ARTICLE

Understanding Defense Industry: A Systems Thinking Perspective

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Abstract

The defense industry can be thought of as a complex system of intense interactions between humans and high-tech machines, platforms and data systems with a large number of dynamically interacting variables. Within the defense industry, many complex decision-making processes take place, in which even very intelligent and highly educated people often make poor decisions due to failure to grasp this complex system as a whole, and/or by using linear or deterministic methods. The present study is structured to offer decision-makers, researchers and practitioners dealing with defense industry subjects new perspectives. The development of new mental models requires new perceptions and even confrontations between different perceptions. The most distinctive developments begin with creative ideas that are the outcomes of particular mental models. The defense industry is among those that continuously seek innovative approaches, creative ideas and new solutions. A systems thinking approach, together with Viable Systems Model (VSM) and system dynamics methodologies is one such innovative approach. One successful application of systems thinking—NATO's Aggregated Resilience Model—can be considered a benchmark in the development of new mental models and creative solutions. The inevitable decision support needed by policy- and decision-makers who pursue innovation in the defense industry can be met by the "systems thinking" approach discussed in this article.

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Introduction

Defense and security are among the paramount areas of global concern today. Looking at the big picture, defense and security issues are so far-reaching that almost all of humanity feels the effects of the concerns, as well as the outcomes produced in this area. This expansive area is addressed by a unique and complex industry—the defense industry—that incorporates boundlessly interconnected agents. The profile of these agents varies from ordinary citizens to superpowers and global stakeholders. Beyond this, the defense industry is a perpetual cornerstone industry in many nations, pioneering different domains such as technology, economics, education and training, standardization, modeling and simulation. Its pioneering role increases the attractiveness of the defense industry. Countries allocate considerable amounts of money to this sector and try to equip their armed forces with up-to-date capabilities, first to maintain their existence, and second to provide and sustain the appropriate conditions to protect their interests by reducing risks in the future in line with their policies and strategies. The multi-domain feature of the sector and the number and variety of the stakeholders seeking new business opportunities and potential investment areas within it add to the defense industry's complexity.

The management of a highly complex and attractive industry deserves exclusive attention. And given its complexity, a holistic understanding must be the starting point for studying and analyzing the industry; the results of fragmented efforts focusing on different parts of the industry, and even the synthesis of disconnected efforts, may not lead us to value-added inferences. Without a holistic perspective, decisionmakers and other authorities might face the risk of making faulty judgments when determining defense industry-related investment decisions in various dimensions such as research and development, training and education, personnel, technology, platforms and systems, infrastructure, etc.

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Having framed the defense industry from a broad perspective, then, we aim to take a closer look in order to offer an innovative approach in this article. This study has been structured to contribute to a process whereby decision-makers, researchers and practitioners dealing with defense industry subjects can gain new perceptions. The development of new mental models requires new perceptions and even the confrontation of different perceptions. The most distinctive developments begin with creative ideas that are the outcomes of particular mental models. The defense industry is among those that continuously seek for creative ideas and solutions.

Given the ever-changing, dynamic conditions of the defense industry, traditional techniques and tools are insufficient. Therefore, we need to take a holistic approach that takes into account an understanding of those dynamic conditions and domains interactively and concurrently. Within the context of the defense industry, holism, meaning a comprehension of the interconnectedness and interrelatedness among all the parts that make up the whole, is a critical concept.[1] In this article, systems thinking, viable systems model (VSM) and system dynamics are discussed and recommended as an innovative and holistic approach and methodology. Systems thinking focuses on revealing the parts of complex structures and their relationships, examining different perspectives toward complex structures, and addressing power relations and potential conflicts of interest among related agents.[2] System dynamics methodology facilitates the policy determination process in the management of complex system behavior over time, as well as the policy application process for adapting to a complex environment.[3] System dynamics models provide foresight about situational behavior changes in a system over time. Importantly, the what-if scenario capacity of the model discussed in this study enables creation of alternative decisions for the policy makers.

Unique Features of the Defense Industry

The key outcomes of the defense industry are the generation and sustainment of "readiness" and "operational availability." The production of these critical outcomes requires addressing various dimensions and their interactions within the defense industry. This unique industry, consisting of intense interactions between humans and machines (high-tech platforms and systems) shall be taken as a complex system.

