SYM-AM-21-063

Excerpt from the Proceedings of the Eighteenth Annual Acquisition Research Symposium

Capability Based Planning in Humanitarian Operations: A Hybrid Optimization and Simulation Framework for Strategic Acquisition in the Armed Forces

May 11–13, 2021

Published: May 10, 2021

Approved for public release; distribution is unlimited.

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

The research presented in this report was supported by the Acquisition Research Program of the Graduate School of Defense Management at the Naval Postgraduate School.

To request defense acquisition research, to become a research sponsor, or to print additional copies of reports, please contact any of the staff listed on the Acquisition Research Program website (www.acquisitionresearch.net).

Acquisition Research Program
Graduate School of Defense Management
Naval Postgraduate School

Capability Based Planning in Humanitarian Operations: A Hybrid Optimization and Simulation Framework for Strategic Acquisition in the Armed Forces

Professor Dr. Stefan Wolfgang Pickl—studied mathematics, electrical engineering, and philosophy at the Technical University of Darmstadt (diploma in 1993; ERASMUS-scholarship at the EPFL Lausanne) and earned a doctor's degree at the TU Darmstadt in 1998, followed by his habilitation at the University of Cologne in 2005. He is Counsellor to the Center for Information Technology and Algorithms (CITA) at the University of Nevada, Las Vegas, as well as an Associated Member of the Center for Network Innovation and Experimentation (CENETIX) at the Naval Postgraduate School (NPS) in Monterey, CA. In cooperation with associated sectors for decision finding, he carries out analyses and supervises international experiments there, especially in the field of Maritime Interdiction Operations (MIO), Sensor Allocation, and Complex Harbor Protection. Within the scope of the Data Farming/ CREATE-Project, he works together with the NUS Singapore in the field of Security Scenario Analysis/Intelligent Design of Transport. [stefan.pickl@unibw.de]

Professor Dr. Max Krüger—is a former officer of the German Navy and, since 2011, has been a professor at Furtwangen University of Applied Sciences in the Department of Business Administration and Engineering. He studied computer science and did his dissertation on game theory at the Bundeswehr University in Munich. From 2006 to 2011, he worked as a Scientific Expert for the Industrieanlagen-Betriebsgesellschaft (IABG mbH) in Ottobrunn in the areas of OR and applied AI. His particular research interests are in Bayesian Networks, classification problems and optimization in general, as well as concrete applications (e.g., in aerial and maritime surveillance). [max.krueger@email.de]

Major General (Ret.) Dr. Dieter Budde—joined the Bundeswehr in 1966 as a paratrooper; 1969–1977, pilot training and assignment in Army Air Units; 1975, Dipl. sc. pol. (political science), Ludwig Maximilian University Munich; General Staff training; General Staff Officer MoD (military policy, arms control); troop assignments; Arms Control Branch, Policy Division, Mons, BE; Chief of Staff 1. Gebirgsdivision; Head of Student Section UniBw Munich; Higher Command and Staff Course (HCSC) Camberley, UK; Commander Army Aviation Transport Regiment; Commander Air Mechanized Brigade; General Army Aviation and Commander Army Aviation School; Commander Air Mobile Operations Division; about 4;500 flying hours on helicopters and fixed wings. 2000 Dr. rer. pol. (political and social sciences) University of the German Armed Forces Munich; 2005 Retired as Major General; 2006–2009 Managing Director StratCons Strategic Consulting GmbH; Member of an advisory board of a company as a supplier to the aviation industry; 2010 Master of Arts (MA) Governance; 2013 Master of Arts (MA) Philosophy; 2013–2015 High Level Advisor with the German Society for International Cooperation (GIZ) in the project "Strengthening the Civil Aviation Oversight of Afghanistan"; 2014 until today Senior Advisor to the Chair for Operations Research and Theoretical Mathematics at the Universität der Bundeswehr, Munich; 2015–2017 Key Expert with the Turkish-EU Project "Technical Assistance for Capacity Building of Safety and Security Training Requirements for Turkish Civil Aviation"; 2019 until today, Lectureship at the University of the Bundeswehr, Munich; 2020 Dr. phil. (Philosophy), University of Cologne. [dibu11@gmx.de]

Gonzalo Barbeito—is a DAAD grant holder and Doctoral Candidate in the Department of Computer Science at the Universität der Bundeswehr München, Germany. Barbeito deals with mathematical optimization, stochastic modeling and computer simulation for operational system analysis. In his doctoral research, he develops an optimization and simulation framework aimed at improving last-mile logistics in the context of humanitarian operations. He pursues a shift from traditional knowledge-based modeling towards a more objective hybrid knowledge-data paradigm. [gonzalo.barbeito@unibw.de]

