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FORMULATION AND IMPLEMENTATION OF A METHOD FOR TECHNOLOGY EVALUATION OF SYSTEM OF SYSTEMS

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Abstract

In a fiscally constrained environment, investments in technologies for military systems of systems (SoS) must yield improvements in operational effectiveness as well as individual system or vehicle performance. The current technology assessment approaches, which focus on system-level impacts, could be enhanced by expanding the design space to a SoS perspective, leading to improved cost/benefit analyses. The methodology presented herein, provides a capability to trade and compare operational benefits of technological upgrades by quantifying the impacts from an SoS perspective. The resulting design space is expanded beyond individual vehicle sizing and performance parameters to include multiple system performance parameters and the resulting measures of effectivness from a mission simulation. A proof-of-concept is demonstrated based on an Australian Humanitarian Aid and Disaster Relief Mission during Cyclone Pam in 2015. The approach is able to identify the impact of advanced vehicle technologies on overall SoS mission-level effectiveness.

1 Introduction

The increasing advancement of information exchange promotes capabilities based on collaboration between independent systems, requiring modern military systems to be defined and evaluated as interconnected Systems of Systems (SoS) [1]. An SoS architecture in a military environment may be comprised of a collection of mission strategies and/or collections of ground vehicles, aircraft, surface ships, and satellites. The new systems being developed today will be interoperable, and related technologies must be designed from an SoS perspective with situational awareness of the intended operating environment, requiring a change in the engineering mindsest.

Typically, most technology evaluations consist of a design space exploration performed at the system level for a fixed mission around a baseline vehicle configuration. In other words, the means to perform this mission are varied while the ways in which the mission is completed are fixed [2]. In a similarly limited process, operational analysis typically involves selecting a fixed vehicle or set of vehicles to investigate alternative tactics to complete a given mission. In this example, the means to perform the mission are fixed while the ways the mission is performed are varied. This disjointed process results in operational inefficiencies as advances in technology increase the need for complex system of systems [3].

The methodology discussed herein allows the impact of new technologies to be assessed from operational measures of effectiveness at the SoS-level by expanding the design space from individual vehicle sizing and performance parameters to include multiple system sizing and performance parameters as well as potential operating conditions, or alternative tactics. By deriving requirements from the top-level for new systems, an improvement in overall future fleet development can be achieved beyond isolated vehicle performance improvements.

The foundation of this approach is based on the Technology Identification, Evaluation, and Selection (TIES) method developed, initially, for commercial transport aircraft [2]. This vehicle technology assessment approach has been modified to include the impact of individual vehicle technologies on Measures of Performance (MoPs), or means, and the impact of complex interactions among multiple elements on mission-level Measures of Effectiveness (MoEs), or ways. With a focus on military transport aircraft, a proof-of-concept example is shown based on an Australian Humanitarian Aid and Disaster Relief Mission (HADR) during Cyclone Pam in 2015. The approach is able to identify the impact of advanced vehicle technologies on overall SoS mission-level effectiveness.

2 Method Description

To aid in the methodology development, the generic decision-making process, shown in Fig. 1, is used as a guide [4]. This process breaks down the fundamental steps of a generic problem and logically constructs the development of a solution. These steps include Establish the Need, Define the Problem, Establish Value, Generate Feasible Alternatives, Evaluate Alternatives, and Make Decision. The need for this methodology

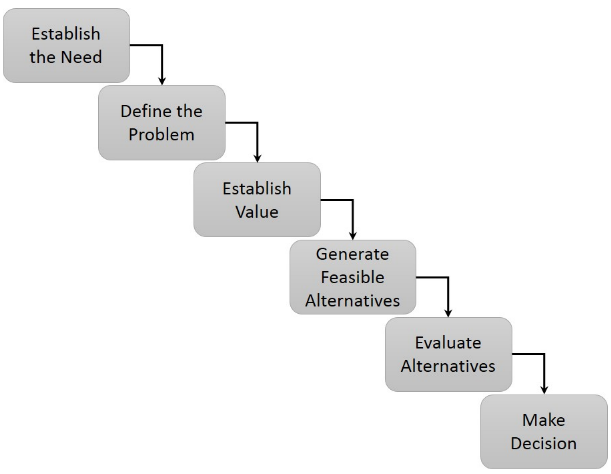

Fig. 1 Generic decision-making process flow chart [4].

was discussed in the introduction, where the need for an SoS-level perspective in vehicle technology assessment was identified based on the increasingly complex and interconnected systems being utilized for military operations. In defining the problem, the challenges in solving it are identified and addressed.

The largest challenge is the vastly increased design space for SoS analysis, which includes innumerable potential combintations and trades between means and ways. To enable these trades to be performed rapidly, key enablers are required. Some of these enablers include integrated analysis models, probabilistic analysis, multi-objective and multi-attribute decision making techniques, creation of a parametric tradeoff environment, and the use of surrogate models. These methods help meet the desire to take a complicated, combinatorial design problem and allow for a thorough examination of the available options in a timely manner.

