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Operationalizing the Tactical Edge Framework (TEF) for Service Provisioning Analysis

Fatma Dandashi
Brian Pridemore
Salim Semy
Jennifer Valentine
Beth Yost
The MITRE Corp.
7515 Colshire Dr.
McLean, VA 22102
703-983-7914, 703-983-7804, 781-271-8429, 703-983-3888, 781-271-8331
dandashi, bpridemo, ssemy, jvalentine, bethyost, at MITRE.org

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ABSTRACT: The paper describes a process for executing operational scenarios to quantitatively assess the implications of provisioning services at particular operational and tactical sites. The challenge lies in determining where traditional Service Oriented Architecture (SOA) approaches apply and where they do not. The process leverages a common vocabulary for describing tactical edge (TE) environments as a set of increasingly restricting constraints; applies the constraints as measures of performance; and through modeling and simulation, enables analysis of alternative service provisioning strategies within required measures of effectiveness.

1. Introduction

The paper describes a process for executing operational scenarios to quantitatively assess the implications of provisioning services at particular operational and tactical sites. The challenge lies in determining where traditional Service Oriented Architecture (SOA) approaches apply and where they do not. The process leverages a common vocabulary [1] for describing tactical edge (TE) environments as a set of increasingly restricting constraints; applies the constraints as measures of performance; and through modeling and simulation, enables analysis of alternative service provisioning strategies within required measures of effectiveness.

1.1 Definitions:

An Operational Model is a collection of related, structured activities or tasks that produce a specific service or product (i.e., serve a particular goal) for a particular warfighter. An operational model begins with a warfighter's needs and ends with a warfighter's need fulfillment.

Measures of Effectiveness (MoE) represent the warfighter view, usually annotated and of qualitative nature. They describe the warfighters' expectations of a product, project or system; the voice of the warfighter.

Measures of Performance (MoP) are the corresponding view of the engineer; a technical specification for a product. Typically MoPs are quantitative and consist of a range of values about a desired point. These values are what an engineer targets when designing the product, by changing shape, materials and manufacturing process, so as to finally achieve the qualities desired by the warfighter.

1.2 Objectives

The objectives of this approach are to 1) utilize modeling and simulation techniques to perform *quantitative* analysis on operational models by executing an operational model and computing achievable Measures of Effectiveness (MoEs); and 2) identify where to provision servers and services given limited capabilities at the particular TE environments while maintaining seamless access to services for warfighters.

1.3 Benefits

This approach of utilizing modeling and simulation techniques with operational models offers the following benefits:

1. Expose concurrency issues within an operational context by modeling and simulation of operational models that reflect information flows and contention for resources

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2. Enable quantitative analysis on operational models since achievable MoEs can be computed from MoPs defined in operational models

2. Tactical Edge Framework (TEF)

The Tactical Edge Framework (TEF) is aimed at defining the technical constraints in providing service-based capabilities to a disadvantaged user. To define the framework and help identify design patterns, we began by gathering use cases, identifying common characteristics of various environments, and then focusing on defining a common vocabulary to describe those environments. Four environments were identified: fixed center, mobile center, mobile platform, and dismounted user. Each environment was then characterized by five dimensions as detailed in **Error! Reference source not found.** below.

Table 2-1: Common Vocabulary for TE Environments

Network	Operational	System
Connectivity Latency Bandwidth Reliability Predictability	Repair-ability Decision Timelines Content System Training	Standard User Interface System Processing Storage Ruggedness Size, Weight, & Power (SWaP)
Physical Environment	Security	
Heating, Ventilation, and Air Conditioning (HVAC) Lighting Hazards	Confidentiality Integrity Availability	

2.1 Common Vocabulary

These five dimensions were further quantified using a set of attributes and a range of possible values for each attribute. In this paper, we use two of the five dimensions, namely the network and system dimensions. The network dimension was characterized by the attributes: connectivity, bandwidth, and latency, where both latency and bandwidth (i.e., speed and capacity) define the throughput of the network. Reliability and predictability were not used as parameters in this paper. The system dimension was characterized by the attributes: processing capacity, storage capacity, power, total system space, and total system weight. For detailed definitions and defined values for the remaining attributes, please see [1, 2, 3].