Abstract

This paper describes an innovative Hybrid Optimization and Simulation approach for assessing acquisition strategies in the Armed Forces. This work has been conceptualized and is currently being developed with and for experts in the field of disaster and emergency management in order to tackle the real issues arising during such crises. As the overarching framework, we operate

under the umbrella of Capability Based Planning (CBP), a methodology widely used by the defense community and referred to by many as the "gold standard" for strategic planning. Drawing from the general building blocks of CBP, we aim to develop an analytic process to transparently assess and explain humanitarian capabilities acquisitions in the Armed Forces and include them in its traditionally defense-oriented strategic planning.

Keywords: Strategic Acquisition, Humanitarian Logistics, Capability Based Planning, Defense Planning

Introduction

The significance of disasters for societies is tremendous. It has been estimated that, every year, more than 500 disasters strike our planet, with a death toll of over 75,000 people and affecting more than 200 million people (Caunhye et al., 2012). Furthermore, several studies have demonstrated an increasing trend in both the frequency and severity of these events (Behl & Dutta, 2019; Habib et al., 2016; Leiras et al., 2014). In order to lessen their effects, be it the loss of human life or the impact on the economy, and to bring society back to a state of normality, the field of Disaster and Emergency Management (DEM) prepares resources and activities that will deal with the humanitarian aspect of emergencies. Due to the sheer complexity of DEM operations, cooperation between military and civilian actors is often required. Beyond the context of war, military forces are particularly well equipped to deal with certain key areas in DEM, like logistics and engineering, among other support possibilities that could be explored to mitigate the impact of disasters on civilian populations.

This paper proposes the integration of these support possibilities in the strategic analysis of the Armed Forces while still maintaining defense-related investments as a priority.

Preliminaries and Background

Capability Based Planning

Capability Based Planning (CBP) is a general planning framework that aims to provide an organization with capabilities suitable for a wide range of modern-day challenges and risks, simultaneously framing these capabilities within an economic framework (Davis, 2002). This approach relies on goals and functional needs for broadly defined scenarios, making planning more responsive to uncertainty and risk, and provides a rational basis for decisions on future acquisitions. In this sense, CBP differs from threat-based planning, a framework popular during and up to the end of the Cold War, where strategic planning was heavily oriented towards specific threats or scenarios (Hales & Chouinard, 2011).

While CBP has been widely adopted by the Defense community, with notable results in the United States, Canada, Australia, and the United Kingdom, its extension to the field of Safety and Security, including DEM, proved challenging (Hales & Chouinard, 2011). These challenges arise, primarily, from perspective differences between the Defense and the DEM communities, and from within the DEM community itself. Going a step further in the analysis, the internationally funded Technical Cooperation Program (Taylor, 2013; Technical Cooperation Program Joint Systems Analysis Group Technical Panel 3, 2004) identified four main building blocks in the general framework of CBP:

1. High level **capability objectives** derived from government guidance.
2. **Operational concepts** for strategic, operational, and tactical levels to describe the systems and possible interactions.
3. Standard groupings of disparate elements in **capability clusters** to make the analysis process more manageable.
4. **Resource constraints** that define the limits within which the capabilities need to be realized.

While these blocks are almost exclusively built and described around defense concepts, it is possible to partially abstract them as an optimization problem. This, in turn, allows the inclusion of tasks and operations outside the typical concepts in defense but connected at its core.

This research proposes an extension of CBP to include humanitarian capabilities and operational concepts while preserving the resource constraints at strategic levels. In essence, we aim to study and expand existing military capabilities befitting humanitarian operations, acknowledging the existing economic restrictions at strategic levels.

Operations Research in the Context of Capability Based Planning

Operations Research (OR) has long been applied to the higher level of strategic defense planning. The following paragraphs describe the intended approach to meet the requirements of all CBP building blocks using OR methodologies.

The definition of OR has been approached from multiple perspectives by many relevant authors in the field. In the interest of clarity and simplicity, we will adopt the OR definition described by the Association of European Operational Research Societies (EURO):

> [Operations Research] can be described as a scientific approach to the solution of problems in the management of complex systems. In a rapidly changing environment, an understanding is sought which will facilitate the choice and the implementation of more effective solutions which, typically, may involve complex interactions among the elements of the system, for instance, people, materials and money.[1]

Closely related to the building blocks of a CBP framework described earlier, an effective CBP implementation requires the developed plan to meet the capability objectives under the defined operational concepts, minimizing risk and cost and complying with the resource and general constraints (Technical Cooperation Program Joint Systems Analysis Group Technical Panel 3, 2004). In order to optimally distribute resources, CBP depends on OR methods to help make better decisions. In particular, this research leverages two powerful techniques found at the intersection between OR and CBP, **Simulation** and **Optimization**.