Another key enabler is the existing TIES methodology, discussed in Ref. [2]. The TIES steps are shown graphically in Fig. 2 and repeated below:

1. Problem definition
2. Baseline and alternative concept identification
3. Modeling and simulation
4. Design space exploration
5. Determination of system feasibility and viability
6. Technology identification
7. Technology evaluation
8. Technology selection

TIES introduces a structured approach to quickly and accurately identify technically feasible and economically viable alternatives. While this process is effective for identifying combinations of technologies that meet both performance and cost requirements for a single vehicle, it currently

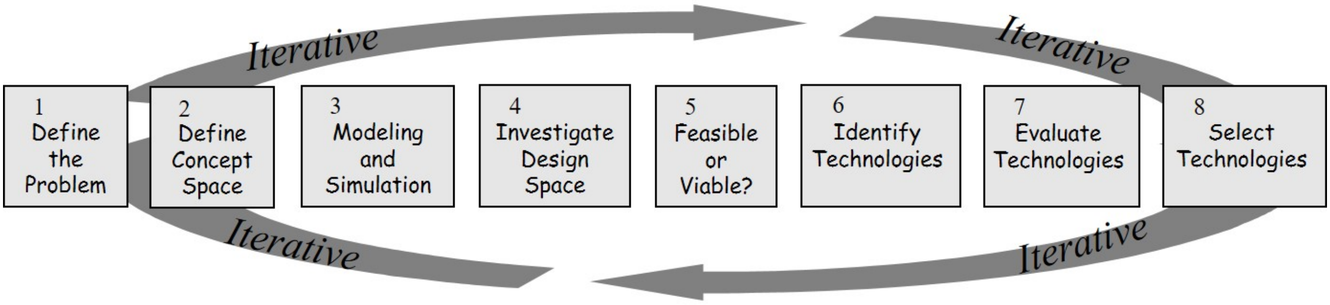

Fig. 2 Technology Identification, Evaluation, and Selection (TIES) [2].

does not consider the impact of multiple assets for a given mission nor does it evaluate alternative tactics for these systems. During the modeling and simulation step of the TIES process, a baseline mission is selected to define the performance requirements on the vehicle being modeled. The vehicle modifications due to technology integration are modeled as changes in the technical metrics that either improve or degrade the vehicle performance during this baseline mission. To overcome these limitations, an expanded and iterative approach to TIES has been developed by the authors to directly address the issues that impact a system of systems.

Fig. 3 introduces the extension of TIES to the SoS problem, TIES-SoS. The steps in TIES-SoS include the use of SoS modeling and simulation techniques to derive vehicle requirements and an iteration of TIES over multiple vehicle and technology alternatives. The entire process is then iterated until peak SoS performance is identified through means vs. ways design space evaluation and tradeoffs.

The next steps in the IPPD guideline coincide with steps in the TIES process. To establish the value of means and ways trades, the vehicles and technology alternatives must be abstracted and defined by MoPs relating to these vehicles, while the simulation of alternative tactics must be abstracted and defined by MoEs. Generating and evaluating means and ways alternatives is an expansion of the TIES technology identification and evaluation steps to include tactical deviations and assessing their operational impact when combined with technology enhancements. Finally, the Make Decision step involves selecting technologies or combinations of technologies for the TIES process and selecting from alternative strategies that include combinations of tactics and technologies for an SoS. These steps are further discussed in the following section, where TIES-SoS is introduced.

2.1 TIES-SoS

Define The Problem: The first step in the TIES methodology is problem definition. This step requires a translation of qualitative customer requirements to quantifiable and testable requirements. Management and planning tools like the Quality Functional Deployment (QFD) are often used in this phase. QFD is a mapping of customer attributes to engineering characteristics. System-level MoPs and mission-level MoEs are identified during this initial step.

Define Concept Space: The conceptual design space for each system includes all options for the various subsystems that satisfy the functional requirements. From a system of systems perspective, this also includes options for the system interactions. For a military campaign, these options could include the number of ground or air vehicles as well the tactics that relate to these options. How are these vehicles/systems going to be operated for a given mission or set of missions? What are the alternative Concepts of Operations (CONOPS)? Do those options change for different system of systems architecture? A baseline vehicle design must be established for every system option in the SoS design space, and a base-