Error! Reference source not found.Error! Reference source not found. illustrates how the four environments of fixed center, mobile center, mobile platform, and dismounted user were characterized for each dimension. Values defined for each attribute appear in cells as detailed below. The classes of TE environments shown in **Error! Reference source not found.** serve as the representational set of environments for which design patterns can be specified. There is nothing Department of Defense (DoD) unique about these environments or their attributes as defined by this TEF. It is therefore possible to apply and use the framework and the common vocabulary to address the needs of non-governmental users.

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		TEF Env 1	TEF Env 2	TEF Env 3	TEF Env 4
		Tactical Fixed Center	Tactical Mobile Center	Mobile Platform	Dismounted User
LAN Network	Connectivity	>85%	>85%	25-84%	5-24%
	Latency	<250 ms	<250 ms	>250ms	>250 ms
	Bandwidth	128 kbps-100 Mbps	128 kbps-100 Mbps	1-128kbps	1-128 kbps
	Reliability	>90%	>90%	>90%	>90%
	Predictability	predictable	mostly predictable	less predictable	unpredictable
WAN Network	Connectivity	>99%	85-99%	25-84%	<5%
	Latency	<250 ms	250-1000ms	250-1000ms	>1000ms
	Bandwidth	<20 Mbps	128-1 Mbps	128-256 kbps	9.6-64 kbps
	Reliability	>90%	>75%	<75%	<75%
	Predictability	predictable	predictable	less predictable	less predictable
System	Standard User Interface	desktop – laptop	desktop - laptop	laptop - tablet - handheld	laptop - tablet - handheld
	Processing	servers – workstations	servers - workstations	single workstations - handhelds	single workstations - handhelds
	Storage	large data storage devices	large data storage devices	single hard drives	single hard drives
	Ruggedness	few ruggedness considerations	few ruggedness considerations	many ruggedness considerations	many ruggedness considerations
	Size	> 10 sq ft	> 10 sq ft	< 10 sq ft	< 3 sq ft
	Weight	100s lbs	100s lbs	10 - 100 lbs	< 10 lbs
	Power	grid, macro generator	generator - batteries	generator - batteries	batteries
Environment	HVAC	HVAC	none	none	none
	Lighting	controlled	controlled	variable	variable
	Hazards	dirt/salt/fog	dirt/salt/fog	dirt/salt/fog/heat/cold/physical	dirt/salt/fog/heat/cold/physical
Operational	Reparability	spares available	some spares available	no spares available	no spares available
	Decision Timelines	minutes – weeks	minutes – days	seconds - minutes	seconds - minutes
	Content	complex	complex	intermediate	simplified
	System Training	extensive - intermediate	extensive - intermediate	intermediate - minimal	intermediate - minimal
Security	Confidentiality	insider threat, packet sniffers	transmission interception	transmission interception	capture
	Integrity	viruses	transmission errors	transmission errors	spoofing
	Availability	denial of service	denial of service	jamming	capture, damage

Figure 2-1: Tactical Edge Framework

2.2 Design Patterns

Design patterns occur in many different disciplines. The concept of design patterns is summarized by the architect Christopher Alexander as a manner to "Describe a problem which occurs over and over again in our environment, and then describe the core of the solution to that problem, in such a way that you can use this solution a million times over, without ever doing it the same way twice." [4] The computer science discipline later adopted Alexander's idea and summarized design patterns as "a description of communicating objects and classes that are customized to solve a general design problem in a particular context." [5]

3. Operationalizing TEF

To validate the TEF and support adoption, the TEF was applied to multiple DoD programs to demonstrate the TEF's contributions to realize services at the TE [3]. This section describes the TEF's applicability throughout the service's acquisition lifecycle, including collecting users' requirements, documenting use cases, designing and developing a service, and managing a portfolio of services at the TE. Figure 3-1 illustrates this process which is detailed in the following paragraphs.

