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SYSTEMS ENGINEERING CAPSTONE PROJECT REPORT

DISTANCE SUPPORT IN-SERVICE ENGINEERING FOR THE HIGH ENERGY LASER

by
Team Raising HEL from a Distance
Cohort 311-133O

March 2015

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DISTANCE SUPPORT IN-SERVICE ENGINEERING FOR THE HIGH ENERGY LASER

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ABSTRACT

The U.S. Navy anticipates moving to a shipboard high-energy laser program of record in the fiscal year 2018 and achieving an initial operational capability by 2020. The design of a distance support capability within the high-energy laser system was expected to assist the Navy in reaching this goal. This capstone project explored the current Navy architecture for distance support and applied system engineering methodologies to develop a conceptual distance support framework with application to the high-energy laser system. A model and simulation of distance support functions were developed and used to analyze the feasibility in terms of performance, cost, and risk. Results of this capstone study showed that the implementation of distance support for the high-energy laser system is feasible and would reduce the total ownership cost over the life of the program. Furthermore, the capstone shows that moving toward the team's recommended distance support framework will address current gaps in the Navy distance support architecture and will provide a methodology tailored to modern enterprise naval systems.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACAT	acquisition category
ACL	access control list
ADNS	Advanced Digital Networking System
AEL	allowance equipment list
AFOM	Applied Figure of Merit
AI	artificial intelligence
ALIS	AEGIS LAN Interconnect System
AMCM	Advanced Mission Cost Model
A_o	Operational Availability
AoA	analysis of alternatives
APL	allowance parts list
ATO	authority to operate
ATP	atmospheric, tracking, and pointing
AWN	automated work notification
AWS	AEGIS Weapon Systems
BIT	built-in test
BITE	built-in test equipment
BoK	body of knowledge
BMDO	Ballistic Missile Defense Organization
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CANES	Consolidated AFLOAT Networks and Enterprise Services
CASREP	casualty report
CBM	Condition Based Maintenance
CBRN	chemical, biological, radioactive, nuclear
CD	compact disc
CDD	Capability Development Document
CDRL	contract data requirements list
CG	guided missile cruiser
CIC	combat information center

CL	chemical lasers
CMMI	Capability Maturity Model Index
CNSSI	Committee of National Security Systems Instruction
CO	commanding officer
COBIT	Control Objectives for Information and Related Technology
COCOMO II	Constructive Cost Model II
CONOPS	concept of operations
COSYSMO	Constructive Systems Engineering Model
COTS	commercial off-the-shelf
CPU	central processing unit
CSSE	Center for Systems and Software Engineering
CSWF	cybersecurity workforce
DARPA	Defense Advanced Research Projects Agency
DAS	Defense Acquisition System
DDG	guided missile destroyer
DISA	Defense Information Systems Agency
DMSMS	diminishing manufacturing sources and material shortages
DMZ	demilitarized zone
DOD	Department of Defense
DODAF	Department of Defense architectural framework
DON	Department of the Navy
DOTMLPF-P	doctrine, organization, training, materiel, leadership and education, personnel, facilities, policy
DS	distance support
DS3	distance support shipboard server
DSX	distance support X
DTE	detect to engage
ECP	engineering change proposal
EMD	engineering and manufacturing development
ESI	enabling / supporting infrastructure
FAM	fleet advisory message
FCC	fire controlman chief

FEL	free-electron lasers
FMECA	failure mode, effect~~s~~, and criticality analysis
FOSS	free open source software
FOUO	for official use only
FSR	firewall service request
GAO	Government Accountability Office
GIG	Global Information Grid
GOTS	government off-the-shelf
HEL	high energy laser
HVAC	heating, ventilation, and air conditioning
I2DF	information integration and data fusion
IAAS	infrastructure as a service
IAM	information assurance manager
IaaS	infrastructure as a service
IATT	interim authority to test
IAVA	information assurance vulnerability alert
ICD	interface control document
I2DF	information integration and data fusion
ICMP	Internet Control Messaging System
ICMS	Integrated Combat Management System
ICOM	input, control, output, and mechanism
IDEF	integrated definition
IDS/IPS	intrusion detection system/intrusion prevention system
IEC	International Electrotechnical Commission
ILS	integrated logistics support
INCOSE	International Council on System Engineering
IOC	initial operational capability
IoT	Internet of Things
IOT&E	initial operational test and evaluation
IP	Internet protocol
IPR	in-progress review
IPT	integrated product team

IS	information system
ISEA	in-service engineering agent
ISNS	Integrated Shipboard Networking System
ISO	International Organization for Standardization
ISP	Internet service provider
IT	information technology
ITC	information technology chief
ITIL	Information Technology Infrastructure Library
JCA	Joint Capability Areas
JCIDS	Joint Capability Integration and Development System
JFFM	Joint Fleet Forces Maintenance Manual
JTO	Joint Technology Office
KPP	key performance parameters
KSA	knowledge, skills, and abilities
KVM	keyboard video mouse
LAN	local area network
LaWS	Laser Weapon System
LCS	littoral combat ship
LIN	Littoral Integrated Network
LORA	level of repair analysis
LoS	line of sight
LPD	low probability of detection
LRU	lowest replaceable unit
M&S	modeling and simulation
MAdmDT	mean administrative delay time
M_{bar}	mean active maintenance time
MDT	mean down time
METOC	meteorological and oceanographic
MFOM	maintenance figure of merit
MFOP	maintenance free operating period
MH	man hours
MIL-STD	military standard

MLDT	mean logistics delay time
MOE	measure of effectiveness
MOP	measure of performance
MOPA	master oscillator, power amplifier
MOSA	modular open system architecture
MPT&E	manpower, personnel, training, and education
MRC	maintenance requirement card
MTBF	mean time between failures
MTBM	mean time between maintenance
MTTR	mean time to repair
MTU	minimum transmit unit
NAS	network attached storage
NAVSEA	Naval Sea System Command
NAVSEAINST	Naval Sea Systems Command Instruction
NCT	Navy Core Test
NIPRNET	Non-Secure Internet Protocol Router Network
NIST	National Institute of Standards and Technology
NMP-MOM	Navy Modernization Process - Maintenance Operations Manual
NOC	network operations center
NPS	Naval Postgraduate School
NSDSA	Naval Systems Data Support Activity
NSS	national security system
NSWC PHD	Naval Sea Warfare Center Port Hueneme Division
NTC	Naval Tactical Cloud
O&S	operation and support
OEM	original equipment manufacturer
OET	Office of Engineering and Technology
OLA	Operational Level Agreement
ONR	Office of Naval Research
ORTS	Operational Readiness Test System
ORTSTARS	Operational Readiness Test System Tech Assist Remote Support
OS	operating system

OSA	open system architecture
OT&E	operational test and evaluation
OV	operational view
PEO IWS	Program Executive Office Integrated Weapon Systems
PESTO	personnel, equipment, supplies, training, ordnance
PIT	platform information technology
PM	program manager
PMBOK	Project Management Book of Knowledge
PMS	planned maintenance systems
POI	platform of interest
POM	program objective memorandum
PPBE	Planning, Programming, Budgeting, and Execution
PPS	ports, protocols and services
PSP	platform service provider
QRC	quick reaction capability
RAID	redundant array of independent disks
RHEL	Red Hat Enterprise Linux
RF	radio frequency
RMC	regional maintenance center
RMF	risk management framework
RMG	risk management guide
S2E	sailor to engineer
S&T	science and technology
SATCOM	satellite communications
SCD	ship change document
SD	standard deviation
SE	Systems Engineering
SEI	Software Engineering Institute
SHF	super-high frequency
SIPRNET	Secure Internet Protocol Router Network
SLA	service level agreement
SLOC	source lines of cod

SME	subject matter expert
SNMP	simple network management protocol
SOVT	system operational verification test
SPAWAR	Space and Naval Warfare System Command
SRA	ship restricted availability
SSA	software support activity
SSL	solid state laser
STIG	Security Technical Implementation Guides
SVN	subversion
SWAN	shipboard wide area network
TCP/IP	transmission control protocol/Internet protocol
Tech Assist	technical assistance
TEMP	test & evaluation master plan
TOC	total ownership cost
TRL	technology readiness level
TSCE	Total Ship Computing Environment
TSCEi	Total Ship Computing Environment Infrastructure
UCC	Unified Code Count
UDP	universal datagram protocol
USB	universal serial bus
USC	University of Southern California
USN	United States Navy
USS	United States Ship
VLAN	virtual local-area Network
VoIP	voice over Internet protocol
WAN	wide-area network
WSESRB	Weapon System Explosive Safety Review Board
XO	executive officer

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EXECUTIVE SUMMARY

In an attempt to reduce mean down times (MDT) and total ownership costs (TOC), the United States Navy (USN) is currently researching the concept of distance support (DS). Distance Support is the process of providing a maintenance/support product or service from an offsite location.

The team developed and analyzed the requirements for implementing a DS system for the high energy laser (HEL). This included what was necessary from the perspective of the DS system itself, as well as what is required of the HEL system to provide a complete interface to a DS system. A generic DS framework was developed to fit the USN's unique requirements and policies. While the DS framework could be applied to any system, the HEL was chosen as the platform of interest (POI).

The team performed functional analysis and allocation. During this step, the DS pillars (primary supporting elements) and architecture were decomposed into the next lower level functions. Additionally, the team started to develop and refine the functional interfaces both internal to the DS system as well as external to the HEL system. It was important to determine and define the DS system level boundaries as this would facilitate the development of the physical requirements for the DS system in the next stage. The system architecture diagrams were developed to describe the system. The team chose to use the IDEF0 as the basis for the conceptual model of the DS system that was tested. IDEF0 was chosen for DSHEL because it is well understood, adapted well for information systems, and aligns to the DS framework and platform service architecture developed.

Through the employment of modeling and simulation (M&S) tools, the effects of three types of support alternatives were analyzed: The Status Quo Distance Support Model based on level of repair analysis (LORA) currently implemented on most USN platforms; the Integrated Distance Support Model representing the model that is proposed in the CONOPS of this effort; and the No Distance Support Model consisting only of sailor actions and contractor in-port support. The baseline status quo DS model (nonintegrated DS) indicated a MDT of 149.0 hours, a standard deviation of 91.5 hours, with a resulting operational availability (A_o) of 0.770. Integrated DS showed significant improvement with a MDT of 83.8 hours, a standard deviation of 44.9 hours, with a resulting A_o of 0.856, an increase of 8.5%. Conversely, elimination of DS was detrimental to reliability with a MDT of 335.1 hours, a standard deviation of 210.5 hours, and A_o of 0.559, decreasing the A_o by 21.1%.

Cost analysis, based on a 20-year life cycle of HEL installed on 30 shipboard platforms, resulted in an estimate of $7M for the addition of a DSHEL component. Given 30 HEL platforms, the integrated results from M&S have shown that DSHEL would begin to show a return on investment once 29 technical assistance requests have occurred.

The conceptual DS framework was developed using a holistic systems engineering approach to provide the HEL with enterprise level support at a distance. This expanded level of support reduces MDT and lowers TOC when compared to systems without DS. Therefore, the capstone team recommends that the Navy adopt an integrated DS framework approach for providing maintenance support to the future HEL system. This would include using the team's conceptual DS framework and incorporating real world data into the capstone's M&S models and cost analysis to obtain a more accurate understanding of the framework and benefits of implementing DS.

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I. INTRODUCTION AND PROJECT OVERVIEW

This capstone report has been developed by a team of students at the Naval Postgraduate School (NPS) in the distance learning cohort 331-133O pursuing either a Master's of Science in Systems Engineering (MSSE) or Master's of Science in Engineering Systems (MSES). The team, all employees of Naval Surface Warfare Center, Port Hueneme Division (NSWC PHD), executed sound system engineering (SE) techniques with extreme prejudice and rigor. Over the course of nine months, the team performed research, analyzed previous contributions to the body of knowledge (BoK), developed a generic distance support (DS) framework, performed functional analysis and architecture design, and executed modeling and simulation (M&S) of DS processes which ultimately fed a cost and risk analysis.

A. BACKGROUND

This section provides an initial baseline of knowledge for the subject matter presented and relates its importance to in-service engineering in the sustainment phase of the HEL life cycle.

1. Distance Support

Currently, DS is performed by the United States Navy (USN) using the following conduits (Naval Surface Warfare Center, Port Hueneme Division 2013):

- Non-Secure Internet Protocol Router Network (NIPRNET) chat
- Secure Internet Protocol Router Network (SIPRNET) chat
- Email
- Phone
- Regional maintenance center (RMC) site visit
- Engineer on-site technical assistance (Tech Assist)
- DS websites (Sailor 2 Engineer, Sailor 2.0)

When a system indicates a fault, sailors take action to correct the fault based on their training, and consulting automated tools for fault diagnostics. In a mature system, the automated systems may provide valid solutions. The next step in diagnostics and troubleshooting is to consult technical manuals and drawings. As systems have become more complex throughout the USN, the ability to effectively read, interpret, and take action based on schematics has failed to keep up with demand. As onboard troubleshooting efforts are exhausted, the ship must contact outside shore support. RMCs provide the second tier of service and the in-service engineering agent (ISEA) the third. These latter two entities provide only as much remote support and guidance as can be gleaned from descriptions of problems from the ship or limited output from the system. When troubleshooting time or problem information provided ashore has been depleted, an engineer or technician must go aboard the ship to resolve the problem. The effort and expense of onboard support may be, in some cases, cost prohibitive.

2. High Energy Laser Weapons System

An example of a fiber solid state laser (SSL) prototype demonstrator developed by the USN is the Laser Weapon System (LaWS). The USN plans to install a LaWS system on the USS Ponce, a ship operating in the Persian Gulf as an interim afloat forward staging base, to conduct continued evaluation of shipboard lasers in an operational setting. The USN reportedly anticipates moving to a shipboard laser program of record in “the FY2018 time frame” and achieving an initial operational capability (IOC) with a shipboard laser in FY2020 or FY2021 (United States Congressional Research Service 2014).

Lasers are being used in the commercial sector for a wide range of projects from eye corrective surgery to tattoo removal. As with any military product, the aspects of DS and maintenance are much more difficult and require more scrutiny and planning. The components of a basic laser must be considered for the purposes of DS planning.

For the purposes of DS, it is necessary to consider the basic lowest replaceable unit (LRU) and parts of a laser that could potentially require attention or maintenance. All portions of a laser must be carefully balanced and maintained to allow for optimum efficiency and results. Under this assumption, it is important to distinguish the basic LRUs or simplest components of a laser.

Since the HEL is still relatively new, the knowledge base and policies in place need time to mature. Lack of past experience and knowledge increases risk in designing a DS system, as there is less historical data to leverage. The LRUs of the laser need to be monitored in order to prepare for and mitigate problems that may arise from operational use and environmental factors.

B. PROBLEM STATEMENT

The USN has no current plan, component, service, or system that addresses all aspects of DS. This capstone report will explore a methodology and design of a DS framework for a HEL system. Additionally, a DS framework will be established for the HEL to address feasibility in terms of cost and risk to the USN.

This effort affects multiple USN systems. When a system is produced and deployed, it is expected that a certain number of parts will break or require maintenance due to anticipated use and wear and tear, and unexpected casualties. This in turn will lead to the need to replace or repair components of the system. The DSHEL capstone team has developed a DS system that is applicable to the HEL, while still maintaining a generic architecture that is relevant to many systems including possible future iterations of different HEL weapon types.

C. PROJECT OBJECTIVES AND RESEARCH QUESTIONS

This section describes the project goals and research questions.

1. Project Goals

The goal of this capstone report was to develop a DS framework and architecture for future shipboard HEL Systems. The team studied a "designed in" implementation of DS rather than a "bolted on after the fact" implementation. Using the USN's Six Pillars of DS as a starting point, the team's objectives were to explore, analyze, and propose methodologies, architectures, and technologies to efficiently effectuate the first four pillars of DS as applicable to surface USN HEL Systems. The Six Pillars are discussed in subsequent chapters.

2. Research Questions

The following research questions were answered by this capstone report:

- How will DS affect the overall cost and risk in HEL shipboard implementation?
- What type of infrastructure is required to adequately perform DS for HEL?
- Are there any existing DS frameworks that can be applied to DSHEL?
- Of the HEL components, which information is the most important to collect?

D. PROJECT ASSUMPTIONS AND CONSTRAINTS

This capstone report was executed under the following assumptions and constraints as detailed in Table 1.

Table 1. Assumptions and Constraints

Type	Assumption or Constraint Description
Constraint	This study is limited to the Solid State Fiber Laser as the HEL system being analyzed. This laser has already been used and installed on a USN ship.
Constraint	This study is limited to the HEL system integrated onto afloat platforms. Afloat platforms were chosen due to stakeholder needs and requirements as detailed later.
Constraint	Of the Six Pillars of DS, this capstone will cover the first four pillars: Remote Technical Assistance, Remote Repair and Validation, Remote Diagnostics, and Remote Monitoring. The last two pillars of DS are outside the scope of this capstone report as the technology available is not yet mature enough to support ePrognostics or Self Repair and Healing.
Constraint	All data and information disclosed within this capstone report has been generalized to conform with Distribution A requirements for release to the public.
Assumption	Labor rates of support personnel are fully burdened at $60/hr. This value was chosen to keep consistent with other previous studies performed by PEO IWS.

Type	Assumption or Constraint Description
Assumption	Travel costs: CONUS: $2,500 /wk., OCONUS: $5,000 /wk. This value is consistent with previous studies performed by PEO IWS.
Assumption	Data rates to/from the installed platform are bounded between 2Mbps to 4 Mbps, given current satellite communication (SATCOM) bandwidth limitations.
Assumption	Multi-tiered technical support shall follow the existing USN hierarchy: Tier 1 – On-board Support Tier 2 – Regional Maintenance Center (RMC) Tier 3 – In-Service Engineering Agent (ISEA) Tier 4 – Original Equipment Manufacturer (OEM)
Assumption	The manufacturing base of key system parts, assemblies, subsystems, components, and LRUs are not stable and will diminish over time.

E. ANALYSIS APPROACH

This section describes the systems engineering and management approach. It elaborates on the design team structure, the stakeholder and project sponsors, as well as technical approach and methodology used for this capstone report.

1. Design Team Structure

The capstone team was comprised of six students from the Naval Surface Warfare Center, Port Hueneme Division (NSWC PHD). The team members had multidisciplinary backgrounds from land attack, littoral, and air defense combat and weapon systems, and educational backgrounds in applied mathematics, architecture, mechanical, computer, software, network, and electronic engineering with system life-cycle experience in acquisition, test and evaluation, modernization, ship installation, and in-service engineering. Table 2 lists the individual's names, roles, and responsibilities. The teams roles are indicated, delineating primary responsibility and lead effort of the capstone subject matter areas; however, all team members were involved in all areas of the capstone report.

Table 2. Team Member Roles and Responsibilities

Team Member	Roles	Responsibilities
Matthew Sheehan	Project CO Enterprise Architect	Supervised and lead the overall project effort including: selection of the team member responsibilities, team conflict resolution, provided team weekly status and IPR briefings, coordinated external support, scheduled external meetings with capstone advisors and programmatic tasks as necessary. Collaborated with stakeholders, leadership, and subject matter experts, to build, formulate, and align the project design in all aspects. These included, but were not limited to: strategy, process, information, technology, design, logistics, mission, and project vision.
Socrates Frangis	Project XO Software Lead	Served as a backup to the Project CO and ensured the team met CO expectations, scheduled internal team meetings, and managed risk. Ensured logical interface design of HEL DS requirements, captured necessary open architecture message types, proper software integration with HEL system, formatted for remote troubleshooting and off board transfer. Performed cost estimation on DSHEL.
Bridget Grajeda	Editor In Chief	Ensured overall documentation contained: relevant content, proper grammar, correct spelling, consistent flow and style, proper citations, and all other formatting necessary for capstone and thesis compliance.
Virginia Shields	Hardware Lead Secretary of Notes	Provided requirement analysis based on component engineering drawing designs, physical, mechanical, material, and weight considerations. Captured minutes and action items during team meetings.
Brian Meadows	Architecture Design Lead	Generated the functional architecture for DSHEL, which included the generation of infrastructure requirements and interface design.
Darron Baida	M&S Lead	Generated M&S effort of ISEA support processes (current HEL without DS vs HEL with DS).

The capstone project team was supported by NPS advisors for guidance and review of the products prior to submission. Table 3 provides the advisor's names, roles and responsibilities while Figure 1 characterizes the overall Team Organizational Structure.

Table 3. Advisor Roles and Responsibilities

Team Member	Roles	Responsibilities
Professor Green	Project Advisor	Provided oversight and involvement with: all major aspects of the project process, review of capstone proposal, the development of the project plan, advising project execution, participation of in-progress review rehearsals, and the review of all report outputs and products.
Professor Nelson	Project Advisor	
Professor Young	Project Advisor	

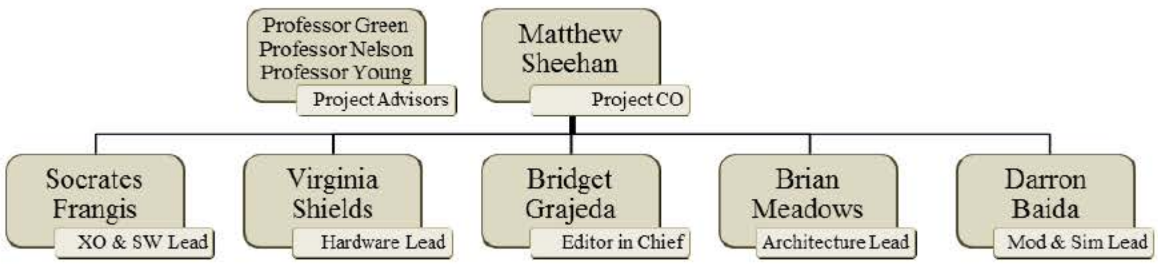

Figure 1. Team Organizational Structure

2. Stakeholder and Project Sponsors

The capstone team solicited inputs from stakeholders regarding challenges and necessary capabilities critical to the in-service sustainment of HEL through the use of DS by means of: customer requirements, thresholds, objectives, and weighted importance for prioritization. Communication channels with the stakeholders were initially determined by local project advisors within the directed energy community. While all stakeholders' inputs were important, some were active in the decision process and had direct input, whereas others were passive and dictated requirements and capabilities through means of naval instructions and enterprise objectives. Stakeholders did transition between the states of active and passive throughout the life cycle of the project; however, Table 4 captures their predominant inputs.

Table 4. Stakeholder Inputs

Stakeholder	Category
Naval Postgraduate School (NPS)	Active
PMS 405 - Directed Energy and Electric Weapon Systems Program Office	Active
Office of Naval Research (ONR)	Passive
NSWC PHD - Office of Engineering and Technology (OET)	Active
NSWC PHD - Distance Support Advocacy Office	Active
Naval Network Operations Center (NOC)	Passive
Naval Sea Systems Command (NAVSEA)	Active
Warfighter, USN	Active

3. System Engineering Process

The capstone team's approach was based on the systems engineering "V" model. The V Model is a way of visually describing the fundamental portions of systems engineering. The use of the V gives a depiction of the flow of work in the SE model. The V is used to give a structured flow from defining requirements (system and performance) and moving into design before testing. This takes the project through a logical high level order that keeps in mind the need for the major milestones of defining the goal of the system, iteratively designing and testing it, and then planning for the practical use of the system. The V model reinforces the key areas of "verification and validation." Following the V forces a systems engineer to constantly and cyclically re-test and re-evaluate the system.

The two major halves of the V model represent the initial portion of the design called "project definition" and "project test and integration." Both of these were used in the DSHEL capstone and are detailed in Figure 2. The first half of the V is where the system engineers/designers must clearly state the purpose and requirements of the system/project to be designed. The second half is where the testing, validation and verification, and integration take place. These two halves of the model are constantly repeated and re-worked through the "verification and validation" portion of the V. In Chapter I, the concept of operations (CONOPS) and background of the DSHEL system are defined; this would fall in the beginning portion of the first half of the V model. Chapter II identifies stakeholder needs, develops a generic distance support framework, and includes the literature review. Chapter III captures applies the distance support framework created, as well as detailing the functional and performance requirements, KPPs, KSAs, MOEs and MOPs. Chapter IV brings the system through concept definition to architecture and interface design. Chapter V employs M&S techniques and uses the second half of the V model. Chapter VI analyzes cost and risk which further follows the second half of the V. The final chapter (VII) provides the project's technical conclusions, recommendations and contributions to the SE BoK.

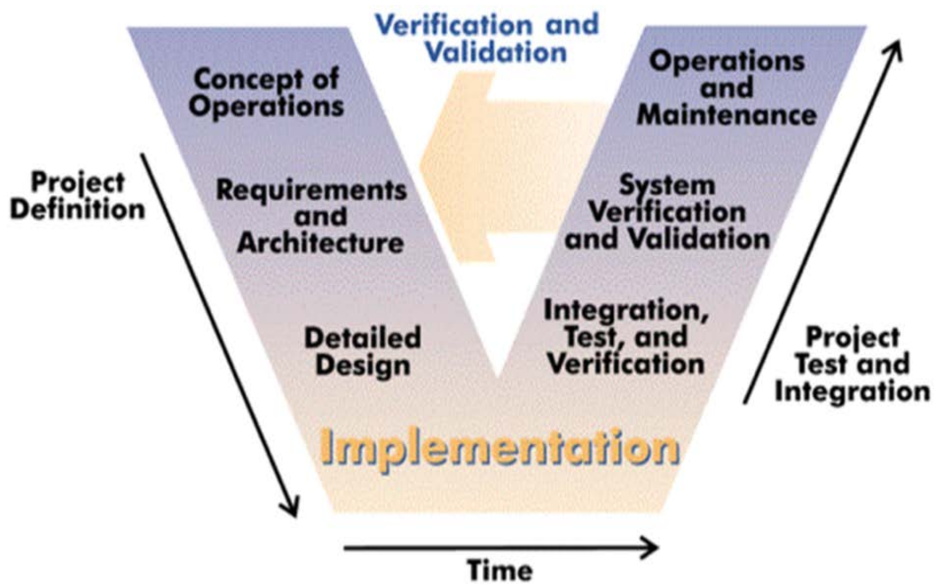

Figure 2. System Engineering V Model (from Eclipse Foundation 2014)

F. SUMMARY

By applying consummate SE judgment and rigor, leveraging emerging technologies, and applying lessons learned from traditional DS practices, a proactive and robust solutions were found with DSHEL. The efforts detailed above show an increase in availability while decreasing the life-cycle cost of the system.

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II. STAKEHOLDER NEEDS ANALYSIS

A. LITERATURE REVIEW

The following sections detail the various topics researched for further information in order to understand the existing BoK in scope and depth concerning DS. Figure 3 shows the literature review methodology used while researching DS for the HEL. Due to DS being a very general and overarching topic, the literature review for DSHEL was divided into two additional focus areas. The material reviewed and research that could be attributed directly to the topic of DSHEL was categorized under the "Explicit Area." This area is reserved for all things related to DS. The second division, "Implicit Area," was reserved for all topics that were important factors contributing to DSHEL, but was not directly related to it. This was done to compensate for all the specific and unique policies, procedures, standards, and requirements levied on DOD programs by government organizations. The topics investigated were selected by their applicability to each research area. These topics were then analyzed for shortcomings, which validated the need for an integrated DS system as supported by a framework devoted to the USN's unique needs.

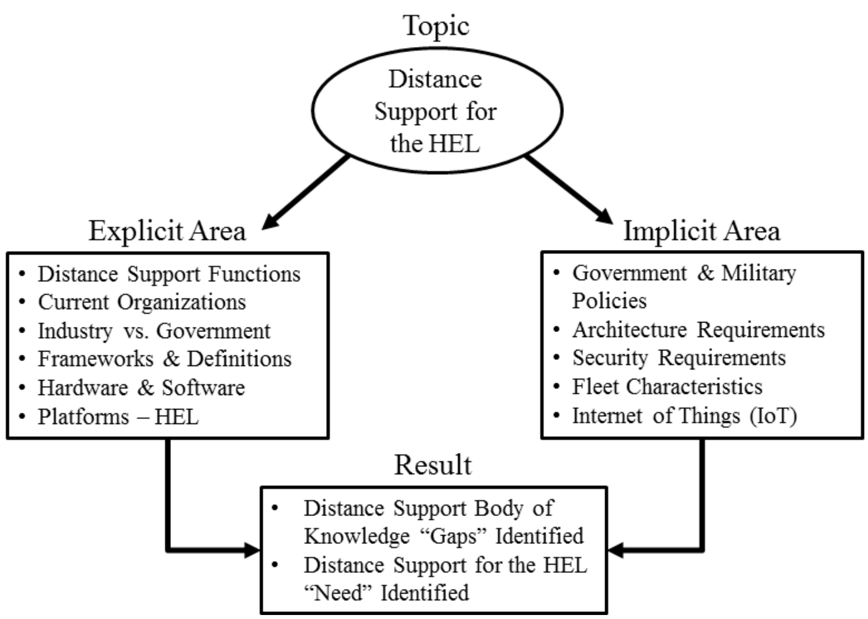

Figure 3. Literature Review Methodology

1. Explicit Areas

The explicit areas (directly related) that were researched and reviewed for DSHEL analyzed the origins, definitions, key theories, concepts and ideas, and major issues, as well as the main questions and problems that have been addressed to date on this topic.

a. Distance Support Beginnings

The concept of DS dates back to advent of the industrial revolution (1760-1840). The creation of heavy manufacturing machinery created the need to have skilled repairmen make routine site visits due to the inability to transport broken machinery (Snider, 2011). As technology progressed, the term DS did as well. The invention of the telephone in 1876 would have a profound impact on how DS was executed. The ability to connect customers/users with service providers in real-time allowed for a greater exchange in knowledge and troubleshooting techniques resulting in reduced downtimes. The result of these reduced downtimes was an increase in customer satisfaction and loyalty which lead to increased profits (Qui and Lee, 2015). The 1960s saw the birth of the modern call center, a single point of contact for corporations to handle customer queries, complaints, and provide support services (Hegde, Sandeep, and Vasudeo 2012, 58). Call centers, now known as help desks, proved to be a valuable tool to connect customer desires with service providers. Another major development in DS was AT&T's creation of the 1–800 numbers in 1968 when a U.S. federal judge ordered Ford Motor Company to establish a free phone line to assist customers in the recall of a faulty car (Hegde, Sandeep, and Vasudeo 2012, 60). This allowed for companies to have a direct, dedicated line to provide support to their customers. With a single-point contact number to a service provider, corporations were now faced with the task of organizing and distributing different customer requests to the proper service expert. This issue was resolved with the creation of the phone menu and multi-tiered technical support. A phone menu is an automated menu that a customer dials to navigate down to the desired information on a particular topic. Figure 4 gives a simple pictorial of how phone menu number selection might be organized. A customer with an inquiry or issues calls the appropriate service line. Companies tend to have one service number to cut down customer confusion on which number to contact concerning topic desire. The customer is then greeted by an automated menu selection. Referring to Figure 4, the customer is presented with three menu options as noted by the numbers “1,” “2,” and “3.” Each of these numbers would be linked to different product topic areas, lines, or business functions. For example, selecting number “1” may connect the customer to a general information line, where selecting number “2” may connect the customer to a billing and accounting department. For companies that have many product lines or business functions, a nested menu may be employed. Selecting number “3” would prompt the customer with another menu offering further choices from which to select, which in turn would connect the customer to the desired product line or business function.

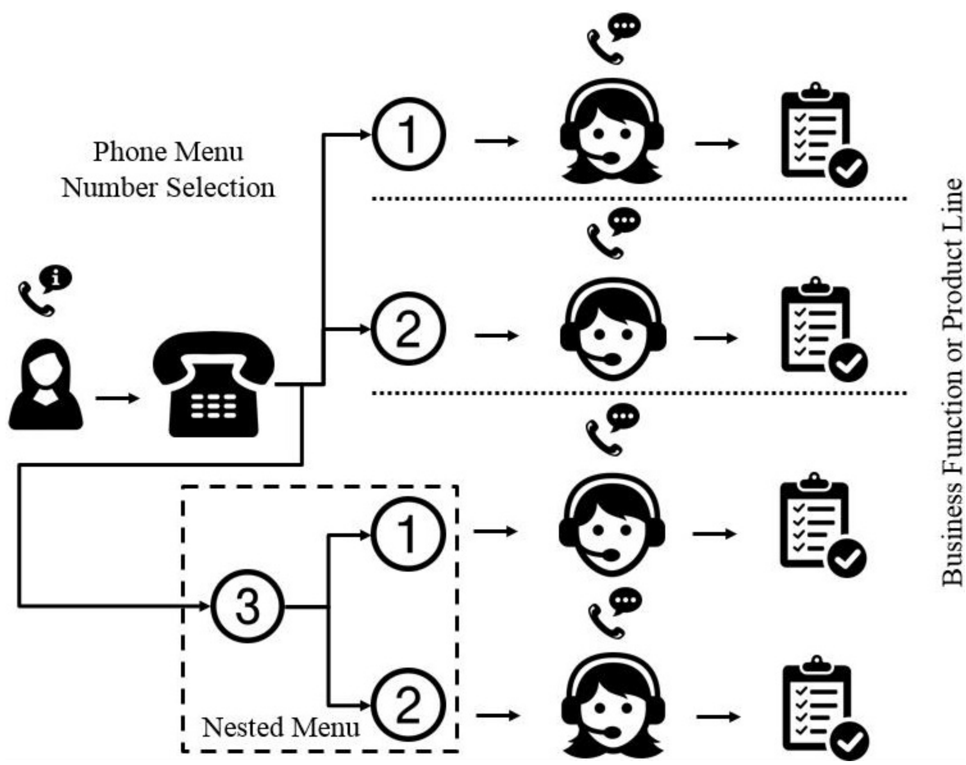

Figure 4. Phone Menu with Nested Menu Example (Icons from Flaticon 2014)

The use of nested menus is important in reduced customer search times for connection to support. If a phone menu used a linear array menu system (all phone menu selections being sequential), a customer would be forced to sit and listen to each option until hearing the selection needed. While this wait time may not seem very long, a user searching for a topic X among *n* selections will, on average, take *O(n)* time (where *O(n)* is big O notation that describes the limiting behavior of the linear function when *n* approaches a set value or infinity). The use of a nested menu, effectively altering the phone menu from a linear array to a tree, will shorten search time to *O(log(n)*) (where *O(log(n))* is big O notation that describes the limiting behavior of the tree function when *n* approaches a set value or infinity). If it takes five seconds to listen to each phone menu option, a customer could be on the phone for quite some time before navigating to the desired product line or business function. Figure 5 shows average phone menu wait times as given by phone menu layout type and number of phone menu options.

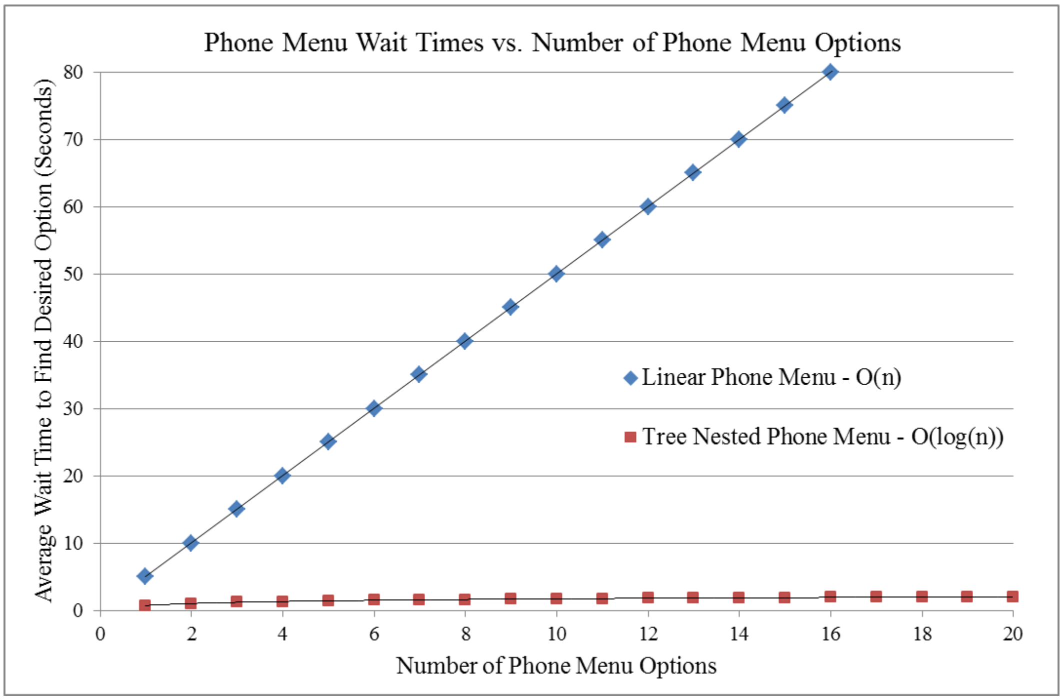

Figure 5. Linear vs. Nested (Tree) Phone Menu Wait Times

Multi-tiered technical support is a system used to organize service support dependent on customer need, level of support required, or business function in order to provide the best possible service in the most efficient time. The higher the tier level, the greater the quality and specificity of the support information will be. Both of these developments, if deployed and executed correctly, lead to decreased customer service wait times and increased service provider productivity. Typically, all customer service inquiries are routed to a low tier level for initial information gathering and high-level investigation as shown in Figure 6 and Figure 7. Low-level technical support, also known as tier zero or tier one, tends to possess broad organizational knowledge, but limited technical insight. This tier can usually only resolve basic customer service questions and relies heavily on scripted question/answer flowchart guides. The next level of technical support, also known as tier two, is directed customer service issues and questions that the lower tier is not equipped to resolve. At this level, support technicians have advanced skills such as troubleshooting and analysis. Customers who provide support for their users usually require this level of support. The highest level of support, commonly known as tier three, is connected to customers by lower levels of technical support for issues that require a subject matter expert. While many customer service issues and inquiries do not make it to this level, the ones that do are typically from customers who specialize in the research, development, or back-end operations of the product field. If customer issues cannot be resolved at this level of technical support, the company will usually work with the original equipment manufacturer (OEM) to ensure the product is repaired upon new version release.

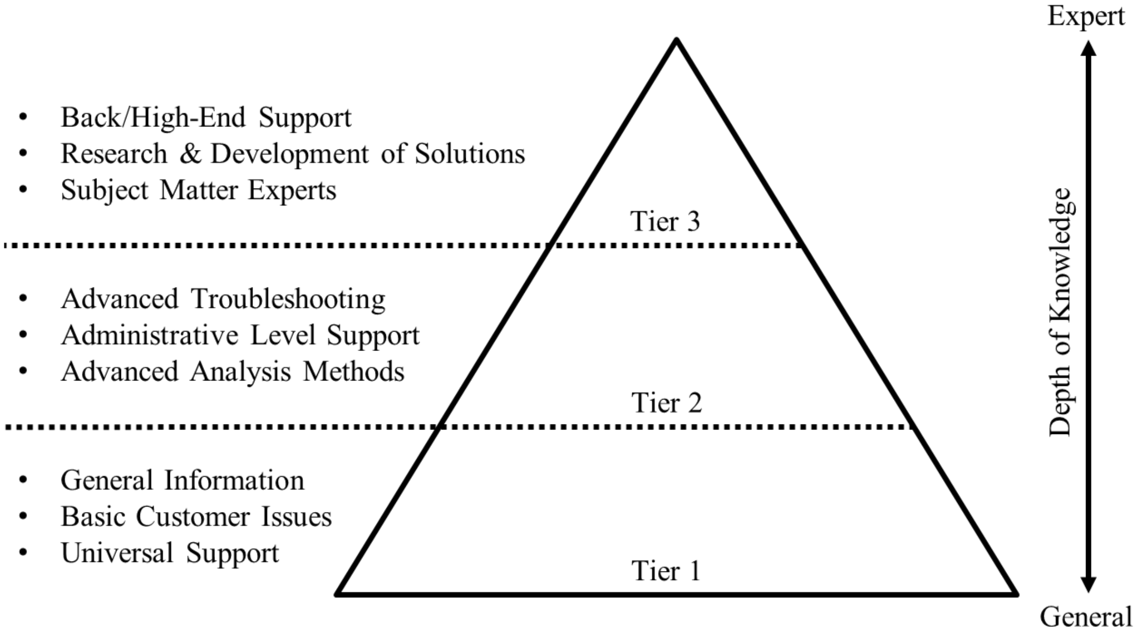

Figure 6. Multi-Tiered Technical Support Hierarchy Example

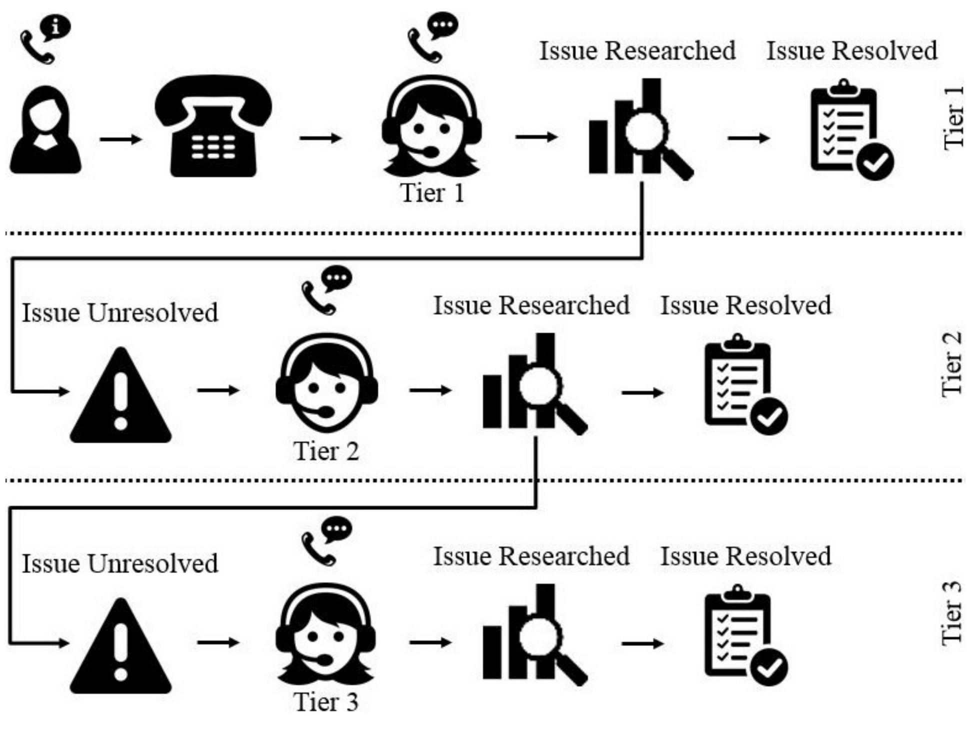

Figure 7. Multi-Level Technical Support Information Flow (Icons from Flaticon 2014)

Most of the improvements to DS have been to the service provider side and not the platform side. The birth and adoption of the Internet and network connected devices changed this imbalance of improvement. Customers no longer have to call the OEM for support. Through social media and video sharing, customers can now search the Internet for technical solutions and workarounds for their products. With customers becoming more “self-sufficient” in providing their own means of support, drying up revenue streams from manufacture service support calls, product manufacturers focused on cutting product cost and improving product quality. The combination of the users being “self-sufficient” in providing their own technical support and improving product quality lead the manufacturing base into “hurting” its bottom line is sales figures. A solution was created that effectively killed DS for all “consumable” goods: planned obsolescence. Planned obsolescence is the practice of designing-in limited life use into a product. This forces the customer to purchase a new product after a predetermined life cycle in order to generate long term sales volume by shortening the amount of time for a customer to make repeated product purchases. Figure 8 shows a standard reliability-engineering graph known as the bathtub curve. The bathtub curve is used to show the failure rate of the hazard function. The three parts or phases of the hazard function are as follows:

- Burn In—Shown to have a decreasing failure rate due to initial products failing early, typically due to manufacturing errors or poor material quality
- Useful Life—Shown to have a constant failure rate due to random product population losses
- Wear Out—Shown to have an increasing failure rate due to product degradation of use

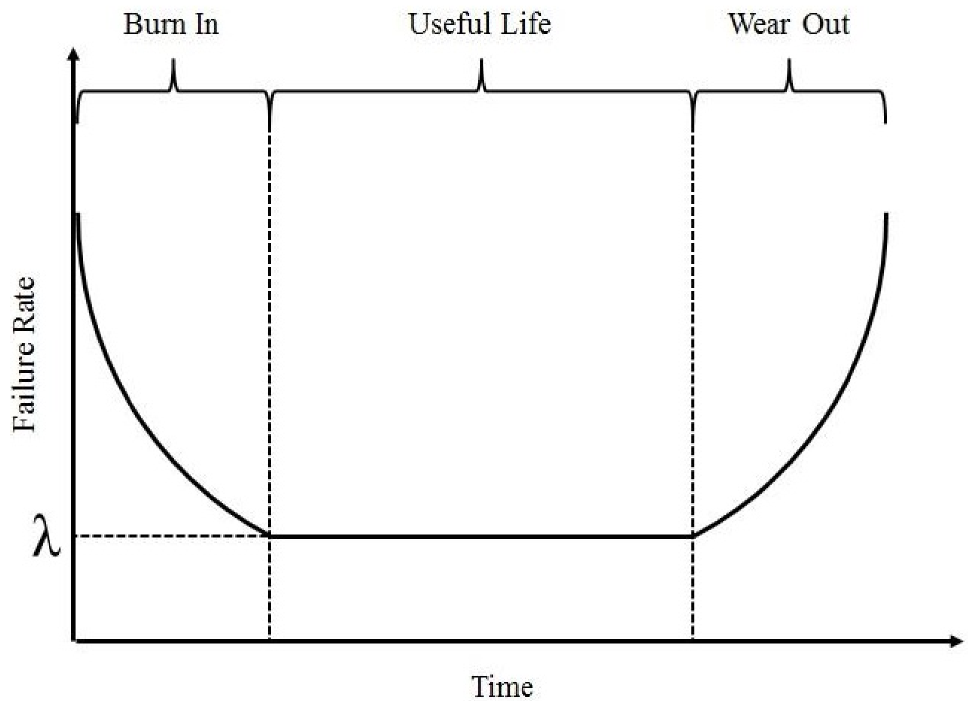

Figure 8. Standard Bathtub Curve (after National Institute of Standards and Technology 2012)

Planned obsolescence, as shown in Figure 9, artificially shifts the wear out phase earlier. This does not necessarily mean that the product itself is "worn out." Artificial shifts of the wear out phase can also be completed by inhibiting or removing product capabilities and delaying product response times.

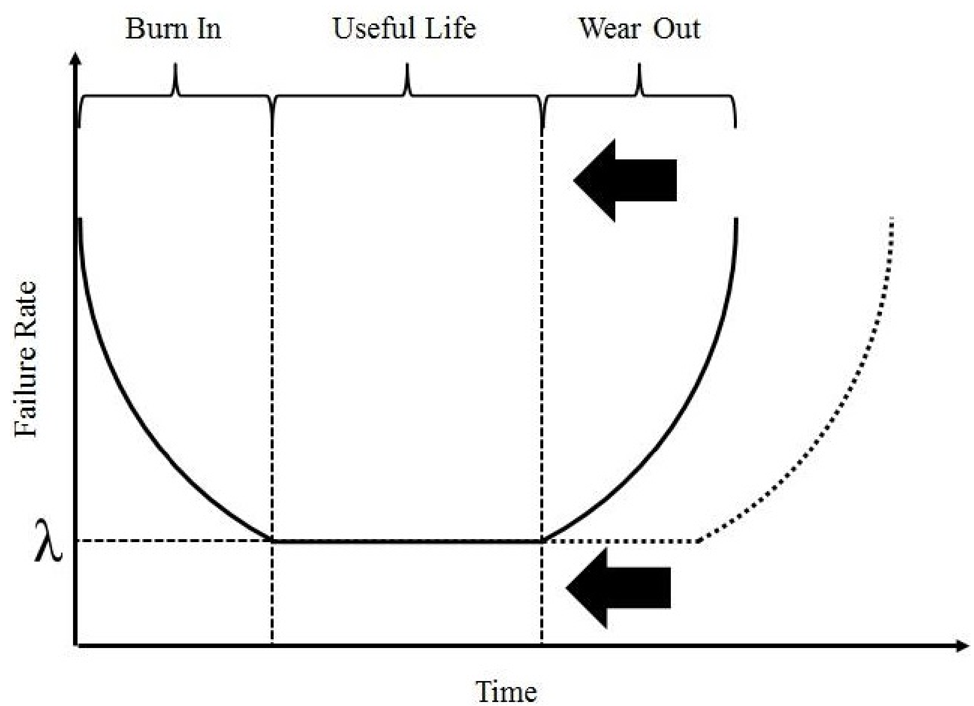

Figure 9. Bathtub Curve with Planned Obsolescence

b. Modern Distance Support

DS today varies between industries and within an industry sector, dependent on product cost and revenue source. In industries where the main form of revenue is a service, like that of Internet service providers (ISPs), DS is initiated and conducted through the customer or service user. This is due the nature of the business model, where the platform service provider owns the hardware that is on loan to the customer to facilitate the desired service. In industries where that main form of revenue is the product, like that of vehicle manufacturers and electronics, DS is a combination of customer inputs and product feedback. The degree and detail of product feedback designed into the product depends on the product's and customer's opportunity cost. In many cases, low value items are deemed to be "consumable" with a lifespan of only three to four years. These items are often replaced outright with no repair or internal product feedback, such as sensors, designed-in. High value items, such as aircraft engines, have multiple sensors designed into them to monitor the health of the product and help avoid costly repairs or expensive replacement. These products have a much longer life cycle than that of the "consumable" genre. The widespread use of sensors in platform systems is predicted to transform the way DS is performed and lead to a "Third Industrial Revolution" (Gerard Meijer 2008, 6). With the use of sensorization (the act of adding sensors to a device), data can be collected readily and analyzed to provide a greater degree of DS in moving from the current reactive methods to that of proactive methods. It should be noted that this area of performing DS is in its infant stages. Prognostic and "expert systems" are still being research and formalized (IEEE 2014). The sensorization of products allows DS to be performed without user initiation and even limited user involvement. Examples include the OnStar™ service, Formula One racing, and space programs. These examples all have the ability to remotely monitor system symptoms and diagnose the issue at hand.

c. USN Distance Support

DS within the USN has historically lagged behind industry (Modigliani 2014). This is not because DS is not a priority, but because of the way in which the armed services acquired systems. Consumer devices tend to be small, assessable, low cost, replaceable, lightweight, network independent and non-mission critical. However, devices found in the Fleet are the opposite. These devices, such as a missile launcher, are often far away and unable to make port to conduct corrective maintenance. Additionally, naval systems have far longer useful service lives than consumer devices. A system may remain functional in the Fleet long after many subcomponents are no longer in production. They are also one-of-a-kind, and thus cannot be easily replaced or manufactured due to the lead times and proprietary designs used by contractors. This creates a unique capability gap when trying to find a viable solution to support the USN and its exclusive requirements. In addition to these unique requirements, the USN used to design and require systems to be certified according to their various standards and specifications. These were known as MIL-HDBK, MIL-SPEC, MIL-STD, MIL-PRF, and MIL-DTL. Each of these standards and specifications, nearly 45,500, had to be followed by any system acquired by the DOD. These stringent requirements, imposed upon systems, raised unit costs and impeded the adoption of cutting edge technology. To combat this, the Secretary of Defense William J. Perry issued a memorandum in 1994 that changed the DOD’s stance on using military standards and specifications to that in favor of using industry standards and increasing access to “commercial state-of-the-art technology” (Perry 1994).

