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Technology and Policy: System Acquisition in a Complex Operational Environment

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Author Note: Cadets Jackson Brownfield, Gabriel Lajeunesse, Ryan Leach, and Christopher Sharfin are fourth-year Cadets attending the United States Military Academy at West Point. Major Arthur Middlebrooks, a United States Army Operations Research & Systems Analyst, currently serves as an Instructor in the Department of Systems Engineering at West Point. The project team is currently engaged with the US Army Engineer Research and Development Center (ERDC), a division of the United States Army Corps of Engineers, to develop a working model that translates the complex world of military systems acquisitions into a simple system dynamics model. The goal of this project is to better understand the factors influencing foreign nations' system acquisitions processes. Applied, this research will assist in the creation of a tabletop board game to simulate the procurement of military systems by foreign powers.

Abstract: The United States' (US) ability to maintain a technological edge in the current operational environment is challenged by the increased ability of near-peer nations to produce military technology. In response to this problem, the US Army Engineer Research and Development Center (ERDC) seeks to model the three key elements of military system acquisition—context, product, and process—to develop a more comprehensive understanding regarding how and why nations acquire technical solutions. Through the application of the System Dynamics Modeling Process (SDMP), this research examines the interactions between the strategic context of Germany, the military products it acquires to address its operational needs, and the processes it employs to acquire military technology. The results of this research indicate that numerous dynamic variables of context impact the acquisitions process for Germany, particularly political support and subsequent monetary allocations to research and development.

Keywords: System Dynamics, System Acquisition, National Defense, Foreign Relations

1. Introduction

One of the most important elements of any nation's defense strategy is its military systems acquisition strategy—the capability to design, develop, and acquire technological solutions to military challenges. The US Army Engineering Research and Development Center (ERDC) seeks to accurately model various foreign military systems acquisition processes to build a deeper understanding of how and why nations choose to acquire certain products. Analyzing Germany provides a basic understanding of the military systems acquisition rules and behaviors of foreign nations. The general hypothesis behind military systems acquisitions is that the national security context of the German state determines which military products to produce, which guides the selection of the appropriate process to employ to acquire the system. As context interacts with the selected products which drive the processes by which Germany acquires military technology, the length of time it takes for Germany to produce military technology changes. This change in length determines Germany's capability to successfully combat operational threats that it faces.

2. Military Acquisitions and the German State

Initial research identified that most countries follow rationalistic and constructive theories associated with military procurement (Suchman and Eyre, 1992). Germany is assumed to follow these theories as well. The rationalistic theory states that countries tend to "select weaponry to meet strategic military needs, based on perceived threats" (Suchman and Eyre, 1992). The constructive theory incorporates the values of a state to determine the levels of military systems procurement (Suchman and Eyre). Germany primarily follows a rationalistic approach in procuring military products, as it feels threatened by "terrorist networks, failed states, and weapons of mass destruction" (Pike, 2019).

This approach, focused on deterring perceived threats to the German state, guides Germany in selecting the military products it seeks to develop. Currently. there are four main capability gaps the German nation currently faces that play a large role in its military procurement process. First, Germany has too few resources to effectively conduct the operations required to surveil and protect the Baltic Sea located at its borders (Nordenman, 2017). Second, Germany is located between nuclear powers, including France and Russia, and highlighted missile defense as an important aspect of defense going into the future (Federal Ministry of Defense, 2016). Third, in the past, cyber-attacks have disabled railway and subway networks as well as blood storage facilities and automobile manufacturing. Cyber-attacks continue to pose a significant threat to German infrastructure (Gostomelsky, 2019). Finally, as a NATO member, Germany has been involved in ongoing operations across the world, including the conflict in Afghanistan, and supplies both combat and support aircraft for these operations in the form of unmanned aerial vehicles and heavy transport planes available for deploying troops to operation zones (Keller, 2015).