The complexity of the defense industry mainly stems from two challenges: (1) to educate and sustain highly skilled personnel and (2) to manage cost, schedule and risk factors during the development, acquisition and operation of integrated military systems. Moreover, the defense industry differs from other industries due to its unique features:

- High stakes, since the payoff of the defense industry's outcomes consists mainly of people's lives;
- The constant need for sustainable, strategic guidance;
- The involvement of high-tech systems, most of which are developed solely for their unique purpose within the industry and are not commercially available;
- The need for highly qualified personnel, who are indispensable yet expensive to employ;
- Time-lag; there is always a delay between taking an action and seeing its results (i.e., the outcomes of R&D or an acquisition may take several years);
- High standards; the defense industry sustains its viability only by adhering to strict international and military standards;
- High-level expectations and ever-changing requirements on the part of end users;
- Strict quality-control, testing and acceptance processes and procedures;
- Scarce resources, the use of which is always disputable;
- The demand that stakeholders produce the most from the least;
- Unique rules in the areas of economy, acquisition and competition.

As a highly complex system, the defense industry inherently involves many complex decision-making processes through which even very intelligent and highly educated people often make poor decisions by failing to see the whole picture, and using linear and/or deterministic methods.[4] Linear and deterministic approaches assume that managers live within a stable environment and are able to make reasonably good decisions about the future.[5] Most of the people dealing with the defense industry have a propensity to focus on tactical-level quantitative data and miss the strategic-level qualitative factors. Moreover, there are times when the problems managers are experiencing are themselves a consequence of flawed mental models. In these situations, managers rely on the wrong set of assumptions and inferences to make decisions that do not solve problems and often make matters worse.[6] So, as the defense environment becomes more complex, the defense industry by its unique structure and features has no other choice to but adapt to this environment.

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The management of these challenges requires good conceptualization and contextualization practices, as traditional engineering and management implementations may fall short.[7] In the defense industry, decision- and policy-makers require innovative approaches to deal with the complex systems for which they are responsible. Hence the need to adopt a holistic approach considering different defense industry domains interactively and concurrently. At this point, among other views, the systems thinking approach and the system dynamics methodology take the stage as a modeling means for understanding strategic and complex phenomena and providing coherent world views[8] and thus policies for defense industry decisionmakers through scenario-based models (what-if analysis). This simulation method is based on calculus, and models of real-world dynamic processes are constructed using integral equations.[9] These simulation models use highly precise values and generate numerically accurate results; this functionality can be used by decisionmakers as "answer generators" for their area of interest.[10]

The first applications of systems thinking started to mature during and after World War II, and basic ideas were put forward in this period. The theorists of these approaches worked independently of each other in different disciplines; consequently, they focused on different problems, and various approaches emerged around systems thinking. The common point between them is that they focus on mutual relations rather than linear cause-effect relationships in scientific studies, and on the process of change rather than static situation assessments.[11]

Evolution of the Defense Industry via a Systems Thinking Approach

Systems may be understood as "coherent wholes" that consist of interrelated sub-systems and parts.[12] The interrelations (feedback loops) within a system, by virtue of their dynamic features, add complexity to that system. While the parts keep their individual importance within a system, the focus in systems thinking shifts to studying the whole system and the systemic behaviors of its various parts.[13] Complex systems with feedback loops and non-linear interrelations can be best understood via the systems thinking approach—and systems dynamics methodology—rather than deterministic techniques.[14] Deterministic methods have inadequacies when it comes to coping with complex systems such as social systems and defense systems. In contrast, systems thinking as a broad approach has the potential to tackle complexity. The systems thinking perception guides us to not break up a complex phenomenon into parts to fully understand it, but to deal with the phenomenon with a global vision to understand how it functions.[15] The core of the systems thinking approach is more about gaining the capacity to see the big picture[16] and creating new mental models—namely strategic planning itself—rather than making forecasts and projections. Systems thinking offers a robust perspective, a specialized terminology and a set of tools that has been proving its capacity with various successful implementations in different areas—including military and defense systems.[17]

