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A Systems-Based Framework for Design and Analysis of an R and D Structure

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Abstract: A critical challenge for managerial effectiveness and competitive advantage in research and development (R and D) organizations is developing an appropriate structural configuration. However, in finding an appropriate structural configuration, R and D managers are faced with unprecedented levels of uncertainty, ambiguity, and accelerating complexity, coupled with demands for increased productivity. This paper develops a systems-based framework to support rigorous design, analysis, and transformation of the structure for R and D organizations. The framework development includes: (1) a review of the literature for the nature and role of the structure in R and D management; (2) setting of the R and D structure problem from a systems perspective; (3) establishing a systems view of R and D structure; (4) articulation of a systems-based framework for R and D structure drawing on management cybernetics and systems theory; and (5) an application of the framework to design the structure for a multidisciplinary R and D center. The paper concludes with implications and utility of the framework for practicing R and D managers challenged with structuring an R and D organization.

Keywords: complexity theory; risk analysis; research and development; management

1. Introduction

The challenges of structure are certainly not new to organizations, including R and D organizations [1–3]. The traditional perspective of structure in complex organizations has been limited to a focus on formal relationships and arrangements, examining such questions as centralized versus decentralized organization [4]. Robbins [5] captures the traditional view of structure as "how tasks are to be allocated, who reports to whom, and the formal coordinating mechanisms and interaction patterns that will be followed" (p. 5). This perspective is somewhat limited in that the focus is restricted to formal mechanisms and patterns, certainly not appreciative of the emergent and uncertain environments characteristic of R and D organizations [6]. The classic exemplar of the traditional view of structure is held in organizational charts, formal procedures, and policy documents. However, the changing landscape of R and D organizations has amplified the necessity for effective structure to deal with new realities of increasingly complex turbulent environments.

The purpose of this paper is to articulate a systems-based framework to more effectively guide design, analysis, maintenance, and transformation of organizational structures in R and D settings. First, the literature for structure in R and D is reviewed. This review serves to set the frame of reference for the R and D structural problem. Second, a systems view of structure in R and D is developed. This view sets a foundation for a deeper understanding of structure from a systemic perspective. Third, a systems-based framework for structuring R and D is developed. This framework is based on foundations from management cybernetics and systems theory, drawing upon the Viable System

Model pioneered by Beer [7,8]. Fourth, the framework is applied to development of the design for an R and D center. The paper concludes with implications for R and D management practitioners seeking a more robust perspective for design and analysis of structure.

2. R and D Structure—Background Literature

This section examines literature related to R and D structure. Although there has been much written with respect to organizational structure [5,9], adaptation to the unique challenges of R and D organizations is sparse.

Much of the R and D literature on organizational structure has evolved from the contingency approach to management. This approach asserts that there is not one best way to manage and that to be effective, planning, organizing, leading, and controlling must be customized to the particular circumstances faced by an organization [10–13]. This approach is particularly applicable to collaborative-type settings, where sharing resources and expertise, combining competencies, and reducing R and D costs and risks are of paramount concern. Byrne [12] describes this as "a group of collaborators that quickly unite to exploit a specific opportunity" (p. 98). The contingency approach offers the advantage gained from stable relationships while being flexible and project-oriented.

Since organizations, people, and situations vary and change over time, formation and structure depends on a complex variety of critical environmental and internal contingencies [11,13]. Past literature has focused on situational factors that affected the structure of an R and D organization with respect to its environment and context [10,14–18] and the appropriate management methods for different situations [19–23]. However, there is a scarcity of literature discussing the formation of appropriate organizational structures for multi-institutional multi-disciplinary R and D that crosses organizational and geographic boundaries. This gap is reiterated in the report Facilitating Interdisciplinary Research from the National Academies of Science [24] which recommended that "Institutions explore alternative administrative structures and business models that facilitate IDR [Interdisciplinary Research] across traditional organizational structures" (p. 185).

Notably, a paper by Simpson [25] purports that with all these "choices" of varying configurations, there is a "deep structure" that is fundamental. However, very little has been written on this supposition. Few have looked directly at appropriate structures that cross boundaries with the exception of some studies that have looked at configurations for virtual teams [10,11,13]. None in the literature reviewed have attempted to use a system-based cybernetic design to inform structure for R and D organizations. Given the current state and challenges facing R and D into the foreseeable future, the time is appropriate for such an examination.

3. The Structural Dilemma for R and D Management

From a systems perspective, the structural dilemma for R and D management can be understood as achieving an appropriate balance within three broad structural tensions (Figure 1) endemic to all complex systems, including R and D organizations. Structure supports the achievement and maintenance of the appropriate balance, based on the unique circumstances of the organization, among these tensions. Ineffective structure can be evidenced by symptoms that suggest an inappropriate balance in one or more of the structural tension dimensions in relationship with the unique circumstances of the organization. The structural tensions exist along three dimensions (shown as axes in Figure 1).