Since the adoption of the policy, the USN has seen an explosive growth in the fielding of commercial off-the-shelf (COTS) products. Many of the products have some limited sensor capability already designed-in which the USN is trying to take advantage of. The main roadblocks in using these additional COTS tools are the lack of frameworks, organizations, infrastructures in place, and integration costs or a combination of the aforementioned.

A recent paper by Nicolas Guertin, PEO-IWS and Paul Bruhns, ManTech International Corp. “Comparing Acquisition Strategies: Maintenance Free Operating Period (MFOP) vs. Traditional Logistics Support” contained some interesting data about cost savings realized through the use of DS. In their discussion of implementing MFOP for existing systems in a stepwise manner, they state:

> The first step is to capture the value of distance support from ship to shore through a network connection that bridges between the operational system maintainers (O) to intermediate subject matter experts and tech assist (I) levels. This O-to-I Level Maintenance Bridge requires little product integration and will immediately generate cost savings. Table 5 highlights an example program that achieved a 15:1 cost savings ratio when employing distance support services over deploying tech assets:

Table 5. FLEET Technical Assist Data

FLEET Technical Assist Data for Submarine Enterprise
120 Fleet Technical Assist (FTA) Events Performed 93 Local (Norfolk) 27 Out-of-Area
100% Distance Support (DS) Attempts (CFFC/Command Policy) 16% Success Rate Overall on All FTA Events 37% Success Rate on Out-of-Area Events
Average Man Hours (MH) per Event 19 MH via DS 164 MH via On-Site Support
Average Cost per Event (Based on $60.00 per Hour) $1,140.00 for DS $9,840.00 Labor and $5,500.00 Travel for On-Site ($15,390.00)

> These methods generated faster response time for solving the system problem, as well as lowering labor and travel costs (from Guertin and Bruhns 2011).

The DS for the HEL capstone project is an in depth SE analysis and M&S of a DS system designed for a generic HEL weapons system. After the initial procurement of the HEL, the USN must provide operation and support (O&S) funds, at approximately 60–80% of the total life cycle of the system (Defense Acquisition University 2011). This capstone explored the theory that providing DS will lead to a lower total ownership cost of the HEL system. Through M&S the goal of the project was to prove this. The project considered pre-existing work on DS, such as the Six Pillars of DS. The Six Pillars of DS, as depicted in Figure 10, consist of: Remote Tech Assist, Remote Diagnostics, Remote Repair/Validation, Remote Monitoring, ePrognostics, and Self-Repair/Healing. Using SE methodologies, the team looked at a subset of the Six Pillars, focusing on: Remote Tech Assist, Remote Diagnostics, Remote Monitoring and Remote Repair/Validation.

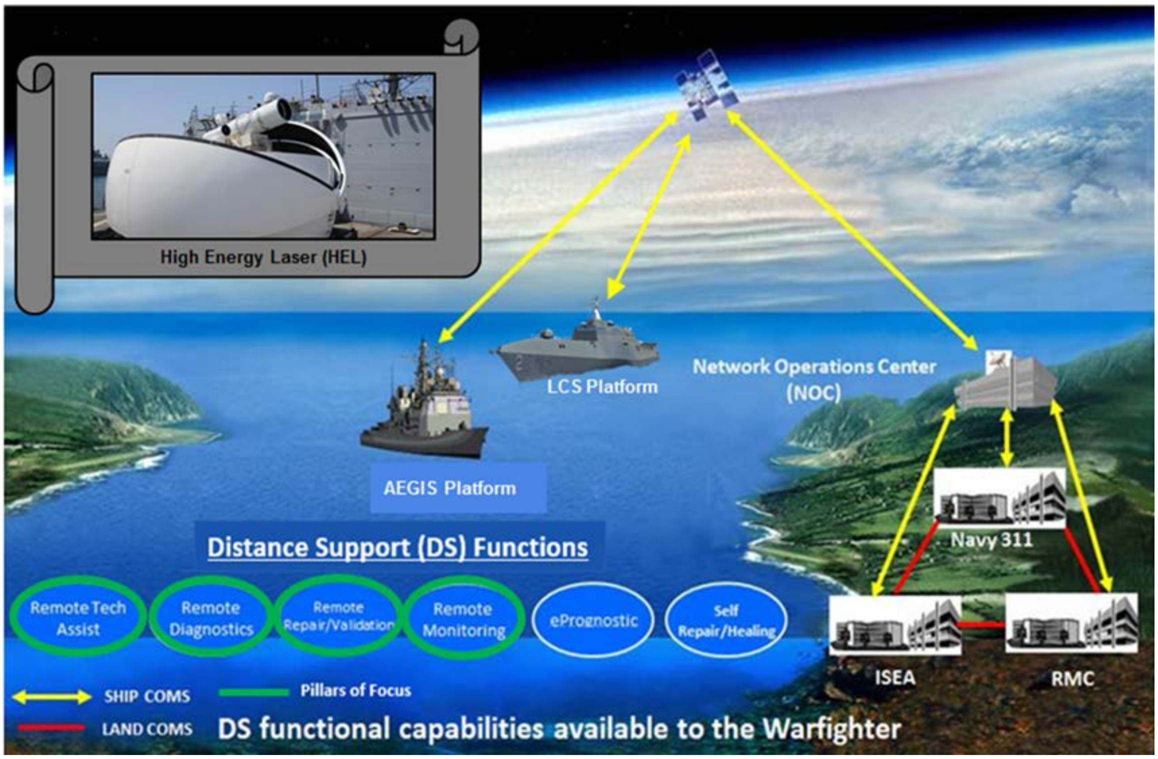

Figure 10. Distance Support Functional Capabilities

According to the Navy Distance Support policy written and signed out in March of 2007,

> Distance support is a Navy Enterprise effort that combines people (e.g., subject matter experts), processes (e.g., remote equipment monitoring, tele-medicine, interactive detailing, etc.), and technology (e.g., data compression and replication) into a collaborative infrastructure without regard to geographic location. Distance support, at a minimum, includes the functional area of logistics; maintenance and modernization; Manpower, Personnel, Training, and Education (MPT&E); and medical support. Distance support remotely projects reactive, proactive, and predictive support to Sailors across these functional areas, in order to achieve the right readiness at the right time, at the right cost. Effective and reliable information transfer is a key prerequisite to enable Distance Support capabilities and processes. (Chief of Naval Operations 2007, 2)

This is a very broad concept spanning multiple disciplines and practices within the USN enterprise. The capstone was specifically interested in how certain DS concepts can be applied to the HEL weapons system and, possibly, combat systems in general for the USN. By narrowing the scope of DS in this manner the discussion can focus on the concept of providing a DS capability for the HEL system. Providing a capability refers to the ability of the ISEA to provide remote technical assistance to the system. Specifically, DS encompasses the ability to resolve issues without travel, monitor issues remotely, troubleshoot and repair remotely, and the ability to anticipate and predict issues before occurrence. It is for this reason that the USN has developed the concept of Six Pillars. These pillars span between reactive and proactive methods of DS technical assistance. The benefits and limitations of each of these areas were covered in depth.

(1) Reactive Methods

Reactive DS is defined as "after the occurrence response" (Naval Surface Warfare Center, Port Hueneme Division 2013). The following methods fall into this category: Remote Technical Assistance, Remote Diagnostics, and Remote Repair and Validation. All of these methods were implementable to date with current COTS technologies.

(a) Remote Technical Assistance

Remote Technical Assistance is the ability to resolve maintenance support issues without travel using tools such as Sailor to Engineer, Sailor 2.0, email, chat and phone (Naval Surface Warfare Center, Port Hueneme Division 2013). Most of the technical assistance provided to the USN still comes in this from. The benefit to this form of technical assistance is that it is low cost, pervasive, and well understood. Email is common within the USN, and the sailors have a direct line of communication to the engineer in many cases. Additionally, in many critical weapons systems, the ISEA participates in group chat with the ships to provide assistance as needed. websites have been created to help provide readily available technical information to the sailor as well as forum support to resolve issues that come up. All of these tools are in use today in the USN.

One of the big issues with Remote Technical Assistance methods explained above is that they are temporal. As time progresses, information becomes stale and less relevant. Two examples to demonstrate this principle as it occurs today in the USN are discussed. First is the concept of email; while email is cheap to set up and relatively well understood, it is difficult to use as a tool for capturing technical information. Limitations to email include: overall file size and communication transmission delay. Limited file size inhibits the amount of information that can be provided to the sailor to resolve an issue. Communication transmission delay can span weeks to months as the accumulated time between email transmissions grows. This is because email is time dependent. If the ship receiving support is in a different time zone than the shore based site, the time to answer email becomes longer. Additionally, the bandwidth on ships for email is constrained, especially when the ship is underway. Once the engineer has successfully provided support to the ship, the solution may be logged to use in future support events. Unfortunately, these solutions are not being stored in a central location to facilitate knowledge management and sharing between technical support groups.

The next example concerns the use of websites within the USN for support. There exist a plethora of support websites that have been created for use by the Fleet. Each website is created and populated with information to help the sailors better execute their duties and resolve issues with their system in a timely manner. The problem with websites is that while they are cheap to create; they are costly to maintain and require constant updates to information. Also, on-line technical support resources are poorly advertised.

Both of these examples paint a challenging view of the remote technical assistance methods of DS. These examples illustrate that while email, websites, and chat programs are prevalent and widespread in terms of use, they are limited as a means of resolving issues within weapons systems.

(b) Remote Diagnostics

Remote Diagnostics is the ability to establish remote connectivity to observe, and diagnose system performance in a manner similar to the engineer being on-site (Naval Surface Warfare Center, Port Hueneme Division 2013). This method of DS is not as pervasive in the USN ecosystem because to tap into this method of DS, the system onboard the ship must have a passive connection to shore via the Global Information Grid (GIG). Typically, weapons systems do not have a direct connection to the GIG as this would change the cybersecurity posture of the system. However, aboard ships there are certain systems that are tactical in nature, but are critical enough to warrant remote diagnostics. One such example of this is the AEGIS weapons system. Due to the critical nature of this weapons system, the system itself has a subsystem known as the Operational Readiness Test System (ORTS). This system is responsible for performing a variety of diagnostics on the AEGIS combat system to determine its overall readiness. Due to the mission criticality of test results produced by ORTS, Naval Surface Warfare Center, Port Hueneme Division (NSWC PHD) developed a ship based system call the Operational Readiness Test Systems Technical Assistance Remote Support (ORTSTARS). ORTSTARS has been successful in allowing engineers to log into the AEGIS combat system on a ship and diagnose problems from shore. All of this is done using a secure connection. This capability offers the ability to:

- assist with fault detection
- isolate faults
- perform intermediate maintenance
- correct faults

This method of DS does not suffer from the same time delay issues that are seen with traditional technical assistance via email. However, Remote Diagnostics is not without its faults. One of the issues is that the information gathered has to be done manually, which is time intensive. Some ORTSTARS sessions with ships can be as long as eight hours depending on the speed of the connection and the location of the ship. The connection may drop unexpectedly causing the session to be reestablished.

ORTSTARS does not control the pipe to which they connect off of ship. This means that close coordination must be maintained with Space and Naval Warfare Systems Command (SPAWAR) through the use of a memorandum of agreement (MOA). These MOAs allow bidirectional flow of information on/off ship and allow connections through the shipboard firewalls. Despite these shortcomings, Remote Diagnostics is an improvement on the traditional technical assistance methods of email and chat.

(c) Remote Repair and Validation

Remote Repair and Validation refers to the ability to remotely re-configure a system to correct problems (Naval Surface Warfare Center, Port Hueneme Division 2013). This method of DS requires not only a direct connection to the system, but it also requires active coordination of ship's force. Unlike Remote Diagnostics, where the connection to the shipboard system is passive in nature, Remote Repair and Validation is an active form of DS. The engineer on shore has an active connection to the system on board ship. During this active connection, the user has the ability to make changes to the system to resolve and correct faults. This is done to provide corrective actions to well-known and established faults that occur in the system which have an approved corrective action. This is a sensitive process when dealing with mission critical systems and requires the sailor to be actively monitoring the procedure that is being run remotely. This active supervision on the part of the sailor satisfies the "two person positive control" critical to the security of systems. The downside to this method of DS is that it is reactive in nature. Additionally, it requires coordination with several outside agencies to establish a secure and reliable inbound connection to the ship. There are several layers of security present in the GIG that must be changed in order to allow this type of connection to the system.

(2) Proactive Methods

Proactive DS is defined as "Remote continuous monitoring and corrective action without shipboard personnel interaction response" (Naval Surface Warfare Center, Port Hueneme Division 2013). The following methods fall into this category: Remote Monitoring, ePrognostics, and Self-Healing/Repair. These methods require more effort to fully implement and are not completely available with current COTS technologies.

(a) Remote Monitoring

Remote Monitoring is the first method of DS that takes a proactive approach to DS (Naval Surface Warfare Center, Port Hueneme Division 2013). In this approach systems are monitored from the shore to determine if there is a fault before the ship initiated a casualty report (CASREP). This method may employ the use of a monitoring system on the ship that captures simple network management protocol (SNMP) information, error logs, and vulnerability scan data, which is then sent off ship to be analyzed from shore. Remote Monitoring assumes this data is being collected and piped off ship in near real-time. A typical example of this type of DS is the monitoring of the network traffic coming off ship by the network operations center (NOC) or the monitoring of radar transmit power. In both of these cases the information is sent to shore in a raw data format that the engineers analyze to determine whether the system is operating within prescribed tolerances. The benefit of this method is that the shore based engineer can look at the data and determine whether the system is operating correctly. Also, this does not require the participation of the sailor to perform this analysis. The downside is that this information may be more than what is required to determine the state of the system, additionally the cost (i.e., the network bandwidth overhead) of performing this type of DS methodology may be too high to implement on a platform that has an older network transport layer or a smaller platform that does not have a large pipe off the ship. Although this method is very useful for the shore, it may not be feasible for every system.

(b) ePrognostics

This method of DS expands on the previous method and uses the idea that for certain types of data (especially analog data) trends can be established. Various stochastic methods can be used to analyze the data for system performance and can then trend this data over time to establish a known "good baseline" for data. Predictive algorithms can be used to detect when a certain data set is trending outside of the known "good baseline." This method of automated DS is still in its infancy for combat system elements, however, for many hull, mechanical, and electrical (HM&E) systems, prognostic condition based maintenance (CBM) is well established.

(c) Self-Repair/Healing

The last method of DS is analogous to what is known as an "expert system." An expert system is a computer system that emulates the decision-making ability of a human expert (Jackson 1998, 2). The system is fully aware of its inner workings as well as its external interfaces and dependencies. Expert systems are systems that have little to no need of human assistance in the event of failure or event execution. These systems have the ability to self-govern (redirect resources to maintain system performance during critical operations) and sometimes use artificial intelligence (AI) to “learn” from previous events. Expert systems have the distinct advantage in needing minimal human interaction to right functions, but these systems can be costly to implement and suffer from a lack of robust resources for knowledge acquisition in order to enable AI machine learning.

d. Distance Support Frameworks

Due to the USN’s unique set of environmental, security, programmatic, and organizational requirements, a “plug-n-play” DS framework does not exist. The following existing frameworks below were studied.

(1) Information Technology Infrastructure Library

Of the existing frameworks available, the Information Technology Infrastructure Library (ITIL) was the optimal candidate to study and glean best practices. ITIL provides a framework of best-practices for the service management of Information Technology (IT) products. Much like the purpose of DSHEL, IT services and data have become essential to business operations as well as strategic assets. The main purpose of ITIL is the continual measurement and improvement of the quality of IT services delivered, from both a business and a customer’s perspective (AXELOS Ltd. 2011, 14). If implemented and executed correctly, ITIL benefits include:

- increased user and customer satisfaction with IT services
- improved service availability, directly leading to increased business profits and revenue
- financial savings from reduced rework or lost time and from improved resource management and usage
- improved time to market for new products and services
- improved decision-making and reduced risk

The ITIL framework is broken down into five associated life-cycle phases: Service Strategy, Service Design, Service Transition, Service Operation, and Continual Service Improvement as described in Figure 11.

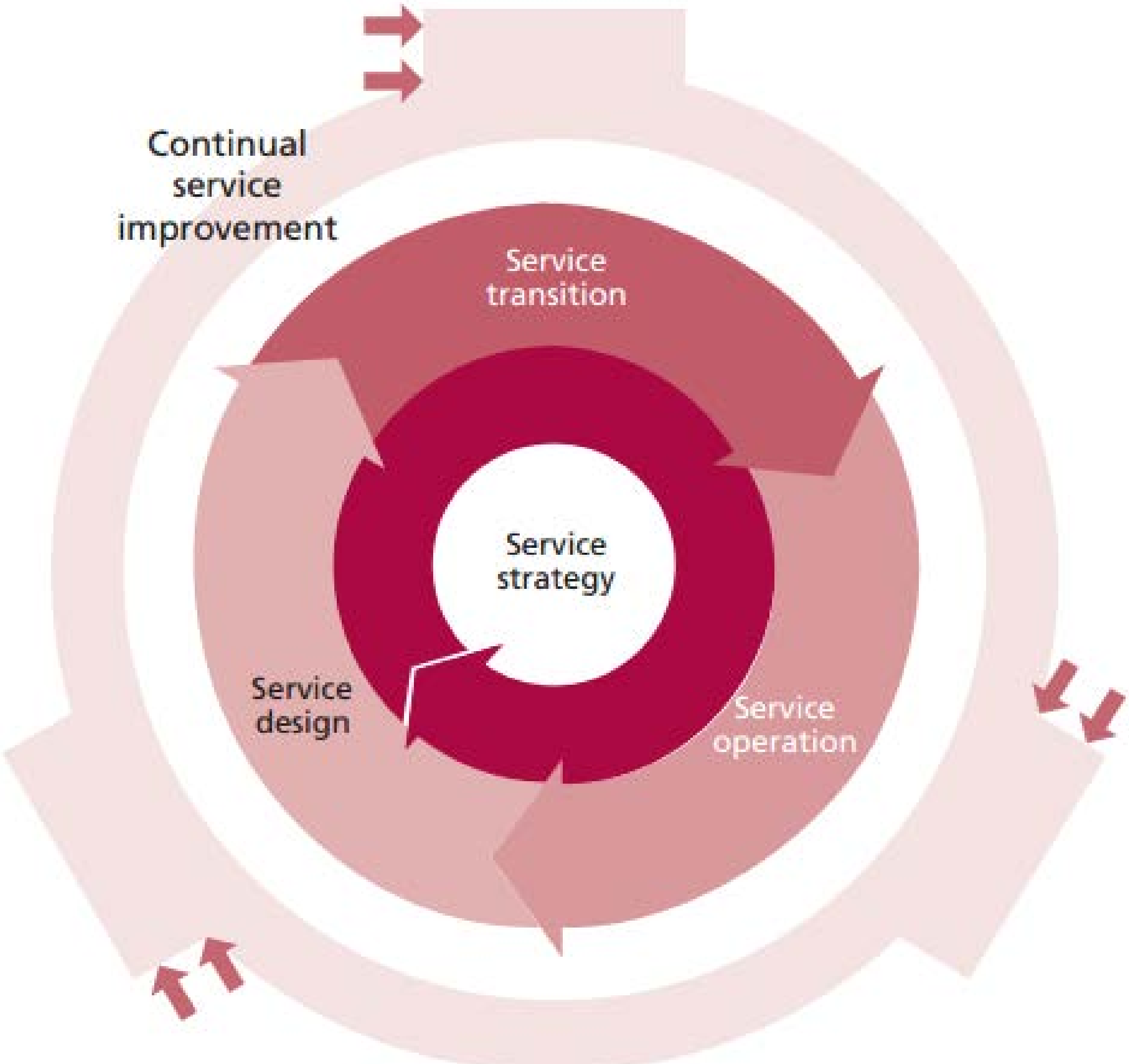

Figure 11. ITIL Service Life cycle (from AXELOS Ltd. 2011, 7)

Figure 12 illustrates how each of these phases is made up of sequential steps and processes that govern and align each life-cycle stage with the business it is supporting.

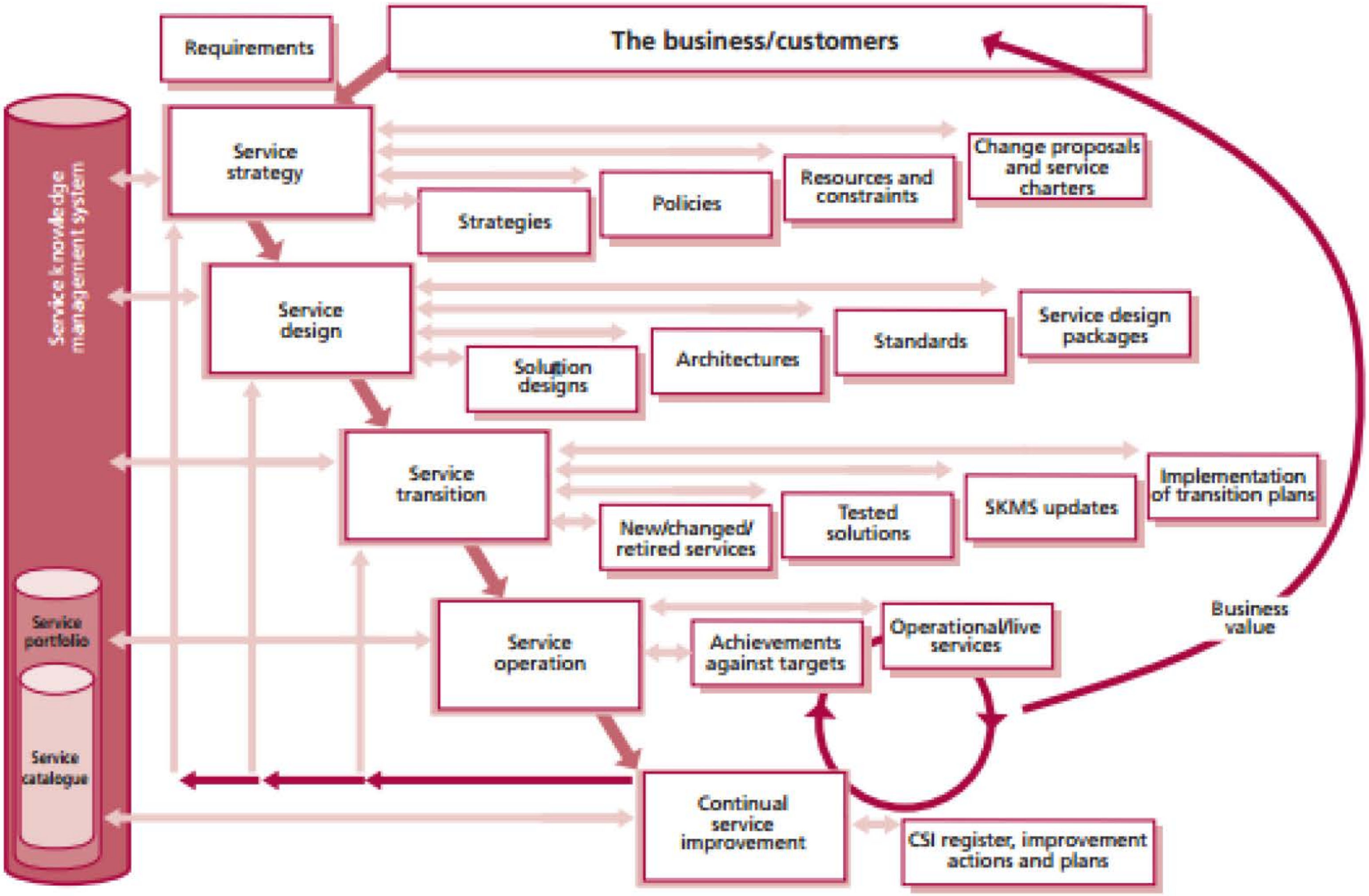

Figure 12. Integration Across the Service Life Cycle (from AXELOS Ltd. 2011, 9)

Each of these phases will be detailed below.

(a) Service Strategy

The service strategy sits at the core of the ITIL framework. This is due to the service strategy being the key plan in providing a solution to the business problem at hand. The service strategy is developed with many parties in order to ensure it meets the needs of the customers and users of the business problem. These needs and requirements are the foundation in which the service strategy is built. This phase also builds understanding among stakeholders in answering: (AXELOS Ltd. 2011, 13)

- What is a service?
- What services should be offered?
- To whom the services should be offered?
- How will service performance be measured?
- What is service value (utility and warranty)?
- What are the service provider types?
- Are there critical success factors?
- How will the services be delivered?
- Who plays what role and how?

(b) Service Design

Service design is the first step into turning the service strategy into a tangible product. Service design involves balancing functionality requirements (service utility), performance requirements (service warranty), resources availability and timescales (AXELOS Ltd. 2011, 22). As these areas are balanced, normally with the use of cost and risk analysis, a holistic solution providing end-to-end quality should emerge. An important part of this phase is the creation of service level agreements (SLAs). A SLA is an agreement between a service provider and an end user (customer). The SLA typically will detail the service, service level targets, quality of service (QoS), and the responsibilities of each party involved (AXELOS Ltd. 2011, 25). In contrast to the USN DS methods, ITIL has differing definitions for reactive and proactive activities.

- Reactive activities are monitoring, measuring, analysis and management of events, incidents and problems involving service unavailability (AXELOS Ltd. 2011, 26)
- Proactive activities are proactive planning, design, recommendation and improvement of availability (AXELOS Ltd. 2011, 26)

In addition to SLAs being created in this phase, information security management (ISM) is also considered. The USN's cybersecurity requirements are more stringent than ITIL, but both do share a set of common terminology and service management activities that were applied.

- Availability means that information is available and usable when required (AXELOS Ltd. 2011, 28).
- Confidentiality means that information is observed by or disclosed to only those who have a right to know (AXELOS Ltd. 2011, 28).
- Integrity means that information is complete, accurate and protected against unauthorized modification (AXELOS Ltd. 2011, 28).
- Authenticity and Non-repudiation means that business transactions, as well as information exchanges, can be trusted (AXELOS Ltd. 2011, 28).

(c) Service Transition

Service transition ensures new, modified, legacy, or retiring services meet the expected or required levels of capability to the business and customer as the service design is implemented throughout the enterprise. As new systems come online and older systems are taken offline, change and configuration management become important supporting processes to ensure service quality.

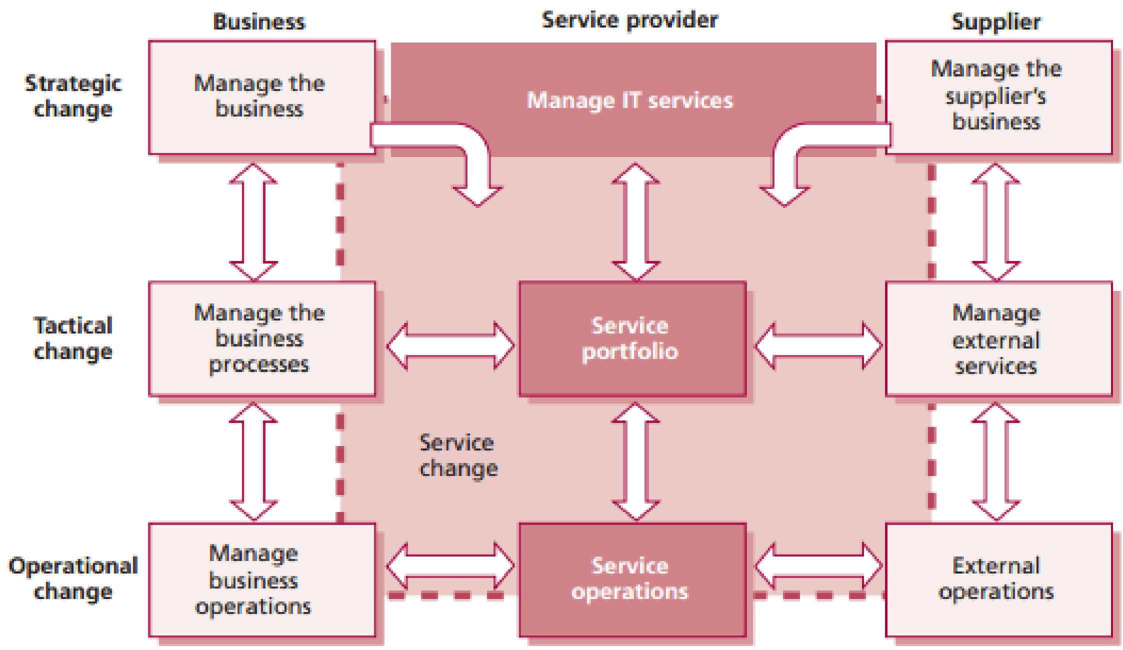

Figure 13. Scope of Change and Release Management for Services (from ITIL 2011, 34)

Another important part in this phase is the execution of service validation and testing. Once the new/old systems have been put/taken on/off line, the whole service is put through verification and validation testing to ensure that no degradation to service quality has occurred. Figure 13 shows the interactions and interfaces required between the parties as changes are made at differing levels.

(d) Service Operation

This phase is the execution of the service design and transition phases. The service is delivered to business and customer as detailed by the SLAs created in the service design phase. This phase not only provides and delivers the service, but also controls events, incidents, requests, problems, access, and other common service operation activities.

(e) Continual Service Improvement

The continual service improvement phase, as shown in Figure 14, is the feedback loop into the first phase of the ITIL framework, service strategy. As is with any superior service, the current model must always be scrutinized for flaws, inefficiencies, gains, technological improvements, and added capability in order to continually strive to provide higher service quality.

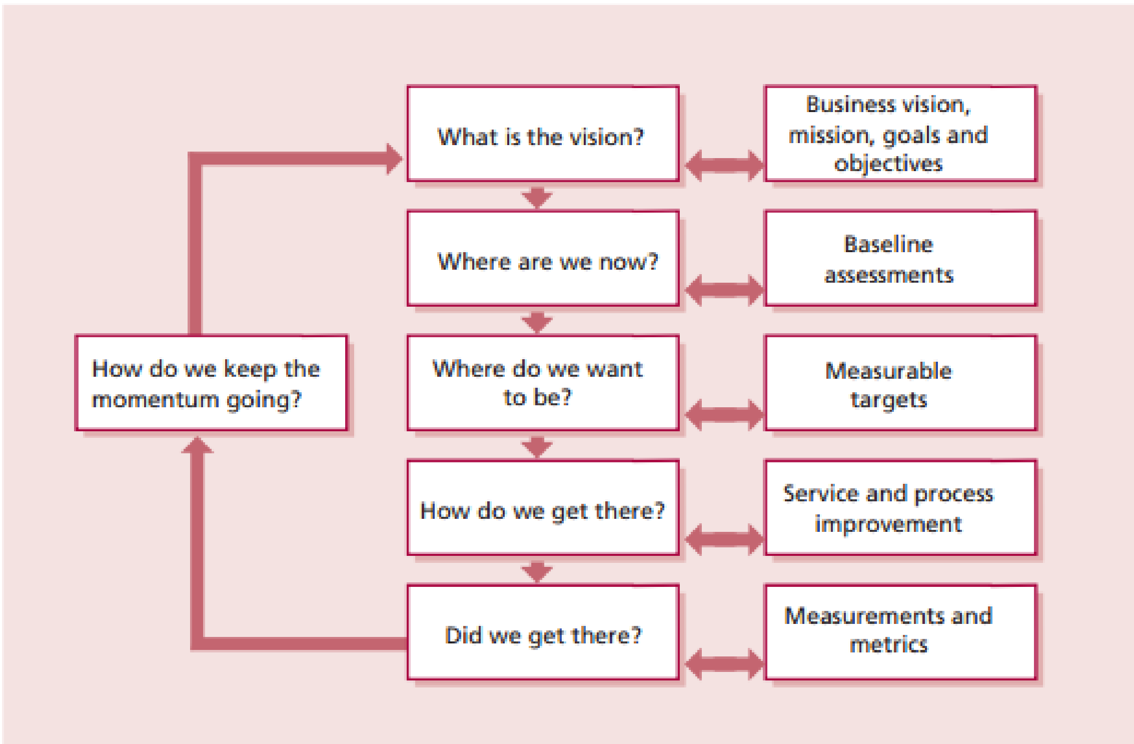

Figure 14. The Continual Service Improvement Approach (from ITIL 2011, 51)

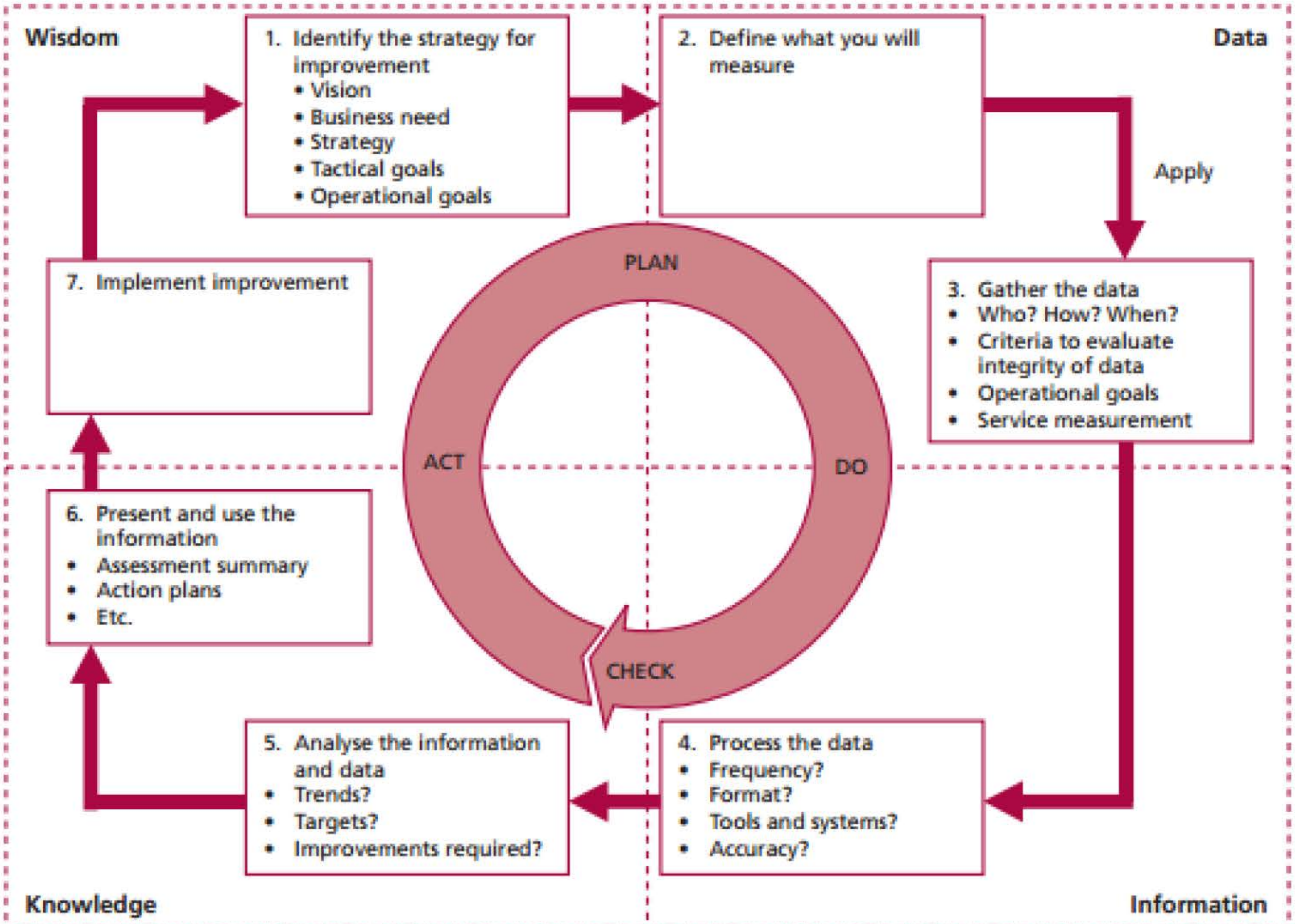

Figure 15. Seven-Step Improvement Process (from ITIL 2011, 52)

Figure 15 shows the Seven-Step Improvement Process. This phase is also where service measurement and reporting play a part in improving future service. Monitoring and measuring aid in this phase by (ITIL 2011, 55):

- Validating previous decisions that have been made.
- Direct activities in order to meet set targets.
- Justify that a course of action is required, with factual evidence or proof.
- Intervene at the appropriate point and take corrective action.

Technology, process, and service metrics also aid in shedding light on the areas above. Metrics are only useful if an established baseline has been created beforehand.

(2) International Organization for Standards (ISO)/International Electrotechnical Commission (IEC) 20000

The ISO/IEC 20000 is a Service Management System (SMS) standard. This standard is a combination of, and allows for the ITIL, Microsoft Operations Framework, and Control Objectives for Information and Related Technology's (both explained further below) IT service management frameworks. ISO/IEC 20000 consists of five parts, as shown in Figure 16, and can be used by (ISO) and the International Electrotechnical Commission (IEC) 2014):

- an organization seeking services from service providers and requiring assurance that their service requirements will be fulfilled
- an organization that requires a consistent approach by all its service providers, including those in a supply chain
- a service provider that intends to demonstrate its capability for the design, transition, delivery and improvement of services that fulfill service requirements
- a service provider to monitor, measure and review its service management processes and services
- a service provider to improve the design, transition, delivery and improvement of services through the effective implementation and operation of the SMS
- an assessor or auditor as the criteria for a conformity assessment of a service provider's SMS to the requirements in ISO/IEC 20000-1:2011

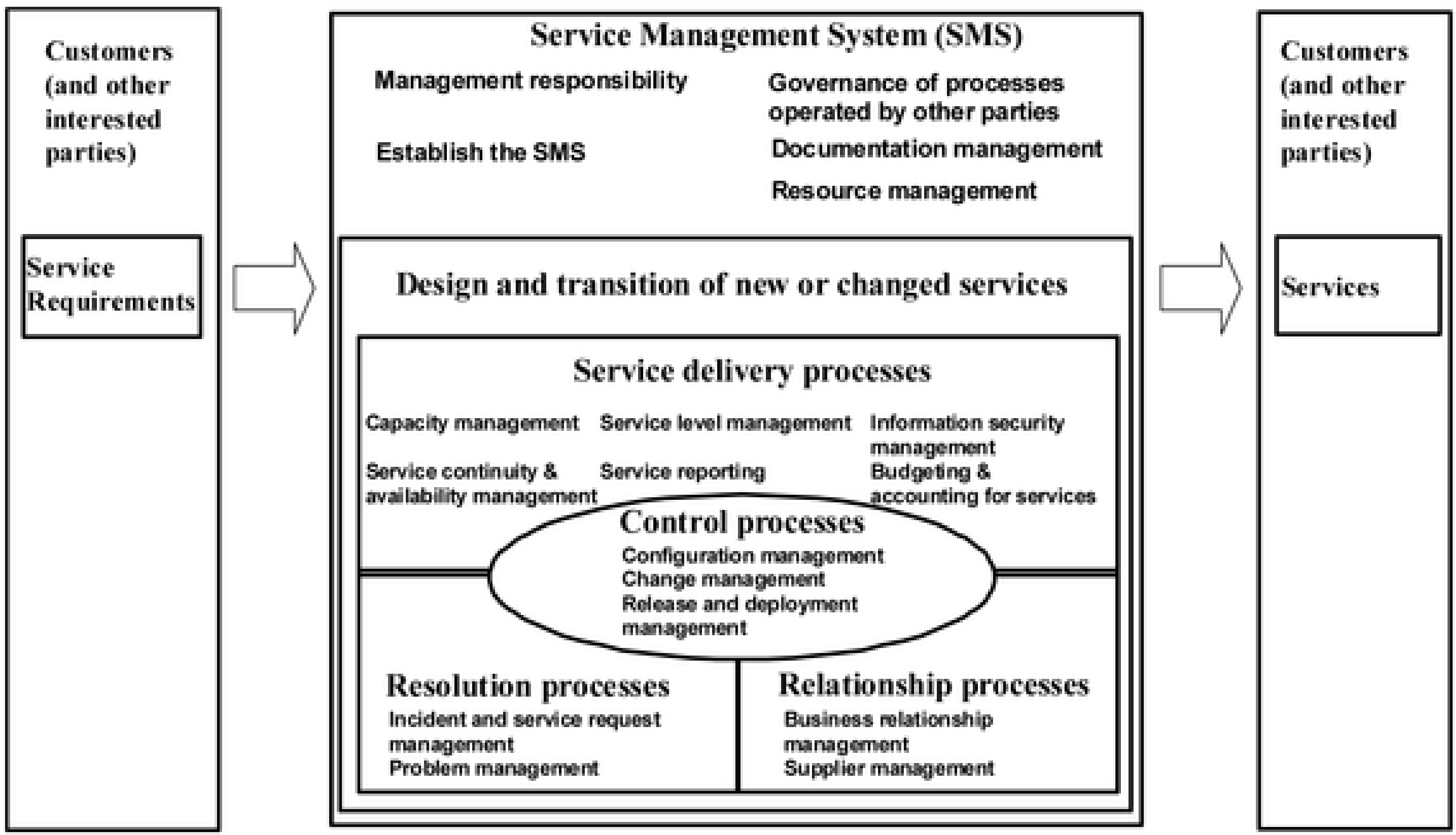

Figure 16. Service Management System (from International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) 2014)

The ISO/IEC 20000 standard has a lot of overlap with the other frameworks investigated, but was useful in understanding how specific requirements for the service provider fulfill agreed service requirements.

(3) Microsoft Operations Framework

The Microsoft Operations Framework (MOF) 4.0 has many similarities to the ITIL and ISO/IEC 20000 standard with the exception that it has a slightly different life-cycle foundation layer and a total of three phases. These phases are: plan phase, deliver phase, and the operate phase included within a manage layer.

Figure 17. Structure of MOF 4.0 (from Alexander 2008)

Figure 17 gives a more detailed view into the MOF 4.0 layer and its phases. While this framework can be readily applied to other software vendor products, the MOF 4.0 framework is mainly geared towards Microsoft products and services. While this framework has the same similarities of the other frameworks mentioned in this report, the MOF is unique in breaking apart the framework into sections that are serviced by products. In analyzing the different Microsoft products that provide these services, DSHEL was able to mirror a similar delineation of system functions.

(4) Control Objectives for Information and Related Technology

The Control Objectives for Information and Related Technology (COBIT) framework, like ITIL, ISO/IEC 20000, and MOF 4.0 is also used for IT management and governance. COBIT is different from the previous frameworks in that it is centered on a number of principles, areas and processes, model and levels, and process attributes. The particular pieces of information to note from COBIT are listed below.

(a) Principles of Control Objectives for Information and Related Technology

There are five key principles for IT management and governance that COBIT follows. They are (ISACA 2013):

1. meeting stakeholder needs
2. covering the enterprise end-to-end
3. applying a single integrated framework
4. enabling a holistic approach
5. separating governance from management

(b) Process Capability Model and Levels

COBIT uses a level rank system in defining the overall maturity of process capabilities. This level rank system is of particular note due to its applicability throughout this capstone in establishing baseline maturity levels for process capability models. The capability model and level explanations are detailed in Table 6.

Table 6. Process Capability Model and Levels (from ISACA 2013)

Maturity Level	Meaning	Description
Level 0	Incomplete	The process is not implemented or fails to achieve its purpose
Level 1	Performed (Informed)	The process is implemented and achieves its purpose
Level 2	Managed (Planned and monitored)	The process is managed and results are specified, controlled and maintained
Level 3	Established (Well defined)	A standard process is defined and used throughout the organization
Level 4	Predictable (Quantitatively managed)	The process is executed consistently within defined limits
Level 5	Optimizing (Continuous improvement)	The process is continuously improved to meet relevant current and projected business goals

e. *Platform of Interest—High Energy Laser*

In response to Section 251 of the National Defense Authorization Act for Fiscal Year (FY) 2000, the DOD outlined its master plan to capitalize on the significant advances of HEL technology in support of emerging national security needs of the 21st century (Department of Defense 2000). The recommendations comprised a restructured perspective in developing HEL weapons. Developing revolutionary capabilities in HEL weapons required a coordinated and focused investment strategy under a new management structure, featuring a Joint Technology Office (JTO) with senior-level oversight provided by a technology council and board of directors. A better balance could be achieved by transitioning large demonstration projects to non-science and technology (S&T) accounts sooner than had been done in the past. As such, the DOD focus was put to three major HEL system types for S&T exploration: chemical lasers (CL), solid state lasers (SSL), and free electron lasers (FEL). While the focus of DSHEL is on the near realization of SSL, requirements, artifacts, architecture, methodologies, and analysis were decoupled such that it could be reused on FEL or CL.

There have already been discussions on how the DOD should address laser technology. Some of the key areas of concern that are discussed in "Report of the High Energy Laser Executive Review Panel, Department of Defense Laser Master Plan, March 24, 2000," include cost, the available talent pool, and the structured approach of how one might organize the developing laser technology in the DOD. This organizational plan cited in the aforementioned document, uses a tiered organizational structure. Technology Area Working Groups are comprised of members from "all DOD stakeholder organizations" for the HEL. This group in turn would report to and work with the Joint Technology Office (JTO), who receives oversight from a senior board of Directors and the Technology Council. Defense Advanced Research Projects Agency (DARPA) and Ballistic Missile Defense Organization (BMDO) are also included for collaboration. This allows for different perspectives and insights. While the large knowledge base would be beneficial, it may also cause difficulties as it could turn into a situation of having too many differing agendas and directions, with a level of oversight that limits productivity.

As laser technology develops, it will be necessary to ensure that the policies develop as well. However, as with any newer technology, the knowledge base, policies in place and SME availability will need time to grow. This affects the manner in which DS can be applied. Lack of past experience and knowledge adds to the increased risk in designing for DS as there is less historical data to leverage. The components of the laser are directly related to the sensorization of LRUs, which were identified by the DHSEL team. The LRUs of the laser need to be monitored in order to prepare and mitigate problems arising from use and environmental factors (Paschotta 2014).

The United States Government Accountability Office (GAO) released a status report in 2005 regarding the DOD implementation of the HEL Master plan (Department of Defense 2000). Overall, S&T had grown proportionally to the planned investments. Considerable advancements in technology were being achieved and the forces had increased applied research to the fielding of HEL weapon systems and overall the plan was being executed as designed. The Department of the Navy (DON) specifically had developed requirements to incorporate technologies based on electric ships, submarines, and aircraft in the areas of FEL and SSL for the maritime environment.

By 2014 the Office of Naval Research (ONR) had begun the stages of test bed demonstration in the Pre-Milestone A phase of the acquisition life cycle known as the quick reaction capability (QRC). While not currently at the stage of transitioning from S&T to a program of record, the technology advancement has so far proven successful and reached the point where lasers capable of countering certain surface and air targets at ranges of about a mile could be made ready for installation on USN surface ships over the next few years. The USN reportedly anticipates moving to a shipboard laser program of record in “the FY2018 time frame” and achieving an initial operational capability (IOC) with a shipboard laser in FY2020 or FY2021 (O’Rourke 2014).

However, there exists a recommendation from the original laser HEL Master Plan which still holds true,

> The Department will not be able to field HEL weapons if the supplier base continues to decline or if universities do not produce enough graduates with the skills or motivation to work in this area. A few well-directed program initiatives could stimulate development of promising new technologies and at the same time create a demand for essential skills. (Department of Defense 2000)

The resource base of SMEs is limited to the point where there was risk in the ability to even field a HEL system. While the SME base has grown to the point where fielding a system became possible, this recommendation was focused solely on fielding a system. To successfully sustain the system throughout the life cycle, DOD is faced with the challenge of connecting the limited group of HEL SMEs to a massive number of fielded laser weapon systems installed on ships throughout the Fleet. A support capability to enable communication of the “few to many” must be evaluated. DSHEL is the proposed capability to fill this gap.

2. Implicit Areas

The implicit areas (indirectly related) that were researched and reviewed for DSHEL analyzed the impact and importance of government and military policies, open architecture requirements, cybersecurity requirements, Internet of Things (IoT) characteristics, platform, and infrastructure considerations.

a. Cybersecurity

The purpose of this section is to identify DOD mandated requirements for cybersecurity, special considerations regarding implementation and management, as well as the effects it has on the systems engineering process in the life cycle of DSHEL. Distance support enables interfaces to the GIG, which must be properly designed and managed for a successful secure implementation.

(1) Programmatic Guidance

Traditionally in DOD, this respective subject matter has been known widely as information assurance (IA), formally defined as information operations that protect and defend information and information systems by ensuring their availability, integrity, authentication, confidentiality, and non-repudiation (Department of Defense Chief Information Officer 2006). This includes providing for the restoration of information systems by incorporating protection, detection, and reaction capabilities. It has a general broadening focus which includes the protection of digital and non-digital information assets, such as paper records. While these methodologies at a high level are still applicable today, much information has been digitized and exists solely in an information system environment. As such, the processes, rules, and regulations, which treated data on a computer in the same sense as a physical record, did not translate well, resulting in a vague, difficult, and inefficient process to properly manage modern systems in the DOD. Due to this, information systems security (cybersecurity) is now the focus. Seen as a subset of information assurance, cybersecurity focuses more on the technical prevention and defense of information systems, which includes computers, networks, programs, and data. Risk management is a core competency of this paradigm and was decomposed further in the risk management section of this capstone report. As of FY2014, the DOD has issued new mandates on guidance in the risk management framework (RMF) regarding the implementation of cybersecurity in all system acquisition spanning from the milestone decision authority, research, developmental, test and evaluation, and sustainment efforts. The information presented here forth is common to all systems, the POI (HEL), and the proposed distance support component implementation of DSHEL.