The main difference between systems and traditional thinking is the dominance of reductionist and dogmatic approaches in traditional thinking, whereas relations, ecosystems and creative solutions are prioritized in systems thinking.[18] While traditional thinking techniques are analytic, system thinking techniques are synthetic.[19] However, it would not be wise to reduce one of these complementary approaches to the other.[20] For instance, the cybernetic approach falling in the system thinking context proposes a framework in which both analysis and synthesis are done concurrently.[21]

Rosnay states that the analytic approach foresees that making a change in one variable helps us understand the whole system, but this prediction can only be true for homogeneous systems. The most important weakness of the analytic approach is that the interrelations among parts are discounted,[22] and the system is not discussed as a whole. Rosnay emphasizes that the analytic approach might be weak when it comes to understanding complex systems.[23] A system is broken into sub-parts and is focused on differences among these parts in the analytic approach, while system thinking focuses on the commonality of parts and investigates patterns or models.[24] Thus, time-based changes in real world cases can be translated into models, and real-time intuitive forecasts can be developed by the adaptation of these models with the real world.[25]

In order to understand problems and find solutions, linear modelling may be sufficient for systems that have simple relations among parts, whereas system thinking and evolutionary modelling techniques are appropriate for more complex systems.[26] Table 1 summarizes some of the salient differences between traditional thinking (i.e., linear, classic or deterministic thinking) and systems thinking.[27]

Table 1: Differences between Traditional Thinking and Systems Thinking

Traditional Thinking	Systems Thinking
Isolates the system, disassembles it and focuses on it.	Takes the system as a whole and focuses on interaction among the parts.
Examines the nature of interactions among parts.	Investigates the effects of interactions among parts on the system.
Focuses on the accuracy of the details of system components.	Takes a holistic view of the system.
Predicts a change in a variable at a given moment.	Simultaneously predicts a change in a group of variables.
Uses time and events in a reversible way.	Uses time and events realistically, i.e., irreversibly.
Tries to verify the facts experimentally within the theoretical framework.	Tries to verify the facts by comparing the created model to reality.
Uses detailed, rigid models that are difficult to implement in real life.	Uses general, soft models that can be implemented easily.
It is effective when interactions among parts are linear and weak.	It is effective when interactions among parts are dynamic and strong.
Directs to individual discipline-oriented education.	Directs to multidisciplinary education.
Foresees application of detailed plans/programs.	Foresees goal-driven applications.
With the knowledge of the details, there are targets that are not fully defined.	Fuzzy details are available with the knowledge of goals.

Source: Joel de Rosnay, *The Macroscope: A New World Scientific System*, New York: Harper & Row, 1979, p. 74.

Among the methodologies employed to understand and define complex systems, the use of Viable Systems Model (VSM) and System Dynamics (SD) has expanded through many applications in various areas and industries. VSM is a functional tool that is very powerful in defining and developing the generic structure of complex systems, whereas SD is very useful in understanding the complex relationships and behaviors of components of a whole system.