Categorizing the different types of products is an important step when modeling the development of different military systems. The six warfighting functions (WFF) are Movement and Maneuver, Fires, Intelligence, Mission Command, Sustainment, and Protection, and provide a good basis for categorizing products (Department of the Army, 2019). Table 1 shows the list of all the WFF, along with their associated products and process timelines for each. Categorizing products by WFF allows research and development times to be assigned to each individual system. This will simplify the product portion of the model, while still showing accurate simulation results for a broad range of military systems.

Table 1. Product Family Categorization by Warfighting Function

	Movement and Maneuver			**Fires**				**Intelligence**		**Mission Command**		**Sustainment**			**Protection**		
	Planes	Tanks	Warships	Air Defense	Artillery Pieces	Missiles	Small Arms	UAVs	Cyber Warfare Products	Communication Products	Battlefield Support Products	Logistics Vehicles	Logistics Aircraft	Medical Products	Body Armor	Cyber Secruity Products	Area Defense Infrastructure
Dev Time	6 years	6 years	2 years	4 years	3 years	6 years	3 years	2 years	1 year	6 years	2 years	3 years	3 years	2 years	1 year	1 year	1 year
Production Time	5 years	2 years	4 years	4 years	4 years	6 years	4 years	3 years	1 year	1 year	3 years	4 years	2 years	3 years	2 years	1 year	1 years
Deployment Time	3 years	5 years	4 years	4 years	2 years	2 years	3 years	3 years	2 years	2 years	4 years	3 years	3 years	4 years	2 years	3 years	3 year
Total Time	14 years	13 years	10 years	12 years	9 years	14 years	10 years	8 years	4 years	9 years	9 years	10 years	8 years	9 years	5 years	5 years	5 years

These products drive the processes that the German state follows to procure the military assets needed by the German military. In Germany, different agencies play significant roles in the procurement of defense systems. The overall responsibility of defense procurement has shifted from the Ministry of Defense to the Federal Office of Defense Technology and Procurement (BWB), as the BWB is now responsible for nearly "all military procurement contracts for the Armed Forces" (Rheinmetall Group, accessed 03 September 2020). The BWB handles the responsibility of negotiating and awarding contracts to different vendors to produce the desired system and then assists in distributing the finished product back to the German armed forces (Kleeman, Glas, & Essig, accessed 18 September 2020). The BWB and defense contractors in Germany have similar systems that produce products fielded to the German armed forces.

Together, the conclusions drawn in this section regarding the context surrounding the German state, the products sought by its military, and the process by which these products are acquired allow for model construction. Ultimately, this enables the accurate depiction of real-world scenarios that ERDC seeks to replicate in a future board game.

3. System Dynamics Modeling

System Dynamics is the methodology behind mathematically modeling and explaining complex real-world problems and is growing in popularity across the academic world (Allena-Ozolina & Bazbauers, 2017). System Dynamics modeling incorporates different visual representations to describe the current problem. Included in this process and employed within this research are a key variable list, causal loop diagrams, and stock and flow diagrams. In terms of the scope of the problem, the team focused on the endogenous variables within the system. The causal loop and stock and flow diagrams represent relationships between variables and the subsequent impact they have on each other within the overall system. The causal loop diagrams have associated influence arrows and polarity (+/-). These attributes show the impact one variable has on another. A positive polarity indicates a relationship in which an increase in one variable causes an increase in another (Sterman, 2000). A negative polarity indicates a relationship in which an increase in one variable causes a decrease in another (Sterman). The polarity defines what could happen to the dependent variable if the independent variable changes at all (Sterman). The loops created in this diagram create a wholistic picture of how each variable plays a key role in the outcome of the system, shown as

causal loops. The stock and flow diagram synthesizes these loops and incorporates stocks, or representations of the physical amounts of an object, to show the real-world behavior of the system. System Dynamics modeling provides the correct tools and methodologies to understand the intricacies of the German defense acquisition system. Utilizing these tools, in concert with the research above, allows for a better understanding of the process by which nations acquire and procure defense systems.

