

The Structure of Enterprise Systems

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1 Introduction

Our goal is to take a *systems engineering approach* to the design and development of service-oriented (SOA) software supporting distributed (sharable, secure, network-centric) enterprise systems. Service-oriented enterprise application systems require rational, scalable, widely applicable and verifiable models of enterprise operations, including identification of core (sharable) governance services and their structural dependencies. This paper provides a synopsis of a coherent *framework* for specification of the primary *structural* characteristics of viable enterprise systems, with particular emphasis on those command (decision) and control services that comprise a *unified governance structure*. For emphasis we focus our attention on *industrial* enterprises that possess a level of technical maturity in their production systems. As a point of reference, we highlight contemporary efforts to employ ANSI/ISA-95.00 and related national and international standards to integrate business-level enterprise resource planning (ERP) and plant-level production control systems.

The governance structure outlined below¹ is supported by four hypotheses about the nature of federated enterprise systems. They are concerned with 1) the structure of sovereign enterprises, 2) the structure of capabilities for exercising unilateral and multilateral control, 3) the structure of enterprise management (command actor) organizations and 4) the structure of their individual and collective performance measurement and analysis capabilities.

1.1 Hypothesis: Federated Enterprises Require Structure

In an internetworked world, sovereign (interdependent, self-governing, decentralized) enterprises, regardless of their size and mission and wishing to collaborate (interoperate), must present to each other formal and stable service-oriented *interfaces*. These interfaces constitute logical boundaries distinguishing an enterprise's internal (private) and external (public) capabilities. Under specific rules of engagement (policies, service level agreements), an enterprise's externally accessible capabilities provide services to other enterprises. Federations (interconnected and interoperable enterprises) are structured by the nature of their public interfaces and the externally valued capabilities they provide. This perspective leads to a model of enterprises as units of value production (VPU) that support formal structures.

1.2 Hypothesis: Federated Control Requires Structure

Effective collaboration among allied enterprises on situations of mutual interest require 1) shared *situational awareness*, 2) *cooperative planning* related to normalized (rationalized) policies and sharable assets and 3) *synchronized execution* and uniform performance assessment. Collaboration supported by these shared services establishes a *unified control structure*.

¹ The enterprise governance structure outlined here is the subject of and protected by US patent applications 10/678297 and 11/149965.

1.3 Hypothesis: Federated Command Requires Structure

Legal, ethical, environmental and economic accountability for actions taken by individual and federated enterprises through the exercise of unified control ultimately rests with human management teams (actors). Effective collaboration requires that actors in federated systems know and honor the roles and responsibilities of peers, superiors and subordinates throughout the federated structure. Decisions (commands) taken by actors in allied organizations ultimately have authority to the degree their roles are well defined and supported by formal actor interface specifications, specifications that define a *unified command structure*.

1.4 Hypothesis: Adaptation Requires a Unified Performance Structure

The effectiveness of actions taken (both positive and negative) through the exercise of unified command (decision) and control determines the performance of an enterprise, both alone and in concert with other enterprises. Performance is measured primarily in terms of how well the enterprise sustains (is aware, learns and adapts) its value propositions under demands exerted by changing conditions within and among federation members. Consequently, unified and shared performance measures are required. Shared performance metrics and assessment processes, associated with unified command and control services, define a *unified performance structure*.

In the following sections we discuss the implications of these hypotheses within the context of industrial (manufacturing) enterprises.

2 Industrial Enterprises

Contemporary industrial enterprise automation efforts rely on an enterprise reference model expressed in the ANSI/ISA-95.00.01-2000, ANSI/ISA-95.00.01-2001 and related standards². The model derives from a Computer Integrated Manufacturing (CIM)³ model originally developed at Purdue University, circa 1989, and extended under various community standards activities (e.g., MAP/TOP, ISA) over the next decade. Figure 1, depicting the role of the standard, shows at a high level of abstraction the two principle structural elements.

CIM Level 4 (L₄) Business Planning and Logistics services, typically based on transactional business process systems, are provided by integrated enterprise resource planning (ERP) applications such as provided by SAP and Oracle. Level 3 (L₃) Manufacturing Operations and Control services, typically associated with manufacturing execution and production resource planning (MES, MRP), provide a factory (plant) governance structure under which Level 2 (L₂) continuous, batch and discrete production controls operate. The ANSI/ISA-95 standards provide the syntax and semantics for transactions radiating from the center of the Figure 2, transactions defining connectivity and interoperation between Levels 3 and 4. Inter-level operation is defined in the original Purdue CIM model and is outlined in Appendix D of the ANSI/ISA-95.00.01-2000 standard.

²http://www.isa.org/Template.cfm?Section=Find_Standards&template=/Ecommerce/ProductDisplay.cfm&ProductID=7958, ISBN: 1-55617-727-5, approved 15 July 2000

³ Not to be confused with the XML-based Common Information Model, <http://www.dmtf.org/standards/cim/>

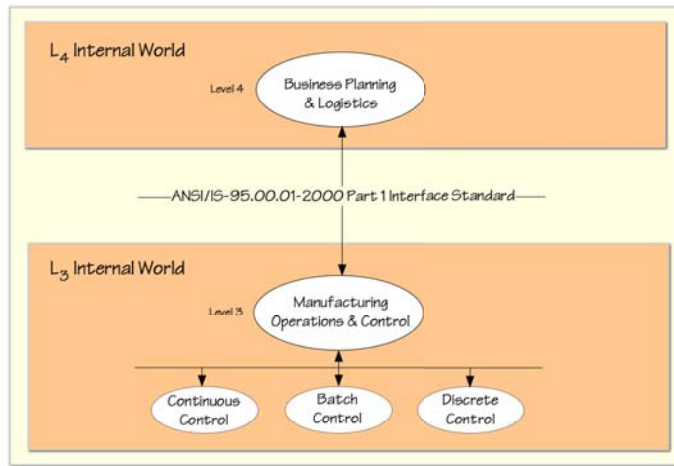


Figure 1 – ANSI/ISA Industrial Enterprise Integration Model

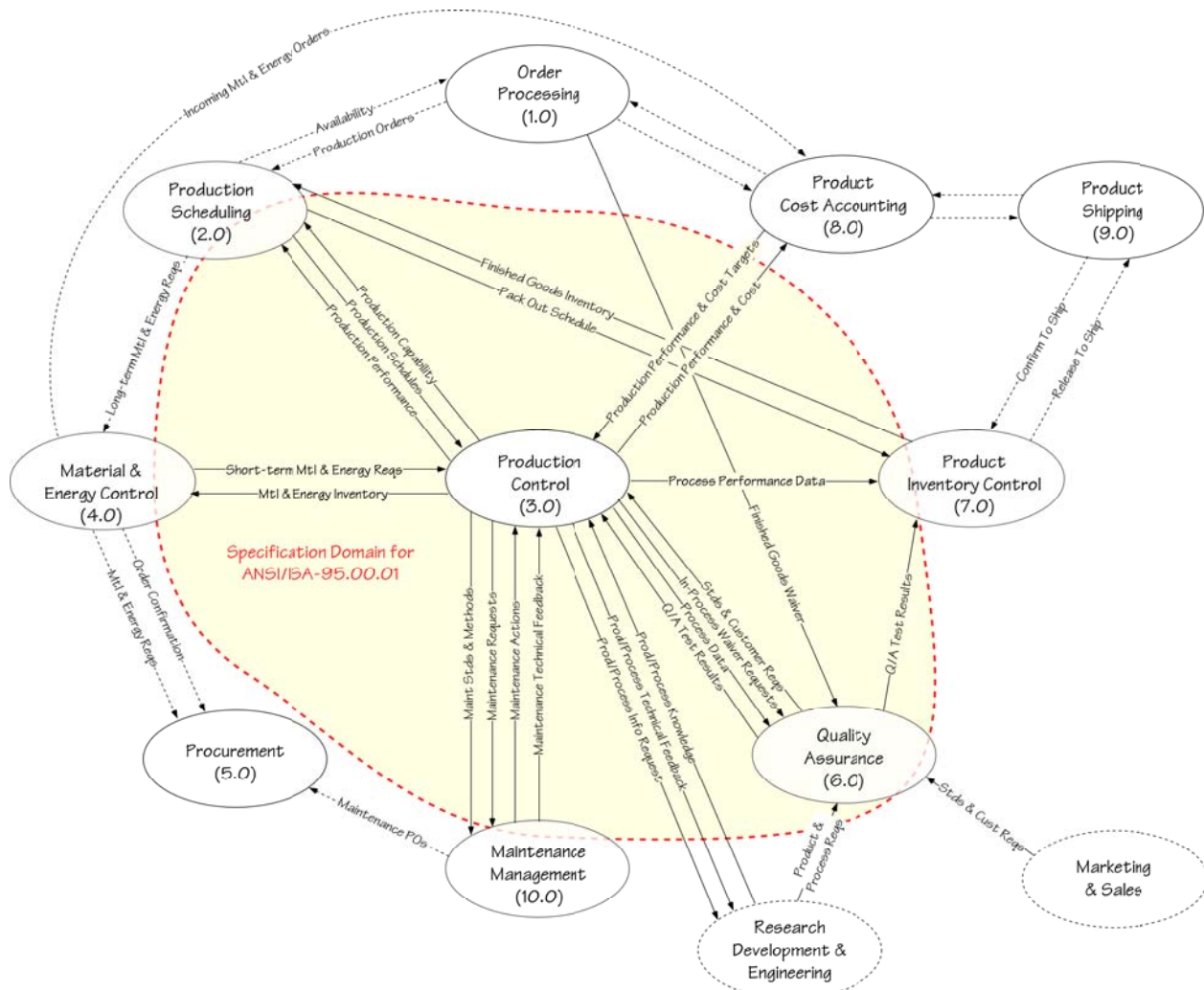


Figure 2 – Inter-level Production Management

Core operational elements addressed by the standard are within the dashed inner region of the figure. Arrayed around this central region are the principal Level 3 (MES/MRP) and Level 4 (ERP) functions. Solid lines connecting these elements in these two domains denote communications (transactions) among the services. Support for these transactions is the primary role of the object model defined in ANSI/ISA-95.00.01.