On the one hand, different simulation methodologies are used for representing operational concepts and to develop and explore the sandbox in which different scenarios will be tested. These are the different techniques used in this work:

- **System Dynamics** (SD) is a modeling a simulation technique for studying the dynamics of complex systems (Sterman, 2000). It uses a set of simple building blocks and entities, namely *Stocks*, *Material,* and *Information Flows* and *Delays* to describe how these systems change over time. Due to a high level of abstraction in the modeling approach, SD is normally regarded as a strategic modeling methodology.
- **Discrete Event Simulation** (DES) is a method that requires the modeler to divide the studied system into a sequence of operations performed across entities over discrete time (i.e., the model clock only advances when something significant happens in the model). It is generally considered to be a low abstraction modeling technique and is used to model processes in-depth (Borshchev, 2013).
- **Agent Based Modeling** (ABM) is a more recent modeling approach, focusing on the behavior of individual interacting entities (namely, agents) to create emergent behavior

[1] from https://www.euro-online.org/

(bottom up approach), instead of the process affecting those entities (top down; Borshchev, 2013).

- In order to exhaustively explore scenarios under uncertainty, **Monte Carlo Simulation** allows the modeler to assess individual simulation run outcomes by stochastically varying input parameter values (Rubinstein & Kroese, 2016). This technique is well suited to deal with systems where the input-output interactions are too complex to assess analytically.

Architecturally, two main streams can be identified with respect to simulation techniques. The first stream combines SD, DES, and ABM into a single model using multimethod modeling (Borshchev, 2013). The second stream considers exclusively the Monte Carlo simulations, running parallelly to the first stream.

Analytical optimization approaches, on the other hand, are also used for finding, at different strategic levels, the best resource allocation strategy from an economic and operative standpoint. These models have been successfully applied in several DEM problems, as shown in Behl and Dutta (2019) and Habib et al. (2016). In this work, two practical optimization problems will be explored: a modification of the vehicle routing problem (VRP; Lahyani et al., 2015; Toth & Vigo, 2002) and a strategic acquisition problem framed as an extension of the classical Knapsack Problem (Bakirli et al., 2014; Brown et al., 2004). Both problems are solved in a sequential workflow, as explained in the Methodology and Concept Description.

Humanitarian Logistics and Capability Based Planning

In a humanitarian context, the term *logistics* represents the processes and systems involved in mobilizing people, resources, skills, and knowledge to help vulnerable people affected after a disaster. Given the wide array of problems that this field encompasses, we will focus on the **Last-Mile Relief Distribution** (LMRD) problem, a well-known problem that will act as a proxy for humanitarian operations (Balcik et al., 2008; Stapleton et al., 2011). In this problem, a fleet of capacitated vehicles must economically distribute relief resources between local depots and affected areas.

An interesting characteristic of the LMRD problem is the trade-off between economic distribution and the life-saving utility: There is a clear correlation between the number of vehicles and the achievable satisfaction of demand. Due to limited resources, however, it is necessary to correctly assess the optimum supply and transport capacity that can successfully satisfy this demand while reducing transportation costs and idle capacities.

The extension of humanitarian logistics to the CBP framework, while not exactly easy, is conceptually quite straightforward: First, the number of transportation units and supply capacities robust against a broad set of disaster scenarios is calculated and immediately compared with present distribution capacities. If a need for improvement in transportation capacities is detected, it will be included in the much broader strategic investment plan, considering the investment priorities of the Armed Forces as a whole.

Research Question

The concrete question that this research aims to answer is *How can humanitarian capabilities for military support in DEM be characterized when framed within a broader strategic acquisition plan in the Armed Forces?*

By answering this question, we expect to bridge an observed gap in military strategic planning, broadening the application potential of CBP by enriching its current defense-oriented paradigm with humanitarian goals.

Methodology and Concept Description

Conceptually, this work is being developed with experts in the field of DEM, both from civil organizations and with military backgrounds.

Figure 1 shows the broad framework description: On the right, the classical capability and investment approach remains unchanged. On the left, we show the proposed extension to the classical approach by linking humanitarian operations to optimal capability requirements—as described in **problem (a)**—and finally conducting a holistic assessment of the acquisition requirements and transparently supporting decision-makers with optimal economic distribution—tackled in **problem (b)**. The connection shown in this figure between the classical CBP approach (right side) and the proposed extension (left side) represents the multi-purpose existing capabilities in the Armed Forces and one key argument to justify military support in humanitarian operations.