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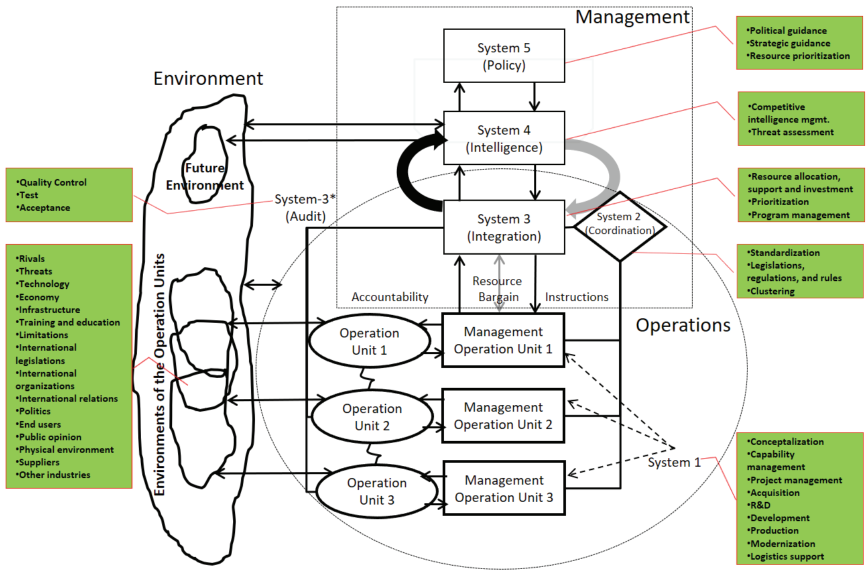
VSM, developed by Beer, can be defined as a tool for modeling an organizational structure by taking the human nervous system as a base model. The model consists of Operational Units, Meta System and Environment. System 1 (Operation) consists of autonomous units that execute main functions and processes to produce outcomes. System 1 can also be called 'system-in-focus.' System 2 (Coordination) are regulatory mechanisms that facilitate the coordination and integration of all the autonomous units' work and reduce possible conflicts among these units (i.e., information systems, production plans, programming tools, processes, procedures, etc.). System 3 (Integration) helps System 1 produce outcomes in coherence with the defined policies and strategies. System 3 allocates resources and creates synergy. System 3 also controls and evaluates effectiveness and efficiency by collecting data via its sub audit system, System 3*. System 4 (Intelligence) consists of mechanisms that observe and analyze the current situation and all possible future states, and making operational and strategic projections in order to adapt to the external environment. System 5 (Policy) is the highest level mechanism where policies and strategies are defined, interactions are managed between System 3 and 4, and an indirect relationship is established with System 1.[28]

VSM considers that all systems resemble each other because of the recursiveness feature. The capacity to understand and analyze complex systems and discuss those complex systems as analyzable and manageable recursive systems make VSM a robust analysis tool.[29]

Figure 1 illustrates the generic structure of the defense industry from a systems thinking perspective. This structure focuses on the essential dimensions and factors that must be considered to define a seamless and viable defense industry. Regardless of its area of activity, a viable defense industry can be constructed, reconstructed or evaluated via its environment and the five main systems provided by VSM, such as policy, intelligence, integration (and audit), coordination and operation.

Figure 1: Defense Industry Generic Structure



Source: Jose M. Perez Rios, *Design and Diagnosis for Sustainable Organizations*, Berlin: Springer-Verlag, 2012.

The defense industry operates in an open environment in which a plethora of factors and agents interact dynamically. These dynamic variables include rivals, threats, technology, economic factors, training and education, limitations, international legislation, international organizations, international relations, politics, end users, public opinion, physical environment, suppliers, other industries, etc. Strategic direction and guidance, in which political, strategic and resource-related priorities are clearly delineated, are needed as the starting point for a viable defense industry. In accordance with this guidance, a robust mechanism should continuously observe the operating environment (including the variables noted above) to execute intelligent threat assessment and management. Having made the necessary assessments, an integration function should be in place, wherein resource allocation, support, investments and prioritizations are made through a program management discipline. At the operation level of the defense industry, relevant stakeholders such as requirement authorities, acquisition bodies, main contractors and sub-contractors implement the primary processes (conceptualization, capability management,

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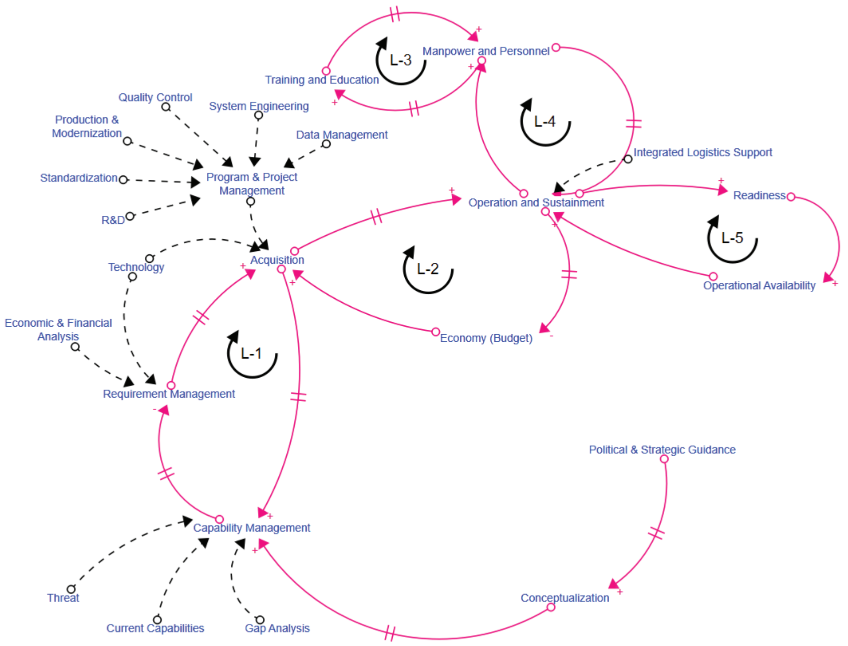
project management, acquisition, research and development, system development, system production, modernization and logistics support) that produce outcomes of the industry. These outcomes shall be controlled, tested and accepted by accountable authorities. The relationship between integration and operation is constructed via a coordination domain where standardization, legislation and clustering functions are executed.