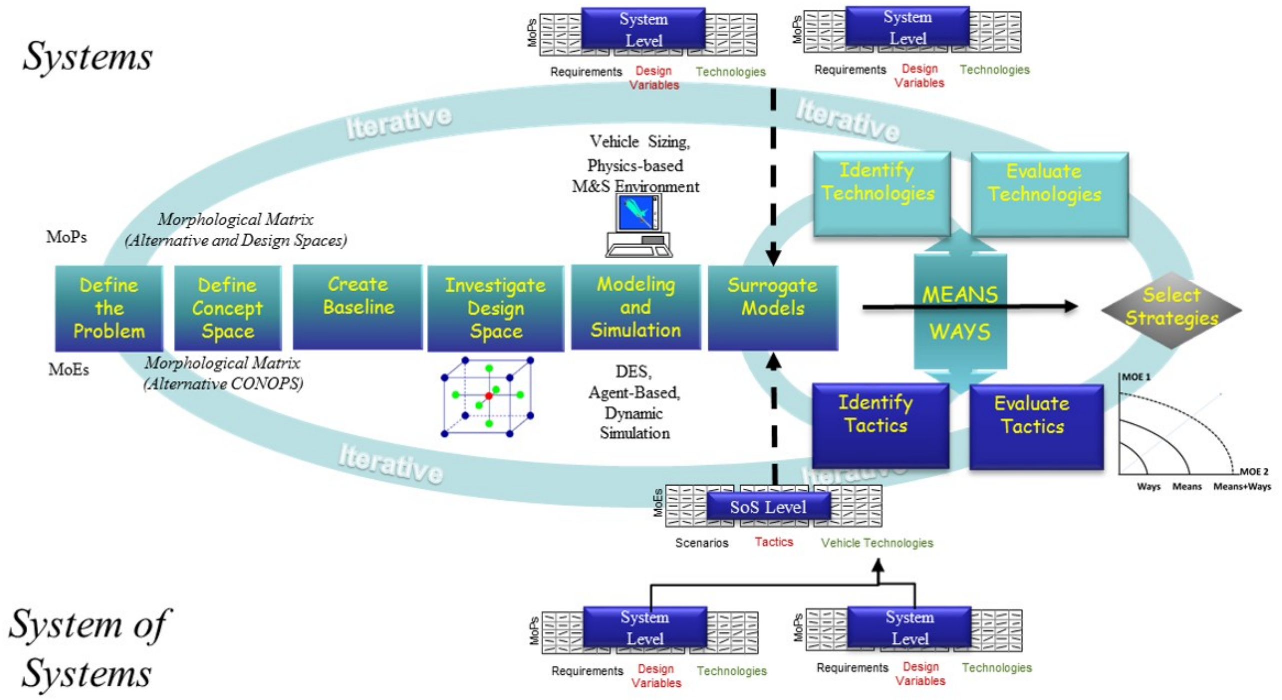

Fig. 3 Technology Identification, Evaluation, and Selection for System of Systems (TIES-SoS)

line set of operational parameters must be established for those vehicles. The options are enumerated in a Morphological Matrix to aid designers in identifying potential combinations of subsystems. A baseline mission and vehicle design is established in this step as a datum point to start the design space exploration. Variations on this baseline are generated by selecting other options in the morphological matrix and are considered alternative vehicle concepts.

Modeling and Simulation: A modeling and simulation environment is used to assess the technical feasibility of the design alternatives and evaluate their system metrics. For systems, these environments can be regressions based on historical data, detailed physics-based analysis, or anything in between. SoS modeling and simulation environments include varying levels of mission abstraction. Typical approaches include system dynamics, discrete event simulation, or agent based models. These techniques will be discussed in more detail later.

Investigate Design Space: The design space exploration begins by determining datum values for the metrics of interest via alternative concept modeling in the M&S environment. The design space for a baseline, or conventional, design is initially investigated by varying the design parameters. There are three probabilistic methods to explore the design space and identify feasible/viable solutions which provide cumulative distribution functions (CDF) for each metric:

- Link simulation code with Monte Carlo simulation
- Create a Metamodel and link to Monte Carlo model
- Monte Carlo simulation methods

Surrogate Models: If the existing design space does not contain feasible viable solutions, the design space can be increased by either relaxing the constraints, implementing alternative tactics, or infusing technologies. The impact of technologies is determined using technology metric k-factors. These k-factors modify disciplinary technical metrics that are calculated using the sizing and synthesis tool. This modification represents the benefit or penalty associated with infusing a new technology. Similarly, the impact of alternative tactics is determined using analogous λ-factors which modify operational effectiveness metrics calculated using SoS scenario simulations. Due to the significant increase is possible alternatives between technology and tactic combinations, surrogate modeling techniques are utilized to approximate the analysis tools. Response Surface Equations and Artificial Neural Networks are two frequent approaches to develop surrogate models.

Identify Means and Ways Alternatives: If no solutions are found in the design space investigation, potential technologies for infusion and additional CONOPS that effectively utilize those technologies must be identified. The k-factor and λ-factor projections for these alternatives require physical compatibilities and quantitative impacts to be determined. A compatibility matrix is used to formalize the technology and tactic compatibilities in a pairwise comparison.

Evaluate Means and Ways Alternatives: A Technology Impact Matrix (TIM) defines the projected quantitative impacts of each technology on the system metrics. The ‘k’ factors modify the technical metrics used during analysis, such as range or specific fuel consumption, simulating technology benefits and penalties. The technology infusion is categorical in nature, where the ordering of the tactics and technologies in the impact matrix does not matter. A notional TIM is shown in Fig. 4. A similar matrix is created to evaluate the impacts of tactical alternatives, represented by vectors of λ-factors. A notional tactic impact matrix is shown in Fig. 5. The impact metrics can be added/removed independently of the others, assuming compatibilities are met, and can be treated as additive during the analysis.