A core difference in the newest guidance is the concept of cybersecurity reciprocity. The implementation of best practices and type accreditation can benefit all and have a greater, more positive outcome for the DOD. Applied appropriately, reciprocity reduces redundant testing, assessing and documentation, and the associated costs in time and resources. In order to facilitate reciprocity, the following concepts and practices are assumed to occur during systems development: acceptance of existing cyber test and assessment results and authorization documentation. IS and PIT systems have only a single valid authorization. Multiple authorizations indicate multiple systems under separate ownership and configuration control. Deploying systems with valid authorizations are to be accepted into receiving organizations without adversely affecting the authorizations of either the deployed system or the receiving enclave or site. An authorization decision for a system cannot be made without completing the required assessments and analysis, as recorded in the security authorization package. Deploying organizations must provide the complete security authorization package to receiving organizations. Overarching organizations and higher-level systems, such as shipboard network infrastructures, should provide core defenses to strengthen cybersecurity and those controls be inherited by the smaller sub-systems. Reciprocity insists that developers will design and accredit their systems with the foresight of maximal re-use by other organizations, and in return, developers can interoperate and reuse other existing systems. This saves the DOD resources in redundant paperwork and delayed accreditation time frames for systems, which are already authorized for use elsewhere.

With these core concepts, the programmatic cybersecurity requirements for a given system help to define the acquisition roadmap, tailoring of systems engineering methodologies, and sustainment of a system throughout the life cycle. However, a core concept of systems realization with cybersecurity includes the training and certification of people throughout the acquisition life cycle. Prior to development taking place, the developer must have the appropriate personnel to perform certain tasking. Qualified cybersecurity personnel must be identified and integrated into all phases of the system development life cycle. The necessary training for the given roles and responsibilities, ensures that acquisition community personnel with IT development responsibilities are qualified in accordance with DOD 8570.10-M. To design, plan, implement, and manage the cybersecurity of systems, special cybersecurity workforce (CSWF) certifications are required.

Along with these updated requirements is a modification to the acquisition roadmap, sometimes known as the defense acquisition “Horse Blanket.” Previous information assurance methodologies only required authority to operate (ATO) certification by the IOC of a systems maturity near Milestone C, with appropriate interim authorities to test (IATT) during development. Now, cybersecurity mandates specific entrance criteria to milestone decisions and development phases as can be seen in the modified acquisition roadmap of Figure 18. These steps are required for HEL regardless of how the DHSEL subsystem is implemented.

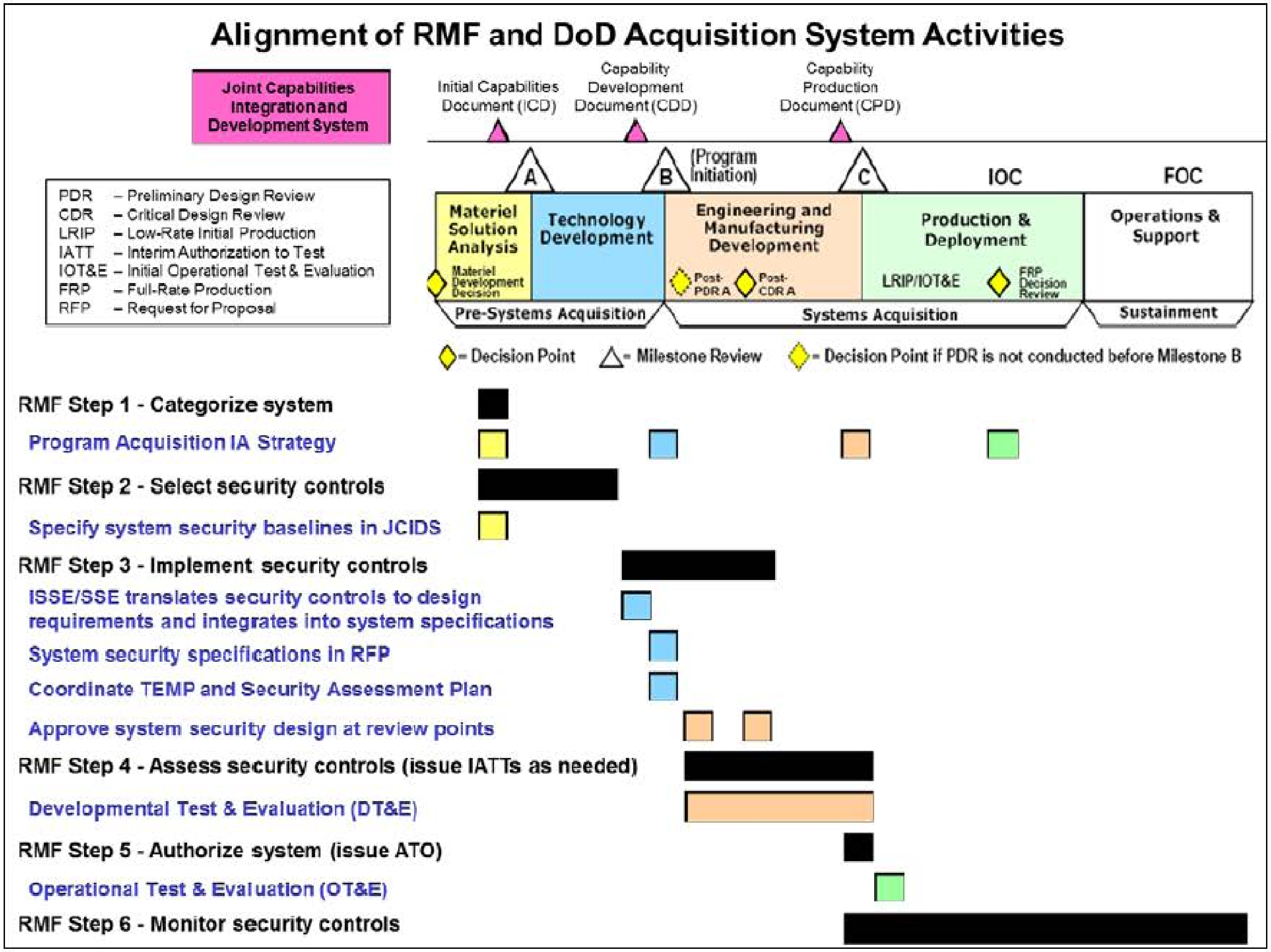

Figure 18. Alignment of RMF and DOD Acquisition System Activities (from Department of Defense 2014)

The above process of RMF steps aligns with the risk management process for cybersecurity. Regarding specific milestones to defense acquisition, the follow requirements are now mandatory for all systems throughout the life cycle. During the Materiel Solution Analysis, Pre Milestone A, the program's information assurance manager (IAM) shall develop an IA strategy. This plan documents the roadmap for accreditation through development and sustainment of a system, alongside the proposed categorization (PIT & IS), as well as the conceptual processes, architecture, and organizations for meeting cybersecurity requirements. This strategy is required to be updated subsequently at every milestone decision as the system enters the next stage of development.

At step two, the security controls from the NIST 800–53 "Recommended Security Controls for Federal Information Systems and Organizations" are selected and made part of the system baseline. They are added to the Joint Capabilities Integration and Development System (JCIDS), which is what DOD uses to designate acquisition requirements and evaluation criteria for defense programs. This translates to a developer that cybersecurity requirements are equally as important as functional requirements, e.g., the security posture of a laser system matters as much as its beam propagation, in terms of defense acquisition.

Program initiation at Milestone B requires the Preliminary Design Review (PDR) to cover and receive programmatic approval for the security design and planning thus far. If it is sufficient and the program proceeds to Engineering and Manufacturing Development (EMD), the appropriate security engineers then take the higher level controls and translate them into technical design. Typically, Defense Information System Agency (DISA) provided Security Technical Implementation Guides (STIGs) are used to "lock down" the system to the point where required functionality and other system key performance parameters are not affected. This ensures that security is designed in up front and can co-exist with functional parameters. This is also a critical stage in development, as the technology matures, the test and evaluation (T&E) teams are preparing the test and evaluation master plan (TEMP) aligned with step four of RMF. New cybersecurity requirements now mandate that security controls go through equal amounts of test and evaluation and are described at high level in the RMF instruction and in great detail throughout DODM-7994 “Procedures for Operational Test and Evaluation of Cybersecurity in Acquisition Programs.” The high level RMF describes penetration testing, where certified independent teams of ethical hackers are brought in to test the security posture of the system. These test results are reviewed and at a minimum meet the measures of effectiveness thresholds described in DODM-7994. Evaluation of cybersecurity during an acquisition T&E event must include independent threat representative penetration, exploitation testing, and evaluation of the complete system cyberspace defenses. This also includes the controls and protections provided by computer network defense service providers. Penetration and exploitation testing must be planned and resourced as part of the DT&E and OT&E via the appropriate program test documentation.

An IATT is a required certification for any developmental test event and must be acquired prior to the beginning of DT for execution of the TEMP during step four. Developmental testing is exceptionally important for cybersecurity, as it will identify controls and technical implementations which may impact system functional performance. These findings are refined if possible, and are managed risks between the program and designation officials. The end goal being to predict the operational baseline and obtain ATO by Milestone C for initial operational test and evaluation (IOT&E) at RMF step five.

Once the system is operational at step six, continuous monitoring and cyber risk management occurs throughout the life cycle until system deactivation and disposal. This requires periodic system configuration scanning on a monthly basis and re-accreditation every four years. Fiscal requirements of the program office thus require programmatic objective memorandum (POM) funding to allocate funding to sustain the system, including resourcing for certified CSWF personnel to provide system patches and upgrades keeping the system secure throughout the life cycle. Even if a system still meets functional requirements and has no high priority user reported items from the Fleet, it is mandated by the accreditation authority that the core operating system software of any system receive security patches on a periodic basis. The periodicity depends on the tactical vs non-tactical use of a system as well as how high of a priority existing security threats present.

Above all, when considering the certification process, it is important to focus on how the system accreditation boundaries are drawn for DSHEL to ensure the system is sustainable. While the DSHEL is proposed as a DS subsystem of HEL, making it physically part of the system, the systems IA boundaries must be decomposed into the parts, which are functionally partitioned. A weapon is typically accredited as a PIT System, where more risk is accepted to freeze the software baseline up to four years. This means information assurance vulnerability alert (IAVA) patches are typically not installed unless a high priority issue affecting safety is discovered. To account for the fact that weapons have an entirely separate certification process through the Weapon System Explosive Safety Review Board (WSERB), extensive integration and shipboard test events are required to certify and lock down a weapon system baseline by the Naval Systems Engineering Directorate (NAVSEA 05), and rolls up into a larger combat system certification. If a weapon were patched on a monthly basis, the cost would be unsustainable for the necessary rigor to ensure the system is still safe, which is why this risk is typically accepted. By partitioning DSHEL from HEL within the cyber security accreditation boundary, the HEL weapon system can maintain its PIT System accreditation whereas the DSHEL would designate as an IS, accredited by ATO. The system is broken into what the functional laser weapon would be by design and its distance support counterpart, permitted to interface by a PIT and an IS interconnect agreement. This in turn allows HEL to have a frozen baseline where the DSHEL, which is the only part communicating with the GIG, can receive periodic IAVA patches to ensure the risk can be managed appropriately without invalidating the NAVSEA05 certification of the laser. Pending the future design of the PoR HEL, it may even be possible to fully accredit the HEL system as PIT, with DHSEL defined as a PIT Interconnect (PITI) if the transfer of data is fully enough defined. This consideration must be fully evaluated at the time of realization with the designated approving authority (DAA). Design considerations are addressed in the Technical Implementation section.

(2) Technical Implementation

The high-level requirements, technical considerations, and security controls of RMF must be rigorously addressed. While full technical design cannot facilitate without proper system functional requirements, the following best practices are used to minimize effort and maximize reuse of existing applications.

By partitioning the HEL and DSHEL accreditation boundaries, a balance can be achieved which does not impose changes to an already rigorously tested and certified HEL weapon system while still providing a secure connection to enable distance support. An interconnect agreement between the DSHEL (Information System) and the HEL (Platform IT) still requires that the interface be managed and secured. This is best achieved at a minimum through the use of a firewall and an approved set of ports, protocols, and services, which are permitted between DSHEL and HEL. The aforementioned is typically referred to as a “white list,” where certain data is identified as permitted and all other formats, ports, and connections are denied. This implementation must be applied to all external interfaces of DSHEL, going to HEL as well as to the shipboard network. In turn, this creates a security wrapper around the information system where only approved ports, protocols, and services will be allowed. DSHEL would then not only be secure by technical design, but can also receive periodic IAVA patches to its operating system (OS) to minimize risk and maintain ATO certification.

The core underlying effort of most cybersecurity is applied to the OS of the computer asset. An OS is software that manages the computer hardware and software resources and provides common services for computer programs. It is an essential component of any system and OS’s exists on network switches, to personal computers, to servers. DISA provided STIG’s guide a security engineer on how to configure a systems OS in order to meet necessary security controls and exist for almost every major COTS software systems: e.g., Microsoft Windows, Red Hat Enterprise Linux (RHEL), CISCO IOS. The application of STIGs takes considerable effort in person hours to accomplish, which is why DISA provides baseline images for free as a download from their site, incorporating a majority of these security controls which do not impact performance, leaving the remaining work to be complete by the program’s security engineer. While the

DISA image is provided for free, it is still the obligation of the Program Sponsor to pay any required licensing fees of the COTS OS manufacturer, a sunk cost considering it must be licensed either way. Given the amount of time it takes to “lock down” a system as well as to maintain the security of a system, up front consideration must be made on COTS selection given the required functionality. It must be noted that DISA images are basically locked down to a point where they are almost not functional, which allows the security engineering to open required services up and provide any addition STIG configurations necessary. The entire process is managing risk, in that how much tradeoff between cybersecurity and functional capability can be accepted as reasonable risk. Leveraging the secured images is a key asset in development, where some programs may make the pitfall of using other OS’s not supported by DISA, such as CentOS or Ubuntu, thus, applying the STIG from a fresh install of Windows or RHEL. This results in a duplication of effort which has already been completed by another government organization.

Alongside the core OS is the defense-in-depth architecture granting least privilege to a user. Legacy systems base their design around being completely open. This induces security risks and maintenance costs to sustain system accreditation. Locking down the system to only the required ports, protocols, and services mitigates much of this risk. In addition, defensive cyber security products (e.g., firewalls, file integrity checkers, virus scanners, intrusion detection systems, anti-malware software) should be included if possible and operate in a GIG connected manner to enhance the exchange of data and shared security policies. Overall, fundamental system requirements for functionality are required to delve further into technical application and were developed by the DSHEL team in the following requirements section; the takeaway is that many options exist for a program to implement secure systems, and they must be investigated early in systems development.

The aforementioned division of HEL from DSHEL accommodates the current “as is” network infrastructure that exists in the Fleet. While current RMF concepts of reciprocity would dictate otherwise to minimize rework of cyber controls, this in turn requires each system to bring aboard their cyber solution and accredit as such. Future shipboard network architectures leverage infrastructure level firewalls, host based security systems, antivirus, and other shared cyber resources, which could be leveraged by the HEL. While it would not fully satisfy all cyber requirements imposed on HEL, many of the controls would reciprocate and be inherited to secure the DHSEL sub-system. As a baseline effort, these requirements were identified in this report and for legacy host platforms must be designed-in to HEL. Future architectures in the developmental stages of the life cycle would then require the HEL developer to perform a requirements analysis to determine which controls were already satisfied by the shipboard infrastructure. If the boundary defense is sufficient in implementation, the DSHEL can avoid being partitioned out as an IS, thus remaining part of the HEL weapon system accreditation, and achieve functional transfer of data off ship by leveraging the infrastructure as a service (IaaS) DS gateway. Potential future implementations of shipboard infrastructure are beyond the scope of this report to go into sufficient detail; however, they were identified as an area of future research in the summary section.

By following the recommended procedures, artifact creation, and technical implementation through the systems engineering process, DSHEL can be realized into a secure functional capability of HEL.

b. Open Systems Architecture

To leverage the abundance of free open source software (FOSS) and COTS applications, which exist to enable DS of HEL, open standards and protocols must be leveraged. The DOD preferred approach for implementation of open systems, previously called modular open systems approach (MOSA), is now called open systems architecture (OSA). Per the Office of the Deputy Assistant Secretary of Defense,

> Technology evolution and lessons learned have led to DOD guidance suggesting the move away from MIL-STD proprietary interfaces, both physical and logical, to the use of industry standard open interfaces such that system modules are decoupled. The use of industry OSA is both a business and technical strategy for developing a new system or modernizing an existing one. OSA enables acquisition and engineering communities to design for affordable change, employ evolutionary acquisition development, spiral development, and develop an integrated

> roadmap for system design and development. Basing design strategies on widely supported open standards increases the chance that future changes to the system will be integrated in a cost-effective manner. Open systems employ modular design, use widely supported and consensus-based standards for their key interfaces, and have been subjected to successful validation and verification tests to ensure the openness of their key interfaces. (United States Department of Defense 2015)

The open systems architecture contract guidebook was released in May 2013, providing passive DOD stakeholder requirements, checklists, and contractual specifications to enable the fundamental principles of OSA as stated in the guidebook (United States Department of Defense, 2013):

> 1. Modular designs based on standards, with loose coupling and high cohesion, that allow for independent acquisition of system components
>
> 2. Enterprise investment strategies, based on collaboration and trust, that maximize reuse of proven hardware system designs and ensure we spend the least to get the best
>
> 3. Transformation of the life-cycle sustainment strategies for software intensive systems through proven technology insertion and software product upgrade techniques
>
> 4. Dramatically lower development risk through transparency of system designs, continuous design disclosure, and government, academia, and industry peer reviews
>
> 5. Strategic use of data rights to ensure a level competitive playing field and access to alternative solutions and sources, across the life cycle

A mandate of OSA is that technical requirements be based to the maximum extent practicable on open standards. Where there are no standards, the OSA methodology creates them. At a minimum, technical standards and related specifications, requirements, source code, metadata, interface control documents (ICDs), and any other implementation and design artifacts that are necessary for a qualified contractor to successfully perform development or maintenance work for the government are made available throughout the life cycle (United States Department of Defense 2013).

Due to this mandate, there are a number of boilerplate requirements, which were to be leveraged for the implementation of DSHEL. This begins with the need for the developer to submit to the government an open system management plan as set forth in the contract data requirements list (CDRL). This begins with the technical approach and decomposes in to design disclosure for technical data rights such that the customer can accept, maintain, and sustain the system with COTS refresh items as acceptable replacements due to the use of OSA standards. This enforces the justification of vendor specific proprietary interfaces when open ones cannot be leveraged.

Early and often technical disclosure is a recent mandate. Submitting plans, which describe the information disclosure methodology, computer resources necessary, are required to enable collaboration and a common knowledge base for all those involved. This technical data also can not have any restrictive markings prohibiting the re-use of source material for the customer. Moreover, the use of FOSS is encouraged as technical data to permit reuse of open standard interfaces among COTS software. The OSA guide not only mandates the use of OSA, but also a sense of fiscal responsibility, which will not inhibit the DOD from life-cycle management of the system.

c. Infrastructure

In order to properly execute DS for the HEL, it is necessary to maintain a reliable ship to shore connection. To accomplish this, it was necessary for this research to capture the requirements and capabilities necessary for effective ship to shore communication. Although data integrity and security of the GIG is of the utmost importance, this section will focus on the performance requirements of the transport layer.

Any connection made from the shore to the ship happens through one of several NOC around the world. In order for a USN shore facility to gain access to the ship through the NOC, a firewall service request (FSR) must be submitted to the NOC indicating the require subnet address space as well as the ports protocols and services (PPS) that will be transmitted through the NOC firewall. Once this has been completed, the NOC firewall will be modified to allow connection to the designated ship.

In the case of the guided missile destroyer (DDG) platform, the inbound connection for TCP/IP happens through the shipboard super high frequency (SHF). Once the radio frequency (RF) signal is received by the SHF antenna, the signal will be decrypted and then passed to the Main Shipboard Routing System for the ship known as the Automated Digital Network System (ADNS). From ADNS, the information will pass to the Integrated Shipboard Network System (ISNS), which acts as the main transport layer for the ship. Since the HEL System is being developed as a ship self-defense weapon system, the data needs to move from the ISNS domain of the ship into the combat systems domain of the ship. The combat systems network on the DDG platform is the Aegis LAN Interconnect System (ALIS). Typically, ALIS does not maintain a persistent connection to ISNS. For the DSHEL system, a persistent connection between ALIS and ISNS would be required. To help provide a layer of security between these two ship domains, the DSHEL system shall employ a boundary firewall to maintain the security of the information and ensure protection of each domain. Once inside the ALIS network, the information would get to the DSHEL system and then to the HEL system itself.

In the case of the LCS platform, the path to the ship is completely the same until the signal hits the ADNS routers. Once the signal passes the ADNS routers, it enters the Total Ship Computing Environment (TSCE). This environment acts as the transport layer for the ship, combining the previous ISNS and ALIS networks into a single backbone. From the TSCE, the signal will travel through the TSCE firewall into the combat virtual local area network (VLAN) and then to the DSHEL system. Figure 19 shows this connection path.

In each of the cases, the total data throughput off the ship through the ADNS routers is allocated to be 2Mbps. Additionally, the SHF is not Line of Sight (LoS); rather it is via satellite communications (SATCOM) over the horizon, which can add an additional 800 ms round trip delay ship to shore. This delay causes significant overhead due to the fact that many TCP/IP packets could potentially exceed the minimum transmit unit (MTU) time provided. These can be dropped in the transmission process. Given the constrained bandwidth environment, it was necessary to have a requirement for the DSHEL system that all data transmitted off ship would have to be analyzed for criticality discarding non-essential data and then compressed prior to transmitting off ship.

d. Big Data and Data Science

Big data is a term that defines extremely large, complex data sets that are challenging to collect, verify, validate, process, analyze, store, search, transport, share, and secure. Data science is the analysis of, and extraction of knowledge from big data. These terms are very general due to there being no standard definition. This paper will use the ONR and RAND definition of big data by the analysis of its characteristics. Big data is defined by four characteristics (Porsche, Wilson, Johnson, Tierney, and Saltzman 2014):

- volume of data
- variety of formats, sources, and types
- velocity of searches and data retrieval
- veracity of conclusions based on data

The reason big data is defined by the characteristics and properties above is due to it being a moving target. The amount of data and the speed at which it is processed is relative to the progression of technology. Even with these relative benchmarks, one fact remains certain: the USN arguably faces one of the most complex big data challenges in the Information Age.

With the growth of the Internet of Things (IoT), interconnected and networked devices have found their way into all aspects of life. From coffee makers to aircraft engines, sensorization of these devices has captured information that can be used to increase product maintainability, availability, and increase capability. In acquiring COTS products, the USN now has access to these data recording and reporting tools that are built into these systems. While these tools bring the promise of the benefits of the product increases listed above, they will also bring about some major challenges.

A typical Boeing 737 engine generates 10 terabytes of data every 30 minutes in flight (Mathai 2011). While this amount of data may seem substantial, all of the information housed in the Library of Congress totals to only be 200 terabytes (Porsche, Wilson, Johnson, Tierney, and Saltzman 2014). A USN Arleigh Burke Class Guided Missile Destroyer has four gas turbine engines. With a typical deployment lasting six months, this means the data generated by the gas turbine engines alone would total to be 87,658 terabytes or 87 petabytes. If this amount of data was to be burned to compact discs (CDs), 125 million CDs would be needed. Stacking each of these CDs on top of one another would result in a tower of CDs reaching 93 miles into the sky. This is 438 times more data than that of the entirety of the Library of Congress. In fact, a single destroyer on deployment would generate the equivalent of a Library of Congress' worth of data in about ten hours. This amount of data only accounts for the gas turbine engines alone and does not include the rest of the systems on board of the ship (such as radar, communication, weapons, mechanical, network). When the complete data picture of USN is put together (logistics, support structures, administrative services, surface, subsurface, air, land, and space), the sheer amount of data becomes mind-boggling, as shown in Figure 19.

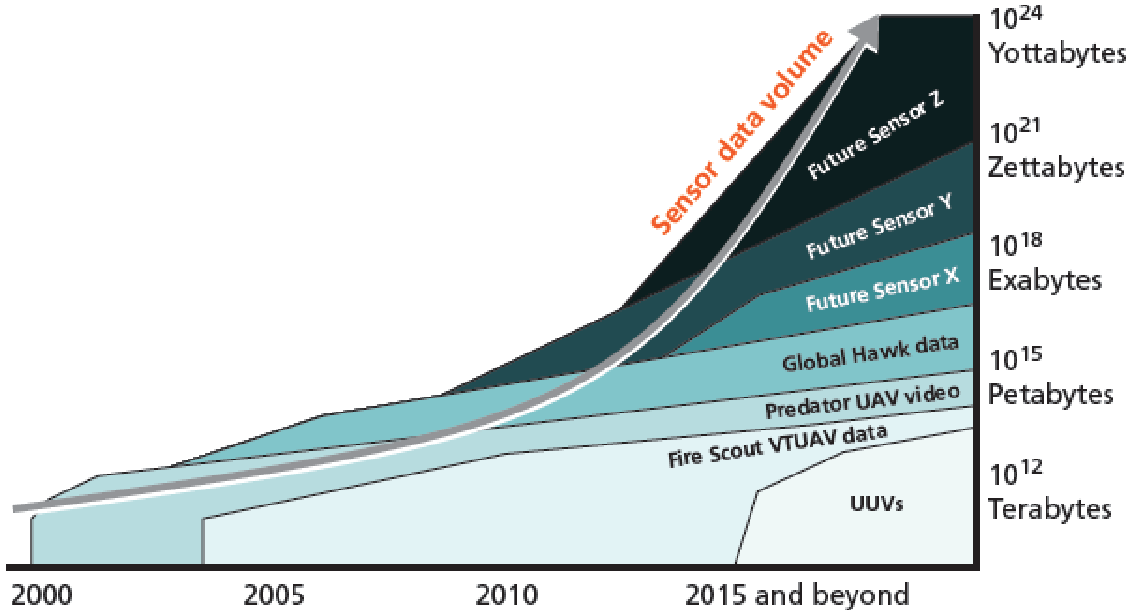

Figure 19. Exponential Increase of Data Generated as USN Acquires New Sensors (from Porche et al. 2011, 5)

It was important for DSHEL to understand the big data challenge because as the current trends show, the amount of data is only increasing and the main information needed to provide support to a system is data.

3. Summary

Throughout DSHEL's literature review, it became apparent that a knowledge gap existed in multiple areas creating a need for a system that DSHEL would fill. The current state of DS is fractured. There lies a functional and communication gap in between the systems and the service provider organizations. In order to provide adequate DS to the HEL, an integrated DS framework must first be created. This solution must be flexible, modular, efficient, maintainable, as well as adhere to all the unique policies and regulations of the USN.

B. DISTANCE SUPPORT FRAMEWORK

At its highest level, DS is a concept that is delivered as a service to a platform through hardware, software, or a combination of both. To execute DS, three basic elements are required: platform service provider (PSP), platform of interest (POI), and the enabling/supporting infrastructure (ESI). Each of these elements work together through a series of level agreements with the goal to provide high quality DS.

1. Product vs. Service

DS is a very general topic and has several meanings depending on the audience. In order to classify DS as a product or a service, these terms must first be defined.

- Product—tangible and discernible items or assets that are produced or manufactured by an organization
- Service—production of significant intangible benefit that satisfies a requirement, need, condition, obligation, or prerequisite

While these definitions are distinct, most products and services come together bundled as one and execute upon each other to deliver an enhanced capability, function, or quality. Figure 20 details how the concept of DS can rapidly bounce back and forth between being defined as a service and as a product. This transformation occurs as the concept of DS matures and grows. The Y-axis of the figure is related to concept maturity. A concept new in its life cycle starts off at a very basic level (i.e., limited knowledge base and no discipline experts). As the concept field grows and expands, a predefined service shifts to become a product through a technological or process enhancement. This enhancement brings added knowledge and capability to the concept field and thus matures the concept discipline. It can be expected for a concept to shift between being a product or service as the concept matures. Once a concept has reached its full maturity, if possible, the concept product and service become one in the same. This would be equivalent to having a system become what is known as an “expert system.” This system has the ability not only to emulate the decision-making ability of a human concept discipline expert, but it also has the ability to perform self-repair and even component replacement. While an expert system like this is many years away, the ability for a DS expert system run by artificial intelligence with part fabrication and replacement abilities via three dimensional printing may be possible in the future.

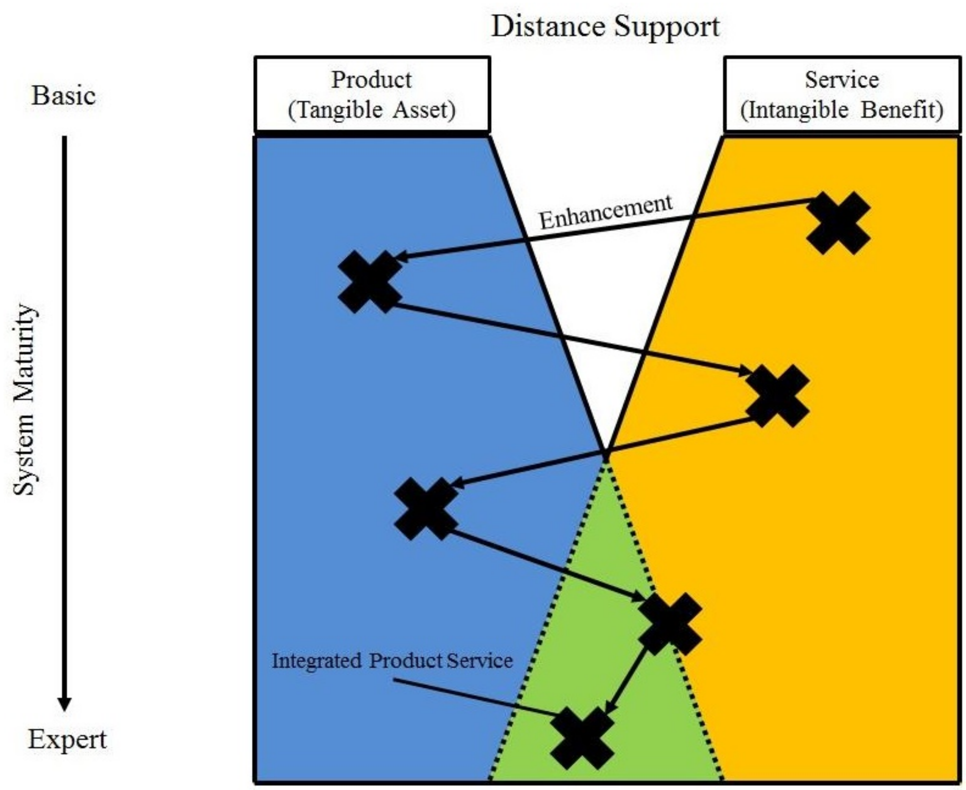

Figure 20. DS Product and Service Comparison

2. Legacy and Future Platforms

DS can be applied to all platforms, regardless of current life-cycle phase. While it is true that there will be shortcomings in the quality and detail of the information generated by the DS product from legacy platforms, it still may be useful to the DS provider.

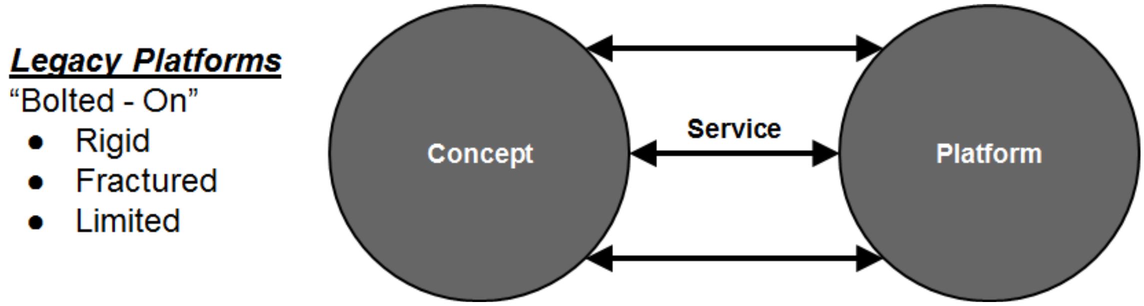

Figure 21. Legacy Platform Service Interaction

In platforms that do not have a concept component "designed-in" but rather "bolted-on," also known as a legacy platform, the interaction between the concept and platform must be facilitated by a service link between the two (illustrated in Figure 21) in order to deliver the concept to the platform. There is a stark difference between the legacy platform construct and the future platform construct. In the legacy platform interaction, the service provided by the concept to the platform is:

- Rigid - With a "bolted-on" concept, providing a services to a platform after the platform design has been completed, concept service requirements no longer become a factor and must adhere to platform characteristic requirements (interface, security, power, form factor).
- Fractured - With a "bolted-on" concept providing services to a platform, system boundary lines are very distinct. This is good in the sense that system ownership is clean, clear, and delineated, but offers interface, integration, security, and potential ancillary system issues.
- Limited - With a "bolted-on" concept providing services to a platform after the platform design has been completed, the level of service is fixed in that it can only provide a level consistent with what the platform can provide as is, at maximum.

In future platforms, the concept is "designed-in." This allows the concept and the platform to have shared requirements and be fully integrated into one another, as denoted by the red dashed box in Figure 22, thus allowing a high level of concept service to be achieved.

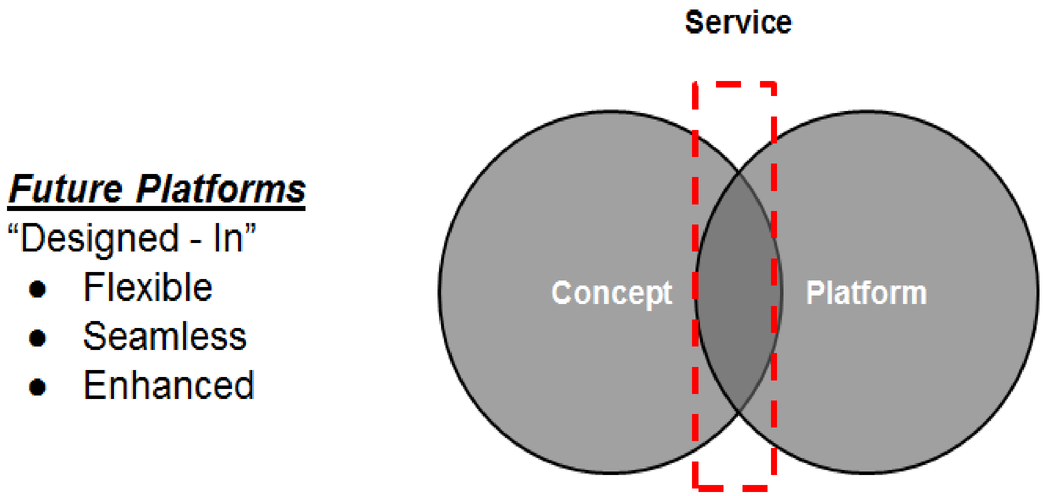

Figure 22. Future Platform Service Interaction

In future platform interaction, the service is no longer provided by the concept to the platform. The concept service is executed on the platform, this means future platform interaction is:

- Flexible - With a "designed-in" concept, level and quality of concept service metrics can be tailored to a setting or threshold consistent with platform service provider / user requirements.
- Seamless - With a "designed-in" concept, the boundary line between the concept, service, and platform is shared. This allows for greater communication between the two and can often lead to better security, interface, and product requirements.
- Enhanced - With a "designed-in" concept, level and quality of concept service being executed on the platform is greater due to being able to gain access to, gather, process, and analyze important service metrics and information.

It should be noted that another significant difference between these concept/platform interactions is that the legacy platforms tend to be more dependent on the customer initiating and executing the support for the platform. While future platforms will still include the customer where needed, they will be less labor intensive.

3. Distance Support Elements

In analyzing the current organization of the USN, along with the roles and responsibilities of these subsequent support organizations, it was determined that a simple three-element framework should be created to take advantage of this organizational structure. The USN's support organizations are funded for providing a capability or service, hence the use of service level and operational level agreements were exploited by this framework. For completeness, each basic element was covered, but the focus of this framework is the breakdown of the POI.

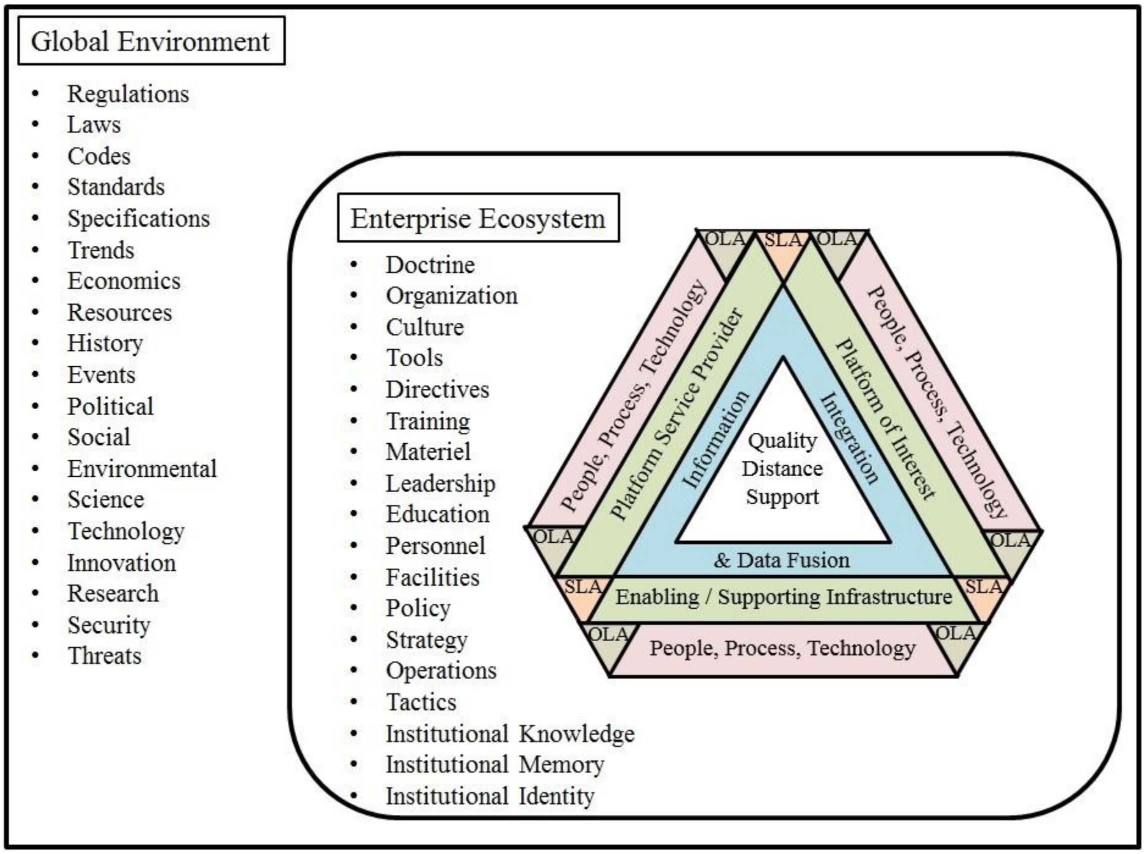

Figure 23. DS Application Context Diagram

Figure 23 describes the application context of DS with internal factors, enterprise ecosystems entities, and global environment externalities that may interact with providing quality DS. Starting from the innermost encompassed item on the DS Application Context Diagram, each item is explained below.

- Quality Distance Support: Goal of the DS framework, the quality provided via product or service delivery should meet or exceed that of the customer service requirements or needs.

- Information Integration and Data Fusion (I2DF): Evidence passed, generated, and shared that the PSP, POI, and ESI collect, verify, record, validate, store, process, filter, log, compress, and analyze to produce quality DS.
- Platform Service Provider (PSP): Organization or agent that provides service, maintenance, and technical support to the POI, its customers, and users.
- Platform of Interest (POI): System that has a need for service.
- Enabling / Supporting Infrastructure (ESI): Facilities, materials, and services necessary to store, transmit, or receive the critical information needed to execute / assist a function.
    - Enable—give someone or something the authority or means to do something
    - Support—give assistance to, help or aid
- Service Level Agreement (SLA): An external agreement between the POI and PSP, POI and ESI, and PSP and ESI, stipulating client service requirements and provider service delivery.
- People, Process, Technology: Three elements that make up successful PSPs, ESIs, and POIs.
- Operational Level Agreement (OLA): An internal agreement detailing how various functions and groups within an element plan to deliver a service or package of services.
- Enterprise Ecosystem: Entities separate from the DS products and services that may need to be considered or adhered to.
- Global Environment: Externalities removed from the Enterprise Ecosystem that may influence and dictate changes to DS products and services.

Figure 24 shows, in a simplified fashion, how these basic elements interact with one another. Typically, DS between the PSP and the POI is facilitated by the ESI. It should be noted that in rare cases, DS can be facilitated between the PSP and the POI without the use of an ESI. This is usually found on the POI side where the ESI fails to meet PSP requirements or the data provided from the POI is non-mission critical. Examples of this include a POI where the data being generated is too great for the ESI to transmit in a timely fashion or the data from the POI is not time critical and can be analyzed "stale."

In general, the POI is the product that the customer is using to perform a given task. As this POI is executing the desired task, data is generated that is then sent back to the PSP via the ESI. The ESI's main function in performing DS is ensuring end-to-end communication between the PSP and POI.

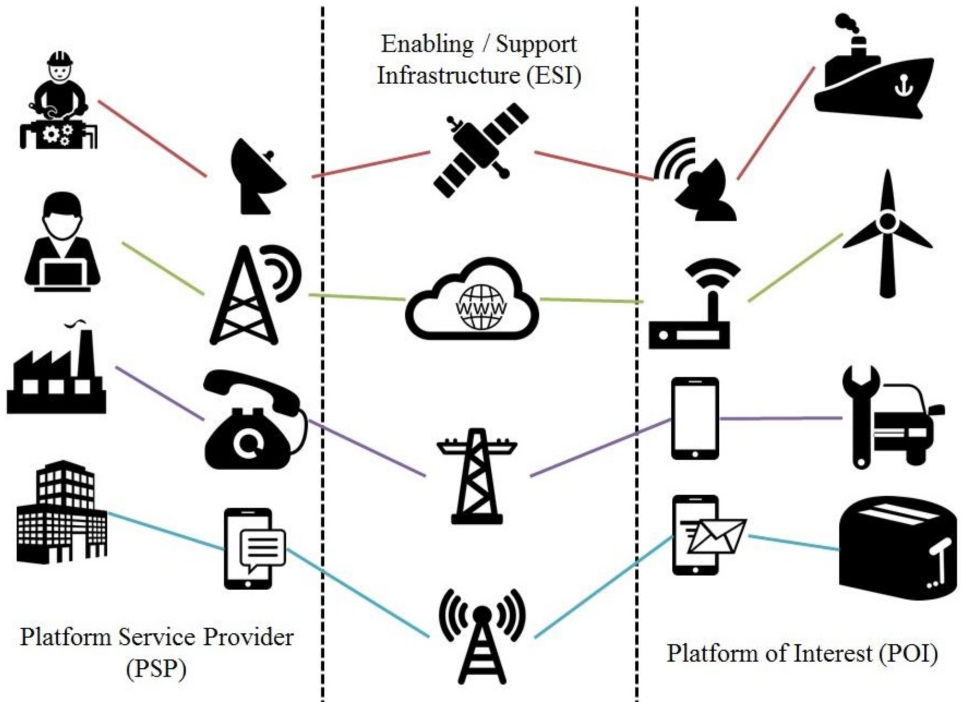

Figure 24. The Three Basic Elements of Distance Support (Icons from Flaticon 2014)

Each of these elements has ownership of their respective domain. That is, no element may cross into another element's domain without proper authorization. The concurrence that allows cross-domain transits are known as service level agreements (SLAs). SLAs are contracts between elements that detail the level of service expected from a provider. In this case, there would be several SLAs:

- PSP to POI: The PSP would have a SLA with the POI that would detail the quality of service (support).
- ESI to PSP: The ESI would have a SLA with the PSP that would detail the quality of service (bandwidth throughput, link availability).
- ESI to POI: In many cases the ESI to PSP SLA would cover this case, but there are times when the two can be separated and thus require another SLA between the two elements.

A good example of SLAs in action is residential Internet access with subscription video streaming services. Typically the customer has a SLA with the ISP (i.e., Comcast /

Time Warner) that details the expected speed and service availability of the network connection. The customer also has a separate SLA with a subscription video streaming service (Netflix/Hulu) that details how many shows he can watch or how often they can watch episodes. In addition to these SLAs, separate SLAs are struck between the ISP and subscription video streaming services that can detail geographic service delivery or total service bandwidth.

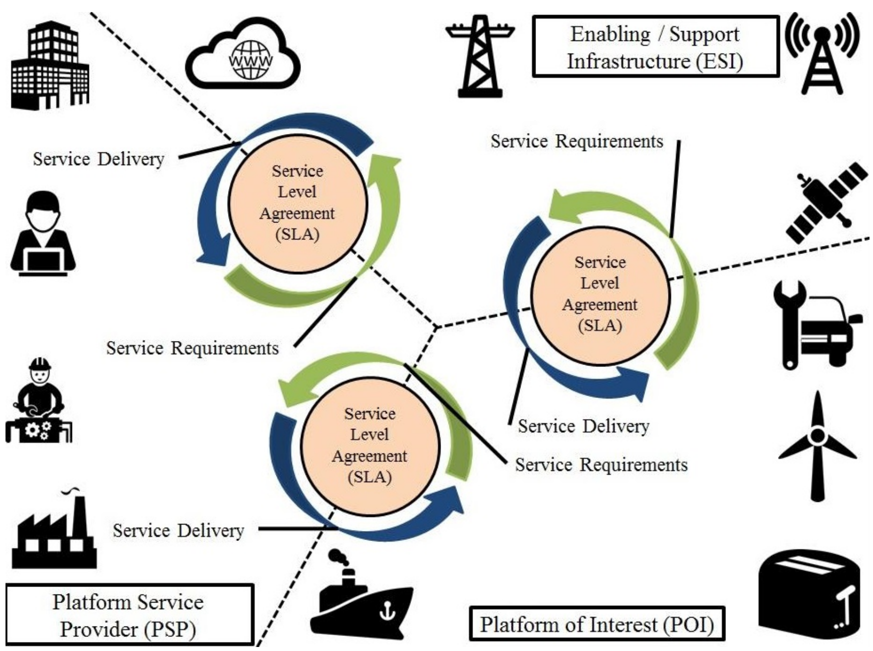

Figure 25. Service Level Agreements between the Three Elements of Distance Support (Icons from Flaticon 2014)

In Figure 25, the green arrows stipulate client service requirements, while the blue arrows stipulate provider service delivery. These SLAs can be renegotiated after the previous service contract has expired. It is important to negotiate an SLA frequently; technology and capability needs often outpace the constraints of an SLA before the SLA expires. A separate SLA with each entity is not always required. Blanket SLAs can be authored to cover more than one element if deemed practical. The most crucial SLA is the one that ties the PSP to the POI. Without this SLA, support (distance or not) does not exist.

A complete SLA should have the following sections listed in Table 7.

Table 7. SLA and OLA Elements

Section Name	Purpose
Agreement Overview	Details the agreement in general. States its validity as well as endorsement by the stakeholders.
Goals and Objectives	States the purpose of the agreement as well as the goal. Typical objectives include: (1) Provide clear reference to service ownership, accountability, roles and / or responsibilities. (2) Present a clear, concise and measurable description of service provision to the customer. (3) Match perceptions of expected service provision with actual service support and delivery.
Stakeholders	List all parties that enter into the agreement. Delineate between the service provider and the customer.
Periodic Review	Agreements should state the effective date, the business relationship manager ("document owner"), review cycle (6-12 months), previous review date, and the next future review date.
Service Scope	List of services that will be offered to the customer.
Customer Requirements	Customer responsibilities and / or requirements.
Service Provider Requirements	Service Provider responsibilities and / or requirements.
Service Assumptions	Assumptions related to in-scope services.
Service Management	Management, maintenance, and support of service.
Service Availability	Service availability parameters.
Service Requests	Details how service request from the customer will be handles and the associated priority they will be assigned.
Service Performance	Volume and Speed metrics.
Service Measurement	Definitions on how metrics will be collected and calculated.
Service Penalty	Addresses ramifications if service provider / customer violate SLA terms.

Within each element's domain there exists another agreement called an operational level agreement (OLA) as shown in Figure 26. An OLA is a contract that details how various functions and groups within an element plan to deliver a service or package of services. Each basic element typically has at least one OLA. The simplest form of an OLA in action is when a business sets priorities. By setting a priority, the business has dictated how its functions will operate with one another concerning topics. OLA structure mirrors that of an SLA, with the exception that it has a greater focus on change requests, incident management, maintenance changes / requests, and reporting.