2.1 Modeling Framework

Figure 3 shows the dimension of the enterprise governance domain, expressing the natural hierarchy formed by the containment (embedding) of a subordinate operational system within a superior system. By use of color shading, the figure places the ANSI/ISA standard and its inter-level services within the modeling framework. As noted, the standard is focused on the interface between Level 2 and Level 3 systems, only indirectly addressing inter-level communications related to higher and lower levels of operation.

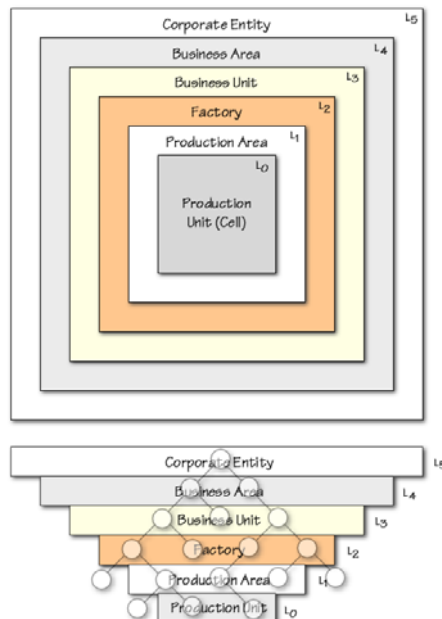


Figure 3 – Embedded (Nested) Control Domains

Figure 4 complements Figure 3 by describing the temporal nature of activities (and transactions) taking place at the various levels of enterprise operations. The figure shows typical event inter-arrival times and requisite planning horizons for command (decision) and control actions at each level. Together, these figures show that a natural accountability hierarchy arises as the basis for unified governance.

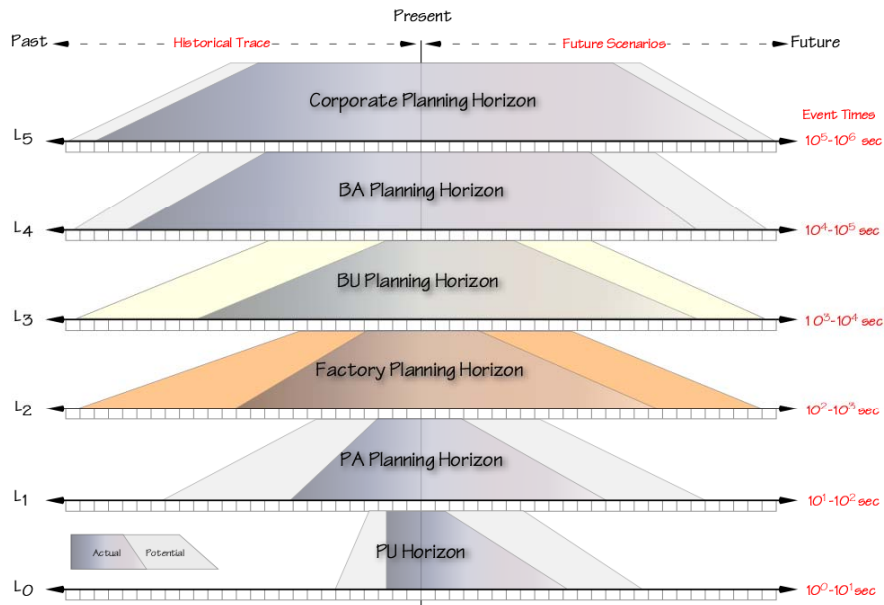


Figure 4 – The Nature of Inter-level Timing

2.2 Limitations of Contemporary Enterprise Automation Activities

Limitations of contemporary enterprise applications and the *ad hoc* integration efforts that bind them, including those related to factory and business unit interoperation, point to weakness in underlying concepts of enterprise governance. Such weakness presents barriers to development of SOA-based (network-centric) governance services and motivates our interest in defining a unified enterprise governance framework from theoretical and technical perspectives.

Limitations arise from several factors, including

- The typically non-proprietary general accounting (AR/AP, HR, sales) roots of transactional business applications
- The typically propriety analytical (physical, chemical, mechanical) roots of production control applications
- The typically social (transaction oriented, non-scientific) management perspectives of business administration practices
- The typically technical (process oriented, scientific) management perspectives of industrial engineering practices
- The limited (focused) requirements of applications and standards—primarily tactical in nature, market-oriented (end-use cases) and platform (e.g., database, operating system, network protocol and programming language) specific
- A slow and methodical consensus process underlying development of community standards among competing vendors whose offerings are proprietary (“closed”) in both architecture and implementation
- The relentless advance of technology development resulting in punctuated product life-cycles with functional requirements evolving at varying rates
- Continuous (re)integration efforts resulting from mergers and acquisitions of enterprises with disparate internal information systems and product lines

- Limited enterprise operational models encompassing both business and engineering concerns
- Limited command (management actor) models supporting a stable and reusable governance structure for guiding logical and incremental enterprise operating system development, at all levels of a nested enterprise
- Limited support for collaborative (federated, joint, cooperative, multilateral, inter-enterprise) decision and control
- Limited (typically financial), non-uniform or non-existent intra- and inter-enterprise performance metrics
- Isolated and incremental application budgeting, acquisition and implementation, with enterprise managements unable or reluctant to plan for integrated operations beyond isolated functions (e.g., production controls v. ERP transaction processing)
- Internally (intra-enterprise) focused solutions, with limited support for creation of enterprise interface capabilities that support set-up and take-down of federated enterprises
- Applications integration solutions focused primarily on communications and data sharing without sufficient concern for process (capability) sharing
- Limited consideration of and shallow investments in innovative approaches to outmoded business management concepts and practices
- Complexity of today's enterprises and limitations of human actors in maintaining awareness of and effectively reacting to evolving situations (ref. failures at Enron, Tyco, HealthSouth, WorldCom, etc)
- Limited training in university business schools for disciplined (technical) management of increasingly complex enterprises (i.e., with increasingly complex IT infrastructures)
- Increasing requirements for operational accountability (e.g., SEC reporting, Sarbanes-Oxley) in public-sector enterprises, at all levels of the governance structure
- Increasing cost of enterprise (IT) applications and the resultant need to amortize these costs across a wider population of users (reusability) over longer time frames (life-extension), all in the face of evolving enterprise mission and structure
- The fact that information technology (IT) is the label given to enterprise automation efforts—IT (an important infrastructural enabler) is at most a secondary consideration; the core issue is how best to support (enable) the evolution an enterprise through more effective governance

These are a few of the important issues facing enterprise management teams as they struggle to operate more effectively in increasingly global, environmentally conscious and competitive markets. At the heart of these challenges is the need to be clear (disciplined) as to the roles and responsibilities of enterprise managers, their relationships to one another and the functioning of systems and services deployed to support their responsibility to govern collectively in the face of uncertainty. On the operational level, sharing, scale economics, agile development and life cycle management are hallmarks of tactical advantage. On the conceptual level, systems science (macroeconomics, cybernetics, game theory) and a solid theoretical basis for value production are hallmarks of strategic advantage.

The limitations listed above in no way negate the importance and value of current application systems and integration efforts, but they do point out how far we have to go to develop more unified enterprise governance capabilities, especially services that support adaptive, interactive and collaborative management systems. To that end and in support of a public dialog on the matter, we offer the following enterprise reference model (ERM).

3 Enterprise Reference Model (ERM)

Two fundamental and complementary objectives motivate development of an *enterprise reference model* (ERM), both predicated on the idea that an enterprise is an object with a defined boundary separating its internal and external operations. To remain viable in the face of competition and environmental change, an enterprise must support adaptation through collaboration among

1. Internal organizations, to enable continuous process improvement of services offered by its private (internally visible) capabilities
2. External organizations, to enable continuous process improvement of services offered by its public (externally visible) capabilities

Independent and coordinated improvements on both sides of an enterprise's boundary are required for a number of compelling reasons, including its ability to achieve and maintain awareness of situations related to changes resulting from

- Its own capabilities resulting from alliances, mergers and acquisitions
- Incorporation of innovations in processes and technologies
- Global product markets
- Global financial markets
- Global manufacturing (outsourcing) capabilities
- Competitive landscapes resulting from business failures, alliance formation or dissolution, mergers and entrepreneurship
- Capabilities resulting from the occurrence of natural or terrorist disasters
- Political conditions
- Domestic and foreign legal conditions
- Environmental and natural resource (commodities) conditions

The enterprise reference model presented here significantly expands upon the context that motivated the ANSI/ISA model introduced in Section 1. We begin by [re]defining an *enterprise* as an arbitrary unit of organization, tasked with a specific mission (goals and objectives), endowed by policy with certain explicit prerogatives and capabilities (assets), and governed by one or more value propositions. As discussed above, enterprises may contain enterprises. Corporations contain business areas; business areas (divisions) contain business units; business units (companies) contain factories (plants); Plants contain production areas (lines) and production lines contain manufacturing cells. Each defines a unit of value production (VPU) and each dedicated management team is tasked with realizing its value propositions.