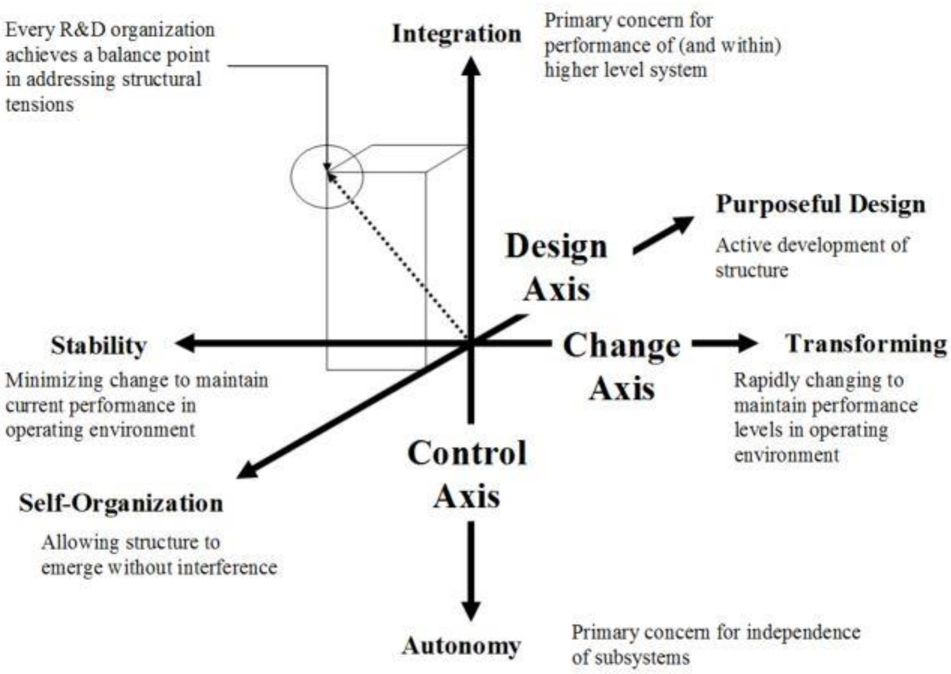

Figure 1. Axes of structural tensions.

3.1. Tension 1: Control

The level of constraint placed upon entities within the system (organization). Balance must be established between the degree of *autonomy* (freedom and independence of decision, action, and interpretation for system elements) and *integration* (maintenance of consistency to function effectively as a whole). For example, excessive emphasis on high level decision approvals in highly dynamic and rapidly changing environiments might be indicative of too much integration. This can result in slow decisions inconsistent with the pace of environmental demands.

3.2. Tension 2: Change

The degree of adjustment of the system (organization) in response to perturbations external to the system. Balance must be achieved between the degree to which the structure accentuates *stability* (minimizing change) or *transforming* (responsive adjustment) based on the specific environment that the system (organization) must operate within. For example, engaging in formal strategic planning forums in turbulent (transforming) environments might suggest an inappropriate approach (balance point) miscalculating the appropriate planning in relationship to environmental instability.

3.3. Tension 3: Design

The degree of 'organization' actively pursued in the establishment and maintenance of the system's functional structure. Balance must be achieved between *self-organization* (allowing the structure to evolve without, or with minimally imposed, constraints) and *purposeful design* (active establishment of structural configuration based on specific intentions). For example, imposition of minimal constraint (self-organization) based structural configurations may be an inappropriate fit to ensure that long range vision will be achieved (purposeful design). There is not a "right" balance point along these structural dimensions for every organization. Structural tensions are a natural occurrence in all R and D organizations. However, at a fundamental level, structural dilemmas find their roots in an inappropriate balance in the tensions. Lack of balance suggests a mismatch of structure to system objectives, the environment, or the organizational context. The effect is an organization (system) that exists, but may be performing below a desirable level of expectations. It is also important to note that the balance point may shift over time and with changing circumstances for an organization. Just as the environment and context for an organization change, so too must the structural configuration be able to change (shift its balance point).

4. Systems View of Structure in R and D Management

Structure is a key factor in system performance, as an organization establishes the appropriate balance among the tensions identified above. Maier and Rechtin [26] suggest that, "Every system and organization has an architecture, or 'structure' broadly defined which largely determines what the system can and can't do" (p. v). The relationship of system structure to effectiveness has been a consistent theme in the systems perspective of organizations [4,27–33]. For a R and D organization, structure can be viewed as a complex system, unique to the organization, that produces the level of viability (existence) achieved. Therefore, R and D effectiveness is largely a function of structure.