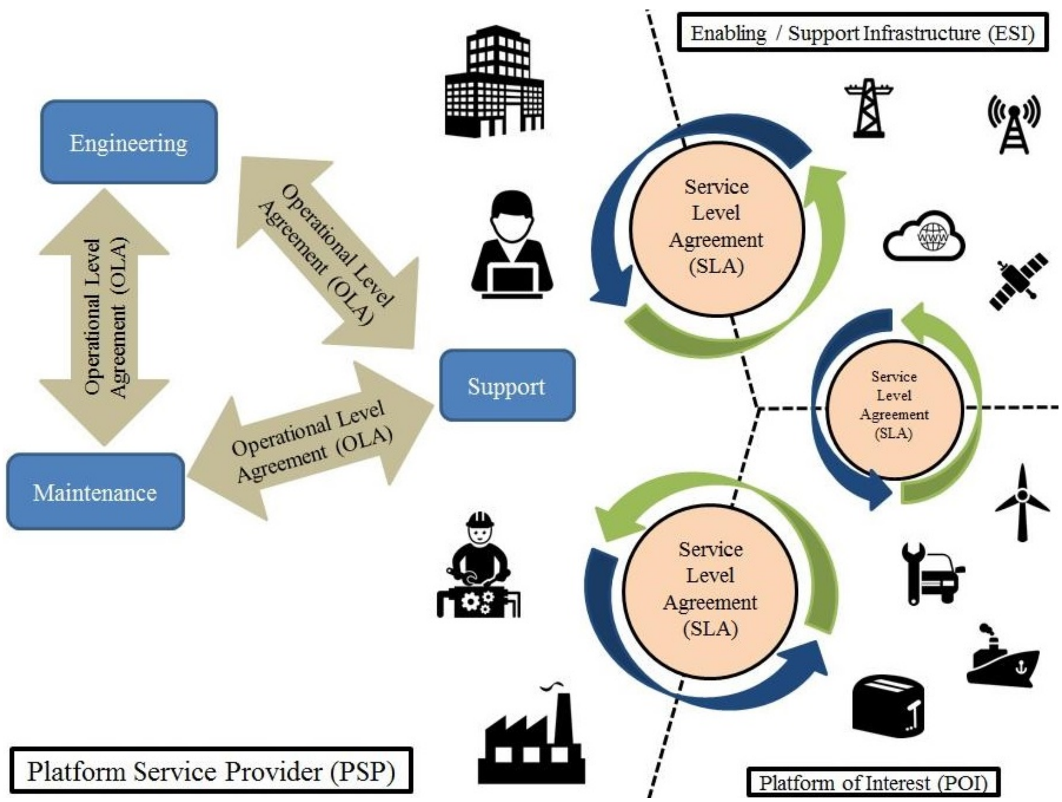

Figure 26. Operational Level Agreements internal to Platform Service Provider (Icons from Flaticon 2014)

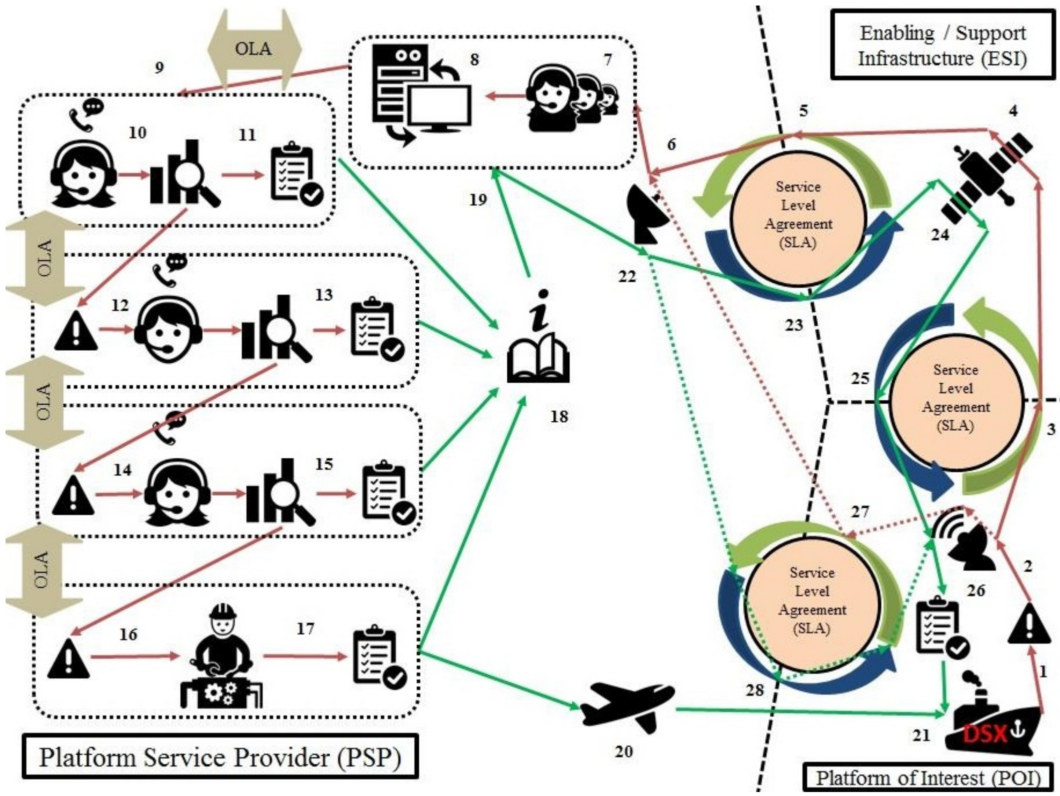

Figure 27. Platform Service Provider DS Walkthrough (Icons from Flaticon 2014)

Figure 27 shows an example of how a PSP and POI interact by highlighting the data and service contract path. The steps have been numbered and listed in Table 8 for ease of comprehension.

Table 8. Data and Service Contract Paths for PSP

Location Point	Next Move	Action
Bottom right of figure	1	The Distance Support X, (DSX) detects a fault in the X system that cannot be resolved.
1	2	An event flag is triggered and the DSX decides that DS should be sought for a solution.
2	3	The fault message is prepared to be sent through the ESI to the PSP.
	27	The fault message data passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract action.
3	4	Using the SLA between the POI and the ESI, the fault message enters the ESI domain.
4	5	The fault message is transported through the ESI.
5	6	Using the SLA between the ESI and the PSP, the fault message enters the PSP domain.
6	7	The fault message is routed to the PSP's "helpdesk."
7	8	The fault message is entered in the system and assigned a tracking number and reclassified as a "help ticket."
8	9	Following the guidelines in the OLA, the "helpdesk" sends the "help ticket" to the multi-tiered technical support group starting at tier one.
9	10	The "help ticket" is received by the tier one technical support staff and research for a solution.
10	11	The tier one technical support staff research provided a solution.
	12	The tier one technical support staff research was unable to provide a solution. The "help ticket" is elevated to tier two technical support following the guidelines in the OLA.
11	18	The technical solution found is updated and recorded in the DS Knowledge Management Library to help build a

Location Point	Next Move	Action
		better knowledge database.
12	13	The "help ticket" is received by the tier two technical support staff and research for a solution.
13	14	The tier two technical support staff research was unable to provide a solution. The "help ticket" is elevated to tier three technical support following the guidelines in the OLA.
	18	The technical solution found is updated and recorded in the DS Knowledge Management Library to help build a better knowledge database.
14	15	The "help ticket" is received by the tier three technical support staff and research for a solution.
15	16	The tier three technical support staff research was unable to provide a solution. The "help ticket" is elevated to tier four / OEM technical support following the guidelines in the OLA.
	18	The technical solution found is updated and recorded in the DS Knowledge Management Library to help build a better knowledge database.
16	17	The tier four / OEM technical support staff research was able to provide a solution. Otherwise the OEM will ensure the product is fixed upon new version release.
17	18	The technical solution found is updated and recorded in the DS Knowledge Management Library to help build a better knowledge database.
	20	The tier four / OEM technical support prepare for site visit due to the technical complexity of the issue.
18	19	The "help ticket" is closed out with the status and outcome of the support inquiry.
19	22	The technical solution is routed from the "help desk" through the PSP.
20	21	The tier four / OEM technical support travel for site visit

Location Point	Next Move	Action
		due to the technical complexity of the issue.
21	COMPLETE	Technical solution resolved.
22	23	The technical solution is routed through the PSP.
	28	The technical solution passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract delivery.
23	24	Using the SLA between the PSP and the ESI, the fault message enters the ESI domain.
24	25	The technical solution is routed through the ESI.
25	26	Using the SLA between the ESI and the POI, the fault message enters the POI domain.
26	21	The technical solution is validated and verified.
27	6	The fault message data passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract action.
28	26	The technical solution passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract delivery.

In the previous walkthrough, the original message fault was routed to a "helpdesk" and then routed to the multi-tiered technical support group. In the previous chapter, wait times were compared with each other to show how effective phone tree menus could be constructed. While the multi-tiered technical support group is not a phone tree, the same principles apply. As illustrated in Figure 28, Figure 29, and Figure 30, there are five main types of waiting lines, or in this case, phone menu systems in use: (1) single-server, single-phase, (2) single-server, multiphase, (3) multi-server, single-line, single-phase, (4) multi-server, multiline, single-phase, and (5) multi-server, multi-phase.

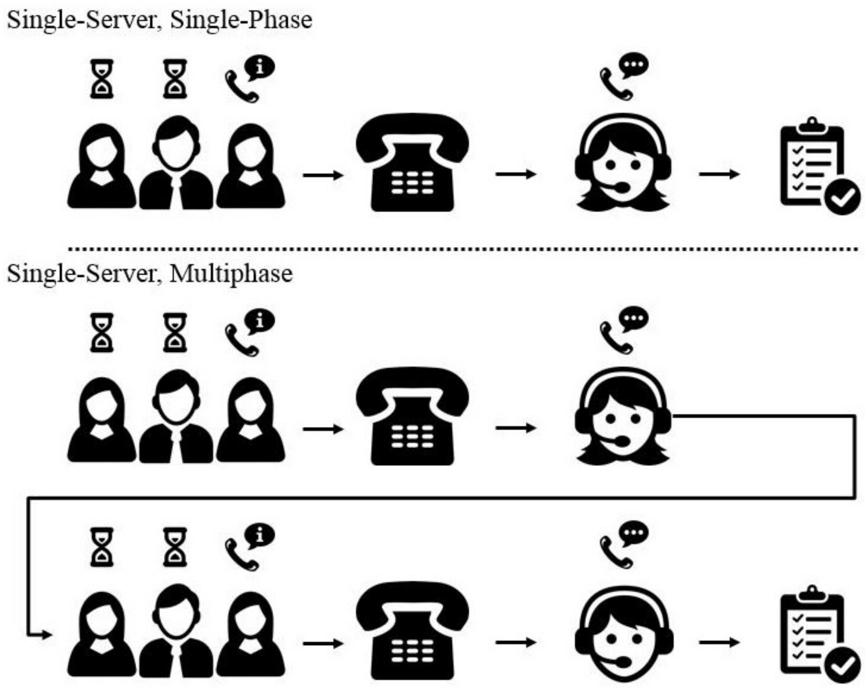

Figure 28. Waiting Line Examples (Icons from Flaticon 2014)

Single-server waiting line models can be used to gain valuable metrics about service organization and efficiency. When modeling single-server waiting line models, the following is assumed (Unknown 2010):

- Customers arrive by a Poisson distribution with a mean arrival rate of λ
- Time between additional customer arrivals follows an exponential distribution with an average of $1/\lambda$
- Customer service rate also follows a Poisson distribution with a mean service rate of μ
- Service time for one customer follows an exponential distribution with an average of $1/\mu$

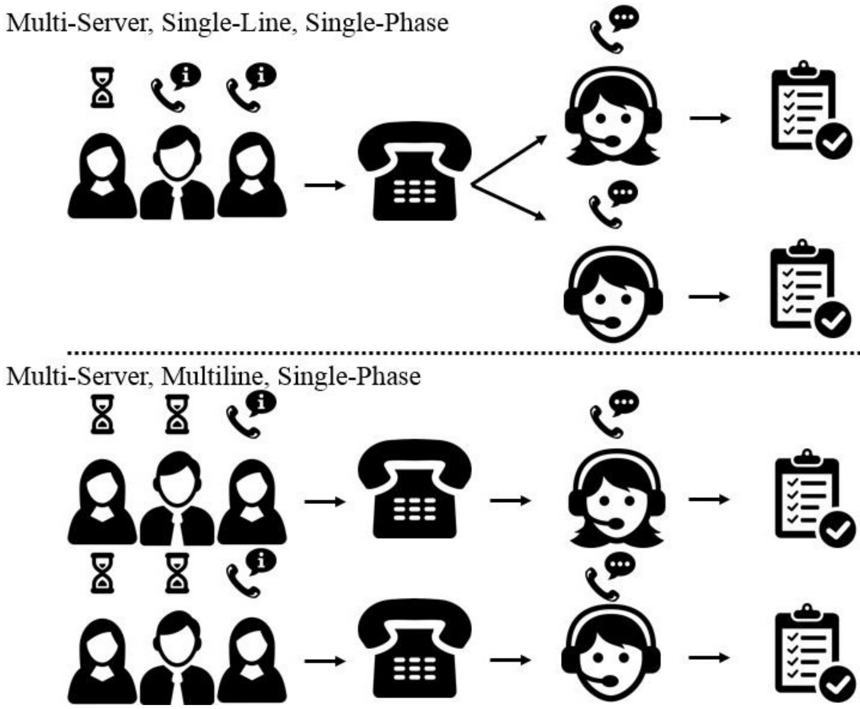

Figure 29. Waiting Line Examples Continued (Icons from Flaticon 2014)

Using the accepted givens above, the following waiting line system characteristics can be calculated as follows (Unknown 2010):

- $\rho = \frac{\lambda}{\mu}$ = average utilization of the system
- $L = \frac{\lambda}{\mu - \lambda}$ = average number of customers in the service system
- $L_Q = \rho L$ = average number of customers waiting in line
- $W = \frac{1}{\mu - \lambda}$ = average time spent waiting in the system, including service
- $W_Q = \rho W$ = average time spent waiting in line
- $P_n = (1 - \rho)\rho^n$ = probability that *n* customers are in the service system at a given time

The service rate must be greater than the arrival rate, $\mu > \lambda$.

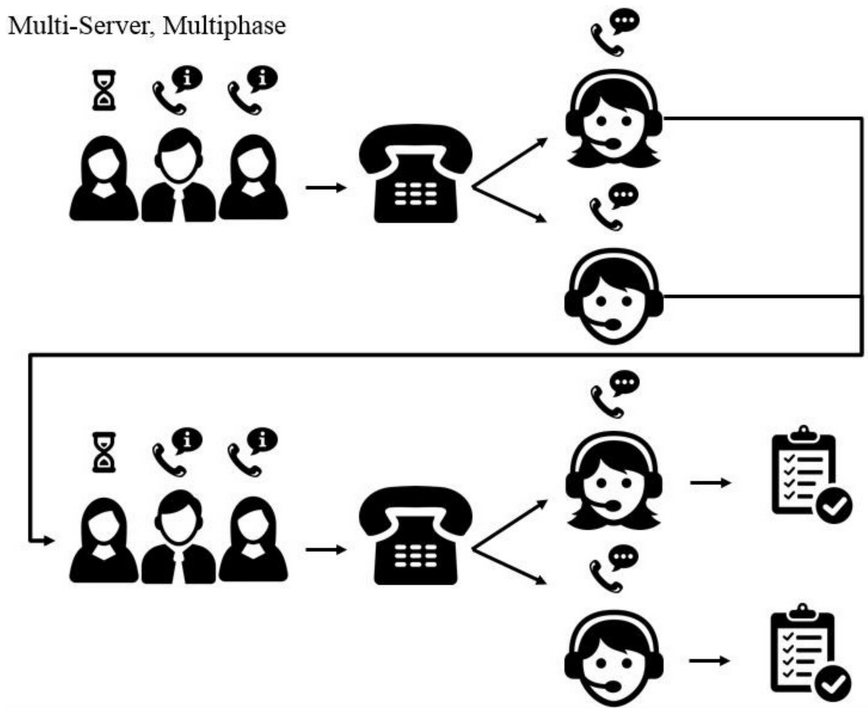

Figure 30. Waiting Line Examples Continued (Icons from Flaticon 2014)

Multi-Server waiting line models can also be modeled using the same given assumptions that were used for the single server waiting line models. Using the accepted givens above, the following waiting line system characteristics can be calculated as follows (Unknown 2010):

- s = the number of servers in the system
- $p = \frac{\lambda}{s\mu}$ = average utilization of the system
- $P_0 = \left[\sum_{n=0}^{s=1} \frac{(\lambda/\mu)^n}{n!} + \frac{(\lambda/\mu)^s}{s!}\left(\frac{1}{1-p}\right)\right]^{-1}$ = the probability that no customers are in the system
- $L_Q = \frac{P_o(\lambda/\mu)^s p}{s!(1-p)^2}$ = average number of customers waiting in line
- $W_Q = \frac{L_Q}{\lambda}$ = average time spent waiting in line
- $W = W_Q + \frac{1}{\mu}$ = average time spent in the system, including service
- $L = \lambda W$ = average number of customers in the service system

- $P_n = \begin{cases} \frac{(\lambda/\mu)^n}{n!} P_0 \; for \; n \leq s \\ \frac{(\lambda/\mu)^n}{s!s^{n-s}} P_0 \; for \; n > s \end{cases}$ = probability the n customers are in the system at a given time

The service rate must be greater than the arrival rate, $s\mu > \lambda$.

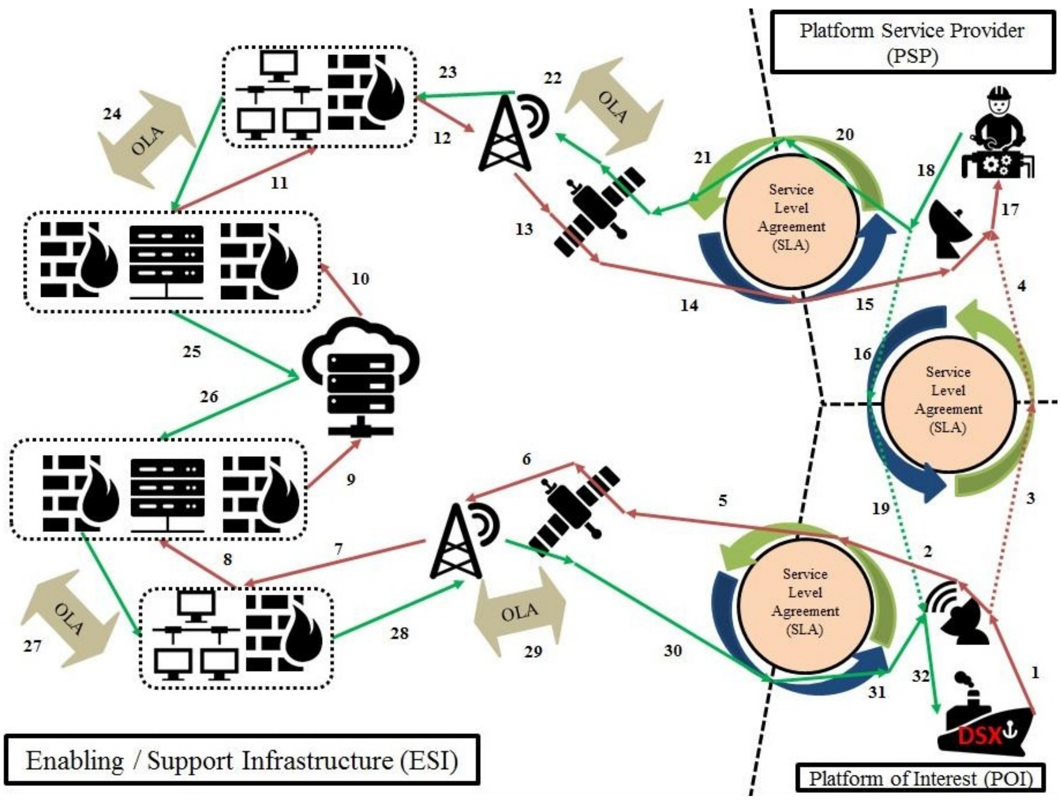

Figure 31. Enabling/Supporting Infrastructure DS Walkthrough (Icons from Flaticon 2014)

Figure 31 shows an example of how the ESI interacts with the other DS elements by highlighting the data and service contract path. The steps have been numbered and listed in Table 9 for ease of comprehension.

Table 9. Data and Service Contract Paths for ESI

Location Point	Next Move	Action
Bottom right of figure	1	The Distance Support X, DSX detects a fault in the X system that cannot be resolved.
1	2	An event flag is triggered and the DSX decides that DS should be sought for a solution.
	3	The fault message data passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract action.
2	5	Using the SLA between the POI and the ESI, the fault message enters the ESI domain.
3	4	The fault message data passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract action.
4	17	The PSP researches the POI inquiry.
5	6	The fault message is routed through the ESI's edge network connections in guidance with the OLA.
6	7	The fault message is routed through the ESI's DMZ and to its LAN in guidance with the OLA.
7	8	The fault message is routed through the ESI's LAN and to its NAP in guidance with the OLA.
8	9	The fault message is routed through the ESI's NAP and to its NOC in guidance with the OLA.
9	10	The fault message is routed through the ESI's NOC in guidance with the OLA.
10	11	The fault message is routed through the ESI's NOC and to its NAP in guidance with the OLA.
11	12	The fault message is routed through the ESI's NAP and to its LAN in guidance with the OLA.
12	13	The fault message is routed through the ESI's LAN and to its DMZ in guidance with the OLA.

Location Point	Next Move	Action
13	14	The fault message is routed through the ESI's edge network connections in guidance with the OLA.
14	15	Using the SLA between the ESI and the PSP, the fault message enters the PSP domain.
15	17	The PSP researches the POI inquiry.
16	19	The technical solution data passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract action.
17	18	A technical solution is found and is sent back to the POI.
18	16	The technical solution data passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract action.
	20	Using the SLA between the ESI and the PSP, the technical solution prepares to enter the PSP domain.
19	32	The technical solution data passes through the ESI SLA, but the SLA with the PSP is used to perform the service contract action.
20	21	Using the SLA between the ESI and the PSP, the technical solution enters the PSP domain.
21	22	The technical solution is routed through the ESI's edge network connections in guidance with the OLA.
22	23	The technical solution is routed through the ESI's DMZ and to its LAN in guidance with the OLA.
23	24	The technical solution is routed through the ESI's LAN and to its NAP in guidance with the OLA.
24	25	The technical solution is routed through the ESI's NAP and to its NOC in guidance with the OLA.
25	26	The technical solution is routed through the ESI's NOC in guidance with the OLA.
26	27	The technical solution is routed through the ESI's NOC

Location Point	Next Move	Action
		and to its NAP in guidance with the OLA.
27	28	The technical solution is routed through the ESI's NAP and to its LAN in guidance with the OLA.
28	29	The technical solution is routed through the ESI's LAN and to its DMZ in guidance with the OLA.
29	30	The technical solution is routed through the ESI's edge network connections in guidance with the OLA.
30	31	Using the SLA between the POI and the ESI, the fault message enters the POI domain.
31	32	The technical solution passes through the POI.
32	COMPLETE	Technical solution resolved.

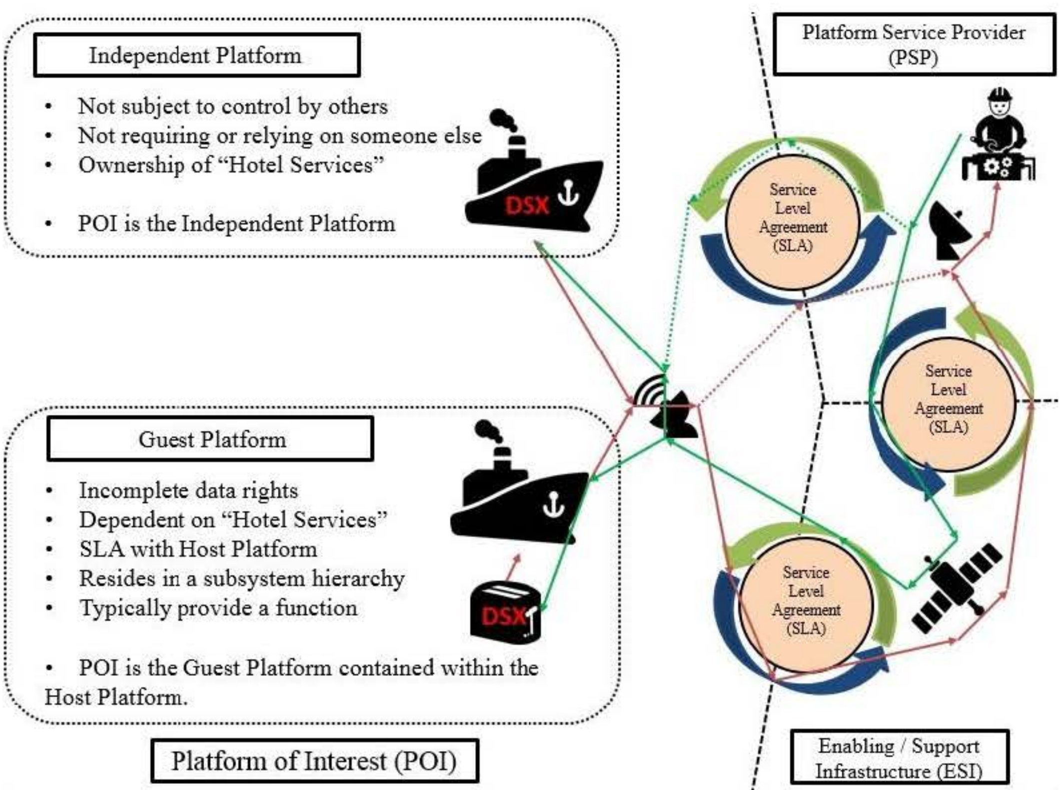

Figure 32. Platform of Interest DS Walkthrough (Icons from Flaticon 2014)

Following the same methodology from the previous two walkthrough figures, Figure 32 conveys the same concept showing the connections and interactions between the three basic elements of DS. The main difference with this walkthrough example is the attention to detail in explaining how the POI can be classified as an independent platform vs. guest platform contained within a host platform. The POI had to be delineated and subdivided to account for POI that resides within another platform. If the POI is not subject to control by other platforms, it does not require or rely on supporting platforms and has complete ownership of its "hotel services." The POI is simply the independent platform itself. If the POI has incomplete data rights, relies on a support structure for "hotel services," has a SLA with a host platform, resides in a subsystem hierarchy, or provides a function to a higher order system, the POI is classified as a guest platform contained within a host platform.

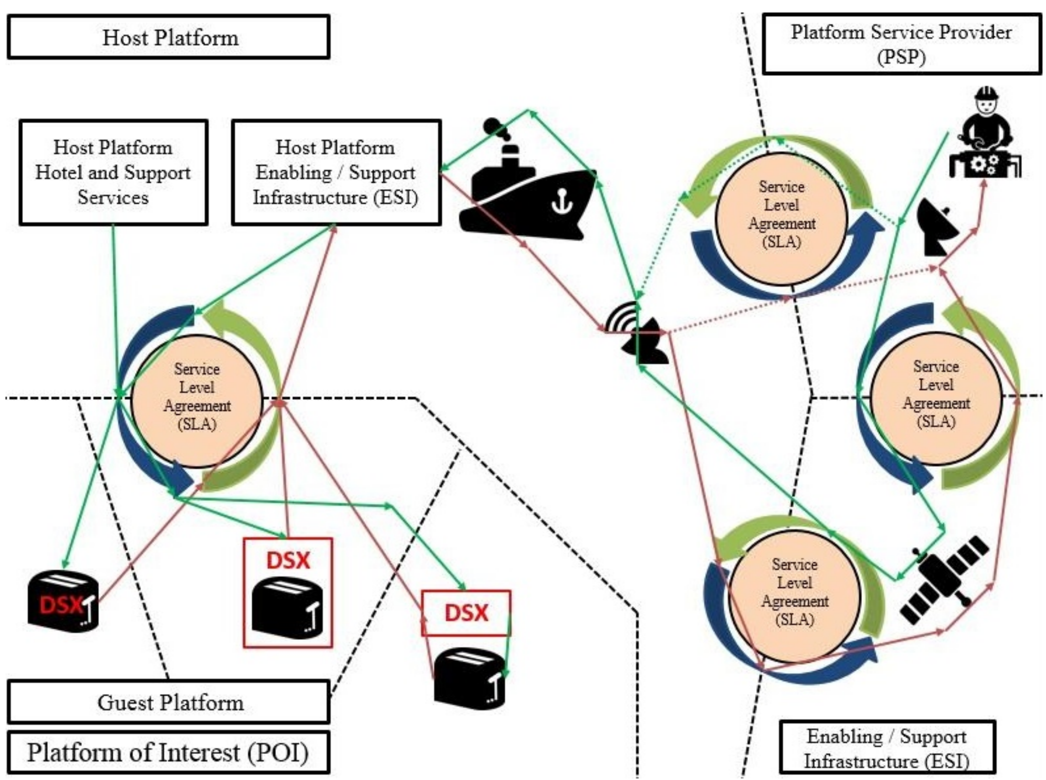

Figure 33. Platform of Interest Guest and Host Interaction DS Walkthrough (Icons from Flaticon 2014)

Figure 33 shows the different types of host and guest platform interactions. The prominent aspect of the interaction diagram is the creation of a new SLA between the guest and host platforms. Since the guest platform is dependent on the host platform for "hotel services," as well as for network connectivity to reach the PSP via the ESI, the guest platform must develop two SLAs, one for the support services and another for access to the host platform's ESI.

Figure 33 also sheds light on the various ways DSX (Distance Support X, where X is the system name) can be configured. This is detailed in the next section.

4. DSX for the POI

DSX configuration depends on the POI, its interactions, support systems, life-cycle phase, as well as the technologies available. The main DSX configurations recommended are as follows:

- Integrated—DSX is designed into the system, single-point all inclusive
- Encompassing—DSX is designed to fit around an existing system (usually used for legacy systems), single-point semi inclusive
- Distributed—DSX has a central node where distributed DSX nodes report, multipoint all/semi inclusive

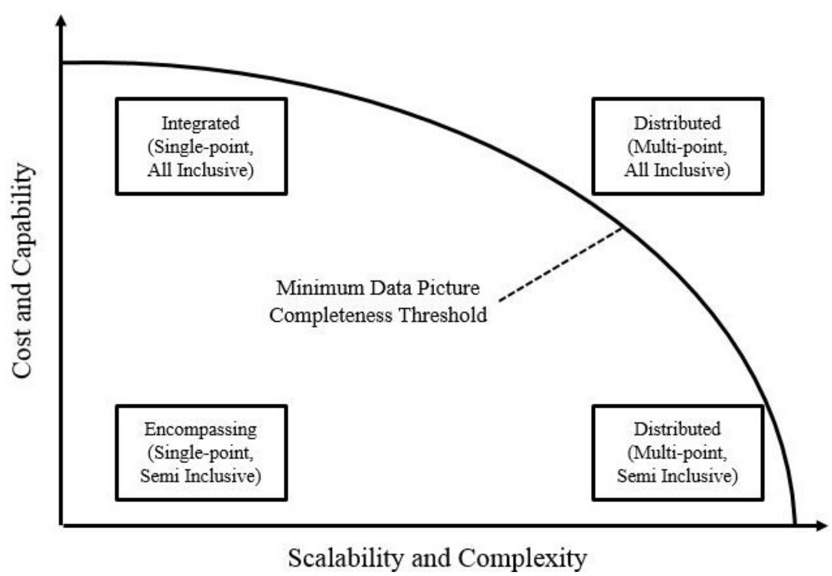

Figure 34. DSX Configurations in terms of Cost, Capability, Scalability, and Complexity

When the DSX configurations are compared to each other in terms of cost, capability, scalability, and complexity, the tradeoffs become clear. In Figure 34, the four DSX configurations were plotted for a fictional system. A "Minimum Data Picture Completeness Threshold" line was then plotted across the chart. This line represents the minimum amount of data that needs to be collected either from multiple sources or a single source to provide meaningful information integration and data fusion (I2DF) so that a quality DS product or service can be delivered. This line and the DSX configurations will differ from system to system.

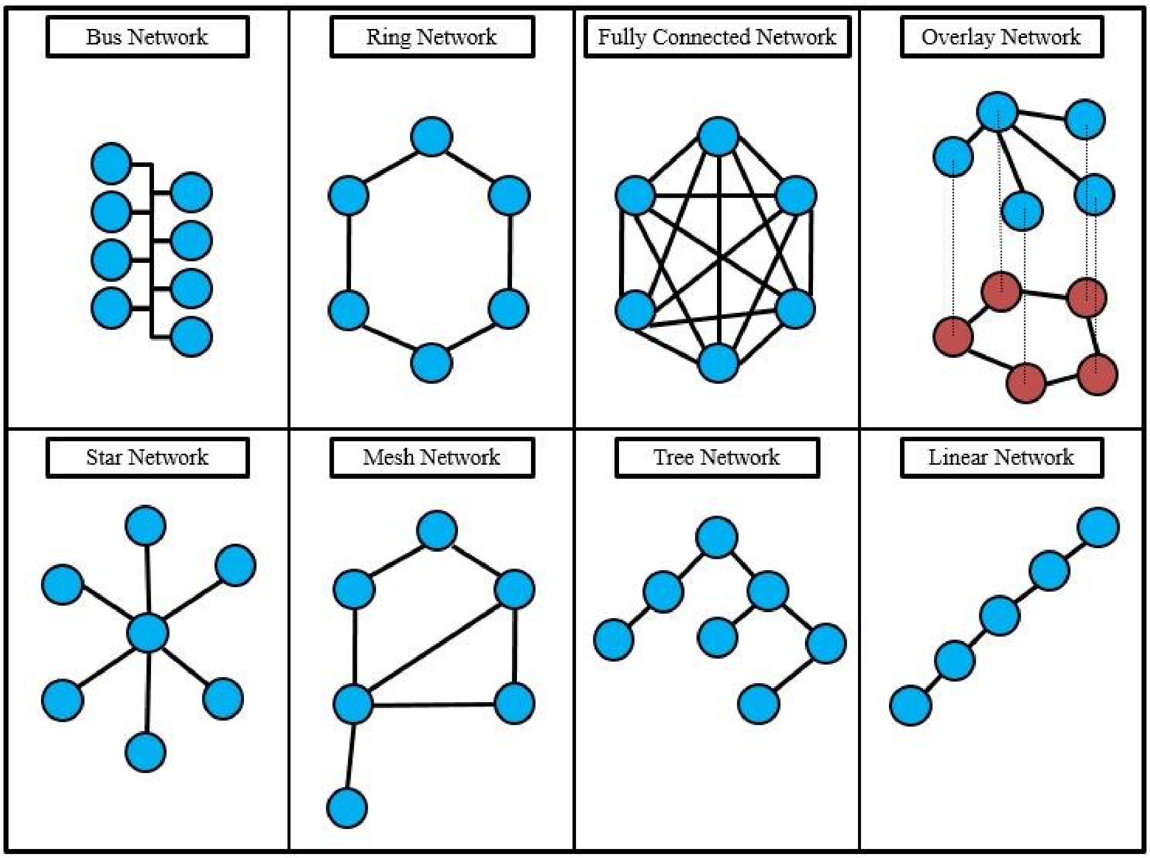

Figure 35. Types of Sensor Collection Networks

Before the first function of the DSX can be assessed, the POI must be analyzed to decide which DSX configuration fits best, as well as the sensor network topology to use. Each network topology (wired or wireless), like each DSX configuration, has advantages and disadvantages. These differences should be weighed against the types of sensors that will be used within the sensor network. Some of these are illustrated in Figure 35 and discussed below (CISCO Inc.):

- Bus Network: A bus network benefits from being easy to connect and requires little cable. Problems arise if the main bus backbone is damaged as it will shut the network down and is difficult to troubleshoot if the network is vast.
- Ring Network: A ring network benefits from being predictable in terms of data path and the independent connections make the network simple to troubleshoot. Problems arise as the network grows in size due to communications delays being proportional to the number of nodes in the network and shared bandwidth resources.
- Fully Connected Network: A fully connected network benefits from multiple link redundancy and the ability to keep network traffic at a minimum. Problems arise when the number of network nodes grow due to the amount of cable needed to link all of the nodes and the sheer amount of connections needed (the number of connections grows quadratically with $c = (n(n-1))/2)$.
- Overlay Network: An overlay network benefits in that the network itself can be defined by the user or data preference through virtual or logical links. Problems arise when complicated preferences distribute resources and load balance network traffic by priority making lower priority services unusable.
- Star Network: A star network benefits from centralization of the center hub and increased network performance. The centralization of the hub allows for network inspection of traffic and usually has a high utilization rate allowing for the hub nodes to limit the number of connections to them. Problems arise from the lack of a robust center hub causing slow throughput speeds. The center hub is a single-point of failure.
- Mesh Network: A mesh network benefits from being a flexible network that can grow and shrink over time. Problems arise when these flexible networks are changed without proper network mapping, leaving parts of the mesh network unconnected or overburdened.
- Tree Network: A tree network benefits from being scalable as well as having fairly fast troubleshooting isolation times. Problems arise when maintenance or failure of a main backbone occurs, leaving the network severely degraded until it is repaired.
- Linear Network: A linear network benefits from being simple to set up as well as low cost. Problems arise if any link between two nodes fail or when the size of the network grows do to communication delays from one side of the network to the other.

After the proper POI has been identified, classified as an Independent Platform or a Guest Platform contained within a Host Platform, DSX configuration chosen, and sensor network topology selected, the POI is ready to begin sensor type selection. The PSP SMEs who have a great understanding of the POI system and the capabilities/limitations of PSP resources should carry out sensor selection.

Figure 36 gives different types of materials that are used to build sensors based on their monitoring environment. Sensors should be chosen to meet the environmental constraints and characteristics to ensure quality data collection.

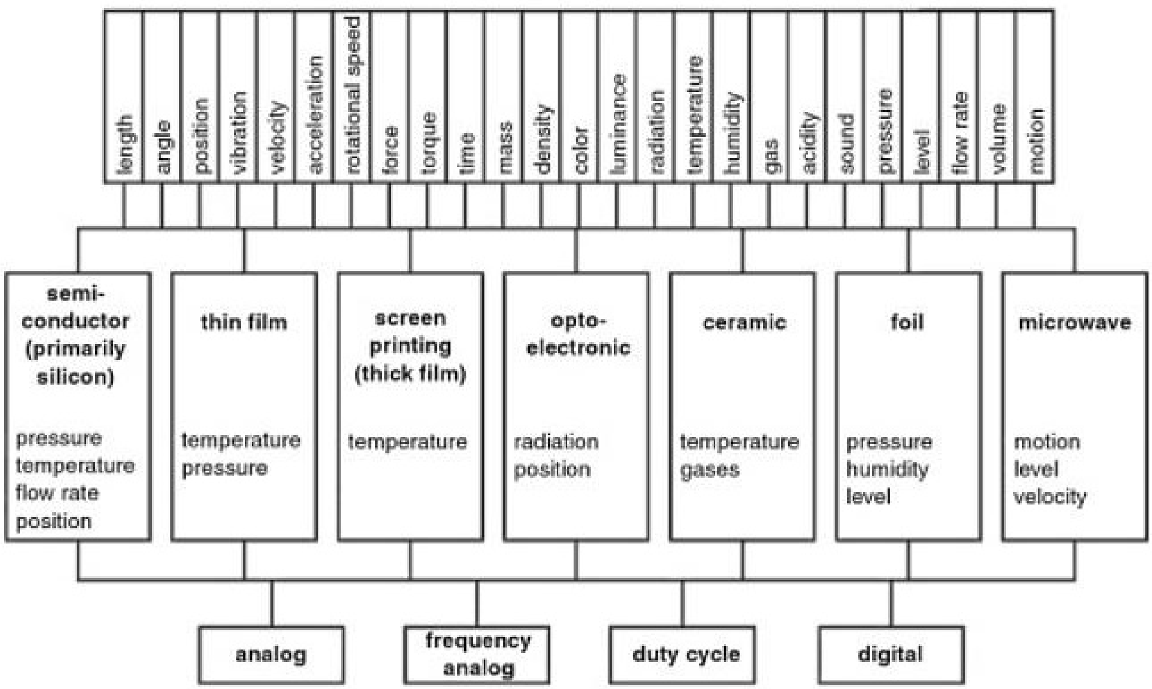

Figure 36. Sensor Materials (Meijer 2008, 6)

Figure 37 shows common parameters that define sensor functionality as sorted by type. The number and type of sensors chosen should be consistent with the DSX configuration, sensor network topology, sensor environment, and meet or exceed the minimum data picture completeness threshold.

1. mechanical parameters of solids
- acceleration
- angle
- area
- diameter
- distance
- elasticity
- expansion
- filling level
- force
- form
- gradient
- hardness
- height
- length
- mass
- mass flow rate
- moment
- movement
- orientation
- pitch
- position
- pressure
- proximity
- revolutions per minute
- rotating velocity
- roughness
- tension
- torque
- torsion
- velocity
- vibration
- way
- weight

2. mechanical parameters of fluids and gases
- density
- flow direction
- flow velocity
- level
- pressure
- rate of flow
- vacuum
- viscosity
- volume

3. thermal parameters
- enthalpy
- entropy
- temperature
- thermal capacity
- thermal conduction
- thermal expansion
- thermal radiation
- thermal radiation temperature

4. optical parameters
- color
- image
- light polarization
- light wave-length
- luminance
- luminous intensity
- reflection
- refractive index

5. acoustic parameters
- sound frequency
- sound intensity
- sound polarization
- sound pressure
- sound velocity
- time of travel

6. nuclear radiation
- ionization degree
- mass absorption
- radiation dose
- radiation energy
- radiation flux
- radiation type

7. magnetic & electrical parameters
- capacity
- charge
- current
- dielectric constant
- electric field
- electric power
- electric resistance
- frequency
- inductivity
- magnetic field
- phase

8. chemical parameters
- cloudiness
- composition
- concentration
- dust concentration
- electrical conductivity
- humidity
- ice
- impurities
- ionization degree
- molar weight
- particle form
- particle size
- percentage of foreign matter
- pH-value
- polymerization degree
- reaction rate
- rendox potential
- thermal conductivity
- water content

9. other significant parameters
- frequency
- pulse duration
- quantity
- time

Figure 37. Sensor Parameters (from Meijer 2008, 7)

Sensor sampling frequency is dependent on the parameter being monitored, its volatility, along with its criticality to function. The monitoring of safety systems will require a higher than average sampling frequency due to the impact of a hazard that may result between sample extractions from a continuous signal. Per the Nyquist-Shannon sampling theorem (Nyquist and Shannon 2012), a sensor should sample a signal at twice its maximum frequency within the bandlimited signal. If a function $x(t)$ contains no frequencies higher than B hertz, it is completely resolved by giving its ordinates at a series of points spaced at $\frac{1}{2B}$.

If monitoring at the Nyquist rate ($2B$) or the Nyquist frequency $\frac{1}{2B}$ is not possible, other signal sampling techniques exists. One such technique is known as compressive sampling or compressive sensing. Compressive sampling theory states that signals can be recovered and potentially acquired with far fewer samples than traditional methods, like that of the Nyquist-Shannon sampling theorem (Candes and Wakin 2008). Compressive sampling relies on two key themes: sparsity and incoherence. Sparsity deals with the fact that a continuous time signal is much less than its bandwidth or a discrete-time signal's number of degrees of freedom is much smaller than its length (Candes and Wakin 2008). Incoherence shows the degree of correlation between the objects having a sparse representation in the domain they are acquired between time and frequency (Candes and Wakin 2008). If a signal meets these two conditions, it may be a candidate for compressive sampling. Compressive sampling has shown to reduce the number of samples needed to be a 4-to-1 ratio, one needs four incoherent samples per unknown nonzero term (Candes and Wakin 2008).

Attention to sensor signal noise needs to be taken into account as well. Common methods to reduce signal noise include the following:

- Reject DC common-mode voltage (National Instruments 2008)
- Reject AC common-mode voltage (National Instruments 2008)
- Break ground loops (National Instruments 2008)
- Use 4–20 mA current loops (National Instruments 2008)
- Use 24 V digital logic (National Instruments 2008)
- Low-pass frequency response filter
- High-pass frequency response filter
- Band-pass frequency response filter
- Band-stop frequency response filter
- Notch frequency response filter
- Comb frequency response filter
- All-pass frequency response filter
- Cutoff frequency response filter
- Roll-off frequency response filter

- Transition frequency response filter
- Ripple frequency response filter
- Butterworth filter
- Chebyshev filter (Type I and II)
- Bessel filter
- Elliptic filter
- Optimum “L” filter
- Gaussian filter
- Hourglass filter
- Raised-cosine filter
- Constant k filter
- M-derived filter
- Infinite impulse response filter
- Finite impulse response filter

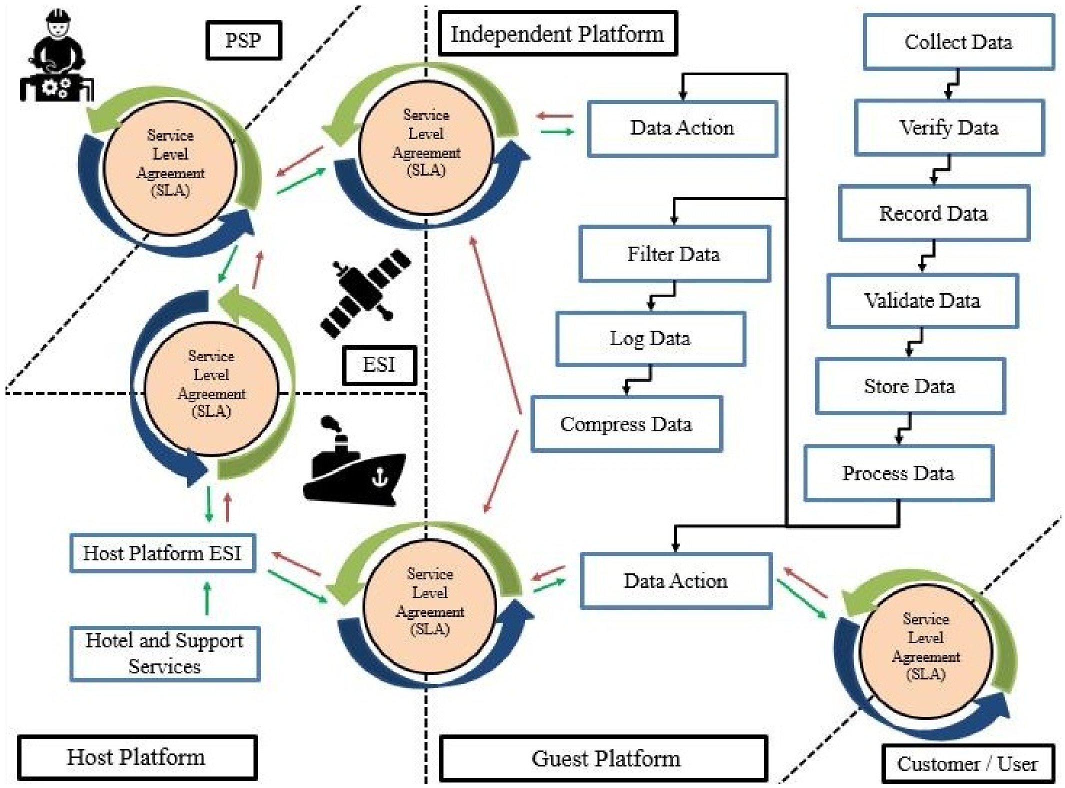

Figure 38. Generic DS Functional Allocation Example (Icons from Flaticon 2014)

The DSX module itself, independent or guest platform, will consist of the same functions. The functions and their definitions, are shown in Figure 38 and listed below.