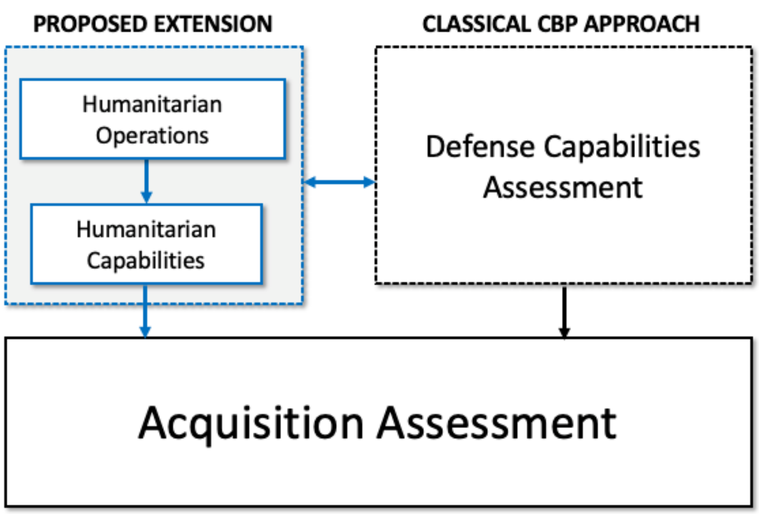


Figure 1. Proposed CBP-Based Acquisition Framework (Left Side)

Architecturally, this work adopts a connected modular approach, developing two different models tackling different organizational levels:

a) the *relief distribution problem*, used to identify a gap in capabilities, and
b) the *acquisition problem*, supporting the acquisition of those capabilities.

Figure 2 shows a conceptual description of the process flow and the connection between both problems, with their corresponding inputs and outputs.

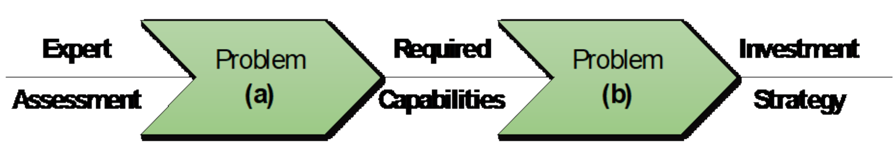


Figure 2: Conceptual Process Flow

Problem (A): Determining Humanitarian Logistics Capabilities

This problem encompasses both the tactical and operational levels observed in the CBP framework and will, for practical purposes, keep a narrow perspective within Humanitarian

Operations. At this level, we developed a multi-method simulation model of a disaster requiring civilian relocation to shelters. The behavior of this model was designed in cooperation with experts in logistics and DEM and follows real constraints and variables to the best extent of the possibilities.

The scenario used to exemplify typical operations observed in this model can be described as follows:

In the aftermath of a disrupting disaster (e.g., earthquake, pandemic with quarantine demands, large scale blackout, among others), the civilian population is relocated to shelters for their safety. Regional military forces are in charge of supplying these shelters using limited structural resources and commodities, with optional civilian support that can be required at higher costs. *The central task at this level is the determination of required vehicles (both military and civilian)—together with corresponding distribution routes—for a timely delivery of relief goods to the population in need.*

There are two main decisions at this level; the first one, of an **operative nature**, involves the cost and time efficient determination of routes and supply schedule for every vehicle, *given specific fleet configurations*.

In order to shift the problem complexity away from the user, a Rich-Vehicle Routing Problem (R-VRP; Lahyani et al., 2015) optimization model is solved parallelly to the simulation, identifying the optimal routing strategy for each vehicle in the fleet. This mathematical model was developed exclusively for this research and captures a complex set of real-world VRP taxonomic features not simultaneously contemplated in previous mathematical VRP models, such as

1. *Split-Delivery*: Multiple vehicles are allowed to visit a single shelter, effectively sharing the supply requirements for that shelter.
2. *Multi-Echelon*: Unlike traditional VRP, in this case, the fleet is not necessarily stationed at the depots and might have their own fleet base (for example, one or more supply regiments)
3. *Multi-Depot*: This problem needs to contemplate multiple sources of relief in the map.
4. *Heterogeneous Fleet*: As observed in real world problems, a fleet normally comprises different types of vehicles, each with its own fuel consumption, fixed usage costs, and load capacities.
5. *Multi-Trip*: Vehicles can travel multiple time between depots and shelters in order to resupply if needed.
6. *Multi-Commodity*: Each vehicle can transport multiple products with different packaging options.