To create a design of experiments that enables a strategic investigation of the tactic and technology tradespace, the number of selections for each alternative is equal to the number of technologies plus the number of tactics, n + m. This design space yields 2^{n+m} combinations, assuming all combinations are possible, and creates a large combinatorial problem. For example, if there were 10 technologies and 30 tactics to consider, the design space would contain 2^{40}, approximately 1.1 trillion combinations. A notional design of experiments is shown in Fig. 6. Additionally, the technology and tactic impacts are probabilistic, implying the need to generate a CDF for each combination.

	Technical "K" Factor Vector	T1	T2	T3
"K" Factor Elements	K1	k_11	k_12	k_13
	K2	k_21	k_22	k_23
	K3	k_31	k_32	k_33
	K4	k_41	k_42	k_43

Fig. 4 Notional technology impact matrix.

	Tactic "λ" Factor Vector	Tc1	Tc2	Tc3
"λ" Factor Elements	λ 1	λ_11	λ _12	λ _13
	λ 2	λ _21	λ _22	λ _23
	λ 3	λ _31	λ _32	λ _33
	λ 4	λ _41	λ _42	λ _43

Fig. 5 Notional tactic impact matrix.

	Design of Experiments					
	T1	T2	T3	Tc1	Tc2	Tc3
Alternative 1	0	1	0	1	1	0
Alternative 2	1	0	0	1	0	0
Alternative 3	0	1	1	0	0	1
...						

Fig. 6 Notional design of experiments for technology and tactical combinations.

The multi-level modeling and simulation environment that includes both system-level sizing models and SoS-level mission analysis are integrated using the surrogate models and ‘k’/‘λ’ factor metric modifiers into a multi-level Unified Tradeoff Environment (UTE) [5]. The UTE, which is shown in the surrogate modeling block of Fig. 3 and is blown up in Fig. 7, allows simultaneous trades to be performed between design variables, requirements, tactics or technologies at each level of the hierarchy. By utilizing surrogate models, a decision-maker can adjust each component and see the impact cascade through the multi-level analysis immediately for real-time sensitivity analysis and trades. Powerful graphical tools like the UTE provide insight into each layer of the problem simultaneously.

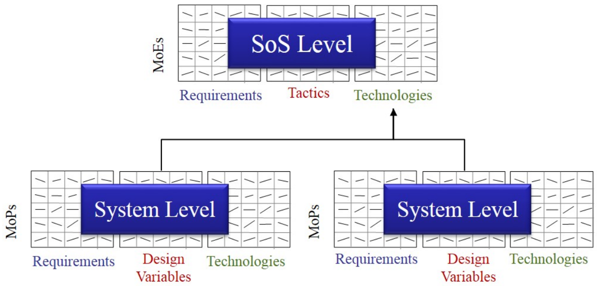

Fig. 7 Hierarchical integrated Unified Tradeoff Environment.

Strategy Selection: Due to the multi-attribute, multi-objective nature of these complex designs, various techniques can be used to select means and ways combinations. Examples include direct resource allocation through 1-1 comparisons, scoring models such as the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS), or frontiers that compare the effectiveness of alternatives technologies and tactics. A notional frontier plot is shown in Fig. 8.

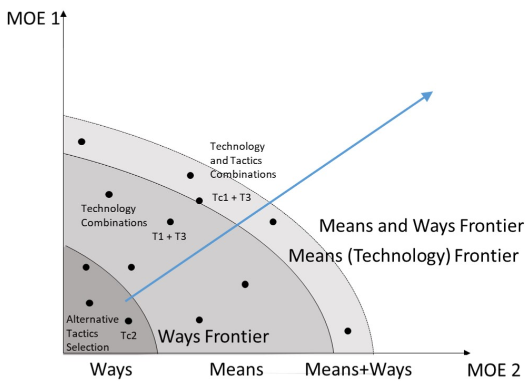

Fig. 8 Notional technology frontier comparing technology effectiveness and investment requirements.

For more immediate effectiveness gains, alternative ways are potentially the quickest change to implement. Investments in technology development, or combinations of technologies, provides the opportunity for further growth. While the combination of technologies and tactics allows for the most improvement, where the technologies can be fully exploited through an ideal set of tactics.

3 System of Systems Modeling and Simulation Approaches

One of the more significant deviations from TIES is the alternative approaches to system of system modeling and simulation as compared to systems modeling, which range in their level of abstraction. For example, manufacturing simulation can range from detailed schedules, latencies, and capacity of individual processes, while supply chain management may not deal with individual packets and use volumes instead. The major approaches include dynamic systems, discrete event simulation, and agent-based models and are shown on an abstraction scale in Fig. 9 [6].

Dynamic systems are systems that are not static, i.e. their state changes over time. The underlying mathematical model consists of physics-based equations or relationships defined through experimentation. This type of modeling is often used in engineering disciplines, such as mechanical, electrical, chemical, etc. [6]. Graphical modeling languages can be used to design control systems using this technique.