- Collect—the POI will have the ability to collect the data of interest as decided by the PSP and User by means of self-test, built-in test (BIT), or component sensorization
- Verify—the data collected will be verified to ensure it is being collected correctly
- Record—data is stored in a short term memory to guard against corruption before data validation
- Validate—data is checked for correctness and meaningfulness
- Store— data is then written to long term storage and backed up
- Process—data is analyzed for trends, flags, or other useful information for the PSP and User
- Filter*—the results from the process step are filtered for content relevance and importance

- Log*—data from the filtered step is logged to create a record of communication in which an event has happened or triggered over a set period of time
- Compress*—important data and logs are encoded and reduced in size to be transported to the PSP
- Action—results from the process data step are used to send commands, actions, or triggers to the User/Customer or PSP for execution

In the steps above, the steps with an (*) beside them denote actions required for transportation of data through the ESI to the PSP only. Another important object of note is the SLA with user/customer inset. The user/customer is typically always a part of the support process and is usually the first line of defense. Figure 39 thru Figure 47 detail each function of the DSX modules

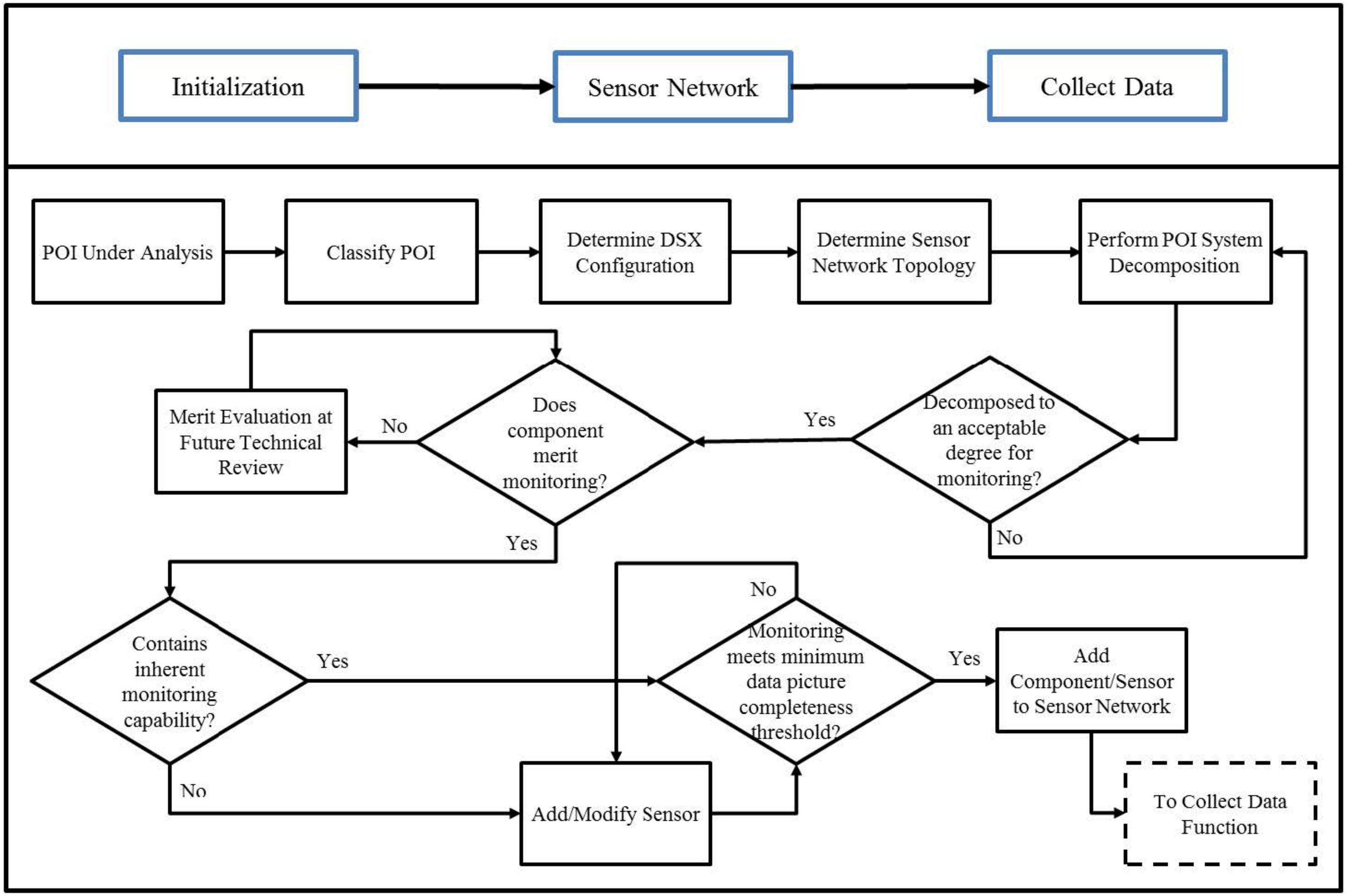

Figure 39. DSX Sensor Network Decision Flow

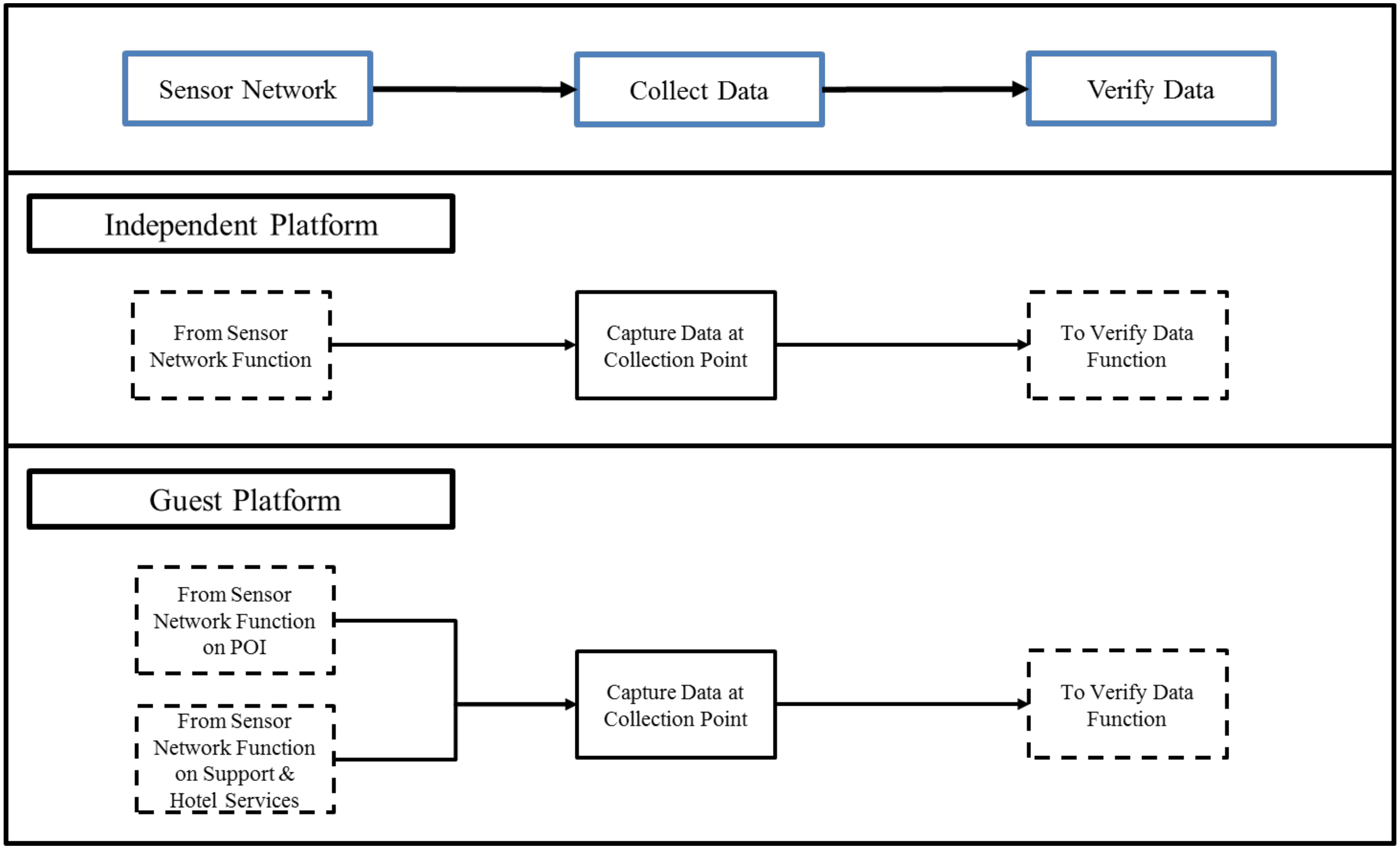

Figure 40. DSX Collect Data Decision Flow

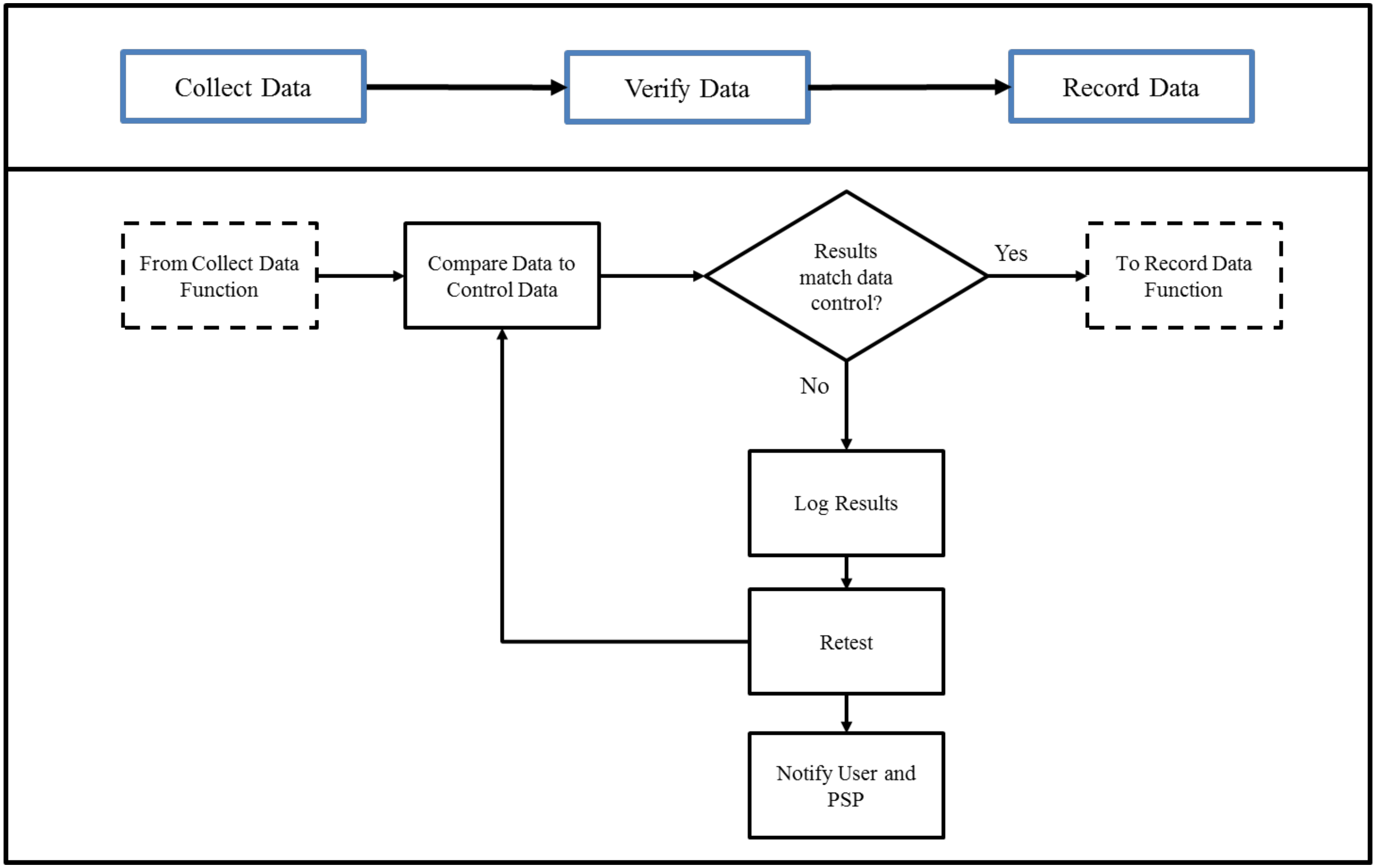

Figure 41. DSX Verify Data Decision Flow

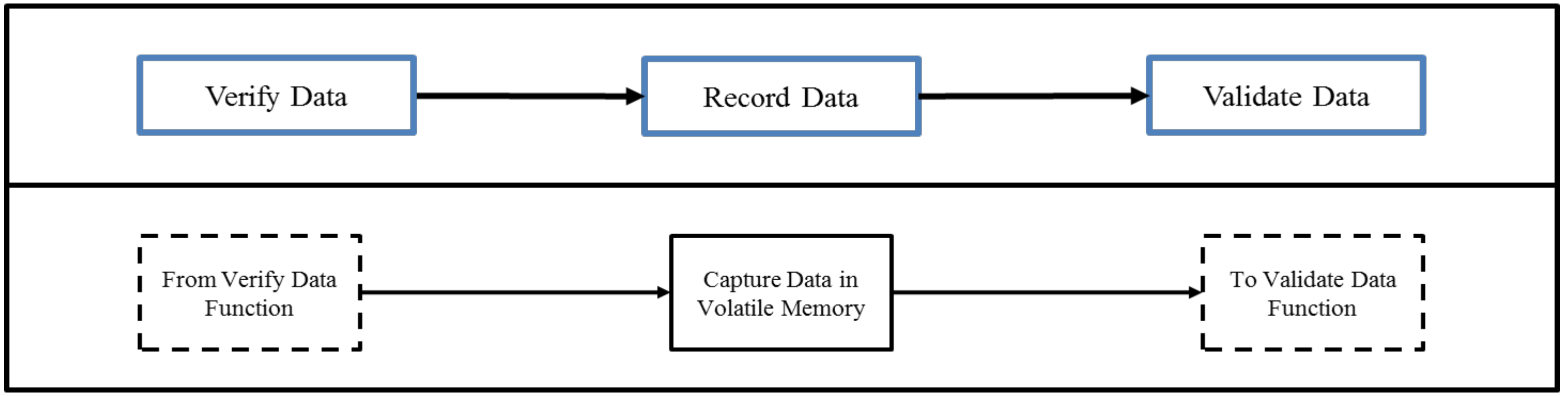

Figure 42. DSX Record Data Decision Flow

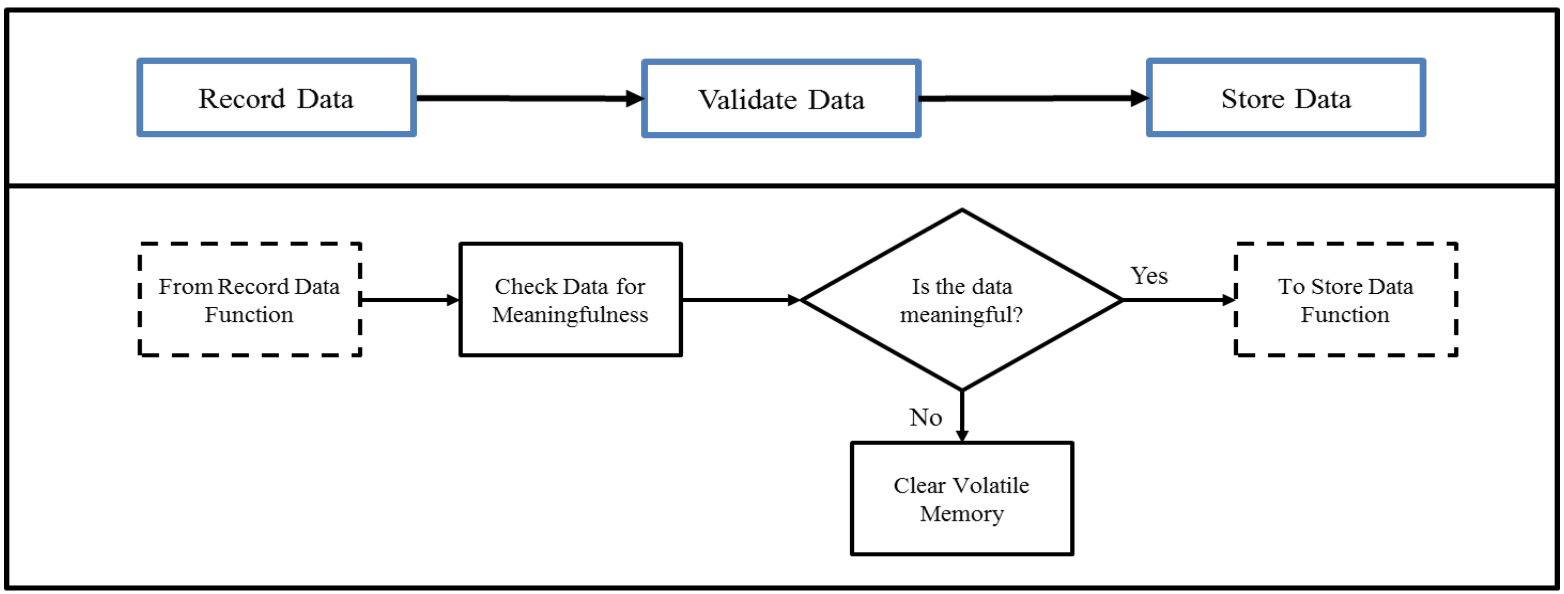

Figure 43. DSX Validate Data Decision Flow

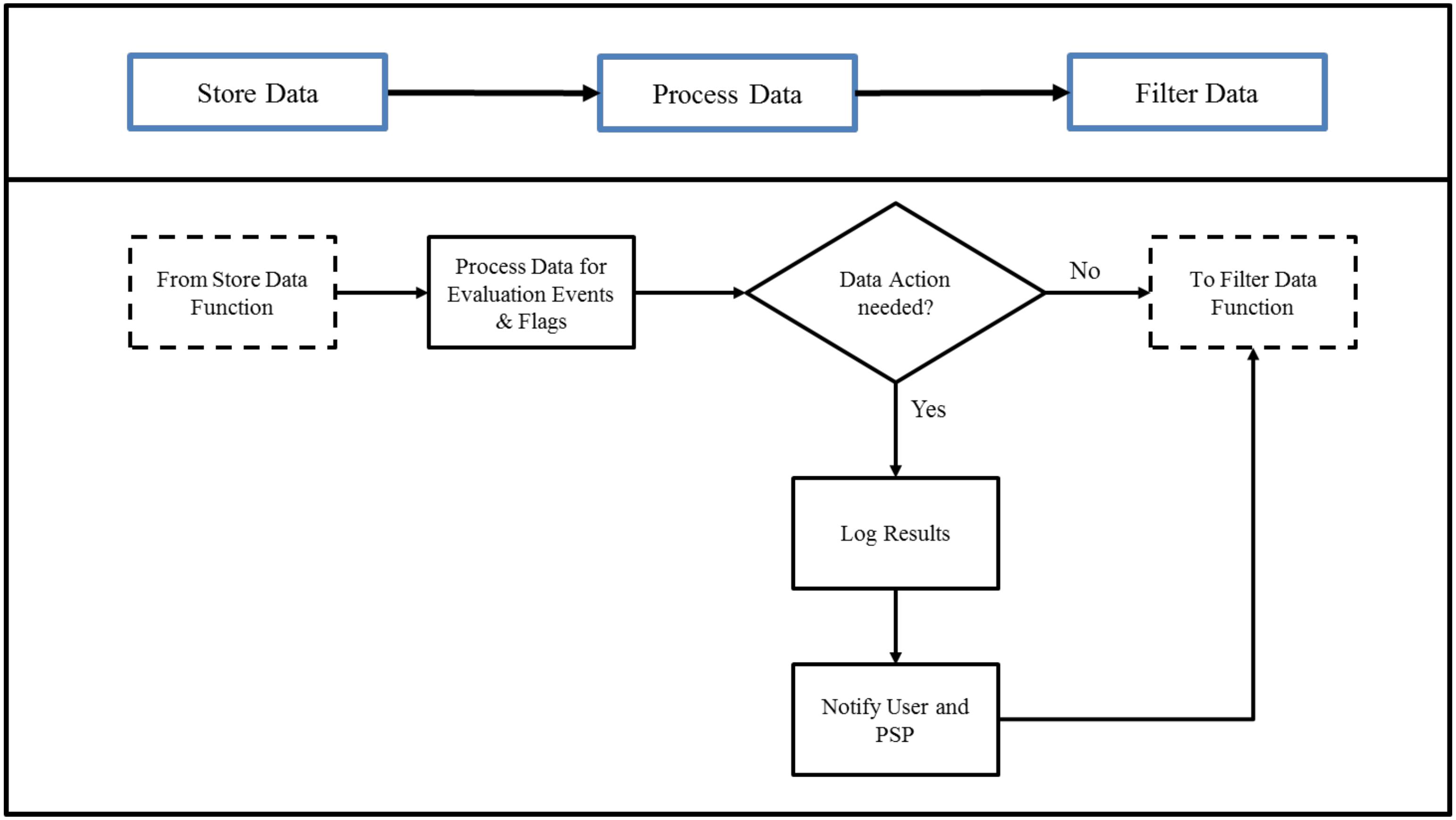

Figure 44. DSX Process Data Decision Flow

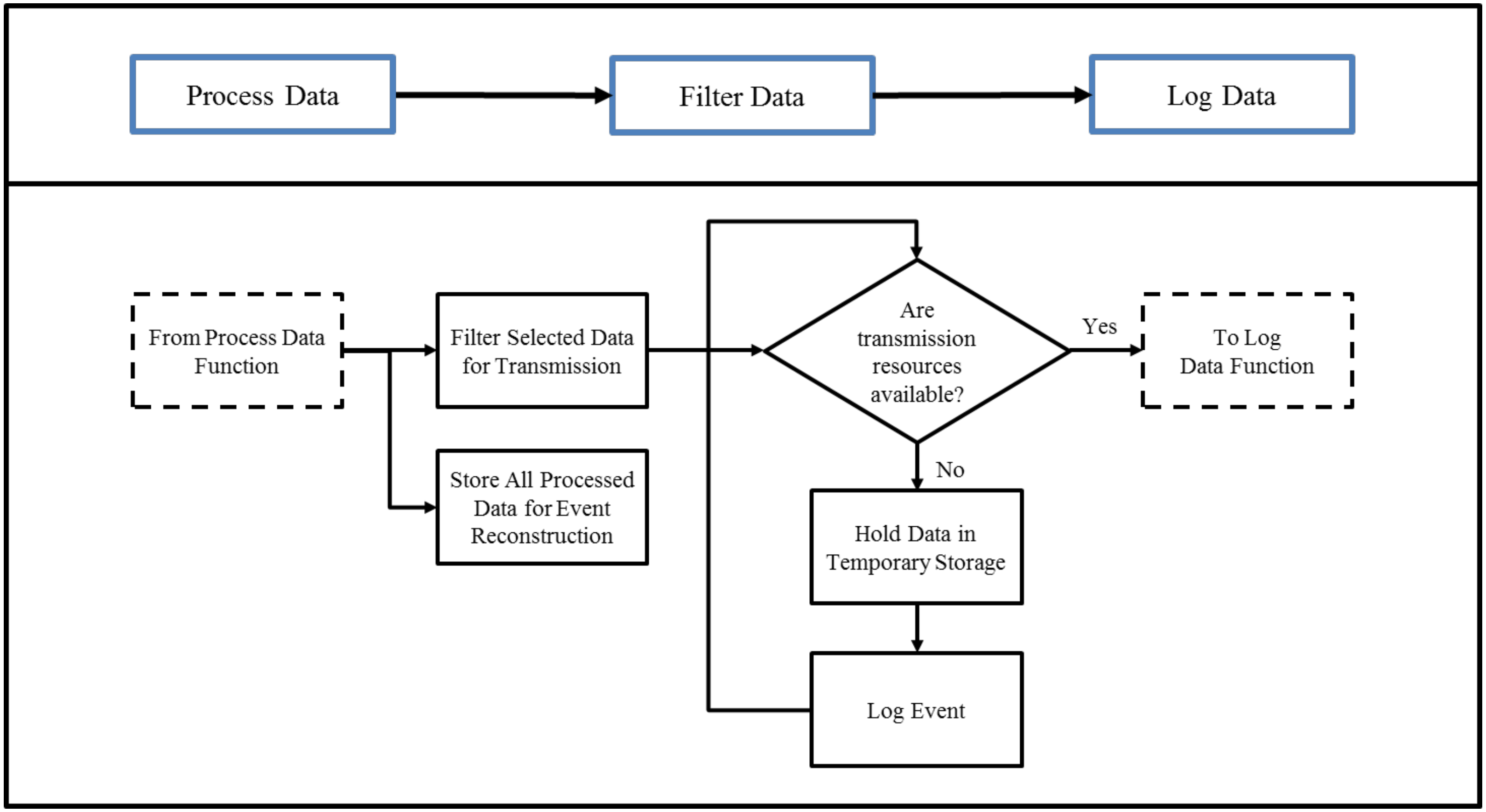

Figure 45. DSX Filter Data Decision Flow

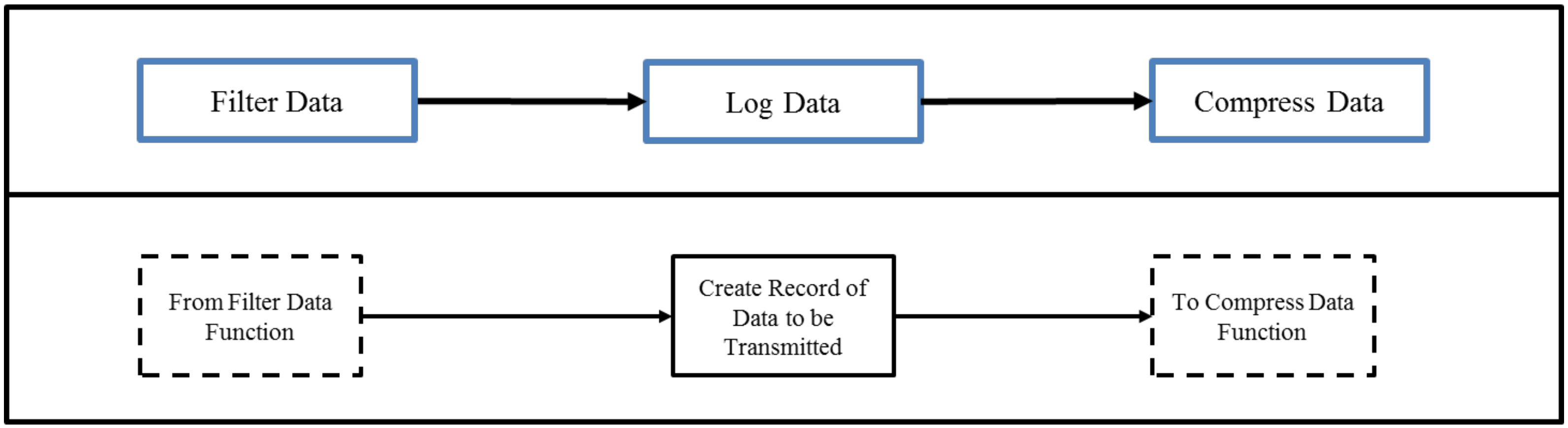

Figure 46. DSX Log Data Decision Flow

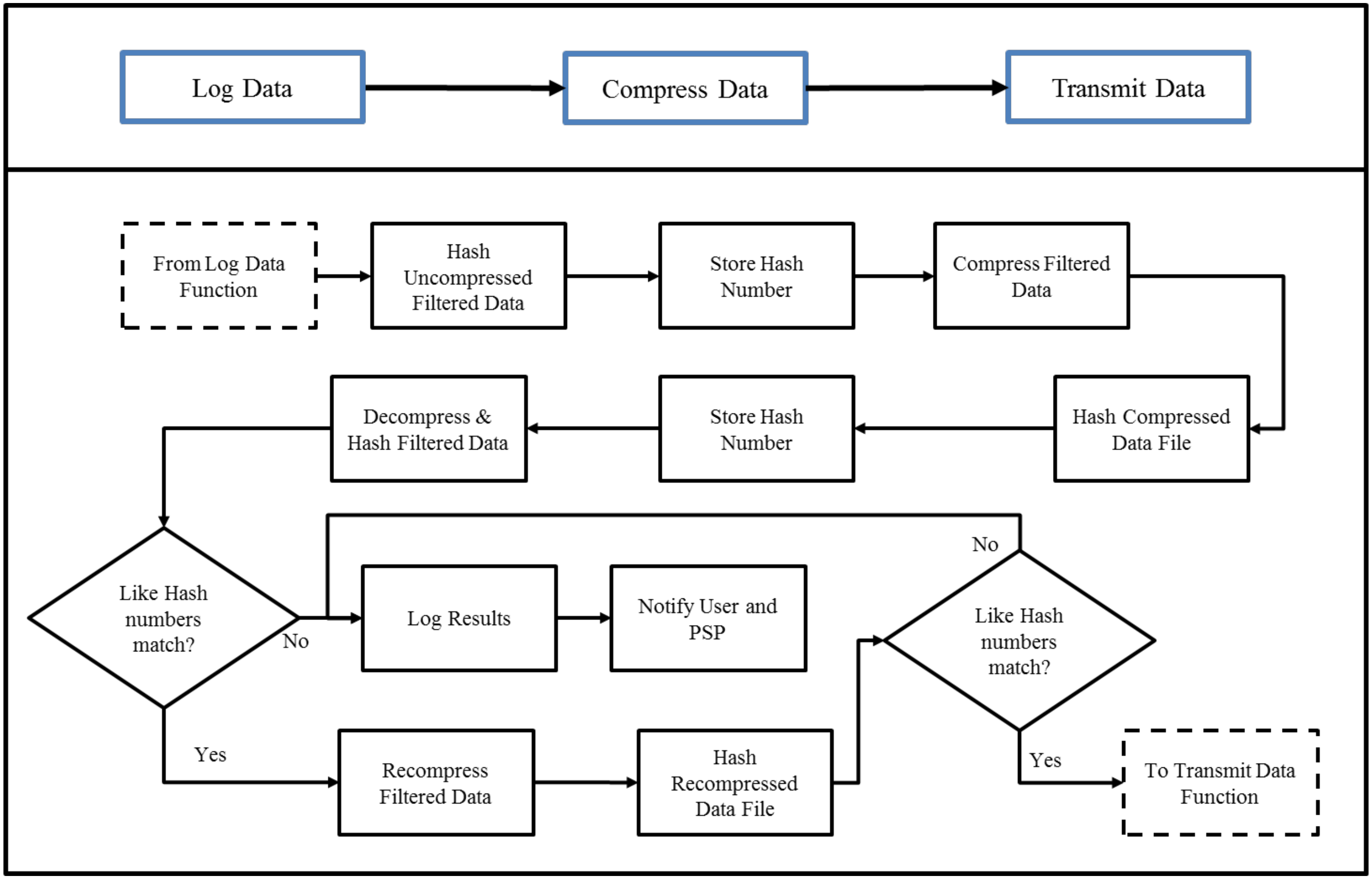

Figure 47. DSX Compress Data Decision Flow

C. STAKEHOLDER ANALYSIS

Stakeholders for this capstone were interviewed and categorized under the three basic elements of DS: PSP, ESI, and POI as indicated in Table 10. While the Naval Postgraduate School (NPS) has an interest in using this capstone to inform instruction and guide follow-on research to enhance the skills of the total workforce, it did not fall into one of the three basic elements of DS and thus was categorized as "administrative."

Table 10. Stakeholder Categories

Stakeholder	Category
Naval Postgraduate School (NPS)	Administrative
PMS 405 - Directed Energy and Electric Weapon Systems Program Office	POI
Office of Naval Research (ONR)	ESI
NSWC PHD - Office of Engineering and Technology (OET)	PSP
NSWC PHD - Distance Support Advocacy Office	PSP
Naval Network Operations Center (NOC)	ESI
Naval Sea Systems Command (NAVSEA)	PSP
Warfighter, USN	PSP

1. Administrative

The only stakeholder that did not fall into one of the three basic DS elements was NPS. NPS was an important stakeholder in guiding the capstone for system engineering and subject matter expertise.

2. Platform Service Provider

The PSPs, along with the POI, were the team's most active stakeholder. Noteworthy, due to the greater number of support organizations classified as a PSP versus the number of organizations classified as POI. This meant that the team was dealing with a complex, multifaceted PSP that was distributed by function, geographic location, funding lines, and responsibility.

The team first met with the NSWC PHD - Distance Support Advocacy Office. The office provided continual project guidance as well as existing DS documentation, studies, and technology roadmaps. NSWC PHD has been developing DS for some time, but is still grappling with issues such as: (1) sensor and data collection mechanisms, (2) ship on-board data storage and processing mechanisms, (3) prognostics health management, (4) ship-to-shore data transfer mechanisms, (5) shore-side data warehousing, (6) mission-based modeling and readiness assessments, and (7) ship system product life-cycle analysis (Naval Surface Warfare Center, Port Hueneme Division, Air Dominance Department 2013).

NSWC PHD began to take an in depth technical implementation of providing DS beyond email, chat, and fly-away teams with the initiation of the AEGIS Wholeness program. The purpose of this program was to assist AEGIS ships in achieving higher readiness and availability metrics (Naval Surface Warfare Center, Port Hueneme Division, Air Dominance Department 2013).

While this program helped to highlight and bring attention to performance issues through in depth analysis, it became apparent that the effort was very labor intensive and burdensome. NSWC PHD - Office of Engineering and Technology began to accept proposals to automate this program and mature the technology needed to provide this capability.

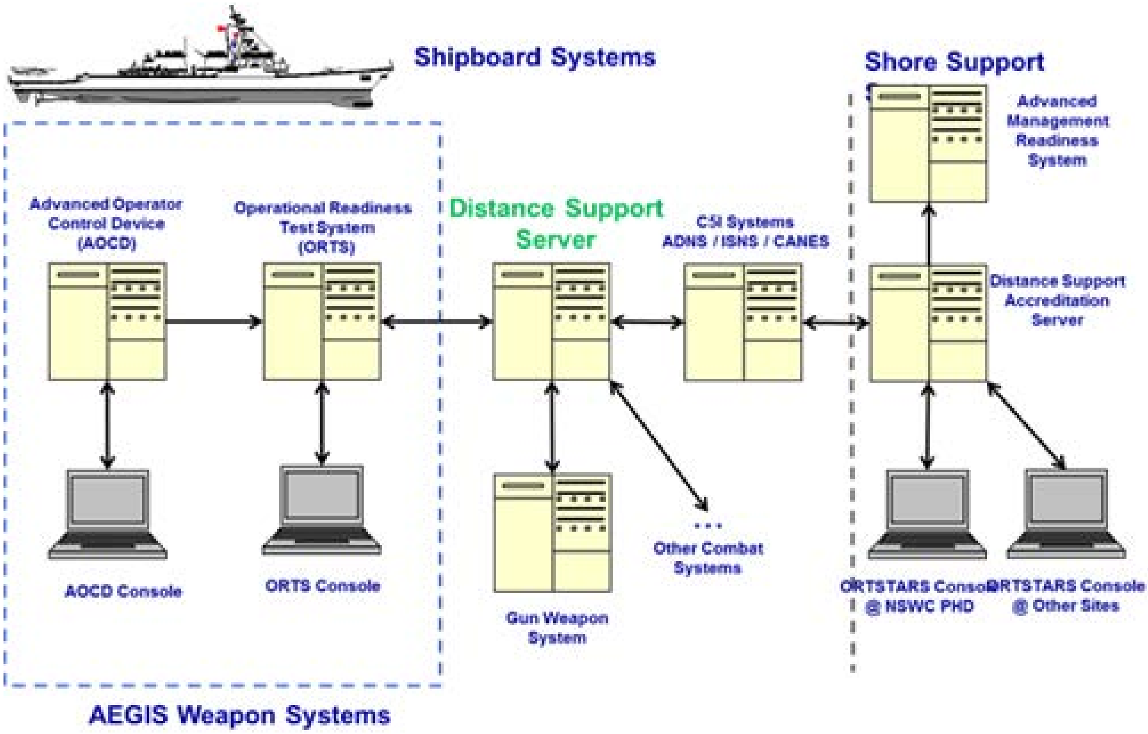

Figure 48. Distance Support Shipboard Server Concept (from Air Dominance Department 2013, 9)

Of the proposals submitted, the DS shipboard server (DS3) concept was a relevant model to emulate with subtle changes. The DS3 concept, as shown in Figure 48, is of interest due to its unique characteristic of being located outside of the AEGIS Weapon Systems (AWS) certification boundary (dotted square on the left-hand side of the figure). Part of the issue NSWC PHD has with trying to monitor or sensorize the AWS is that any modification to the AWS requires a complete combat system re-certification. This re-certification is very time consuming and costly. With the DS3 being located outside the AWS boundary, no re-certification is needed as the system has a separate accreditation boundary around itself. This is also particularly useful in that the DS3 can execute programs that are not certified for the combat system, as well as keep them updated with patches as needed.

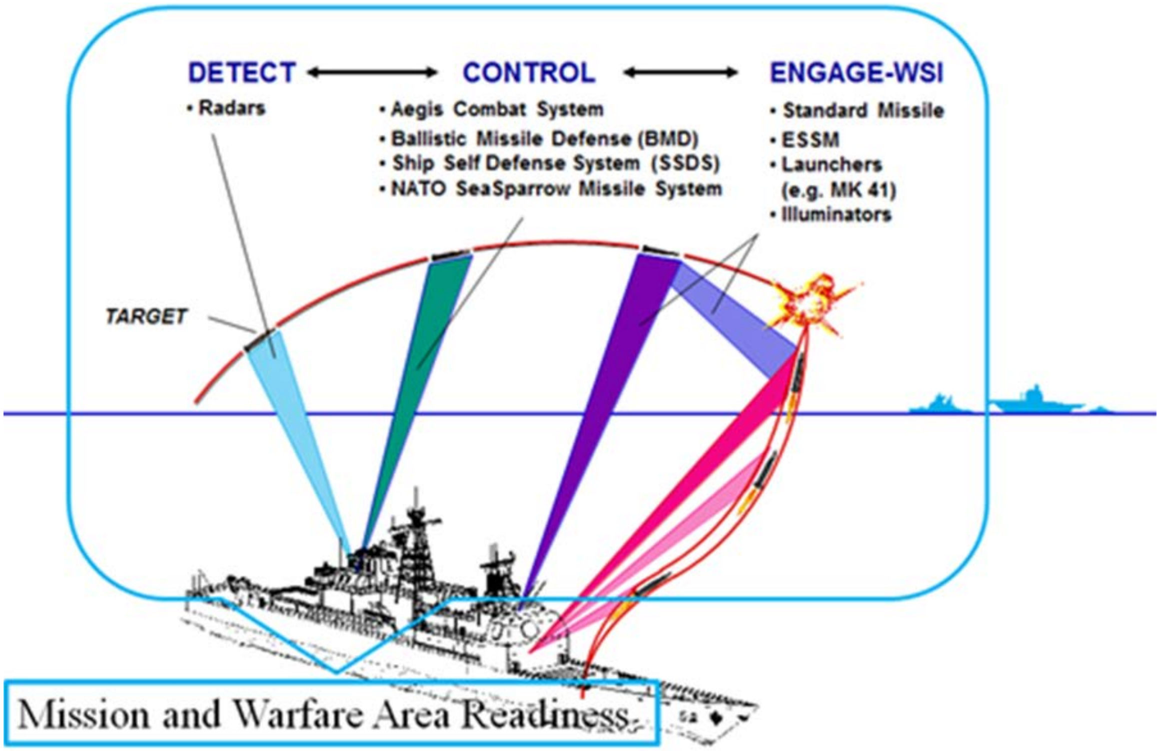

Figure 49. Future Vision of Readiness (from Air Dominance Department 2013, 11)

NSWC PHD has future visions of being able to monitor the entire ship and transform the ship into an expert system. Figure 49 gives the next stage of monitoring in terms of the detect-to-engage chain to create readiness models based on mission capability. This will tie real-time system information into decision making for warfare area resource assignments.

In reviewing the stakeholder needs, the team determined that the PSPs did not need a shore infrastructure or a DS center but rather a framework and designed-in DS module as part of future systems to help better facilitate DS from the PSPs. Figure 50 was also analyzed to ensure all NSWC PHD core values were touched upon in designing a DS solution.

Figure 50. NSWC PHD Next Generation Readiness (from Naval Surface Warfare Center, Port Hueneme Division 2003)

3. Enabling/Supporting Infrastructure

The stakeholders that were categorized as ESI were mainly passive, information sources for the team. This was due to the nature of relationship and business contract management through the use of SLAs. One particular stakeholder was kept on the team's watchlist for technical risk. This was the Office of Naval Research (ONR). ONR in conjunction with Space and Naval Warfare System Command (SPAWAR) are in the process of developing a capability known as Naval Tactical Cloud (NTC). NTC's purpose, as depicted in Figure 51, is to improve warfighting effectiveness while operating inside adversary kill chains. This was an important development to watch closely as the requirements set forth by the NTC could have had an impact on the amount, type, or even classification of data being transmitted.

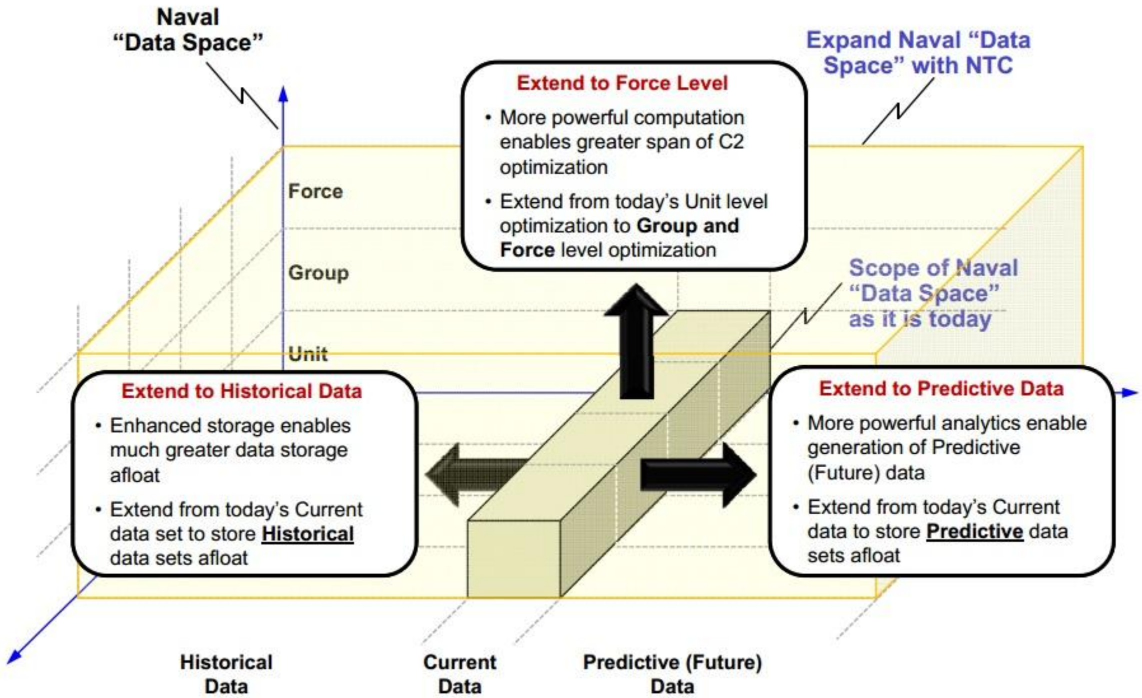

Figure 51. Naval "Data Space" (from Office of Naval Research 2014, 9)

The last technical risk the team had to watch ONR for was the potential for all data to change from existing classification domains, as shown in Figure 52, to a single classified domain. This was unlikely to happen in the near future, but it did provide a thought provoking design consideration when analyzing the POI and what to monitor and how the data should be treated.

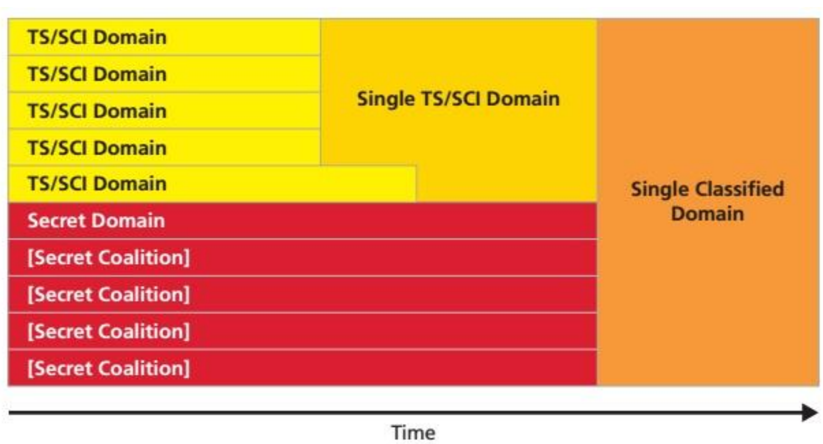

Figure 52. Future Security Domains (from Porsche, et al. 2014, 21)

4. Platform of Interest

The POI for this capstone was selected to be the HEL. The team met with stakeholders from PMS 405 - Directed Energy and Electric Weapon Systems Program Office to gather information about the HEL and issues concerning support. These issues ranged from frequent component failure to environmental degradation. The team first took on the approach of analyzing the HEL currently being installed on the USS PONCE (Office of Naval Research 2014), but was later guided by NPS advisors to take a more general HEL analysis so that the conclusions would not be centered on one particular make and model. The information about the make-up of the HEL was provided by NPS, while the information about the host platform was provided by NSWC PHD. The host platform for this capstone was chosen to be the AEGIS and LCS class ships. Information about the host platforms was limited to the "hotel services" provided and the internal network connectivity of the platform.

D. CONCEPT OF OPERATIONS

This CONOPS describes the POI capabilities required to allow the PSP to accomplish DS as determined by the appropriate SLAs and OLAs. In addition, this CONOPS will explore how the PSP will support the POI to provide the best level of service.

- Operating Concept: The DSHEL will operate within AEGIS and LCS class ships while maintaining connection to the complex net-centric architecture of the USN. The overall POI is the HEL. The HEL is a guest platform being supported on the host platforms AEGIS and LCS class ships. Important data is collected and analyzed from the HEL via the DSHEL module and then routed through ships network off board to the NOC. From the NOC, the data will be routed to Navy 311 and then down the USN's multi-tiered technical support infrastructure to the proper PSP.
- Operating Schedule: The DSHEL will be able to operate continuously as needed 24 hours a day, 7 days a week. This operating schedule can be autonomous or manually controlled. DSHEL will have the ability to suspend diagnostics or other resource impacting functions while maintaining HEL passive sensor recording. The amount of data transmitted from DSHEL to the NOC will be consistent with the internal data storage. This function can also be suspended in times of link traffic prioritization.

- Mission Support Description: The overall mission support of the DSHEL will be the responsibility of the HEL or the ISEA to which it is assigned. As the HEL is owned by PMS 405, the responsibility will fall to them to fund the proper ISEA who maintains ownership of the combat system (NSWC PHD). The ESI will be maintained by SPAWAR who will provide the proper SLA.
- Personnel: All individuals conducting support will need knowledge of the DSHEL. The DSHEL will not be serviced or maintained by ship's crew. The ISEA will maintain the DSHEL as it will be an extension of the HEL.
- Training: DSHEL training will be accomplished through individual On the Job Training (OJT) with special attention given to sensorization, network administration, and HEL characteristics. Shore support personnel will receive sustainment training and data analysis training that is focused programming, scripting, and modeling and simulation.
- Equipment: The DSHEL equipment will be designed and built to meet common open architecture standards and to minimize life-cycle costs. The equipment will use the same baseline system equipment that other programs of record currently procure to keep logistical footprints small. The equipment will have maintenance cards detailing all information necessary to provide support.
- Support: Preventative maintenance and non-major repairs will typically be conducted during scheduled maintenance windows in-port or underway. Critical repairs will be conducted with the help of the Integrated Logistics Support (ILS) team. Preventive maintenance will be limited to the sensors and other functions of DSHEL that accrue wear. The hardware and processing functions of DSHEL will follow the standard ship class hardware life-cycle replacement.
- Supply: Onboard sparing will be limited to components that have required preventative maintenance. DSHEL hardware and processing spares will be kept shore side at the appropriate PSP provider for storage. One DSHEL unit will be installed for use at the land based test site for directed energy.
- Infrastructure: Infrastructure cost will not include the PSP or the ESI. Infrastructure costs for the DSHEL will be limited to the hardware, software, processing, and data collection devices used. Hotel services from the host platform will be required to operate DSHEL.
- Information: Information concerning the DSHEL will be documented electronically and stored within the requirements of NSDSA. Information generated and transmitted by DSHEL will undergo analysis and archived for long-term storage. This data will be used for trending as well as for future support endeavors like expert system creation and prognostics.
- Operating Environment: The DSHEL will operate in the standard computing enclosure as dictated by the host platform ship class. This environment should

mirror that of an enclosed server rack with proper temperature, power, shock and vibration management. The data collection devices on DSHEL will vary greatly depending on the POI and the stage at which DSHEL is installed. For future systems, data collection devices will be integrated and selected by the design team with PSP input.

- Missions: DSHEL is a key element in supporting the HEL by maintaining a picture of the HEL's health. The DSHEL will meet this challenge through the employment of multiple data collection devices at key interfaces, critical components, and signals of interest. DSHEL will verify and validate that all data collected is correct and meaningful. DSHEL will store and process data for action, event reconstruction, transit, trending, and other future developments.
- Interoperability with Other Elements: DSHEL will operate with all host platform "hotel services" such as power, water, heating, ventilation, air conditioning (HVAC), and network connectivity. The ESI and the POI will agree upon specified levels of service through the use of SLAs. Proper OLAs will be authored within the PSP to ensure support for the HEL via DSHEL is complete. If DSHEL is installed on a legacy guest platform, DSHEL will report relevant data actions to the user as specified with the user through a SLA.
- Users and Other Stakeholders: The core users of DSHEL will be the PSP. Other users within the main PSP will be secondary users as established by various OLAs. If DSHEL is installed on a legacy guest platform, DSHEL will report relevant data actions to the user as specified with the user through a SLA.
- Potential Impacts: DSHEL has the potential to impact network traffic depending on the degree of data collection and visibility required by the PSP. Careful attention to data processing, filtering, and compression will be given to ensure that this does not become an issue. Other workarounds include large on-board data storage and dynamic information throttling when network resources are taxed.

E. DESIGN REFERENCE MISSION

The design reference mission that was developed for the DSHEL system is depicted with the OV-1 diagram for DSHEL.

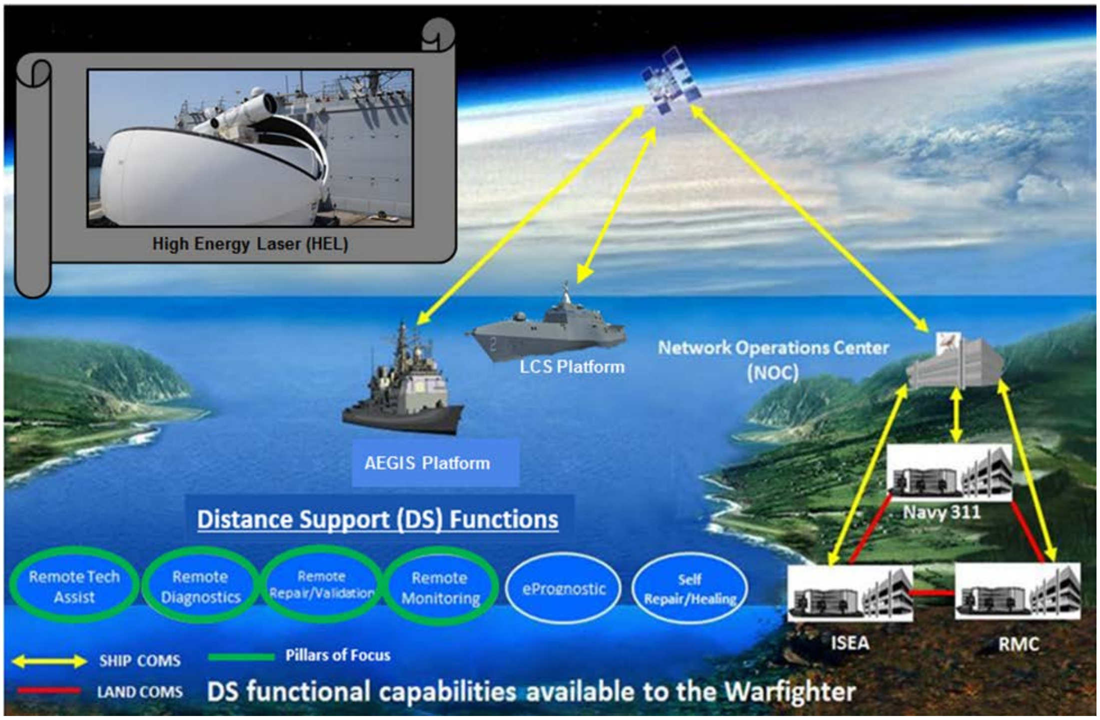

Figure 53. DSHEL OV-1 Diagram

Figure 53 shows the types of DS methods that the DSHEL system will support. Additionally, it shows the platforms the DSHEL system will be implemented on, as well as the shore-based facilities where the information will be used by Fleet support personnel.

The DSHEL system will not be operated or maintained by the sailor in any way. Information shall be collected in a passive and active manner by the shore-based support sites (ISEA, RMC, and Navy 311) and used to provide support for the HEL weapons system. The information will be disseminated in accordance with the Joint Fleet Forces Maintenance Manual (JFFM). Specifically, when the ship has an issue with the HEL system, the sailors will submit a ticket with Navy 311. The ticket will then be routed to the Regional Maintenance Center (RMC) for assistance. The RMC will have the ability to gather diagnostic information from DSHEL to provide direction on parts that may have failed or further troubleshooting that may need to take place. If the RMC is unable to resolve the ticket within 90 days of submission (Navy 2013), the ticket will be forwarded to the ISEA for resolution. The ISEA will have privileged capability with the DSHEL system, allowing remote connectivity to the system. Privileged capabilities refer to an extended and enhanced set of functions for the ISEA which aren't typically available to the RMC support staff. When parts fail, the DSHEL system will immediately report the information back to shore in advance of any ticket being generated by the crew. This will allow the shore support infrastructure to take a more proactive role in the support of the HEL system.