From a systems view, structure is not the traditional organizational chart, or arrangement of system entities. In fact, the systems perspective has been critical of the traditional view of organizational structure [34,35]. From a systems perspective, Beer [8,36] suggests that structure must be understood in terms of performing fundamental system functions necessary to maintain viability, not on managing neatly drawn 'boxes' on a chart. Jackson [28] notes that a system maintains viability if "it is capable of responding to environmental changes even if those changes could not have been foreseen at the time the system was designed" (p. 105). Structure provides viability in the face of changing environmental conditions and balances the tensions identified in Figure 1. Espejo et al. [29], capture the systems view of structure succinctly, suggesting system structure as "the set of arrangements by which the resources of an organization, human and others, are connected through relationships" (p. 20). Therefore, structure embodies the coupling of physical entities as well as the relationships that exist between those entities. As a system functions, formal and informal relationships are forged among people, technology, and implementing mechanisms. The products of these interrelationships produce the unique system patterns that permit the system (organization) to maintain viability. These relationships occur through mechanisms of interaction. For example, a weekly staff meeting of a R and D department would be considered a structural mechanism that allows relationships to be forged.

In sum, the systems view suggests that structure includes the physical entities as well as the relationships (formal and informal) that emerge through mechanisms (mediums of interface) that facilitate interaction. The particular arrangement of the total set of formal and informal mechanisms that allow an entity to function (i.e., maintain a balance of tensions in response to shifts in environmental conditions) constitutes the 'system structure' for an R and D organization. The essence of structure, from the systems perspective, is to integrate people and technology through relationships that pursue desired purposes.

To support the system view of R and D structure, and the subsequent framework development, there are several concepts from systems science that are essential. These concepts are summarized in Table 1 and expanded in Katina [37] and Whitney et al. [38].

Table 1. Systems concepts for R and D structure.

Systems Concepts and Reference	R and D Structural Implications
Emergence [39]	The R and D structure may exist in an unstable environment and be subject to emergent behavioral, structural, and interpretation patterns that cannot be known in advance and develop over time—despite the most well intended emphasis on thorough design.
Mechanism [29]	Mechanisms are the vehicles through which the R and D system structure functions—executed through relationships among people within the system. In essence they are structural artifacts, that may take the form of procedures, processes, or relationships (formal or informal).
Complementarity [40]	There exist multiple perspectives of the R and D structure. Each perspective is both correct and incorrect, depending upon the vantage point from which the structure is viewed. Consistency in decision, action, and interpretation is a result of congruence of perspectives.

Table 1. *Cont.*

Systems Concepts and Reference	R and D Structural Implications
Pluralism [41]	There may exist widely divergent, potentially tacit, expectations with respect to the purpose and nature of the R and D structure—potentially detrimental to performance or alignment. This challenges untested assumptions of unity (singularity) of purposes.
Incompleteness [42]	Our understanding of a R and D structure can never be complete and is always fallible. New structural knowledge will increase through operation of the structure, potentially rendering previous knowledge obsolete
Boundaries [42]	The boundaries, and boundary criteria, for R and D organizational structures are dynamic and must evolve with new understanding. Assumptions of unambiguous, unchanging, and definitive boundaries and boundary conditions are illusionary at best.
Context [43]	The more complex a R and D organization, the higher the potential to experience "soft" (e.g., political) influences that lie beyond traditional views of structure to capture or address.

In summary, from a systems view, structure is taken broadly to encompass both the physical entities as well as the patterns of relationship that emerge from the interaction of those entities [44]. Every R and D organization, regardless of size or purpose, has: (1) a unique system structure; (2) a level of system performance and achievement of objectives produced by the operation of that structure within the specific environment and context of the organization; and (3) potential structural inadequacies which limit performance and can be experienced as an imbalance among the structural tensions, as shown in Figure 1. Therefore, it is essential that R and D managers are aware of the influence of structure and have a deeper level of understanding of implications for design, analysis, and evolution of R and D organizational structure. Subsequently, the following section discusses the development of a framework, drawn from systems theory and cybernetics, to provide R and D managers a more informed perspective for design and analysis of structure.

5. Systems-Based Framework for R and D Structural Design and Analysis

Systems science provides a robust theoretical foundation for understanding system structure. Probably the most well-known systems science theory of structure is the Viable System Model (VSM) [7,8,36]. The VSM offers a comprehensive systems perspective of structure and has been successfully applied to understand structure in a variety of organizational settings ranging from business to non-profit enterprises. The VSM is particularly appropriate for R and D organizations since it provides a template for structuring new operational designs as well as diagnosing existing operational structures. The VSM achieves balance of the system structural tensions through design of a set of functions that must be performed by any system to maintain viability (existence). Viability, according to Espejo et al. [29], is maintained by a system if "it is capable of responding to environmental changes even if those changes could not have been foreseen at the time the system was designed" (p. 105). In effect, the VSM guides effective system designs for organizations that must be sufficiently robust to operate in highly turbulent, uncertain, and shifting environments. The degree to which a system accounts for and executes the VSM system functions determines the efficacy of the system structure and ultimately influences the level of system performance.

