidance.

Table 3 – EC2 Command Applications (Services)

Name	Application Services	End-User	Associated Database
ModMan	Model management; maintenance of the VPU's world model and supporting simulation and training services	E4 Planner-Analyst	VPU and World Model DB, Historical DB
PlanMan	Plan management; maintenance of potential courses of action (scenarios); filtering, triage and analysis of input streams	E4 Planner-Analyst	Event Filter DB, Situation Pattern DB, and Response Scenario DB
RuleMan	Policy management; maintenance of policies ("rules of engagement") used to qualify potential courses of actions	E5 Commander	Rule (Policy) DB
AssetMan	Asset (Resource) management; maintenance of the state of and reservations for all shared resources	E3 Operator	Asset (Resource) status and reservations DB
SuperMan	Command management; plan/task authorization and course grain scheduling	E5 Commander	Command and CONOPS DB
OpMan	Operations management; plan/task execution; fine grain scheduling; synchronization; performance measurement	E3 Operator	Execution profile and status DB

## IX. CONCLUSIONS

We have outlined three key elements of a theory of enterprise command and control: 1) the object of governance, an enterprise; 2) a control services model providing for situation assessment, plan generation and plan execution and 3) a command services model defining the principle command actors, their relationships and supporting applications they require to be effective.

Several recent publications present related aspects of the EC2 theory introduced here. [15] discusses the *performance measurement services* (PMS), [16] outlines elements of the VPU software *object model*, [17] presents elements of *policy management* in the real-time regulation of enterprise behavior, [18] discusses the *scale free* nature of the command model and [19] applies the theory to the design of C2 systems supporting the DOD's *Joint Task Force* (JTF) concept.

## X. REFERENCES

A more comprehensive list of references related to the subject of EC2 requirements and theory, including those listed below, may be found at <http://www.echelon4.com/references.htm>.

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