F. SUMMARY

From the stakeholder analysis and literature review, it was determined that the focus of the capstone should be on the creation of a DS framework and its application to the HEL. The DS framework in this chapter was kept high level and generic due to the overall concept of the framework being flexible and modular enough to fit within the rigid organizational structure of the USN. Chapter III shows how the DS framework was applied to the USN's current organizational structure as well as the POI, HEL. The analysis of the HEL was also kept at a high level to ensure that it would be applicable to future HELs.

III. REQUIREMENTS ANALYSIS

In this chapter, the DS framework is applied to the USN's organizational structure and to the POI, the HEL. From this application and subsequent breakdown, requirement areas were identified and noted as operational, functional, and performance. While the team cannot generate requirements that a platform service provider (PSP), enabling/supporting infrastructure (ESI), and platform of interest (POI) must adhere to, these specific areas should be scrutinized for requirements as they have a great effect on DS.

A. PRIME DIRECTIVE

Any system that is composed of multiple parts will have parts that wear out, or require special conditions to work properly. There are no perpetual motion machines or perfect systems which never degrade. As a result, it is necessary to be able to support these systems by a combination of anticipating and addressing their needs. This multifaceted type of maintenance is called DS. DS allows for information about a system to be analyzed and issues corrected without having engineers or technicians on-site with the system. DS has three main phases. First would be obtaining the necessary information, second the analysis of this information, and finally reacting to the analysis. DS incorporates all three of these phases in order to monitor and address issues within a system without being physically present on the examined system. DSHEL's goal is to provide secure, remote maintenance and support services to the HEL system when fielded by the USN.

B. SYSTEM DEFINITION

In this section, each element of the DS framework in reference to the DSHEL Application Context Diagram (Figure 54) was assigned to the proper USN organization and the subsequent POI. This capstone's focus was the POI and thus, the PSP, ESI, and the agreements between them (SLAs and OLAs) were not detailed.

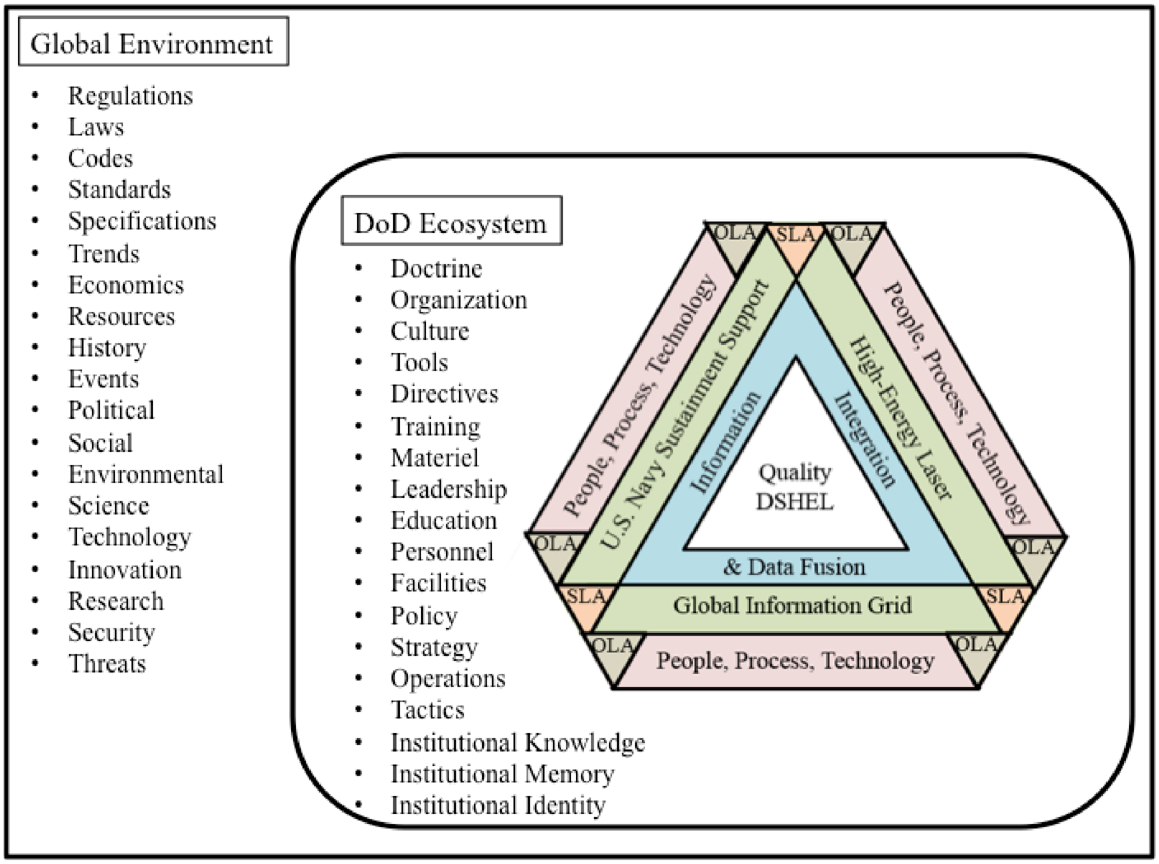

Figure 54. DSHEL Application Context Diagram

1. Platform Service Provider

The PSP for the USN is highly dependent on the POI. Different support organizations are in charge of different platforms based on platform capability and type of support needed. This section will focus on the USN support organizations that provide expertise to combat system elements and weapons installed on AEGIS and LCS surface combatants.

Figure 55 illustrates the typical flow of information from the POI to the PSP within the USN. In this setup, any ESI involvement is not visible to the parties and appears to be seamless. When an issue arises from a system (POI) on the ship, the sailor takes action to remedy the issue. Due to this action, the sailor is often considered a Tier 1 technical support member. This means the sailor has not only an OLA with the ship but also an SLA with the POI. SLAs and OLAs on board a ship are different. A SLA is an action the sailor completes to keep the POI operational (execution of a maintenance requirement card (MRC)). An OLA on board a ship for a sailor may be an action, such as performing assigned duties or operating system equipment. The SLA dividing the sailor from the Help Desk represents the SLA between the POI and PSP. The POI is owned by an organization different from the organization providing the support services. Many SLAs and OLAs are not shown within the graphic in order to simplify the process.

If a sailor, also considered Tier 1 technical support, cannot remedy the issue on the POI, he contacts the USN Help Desk, also known as Navy 311. Different programs and platform have distinct ways in which they contact shore support. For AEGIS systems, the sailor contacts Navy 311 directly to initiate support. For LCS systems, the sailor uses a system called maintenance figure of merit (MFOM) automated work notification (AWN) to initiate support and then contacts Navy 311 to file a service ticket for record keeping purposes. Once these systems have been contacted and the support request initiated, they begin their travel through the multi-tiered technical support group as defined by the Joint Fleet Maintenance Manual (JFFM) and private industry support organizations managed with OLAs and SLAs. Tier 2 technical support is managed by the regional maintenance centers (RMC). They are a dock-side organization that can handle most technical issues not involving combat system specific hardware and software. RMCs also provide standardized maintenance and modernizations to ship systems. These include the Southwest RMC, Southeast RMC, Puget Sound Naval Shipyard and Intermediate Maintenance Facility, Norfolk Ship Support Activity, U.S. Naval Ship Repair Facility and Japan RMC, Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility, as well as the Commander, USN RMC.

If the RMC is unable to resolve the issue, it is routed to the appropriate Tier 3 in-service engineering agent (ISEA). The ISEA is responsible for support on systems installed on the ship. Their functions include installation, certification, training and qualification of system users, logistical support, and test and evaluation. Most issues are solved at this level of technical support.

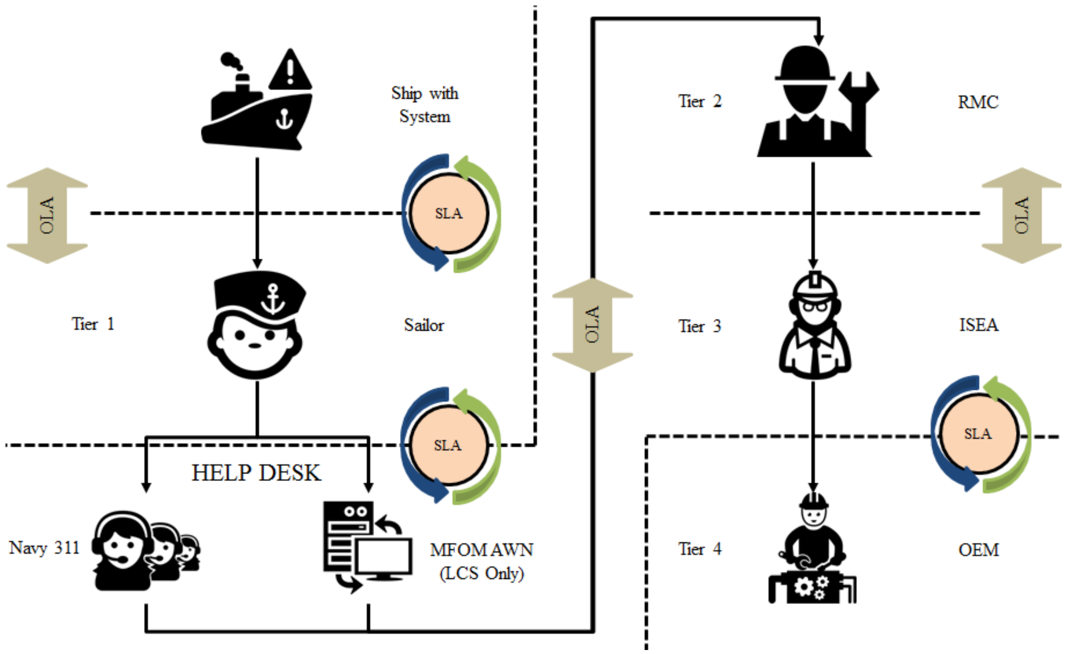

Figure 55. USN Platform Service Provider Flow (Icons from Flaticon 2014)

The last and final support tier, Tier 4, is the original equipment manufacturer (OEM). The OEM will vary from system to system based on the particular design agent. This level of technical support is reserved for issues that are the most complex and typically require design changes/solutions to the hardware or software.

2. Enabling/Supporting Infrastructure

The ESI for the USN in terms of tactical communication is an organization named Space and Naval Warfare Systems Command (SPAWAR). SPAWAR is the technical authority and acquisition command for Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) systems. They also develop, deliver, and sustain communication and information capabilities for the Fleet. Figure 56 shows how SPAWAR interacts as the ESI.

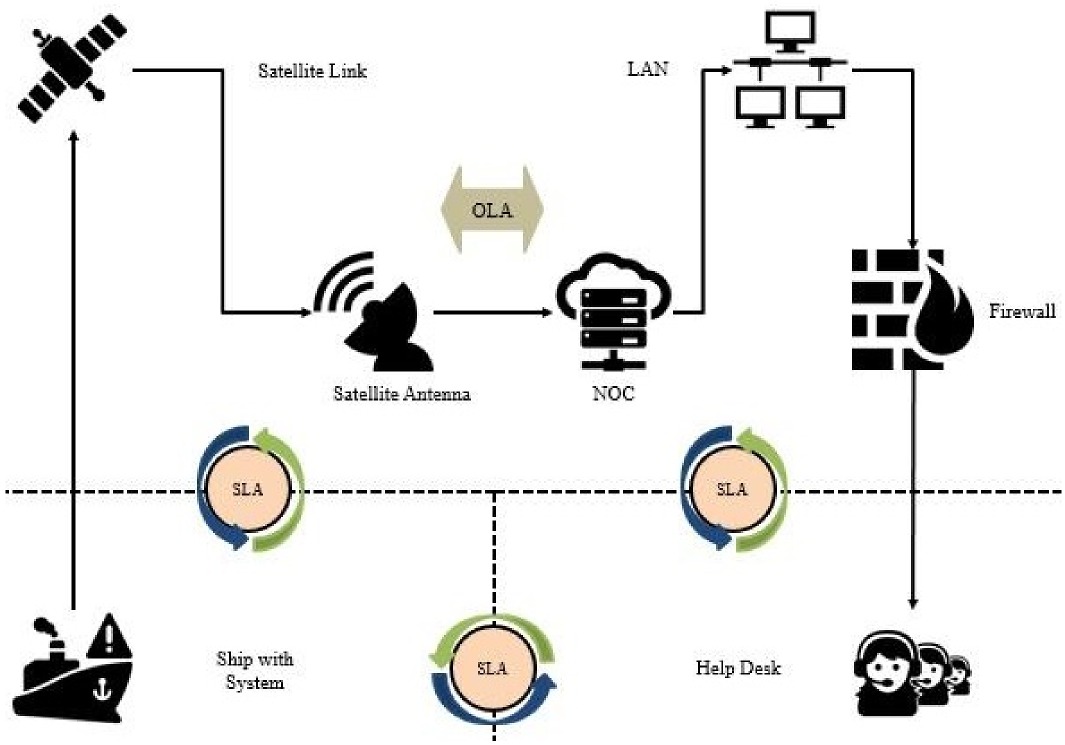

Figure 56. USN Enabling/Supporting Infrastructure Flow (Icons from Flaticon 2014)

All communications between the ship and the shore must go through SPAWAR. When the sailor contacts the PSP for support, a communication circuit must be established with a satellite link using the SHF band. AEGIS and LCS ships both use this link structure. The inbound communication link from the ship is received by a satellite antenna shore center which routes the information to the nearest NOC. Due to the USN's global presence, NOCs are established all over the world. From the NOC, the support request is routed through SPAWAR's WAN/LAN to the appropriate network boundary firewall to be forwarded to the shore support installation.

3. Platform of Interest

With the installation of the solid state laser - quick reaction capability (SSL-QRC) AN/SEQ-3 (XN-1) Laser Weapon Systems (LaWS) on the USS PONCE, it is apparent that the POI is a guest platform contained within a host platform. This capstone used a more generic approach in analyzing the HEL; the host platform analysis was done from the standpoint of AEGIS and LCS surface combatants. Due to weapon systems being installed on ships, this inherently makes those weapons systems categorically guest platforms contained within host platforms.

a. Host Platform

The host platform plays an import role in providing for the POI. As illustrated in Figure 57, for HEL, the host platform would be in charge of:

- Hotel services
  - Ship form factor space
    - Above deck—Provide location and space for the HEL and its required infrastructure such as an enclosure.
    - Below deck—Provide location and space for the HEL system sub-components. The HEL system sub-components will most likely be distributed throughout the ship to meet survivability requirements.
  - Conditioned power—Provide stable and clean power from the ship at the proper utility frequency and phase.
  - Chilled water—Provide cooled water from the ship's plant. This water can be chilled seawater, fresh water, or deionized water and has variable flow rates.
  - Electronic dry air—Provide air conditioning for specific humidity levels to cool electronic devices without harm.
- Support services
  - HM&E support—Provide technician level support for all components of the HEL system that fall into mechanic level maintenance such as hydraulic lines, pumps, voids, and tanks.
  - Tier 1 technical support—Provide sailor support in the form of Planned Maintenance Systems (PMS) and execution of MRCs.
  - Meteorological and oceanographic (METOC) data—Provide information describing, characterizing, and detailing the current environment external to the ship.
- Command and control systems
  - Detect to engage (DTE) kill chain command—Provide kill chain actions and events that take place when an engagement is deemed necessary. The DTE kill chain is made up of the following steps:
    - Detect—Responsible for the planning, detection, entry, tracking, and identification of targets.

- Control—Responsible for the threat evaluation and weapons pairing step for the combat system including fine/rough course track, gimbal pointing, and sensor detection.
- Engage—Responsible for the engagement and engagement evaluation of the target.

- Network communications—Provide network backbone within the ship that allows all communication between system, operators, and command centers
- Display systems—Provide control and maintenance displays of the HEL will be located throughout the ship.
- Operator control console—Provide physical HEL weapon console will be located with the ships combat information center (CIC). This console can be unique to the particular system or can be a service that any console can operate as in the defined sub mode.

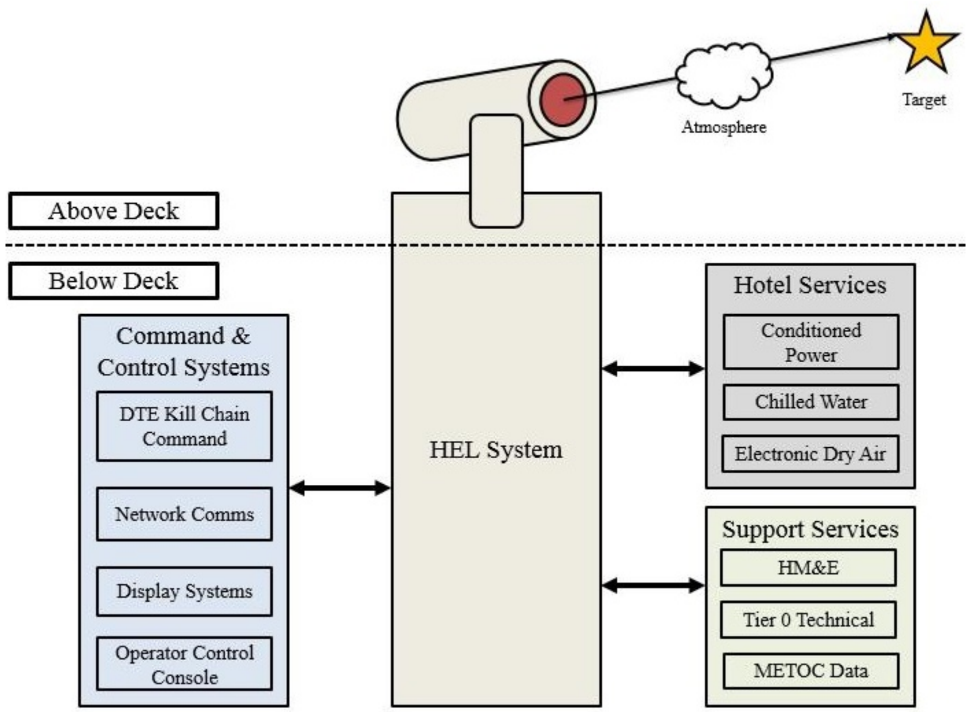

Figure 57. Host Platform and Guest Platform Interaction

The host platform will be analyzed in a later section for important data needed to construct the minimum data picture threshold in order to perform DS on the HEL.

b. Guest Platform

The guest platform and POI is the HEL. An in depth analysis of the SSL-QRC AN/SEQ-3 (XN-1) LaWS on the USS PONCE would be limited to the program itself, thus the HEL under analysis will be a generic version (SSL and FEL) so that the results from this capstone can be applied to future HEL designs.

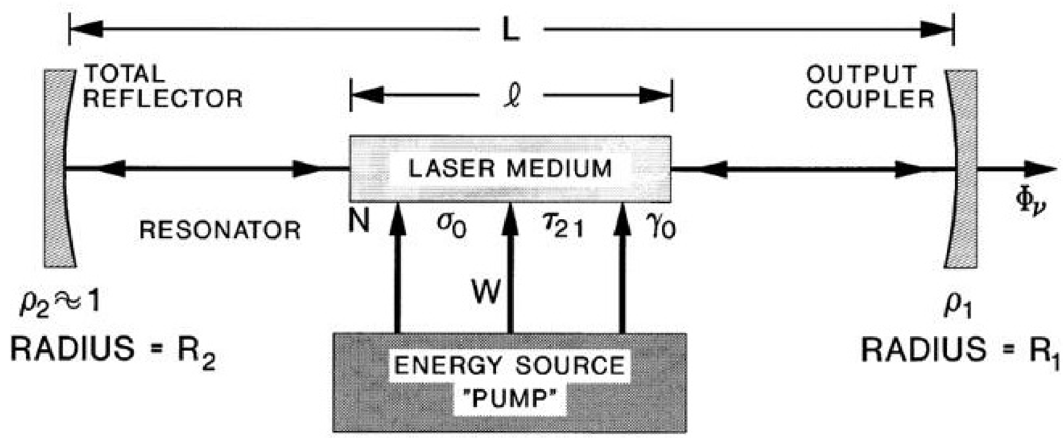

Figure 58. Basic Laser Cross Section (from Harney 2013, 85)

Figure 58 shows a simple schematic diagram of a simple laser model. The basics of laser operation involve the following components: an energy source (also known as a "pump"), laser medium (also known as a gain medium), and two reflectors (also known as the laser cavity/optical resonator). There are many types of lasers available, these include: gas lasers, chemical lasers, dye lasers, metal-vapor lasers, solid-state lasers, semiconductor lasers, free electron lasers, gas dynamic lasers, Samarium lasers, Raman lasers, and nuclear pumped lasers.

The team determined that of the lasers available, the solid state and free electron lasers would be analyzed as they proved to be the most viable options for installation and fielding due to current USN requirements. The basic elements for all lasers and similar with the exceptions coming from laser excitation mechanism (pumping) used to generate population inversion inside the laser medium and the laser medium itself.

Most SSL implement three common forms of optical pumping to achieve a population inversion. These three common optical pumping methods are known as flashlamps, diode lasers, and other lasers (Harney 2012). Figure 59 gives some possible advantages and disadvantages in SSL pumping mechanisms and shows the geometries used in pumping the laser rod.

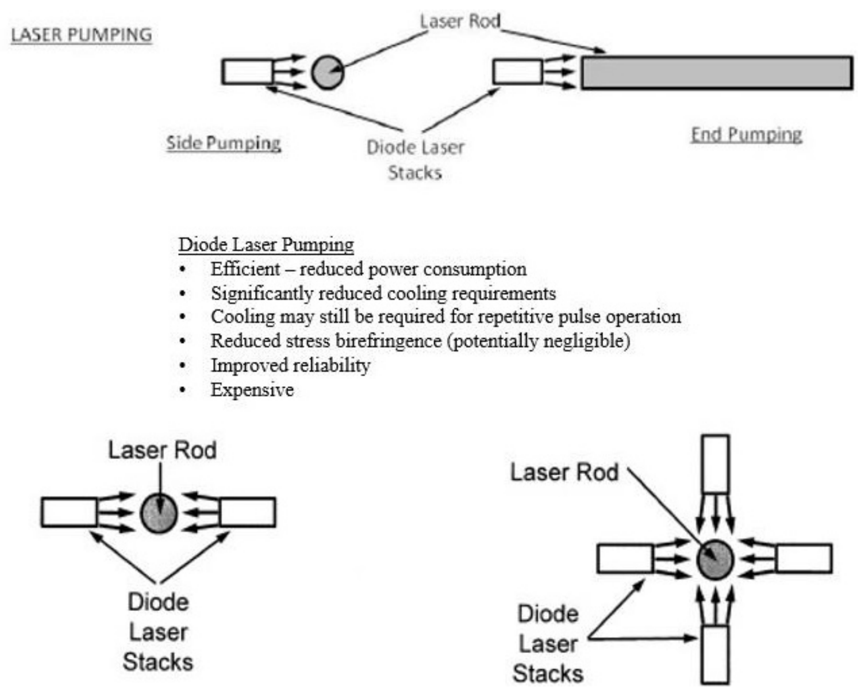

Figure 59. Diode Laser Pumping Characteristics and Geometries (from Harney 2012)

Figure 60 gives some possible advantages and disadvantages in flashlamp pumping mechanisms and shows the geometries used in pumping the laser rod.

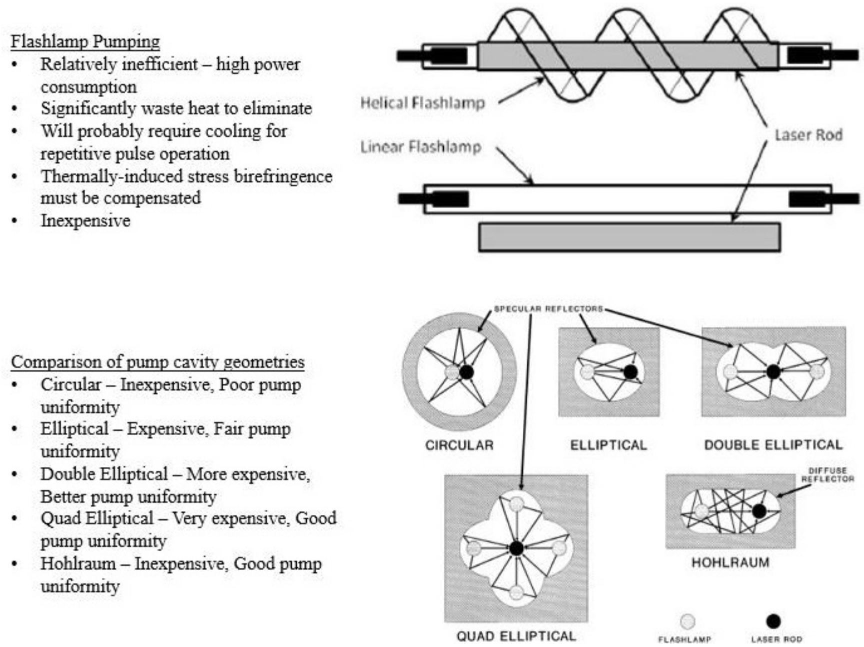

Figure 60. Flashlamp Pumping Characteristics and Geometries (after Harney 2012)

Free electron lasers (FELs) use considerably more power and have a much larger infrastructure footprint due to how they produce stimulated emission. Instead of pumping a medium to produce stimulated emission, FELs use a relativistic beam from a particle accelerator to "fire" electrons through a series of strong magnetic fields which alternate directions causing the electrons to emit radiation (Harney 2012). The emitted radiation then propagates in the lasing cavity until it exits. Figure 61 shows a schematic diagram of a FEL. The FEL is still in its development stages and suffers from extremely complex hardware as well as radiation issues.

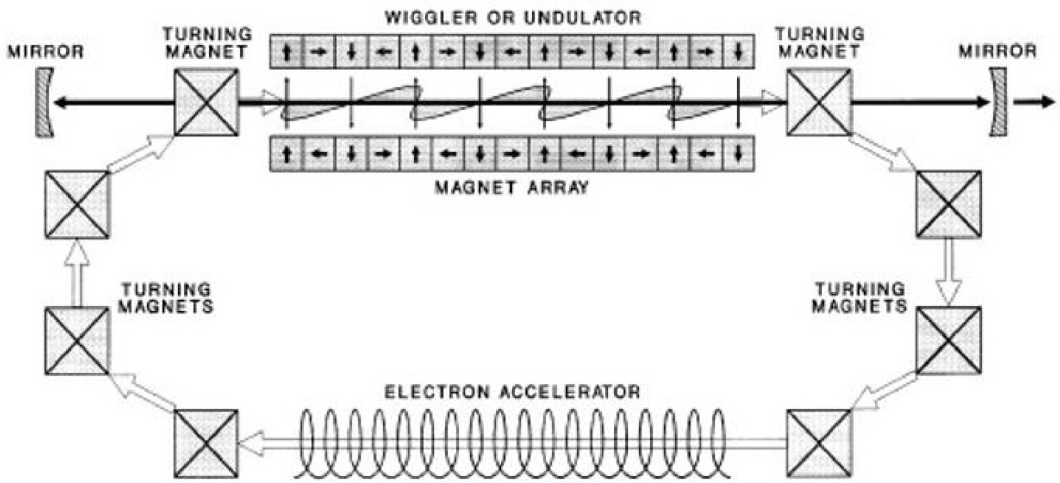

Figure 61. Free Electron Laser Diagram (from Harney 2012, 216)

The HEL system itself has many internal systems that need to be analyzed. These systems include, but are not limited to:

- Laser
    - Energy source—power generation and storage for the HEL system
    - Laser cavity and gain medium—cavity where the gain medium is pumped to reach proper population inversion levels
    - Diode pump—pumps the laser rod (gain material)
    - Phase adjuster and control electronics—beam and phase control equipment for the pump diodes/fibers
    - Master oscillator, power amplifier (MOPA)—scalable approach to achieving higher power with the combination of lower power lasers; master oscillator seeds other laser amplifiers
    - Thermal management systems—cooling equipment for excess waste heat created by the HEL
    - Safety systems—fire, personnel, operation, and system interlocks to meet safety requirements
    - Control systems—systems needed to control the HEL in terms of mechanics, operation, communication, health, predictive avoidance, and maintenance
    - Magnetic array (FEL only)—large magnets used to oscillate the electron beam.
    - Particle accelerator (FEL only)—relativistic beam used to accelerate electrons

    - Electron beam transport (FEL only) —strong magnets used to direct the electron beam to and from the magnetic array

- Beam control
    - Wavefront sensors—sensors that sample beam quality to ensure operation at expected levels
    - Reflectors
        - Deformable—adjustable surfaces to shape and direct beam as desired
        - Segmented—series of mirrors used to combine smaller beams into one
        - Fast Steering—high performance two dimensional directing mirror
        - Corner Cube—three mirror or prism used to redirect the beam
        - Piezoelectric—high speed, solid state mirror
        - Primary, secondary, tertiary – reflectors located in the telescope
    - Optics
        - Collimating lenses—optic used to narrow out beams.
        - Diffractive or spectral combiner—optics used to combine beams.
        - Adaptive—optics used to improve performance by reducing wavefront distortion at the point of interest
    - Beam window—glass cover that protects the HEL from the outside elements
- Atmospheric, tracking, and pointing (ATP)
    - Illuminator—system used to highlight target before engaging
    - Fine and coarse tracker—tracking system used to track target object in differing wavelengths depending on operation mode
    - Gimbal and stabilization—equipment used to point the HEL in different directions and stabilize optics for use
    - Enclosure—above deck cover for equipment

Figure 62 shows the basic elements of a HEL. The basic elements of any HEL can be categorized into one of the three following groups: laser, beam control, or ATP. Figure 63 shows the breakdown of a potential SSL laser element. Figure 64 is the breakdown as applied to a FEL. While the internal architecture may change, the basic principles are the same.

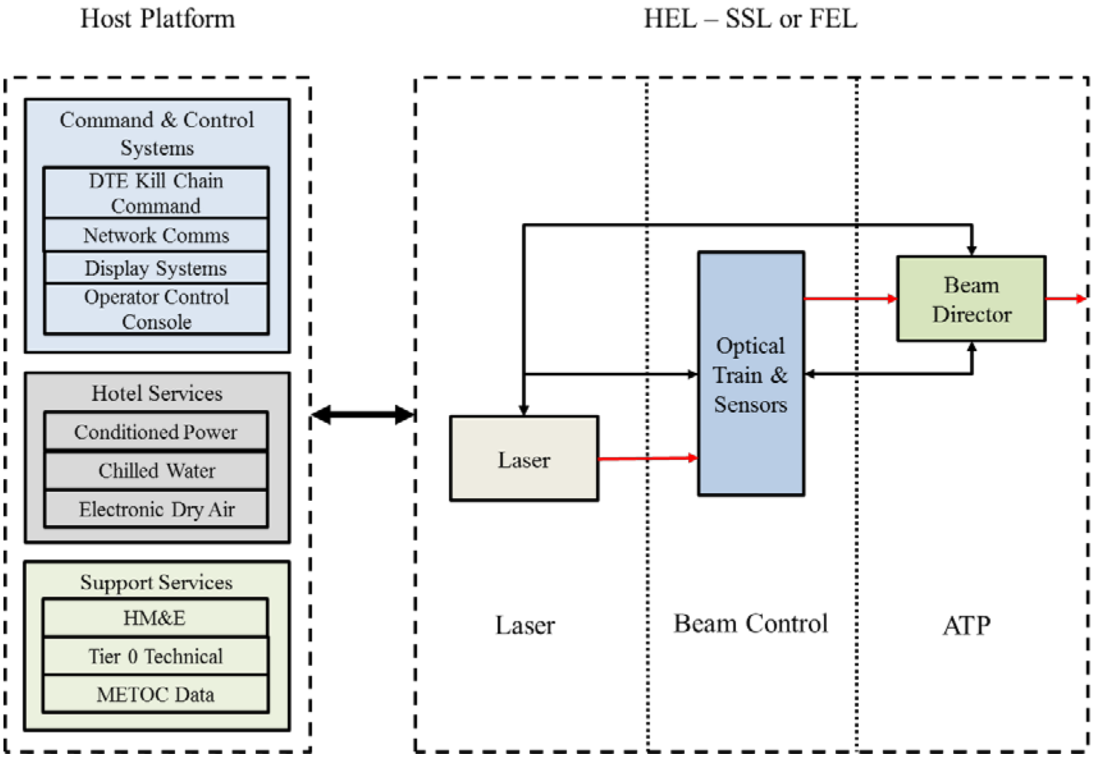

Figure 62. HEL Basic Elements

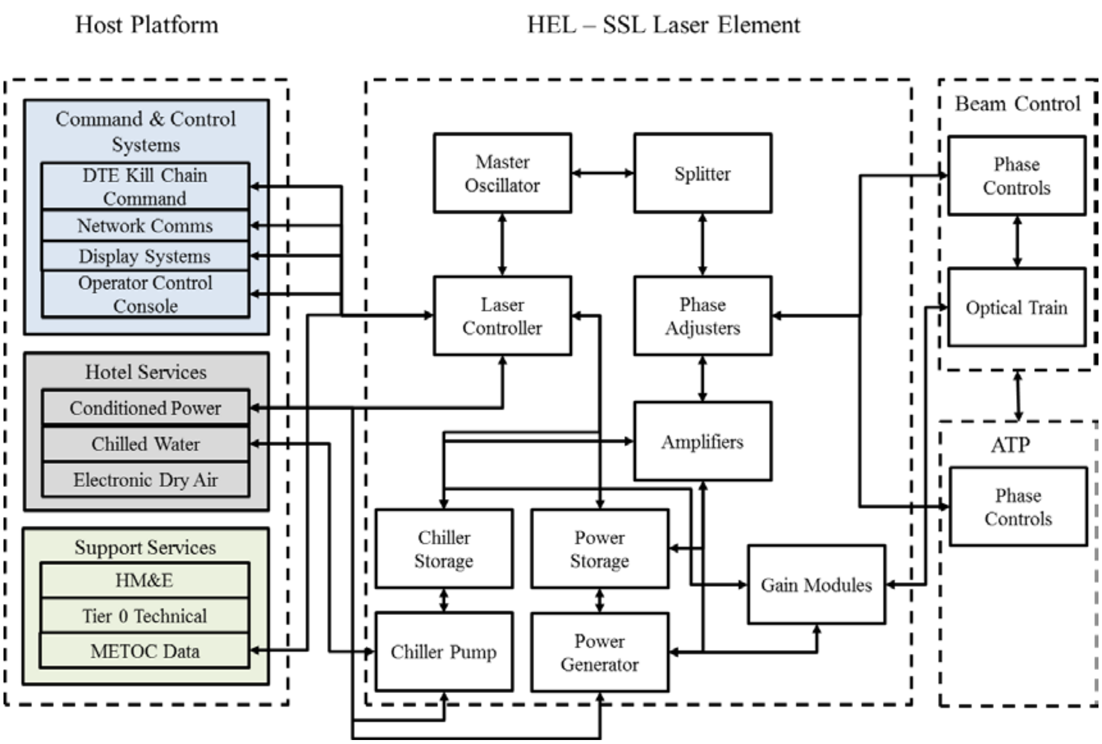

Figure 63. HEL - SSL Laser Element Interactions and Makeup

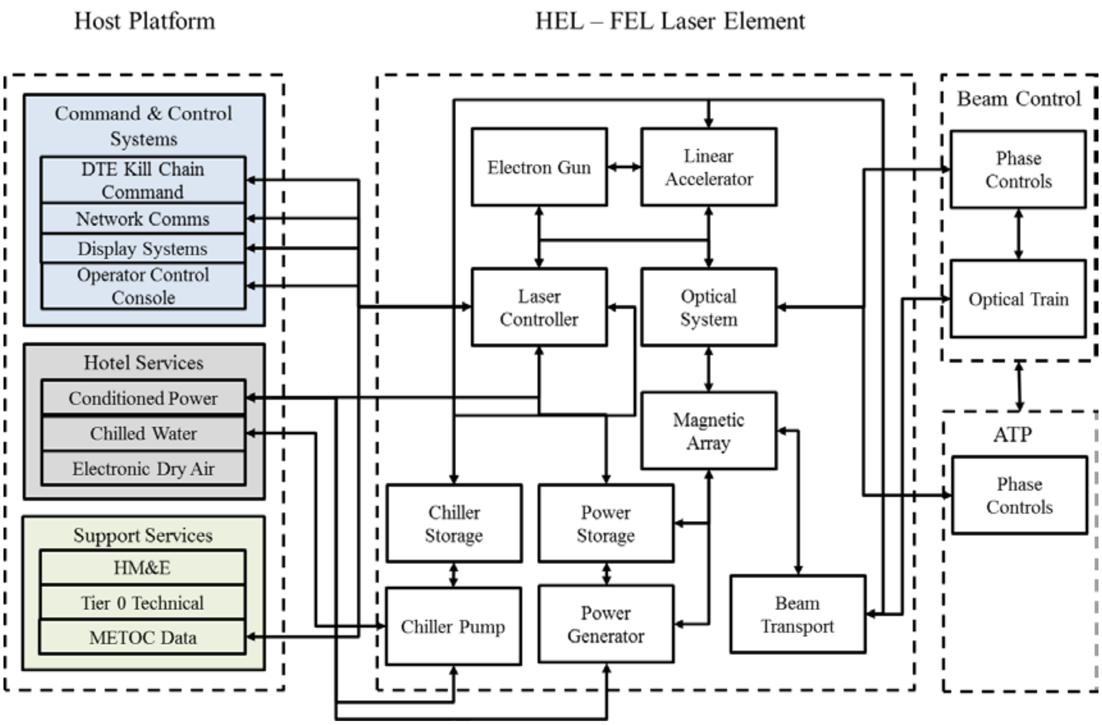

Figure 64. HEL - FEL Laser Element Interactions and Makeup

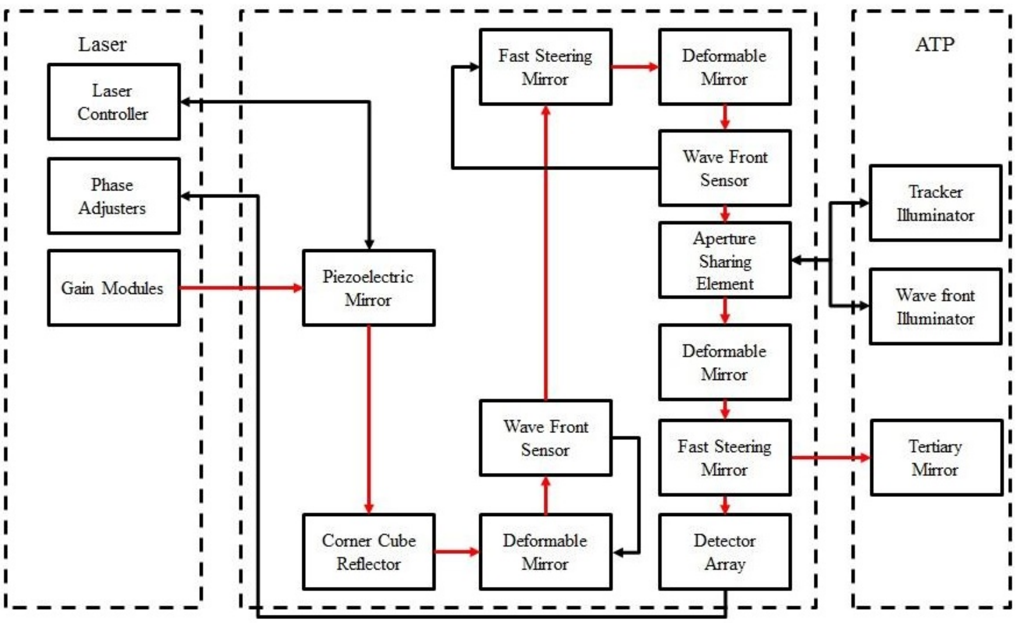

Figure 65. HEL Beam Control Element Interactions and Makeup

The beam control configurations, as illustrated in Figure 65 and Figure 66, can also vary due to requirements, space form factor, capability, and environment. In general, the beam control elements look to maintain beam stability and quality.

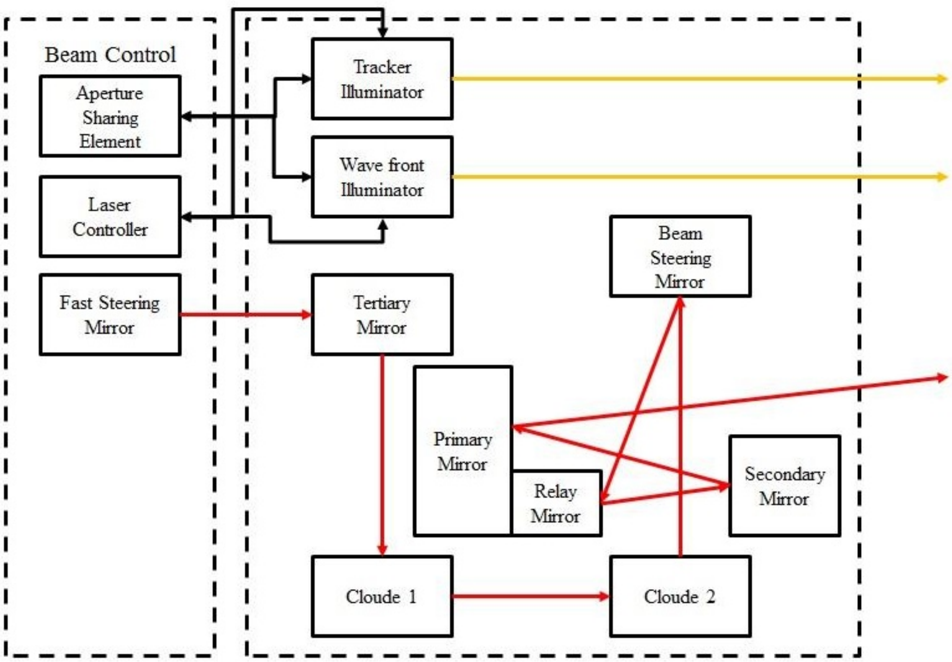

Figure 66. HEL ATP Element Interactions and Makeup

Similar to the beam control element, the ATP element also varies from requirements, space form factor, capability, and environment. There are many different telescope configurations.

4. DSX to DSHEL

In following the DS framework, the DSX configuration chosen was the Distributed - Multipoint, All Inclusive. This configuration was chosen due to the multiple data sources that need to be sensorized from the host platform. This configuration was also chosen due to surface combatant requirements to have the HEL system distributed throughout the ship to meet survivability requirements.

The sensor collection network configuration chosen, as indicated in Figure 67, will be a combination of a star and mesh topology. The star methodology will be used with major HEL system elements as well as hardware cabinets. This will allow two main nodes (for redundancy) with each local network to report out the sensor status of the internal nodes to the main DSHEL controller. The mesh topology will govern the star main nodes. This allows a fault tolerant network to be created when sharing control information and status requests from the DSHEL controller.

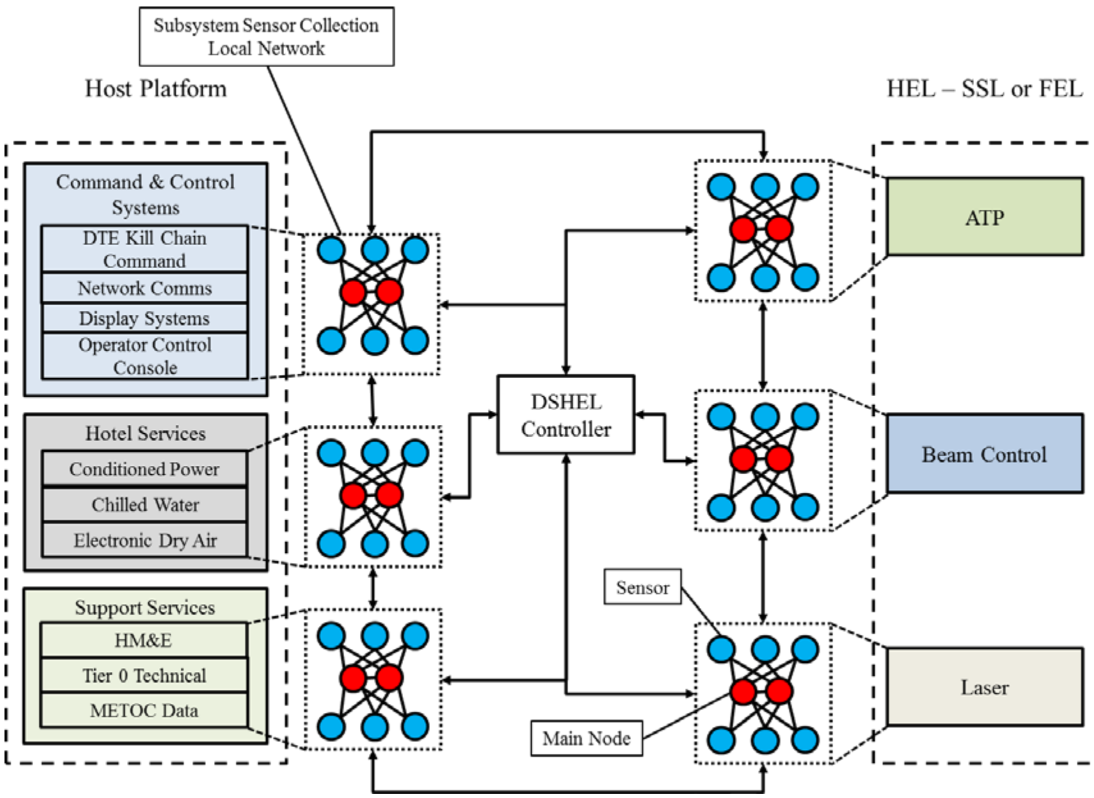

Figure 67. DSHEL Sensor Collection Network

The sensor collection network will monitor and report the following parameters as categorized by host platform and POI:

- Hotel services
    - Ship form factor space
        - Above deck—temperature, pressure, wind speed, wind direction, humidity, precipitation rate, visibility, cloud height, shock, vibration, and cloud coverage
        - Below deck—Temperature and humidity

- Conditioned power—Voltage, current, phase, surge, and ground signal
    - Chilled water—flow rate, temperature, purity, and pH level
    - Electronic dry air—temperature, humidity, and flow rate
- Support services
    - HM&E support—hydraulic pressure
    - Tier 1 technical support—maintenance actions and events
    - Meteorological and oceanographic (METOC) data – see hotel services – above deck, sea state, and ship motion.
- Command and control systems
    - Detect to engage (DTE) kill chain command – connectivity with DTE and commands sent
    - Network communications – link utilization, hop count, speed, packet loss, latency, path reliability, path bandwidth, throughput, load, and maximum transmission unit
    - Display systems—signals sent and received
    - Operator control console—signals sent and received
- Laser, beam control, and atmospheric, tracking, and pointing (ATP)
    - Total intensity over time (Harney 2012, 401)
    - Total energy in pulse (Harney 2012, 401)
    - Spectral content (Harney 2012, 401)
    - Degree of polarization (Harney 2012, 401)
    - Angular divergence (Harney 2012, 401)
    - Intensity profile (Harney 2012, 401)
    - Shock and vibration
    - Temperature (optics, mirrors)
    - Hardware utilization
    - Software execution (running on hardware)
    - Usage modes and associated time
    - Aperture radius
    - Cavity loss coefficient
    - Magnetic field (FEL only)
    - Beam quality
    - Wavelength, phase

- Greenwood frequency
- Gain
- Decay rate
- Irradiance
- Wiggler vector potential (FEL only)
- Cavity length
- Wiggler period (FEL only)
- Number of wiggler periods (FEL only)
- Isoplanatic angle (if available)
- Fried coherence length
- Object distance
- Dwell time
- Laser spot size

While many of the items listed above cannot be measured via sensorization because they are inherent characteristics of the system, the parameters above are important in determining behavior profiles of the HEL.

C. REQUIREMENTS SYNOPSIS

Requirements were elicited from multiple viewpoints, topic areas, and stakeholders. These were key for the documentation of physical and functional needs of the DSHEL product, processes, and services. The DSHEL structure and characteristics of the requirements generated are laid out below.

1. Structure

The language of requirements can be very confusing, especially when terms like "shall," "will," and "must" all have similar meanings. To avoid confusion, requirements for DSHEL followed the structured language format below:

- "Shall," the emphatic form of the verb, shall is used throughout sections the specification whenever a requirement is intended to express a provision that is binding (Department of Defense 2014, 11).

- “Will” is used to express a declaration of purpose on the part of the Government. “Will” is also used in cases where simple futurity is required (Department of Defense 2014, 11).
- “Should” is used to express non-mandatory provisions (Department of Defense 2014, 11).
- “May” is used to express non-mandatory provisions (Department of Defense 2014, 11).
- “Must” is used to express mandatory provisions. “Shall” is used instead (Department of Defense 2014, 11).
- Indefinite terms, such as “and/or,” “suitable,” “adequate,” “first rate,” “best possible,” “and others,” and “the like” are not used. The use of “e.g.,” “etc.,” and “i.e.,” are avoided (Department of Defense 2014, 12).
- Ambiguous Adverbs and Adjectives, such as “almost always,” “significant,” “minimal,” “timely,” “real-time,” “precisely,” “appropriately,” “approximately,” “various,” “multiple,” “many,”
- “Few,” “limited,” and “accordingly” are avoided (International Council On Systems Engineering 2010, 79).
- Open-Ended, Non-Verifiable Terms, such as “provide support,” “but not limited to,” and “as a minimum” are avoided (International Council On Systems Engineering 2010, 79).
- Comparative Phrases, such as “better than” and “higher quality” are avoided (International Council On Systems Engineering 2010, 79).
- Loopholes, such as “if possible,” “as appropriate,” and “as applicable” are avoided (International Council On Systems Engineering 2010, 79).
- Other Indefinites, such as “etc.,” “and so on,” “to be determined (TBD),” “to be reviewed (TBR),” and “to be supplied (TBS).” are avoided (International Council On Systems Engineering 2010, 79).

2. Characteristics

Requirement characteristics of DSHEL had the following:

- Necessary—Authoring or levying additional requirements that add no capability or performance to the system are of no value. Additional “useless” requirements come in two varieties: (1) unnecessary specification of design, which should be left to the discretion of the designer, and (2) a redundant requirement covered in some other combination of requirements (International Council On Systems Engineering 2010, 76).