Discrete Event Simulation (DES) is a technique which models the event-based behavior of a system. Using mathematical or logical models of the physical system, DES portrays state changes at precise points in simulated time [7, 8]. A DES is comprised of active entities, where actions are performed as part of the system model, and passive entities, which include time delays or queues and resource utilization. DES is frequently used to model the real-life behavior of a facility or system, including manufacturing process flows and military logistics [9]. For these problems, the activity-based approach to DES allows the vehicle abstraction required of this solution, while minimizing the behavioral uncer-

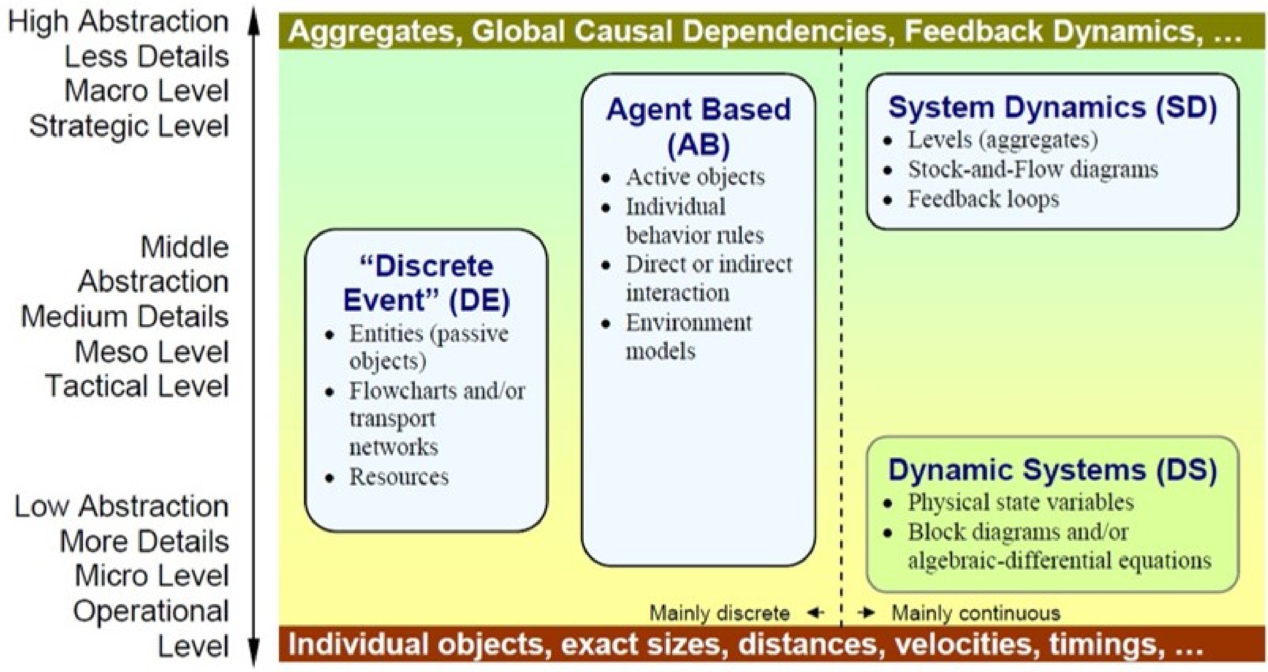

Fig. 9 Approaches in Simulation Modeling on Abstraction Scale [6].

tainty. It models the resource limitation challenge that is key to any logistics problem, and can include stochasticity of random, unscheduled events.

Agent-based modeling (ABM) is a more complex modeling technique commonly used in fields ranging from ecology, game theory, and SoS design [6]. These models are created by defining the simple behaviors of individual, low-level agents through a set of rules, and then initiating the simulation to observe how these agents interact [6, 10]. This type of simulation is designed to identify and explain emergent behaviors that result when many systems interact [11]. The primary characteristics for these multi-agent systems include the restriction of information and capabilities to each agent, the distributed system control, decentralization of data, and asynchronous computation [12]. This modeling technique is advantageous for military engagement modeling, where the logic of individual systems (soldiers, ground vehicles, autonomous vehicle swarms, etc) are easier to define than their complex interactions. While this technique requires more complex modeling, the valuation of complex interactions can provide critical information for military mission analysis [13].

4 Proof of Concept Implementation

The TIES-SoS approach is demonstrated on a humanitarian aid/disaster relief (HADR) mission occurring in the geographically dispersed islands of Fiji, based on the role of the Australian military during Cyclone Pam in 2015. In this application example, the goal is to inform the requirements of modern military acquisition processes by examining the mission effectiveness of Vertical Takeoff and Landing (VTOL) asset acquisition alternatives. The overall technical approach utilized for this proof-of-concept is shown in Fig. 10. In this graphical representation, the TIES-SoS steps can be seen throughout the implementation, including defining the baseline mission by selecting a CONOPS, identifying means and ways alternatives by researching relevant technologies and possible operational methods, among others. A full description of the framework developed in this example and the detailed results can be found in Ref. [14].