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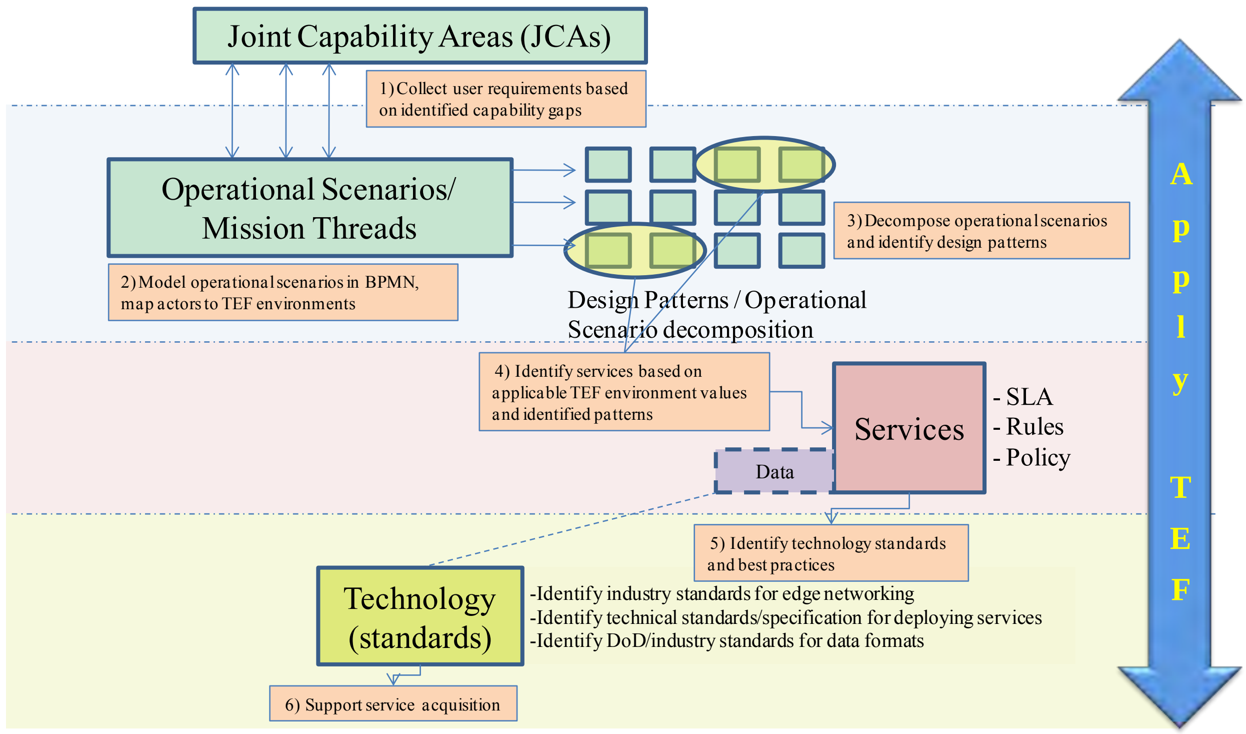

Figure 3-1: Applying the TEF

3.1 Collect User Requirements

In the process of defining strategic roadmaps, it is important to start by determining users' needs, defining the strategic goals for capability development, and using this information to identify capability gaps. While some capability gaps can emerge from the portfolio management processes, interviewing users is also a key component of identifying capability gaps and collecting requirements for future capabilities. The TEF can be utilized in this process to identify capability gaps by asking end-users about their functional operational needs, documenting operational scenarios (e.g., how they accomplish their tasks), and by inquiring about their TE environment's constraints using the TEF's common vocabulary and attribute values as guidance. This results in capturing end-user requirements in the context of the constraints of the environment. Once the necessary functions are identified for specific constrained environments, identifying where current or planned solutions might be inadequate becomes evident as TEF guidance, which includes a set of design patterns that are useful for specific environments. In this manner, capability gaps are flagged and can be documented (i.e., where current or planned services do not intersect with recommended guidance).

3.2 Model Operational Scenarios

Using the capability gaps and user requirements as a starting point, the next step is to document use cases through the development of operational scenarios, which in essence defines the Concept of Operations of the needed capability. Operational scenarios can include interaction patterns between participants. The participants in a TE operational scenario can be characterized by using the TEF's common vocabulary and then using the TEF's common vocabulary to bin operational scenario participants into one of the four classes of TE environments (i.e., Tactical Fixed Center, Tactical Mobile Center, Mobile Platform, and Dismounted User). This is the equivalent of mapping each swim lane in a Business Process Model & Notation [6] process flow diagram to the applicable TE environment. The benefit of this alignment is that it identifies the constraints that need to be taken into account within and across multiple classes of TE environments.