System dynamics, developed by Jay Forrester in the 1960s, is a powerful methodology that may be used to understand and model complex systemic behavior, including the behavior of system components, and express those behaviors by means of differential equations. System dynamics methodology can be used successfully during the policy development process in complex system management for adapting to a complex environment. Comprehensive, simple and adaptive models can be created by the help of system dynamics.[30] System dynamics models provide foresight into behavior changes in a system over time. One of the strengths of system dynamics is its capability to capture feedback loops that inherently exist in complex systems, either in the form of positive (reinforcing) or negative (balancing) polarity.[31] Causal Loop Diagrams (CLD) are used for this purpose. These diagrams help us focus on the important feedback that is responsible for the complexity in the system.[32] Positive loops express a causal relation wherein a change in one variable causes a change in another variable in the same direction. Conversely, we see a change in the opposite direction within the negative loops. The polarities of the loops are denoted with "+" and "-" on the diagrams. Delays, as the most salient factors that create dynamics, are denoted with double stripes on the links. Feedback loops represent interactions among the parts of a system and enable better understanding of complex systems.

Figure 2 depicts a generic causal loop diagram for the defense industry. The casual flow starts with political and strategic guidance and continues through main nodes/variables (conceptualization, capability management, requirement management, acquisition, operation and sustainment, readiness and operational availability) that continuously provide feedback to each other.

Figure 2: Generic Causal Loop Diagram for the Defense Industry



The red lines in Figure 2 express direct connections, whereas dotted lines depict information flows within the above CLD that consists of five main loops. Loop-1 (reinforcing) covers the management of capabilities, requirements and acquisition, wherein a positive causality relationships exists, such that as the capability gap increases or decreases, the requirement increases or decreases; the rise or fall in requirement causes a corresponding increase or decrease in acquisition, and (positive) feedback flows to the capability variable. Loop-2 (balancing) depicts the relationships among acquisition, operation & sustainment and economy. In this loop, acquisition has an effect on operation & sustainment in the same direction; and operation & sustainment will affect economy in the opposite direction (i.e., an increase in operation & sustainment causes a decrease in economy), whereas economy and acquisition behave in the same direction (i.e., as the economy rises, acquisition rises too). Loop-3 (reinforcing) deals with the training and education of human resources, where both variables affect each other in the same direction (for instance; an increase in the number of personnel will increase the need for education and training and vice versa). A similar feedback flow exists in Loop-4 (reinforcing), in which operation & sustainment and human resources affect each other in the same direction. Loop-5 (reinforcing) is the last loop in the CLD, where any increase or decrease in operation & sustainment will cause affect the readiness and operational availability variables accordingly.

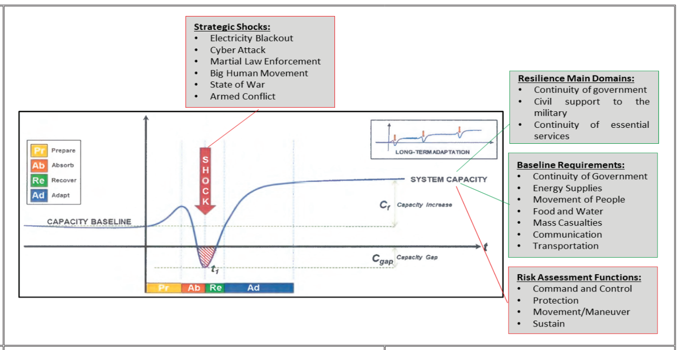
The basic CLD depicted in Figure 2gives an idea about the structure of the defense industry as a complex system. In other words, it clearly models what would happen within the overall system if any change in one of the variables were to occur. The CLD thus provides a picture of a mental model of the defense industry. Through the CLD structure, the behaviors of this complex system can be understood and modeled with the help of stocks and flows. Stocks and flows give an idea about the actual states of the complex systems by showing how the variables actually behave (in a non-linear way) in the event of specific decisions and actions within the defined structure.