- Implementation Independent—Requirements were created and applied by dictating what was to be performed by the system, not how the system was to perform the task (International Council On Systems Engineering 2010, 76).
- Clear and Concise—Requirements were exact, used clear language, and detailed enough to rule out any and all other interpretations (International Council On Systems Engineering 2010, 76).
- Complete—Requirements stood on their own, measurable and not in need of further investigation to provide capabilities and characteristics (International Council On Systems Engineering 2010, 76).
- Consistent—Requirements were not in disagreement with each other. Adhesion to similar/like standards, units, conversion values, interfaces, and specifications was best ((International Council On Systems Engineering 2010, 77).
- Achievable—Requirements had the ability of being attained and securable. Requirement achievability is directly related to the ability to measure and rate the effectiveness of data collected about a particular requirement (International Council On Systems Engineering 2010, 77).
- Traceable—Requirements flowed from higher level specifications down to lower levels. Complex, non-obvious requirements were made up of multiple, lower level, simple requirements (International Council On Systems Engineering 2010, 77).
- Verifiable—Requirements were verified and validated by at least one of the following methods: inspection, analysis, demonstration, or test (International Council On Systems Engineering 2010, 77).

3. Sources

DSHEL requirement sources came from all environments and user interaction levels. The requirements were generated from customers, end users, organizations, support structures, environmental factors, geographic locations, policies, laws, and regulations. Below are the chosen pre-existing frameworks and methodologies that were analyzed for requirement generation.

a. International Council on System Engineering

The International Council on System Engineering (INCOSE) framework, Figure 68, offered DSHEL detailed insight into the impact on requirements generation by external, organizational, and project environments.

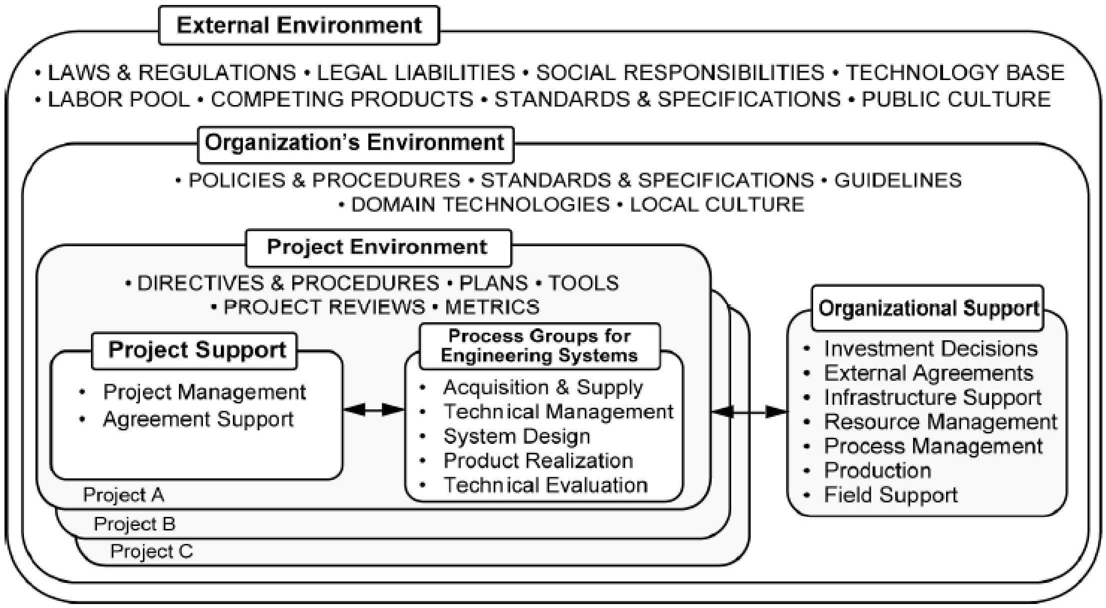

Figure 68. INCOSE Requirements Elicitation Areas (from INCOSE 2012, 75)

b. DOTMLPF-P

DOTMLPF-P is a solution space framework used by the DOD that pertains to the eight possible non-materiel elements involved in solving warfighting capability gaps (Defense Acquisition University 2014). The eight non-materiel elements are as follows:

- **D**octrine: the way we fight (e.g., emphasizing maneuver warfare, combined air-ground campaigns).
- **O**rganization: how we organize to fight (e.g., divisions, air wings, Marine-Air Ground Task Forces).
- **T**raining: how we prepare to fight tactically (basic training to advanced individual training, unit training, joint exercises, etc).
- **M**aterial: all the "stuff" necessary to equip our forces that DOES NOT require a new development effort (weapons, spares, test sets, etc that are "off the shelf" both commercially and within the government).
- **L**eadership and education: how we prepare our leaders to lead the fight (squad leader to 4-star general/admiral - professional development).
- **P**ersonnel: availability of qualified people for peacetime, wartime, and various contingency operations.
- **F**acilities: real property, installations, and industrial facilities (e.g., government owned ammunition production facilities).

- **P**olicy: DOD, interagency, or international policy that impacts the other seven non-materiel elements.

c. Integrated Logistics Support Elements

Integrated logistics support (ILS) elements are a set of 12 items that are used to enable system readiness and availability. The 12 ILS elements are shown in Figure 69.

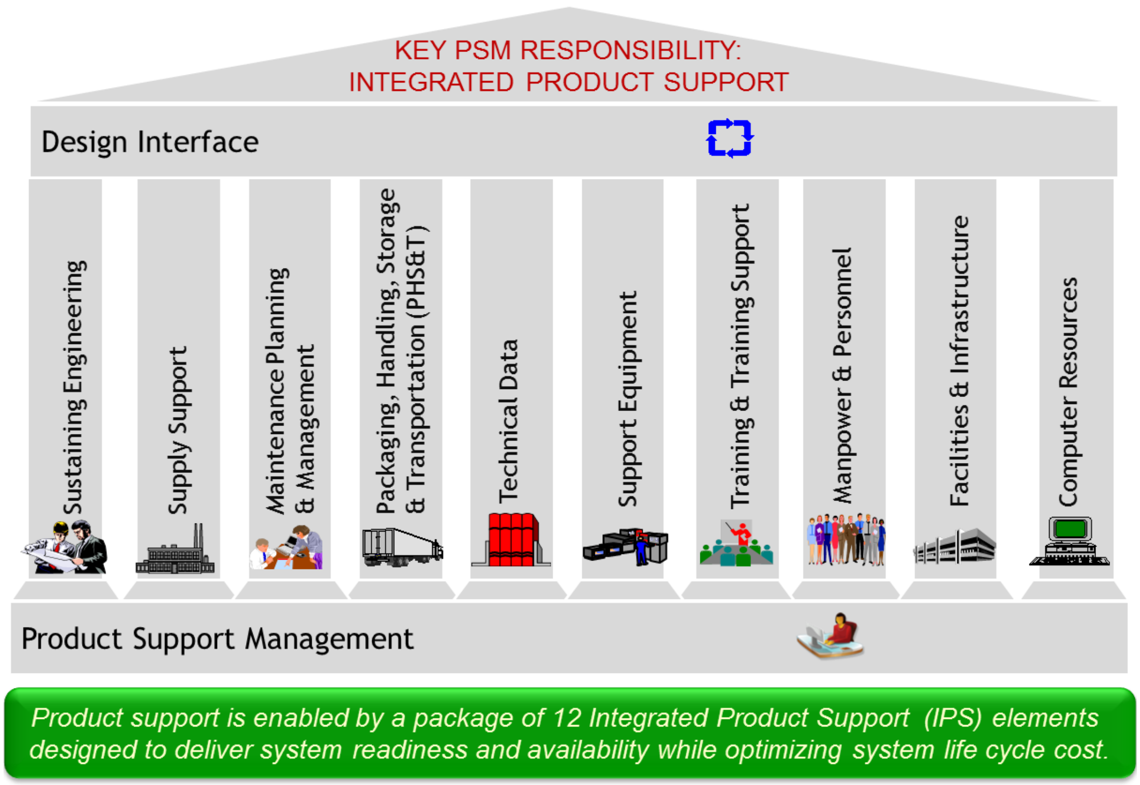

Figure 69. ILS Elements (from Defense Acquisition University 2010)

d. PESTO

PESTO is an acronym that relates to measures of performance or readiness (Webb and Candreva 2006). The letters in PESTO are identified below (Department of Navy 2015).

- **P**ersonnel—Represents a detailed capture of individual skills that affect the ability of a unit to perform its mission

- **E**quipment—Represents the equipment material condition for performing each assigned capability
- **S**upplies—Represents the availability of supplies necessary for performing each assigned capability
- **T**raining—Represents the performance and experience of the crew for performing each assigned capability
- **O**rdnance—Represents the standardized distribution load allowances available for performing each capability

D. FUNCTIONAL REQUIREMENTS

A functional requirement is distinguished from other requirements by its emphasis on what it is the system is "required to do" (Halligan 2014). It was important to consider how functional requirements would be incorporated into and become a part of DSHEL. In addition to this, functional flow diagrams depicted the main aspects and sub components of some of the key functional requirements and are shown throughout this section. Requirements must be worded in such a way that they are clear and to the point, not open to interpretation. Unclear requirement wording can end in an unsatisfactory final product and re-work.

The DSHEL team did not write the requirements for the HEL system. Any requirements for the HEL system itself were not within the control of the DSHEL team due to the current developmental status of HEL. While it was not within the team's jurisdiction to dictate DSHEL's requirements, there are several areas that were recognized as being worthy of suggestion. It would have been possible for the team to branch out into other areas as well: security, equipment mean time between failures (MTBF), and logistical requirements could have been the focus. Data transfer and the platform of interest (HEL) were singled out because of their immense impact on the basic functions of a DS system. These were considered to be the monitoring of environmental and internal statuses of components of the system and the subsequent sharing (data transmission) of that information.

Some examples of functional requirements the DSHEL team considered included the following:

- Distance support shall remotely monitor data, without any on-site assistance when operating at working conditions.
- Distance support shall transport monitored data to off-site recipients.
- Distance support shall transport data/information between off-site and on-site recipients.
- Data transmitted for data support shall be in a pre-set format.

The reason that data transfer, storage, and processing were focused on as major areas were due to the fact that resources were not infinite. The DSHEL team had to consider during the design process that there would be limitations. Considerations were how much data could be transferred, how much data could be stored, and how fast and frequently data could be transferred.

In order to better express how data size and transmission capabilities were linked into the frequency with which data can be obtained, the following example was used to demonstrate the relationship between “pipe size,” or the data restriction a system is under to transport data, “data size,” or the amount of data trying to be transported, and their relationship to time. The combination of a small mode of transport and a large amount of data will cause the system to be slower in obtaining and transmitting data, just as the opposite combination would cause a faster transmission. Figure 70, gives a visual of this idea using four common, standard link speeds.

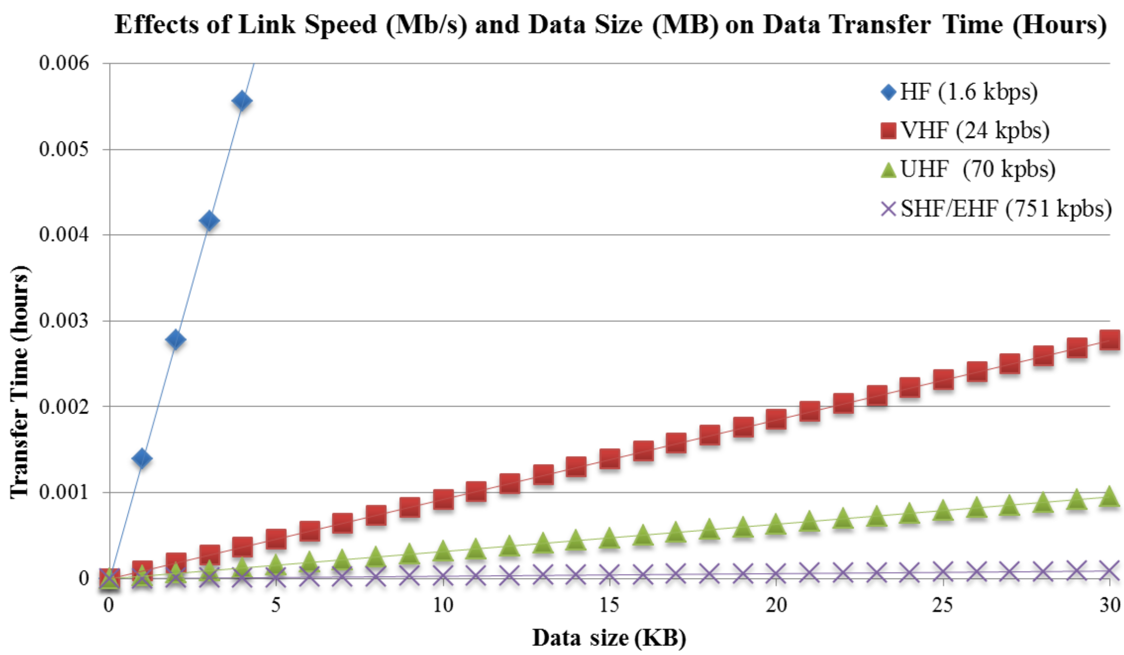

Figure 70. "Pipe Size," Data Size, and Their Effect on Data Transfer Time

Each of the four lines in Figure 70 represented a different technology, which was in turn associated with a link speed in kbps. These link speeds were divided by a generic data size in KB, which were varied incrementally from one to one hundred KB and then divided by 3600 to convert these chosen link speeds to hours. The graph is, therefore, indicative of the difficulties of attempting to transfer large amounts of data over low link speeds as shown by the slope of each line. The steeper the slope, the more time it would take for data to be transmitted. For example for 10 KB, HF takes 0.0139 hours, or 0.834 minutes, while the SHF/EHF takes $2.96 * 10^{-5}$ hours, or 0.0018 minutes. As a result, the requirements were suggested to include: amount of data transferred, mode of data transfer, amount of "pipe" or transfer medium available, necessary frequency with which data needs to be obtained, and the form in which data shall be transmitted and received in.

The importance and potentially severe impact of data is detailed in Figure 71:

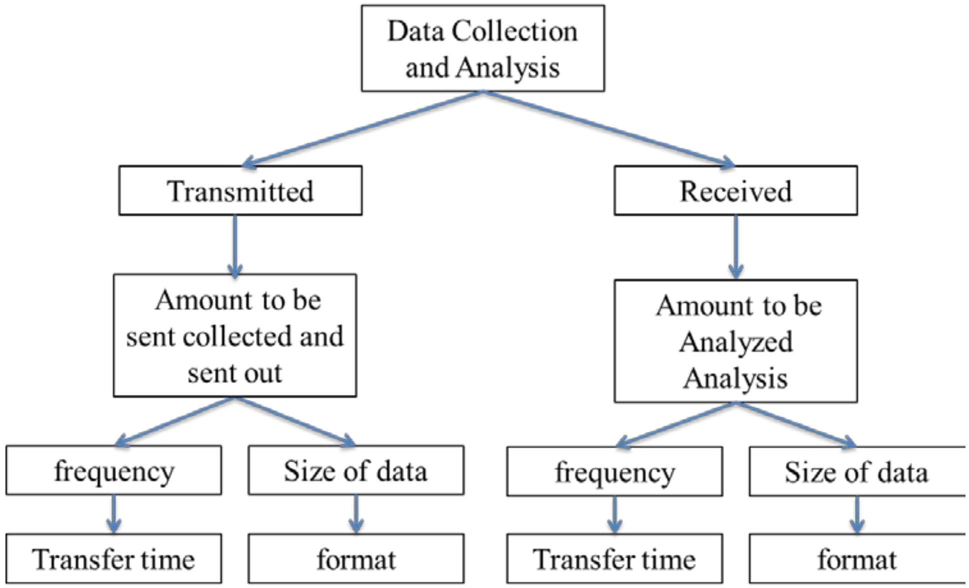

Figure 71. Sample Functional Flow for Data

After the above internal consideration of functional requirements, the DSHEL team consulted the Distance Support Handbook to consider what pre-existing requirements study had been done with regards to DS. From this handbook, 19 key requirements were obtained (Naval Surface Warfare Center, Port Hueneme Division 2013):

1. "The system architecture shall provide real-time communication. Real time communication includes chat, telephone, interactive video, etc., from shipboard to shore personnel and vice versa."

2. "The system architecture shall provide system status or health of the system. System status data will include indicators of whether a system or equipment is operational, off-line, degraded, or failed."

3. "The system architecture shall extract and record diagnostics data to a system attached or networked storage. Data includes information to remotely isolate failure to a single component at the Lowest Replaceable Unit (LRU) method from post analysis or specific BIT capabilities run at a periodic or aperiodic basis."

4. "The system architecture shall provide shore-based remote reconfiguration to correct hardware failures. It may require a realignment of a klystron, radar receiver, optical system, etc."

5. “The system architecture shall collect information that is available for supporting immediate troubleshooting of a casualty and is typically not used for trend or historical analysis.”

6. “The system architecture shall include periodic information regarding environmental conditions. Environmental monitoring data will be defined for each system’s architecture component. This includes information that is primarily used for trend analysis and CBM to provide overall indicators of system performance.”

7. “The system architecture shall contain information that is available for supporting immediate troubleshooting of a casualty. This includes information that is driven by configuration changes to hardware, software, and firmware.”

8. “The system architecture shall allow the shore-based Subject Matter Expert (SME) determine data that is pertinent for DS and defines the frequency in which the data is pulled from the ship. Data location can be viewed or captured by an inherent or external monitoring system.”

9. “The system architecture shall provide shipboard data reduction capability to support reduced bandwidths or transmission of data for periodic or aperiodic data reports. This refers to the compression of data before periodic data transmission or storage.”

10. “The network communication layer shall include a data transmission path from ship to shore; either directly from the shipboard system to the Global Information Grid (GIG) or indirectly via an interconnect proxy which is already connected to the GIG. This includes bandwidth requirements that will vary based on the type of DS being implemented and the data type. This also includes the fixed Minimum Transmission Unit (MTU) roundtrip delay time from ship to shore. The MTU for each DS tool implemented must be set to be greater than the fixed MTU from ship to shore.”

11. “The shore-based infrastructure shall include common system/equipment reported data (e.g., health status, environment monitoring data, system faults, event data recording) repository located at a central shore-based site. This data repository differs from the Data Aggregation Center as it maintains raw system data before being reviewed/analyzed and aggregated with other data/metrics by a system SME.”

12. “The shore-based infrastructure shall provide near-real-time collaboration. Near real time communication includes email, recorded video, etc., from shipboard to shore personnel and vice versa.”

13. “The DS infrastructure components shall have appropriate Defense Information Systems Agency (DISA) Security Technical Implementation Guide (STIG) controls applied.”

14. “The shore-based infrastructure shall provide algorithms used by the shore data architecture (and supporting information systems) that incorporate operational, health, and readiness data to develop prognostic and predictive failure analyses prior to failure.”

15. “The shore-based infrastructure shall provide shore-based personnel to have access to all technical documentation required to support the Fleet.”

16. “The shore-based infrastructure shall provide access to data that provides on-board parts availability, estimated delivery dates or status, shore inventory, part location, condition/repair code, and ship requisition information.”

17. “The shore-based infrastructure shall provide access to Hardware, Software, and Firmware configuration information that is installed in the shipboard system. Also includes configuration data on allowance parts list (APL) / allowance equipment list (AEL), technical bulletins, and technical manuals.”

18. “The computing infrastructure shall define the ability of aggregating system data and to send that data via the system architecture for transmission on the internal network or external communication transport defined by the data transmission path. Network access for data assumes automated capability through system interfaces without shipboard personnel interface.”

19. “The shore-based infrastructure shall provide current status of issues, historical record of what has been accomplished to resolve the issue, who is assigned to work problem, and priority or classification of issue. This information will be used for turn-over between SME or to/from ISEA to RMC.”

The second key category that was focused on for requirements was the platform of interest, or HEL. Any system that is placed on a ship will be subjected to an extremely harsh environment. Equipment will be exposed to salt, temperature extremes, moisture, corrosion, thermal damage, as well as overall wear and tear from intended use. It was important to consider the basic components or lowest replaceable units (LRUs) of a laser system. Understanding the LRUs of the HEL allowed the team to consider what would be important to focus on for monitoring the HEL system for distance support.

The purpose of distance support is to collect information on the status of the system. For HEL, there are various areas that were key to effectively supporting the system. Requirements relating to the platform of interest include:

- Temperature of various elements of HEL shall be monitored. These elements include but are not limited to:
    - Mirrors
    - Flashlamp/Diode/Fiber
    - Lasing medium
    - Chamber
- System shall monitor the motion and positioning of all components
- System shall monitor degradation and status of the lasing material

These functional requirements combined into a flow diagram would be as illustrated in Figure 72.

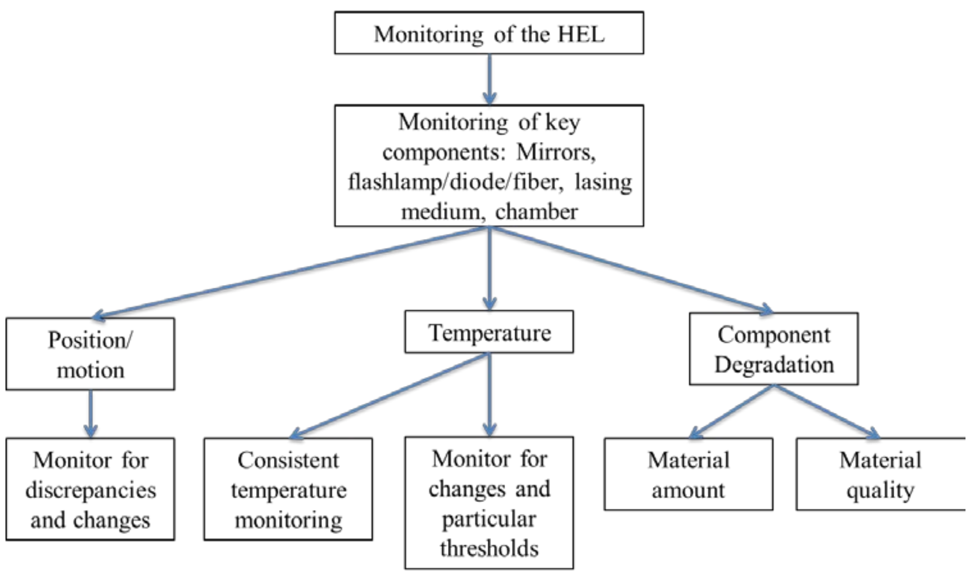

Figure 72. Sample Functional Flow for HEL Monitoring

E. PERFORMANCE REQUIREMENTS

Performance requirements reflected the functional requirements in terms of subject. However, the difference between the two types of requirements is that while a functional requirement states what the system will do, a performance requirement is concerned with to what extent or “how well the system is to do what it is to do.” (Halligan 2014)

As requirements considerations were developed, the concept of “ilities” or how a system would actually perform the aforementioned requirements were considered. Performance requirements were closely related to these “ilities.” In order for the requirements analysis to tie into the cost analysis portion of the capstone, the number of requirements would be necessary for calculations. However, as far as the “ilities” were concerned, no tally was necessary as the Level of Service Requirements assessment is performed differently. Instead the COSYSMO model, which is utilized in the cost estimation analysis, required levels of use. For example, COSYSMO used the terms “very high, high, medium, and low,” in place of a numerical tally.

Performance requirements with regards to DSHEL, which were a continuation of the 19 functional requirements detailed above, should answer the following questions once a HEL PoR exists:

- DSHEL shall transport data at X speed.
- DSHEL shall monitor temperature of critical components.
- DSHEL shall monitor alignment of all calibrated components.
- DSHEL shall monitor the health status of all components.
- DSHEL shall collect a X level of information to be available to SMEs.
- DSHEL shall provide collect data at X intervals.
- DSHEL shall transfer data at X rate to the host platform.
- DSHEL shall monitor system vibration.

Performance requirements were necessary to take the next step in product development. After the functional requirements had established the non-negotiable needs of the system design, the performance requirements added the quantitative values to each.

F. SUMMARY

As with the previous discussion of requirements language and their genesis, it is important to understand the origin of these concepts. However, it was the intent of the DSHEL team to apply these concepts to distance support, rather than to describe them abstractly. KPPs, KSAs, MOEs, and MOPs were, therefore, suggested to be primarily focused in the same areas as the requirements discussed above, namely data transfer and the POI. A functional or performance requirement is an answer to a question that either focuses on what the system is to do, or the degree to which it is to do it. There were particular areas of interest for future requirements: data, its handling, processing and transfer, and the POI. Since a functional requirement is a statement about what the system is to do, the first step was to lay out simply what distance support's functions were. DS involves obtaining, analyzing, and transmitting information and data. Functional requirements can be understood to be the qualitative analysis of a system. The functional requirements (19) came from the Distance Support Handbook and were then expanded upon in the performance requirements. Clearly, there would be more than 19 high level functional requirements if the latter two DS Pillars were included. For both performance and functional requirements, it was vital to the final integrity of the system to remember that requirements must be clear, not be open to interpretation. Clear, distinct requirements were the key to ensuring that the resultant DSHEL system was representative of the original idea for the system. Clarity that would affect not only the requirements written, but also the subsequent KPPs, KSAs, MOPs and MOEs which in turn define the true blueprint of the system and therefore the system itself. Requirements, KPPs, KSAs, MOEs, and MOPs were influenced heavily by the POI, DS requirements and needs, as well as security, resource management and usability concerns.

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IV. CONCEPT DEFINITION AND DESIGN

This chapter discusses the architectural approach that was employed in the development of DSHEL, as well as the design method and the actual artifact that came out of the application of the design process. In addition to this, a discussion of the method that would be used in order to test and evaluate the design as well as the validation and verification that the design satisfies the requirements discussed in the previous chapter.

A. ARCHITECTURAL DESIGN APPROACH

The approach for the architecture design was twofold in nature. First a framework was developed for the application of DS for maritime tactical weapon and sensor systems. Second this framework was applied to a specific use case for a HEL system, hereafter called the DSHEL system. Levis defined an analytical systems engineering process that begins with the system's operational concept and includes the development of three separate architectures (functional, physical, and allocated) as part of the decomposition (Levis 1993). This section will provide an overview of these three architectures.

1. Functional Architecture

Before going into the approach that was used for developing the functional architecture, it was important to clarify terminology for functional architectures, as this was critical to establishing an understanding of the logical aspects of a system.

a. Functional Architecture Terminology

When considering the functional architecture of a system, it was necessary to distinguish between a system's modes, states, and functions. A system mode was defined to be a distinct operating capability during which some or all of the system's functions may be performed to a full or limited degree. These modes may be: the operational mode, a maintenance mode, or a particular failure mode. The DS framework that was developed for DSHEL was designed to be able to understand the nature of the operational mode of the HEL system, detect when the HEL system had entered a particular failure mode and respond accordingly.

A system state was defined as a static moment in time of the set of metrics or variables needed to describe in detail the system capabilities to perform the system's functions. In general, the state of the system can be described by a list of state variables at a particular point in time (Buede 2009). The state variables do not change over time; however, the value of each of the state variables does change. The DSHEL system stored these state variables of the HEL system and performed analysis over time to determine whether the HEL system was staying within its operational mode.

A system function was defined as a process that takes inputs and transforms them into outputs. A function was defined as a transformation and had the potential to change the state of the system. A function had a set of criteria under which it could be activated. The set of criteria included both the availability of physical resources and the arrival of a triggering input (Buede 2009). A function also had an exit criterion, which determined when the transformation of the input information into output information was complete.

b. Functional Architecture Development

The Integrated Definition for Functional Modeling (IDEF0) was chosen as an applicable model for DSHEL. IDEF0 is a graphical representation of the interactions of the functional and physical elements of a system. A function or activity was represented by a box and was described by a verb-noun phrase and numbered to provide context within the model. The inputs and outputs to and from the function are represented by arrows entering from the left and leaving from the right of each box. Additionally, controls or conditions under which the function may occur are shown by arrows entering the top of the box. Finally, mechanisms or the physical resource required to perform the function, are shown by arrows entering the box from the bottom (National Institute of Standards and Technology 1993). The Figure 73 demonstrated this basic syntax.

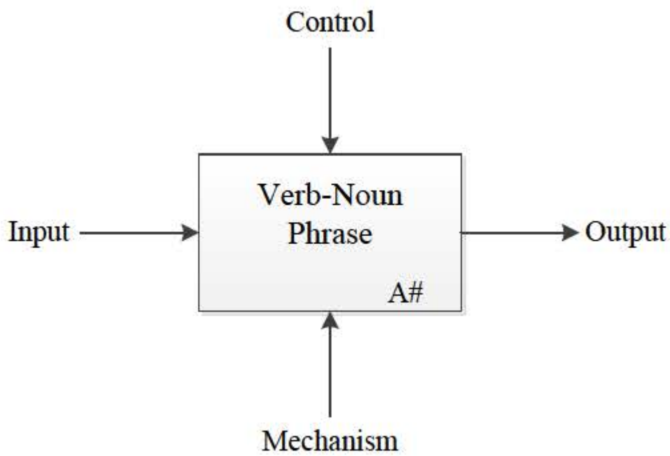

Figure 73. IDEF0 Syntax

The context diagram defines the inputs, controls, outputs, and mechanisms for a single, top-level function, labeled A0. The context page establishes the boundaries of the system or organization being modeled. Other pages of the model represent a decomposition of a function on a higher page following the same syntax.

2. Physical Architecture

The physical architecture of a system was the hierarchical description of the resources that comprise the system. This hierarchy began with the system and the system's top-level components and progressed down to the configuration items that comprise each intermediate component. The physical architecture can be described either by a generic or instantiated physical architecture (National Institute of Standards and Technology 1993). DSHEL utilized a generic physical architecture as opposed to instantiated architecture due to the fact that the DSHEL system was theoretical.

3. Allocated Architecture

The allocated architecture provided a complete description of the system design including the functional architecture allocated to the physical architecture (National Institute of Standards and Technology 1993). For the DSHEL system this concept was defined in the IDEF0 diagrams. The physical components were described by the mechanisms for each activity. Each physical component described in the physical architecture breakdown was described by a specific mechanism in the IDEF0 models.

The IDEF0 architecture framework was chosen for the DSHEL due to the current emphasis on the methods of support, the Six Pillars, promulgated by the USN. Additionally, this provided a better mechanism to determine specific attributes that would be required in all aspects of the system.

B. ARCHITECTURAL DESIGN

This section details the applied application of the IDEF0 diagrams created. To assist the reader in understanding the IDEF0 diagrams, Table 11 is provided to identify the ICOM references as they apply to the diagrams presented in this section.

Table 11. ICOM References

Diagram Number	ICOM Label	Detailed ICOM Reference
A0	I1	HEL System Information
A0	I2	HEL System Casualty Report
A0	I3	Ship Maintenance Action Form for HEL System
A0	C1	System Faults Detected
A0	C2	Technical Support Requested
A0	O1	Closed Casualty Report
A0	O2	Fleet Advisory Message Released
A0	O3	Closed Ship Maintenance Action
A0	O4	Tech Bulletin Released
A0	O5	Parts Ordered
A0	M1	DSHEL
A1	I1	HEL System Casualty Report
A1	I2	Ship Maintenance Action Form for HEL System
A1	I3	System Baseline Faults
A1	C1	Reported System Faults
A1	C2	Technical Support Requested
A1	O1	Closed Casualty Report
A1	O2	Fleet Advisory Message Released
A1	O3	Closed Ship Maintenance Action
A1	O4	Tech Bulletin Released
A1	O5	Parts Ordered

Diagram Number	ICOM Label	Detailed ICOM Reference
A1	M1	Technical Assistance Interface Component
A2	I1	HEL System Casualty Report
A2	C1	Technical Support Requested
A2	O1	Performance Data
A2	O2	System Status Data
A2	O3	Fault Data and Error Codes
A2	M1	Remote Diagnostic Component
A3	I1	Performance Data
A3	I2	System Status Data
A3	I3	Fault Data and Error Codes
A3	I4	HEL System Information
A3	C1	Technical Support Requested
A3	C2	Troubleshooting Procedures
A3	O1	System Baseline Faults
A3	M1	Remote Connection Component
A4	I1	HEL System Information
A4	C1	System Faults Detected
A4	O1	Reported System Faults
A4	M1	Remote Monitoring Component

This section also covered the proposed system/subsystem decomposition required by the physical architecture breakdown. The system level interface diagrams detail the major interfaces between the HEL system and DSHEL, as well as DSHEL and the shipboard network.

1. Integrated Definition for Functional Modeling (IDEF0)

First, the context diagram for the DSHEL system was developed, as shown in Figure 74. As described in the previous section, the context diagram provides the top-level description of the system being discussed. The top-level function for the DSHEL system was to provide distance support services. In order to provide DS services for the HEL system, the DSHEL system required HEL system information. Additionally, since this system was studied as it applied for shipboard tactical systems, a HEL CASREP or a ship maintenance action form for the HEL system would also be required. These artifacts would provide useful information.

The controls that triggered the function of DS being provided were “System Faults Detected” and “Technical Support Requested.” The outputs for DS services included “Closed Casualty Report,” “Fleet Advisory Message (FAM) Released,” “Closed Ship Maintenance Action,” “Tech Bulletin Released,” or “Parts Ordered.”

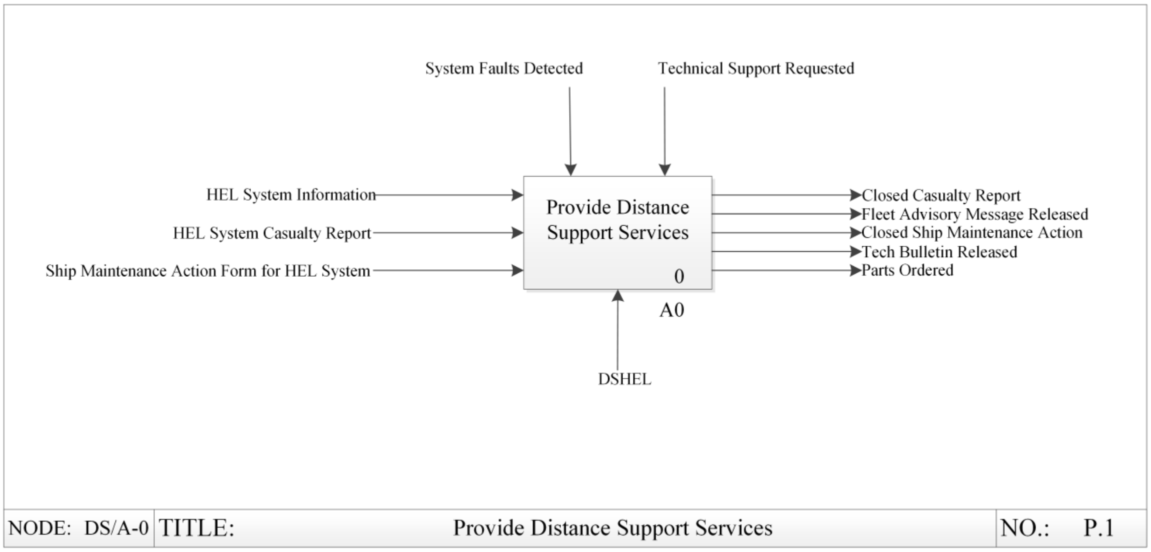

Figure 74. Context Diagram

Once the context diagram was completed, the next diagram broke out the top level function into major sub functions. In the case of the DSHEL system, those major functions were each of the pillars of DS. This diagram is shown below in Figure 75. Per the design standards for IDEF0 diagram’s higher-level inputs, controls, outputs, and mechanisms (ICOMs) are shortened to I, C, O, and M respectively. The number assigned to each ICOM was determined by the position in the higher-level diagram from top to bottom or left to right. This diagram demonstrates that the inputs related to CASREPs (I2) and maintenance action forms (I3) were inputs into the first DS function “Provide Remote Technical Assistance” as well as the output from box 3 “System Baseline Faults.” The controls which activate the “Provide Remote Technical Assistance” function were “Technical Support Requested” (C2) or the output from function box 4 “Perform Remote Monitoring,” which were detected system faults.

All outputs from the context diagram came from the first function. Further analysis determined that this is due to organizational constraints within the USN. Currently, the policy for the USN is that all DS is initiated by the Fleet al.though from a shore perspective, it may be possible to reach into the system remotely to provide support. This is not possible without Fleet approval, and any information gained from these remote sessions is fed back via email. While this is the case currently, it can be inferred that at a later time this policy may change, and it would be possible to see the main outputs shift to the other functions of DS. The mechanism for box 1 was the technical assistance interface component.

The second function was shown in box 2 "Perform Remote Diagnostics." The input for this function was "HEL System Information" (I2). The control under which this function was activated was "System Faults Detected" (C2). This function produced several outputs; the first output from this function was "Performance Data," which would be related to the performance of the HEL system. This information may include elements such as: the amount of beam jitter that exists, the power output of the battery storage system, the beam quality, and the cleanliness of the director mirrors. The second output of function 2 was "System Status Data." This category could include the status of link data cables for the HEL system and whether all major subsystems were reporting operational. The last output from function 2 was "Fault Data and Error Codes" this may include application error codes being reported from the HEL system, or the results from BIT from the HEL system. The mechanism under which function 2 was completed was the "Remote Diagnostic Component."

The third function was shown in box 3 "Perform Remote Repair and Validation." In addition to "HEL system information" (I1), this function took all the outputs from function 2. The controls for the activation of this function were both a "Request for Technical Assistance" and "Trouble Shooting Procedures." Operationally speaking, when support is provided remotely to a system, every opportunity is made to obtain as much information from the system as possible before attempting a remote connection. This connection will be made in a bandwidth constrained environment, so it should be accompanied by troubleshooting procedures to minimize the duration of the remote connection. The output from this function was the collection of “System Baseline Faults.” These “System Baseline Faults” could include a missing adaptation load or a network configuration setting that was out of an approved baseline. These baseline faults are reported back to the Fleet through email (indicated as an input to function 1). The mechanism under which function 3 was accomplished was the remote connection component.

The last function was “Perform Remote Monitoring.” This was the proactive form of DS that was modeled. The input to this function was “HEL System Information.” The control under which this function was activated was “System Faults Being Detected.” What this implied was that remote monitoring of the HEL system was continuous in nature and that this function was actually the report out of system faults. This function was activated when a system fault was detected, which would result in the DSHEL system reporting out. This report was to be used as a way to initiate a remote tech assist, indicated by showing the output from function 4 as a control to function 1. The mechanism under which function 4 was performed was the “Remote Monitoring Component.”

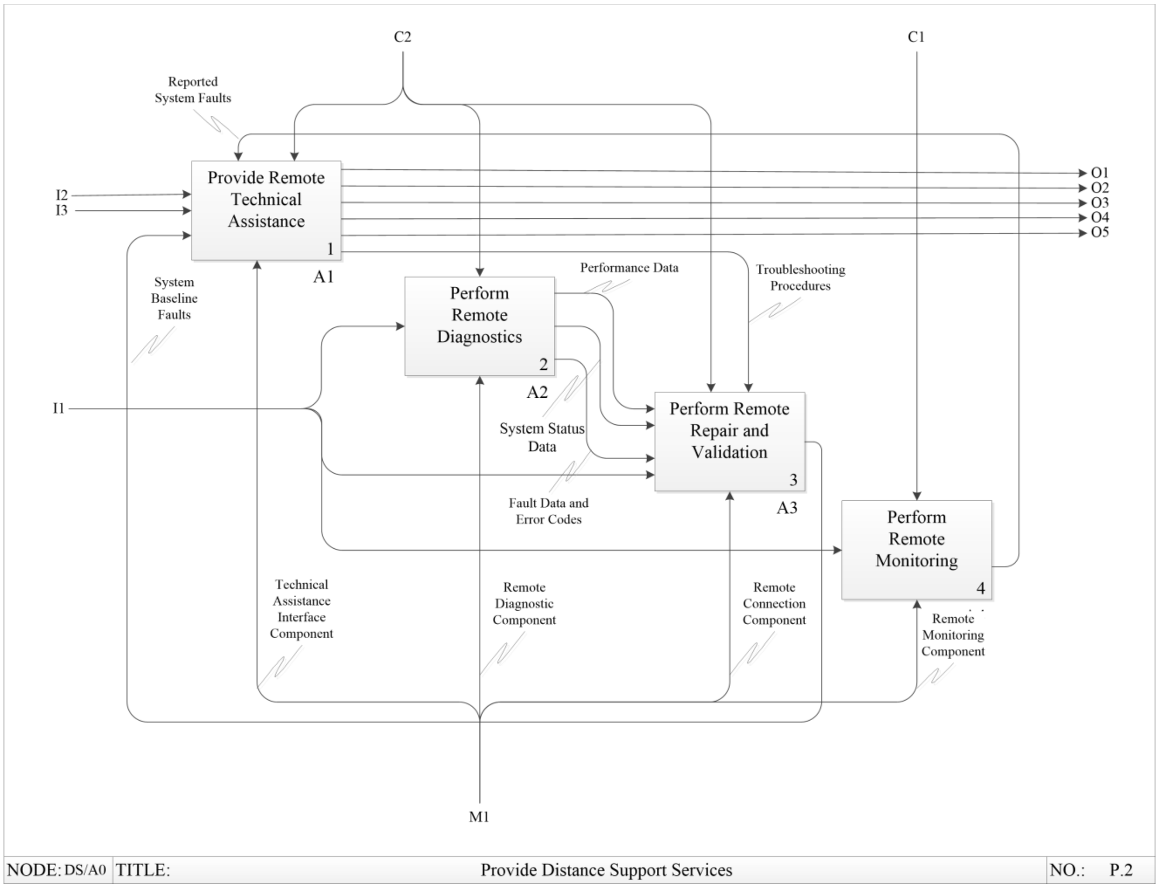

Figure 75. Provide Distance Support Services

The next diagram, A1 shown in Figure 76, breaks out the "Provide Remote Technical Assistance" function into various sub-functions. This diagram shows three sub-functions that make up the top-level function. Function 11 was "Provide Email Support." All the outputs shown are derived from this function. This was operationally driven rather than system driven. The other outputs that should be noted from this function were the request for chat support or phone support, which served as controls for the other two functions in this diagram. The outputs from functions 12 and 13 are shown with tunneling arrows, which indicates that they are not shown on higher-level diagrams. This was allowed for simple functions under the IDEF0 specifications. This was used when the function output was simple and did not relate to any other system or function. The mechanisms that supported each of these functions were an email client, chat client, and Voice over Internet Protocol (VoIP) client.

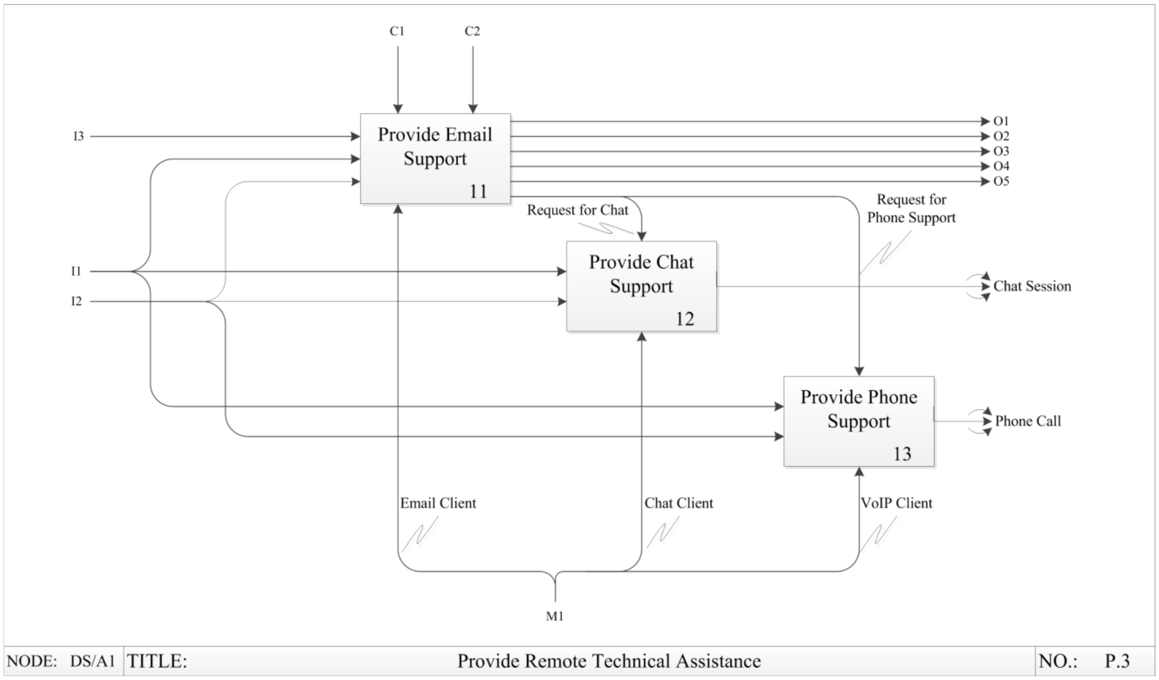

Figure 76. Provide Remote Technical Assistance

The next function that was broken out can be seen in A2 shown in Figure 77 "Perform Remote Diagnostics." These functions include "Observe System Performance," "Observe System Status," and "Observe System Faults" (21, 22, and 23 respectively). The aforementioned took "HEL System Information" as an input, and output "System Performance Data," "System Status Data," and "Fault Data and Error Codes." The mechanism under which each of these functions was accomplished was the "Performance Monitoring Element," "System Status Monitoring Element," and the "Fault Detection Fault Isolation Element." This function was not broken down further for the purposes of DSHEL.

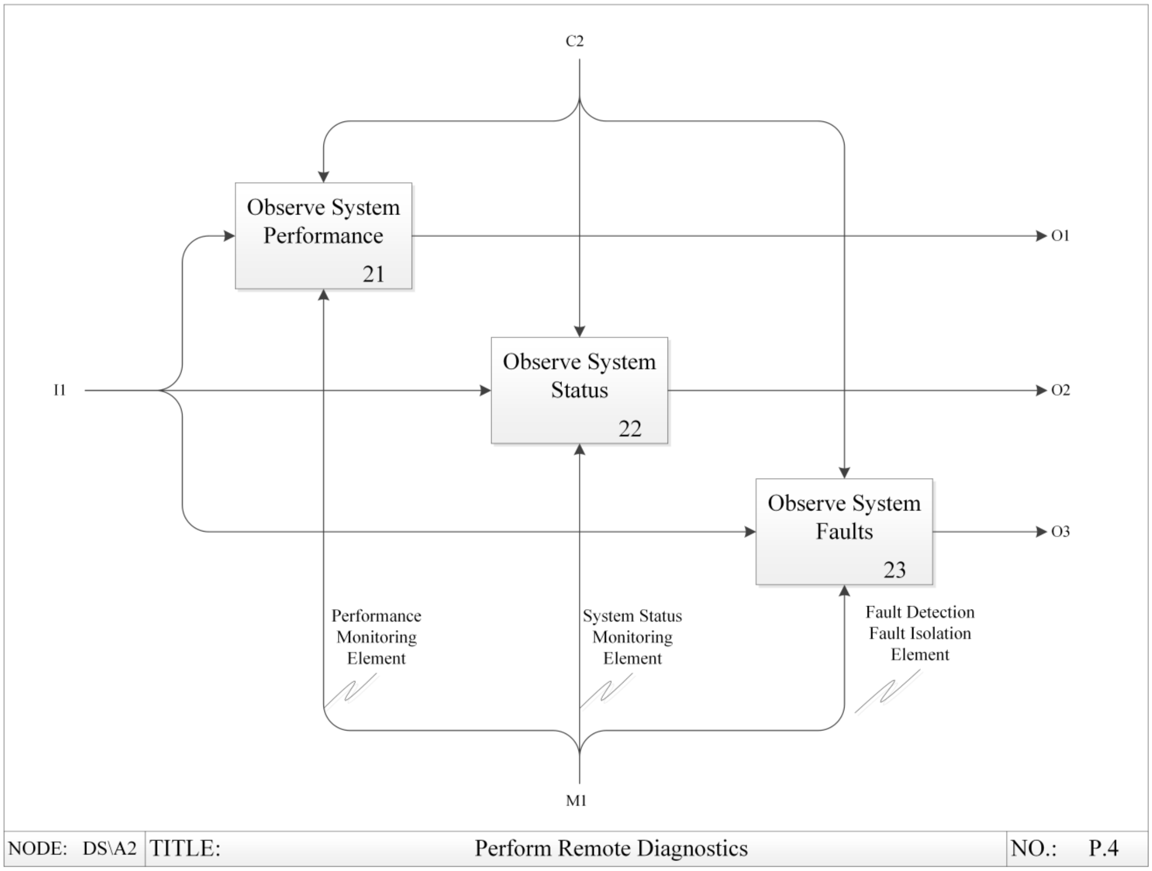

Figure 77. Perform Remote Diagnostics

The next decomposed function was A3, “Perform Remote Repair and Validation.” illustrated in Figure 78. The first sub function was 31 “Verify Adaptation Data Load.” This function took as an input the “HEL System Information” and provides as an output “System Baseline Faults.” The mechanism that would perform this function was the “Adaptation Data Checker.” The next function was 32 “Verify Baseline Configuration.” This function took as an input “HEL System Information” and provided as an output “System Baseline Faults.” The mechanism that would perform this function was the “Configuration Baseline Manager.” The next function was 33 “Run System Diagnostic Tests.” This function took as an input “HEL System Information” as well as “Performance Data,” and “Fault Data and Error Codes.” The mechanism under which this function was performed was the “System Diagnostic Tool.” The output from this function was “System Baseline Faults.” The last function was 34 “View System Status Logs.” The inputs to this function are “HEL System Information,” and “System Status

Data." The output from this function was "System Baseline Faults" and the mechanism under which this function was performed was the "Log Viewer." All of these functions would be performed when both a "Technical Assistance Request" was received from the Fleet and when "Troubleshooting Procedures" had been developed to perform the remote repair and validation.