3.3 Identify Design Patterns

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Aligning operational scenarios with the TEF allows one to identify applicable design patterns and other guidance, which enables the delivery of effective services to support the operational scenarios. Design patterns are first associated with the TEF's attribute constraints that they can help mitigate. (See [2], Appendix C.) For example, a design pattern can be associated with intermittent connectivity and low bandwidth. Services are aligned with the TEF's classes of environments in which they were designed to function.

3.4 Identify Services

Aligning an operational scenario's participants with the applicable TEF class of environment allows for the identification of services and design patterns that provide options to help in mitigating the constraints for a particular TE operational scenario. The design patterns can then be incorporated into service specifications to ensure that the results can provide the needed capabilities given the constraints of the classes of TE environments. In addition, aligning service solutions to the TEF (i.e., mapping service solutions to the classes of TE environments in which they currently, or are intended to, operate) allows Portfolio Managers (PMs) to assess the existing portfolio to determine if a newly identified capability need can be met with existing solutions, and if such solutions will support use in the intended TE environment. In other words, mapping services to TEF classes of environments allows PMs to look across an existing portfolio of services and commercial off-the-shelf (COTS) tools to identify existing solutions built with the necessary underlying assumptions about constraints. The TEF classes of environments allow for comparisons across DoD components and various types of TE platforms that otherwise can have appeared as distinct entities.

3.5 Identify Technology Standards and Best Practices

Best practices and standards are a crucial enabler of interoperable systems, because they promote a reasonable degree of consistency across service implementations. One challenge in employing this guidance is determining what is applicable; it is often difficult to identify the specific guidance that applies to a particular situation. For example, a developer might focus on defining a data staging strategy for users who have connectivity only 10-40% of the time.

The TEF can be used to organize best practices and standards for developers. Within the TEF, mapping the classes of TE environments to the best practices and standards organizes the guidance so it can be navigated by a particular TE environment or constraint. The TEF allows developers to identify specific guidance based on a particular context (e.g., user interfaces for dismounted users). The guidance can also be tailored to address a particular challenge in a TE environment. The intent is to provide a TE perspective on the multiple volumes of guidance, so a user developing services for the TE can employ the TEF to navigate through the material and identify relevant and possibly tailored guidance. The guidance is aligned with the constraints of the TE environment to support binning the guidance by the constraints as well as clustering it by the classes of TE environments.

3.6 Support Service Acquisition

A challenge with acquiring systems for the TE is identifying quantifiable criteria to assess the readiness of the systems that will operate within TE environments. Aligning operational scenarios to the TEF provides a means to characterize the constraints of the classes of TE environments using a common vocabulary and to derive the non-functional requirements (MoPs and MoEs) that can be part of a Request for Proposal (RFP). These non-functional requirements characterize the unique considerations of each TE environment in which the system will be deployed.

4. Executable Operational Models-Technical Approach

The process defined above leads to developing an operational model through a series of steps:

3. Work with Subject Matter Experts (SMEs) from the problem domain to:
    a. identify the various roles that take part in the operational scenarios being modeled,
    b. identify desired MoEs
4. Characterize operational models in the context of the TEF with respect to network and system resources (MoPs)
5. Develop the operational model in a process flow diagram using a rigorous modeling language such as Business Process Model & Notation (BPMN) [6]. Swim lanes correspond to TE environments
6. Apply constraints to swim lanes corresponding to TEF environments

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7. Use simulation and resource loading to derive achievable MoEs from MoPs defined in operational models
8. Perform quantitative analysis on operational models
9. Refine operational models and introduce alternative technical solutions
10. Assess operational effectiveness of alternative technical solutions
11. Repeat Steps 5-8 as needed
12. Make recommendations on technical solutions and service provisioning at the TE

5. Reference Implementation

The purpose of the reference implementation is to demonstrate the feasibility of the technical approach on a real-world operational scenario. In this section, we apply the TEF attributes and the technical approach described above to a Joint Close Air Support (JCAS) operational scenario. The model describes the process used by a warfighter to call for and receive approval for close air support (CAS). For the purpose of this analysis, we define an acceptable time window for the request response time to be no more than 40 minutes.