The VSM is focused on two primary concerns with respect to system structure. First, the VSM considers the arrangements of the structural entities that perform the essential functions of a viable system. Beer [7,8,36] identifies six primary system functions essential to viability of an operational system. These functions, identified as systems within the VSM, include: operations, co-ordination, control, monitoring, development, and identity (policy). The second concern of the VSM is the flow of information (communications) that maintains the relationships necessary to carry out the viable system functions. Functions and communications are achieved via mechanisms (artifacts designed and executed to perform functions or provide for communications).

Based on the seminal work of Beer [7,8,36] and supplementary expositions by Espejo and Harnden [45], Espejo, et al. [29], Jackson [28], and Flood [46], an overview of the VSM functions follows. These functions are necessary to retain system viability for any system, including R and D organizations (systems). Stemming from application experiences [47], the VSM was supplemented with an additional system, System 4 * (read: System 4 Star), to address learning as a viable system function. Figure 2 presents the VSM structure and systems within the model.

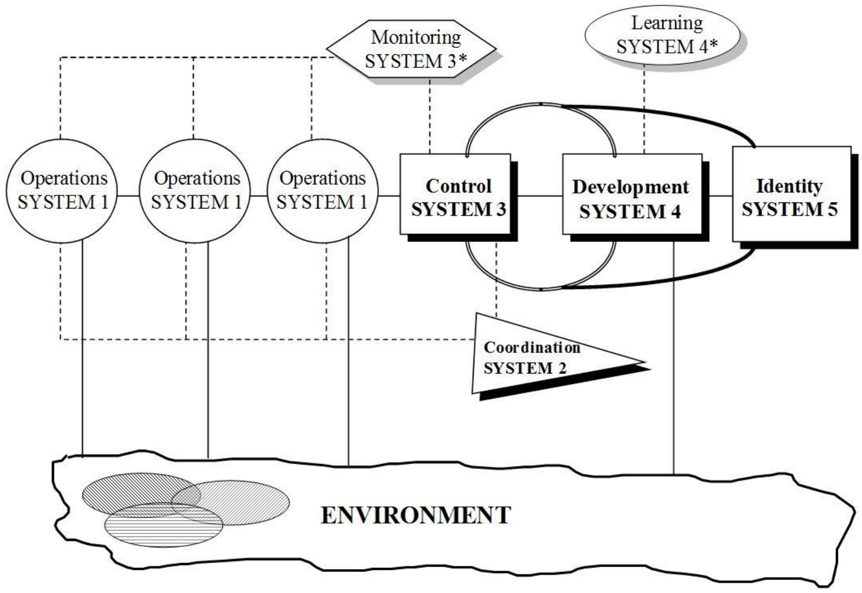

Figure 2. The structure of the Viable System Model.

5.1. System 1—Operations

This VSM system functions to produce that which provides extrinsic value (products, services, information) consumed by the environment. The remaining functions of viability exist to facilitate System 1 production of products, services, or information. For example, in an R and D organization, System 1 entities might include particular research areas or product lines. Each System 1 has an internal management function responsible for the organization of System 1 to perform work, thereby posturing each System 1 as a semi-autonomous unit within the larger system (metasystem). There can be multiple System 1s in a viable system and they can be added or eliminated with minimal impact on the structural configuration, based on changing circumstances. For example, an R and D organization might acquire a new technology for development. That would not require a new system structure, but rather simply add an additional 'System 1' to the organization.

5.2. System 2—Co-Ordination

This VSM system provides system stability by synchronizing the different operational entities (System 1s). System 2 prevents unnecessary oscillation (resource waste) due the potentially uncoordinated activities of the different System 1 entities. For example, standardized procedures, cross-functional planning groups, and standards groups are examples of structural mechanisms designed to accomplish System 2 functions.

5.3. System 3—Control

System 3 functions to maintain operational performance on a day-to-day basis. As such, this system provides for the execution of policy, distribution of resources, and accountability. The focus of System 3 is internal to the system. Traditional day-to-day management of operations, including activities such as planning, operational decisions, and resource allocation would be considered System 3 activities. For example, making system level decisions concerning R and D capital budget allocations to support operational priorities would be a System 3 activity.

5.4. System 3 *—Monitoring/Audit

Within System 3 is a separate system to provide monitoring of operations for problems or deviations in performance. The primary function of System 3 * (read System 3 Star) is auditing of operations. System 3 * performs both routine and sporadic audits of problematic areas. For example, review of compliance to new safety standards (routine audit) or an examination of the failure to meet agreed upon performance standards (sporadic audit) are both examples of performing a System 3 * monitoring activity.

5.5. System 4—Development

System 4 captures and interprets environmental information. The environmental information is intelligence that is interpreted for operational as well as strategic implications. The focus for this system is directed externally and to the future, primarily concerned with gathering and processing environmental intelligence. Strategic planning, environmental scanning, recruitment, and socioeconomic trends assessment, and emerging technology evaluations are examples of System 4 activities.