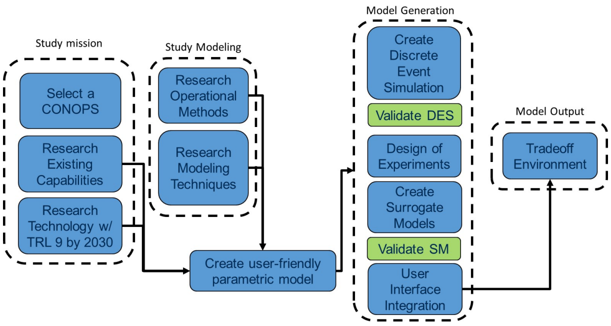

Fig. 10 Graphical representation of technical approach for the modeling and simulation environment.

4.1 Problem Definition

Experience with cyclones Pam and Winston has shown that the first five days of relief efforts are the critical window to maximize efforts of vertical lift assets before naval assets arrive with additional capabilities and support. However, some of the five days are consumed by transporting vertical lift assets to the area of operations (AO) due to the distance. Maximizing sortie generation of direct-support vertical lift assets in the AO in the five-day window is a primary metric, which is analogous to maximizing the number of relief-packages delivered. Limiting support personnel, minimizing vehicle downtime, and quickly identifying priority areas for relief are other critical factors affecting mission success. These critical factors are then translated to MoPs for the vertical lift assets and MoEs for the HADR mission.

4.2 Define Concept Space

The morphological matrix shown in Fig. 11 enumerates the vehicle architecture and tactical options for the HADR mission. The vehicle architecture options must be selected for each type of vehicle that is operating in the SoS, including the number available, the range and capacity of that vehicle, transit frequency, alternative features, and capability in extreme weather. The tactical options for these architectures include package delivery methods, refueling capability and operability, and degree of autonomous operations for any autonomous vehicles considered. Operational MOPs for the five-day operation are the time available for mission, down-time of vehicles, number of sorties generated in theater, and number of hours flown by vehicles. The Operational MOEs for the five-day operation are the number of packages delivered and the number of Tikinas (analogous to counties) visited. These MOEs translate directly to percent of people serviced and percent of country serviced, respectively.

4.3 Baseline Mission/Asset Definition and Alternative Concept Identification

The phases of a disaster relief operation are defined by different goals and sets of actions, where each can be modeled individually. Phases 0 and I, ‘Receipt of Mission’ and ‘Pre-deployment/Staging Operations’ respectively, are awareness and prepping stages. Phase 0 includes prioritizing goals, identifying constraints, determining resources required and resources available, and determining the availability of units for deployment. Phase I includes mobilizing, preparing personnel and equipment for transportation, and loading the strategic airlift. For this proof of concept, Phases 0 and I are not included in the simulation. It is assumed that the available HADR assets are already prepped in the staging area.

The five day window for operations in this simulation begins with Phase II, ‘Deployment’. Deployment options for relief assets include either self-deployment or transportation via C-17 to the AO. The simulation time clock begins at this stage, and the transportation time to the AO is determined based on method of deployment. Transit time for assets that are strategically airlifted is equivalent to the transit time of the strategic airlift (STRATAIR). The self-deployed units require additional resources and time for refueling and stopovers as necessary. Phase III, ‘Reception, Staging, Onward movement, and Integration (RSOI)’ consists of support personnel and equipment arrival and preparation for relief operations. Staging for all assets is assumed to be in place and not accounted for in the model. The

Vehicles	Relative Quantity		Many	Average	Few	None
	Size/Capacity		Large	Moderate	Small	
	Range		Long	Moderate	Short	
	Transit Frequency		Weekly	Biweekly	Daily	12 Hourly
	Features	Component Robustness	Majority Consumable	Balanced Consumable/Repairable	Majority Repairable	
		Security Architecture	Complete Threat Avoidance	Most Prevalent Threat Avoidance	Minimal Threat Avoidance	
		Comm/Nav Redundancy	All Systems Redundant	Critical Systems Redundant	No Redundancy	
	Weather/Environmental		Extreme	Moderate	Limited	
Tactics	Package Delivery		Manned	Unmanned		
	Refueling Capability		Ferry Tank	Aerial Refuel		
	Refueling Operability		Gas-Go	Remain Over Night		
	Level of Autonomy		Fully Autonomous	Semi-Autonomous	Teleoperated	

Fig. 11 Morphological Matrix enumerating vehicle and tactical options for the HADR mission.

STRATAIR deployment method requires the assets to be reassembled and to undergo test flights before they are considered operational, consuming time in the simulation. Phase IV, 'Conduct Operations' is all of the relief mission logistics and operations, including distribution of aid packages, medical evacuations, or any other necessary support. Phase V is 'Redeploy', which occurs after the initial assigned HADR operations are complete, and is therefore, not considered in this simulation.

To define the baseline vehicle assets, a review of the existing Australian Army medium and heavy-lift helicopters was conducted. These vehicles include the CH-47F (Chinook), MRH-90, and S-70A-9 (Black Hawk). To define these baseline vehicles for the modeling and simulation environment, the performance parameters, geometric constraints, and operating conditions for each of these vehicles was identified. These baseline values are used in the modeling and simulation environment to determine the throughput capabilities of baseline SoS architecture combinations.