The objectives of the simulation are to:

- determine impact on the scenario/mission of transitioning TE communications from analog to digital in 2016,
- verify the needed digital communication physical measures (MoP) to achieve required 40 minutes response time (MoE) to JCAS request, and
- explore alternative logical communication strategies within identified physical constraints.

5.1 Joint Close Air Support Operational Scenario Description

The various groups participating in this scenario were identified and in working with SMEs, the applicability of each TEF environment was determined. Four groups of participants were identified, and three of the TEF environments were applicable. This resulted in identifying attributes for the network and system resources available to each. BPMN was used to create the model in a standard modeling language. Using BPMN, participants were modeled as swim lanes. Activities, sequence flows, and information flows were each modeled using BPMN defined notation such as rectangular boxes, solid, and dotted lines across swim lanes, respectively. Participants in the Battle Area were assigned TEF attributes applicable to TEF environment 4 (Dismounted User); participants conducting Intermediate Command and Control (C2) and those operating at the Air Support Operations Center were both assigned TEF attributes applicable to TEF environment 2 (Tactical Mobile Center); participants conducting Operational Level C2 were assigned TEF attributes applicable to TEF environment 1 (Tactical Fixed Center). Figure 5-1 is a snapshot of the top level JCAS process diagram developed for this reference implementation and does not depict actual scenarios of the JCAS mission area. TEF environments applicable to each swim lane are also indicated.

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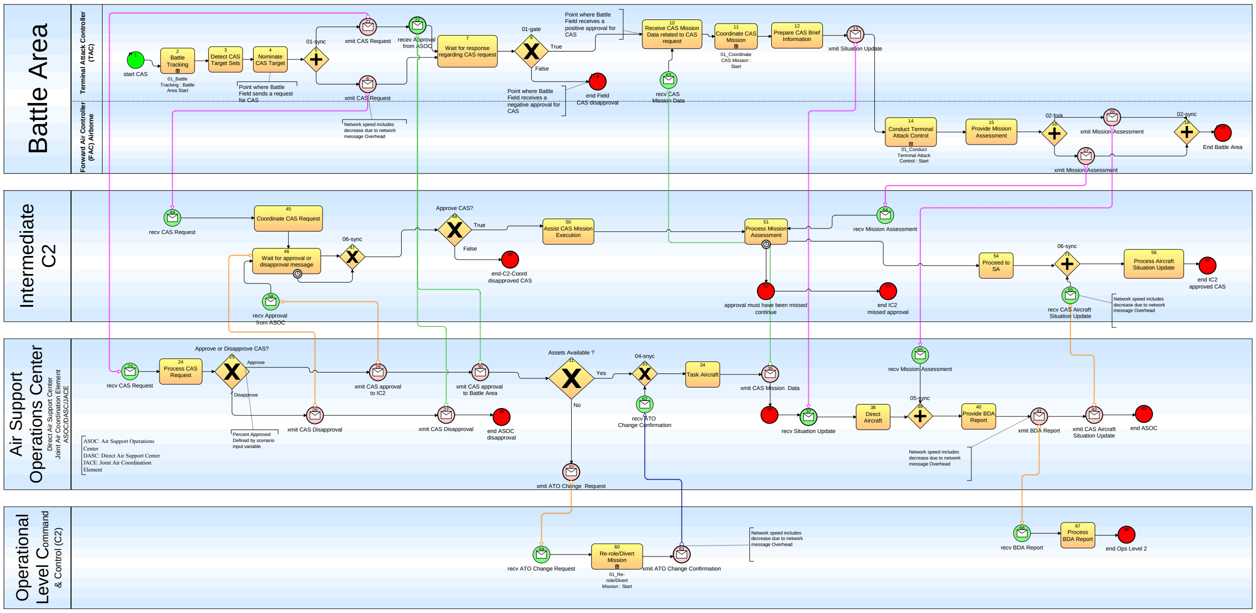

Figure 5-1: JCAS Operational Model

5.2 Joint Close Air Support Executable Operational Model Characteristics and Quantitative Measures

The following MoPs were identified and applied to each of the JCAS participants as attributes in the model. The attribute values for connectivity, time, bandwidth, and processing are nominal values identified in the TEF and were used to accomplish sensitivity analysis and demonstrate the capabilities of the modeling and simulation approach.