5.6. System 4 *—Learning and Transformation

This system provides for purposeful learning and guides exploration of system transformation implications. System 4 * learning is concerned with errors which are rooted in an inadequate system design, as opposed to faulty execution of the design. Errors are produced when the expected results of system operation are incongruent with what actually happens. While System 3 * is focused internally on deviations in operational performance, System 4 * questions errors which may be a consequence of a faulty system design. The correction of System 4 * identified errors requires modification in the operational system or transformation of the entire system. For example, a new breakthrough technology with potential impacts on R and D productivity or priorities would be a candidate for a System 4 * inquiry and potential modification of structural design.

5.7. System 5—Identity

This system assumes responsibility for the strategic decisions and direction that maintain the identity of the system. Identity consists of those unique characteristics and attributes that differentiate a system from all others. Additionally, this system monitors and maintains a balance between the long-term external focus of System 4 and the short-term internal focus of System 3. The opposite foci of Systems 3 and 4 create a natural and predicted tension. System 5 monitors and directs appropriate balance between present operational concerns and future development considerations. Establishment of long-term vision, mission clarification, strategic investment decisions, and corporate policy development are examples of System 5 activities.

The second critical aspect of the VSM is information flow (communications) within the viable system. Communication occurs through channels. These channels provide flow of information through mechanisms, which permit relationships to be established in support of maintaining system viability. Based on Beer's [7,8,36] work with the VSM, the primary communications channels, their function, and example mechanisms are provided in Table 2. The table also includes several additional channels (identified by asterisks) that have been added based on experiences in application of the VSM [48].

The design for communication channel mechanisms focuses on four primary considerations: First, there must be a sufficient 'set' of mechanisms present to fulfill the function of each channel. This ensures that each aspect of communications viability is purposefully considered. Second, each specific mechanism deployed to achieve each communication channel function is evaluated for effectiveness during system operation. A comprehensive set of mechanisms that is poorly executed is still ineffective. Poorly functioning communication mechanisms waste scarce resources. Third, the communication mechanisms (formal and informal) must be selected for compatibility with the organization, context, and managerial style. Incompatible communication mechanisms are also likely to be ineffective. Fourth, as the R and D organization matures, so too must the communication mechanisms evolve in light of changing circumstances. It is unlikely that the same mechanisms will be appropriate throughout the life cycle of the R and D organization. Therefore, communication channels and supporting mechanisms must be continually evaluated for appropriateness, effectiveness, and efficiency.

Table 2. Communication channels in a Viable R and D system structure.

Communication Channel	Primary Functions	R and D Organization Examples
Command	Provides direction to operational units Primarily from the System 3 (control) function to the System 1 (operations) function	Direction for new regulatory reporting Organization wide policy directive New technology standards
Resource bargain/ Accountability	Provides/determines the resources (manpower, material, money, information, support) for operational units. Primarily directed between System 3 and System 1. Defines performance levels to which operational units will be held responsible Determines how operational units will report and be held accountable for performance requirements	Capital budgeting process Resource allocation procedures Performance measurements Quarterly performance review Annual performance objectives
Operations	Provides for the routine interface between operational units and from System 3 to System 1s. Direct link between System 1s without external interference or monitoring	Staff meeting Activity Resource Procedure
Coordination	Provides for system balance and stability by ensuring that information concerning decisions and actions necessary to prevent disturbances are shared among operational units. Also, establishes standardization necessary to prevent oscillation	Information technology Standardization Interface protocols Common job descriptions and promotion protocols
Audit	Provides routine and sporadic feedback on the performance of selected operational attributes Reports and investigates areas identified by the System 3 function as problematic. Primarily a System 3 * channel for communicating between System 1s and System 3	Financial audit Performance variance inquiry Safety compliance audit Product liability investigation
Algedonic	Provides instant alert to crisis or potentially catastrophic situations Direct from any system entity to the policy/identity function. Bypasses routine communications channels and structure	Catastrophic event notification Legal or ethics violation Potential Unforseen Opportunities System security breech Notification
Environmental Scanning	Provides for continuous monitoring of the system environment to identify trends, patterns, events, or activities with potential impact to the system Senses shifts in the environment and captures implications for the system (postitive or negative)	Periodic environmental analysis Diagnostic assessment of technology trends Future environment scenario analysis
* Dialog	Provides examination and interpretation of organizational decisions, actions, and events Aligns perspectives and creates shared understandings in light of system purpose and identity Permits exploration to challenge legitimacy of decisions and actions consistent with identity	Critical decision forum Town hall meeting Failure review and analysis System performance discussion
* System Learning	Supports the System 4 * function Provides detection and correction of system errors, testing of assumptions, and identification of system design deficiencies Continual questioning of adequacy of system design and execution for transformation implications	Conference impact review External customer discrepancy review Project performance critique
* Informing	Designed to provide routine transmission of information throughout the system. Captures and disseminates information not appropriate for other channels	Electronic newsletter Annual report Weekly staff briefing Town hall meeting
* System Identity	Supports the System 5 function Provides for questioning the nature and purpose of the system Establishes the mechanisms for purposeful exploration, maintenance, and evolution of the identity for the system	Annual strategic retreat Internal leadership conference Governing council Values clarification forum