4.4 Investigate Design Space

Investigating the design space entails identifying any scenario requirements and constraints and enumerating the existing options that potentially meet those requirements. Often this exploration leads to the realization that there are few to no feasible existing options, driving the need for evaluating alternative CONOPS and/or infusing new technologies. The Fiji scenario reduces the design space based on local geography and resources. Access to available airports or air bases for STRATAIR and VTOL assets, environmental considerations including limited visibility and presence of wind gusts due to rough weather, the state of existing local communication structures, etc. are all potential factors in this mission scenario. For the proof-of-concept problem, only 2 C-17s are available for relief operations and are limited to two sorties. The local command and control center is assumed to have no communications with outlying islands, and a distribution method was implemented based on existing population statistics. Based on the baseline vehicle performance parameters, only the CH-47 and MRH-90 are able to reach the outermost Fiji islands from the Royal Australian Air Force base in Amberley.

4.5 Modeling and Simulation

Discrete Event Simulation, which is commonly used for military logistics problems, was chosen for this problem. The structure of the DES is capable of handling parallel tasks and events, but requires a new simulation to be run for new vehicles or changes in the operational procedures. To speed up the run time and reduce computational resources required, surrogate models were used to capture the impact of vehicle and mission changes on the MoPs and MoEs.

4.6 Surrogate Modeling

A design of experiments (DOE) was created around the discretized operation and performance metrics used to define the baseline vehicle and mission scenarios within the simulation environment. Separate DOEs for each asset type were created due to the categorical nature of the problem, with variations on the performance metrics of a fixed percentage from the baseline. Neural Networks were used to create a surrogate model from the resulting DOE data, and the surrogate model fits were evaluated based on Ref. [15]. The considered assets did not cover the full range for each performance metric aggregated across vehicle types using this approach. While the surrogate models performed better by limiting the baseline variations, there were gaps in capability for potential alternatives.

4.7 Identify Means and Ways Alternatives

To generate the means and ways alternatives, the mission operating parameters and vehicle performance parameters are decomposed as shown in Table 1 [14]. The operating parameters represent tactical options or ways, while the vehicle parameters represent different technologies or means.

Means: Technology improvements were divided into three different types: general airframe technologies, reduced/zero maintenance technologies, and engine core technologies. General airframe technologies encompass potential technologies that could be developed to reduce drag, rotor tip losses, aircraft weight, or the like. This may include technologies such as swept rotor tips or composite landing gear. Reduced/Zero Maintenance technologies reflect technologies currently under development which may be applied to multiple systems in the aircraft, most notably within the powertrain and engines, dramatically reducing the amount of maintenance required both in terms of scheduled downtime as well as mean time between failure. Engine core technologies improve engine core cycle performance, particularly in the specific fuel consumption. Possible technologies include compressor blisks and thermal barrier coated turbine blades. The vehicle parameters affected by these technologies were translated to ‘k’-factors that vary as a percent change from baseline values for each aircraft considered. Empty weight, maximum take-off weight, and cruise specific fuel consumption were varied up to $\pm 15\%$ from baseline, and all other parameters were varied up to $\pm 25\%$ from baseline.

Ways: Transport to the AO for these assets can be accomplished by either self-deployment or strategic airlift via cargo transport. Self-deployment requires refueling options for vertical airlift vehicles that cannot fly to the destination in one tank of fuel. Options for refueling include aerial refuel or gas-go, which requires landing at a waypoint en-route to the destination. Depending on the time required and crew rest limitations, the asset can simply refuel or may be required to remain over night. Strategic airlift eliminates the need for refueling transporting the asset within a cargo aircraft in a direct flight, but requires the assets to be reassembled upon arrival and to undergo test flights before they are considered operational. The deployment method significantly impacts the total time available for the mission, and should be minimized where possible.

Autonomous operations primarily relaxed constraints on crew requirements for each vehicle. HADR missions are sensitive to the number of personnel on site. As the number of personnel increases, the required infrastructure over-

Table 1 Potential technologies and tactics for HADR mission.

Parameter Group	Alternative	Aircraft Parameter
Vehicle Parameters	General Airframe Technologies	Maximum Takeoff Weight
		Empty Weight
		Maximum Fuel Available
		Cruise Speed
	Reduced/Zero Maintenance Technologies	Mean Time Between Failure
		Mean Scheduled Downtime
	Engine Core Technologies	Cruise Specific Fuel Consumption
		Combat Radius
Operating Parameters	Deployment Alternatives	Aerial Refuel
	Autonomy Alternatives	Autonomous Operations
		Semi-Autonomous Operations
		Teleoperations

head to support the mission will also increase. Autonomy potentially allows the amount of personnel on site to be reduced while retaining mission effectiveness. While other effects may exist, these were not considered as part of this study. The levels of autonomy were mapped to different numbers of crew per vehicle. Fully autonomous systems assumed zero crews per vehicle, semi-autonomous and teleoperated systems assumed 0.5 crews per vehicle. Conventional systems retained the one crew or more per vehicle requirement. In this context, 'crews' refer to pilots and operating crewmembers exclusively. These alternative operating parameters are mapped to λ-factors affecting the simulation.