Network connectivity: (% of the simulation time that a network connection is available) for each participant was set per TEF environment at 99%, 85%, and 5% available for TEF environment 1, 2, and 4, respectively.

Time: Amount of time required to complete the task including all given delays that may occur; e.g., 3 days (includes time for manager approval). Example Time delays in regular tasks while a network connection remains live over Satellite Communications (SATCOM) link. Time away (when disconnected) was varied by terrain type for TEF environment 4 at simulation time. Three terrain types were identified for TEF environment 4: desert, mountain, and urban terrains. Terrain types affect the amount of time a satellite network connection may be unavailable to the user operating in TEF environment 4.

Bandwidth: The term bandwidth is used to refer to the rate at which data can be transmitted over a given communications circuit. Bandwidth is usually expressed in either kilobits per second (Kbps) or megabits per second (MBps). For TEF environments 1, 2, & 4, these were defined as: 20MBps, 1MBps, and 10Kbps, respectively.

Processing: The rate at which a computing device performs operations (clock rate or speed of Computer Processing Unit [CPU]). TEF environment 4 operates at 0.5 speed of layers 1 and 2.

Table 5-1 details these values.

Table 5-1: Terrain Types and Parameters

Terrains	Desert	Mountain	Urban
Connectivity %	85 %	70 %	10 %
Time Away	2 hours	1 hour	30 seconds

Computation Resources (i.e., system dimension): The rate at which a computing device performs operations (clock rate or speed of CPU). System resources were simulated to be more powerful (operating at twice the processing speed) for TEF environments 1-2 vs. TEF environment 4, and these were set as applicable for the various participants.

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Participants that use satellites to communicate were straddled with an extra restriction of adding latency to their communications as defined by TEF. Bandwidth variables were also set for each participant and message size was varied for various runs to determine effect on MoE.

Volume or Traffic: Number of times a task (e.g., an email is sent) is performed; e.g. 10,000/hour or 50/minute. The simulation was run by varying the number of request coming in per hour from 50 to 200. Message Size is not defined by TEF, but was varied for this simulation between 192, 256, and 512 bytes. CAS approval rates were also varied from 50% approval to a 90 % approval rate of all requests received.

5.3 Simulation Results

The iGrafx [7] COTS tool was used for developing the model and running the simulation. Minitab [7] was used in conjunction with iGrafx to export simulation results and to conduct the analysis. The JCAS results convey the utility of the TEF process and sensitivity analysis using modeling and simulation techniques, and do not depict actual results for systems being used in the JCAS mission area. The results of the simulation are summarized in Table 5-2.

Table 5-2: Simulation Results and Analysis

	Desert 85% 0-4 hours	Mountain 70% 0-2 hour	Urban 10% 0-1 minute
50% @ 192 bytes	7.12 min @ 150	8.67 min @ 150	133 min @ 150 9.94 min @ 100
50% @ 256 bytes	8.50 min @ 150	8.85 min @ 150	590.58 min @ 150 25.44 min @ 100
50% @ 512 bytes	9.98 min @ 150	10.26 min @ 150	588 min@ 75 866min @ 100
90% @ 192 bytes	13.56 min @ 150	15.61 min @ 150 7.65 min @ 100	6.89 min @ 75 17.73 min @ 100 923 min @ 150
90% @ 256 bytes	13.33 min @ 150	15.74 min @ 150	300min @ 100 831 min @ 150
90% @ 512 bytes	13.89 min @ 150	17.03 min @ 150	839 min @ 75

Results of the simulation indicate that the JCAS Request-to-Response time of < 40 min can be met in desert and mountain operating areas. However, for operators in an urban environment, with a rate of 100-150 requests per hour, mission performance is affected assuming a 50% approval rate and messages sizes @ 192 and 256 bytes; or a 90% approval rate and messages sizes @ 192 bytes. Mission performance is severely affected (Request-to-Response time of > 40 min) when messages sizes are @ 512 bytes; with a rate of 75-100 requests per hour.