The transportation parameters used in this problem are shown in Figure 3.

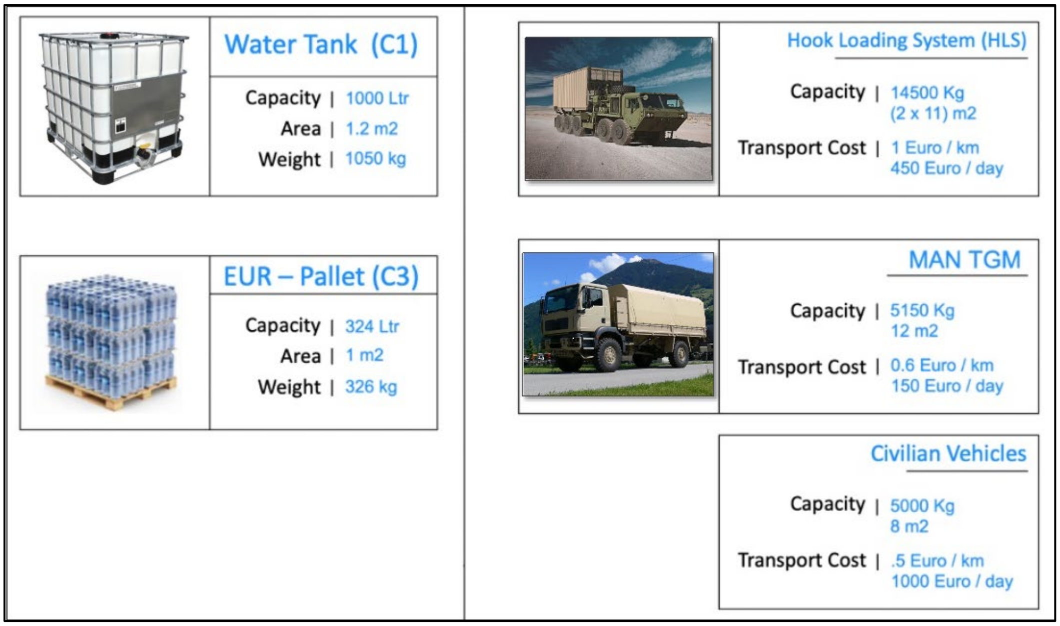


Figure 3. Load Transportation Parameters

(Note: This figure is the authors' own elaboration with image captions from https://commons.wikimedia.org.)

A conceptual description of the user interface designed for this level can be seen in Figure 4. Shelters and Depots show a live feed of their stock levels (red and green bars), and the position of every vehicle in the fleet is updated in a GIS environment. Using this module as a sandbox, users can modify input parameters and observe the success potential of different supplying strategies.