An example of a defense industry application of the systems thinking approach and system dynamics methodology may be illuminative to show how a complex system or problem can be considered, conceptualized, structured and modeled. The "NATO Aggregated Resilience Model" developed by STM ThinkTech (Future Technology Institute) is an exemplary model. The subject of the model is 'resilience,' a complex and vague phenomenon that NATO has been in search of an innovative approach to deal with. Because of its complexity, NATO adopted systems thinking as an innovative approach to be used for the model development.

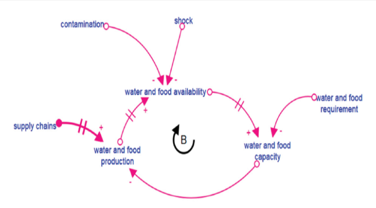
Figure 3 depicts the modelling process starting from articulating the complex system, modeling the structure and behavior of the system, and presenting the outcomes of the model via a strategic dashboard. In the model, the NATO's strategic resilience concept is addressed as a complex system. Strategic resilience is an adaptive process in which resilience performance is measured by absorbing strategic shocks (electricity blackout, cyber-attack, large-scale human movement etc.) with minimal risk effects (command and control, protection, movement, sustainability) while maintaining essential functions (continuity of government, civil support to the military, continuity of essential services) at an acceptable level, then recovering functionality within a reasonable time and at a reasonable cost. This complex system is understood and modeled via CLDs and stock and flow diagrams in which a considerable number of variables are interconnected. Then, a simulation model was developed with which users can create what-if scenarios and see the outcomes through various dashboards. The resilience model is capable of quantitatively representing the resilience-related factors of countries in a complex operational environment in a dynamic way.[33]

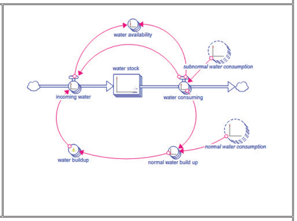
Figure 3: Generic Modelling Flow of Resilience

Articulation of complex system (Resilience)

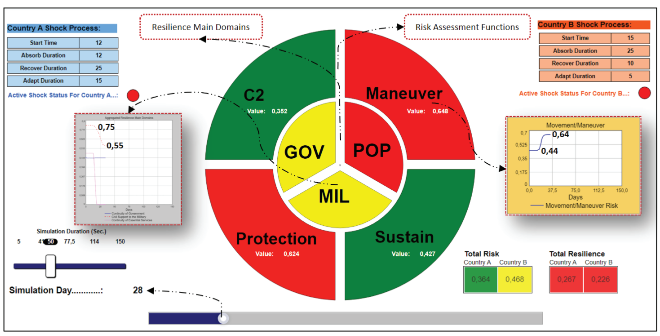


Understanding and modeling the structure (CLD) and behavior (stocks and flows) of the complex system





Scenario-based strategic dashboard of the resilience model



Source: Jan Hodicky et al, "Dynamic Modeling for Resilience Measurement: NATO Resilience Decision Support Model," *Applied Science*, Vol. 10, No. 2639 (2020), pp. 1–10.

One of the critical outcomes of this aggregated model is its capacity to provide views on the future behavior of both the overall system itself and its sub-systems. Meadow et al. discuss such outcomes by providing a valuable threefold classification:[34]

- *Absolute, precise predictions*. The model provides realistic foresight about the consequences of one or more simultaneous, strategic shocks on baseline requirements by representing the impacts of those shocks with their behavioral shape, depth and length along the simulation period.