There are several important concluding points concerning the VSM value and significance for the structure in R and D management:

1. Every organization has a unique structure that must achieve basic system functions (operations, management, development, co-ordination, etc.) and find the appropriate balance in the design, change, and control structural dimensions.
2. Structures consist of physical entities as well as relationships, both those that are purposefully designed, as well as those that are emergent. This structure must accomplish basic functions to maintain existence (viability) of the system.
3. The execution of structure occurs through mechanisms (technical vehicles that sustain relationships within and external to the system) that achieve system functions and communications.
4. The appropriateness of a unique structure is determined by the ability of the structure to maintain viability (continued existence) in response to changing conditions over time. Additionally, trajectory toward a desirable organizational future must be supported by an evolving structure.
5. To remain viable, a system structure must retain a fit to the environment that permits continued achievement of objectives in the face of environmental turbulence. Inability to maintain this fit produces structural imbalance in the relevant tensions.
6. A structure is obsolete when it can no longer maintain viability or achieve operational objectives at desirable levels of performance.
7. Communication mechanisms, within and external to the system, must be designed for compatibility with the organizational context, as well as completeness, in fulfilling communication channel functions.

6. Application of the Framework for R and D Structure Design

Drawing from the systems-based framework, a design for a multidisciplinary R and D center was established. The approach was a collaborative effort to address the challenge, *how do we best design the center structure to achieve R and D excellence?* Struggling with this question, the VSM was taken as a more informed framework to guide structuring the center (The name of center in question is removed for anonymity purposes). The VSM framework had previously been used as a basis for a similar, but smaller, multidisciplinary R and D center development. Therefore, there was a familiarity with the framework, application issues, and design considerations for developing the structure for another R and D center initiative. Several key results from the design effort are summarized in this section. Elaborate details of the design or the design process are omitted. Instead, the discussion is focused on presenting the center structure in contrast to the VSM in a manner that will provide high level understanding of the contributions this approach provided for the difficult questions regarding structuring an R and D organization. Thus, the unique design for achievement of the VSM viability functions are the primary subject of discussion. Figure 3 below is a representation of the different specific functions for the R and D structure based on the VSM.

The application of the framework begins with a brief context for the R and D center design development. The R and D center design was established to support fundamental and applied multidisciplinary research with the following mission: *Stimulate development, interpretation, dissemination, and integration of core knowledge to inform and enhance practice, policy, decision, and research capabilities to most effectively address complex issues in border security and immigration.* There were three supporting objectives established to guide the center's development:

a. Access for practitioners, decision-makers, policy-makers, and researchers to the most advanced knowledge and expertise in border security and immigration.
b. Leadership in multidisciplinary border security and immigration research and education that defines excellence for research and practice.
c. Leverage research investment through effective governance of intellectual, fiscal, extended research network, and operational activities that promote excellence in border security and immigration.

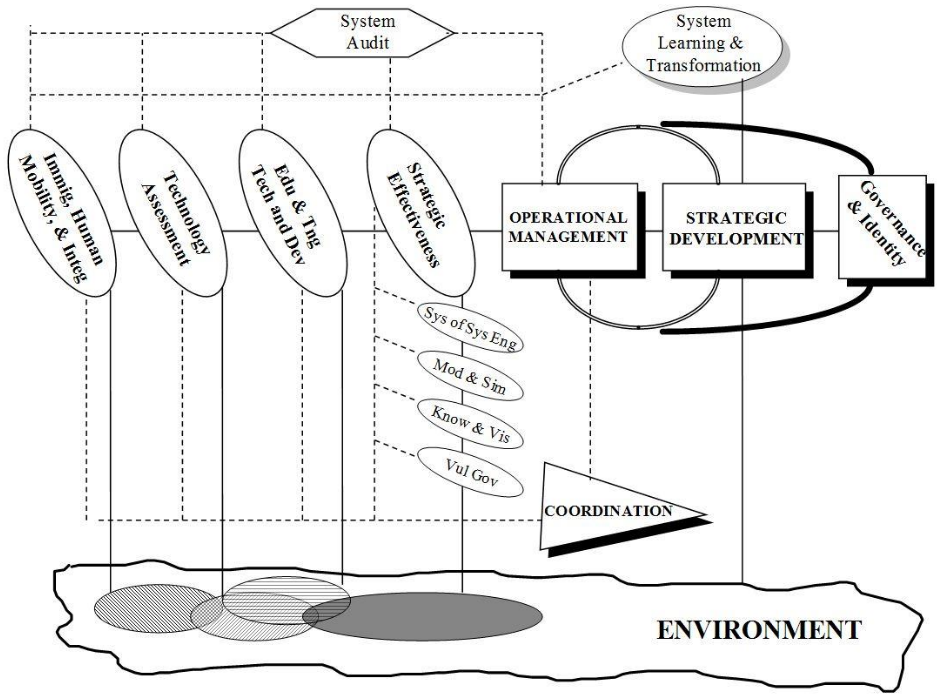

Figure 3. Structural configuration of the R and D center.