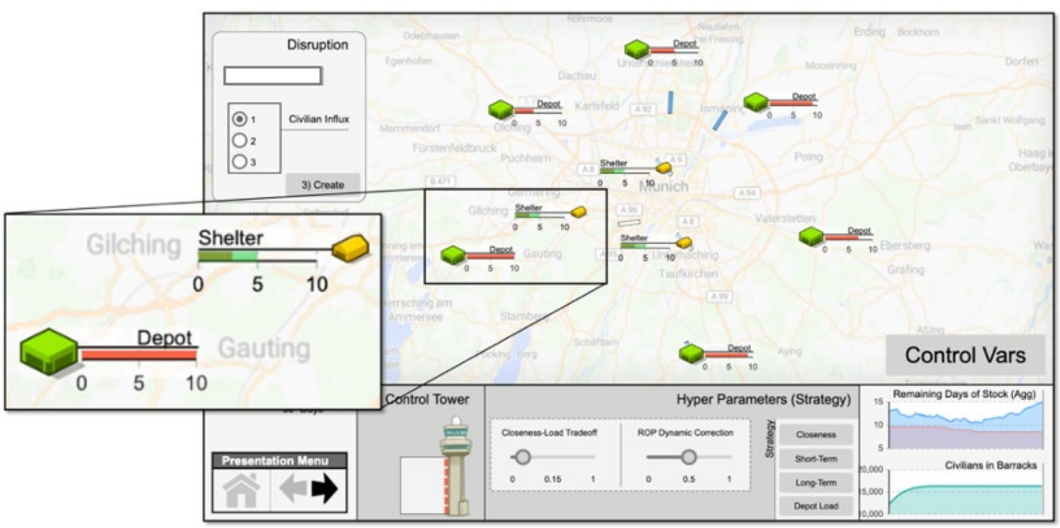


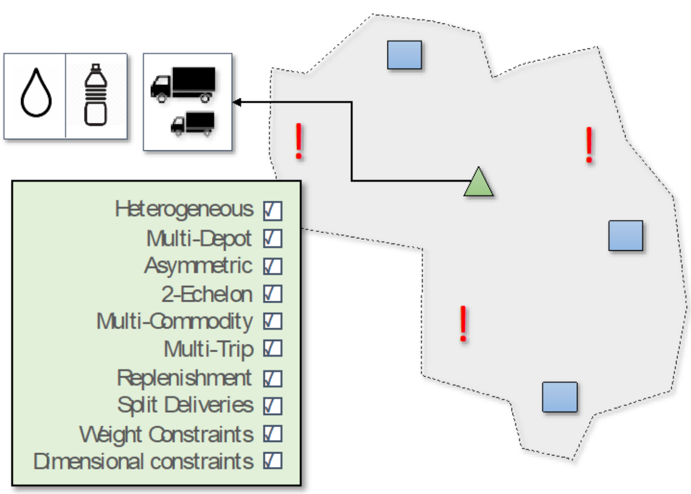
Figure 4. Proposed User Interface for the Humanitarian Logistics Model (Problem [a])

The second type of decision in problem (a) is of a **strategic nature** and aims to explore and identify the best combination of structural and fixed-operational resources to successfully see the delivery plan through to completion.

Essentially, the structural resources to define at this stage are

- Transport capabilities (number and type of vehicles in the fleet)
- Supply capacities (units per day of each product that depots can supply)

In Figure 5, an example is shown based on a real case study that has been anonymized for presentation purposes. The problem includes *a fleet base* (green triangle), *three depots* (blue squares) and *three shelters* (red exclamation marks). The goal is to design the optimal distribution plan for a fleet of heterogeneous vehicles starting from and returning to the fleet base. Each vehicle must pick up two types of commodities at the depots and distribute them to the different shelters. The Rich-VRP features included in this model are shown in the green box in Figure 5. The right side of this figure shows the results of wrapping the optimization model in a Monte Carlo framework, stochastically varying the population sizes at the shelters (first three columns), and defining a new demand composition at each scenario. The last three columns show the optimum number of truck types for each scenario and the cost of that solution, respectively. The row in blue indicates the highest demand scenario.



Input			Results		
Pop S_1	Pop S_2	Pop S_3	Trucks A	Trucks B	Cost
500	500	500	2	0	1634
2000	2000	2000	5	0	4677
5000	5000	5000	8	6	13078
500	5000	500	4	0	4784
5000	500	500	6	0	5975
500	500	5000	4	1	5141
2000	2000	5000	7	0	7646
2000	5000	2000	6	0	7363
5000	2000	2000	6	2	8087

Figure 5. Conceptual Map and Different Scenarios Designed in a Complex Rich-VRP

Problem (B): Strategic Acquisition Plan, Defense Structure Coupled With Humanitarian Operations

The acquisition problem represents the strategic level and takes as input an explicit formulation of capability requirements from multiple defense branches in the Armed Forces and the humanitarian capabilities determined in problem (a). **The goal at this level is to formulate the acquisition strategy that maximizes the capability needs of the army for both defense and humanitarian considerations.** This problem assumes that all inputs provided by the defense branches are the output of similar analytic assessments conducted by experts and, hence, out of the scope of this project. The generic hierarchical structure used in this problem is shown in Figure 6.