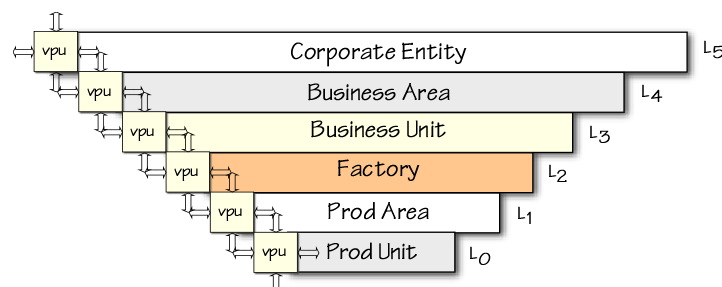


Figure 5 – Nested Value Production Units

As noted in Figure 5, each level of the enterprise (accountability) hierarchy contains one or more value production units (VPU), each in turn a locus of sovereign governance.

3.1 Enterprise – A Value Production Unit (VPU)

An enterprise is a quantifiable unit of value production with a sovereign governance structure sufficient to realize its value propositions. As diagrammed in Figure 6, a VPU operates on two [orthogonal] axes—a vertical *command axis* (superior-subordinate network or asset chain) and a horizontal *production axis* (producer-consumer network or supply chain). The goal of enterprise governance is to simultaneously satisfy demands of neighbors on each axis within its capabilities and under constraints imposed by its policies, all while complying with its value propositions.

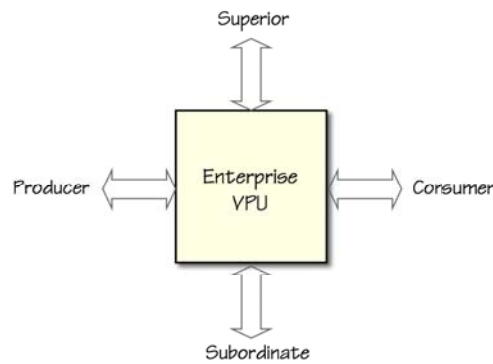


Figure 6 – Enterprise: A Value Production Unit (VPU)

Enterprises do not operate in isolation; they collaborate to form unions or federations (compound enterprises) with other enterprises in order to exploit opportunities that result in mutual benefit. Figure 7 depicts such a federated enterprise, shows a third “federation” dimension and introduces a naming (indexing) convention for uniquely identifying an enterprise in this three dimensional space.

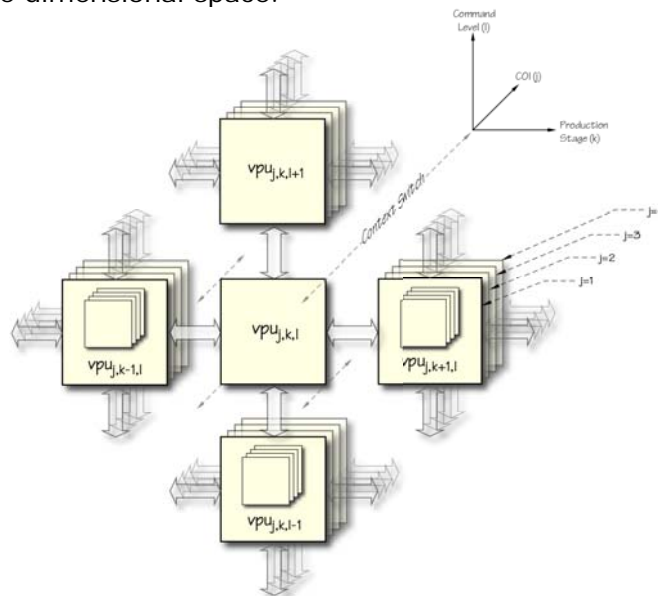


Figure 7 – Federated Enterprise Structure (VPU Lattice)

The focus of Figure 7 is the central enterprise designated $VPU_{j,k,l}$. Index "j" identifies the current policy domain (federation or "community of mutual interest," COI), index "k" denotes the horizontal position in that federation's production network and index "l" represents the location (level) in its vertical command network. The enterprise VPU has a single *superior* per policy domain⁴, 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 that each supplier, customer and subordinate may actually represent (be a proxy for) multiple associations. Said differently, within federation "j" $VPU_{j,k,l}$ is *subordinate* and therefore accountable to $VPU_{j,k,l+1}$, and is a *superior* to and therefore responsible for $VPU_{j,k,l-1}$ in the asset chain. $VPU_{j,k,l}$ is a *server* or service provider and therefore committed to $VPU_{j,k+1,l}$, and a *client* of and therefore dependent upon $VPU_{j,k-1,l}$ in the supply chain.

An essential requirement for effective enterprise governance is the ability to *context switch* (along the "j" axis in Figure 7) among federations in order to support value production commitments (contracts, service level agreements, etc) made to each. Such a requirement is completely analogous to the requirement for a computer system's operating system (kernel), in order to effectively manage its various computational resources (CPU, memory, IO), to context switch among resident applications in order to efficiently support their apparent concurrent execution (i.e., *virtual machine* or *multiprogramming* paradigm).

3.2 Enterprise Governance

Enterprise viability is the result of good fortune and good governance. Governance is about insight (awareness) and effective management of capabilities, directly and indirectly through manipulation of services provided by enterprise command and control (EC2) systems. The principal objective of governance is maintaining enterprise value propositions, as measured by specific internal and external performance indices. Overall, an enterprise is *viable* to the degree its goods and services are valued by enterprises with which it trades.

Enterprise governance occurs through human awareness and supervised action (reaction and proaction) related to occurrence of *situations* of interest to the enterprise. Situations result from patterns of events generated by internal (self) and external (environmental) processes. Situations are affected by independent (unilateral) and group (multilateral) awareness and the resultant actions they invoke.

Enterprise governance is achieved through human actors exercising their prerogatives through command (decision) and control capabilities. *Command service* capabilities provide *guidance* in the conduct of enterprise activities; *control service* capabilities provide the necessary *forces* to affect change in enterprise activities. Figure 8 identifies these two key operational elements, complementary structures defining an enterprise VPU's internal governance capabilities. Control, on the right, is the means for an enterprise (to employ *force*) to maintain its viability and, consequently, its value propositions. Command, on the left, is the means for accountable and specialized (role-specific) human actors to exercise effective guidance of those controlled forces. We discuss each aspect separately, beginning with the *control structure*.

The VPU's command structure defines relationships among human (and automated) actors responsible (accountable) for enterprise operations. The VPU's control structure defines the

⁴ Requiring a single superior per policy domain is a logical result of existence of causal relations between commands (directives) and their subsequent effects (consequences). This requirement derives from the need for *accountability* in human-directed affairs.

cyclic (iterative) processes of situation assessment, planning (both reactive and proactive) and performance managed plan execution.

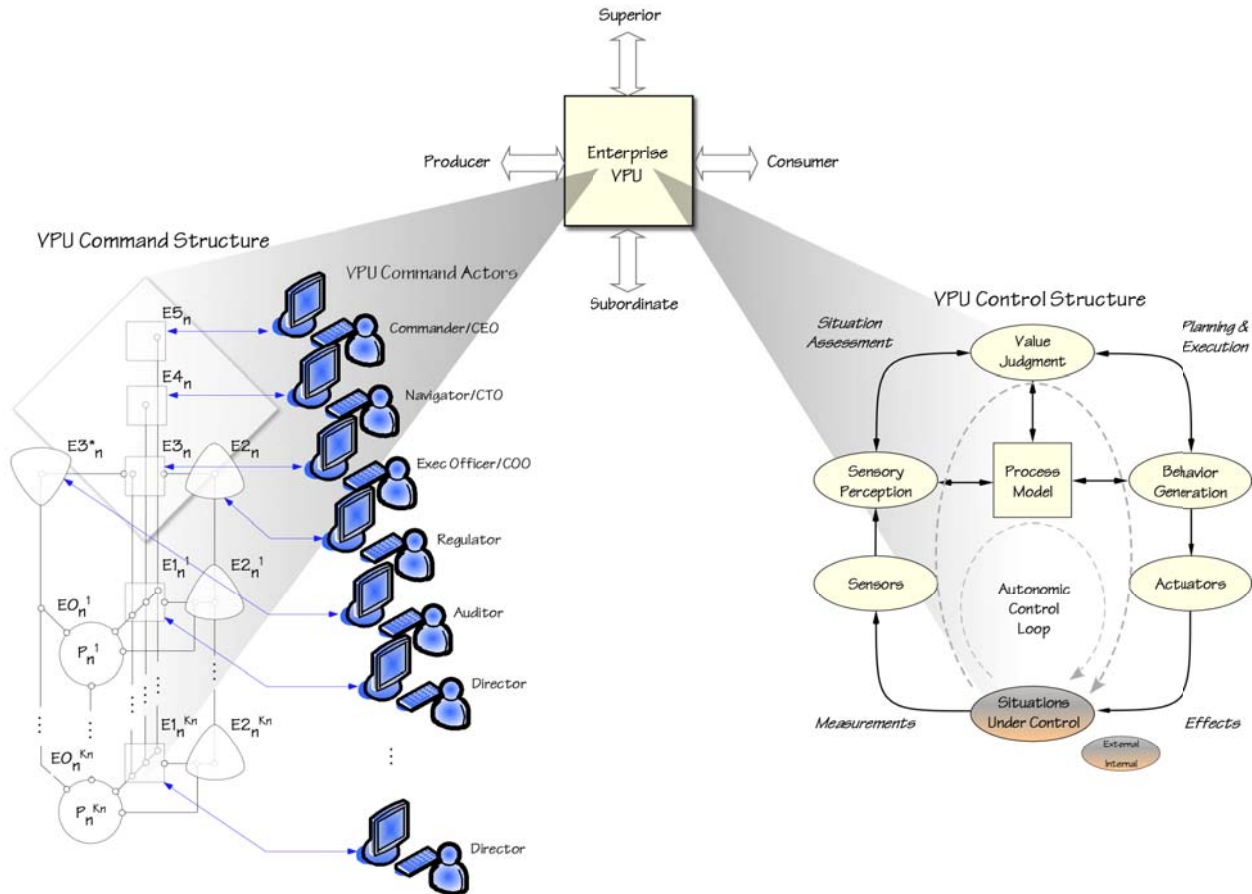


Figure 8 – Complementary Enterprise Command and Control (EC2) Structures

The command and control structures diagrammed in Figure 8 occur within each and every VPU throughout a compound enterprise, vertically along the command axis and horizontally along the production axis. Each VPU is considered a [semi-] independent (sovereign) entity responsible for its own value proposition(s).