- *Conditional, precise predictions.* The model also synthesizes multi-domain dynamism; if there is a strategic shock(s), the model depicts its effect on a baseline requirement, as well as the impact that the affected baseline requirement will have on others.
- *Conditional, imprecise projections of dynamic behavior.* The model has the capacity to project the dynamic behavioral pattern of demands. For instance, users can review the communication demand patterns through ordinary states where everything is normal (steady-state pattern) and through extraordinary situations where a cyber-attack shock takes place (increasing inclination pattern).[35]

System dynamics models were inspired by and stem from the practical world of normal managerial domains such as economics, politics and defense and security. It does not begin with abstract theory, nor is it restricted to the limited information available in numerical form. Instead, system dynamics uses the descriptive knowledge of the operating arena about structure, along with available experience about decision-making as inputs. Such inputs are augmented where possible by written description, theory and numerical data. For example, feedback theory is one of the prominent theories used as a guide for selecting and filtering information to yield the structure and numerical values for a dynamic simulation model. These dynamic models are good for tackling complex intuitive or mathematical problems, as their advanced features are capable of simulating an almost infinite number of parts of a system to determine how they will interact with one another to produce changing patterns of behavior.

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Conclusion

The ever-increasing volume of complexity aggravates the challenges for the decision support processes within the defense industry.[36] Therefore, the defense industry, with its dynamically interconnected agents (environmental factors, stakeholders, legislation, standards, operations, etc.), should be addressed and studied by means of innovative approaches and methodologies. A systems thinking approach, together with VSM and system dynamics methodologies can be deemed among those innovative approaches. Many successful applications in various areas such as the NATO aggregated resilience model mentioned above can be benchmarked in the development of new mental models and creative solutions.

A Systems Thinking approach and System Dynamics methodology can be used for structuring complex defense phenomenon, formulating the interrelationships among defense industry actors, and developing dynamic models. Although generic processes have already been mentioned, some of the high-level modelling points can be touched as: (1) Relevant mental and written information, experience, and judgements shall be gathered from the defense industry ecosystem with participatory techniques such as a community-based modeling approach; (2) A specific subject or problem shall be identified; (3) The identified subject or problem shall be framed in terms of pattern of behavior over time via scientific thinking; (4) Closed-Loop thinking shall be implemented by viewing and quantifying causality as an ongoing process, not a one-time event; (5) The behavior of the defense industry shall be evaluated via the interactions of its components.

The proposed approach and methodology for the conceptualization and contextualization of the defense industry provides the following potential benefits:

- Unique and applicable approaches for both theorists and practitioners in the defense sector so that they could be able to possess a comprehensive look
- A powerful methodology to translate and reflect tacit knowledge and mental models about defense and security into usable models and tools;
- A clean lens through which to see the complex interconnectedness among various agents in the sector;
- A functional tool to understand and evaluate dynamic behavioral relations among those agents (i.e., which causes create which effects, and how);
- A supportive means for approaching political and strategic level decision-making processes and procedures by providing:
  - Understanding of the interdependencies among defense industry agents (different domains, stakeholders, different aspects, etc.);
  - Use of all available related datasets as inputs in various formats, including graphical behavior inputs;
  - Ability to analyze alternative options and evaluate courses of action across different domains;
  - A realistic multi-domain picture (i.e., of the defense industry itself);
  - A model where almost limitless what-if scenarios can be created and tested within that multi-domain picture;
  - Understanding of the potential intended and unintended effects of decisions;

- Mitigating biased decision-making probability
- Superior situational awareness that includes interdependencies and trends;
- A risk-free and cheap environment to make all the necessary tests before executing the decisions in the real operational arena;
- State-of-the-art and lean visualization of analysis and synthesis results.

The inevitable decision support needed by policy- and decisionmakers who seek innovative means in the defense industry can be met by the systems thinking approach and system dynamics methodology discussed in this article. In the future, the most likely applications for this approach and methodology will be in the areas of: (1) defense planning and programming, (2) defense acquisition, (3) defense investment and (4) the operation and maintenance of defense platforms.

Last but not least, the discussion presented in this article should help to increase situational awareness about the existence of new paradigms (systems thinking and system dynamics) that could be gainfully utilized within the defense industry. The application of these paradigms will add value to the defense industry as a whole ecosystem.

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