4. Problem Definition

In order to define the problem, research into context, product, and process, as they relate to Germany, formulated a large initial list of variables. Prior research references "internal" and "external" environmental variables that govern the acquisitions process to include political, economic, and military factors (Bartolomei, 2001). These variables are political, economic, and military in nature as shown in Table 2. These variables are all known as endogenous variables, those that pertain and are directly related to systems acquisitions. Listed in Table 2, the variables that are deemed to be endogenous to the model and have a direct impact on its overall behavior. The variables are classified based on the three major categories of the project: context, product, and process. The dynamic hypothesis states that context drives product selection, which drives selection of the appropriate process. This hypothesis helped determine the necessary variables to include in the model and their associated categories. The context category includes variables that help describe the context of Germany at a certain point in time, specifically economic, political, and social factors that exist within the country. The product category includes variables that specify the idea or type of product to be created in order to meet military requirements. Process variables are those that impact the acquisitions process within Germany. Once categorized as either variables of context, product, or process, relationships between these variables were visually represented via causal loop diagramming.

Table 2. Key Variables List

Key Variable	Classification	Units
Political Majority Support	Context	Members
Population Against	Context	Dmnl
Population Support	Context	Dmnl
DAX	Context	Dollars/Year
GDP	Context	Dollars/Year
Contracts Completed	Context	Contracts/Year
Government Contracts	Context	Contracts
R&D Budget	Context	Dollars/Year
Defense Budget	Context	Dollars/Year
Mil. Needs	Context	Contracts

Key Variable	Classification	Units
Mil. Wants	Context	Contracts
Threats	Context	Threats
Threat Level	Context	Dmnl
Militay Operations	Context	Dmnl
Product Ideas	Product	Units
Undeveloped Products	Process	Units
Currently Developing Products	Process	Units
Developed Products	Process	Units
Fielded Products	Process	Units
Failed Products	Process	Units

5. Military Acquisitions System Structure

Using the key variables list, relationships within the military acquisitions process in Germany were translated into causal loop diagrams. These diagrams are visual representations of the key variables showing their relationships to their surroundings. These diagrams allow system dynamic modelers the ability to quickly understand the positive and negative relationships that influence the behavior of a system.

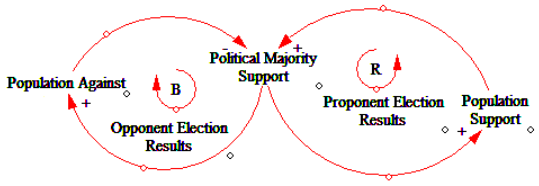

Figure 1. Political Casual Loop

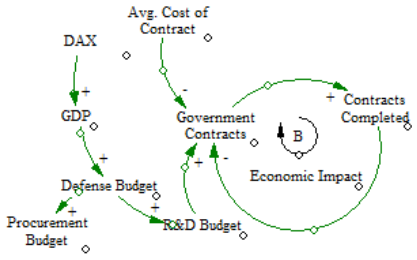

Figure 2. Economic Casual Loop

The first of these loops describes the political aspect of military acquisitions, seen in Figure 1. In the political sector of military acquisitions, those members of the government that support military spending drive the procurement process. These members determine military needs, set budgets, and select projects in some countries. As shown in the diagram, election results drive the number of members of the German parliament that support military spending. These elections provide additional context which further develops understanding of the military procurement process within nations, particularly in Germany.

The second causal loop describes the economic context within Germany that influences the procurement of military systems, seen in Figure 2. In the German context, it is assumed that the overall health of the Deutscher Aktien Index (DAX) is an adequate measure of the overall health of the German economy. Research into defense acquisitions showed that the economic health of a country influences a state's ability to produce military systems (Fox, 1974). Within the German context, the size of the GDP determines the size of its national defense budget (Townsend, 2018). A defense budget has multiple sub-categories, however, important to this problem are both the research and procurement fund categories. These funds allow Germany to acquire military systems through purchase or through internal development. These funds directly impact the number of contracts awarded to defense contractors by the German government.