The structural design for the center had to integrate 15 research entities (geographically separated), across seven major research areas, and eight multidisciplinary research projects. Our discussion of implementing R and D structure designed to support the mission and objectives is organized around two development themes: (1) the high-level VSM-based structural functions for the R and D center; and (2) the function of communications for the R and D center.

6.1. High-Level Structure for R and D Excellence

The presentation of the structural configuration is provided in the Table 3. The structural configuration identified four primary System 1s for the R and D Center of Excellence. The System 1s included: (1) immigration, human mobility, and integration; (2) technology assessment; (3) education and training: technology and development; and (4) strategic effectiveness. In addition, the Strategic Effectiveness System 1 was further expanded into (Subsystem 1s under strategic effectiveness), including system of systems engineering, modeling and simulation, knowledge and visualization, and vulnerability governance. in addition, the supporting design for coordination (system 2), operational management (System 3), monitoring/audit (System 3 *), strategic development (System 4), learning and transformation (System 4 *), and governance and identity (System 5) were developed.

Table 3. VSM structural configuration for the R and D Center.

VSM Functions	Structural Responsibilities
System 1s—Productive Functions	*Assessment and maintenance* of the state of the knowledge in their area, including available, emerging, and horizon knowledge, *Identification* and publication of knowledge implications for border security and immigration, *Joint examination* of knowledge implications, internal/external to the R and D center, for potential leverage, *Perform breakthrough research*, within scope, to enhance border security and immigration performance, and *Identification of educational/training implications* and potential products for propagation within federal, state, and local agencies involved with border security and immigration
System 2—Coordination	Establishes and maintains coordination among R and D center major research areas Ensures efficiency by identifying unnecessary or redundant resource use across major resource areas and available/accessible research infrastructure Identifies R and D center integration issues for major research areas Identifies and manages emergent conflict and coordination standards within major research areas

Table 3. *Cont.*

VSM Functions	Structural Responsibilities
System 3—Operations	R and D center planning and control for ongoing day to day center operational effectiveness, Develop near term R and D center design response to evolving operational issues and monitor performance measures Operationally interprets and ensures implementation of the R and D center policies and direction Interpretation and translation of implications of environmental shifts for operations Provide resources, expectations, and performance measurement for operational performance Design for accountability and performance reporting for operations
System 3 *—Monitoring/Audit	Provides sporadic feedback on operational performance Investigation and reporting concerning deviant performance, conditions, and trends
System 4—Development	R and D center system planning for long range strategic development and integration Environmental scanning, analysis, and interpretation of environmental shifts and their impacts Maintenance of models of the R and D center environment, current R and D center design, systemic barriers, target transformation objectives, and future R and D center directions Analysis and action implications for the R and D center based on environmental scanning Disseminates essential environmental information and shifts throughout the system Interpretation of strategic direction implications stemming from environmental scanning, governance direction and strategic analysis Designs for establishment and expansion of the expanded the R and D center network Scanning of the center and wider environment for changes/trends
System 4 *—Learning & Transformation	Coordinates orderly learning, evolution, and transformation of R and D center system. Collects and disseminates knowledge throughout the center. Maintenance of system strategic performance and achievement status Suggests adjustments for the R and D center's system transformation in conjunction with operational performance Primary channel for dissemination of environmental and contextual information and implications for the security system operation
System 5—Governance and Identity	Establishes and maintains the R and D center's identity in the face of changing environment and shifting context Defines, clarifies and propagates the R and D center's vision, strategic direction, purpose, mission, and interpretation Active determination and balance for the R and D center's focus between present and future requirements; fundamental and applied research Establishes R and D Center policy direction and maintains strategic identity of the R and D center—executed through strategic direction Represents the interests of the R and D center to external constituents Integrates the expanded network for the R and D center

6.2. Function of Communications for the Center

With respect to communications, the design for the center focused on achieving one principal objective. This objective was to establish a sufficiently robust set of initial mechanisms to provide for each of the channels identified. Only after operation of the center and deployment of the mechanisms would adequacy (contribution) of each of the mechanisms be determined. For illustrative purposes the communication channel mechanisms designed for the resource bargain-accountability channel are identified (Table 4).

Table 4. Resource bargain: accountability channel communication mechanisms.