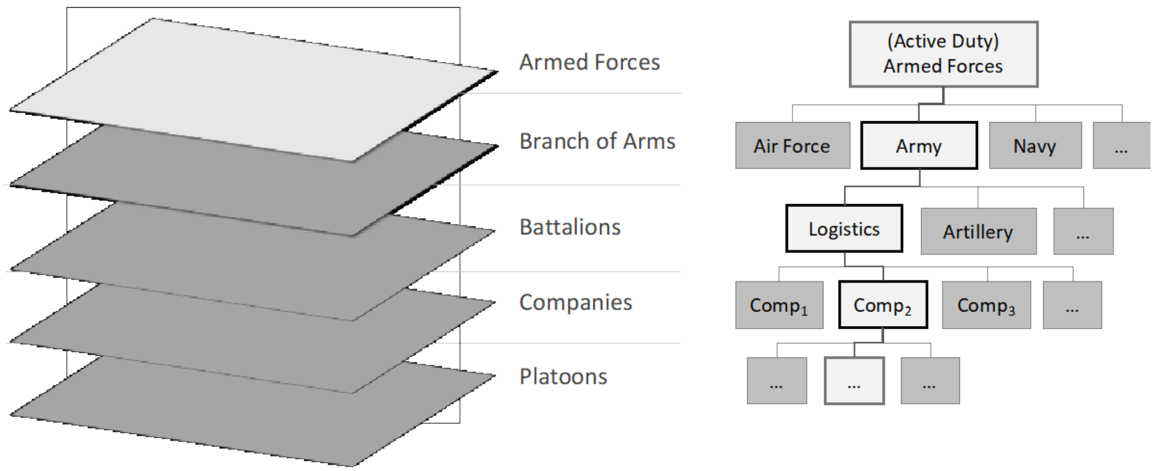


Figure 6. Example of a Generic Hierarchical Structure in the Armed Forces

The implementation of this problem consists of a modified knapsack optimization model aiming to maximize the value of an investment while not exceeding the available budget. Built on top of this optimization model, a user interface allows experts and decision-makers to explore and configure different parameters at each strategic level in the army.

The designed interface, shown in Figure 7, gives an overview of the outputs produced by the model, with the total distribution of funds for each branch of arms and the capability of exploring and parameterizing specific hierarchical levels individually. At this point, it is worth noting that the outputs of this model do not replace by any means the need for expert assessment or decision-makers. These results are exclusively meant to support the decision-making process and reduce the burden of computing complex calculations on the user.

Finally, both problems are merged in a single platform and under a comprehensive management dashboard in order to provide tactical, operative, and strategic information of the different scenarios contemplated for analysis.

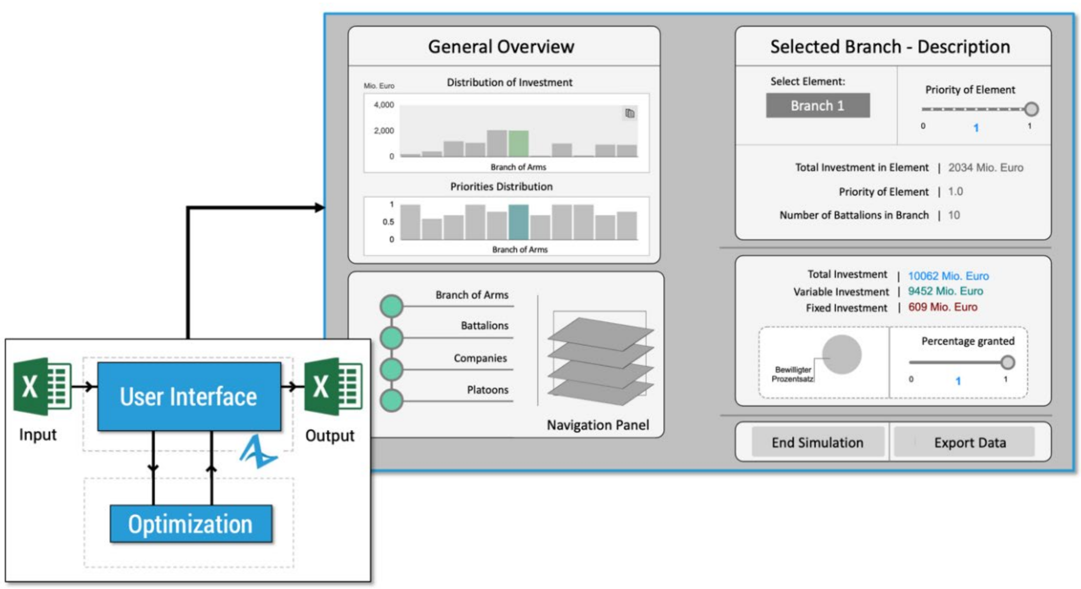


Figure 7. User Interface for the Strategic Acquisition Problem With Detail for Higher Hierarchical Level (Armed Forces Strategic Command)

First Results

Due to the early stage of this project and the sensitive nature of the information used, results will be presented on a qualitative basis, with the goal of assessing feasibility and scalability of the approach. With respect to the former, the approach yields promising results: Figure 4 and Figure 6 showcase not simply conceptual designs, but actual results of this framework, specifically from the management dashboard, in a dynamic environment with which the user can interact. Furthermore, the quantitative values in those figures correspond to real values calculated using the underlying mathematical models. An analysis of those values in these lines would not be of interest since all values shown are generic, given the confidentiality of the information handled.