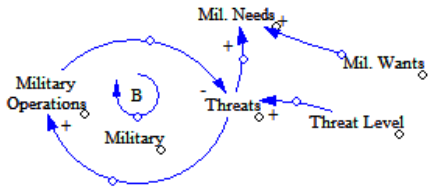

Figure 3. Military Casual Loop

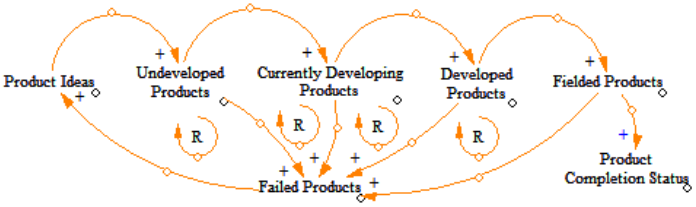

Figure 4. Process Casual Loop

While both the political and economic aspects of systems acquisitions provide contextual layers to systems acquisitions within Germany, the German military remains the primary force driving its acquisitions process, as displayed in Figure 3. As threats to its national security increases, the German military seeks to effectively combat them through military operations and the implementation of military products.

German military contractors receive contracts for product development, shown in Figure 4. These products undergo a process that transforms a needed product into a fielded product. This process adds an additional dimension to the military acquisitions program in Germany. Within the process, products undergo four main phases. These phases are "undeveloped", "developed", "currently developed" and "fielded". As products go through this process, however, some fail to meet specified criteria. Discarded and recycled, these failures cycle back to one of the four phases which further influences the flow of product ideas into the military systems development process. These relationships between phases in development add additional perspectives that show complexities and interdependencies that exist in the German model of systems acquisitions.

6. Results and Future Work

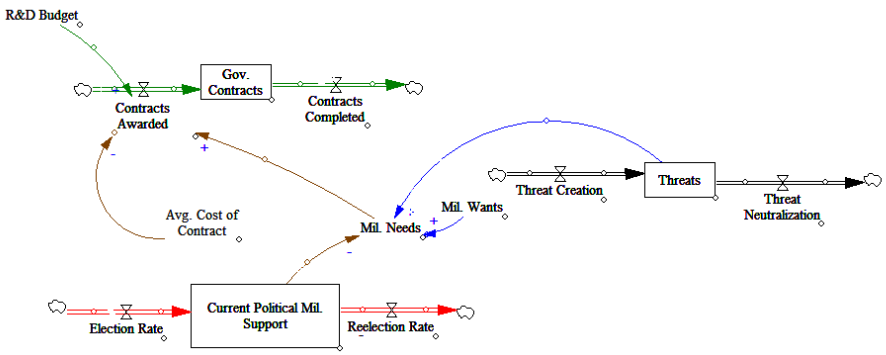

Figure 5. Simplified Stock and Flow Model

The casual loop relationships above were combined in a single stock and flow model which translates casual loop relationships into a set of mathematical relationships. By transforming the causal loop diagrams above, causal relationships become equations which produce numeric values representing the completion status of a variety of different military products.

When set to real world parameters found through careful research, to include the number of seats in the German parliament, the cycle time of Germany's elections, the average cost allocated by the German government to defense contracts, and the size of Germany's defense budget, the causal relationships shown in the previous section all work to influence the number of defense contracts awarded by the German government (Carter, 2021).