The ANSI/ISA-95.00 standard is silent on several key elements of enterprise management. Its stated focus is on the transactional interface between MES and ERP systems, clearly critical L₃-L₂ communications matters. However, there is no discussion of collateral issues of horizontal or vertical control (situation awareness, planning and plan execution) or the role players (actors) and their respective command functions and authority. As a consequence, the standard provides no guidance as to the internal workings of an enterprise or its relationship to other federated enterprise allies.

4 Enterprise Command Structure

The command structure provides an enterprise with a formalized configuration of actors and their roles in the accountability hierarchy. The behavior of VPU is governed through its own local sovereign enterprise command structure. Figure 9 introduces the principal actors

responsible for guiding its behavior. These per-VPU actors include a single commander (CEO or supervisor, denoted echelon five, E5) representing the highest authority within the VPU; a single navigator⁵ (CTO or planner/analyst, denoted echelon four, E4) responsible for modeling, planning (e.g., marketing and R&D) and analysis functions (i.e., adaptation and change management); and a single operator (COO or operations executive, denoted echelon three, E3) responsible for execution of authorized VPU plans of record.

Supporting the three principals are two or more subordinate *directors* (denoted echelon one, E1) of embedded enterprise capabilities (VPUs, at least one serving the vertical asset chain, and one serving the horizontal supply chain), *regulators* (denoted 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, an *auditor* (denoted echelon three star, E3*) responsible to E3 for continuously measuring and reporting on the performance of the subordinate VPUs, and the two or more embedded value production *processes* themselves (denoted as echelon zero, E0) that are managed by their respective E1 directors.

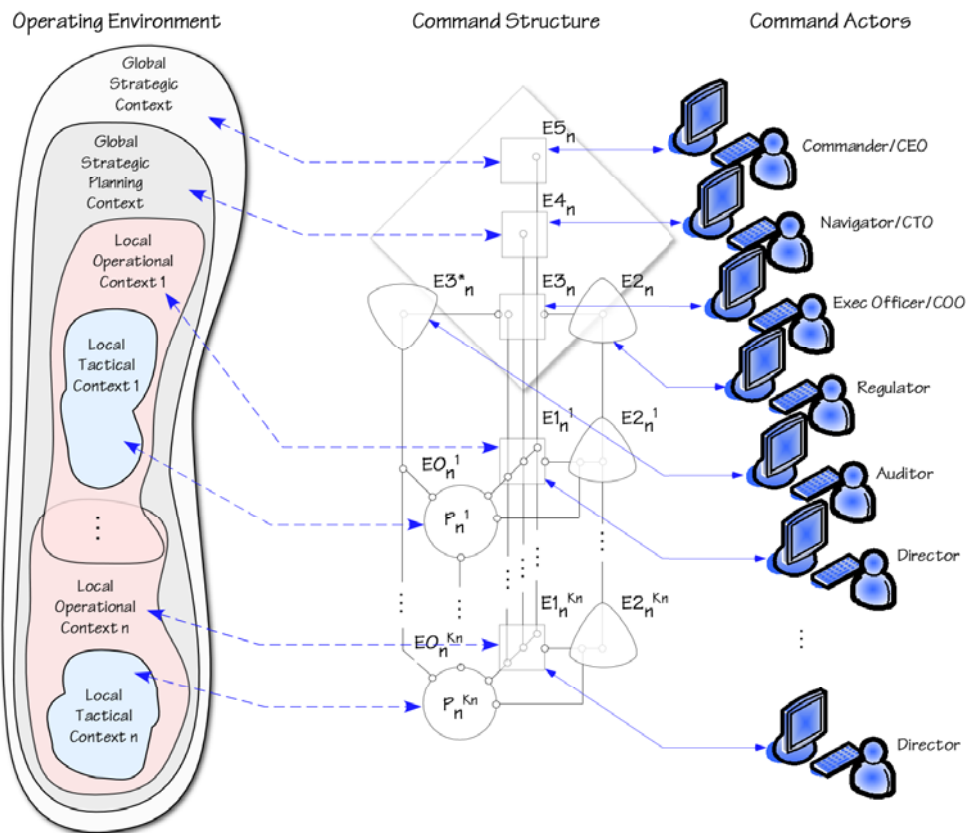


Figure 9 – Enterprise Command Structure

⁵ We use the term “navigator” to emphasize that this function concerns forward-planning and change management, setting long-range strategic command and production chain agendas, including marketing (CMO), technology development (CTO), business development, operational infrastructure (IT) and financial investment plans (CFO). Clearly this function involves several human actors, but because strategies must ultimately be conformal, we assign it a unique (consolidated) actor role.

It is important to note that this command structure is intentionally recursive in nature. The E5-E4-E3 triumvirate is contained within a rectangle rotated 45°. The E1 symbol is also a rotated rectangle, containing three internal connections. E1 represents the E5-E4-E3 structure at the next lower level of command. For example, if E1 represents a business unit (BU) management team within a given business area (BA), a BA E1 represents the E5-E4-E3 triumvirate within the BU. This recursive (fractal) property of the command structure is not merely a clever graphical nuance; it represents an important technical concept with numerous benefits.

First, the command model *scales*, allowing command applications developed for one level of an enterprise to be applied to other levels (ref. Figure 10). Second, documentation and training materials apply to multiple levels, supporting the migration of experienced human actors throughout an enterprise. Third, validation of command protocols at one level provides validation at all levels. Fourth, consistent roles and supporting command applications provide the basis for unified peer-level command relationships required of federated systems. Fifth, role-based actors can focus their attention on specific operating environments, improving (shared) situational awareness and subsequent planning and execution. Sixth, environmental focus leads to improvements in historical record keeping, trending (analysis) and simulation of possible future scenarios, providing improved institutional learning within and sharing across organizational boundaries. Seventh, the structure supports autonomy, since each enterprise (unit of value production) has at its disposal the entire means of command. Lastly, the command structure provides a formal means of coordination (synchronization, via E2) supporting the scheduling of shared resources and rendezvous in time, thus providing formal mechanisms for effective asset utilization within and among enterprises.