5.4 Potential Communication Solutions: Design Patterns/Services:

One potential solution to improve mission performance and effectiveness is to reduce bandwidth use by deploying the following service patterns:

- Protocol: Store data at email server and only send an email message with a URL link as a notification
- Data compression (reduce bandwidth requirements)
- Data Formatting: Reduce message size at TE by varying data formats. Users receive data in formats that are optimized to meet their operational needs and environment constraints
- Dropping Stale Messages: Messages are time stamped so newer messages are delivered first, tagged messages (with obsolete data) are de-queued after a specific time period and never delivered

Another potential solution to overcome connectivity issues and (improve) bandwidth use after connectivity is to employ the following service patterns:

- Messages produced by the service provider are queued at intermediate gateway, until the service requestor asks for the messages
- Store and forward: Data replication, store data at location nearest users who need it most (also improves storage and processing use)

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6. Summary

By assigning attributes and varying values of TEF-defined network and system resources at the operational level, we can conduct analyses on the adequacy of proposed technical solutions, and determine early in the systems engineering process (during operational analysis), the role/contribution of alternative technical solutions to operational effectiveness. In this paper, we provided an operational scenario where TEF was employed to analyze alternative technical solutions and service provisioning strategies. By employing the TEF operationalization process, we showed how one can quantitatively assess the implications of placing services at particular operating environments and further out at TE (as defined by the TEF) to support the warfighter. The process leverages a common vocabulary for describing TE environments as a set of increasingly restricting constraints; applies the constraints as MoP; and through modeling and simulation, enables analysis of alternative service provisioning strategies within required MoE. Mission effectiveness may be improved for time-sensitive tactical applications by tweaking or adaption of technical solutions through deployment of specific protocols or design patterns/services such as compression, caching, and chatty protocols.

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Author Biographies

Dr. Fatma Dandashi is currently supporting an Object Management Group (OMG) effort to update the Unified Profile for DoDAF and MODAF (UPDM) to DODAF v2.0. Dr. Dandashi continues to support the Air Force on updating architecture-related policy and guidance. Dr. Dandashi also serves as the AF representative on the DoDAF metamodel working group for DoDAF v2.0. Dr. Dandashi holds a PhD in Information Technology from George Mason University, a Master of Science Degree in Computer Science from the University of Louisiana (Lafayette), and a Bachelor of Arts degree in Computers/Business Administration from the Lebanese American University.

Brian Pridemore has been supporting Modeling and Simulation efforts since he joined The MITRE Corporation in 2000. In recent years at The MITRE Corporation he has been working on Mission Level Modeling (MLM) where his focus and major contribution has been on mission thread modeling, simulation, and analysis (MS&A) and Six Sigma methodologies to identify and exploit areas for process improvement and information sharing strategies. Pridemore received a double major with a BS Mathematics and BS Computer Science from Ohio University and an MS in Systems Engineering from Johns Hopkins University.

Salim Semy is a lead software systems engineer for The MITRE Corporation's Command and Control Center. Most recently, he focused on developing a framework and identifying design patterns to deliver service-oriented solutions to constrained networking and computing environments. Semy has a bachelor's

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degree in software engineering from the University of Toronto and a master's degree in biomedical sciences from Boston University's School of Medicine.

Jennifer Valentine is a Lead Network Systems Engineer at the MITRE Corporation. She co-developed the application of the Tactical Edge Framework model as well as worked on Volume 3 of the Tactical Edge Framework. She holds a BA in Mathematics from Boston University and a MS in Information Resource Management from the Air Force Institute of Technology.

Dr. Beth Yost is a Senior Human Factors Engineer at the MITRE Corporation and has contributed to the development of the Tactical Edge Framework. Dr. Yost holds a PhD in Computer Science from Virginia Tech, an MS in Computer Science from Virginia Tech, and Bachelor of Arts degrees in Computer Science and in Psychology from Elon University.