4.8 Evaluate Means and Ways Alternatives and Select Strategies

In this example, a parametric dashboard was created to allow users to interactively compare acquisition alternatives for existing and technology-infused assets under different operating conditions. The multi-attribute decision-making (MADM) tool is shown in Fig. 12 and consists of three primary sections: location selection, input variables, and output graphs. The inputs include asset selection and its associated deployment method, crew availability, and loading type. These selections are used to define the baseline values for all aircraft parameters.

The MoP and MoE analysis results are all plotted in the output section, which is divided into three different categories: mission details, mission results, and mission resources. The outputs include time available for operation, flight hours, and maintenance hours for mission details; number of tikinas visited, sorties generated, and packages delivered for mission results; and total cost, fuel required, and personnel required for mission resources. The user can change CONOPS, dial-in technology combinations through vehicle parameters and cost parameters of selected vehicles to see the rapid response of the measure of effectiveness from surrogate models as described above. Through the evaluation of alternatives in this parametric environment, the user can determine the vehicle acquisition requirements that meet the intended operational effectiveness goals for future aircraft fleets.

5 Conclusion

A framework has been created that expands upon traditional technology assessment techniques, like TIES, to simultaneously examine the impact of system-level technology infusion and system of systems mission effectiveness for alternative tactics. A decision maker can benefit from the real-time sensitivity analysis and trades performed parametrically. A proof-of-concept

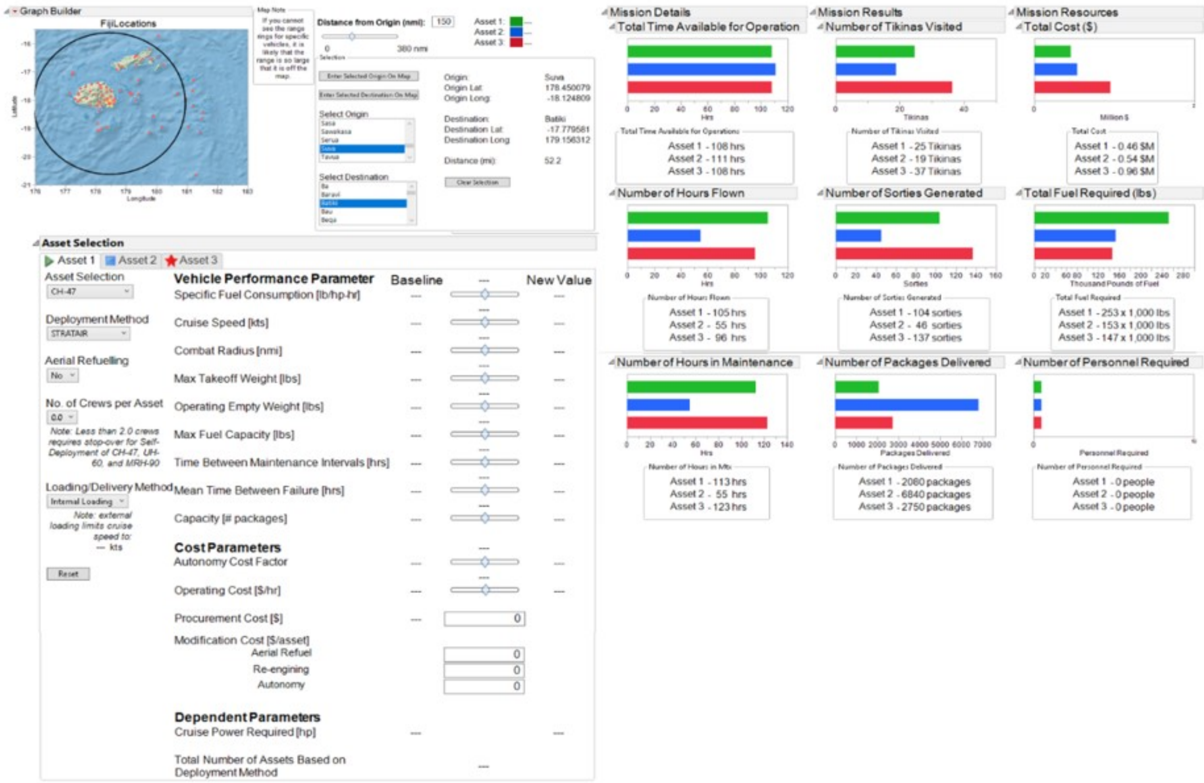

Fig. 12 Decision Support Environment.

demonstration was shown with a HADR mission, evaluating alternative vertical lift asset acquisitions for the Australian military. The system and SoS level surrogate models created from the DES were integrated into the parametric dashboard, allowing the user to change the CONOPS, dial-in technology combinations of different VTOL assets and immediately see the impact on MoEs. By evaluating the MoEs and MoPs of the hierarchical analysis environment, this approach can be used to define requirements for system acquisition or new system development.

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