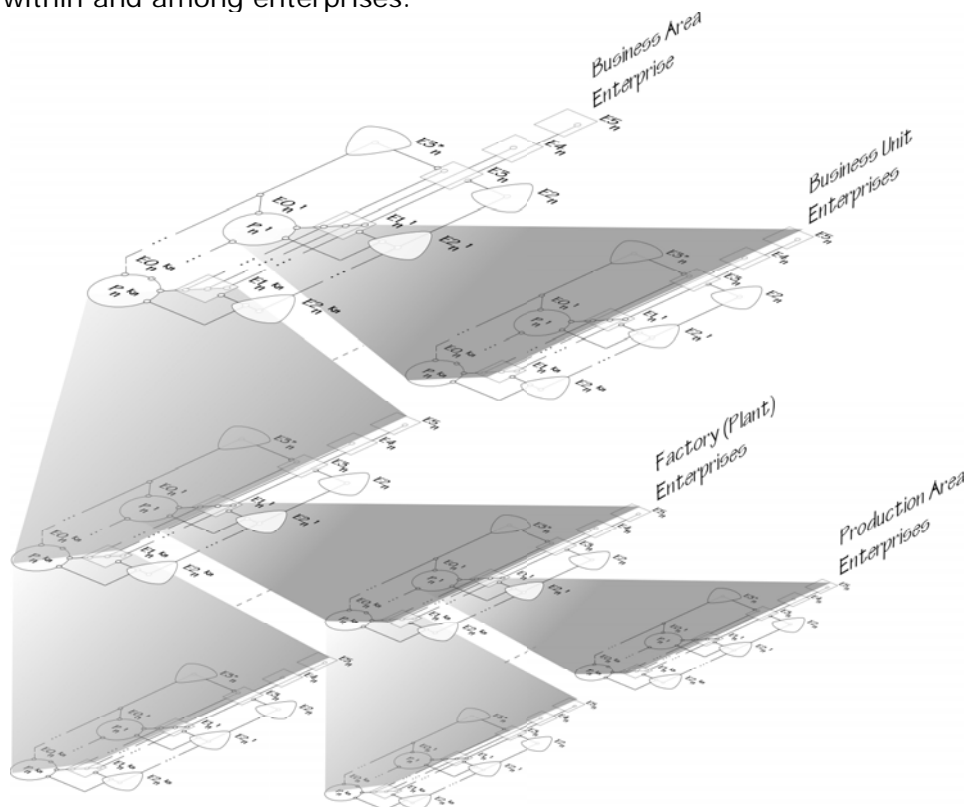


Figure 10 – Structure of Compound (Nested) Enterprises

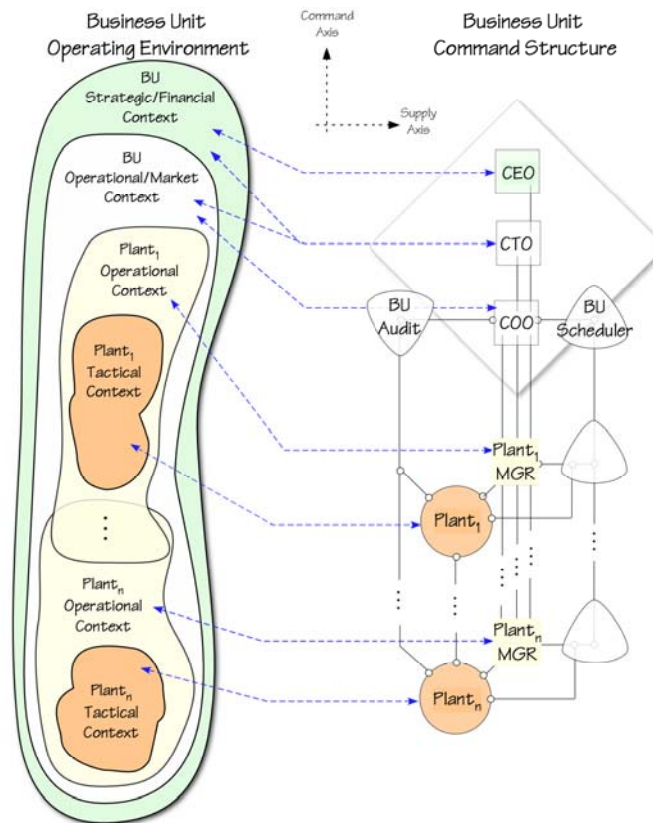


Figure 11 – Manufacturing Domains: (L₃-L₂) Command Structure

In concert with the ANSI/ISA-95.00 standard, the command structure may be focused (scaled) and labeled to support a L₃ business unit (BU) and its subordinate L₂ factories. Figure 11 shows the BU and its "n" subordinate factories, labeled *Plant₁* through *Plant_n*. Note also that each command function is associated with a specific external operating environment. The E5 CEO is responsible for the global strategic (primarily financial) context of the enterprise. The E4 CTO focuses on the future operational (planning) context. The E3 COO pays attention to the current operating (execution) environment encapsulating his subordinate value production units (e.g., suppliers, customers, factories). E1 plant managers focus on their respective operational production domains. Their respective plants each focus on their tactical supply (logistics) chains.

Three primary internal decision loops are identified in Figures 12(a) through 12(c). 12(a) represents the executive strategic planning cycle; 12(b) represents operational coordination of subordinate VPUs; and 12(c) represents the tactical (regulatory) control loop within subordinate organizations.

Figures 13(a) through 13(c) identifies decision loops that exist between an enterprise and its external environment (axis neighbors, as in Figure 7). 13(a) represents the executive management's strategic engagement with peer and superior organizations along the command axis; 13(b) represents operational engagements with peers along the production

axis; and 13(c) represents tactical connection with peers along the production axis for the purpose of synchronization in time and among shared resources.

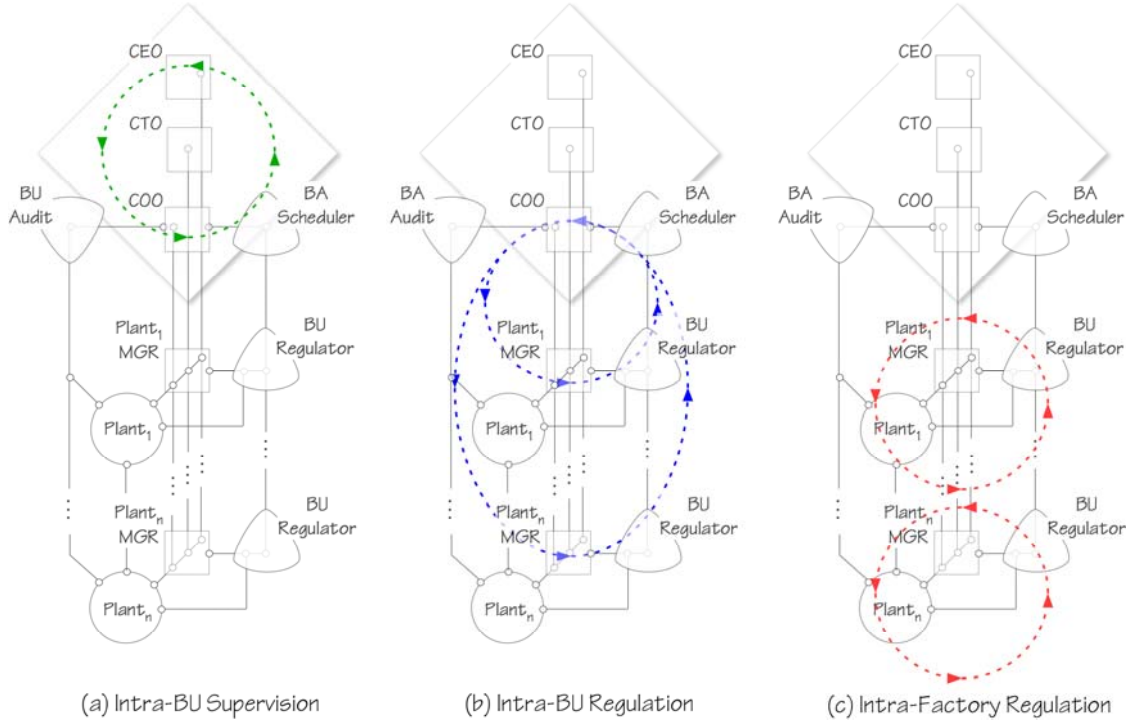


Figure 12 – Command Axis Decision (Control) Cycles

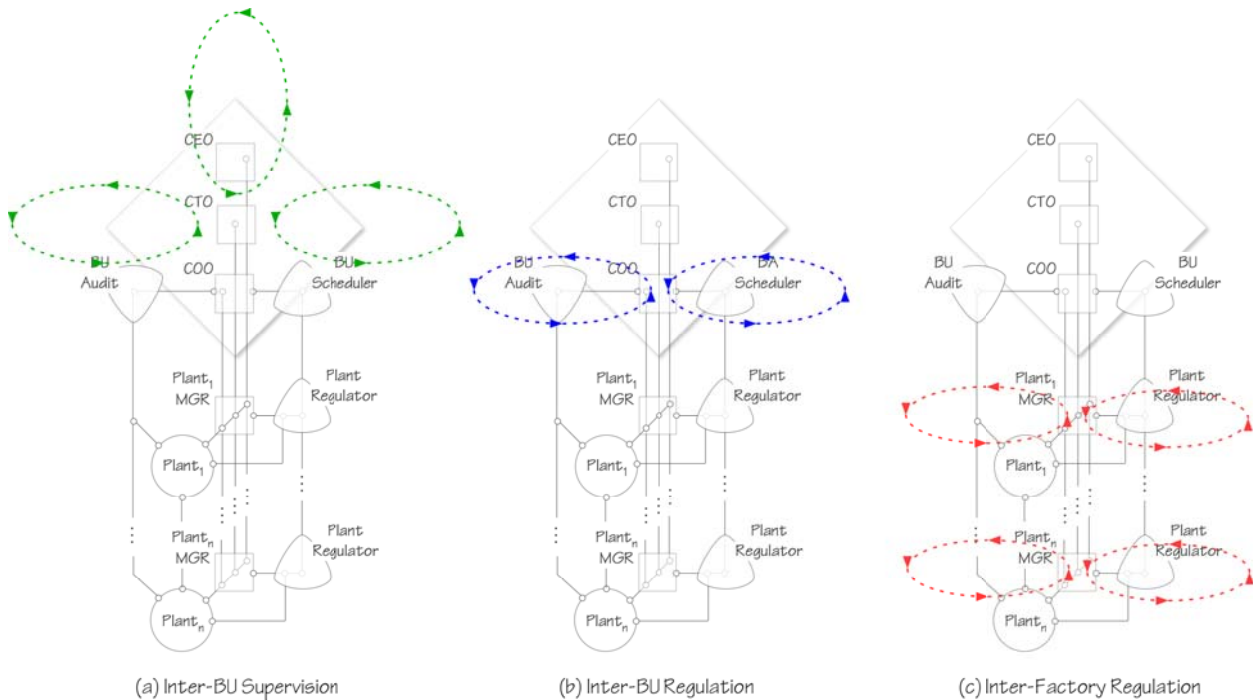


Figure 13 – Production Axis Decision (Control) Cycles

Details of the operation of these decision and control loops are the subject of a 2005 paper⁶ presented at the DOD's Command and Control Research and Technology Symposium.

5 Enterprise Control Structure

Control capabilities (services) provide an enterprise with its situational awareness, planning and control services, activities modeled⁷ after human cognitive processes, as depicted in Figure 14(a)⁸. This cyclic feedback-control process is fundamental to the systems sciences, and especially its more holistic branch cybernetics. Figure 14(b) provides a simplified version emphasizing the situation assessment, planning and execution phases of the cognitive loop. Figure 14(c) simplifies the diagram even further, and will be used in subsequent figures to represent the control services. The inner loop of Figure 14(a) describes the autonomic (automatic, regulatory) path from awareness to action. The outer loop of Figure 14(a) describes the interactive (supervisory) path that provides for human value judgment to inter the decision and control process.