Communication Channel	Communication Mechanisms
Resource Bargain—Accountability Channel	*Assigned Budget*—negotiated with each System 1 for work to be performed. Monthly progress for budget reported. *Measures of Effectiveness Contribution*—agreed upon standards that establish the degree to which the R and D Center is meeting its purpose and the particular contribution of each System 1 *Measures of Performance*—established metrics to track performance in pursuit of objectives for each functioning System 1 *Expectation Summit*—system level exploration of performance expectations and resource consistency with expectations *Research Budgeting Process*—establishment of expenditure allocations in support of strategic investments and objectives profile

7. Conclusions and Implications

The design for the R and D center structure provided several insights into the design of the structure for R and D organizations. First, the systems-based framework demanded a 'holistic' consideration of the structural configuration. Beyond thinking in terms of organizational charts or matrix configurations, the framework forced a deeper consideration of fundamental structural issues that had to be accounted for in the initial design. Each VSM function had to be accounted for in the design. Second, the logical relationships among the productive (System 1s) entities for the center had to be purposefully designed to balance the natural tension between self-organizing autonomy and system-level integration. Third, the communication channels required a thoughtful establishment of the design considerations with respect to interface, accountability, and expectations. This was instrumental in surfacing critical interface issues early in the design stages, where modification entailed minimal disruption. Fourth, the completeness of the design considerations provided for an adaptive structure, capable of adjusting to changing circumstances and conditions. By having a 'complete' structure, modification of specific mechanisms can be accomplished without impacting the 'holistic' integrity of the structure. Functions/channels remain the same in the wake of modifying specific mechanisms to achieve them. The importance of this point is critical. The VSM design permits stability while also allowing for changes based on shifting circumstances. This ability to support a dynamic stability in the face of turbulence is a central strength of the VSM approach to design and maintenance of system (organizational) structure. In effect, both stability and change are simultaneously supported.

Developing an appropriate and effective structure is one of the most vexing tasks for management of R and D organizations. Through the application of a systems-based framework a deeper level of purposeful design and analysis of R and D structure can be achieved. For the remainder of this section discussion will focus on the utility and implications of the framework for R and D managers faced with the dilemma of designing or analyzing structure.

Every R and D organization has a structure. Structure is largely responsible for realization of the potential capacity to perform. The responsibility for design, analysis, and maintenance of the structure exists as an R and D management function. Therefore, deeper understanding and appreciation of structure is essential to more effective R and D management. A framework, based on management cybernetics and systems theory was introduced as a means of more effectively designing the structure to deal with the increasing complexities faced by R and D organizations. The essence of this framework is to provide a rigorous accounting of system functions and communications channels essential to high performance. It is important to note that, just as every organization is unique, so too must the corresponding structure be unique. The power of the systems-based framework is that is does not specify 'how', or to what 'degree', the functions must be achieved. On the contrary, the framework only specifies 'what' must be achieved for a system to maintain viability. The utility of the framework is to guide R and D managers through a more robust accounting of structure and tailoring to the uniqueness of their particular organization and environment. While each R and D organization must perform the functions, precisely how they achieve those functions is as unique as their organization and its particular circumstances.

The simplistic nature of system structure is that it produces performance (behavior), enacts strategic intent, and largely determines what the organization can and cannot achieve. When performance falls below expectations, the structure should be among the first suspects. In effect, a system (organization) structure can only produce what it is producing. If the system is failing to meet expectations, structure is a logical first place to look for the source of performance issues. The systems-based framework developed in this work provides an effective starting point to assess structural adequacy in light of undesirable performance.

There are several pathologies [6,37] that might be indicative of structural problems, including such problem areas as: (1) failure to meet productivity targets; (2) organizational 'turf' battles over responsibilities, authorities, and accountabilities; (3) diversion of resources during crises that cause future focused activities to be sacrificed; (4) management 'meddling' in the affairs of subordinate units; (5) poor communications, and (6) high levels of ambiguity and uncertainty disrupting productivity. Although every organizational problem is not necessarily a structural problem, structural analysis and development may preclude unnecessary expenditure of resources and human capital.

The responsibility of R and D management for structure is critical. To assist in execution of this responsibility, the systems-based framework provides a rigorous starting point. The application of the framework has shown how it can support 'holistic' design and analysis of structure. Examination of the structural configuration and execution can offer help to provide structures that are more conducive to higher productivity in R and D organizations. Flexibility, adaptability, and responsiveness are characteristics embodied by sound systems based structures that must exist in increasingly turbulent environments. In addition, the framework can also assist R and D managers in diagnostic analysis of organizational issues that may be rooted in deeper structural inadequacies or incompatibilities. Finally, structure is not a one-time effort. Rather, R and D managers must view structure as an artifact that requires continuous maintenance. Otherwise, the structure runs the risk of becoming obsolete in the midst of changing context and environment of the organization. Structure must evolve and adapt as the organization and its environment change. Otherwise, the structure will eventually become inconsistent with the demands of a changing environment and context.

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