With respect to scalability, it was observed that the bottleneck of this approach is the *relief distribution problem (a)*, which might struggle when the problem is too expressive (e.g., due to multiple transportation options and complex routing strategies considered) or too large. As a reference, the current optimization model correctly handled maps with simple behavior with up to 75 nodes; however, it struggled with larger instances. For the full expressiveness of the model, instances with up to 16 nodes were solved in realistic time.

Conclusion and Outlook

This paper described the concept behind a streamlined framework for the integration of humanitarian operations within the strategic planning of the Armed Forces. Concretely, this research bridges an observed gap in military strategic planning, broadening the application potential of Capability Based Planning by enriching its current defense-oriented paradigm with humanitarian goals. Even though the project has an already working implementation of the described concept, several validation steps are still needed, as well as a deeper development regarding the hierarchical army sub-structures and the specifics of each disaster tackled.

References

Bakirli, B., Gencer, C., & Aydog, E. (2014). A combined approach for fuzzy multi-objective multiple knapsack problems for defence project selection. *Journal of the Operational Research Society*, *65*(7), 1001–1016. https://doi.org/10.1057/jors.2013.36

Balcik, B., Beamon, B. M., & Smilowitz, K. (2008). Last mile distribution in humanitarian relief. *Journal of Intelligent Transportation Systems: Technology, Planning, and Operations*, *12*(2), 51–63. https://doi.org/10.1080/15472450802023329

Behl, A., & Dutta, P. (2019). Humanitarian supply chain management: A thematic literature review and future directions of research. *Annals of Operations Research*, *283*(1–2), 1001–1044. https://doi.org/10.1007/s10479-018-2806-2

Borshchev, A. (2013). *The big book of simulation modeling. Simulation modeling with anylogic: Agent based, discrete event and system dynamics methods*.

Brown, G. G., Dell, R. F., & Newman, A. M. (2004). Optimizing military capital planning. *INFORMS Journal on Applied Analytics*, *34*(6). https://doi.org/10.1287/inte.1040.0107

Caunhye, A. M., Nie, X., & Pokharel, S. (2012). Optimization models in emergency logistics: A literature review. *Socio-Economic Planning Sciences*, *46*(1), 4–13. https://doi.org/10.1016/j.seps.2011.04.004

Davis, P. K. (2002). *Analytic architecture for capabilities-based planning, mission-system analysis and transformation*. https://www.researchgate.net/publication/228769350_Analytic_Architecture_for_Capabilities-Based_Planning_Mission-System_Analysis_and_Transformation

Habib, M. S., Lee, Y. H., & Memon, M. S. (2016). Mathematical models in humanitarian supply chain management: A systematic literature review. *Mathematical Problems in Engineering*, *2016*. https://doi.org/10.1155/2016/3212095

Hales, D., & Chouinard, P. (2011). *Implementing capability based planning within the public safety and security sector: Lessons from the defence experience*. Defence R&D Canada – Centre for Security Science.

Lahyani, R., Khemakhem, M., & Semet, F. (2015). Rich vehicle routing problems: From a taxonomy to a definition. *European Journal of Operational Research*, *241*(1), 1–14. https://doi.org/10.1016/j.ejor.2014.07.048

Leiras, A., de Brito, I., Queiroz Peres, E., Rejane Bertazzo, T., & Tsugunobu Yoshida Yoshizaki, H. (2014). Literature review of humanitarian logistics research: Trends and challenges. *Journal of Humanitarian Logistics and Supply Chain Management*, *4*(1), 95–130.

Rubinstein, R., & Kroese, D. P. (2016). *Simulation and the Monte Carlo method* (Vol. 10). John Wiley & Sons.

Stapleton, O., Pedraza Martinez, A., & Van Wassenhove, L. N. (2011). Last mile vehicle supply chain in the International Federation of Red Cross and Red Crescent Societies. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1437978

Sterman, J. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Irwin/McGraw-Hill. http://web.mit.edu/jsterman/www/BusDyn2.html

Taylor, B. *Analysis support to strategic planning* (TR-JSA-2-2012). The Technocal Cooperation Program. https://cradpdf.drdc-rddc.gc.ca/PDFS/unc194/p801995_A1b.pdf

Technical Cooperation Program Joint Systems Analysis Group Technical Panel 3. (2004). *Guide to capability-based planning*. DoD. https://www.hsdl.org/?view&did=461818

Toth, P., & Vigo, D. (2002). An overview of vehicle routing problems. In *The vehicle routing problem* (pp. 1–26). https://doi.org/10.1137/1.9780898718515.ch1

Acquisition Research Program
Graduate School of Defense Management
Naval Postgraduate School
555 Dyer Road, Ingersoll Hall
Monterey, CA 93943

www.acquisitionresearch.net