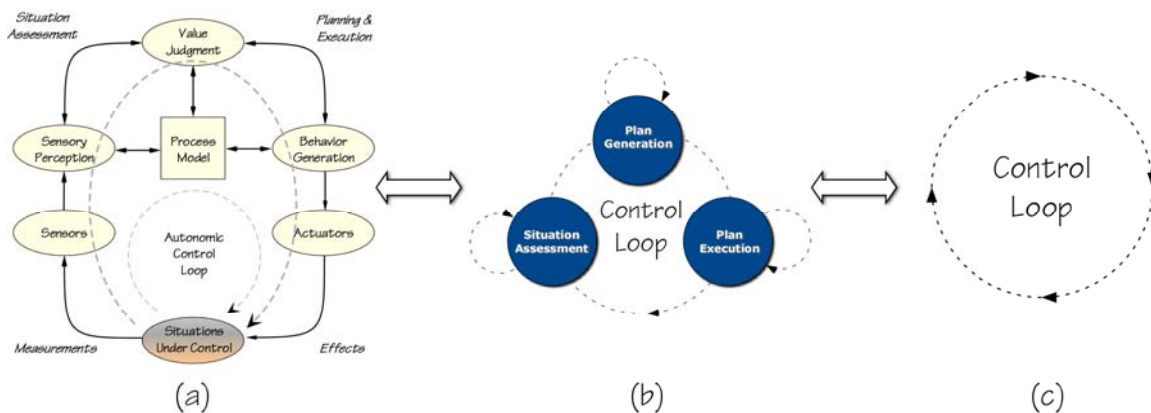


Figure 14 – Enterprise Control Loop

Control [software] services provide a VPU with its means of achieving and maintaining awareness of and subsequent response to situations arising from both *external* and *internal* forces. This dual and interdependent role is provided by the components identified in Figure 15. The primary control services within $VPU_{j,k,l}$ is in performing situation assessment, planning and plan execution related to both internal and external situations. Information related to internal events is derived from the VPU's internal command structure. Information related to external events arrives from neighbors on the VPU's command and production axes (ref. Figure 6) and external information subscriptions.

⁶ <http://www.dodccrp.org/events/2005/10th/CD/papers/018.pdf>

⁷ This feedback control model is core to the system sciences, especially cybernetics, and the notion of [self-adaptive] regulatory control in dynamic probabilistic systems. The model is the basis for aircraft autopilots, nuclear power plant controls, unmanned spacecraft and many other complex man-made (robotic) systems.

⁸ This cyclic model, with roots in classical feedback control theory (e.g., the flying ball governor for steam power boilers), was made popular in the military following the Korean War as Col Boyd's "Observe, Orient, Decide and Act" (OODA) Loop.

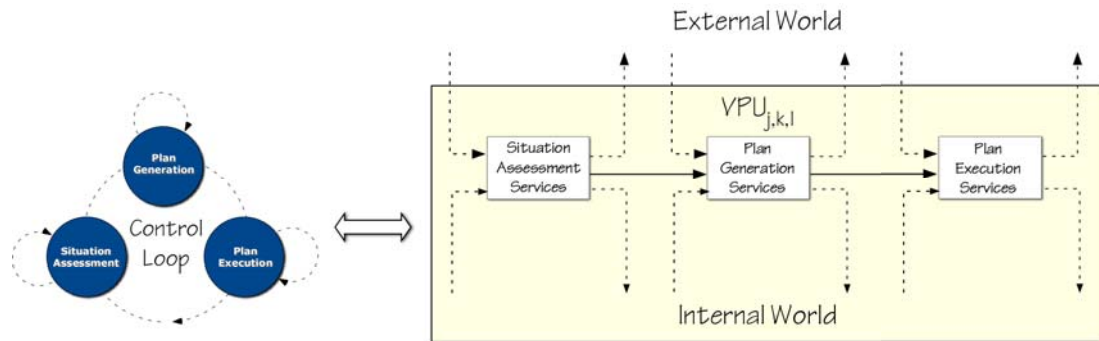


Figure 15 – Primary Control Services [Software] Components

Control is actually iterative in several domains, forming eddies and currents in the left-to-right flow, similar to non-laminar fluid flows. Figure 16 shows several of the more prominent primary and secondary cycles found within and among control domains of collaborating enterprises. Primary cycles represent control strategies encompassing the feedback loop shown in Figure 14(a). Secondary cycles (“eddies”) represent per-stage dialogs among collaborating actors, both internally and among external allies.

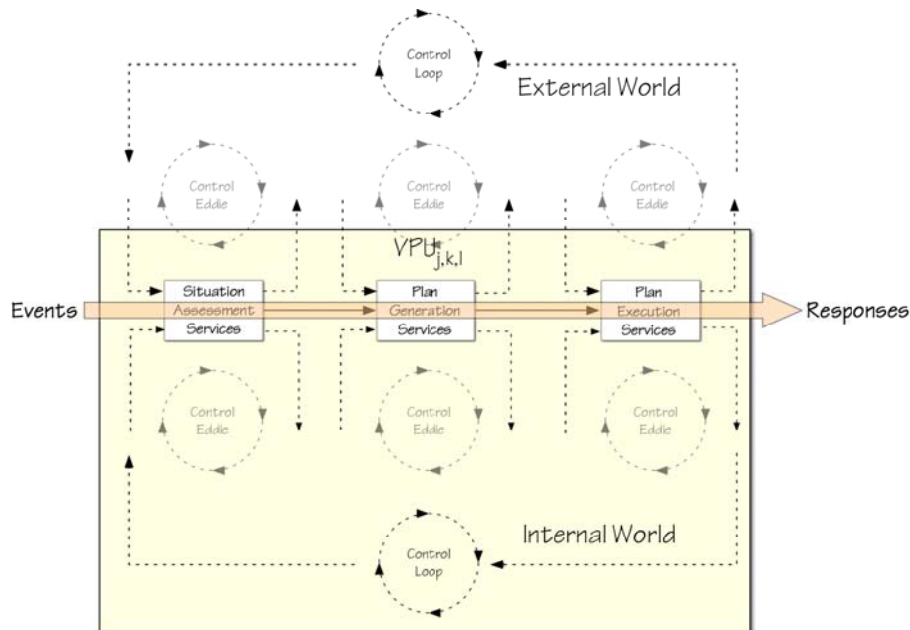


Figure 16 – Enterprise Control Cycles

Eddies represent decision cycles engaging human actors responsible (accountable) for the performance of each stage in the control loop. For example, plan generation services engage actors internal to $VPU_{j,k,l}$ and externally among allied actors in neighboring VPUs along the interconnecting command and production axes.

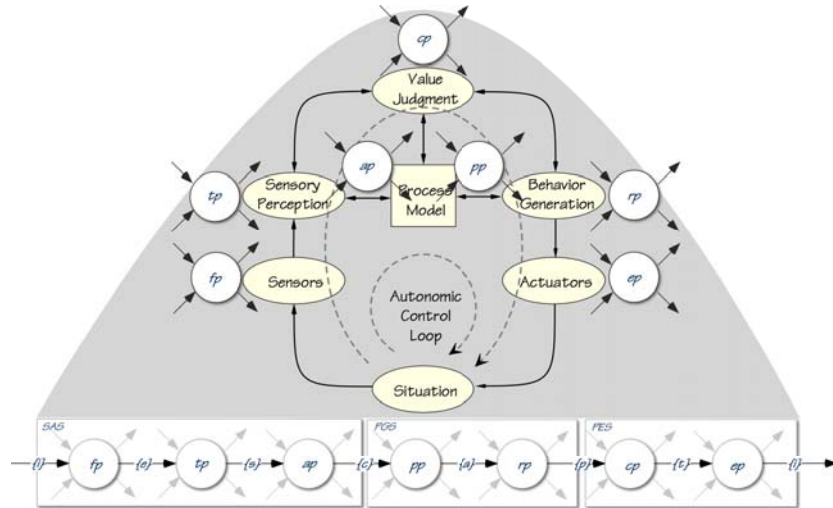


Figure 17 – Control Services Model

	CPF Stage	Stage Services	Stage Inputs	Stage Outputs
	Filter Process	Processing information feeds {i} from sources in order to identify information objects of interest that produce subsequent alarm and event notifications {e}	Information sources {i}, including RSS feeds, web services, databases, and related voice, video and data sources.	Alarm and event notifications objects {e}
	Triage Process	Processing sequences of alarm and event notifications {e} in order to identify situations {s} related to the VPU's current tasks	Alarm and event notification objects {e}	Situation notification objects {s}
	Analysis Process	Processing identified situations {s} and associating them with one or more potential courses of action (COA) {c} with which to respond	Situation notification objects {s}	COA notification objects {c}
	Policy Process	Identifying all policies that govern COA {c} in order to evaluate compliance and risk, reducing the list of possible COA to single plan of action (POA) {a}	COA notification objects {c}	POA notification objects {a}
	Resource Process	Identifying resources required of POA {a} in order to properly "fund" it, converting it to an executable plan of record (POR) {p}	POA notification objects {a}	POR notification objects {p}
	Command Process	Authorization of new POR {p} such that they "fit" into current activities by developing a new schedules and issuing new tasking orders (TO) {t}	POR notification objects {p}	TO notification objects {t}
	Control (Execution) Process	Execution of authorized TO {t}, including management and synchronization of shared resources, producing effects-based results {i}	TO notification objects {t}	Information notification objects {i}

Table 1 - Control Processing Stages

Operationally, control services implement the control loop introduced in Figure 14(a). Our conceptual implementation of this loop is shown in Figure 17, where we identify its three primary stages (SAS, PGS and PES) and the key processing services in each stage. The function of each of service is summarized in Table 1 below.

Each of the services identified in Table 1 require human interfaces (applications) through which the command structure exercises its supervisory responsibilities. These command (user) interfaces are outlined in the following three sections.