A simplified image of the model, displayed in Figure 5, illustrates the various relationships that effect the number of German defense contracts. Within the model, Government contracts awarded is a function of primarily the Economic and Military Casual Loop diagrams, with the Political Loop having a secondary affect through its influence on the Military Loop. The Contracts Variable's mathematical equation is shown below in Equation 1.

$$Contacts\ Awarded = \frac{Mil.Needs}{Avg.Cost\ of\ Contract} * R\&D\ Budget \quad (1)$$

Equation 1. Contracts Awarded Equation

The results from the mathematical equation above, along with the product development times associated with each phase of product development shown in Table 1, are shown in in Figure 6 which depict the impact of the German national context, developmental process, and military products desired on the allocation of defense contracts. This allocation effects the product completion rate, as shown in Figure 7. This graph shows how the development of an unmanned aerial vehicle starting at zero percent (0%) completed, reaches 100% completion in just under six years.

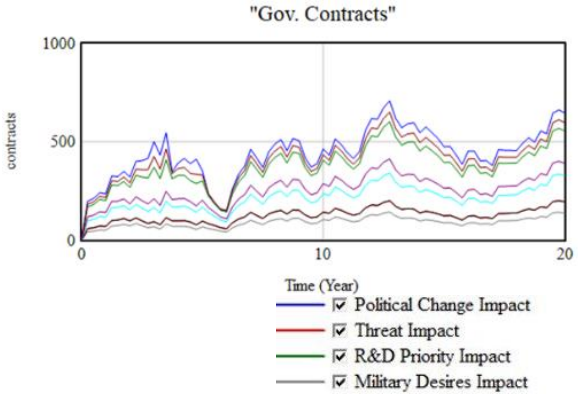

Figure 6. Initial Gov. Contracts Output

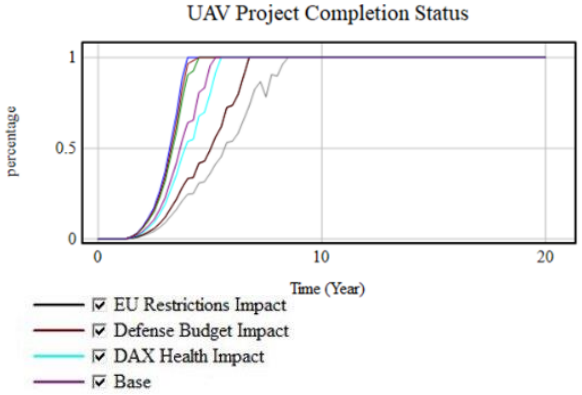

Figure 7. Initial Project Completion Output

As Germany's national context changes, the completion rate of projects may fluctuate as budgets, threats, political support, and military desires all effect national context. To determine the most sensitive variables within the German model of military acquisitions, each starting parameter was modified +/- 25% of its original value. When either the number of members of the political support majority changed, the monetary amount of the German defense budget grew or decreased, including the percentage of its allocations to Research and Development, a significant impact to the project completion rate, with military product development time shrinking by at least three years.

Through this sensitivity test, an understanding of the effect of German national contexts on the development of military products begins to take shape. This understanding allows future research to validate the effects of the relationships captured in this model using real world data. The model's behavior suggests that the change in the German national context significantly impacts the rate at which military products are developed. Future work will seek to validate the model and its underlying assumptions by comparing the data captured in this study, to real world data obtained through academic inquiry.

7. Conclusion

The research, analysis, and relationships outlined in this report describe the complexity foreign nations must address with respect to military systems acquisition. Focusing on Germany reveals key details surrounding the acquisition process, which guides its national context. This context is critical, as it leads to the military products in which Germany chooses to develop and acquire, which drives the nature of length of the process by which Germany chooses to produce its products. The model created during this project identifies certain variables that impact the acquisitions process for Germany. The model results and sensitivity analysis show that a change in political support for the military greatly impacts the overall system. To increase the amount of defense products either acquired or produced, the model shows that Germany should focus on increasing

the amount of political support for the military. Future work will aim to validate these findings through research and will analyze the behaviors of other nations as they seek to develop military technology. Validation of these assumptions will solidify the dynamic hypothesis described earlier: the context of a nation drives the military products a nation chooses to develop, which drives the process of development.

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