5.1 Situation Assessment Services (SAS)

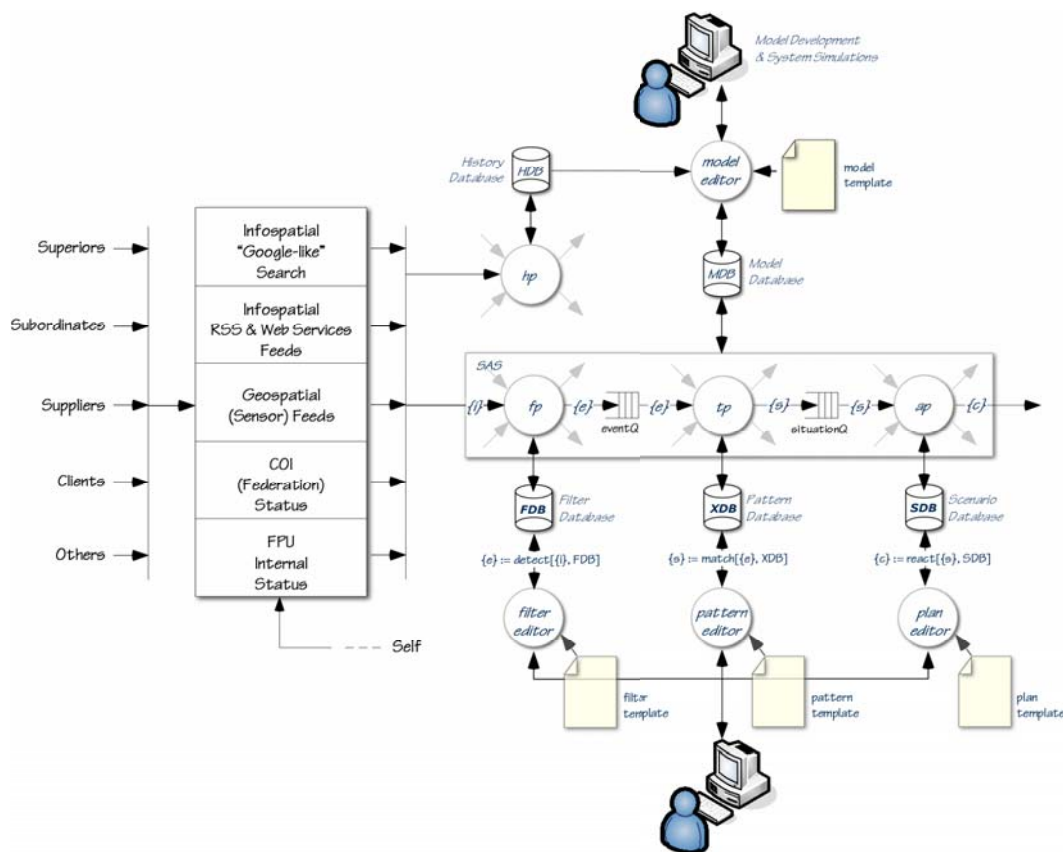


Figure 18 – Situation Assessment Services (SAS)

Situation assessment services provide command staffs with information relevant to the recognition of situations of interest or significant changes in recognized situations. This activity is also referred to as striving for and achieving *situational awareness*. The basic process is to look for significant events ("fp"), followed by identifying situations defined by specific sequences of these events ("tp") and concluding by associating the situation with a proposed course of action ("ap").

Governing this primary left-right flow, from raw information (subscriptions) to courses of action (COA), are the command interfaces to each function. Operation of these use

interfaces is described in detail in the text *Theory of Enterprise Command and Control*⁹. The principal actor at this stage is E4, our combined CTO/CIO/CMO and business development function (ref. Figure 12(a)).

5.2 Plan Generation Services (PGS)

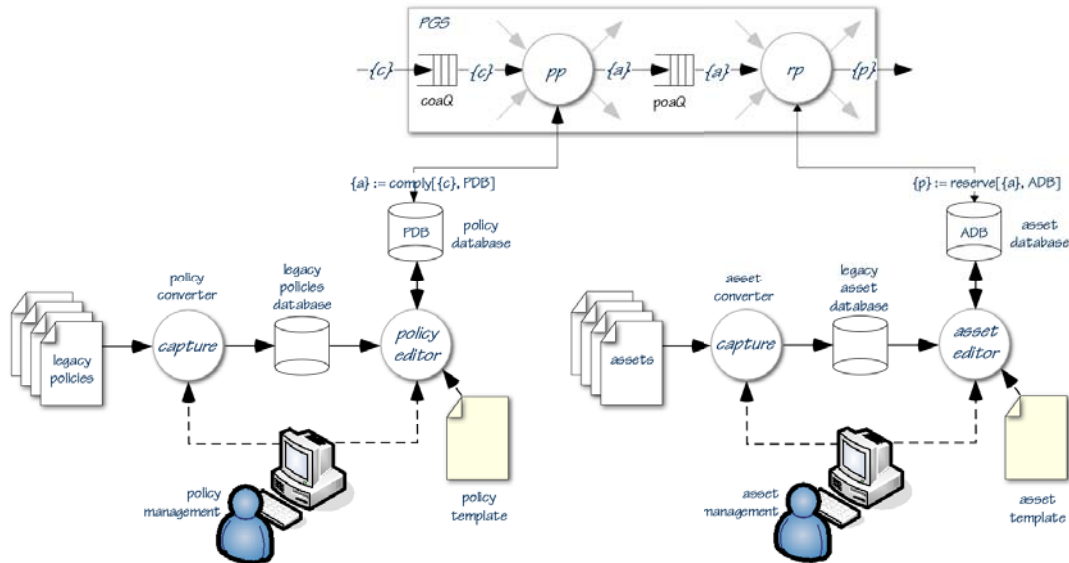


Figure 19 – Plan Generation Services (PGS)

Plan generation services provide command staffs with two critical adjustments to proposed and as yet un-executable courses of action (COA): policy compliance and resource (asset) reservations. In order for a COA to be executable, it must conform to (not violate, comply with) extant policies. Policies include rules of engagement, service level agreements, legal and financial guidelines, environmental or human resources requirements, and so on. If a COA violates one or more policies an exception is thrown apprising E5 (CEO) of potential risks. Given exceptions, E5 may chose to authorize or to request modifications, with the COA subsequently emerging as an acceptable plan of action (POA).

POA next enter the resource reservation stage where required assets are identified and, if available, reserved in order to meet the execution (e.g., completion time) requirements of the plan. The actor responsible for resource reservations is E3 (COO) who is also responsible for the subsequent execution of plans¹⁰. The goal of this stage is to provide “course grain” scheduling to allow the pending POA to maximize its completion time requirements while at the same time allowing other plans (responding to other situations) to meet theirs. Reservations achieved through course grain scheduling attempts to maximize the utilization of share resources, and therefore maximize the utility of [the overall value proposition of] the enterprise. If a feasible schedule is achieved, the POA emerges from resource scheduling as an executable plan of record (POR).

⁹ <http://www.echelon4.com/content%20files/TEC2%20v2%20.pdf>

¹⁰ This is a critical element of the command structure. Assets currently assigned to executing plans may be needed for the pending plan, requiring the COO to abort or suspend plans in execution in order to force the release of their held assets. The continuous balance of pending and executing plans and the coordination of both shared resources and subordinate organizations (VPUs) is the principle operational challenge of all enterprises (ref. Figure 12(b)).

5.3 Plan Execution Services (PES)

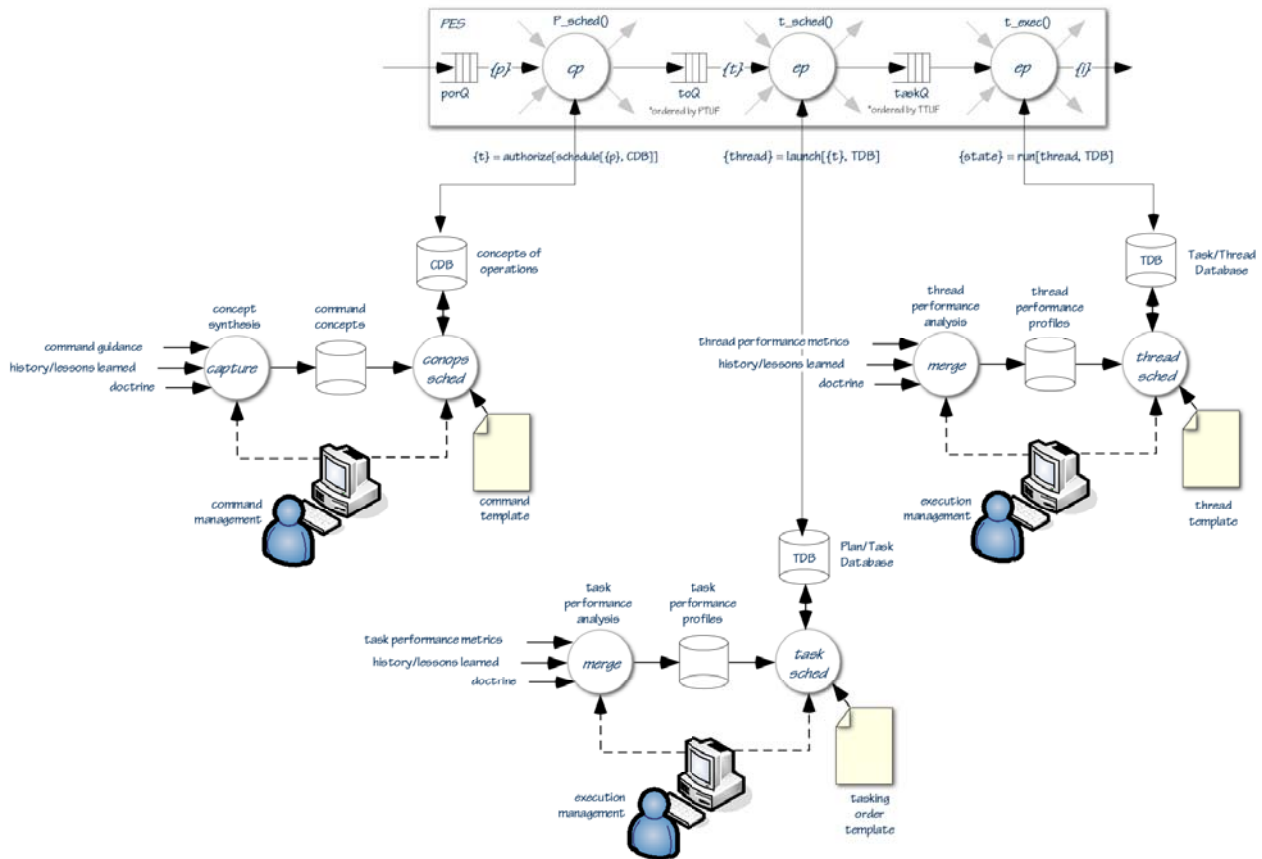


Figure 20 – Plan Execution Services (PES)

Plan execution services provide command staffs with tactical management of plans of record (POR) that emerge from the PGS stage. The first step is with E5's (COO) command process ("cp") for plan authorization. This is where "the buck stops" and accountability for action is established within the enterprise. The technical effect of this authorization is the high-level commitment to the completion time requirements of the POR.

The next action, taking place in the execution process ("ep"), is the fine-grain scheduling of the plan, forcing if necessary abortion and/or rescheduling of active plans. This process is quite complex and involves run-time computation of "time-utility" functions¹¹ in order to make the scheduling decisions.

The final stage of PES involves the dynamic scheduling of all authorized and executing tasks (threads). This stage is analogous the function of an operating systems kernel as it schedules tasks in a multi-programmed computer system.

¹¹ See, for example, <http://www.real-time.org/timeutilityfunctions.htm>

6 Enterprise Performance Measurement Services

Collaborative (unified) command and control requires some form of shared performance measurement. Actors responsible for exercising control over situations of mutual interest, especially when they contribute their valuable assets to achieve common objectives, must evaluate their effectiveness in order to compute their respective value propositions. If they do not utilize a common set of metrics, it is difficult to judge effects achieved by their individual and joint actions, to assess situations of mutual interest in a common light or to make enlightened decisions as to subsequent courses of action.

The ability to continuously measure and assess the performance of a complex system in relation to constraints imposed by its external environment is critical to self-regulation. Furthermore, when systems collaborate in one or more federated communities of interest the measurement system must also apply to interactions between and among members. Due to the varied and often unique character of collaborating VPUs, the measurement system must use metrics that are uniformly applicable and therefore neutral to operational peculiarities of any single enterprise. Such neutrality forms the basis of objective comparisons about individual enterprises and the performance of federations in which they participate. PMS is a therefore relativistic measurement system.

Figure 21 introduces a performance measurement concept that compliments the enterprise command structure. It presents a set of application neutral metrics for describing enterprise performance, individually and collectively. Such neutrality is also required to evaluate the performance of federated enterprises, within their respective vertical command and horizontal production networks.

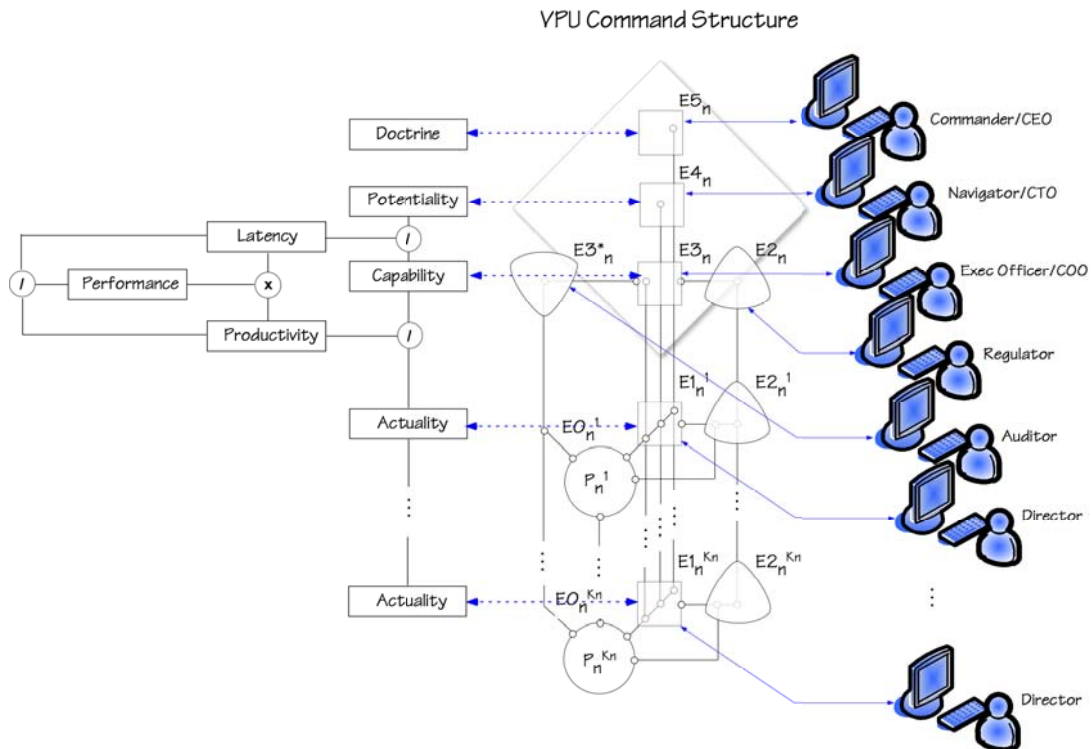


Figure 21 - Enterprise Performance Measurement



The PMS defines six key performance indices (KPI), three independent and three derived. The figure also identifies their respective measurement sources within the enterprise command structure.

6.1 Potentiality

Potentiality (potential) is the architected (i.e., maximum design) capability of a system when fully resourced and operating without functional defects (faults). This index is typically normalized in a manner that makes potentiality equal to unity (1, or 100%). The other indices then become percentages of some maximum potential.

6.2 Capability

Capability (capacity) is the ability of a system given its current level of resources (assets) and its current functional defect (fault) level. A system's capability is always less than or equal to its potential.

6.3 Actuality

Actuality (reality) is the current production level (e.g., throughput yield) of a system, what the enterprise is actually doing at this time with its current capability.

6.4 Latency

Latency (latent potential) is the ratio of current capability to design potential, expressing the design "headroom" or unused potential remaining in the system if additional resources are applied and existing defects (faults) are eliminated.

6.5 Productivity

Productivity is the ratio of actuality to capability, expressing the effectiveness (productiveness) of current capability in supporting value production.

6.6 Performance

Performance (relative) is the ratio of actuality to potential (or the product of latency and productivity), expressing how well the enterprise is performing against its design potential.

By way of example, Figure 22 diagrams relations among these indices for a hypothetical enterprise (VPU).

Given (as measured):

- The VPU is operating with an actuality of 35%
The VPU's current capability is 75%

Results (as computed):

- The VPU's latent potential is 75%
Its productivity is currently 47%
Its absolute performance is currently 35%

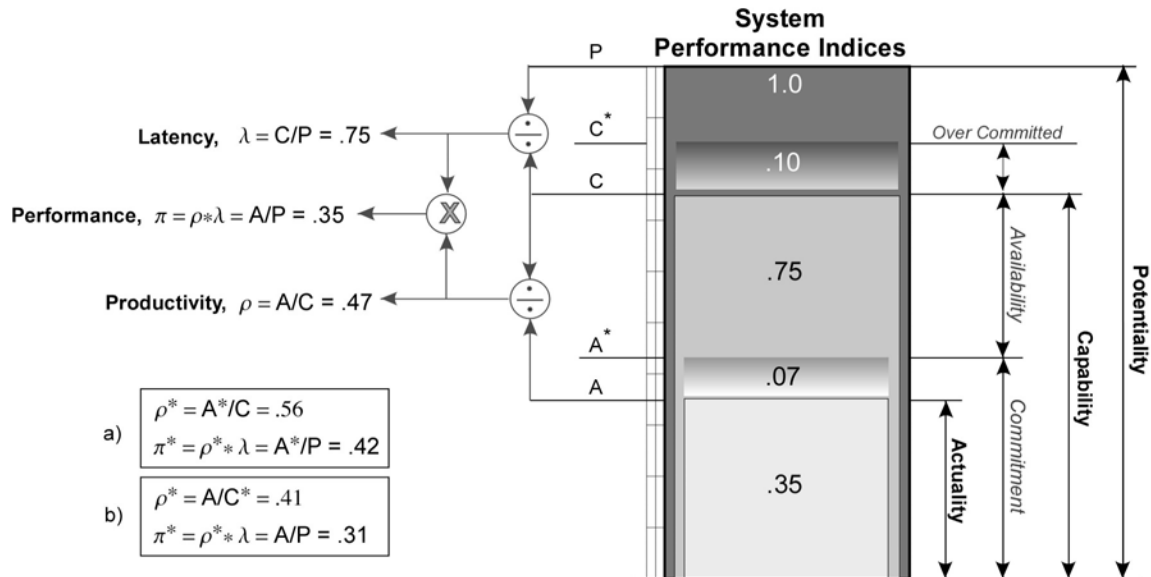


Figure 22 - Enterprise Performance Indices

For this example VPU there is significant capacity available to absorb more work given that the VPU can realize improvements in productivity of its deployed assets.

Figure also expresses two examples, identified as scenarios a) and b), of the value of these metrics in enterprise planning activities:

- That the VPU's current "commitment" level (denoted A^*) of 42% (.35 + .07), resulting in an "availability" level of 33% (.75-.42). In a) the impact of the commitment would be to raise *productivity* to 56% and raise *performance* to 42%.
- There is a potential "over commitment" of 10% (denoted C^*) above *capability*. The effect of over commitment b) would be to lower *productivity* to 41% with a corresponding lowering of *performance* to 31%.

7 Conclusions

We have presented a unified enterprise command and control (EC2) structure that addresses many weaknesses identified with current approaches to network-mediated enterprise governance. In particular, our focus on unified network-centric command, control and performance services provides an operational framework in which to conceive, specify, design, develop and deploy federated enterprise governance services. We propose this structure as the basis for the next generation of service-oriented applications supporting intelligent (learning) and adaptive (evolutionary) enterprise systems.