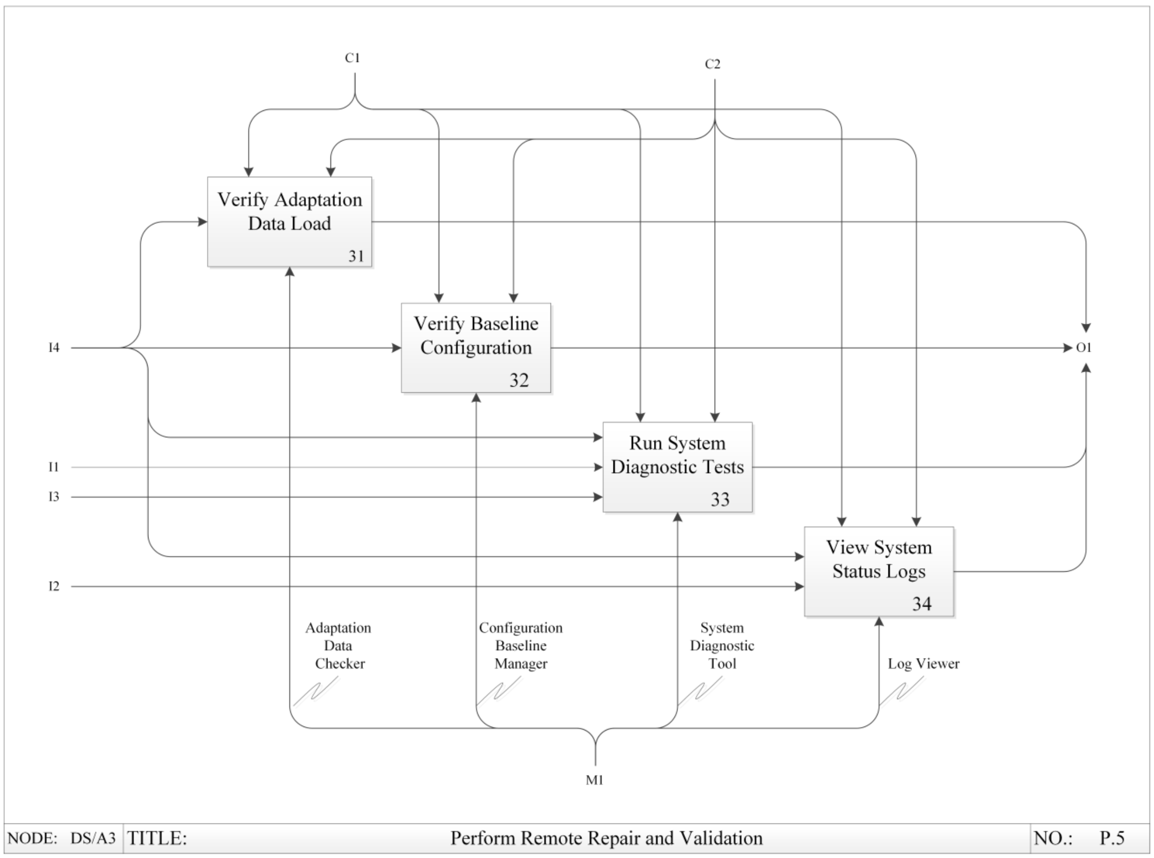

Figure 78. Perform Remote Repair and Validation

The last major function decomposed was A4 "Perform Remote Monitoring" shown in Figure 79. This was the proactive type of DS which was modeled in this capstone. This function was made up of four sub-functions "Collect System Status Information," "Collect Fault Information," "Collect Logs," and "Collect Performance Information." This function breakdown was very similar to the major function A2 "Perform Remote Diagnostics." The difference between these two functions is that, in A4 the DSHEL system was continuously monitoring the HEL system and harvesting data which was analyzed for discrepancies and sent back to shore for further analysis by the SME. All of these functions take in "HEL System Information" as the main input and output any "Reported System Faults." The control under which a system fault would be reported is "System Faults Are Detected." Function 41 was performed by the "System Status Collection Tool." Function 42 was performed by the "Fault Analysis Collection Tool." Function 43 was performed by the "Log Collection Tool." Function 44 was performed by the "Performance Collection Tool."

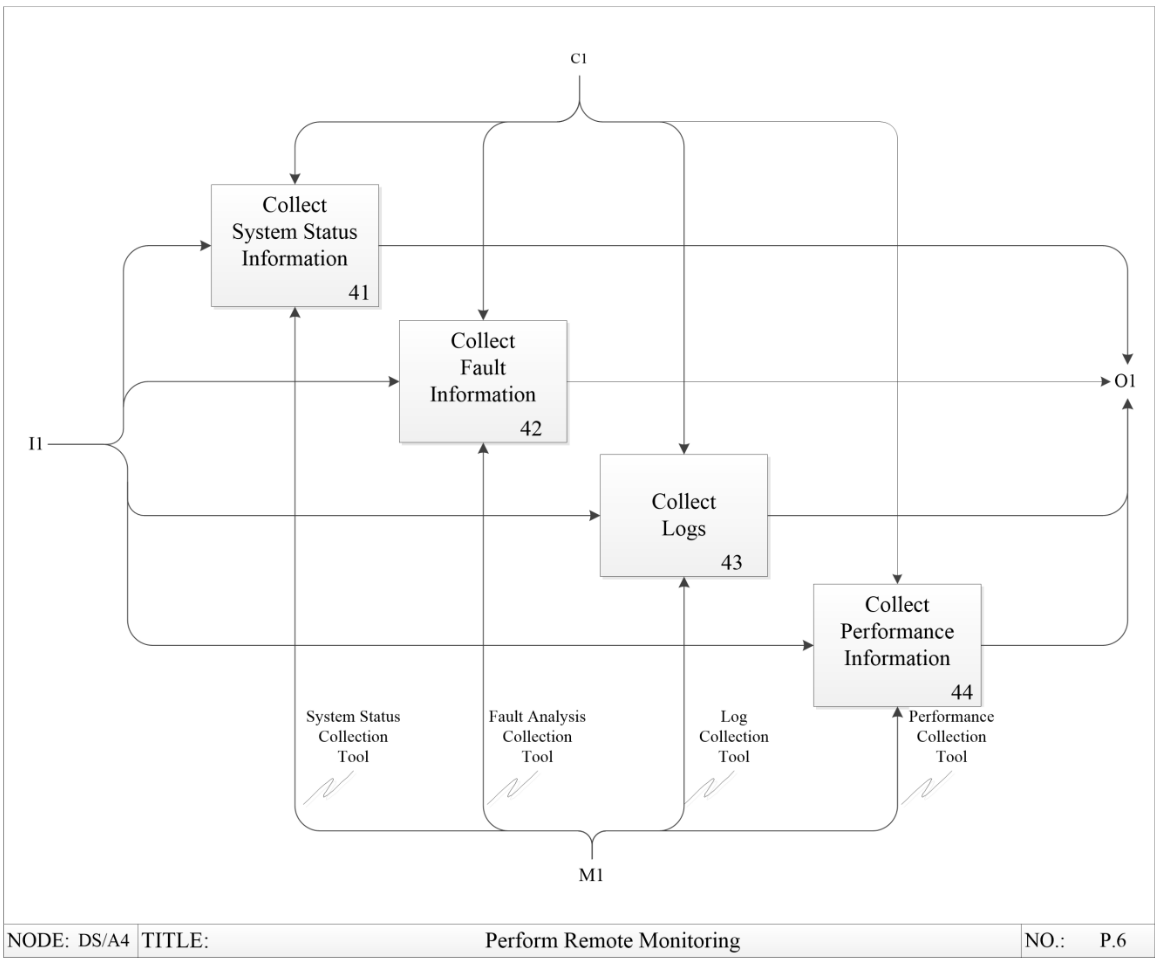

Figure 79. Perform Remote Monitoring

2. Proposed DSHEL System/Subsystem

This section introduces a notional DSHEL system sub-system design based on the IDEF0 diagram. Figure 80 shows a physical breakdown hierarchy tree, which correlates to the IDEF0 diagrams discussed in the previous section.

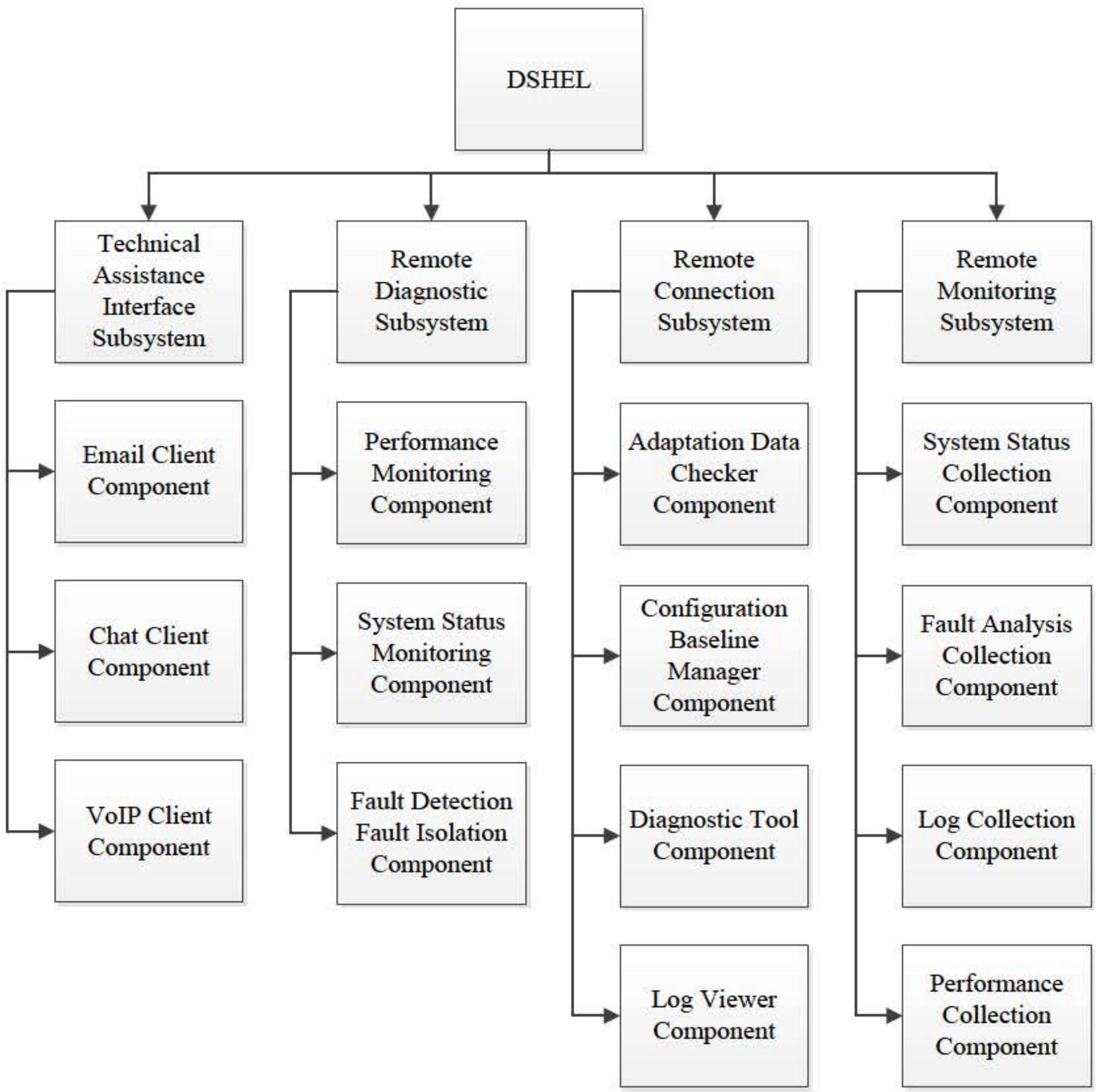

Figure 80. Physical Architecture

It should be noted that, although the physical architecture depicted separate physical components for the performance of each function, in reality several components may be software based and covered under a single piece of software. To illustrate this point, a notional system design was developed to show both the physical hardware and software components as depicted in Figure 81.

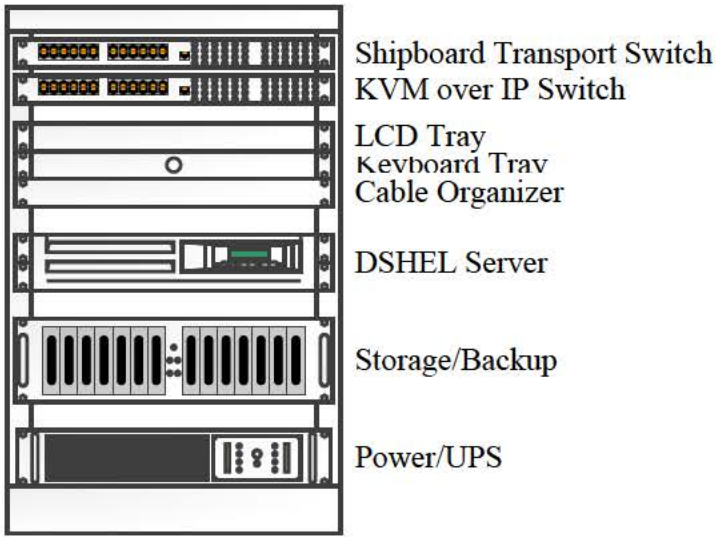

Figure 81. Notional DSHEL Hardware Architecture

The hardware architecture for the DSHEL system would consist of a high performance rack server that would be capable of hosting two separate virtual machine environments. Additionally, secure remote connection into the DSHEL system would occur through the use of an enterprise level KVM over IP switch. Local administration of the DSHEL system itself could occur through the use of the keyboard and monitor pull out tray. Data being stored on the system for trending and analysis, as well as backup of the virtual machine environments, would be satisfied through the use of an enterprise backup solution. It should be noted that many of the functions internal to the DSHEL system, such as backup and local administration, were not captured in the IDEF0 functional analysis. The focus was on the distance support service framework and not necessarily the DSHEL system; therefore, this functionality was not included. If this design was to be moved forward, it would be advisable that the scope and analysis of the IDEF0 architecture be decomposed further to include the internal functionality of the DSHEL system.

The software architecture in Figure 82 illustrates a notional application of software to implement the various distance support services. Modern shipboard hotel services are provided using a Windows-based environment. Therefore, it was determined that the technical assistance function would best be accomplished by leveraging the existing shipboard infrastructure for email, chat, and VoIP services. Additionally, although not shown here, the DSHEL system would also inherit many of the information security features inherent in the shipboard network such as Firewalls, IDS/IPS, and host based security. The main applications providing the functionality for remote monitoring, diagnostics, repair and validation would be accomplished by the Red Hat Enterprise Linux operating environment hosting the various data processing applications. Leveraging a virtual infrastructure for this distance support operating environment allows for better redundancy and decoupled the hardware and software environments, which would enhance future supportability of the DSHEL system.

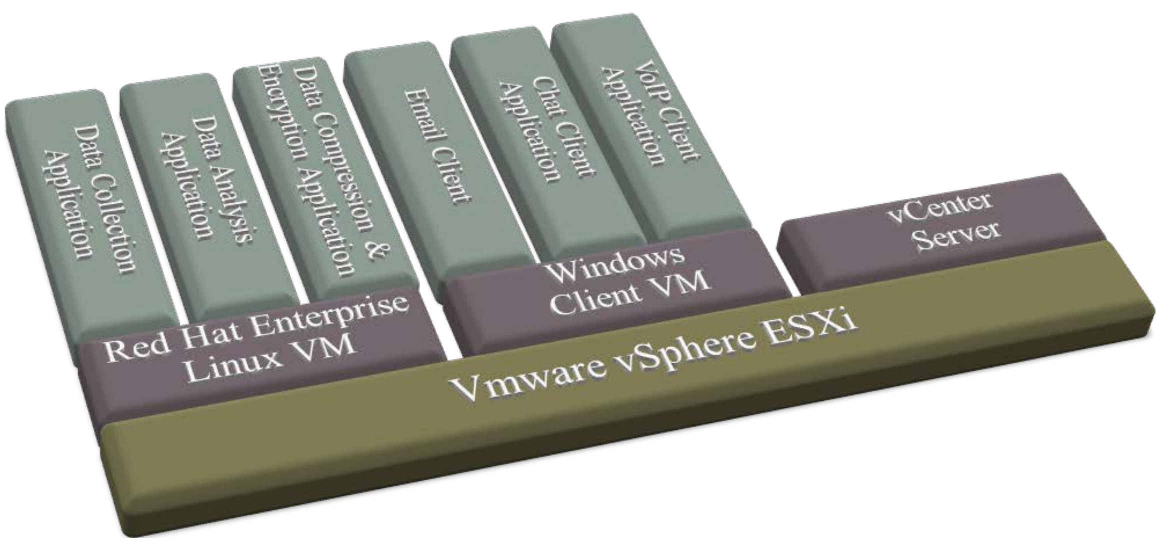

Figure 82. Notional Software Architecture

The hardware and software architecture for the DSHEL system are independent of the HEL system. This hardware could be used to monitor any tactical weapon or sensor system on a ship. It should be noted that although the hardware is shown as a separate rack of equipment, every attempt should be made to integrate this equipment into the host system that requires DS services. This would leverage the existing hardware and reduce cost. The choice of software was based on existing best practices within the USN. In general Windows, Red Hat, and VMware have become the standard for the USN when it comes to OS and virtualization software. It was the assumption of the team that whenever possible, the choice of components should align to prescribed USN guidance.

3. Notional DSHEL to HEL Interface

This section discusses information that the DSHEL system might collect. Figure 83 shows a notional architecture for the interface between the DSHEL system and the HEL system.

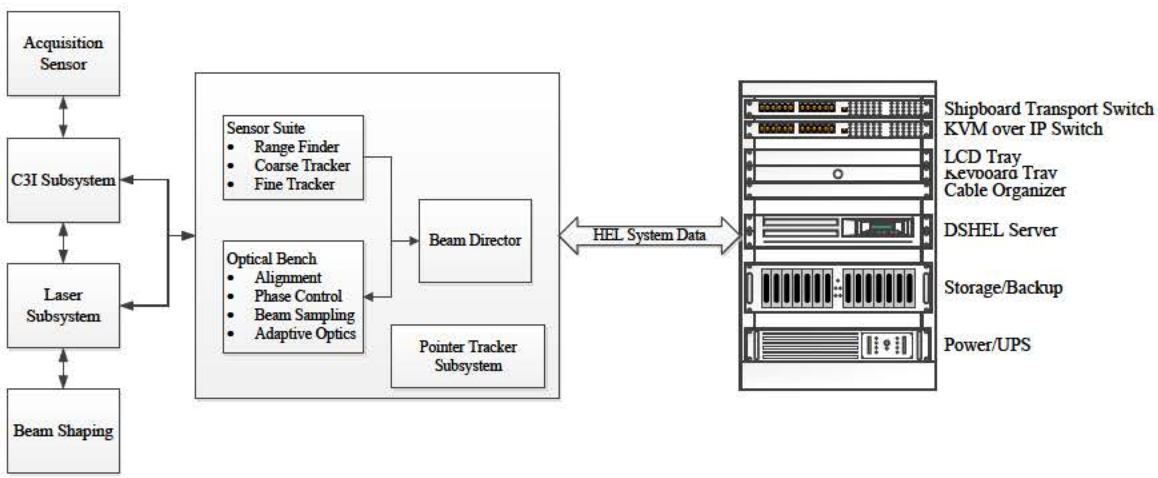

Figure 83. Notional DSHEL to HEL Interface

DSHEL will be collecting system performance data, as well as system faults as they occur. The basic HEL system and common system fault detection that would be onboard USN platforms was discussed next. This should in no way be interpreted as an exhaustive list of parameters that can be monitored in general; these parameters were developed given the assumptions at the time of DSHEL's creation. This list would, in the future, require further refinement in the event the DSHEL system is implemented.

A laser weapon damages a target by focusing a beam of light for a finite period of time on a specific aim point. The effectiveness of the weapon system depends critically on the following (Perram, Salvatore, Hengehold, and Fiorino 2010):

- the power *P* of the laser
- the wavelength of light λ
- the diameter of the primary mirror *I*
- the range to the target *R*
- the dwell time τ_D

These are the main parameters that affect the performance of the laser; however, there are many other parameters which should be discussed that are of interest from a monitoring perspective.

The *irradiance,* with typical units of watts per centimeter, represents the delivered laser power divided by the beam area.

$$I = \frac{P}{A}$$

Fluence, or energy per unit area, delivered by the HEL to the target represents the irradiance accumulated over the dwell time, and is defined as:

$$F = P\tau_D \left(\frac{\pi D^2}{4R^2\lambda^2}\right)$$

The laser power, wavelength, and mirror diameter are parameter associated with the laser weapons system, whereas the range and dwell time depend on the engagement. Typically, these types of parameters are grouped separately:

$$F = B\frac{\tau_D}{R^2}$$

Where the collection of source parameters is called the brightness:

$$B = S\frac{\pi P}{4(\lambda/D)^2}$$

The system Strehl (S) is the value less than unity representing many effects that might increase the effective spot size beyond the diffraction limit. When S=1, the maximum performance is achieved and the brightness is diffraction limited. Strehl is usually defined as the ratio of on-axis irradiance to the diffraction –limited on-axis irradiance:

$$S = \frac{I(r=0)}{I_{DL}(r=0)}$$

Many real-world effects are buried in the overall system Strehl, including jitter, atmospheric turbulence, thermal blooming, and adaptive optics effectiveness. The details of these phenomena are critical to the performance of most HEL weapon systems (Perram, Salvatore, Hengehold, and Fiorino 2010).

In general, the DSHEL system collected information from the HEL system that could be used to determine the overall beam quality. This refers to monitoring the beam drift, jitter, scattering, absorption, turbulence, and thermal blooming. The beam control system attempts to maintain a small focused spot on a given aim point throughout an engagement. Beam control can be thought of as three separate categories of beam control, acquisition, and beam propagation.

In all of these various parameters, the assumption was made that the HEL system was logging and monitoring all of the aforementioned parameters internal to the HEL system. Additionally, the assumption was made that the acquiring of this data by the DSHEL system can be made through simple interfaces either from standard RJ45 Ethernet connections, RS-232/RS-422 serial connections, or USB connections. In certain cases it may be necessary to collect environmental data from the HEL system such as ambient temperature around the HEL system, or vibrational information from the adaptive optical sub-system. An additional assumption was made that this data was also being collected by the HEL system and could be acquired through standard interfaces, and that the data was transmitted through standard protocols such as UDP, TCP/IP, and SNMP.

4. Notional DSHEL to Shipboard Network Interface

In addition to the interface between the DSHEL system and the HEL weapons system, there also exists an interface between the DSHEL system and the rest of the shipboard network. Since the DSHEL system requires off ship connectivity, the typical path that the DSHEL system would take was considered. It was assumed that a typical shipboard environment with the necessary enclave security requirements in place such that the DSHEL system could accept secure connections from off ship as well as transport data off ship in a secure manner. Figure 84 shows a typical shipboard architecture.

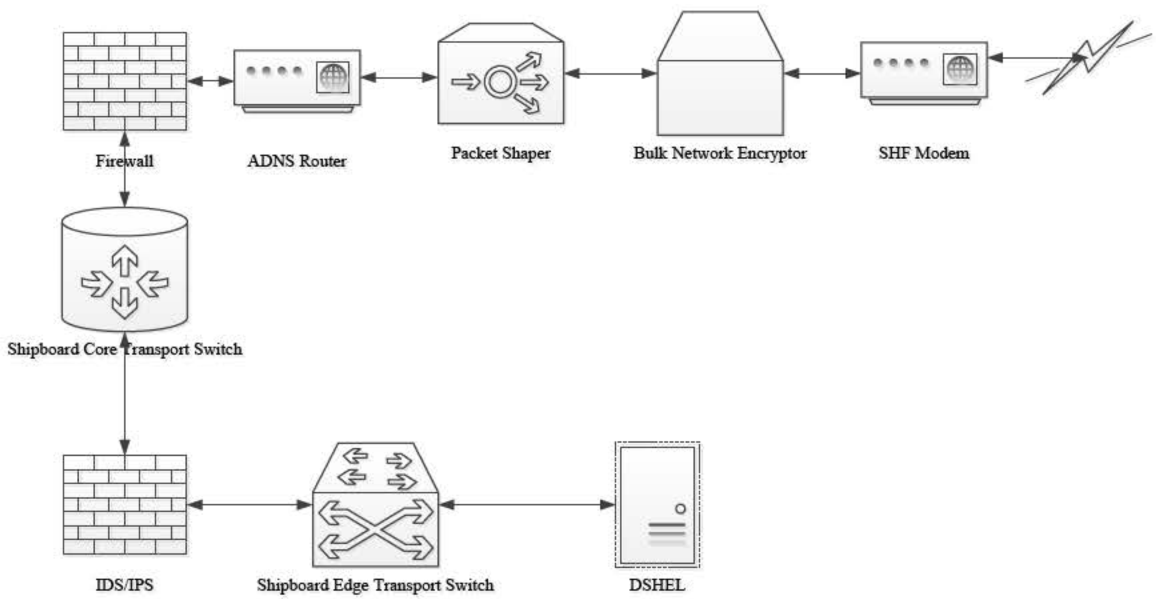

Figure 84. DSHEL to Shipboard Network Interface

Starting from the DSHEL system, the server would maintain a persistent connection to a shipboard edge transport switch. Protection at the transport layer for inbound/outbound connections internal to the network, as well as off ship, was provided through the employment of an IDS and an IPS. An IDS/IPS is a network security appliance that monitors network traffic for malicious activity. From the IDS/IPS, the data was passed to the shipboard core transport switch. Next, the signal must pass through the shipboard firewall. The function of the firewall in a shipboard environment is to establish a barrier between a trusted secure internal network (shipboard) and another network, in this case the SIPR/NIPR network.

Once the data negotiates through the firewall, it would pass through the ADNS router, and priority would be assigned via a packet shaper. Finally, all traffic flowing off ship goes through a bulk network encryption device. It was assumed for the purpose of this capstone that the bandwidth off ship was constrained and that significant testing would need to be accomplished in order to ensure that the level of distance support needed by the HEL system could be provided.

The configuration and maintenance of this connection was critical to the ability to provide the DS capability. As such, it was determined that it would be necessary to develop a service level agreement (SLA) that would describe the connection configuration as well as the accepted level of performance in order to provide the DS capability for the HEL system.

The entire design of the DSHEL system started with the internal functional analysis of the system describing the DS services which DSHEL provided and by utilizing the IDEF0 modeling framework. The section went on to describe the physical architecture of the DSHEL system, as well as notional hardware and software architectures. Finally, interface requirements were considered when developing the relationship between DSHEL and HEL, as well as between DSHEL and the shipboard environment.

C. TEST AND EVALUATION

The implementation of the DSHEL system would require significant testing to ensure requirements for DS are met. This section discusses the testing and evaluation that was scoped for DSHEL. In addition to the testing and evaluation methodology that was determined to be sufficient to meet the requirements for DSHEL, as well as each of the three phases of testing that should be pursued for implementation of the DSHEL system. These three phases of testing were shore-based testing, transport layer testing, and shipboard testing.

1. Test and Evaluation Methodology

Several types of test and evaluation are performed depending on the phase and effectiveness of the evaluation effort. These testing phases are broken into four types of testing. Type 1 testing would take place during the initial phase of detail design and covers the testing of system components for function and performance. This would include the testing of various operating and logistic support actions that are directly comparable to tasks performed in a real operational situation. Type 2 testing is the point when preproduction prototype equipment, software, and formal procedures are available. Type 3 testing would cover the production model testing at designated test sites. Type 4 testing would be conducted during operational utilization and support phase, measuring the system utilization rate to determine the total system effectiveness and on life-cycle costs (Blanchard and Fabrycky 2011).

The goal of testing the DSHEL system is to provide assurance to all stakeholders that requirements and objectives are met. It is assumed that once the DSHEL system design had been formalized and executed, then the system would be tested in accordance with a formal test and evaluation master plan (TEMP) that was assumed to be part of the larger HEL acquisition program. An assumption was made that all testing related to the DSHEL system would align closely with the developmental and operational testing of the HEL system. Based on these assumptions, this section will cover in more detail the Type 3 testing that would occur for the DSHEL system. More detail will be provided to outline a phased approach to testing during the initial operational test and evaluation (IOTE) phase of the HEL development. This will include a shore-based testing phase, transport layer testing phase, and shipboard testing phase.

Testing is segregated in this fashion to separate the major interface testing from the integration testing. The shore based testing will be used to test the DSHEL system itself and the major interfaces between the DSHEL system and the HEL system. The transport layer testing will evaluate the major interfaces between the DSHEL system and the shipboard network in a land based facility excluding any connection with the HEL system itself. Finally, the shipboard end to end testing will cover full integration from HEL to DSHEL to shipboard network.

2. Shore Based Testing

The shore based testing includes the development and execution of system operational verification tests (SOVT) of the DSHEL system itself. This test ensures that both components, hardware and software, are operating as required.

The shore-based test also assesses all of the major interfaces between the DSHEL system and the HEL weapon system. This includes testing to ensure all formats of the data could be collected from the major subsystems of the HEL. The testing also evaluates how well the DSHEL system performs each of the major DS functions using approved measures of effectiveness (MOEs).

3. Transport Layer Testing

The transport layer testing demonstrates the connection between the DSHEL system and the shipboard transport layer. This also includes testing the connection between the ship and shore; it is used to validate the functionality of the DSHEL over a low bandwidth connection in a controlled environment and includes two tests. The first test covers the usability of the DSHEL system as a function of bandwidth. The second test covers the usability of the DSHEL system as a function of overall satellite delay. The bandwidth test would determine the lowest acceptable bandwidth in which the DSHEL system can operate while remaining fully functional. The satellite delay test would determine the longest delay time the DSHEL system can operate with before the connection was lost.

4. Shipboard Testing

The shipboard testing was the final phase in support of the DSHEL system integration. This testing consisted of an end-to-end test from shore to HEL. It is advisable that this testing be conducted in conjunction with the installation of the DSHEL system on a specific platform, which would usually coincide with a ship restricted availability (SRA). After installation of the DSHEL system on a particular ship platform, a SOVT was performed on the DSHEL system. This test included various internal components of the DSHEL system as well interfaces to the HEL system and the shipboard network. Following the end of the SRA period, an underway test needs to be conducted to ensure the DSHEL system is communicating to shore via satellite.

Taking this phased approach to the testing and integration of the DSHEL system was very indicative of the ISEA process for testing used to bring a new installation onto a ship. This approach allows the ISEA and the OEM to determine at each phase of development whether the design is mature enough and effectively identify any difficulties with the design prior to installation on ship. This would mitigate the overall risk to final installation and use of the DSHEL.

D. VERIFICATION AND VALIDATION

Verification and validation are procedures used together to check that the DSHEL system meets the requirements and specifications and that it fulfills its intended purpose. The Project Management Book of Knowledge (PMBOK) defines verification and validation as (Project Management Institute 2004):

- Validation: the assurance that a product, service, or system meets the needs of the customer and other identified stakeholders. It often involves acceptance and suitability with external customers.
- Verification: the evaluation of whether or not a product, service, or system complies with regulation, requirement, specification, or imposed condition. It is often an internal process.

In general, verification is focused on determining whether the system meets the requirement of design. Validation is focused on whether the system meets the operational needs of the user.

1. Verification and Validation Methodology

The first step to understanding whether the requirements of a system have been met, is to understand which characteristics of the system require evaluation and assessment. Many systems in the field today lack the necessary feedback into true operation. It is for this reason that it is important to understand what factors need to be measured and what information is required to be monitored and recorded (Blanchard and Fabrycky 2011). Once the data requirements were defined, the next step was to design the DSHEL system to collect this information appropriately. Chapter II discussed the process by which the determination would be made for data that needed to be collected and monitored. Once this determination has been made, it is necessary to verify that the data was correct. If the determination is made that the data reveals issues with HEL, it is important to next consider how this information could be used to inform the program of design changes that might need to be made.

2. Verification and Validation Analysis

The process for the Verification and Validation of the HEL System by DSHEL is shown in Figure 85 which was adapted from the System Evaluation and corrective action loop (Blanchard and Fabrycky 2011). This process included a feedback loop allowing the information collected from the HEL system onboard ship to provide the program office and stakeholder's data which would eventually inform design decisions through sustainment.

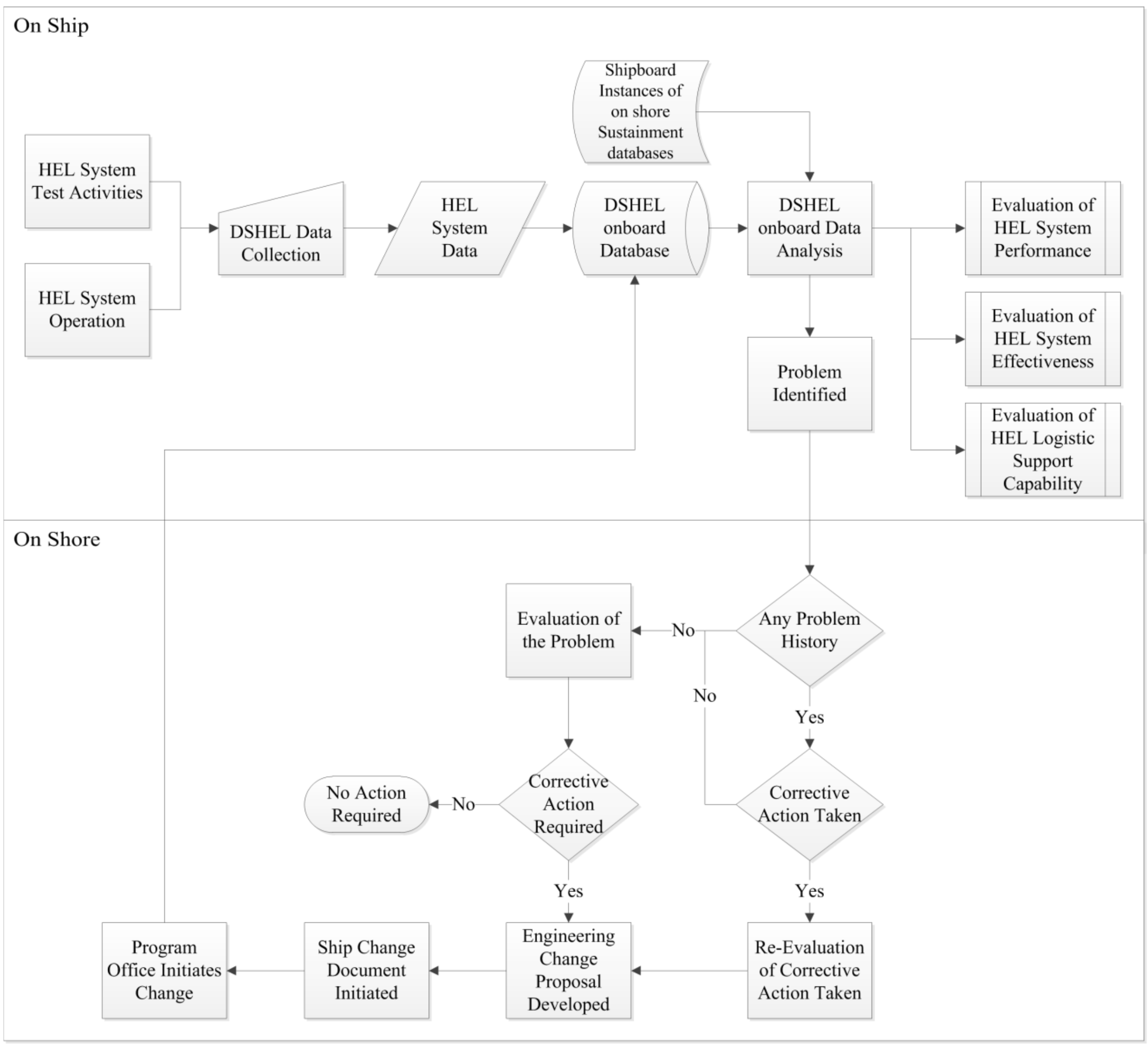

Figure 85. Verification And Validation Feedback Loop (after Blanchard and Fabrycky 2012)

The process began under the assumption that most data would be collected during either test activities or general shipboard operation activities, (indicated by rectangular process blocks). The main entity for collection and processing of this information would be the DSHEL system (indicated by the trapezoid). Many of the collection points were discussed in the previous section covering the physical architecture and were therefore not discussed here. All raw HEL system data (indicated by the rhombus) was collected, formatted, and stored in the onboard DSHEL database (indicated by the three dimensional cylinder). Once the information was stored, through a combination of automated analysis tools and user analysis tools the HEL system data would be correlated with on shore sustainment databases (indicated by the two dimensional cylinder) and analyzed to collect higher level metrics on performance, system effectiveness, and logistic support capability (indicated by the rectangular sub process blocks with the lines on either side).

These higher level metrics are to be forwarded to shore. In the event that a problem in the HEL system performance, effectiveness, or logistic support capability was detected, all relevant information related to the problem being detected is sent to shore. Once on shore, the problem is analyzed and correlated with historical information for the specific HEL baseline as well as other HEL baselines currently in operation within the Fleet. If historical information existed related to the observed problem, then it was used in conjunction with any corrective procedures that already existed to resolve the issue. These corrective procedures would, in many cases, fall under one of the major outputs from the previously described top level IDEF0 context diagram.

In addition to the corrective action being taken to remedy the immediate problem being seen on the specific platform, an evaluation of whether the problem was systemic in nature should be accomplished. If a determination was made that the problem was systemic in nature, affecting the whole baseline, then an engineering change proposal (ECP) would be developed.

This ECP includes an analysis of alternatives (AoA) and a long term cost analysis to enable the program office (PO) to make an informed decision on the HEL system design. Any changes that are proposed by the system engineer are to be traced back to system requirements that are not being met as a result of the current design. If the ECP is approved, then a more formal ship change document (SCD) is initiated. An SCD is the only approved path for implementation of a change on a fleet ship. The SCD process will not be discussed here; however, if the reader wishes to understand this process further, the SCD process is governed under the Navy Modernization Process – Maintenance Operations Manual (NMP-MOM). An SCD is a living document that outlines all aspects of a system that might be affected by said change. This includes, not only a description of the changes, but an identification of all logistical impacts, distributed system impacts, a detailed cost benefit analysis, fielding plan, Applied Figure of Merit (AFOM), as well as identification of any testing that may be required for the system should this change be approved.

Once the SCD had been initiated and approved by the Fleet for installation on hull, the information would be fed back to the DSHEL onboard ship. Updates to the analysis portion of the DSHEL system would inform the user of the long-term corrective actions in place.

The verification and validation feedback loop for the DSHEL design provided a critical component to the sustainment of the HEL system that is lacking in many of the fielded systems today. Furthermore, the feedback loop aligns to existing USN procedures for configuration management (CM) and ship change processes. Any analysis done by the DSHEL system was not lost rather it allowed the HEL system design to mature over time causing the system to become more reliable. Ultimately, this would allow the stakeholders for the HEL system to realize a lower life-cycle total ownership cost.

E. SUMMARY

This chapter discussed several important factors related to the DSHEL system. Building on the stakeholder needs analysis and the requirements analysis that was discussed in Chapter II and III respectively, this chapter provided a concept definition and design. The chapter began with a discussion of the architectural design approach that was used by the team. This included a discussion of the functional physical and allocated architecture concepts. The chapter went into the actual architecture design for the

DSHEL system. Included in this effort, were the requirements which drove the development of the functional IDEF0 diagrams for the system, proposed system sub-system diagrams, notional major interface diagrams between DSHEL and HEL, as well as the DSHEL and the shipboard network. The T&E methodology for the DSHEL system, as well as the verification and validation process for DSHEL, produced findings which would inform decisions made for the HEL throughout its life cycle.

V. MODELING AND SIMULATION

The following sections detail the modeling and simulation (M&S) effort performed to analyze the models of DS: Status Quo Distance Support, Integrated Distance Support, and No Distance Support.

The purpose of M&S is to quantify and gain insight into the effects of integrated DS implementation. The primary objective for M&S was to establish easy to understand, flexible models that can be used to make decisions on how to implement DS. A secondary objective was to enter unbiased, publically releasable values and distributions into the models to study the results. The final objective was to create a theoretical "No Support" model to show the effects of non-existent DS from future systems and platforms.

A. MODELING AND SIMULATION METHODOLOGY

Two complementary methods were utilized to create a complete picture of DS impact. A frequency model was created as a spreadsheet to assess system A_o in a format that is commonly reported. The second method utilized a modeling and simulation tool to go beyond a single number result and explore the time-based result of distance support implantation.

1. Frequency Modeling

The frequency model uses spreadsheet analysis, as is commonly performed in annual reviews for system effectiveness. The analysis seeks to determine HEL System A_o. This information was used conjunction with maintenance costs to make an effective AoA. Strong variation in administrative delay time and active maintenance time are expected between models. Benefits of this method include: common format currently presented to decision makers, only high-level average values are necessary for input, and simple calculations determine all results. The primary downside of this analysis is that a single value for A_o and maintenance times is produced. Larger data sets result in higher fidelity of decision making, whereas a single value is limiting.

2. Time Modeling

The time model uses M&S tools to take basic values and answers to simple questions to determine time-based distributions. The analysis method also seeks to determine HEL Down Time, which is an input used to determining A_o.

B. MODELING AND SIMULATION TOOLS

Two software tools were utilized for the M&S effort:

- Microsoft Excel 2010
- Imagine That ExtendSim Version 9.1

These two tools were utilized due to their familiarity and wide spread use in industry and USN academia.

C. MODEL DESCRIPTION

Three models were created for the M&S effort: Status Quo Distance Support, Integrated Distance Support, and No Distance Support. Below, each of these models is explained through in-depth analysis.

1. Status Quo Distance Support

The Status Quo Distance Support Model is based on level of repair analysis (LORA) currently implemented on most USN platforms. A basic depiction of the process can be seen in Figure 86 where many problems are encountered at the Organizational Level. Some are resolved and the rest are passed to the next level of repair, and so forth. The Status Quo Model depicts a multi-stage support model. There are four levels of support: Organizational Level Repair, Intermediate Level Repair, ISEA Level Repair, and Flyaway Repair. Figure 87 details the model logic and functional flow decision process which governs the simulation. In the model decision flow diagram, rectangles represent processes which cause time expenditures and diamonds represent decision points or path selection.

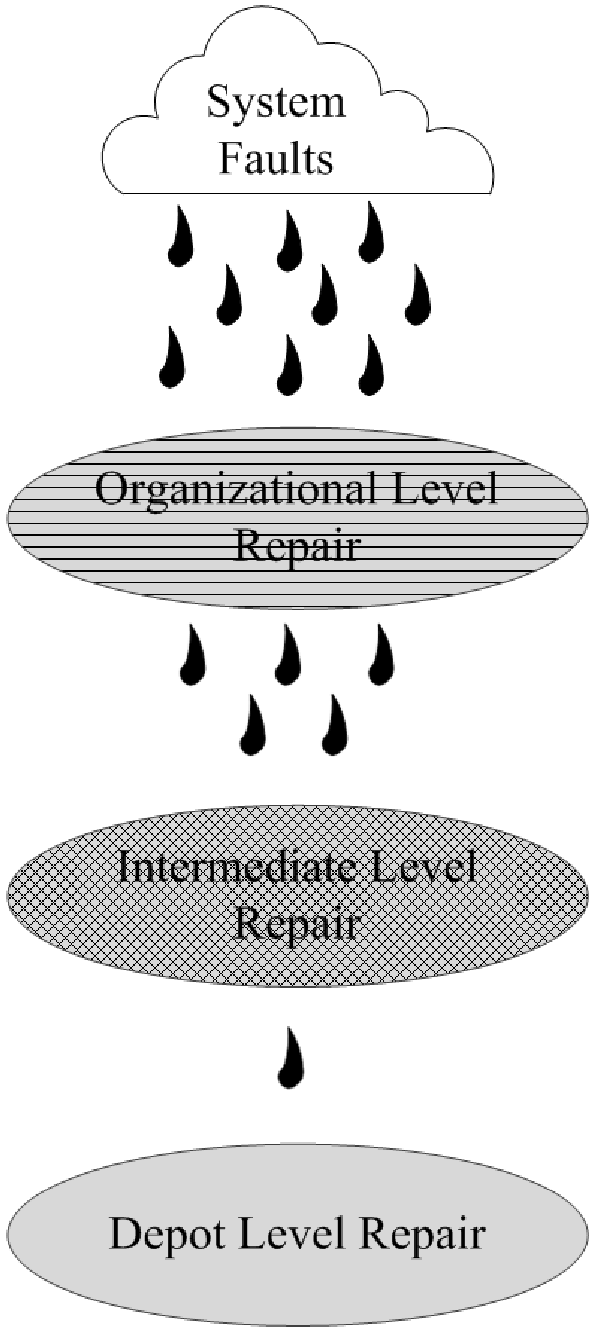

Figure 86. Levels of Repair - Status Quo

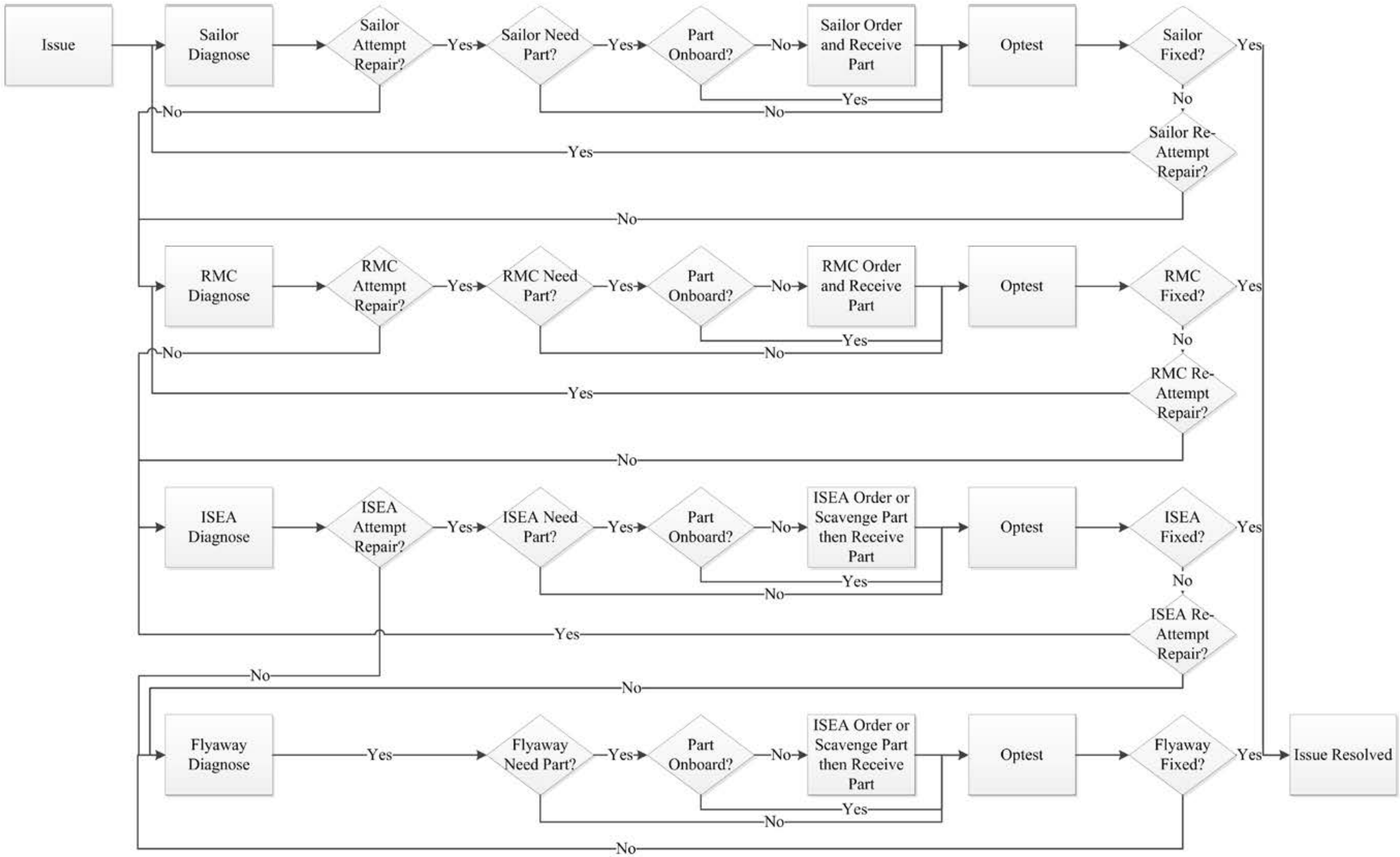

Figure 87. DSHEL - Status Quo Model Decisional Flow

The DSHEL – Status Quo Model Decisional Flow Diagram shows the decision path for system issue resolution in its current state. It represents a multi-tier level of support structure as described in DODD 4151.18 (United States Department of Defense 2004):

- Organizational-Level Maintenance. Maintenance normally performed by an operating unit on a day-to-day basis in support of its own operations. The organizational-level maintenance mission is to maintain assigned equipment in a full mission-capable status while continually improving the process. Organizational-level maintenance can be grouped under categories of "inspections," "servicing," "handling," and "preventive maintenance."
- Intermediate-Level Maintenance. That materiel maintenance that is the responsibility of, and performed by, designated maintenance activities in support of using organizations. The intermediate-level maintenance mission is to enhance and sustain the combat readiness and mission capability of supported activities by providing quality and timely materiel support at the nearest location with the lowest practical resource expenditure. Intermediate-level maintenance includes limited repair of commodity-orientated components and end items, job shop, bay, and production line operations for special mission requirements; repair of printed circuit boards, software maintenance, and fabrication or manufacture of repair parts; assemblies, components, and jigs and fixtures, when approved by higher levels.
- Depot Maintenance. That materiel maintenance requiring major overhaul or a complete rebuilding of parts, assemblies, subassemblies, and end items, including the manufacture of parts, modifications, testing, and reclamation as required. Depot maintenance serves to support lower categories of maintenance by providing technical assistance and performing that maintenance beyond their responsibility. Depot maintenance provides stocks of serviceable equipment because it has available more extensive facilities for repair than are available in lower maintenance activities. Depot maintenance includes all aspects of software maintenance.

In the decisional flow model, the sailor represents the Organizational-Level Maintenance. The sailor recognizes the failure and performs diagnostics on the system. If it is within the sailor's ability, he will attempt repair of the system. If the sailor feels the problem is beyond their ability, the problem is immediately elevated to the RMC. If repair is attempted by the sailor, it is assessed if a part is needed. It will next be necessary to determine whether or not the part is available onboard. If not onboard, the part must be ordered through the supply system and delivered to the ship. If all required materials are present (a part is not needed, a part is needed but onboard, or a part is ordered and received), then the repair attempt is made on the system and operationally tested. Upon completion of the operational test, the system is assessed as fixed or not fixed. If the problem is fixed, then the flow ends with a resolved issue. If the issue is assessed as not fixed, the sailor may or may not re-attempt repair of the issue. If re-attempt is decided, sailor diagnostics is repeated. If re-attempt is considered beyond the ability of the sailor, then the issue is elevated to the RMC.

In the decisional flow model, the RMC represents the Intermediate-Level Maintenance as it relates to DODD 4151.18. The RMC receives failure notification and performs diagnostics on the system. If it is within the RMC's resources and abilities, it will attempt to repair the system. If the RMC feels the problem is beyond its resources or abilities, the problem is immediately elevated to the ISEA. If repair is attempted by the RMC, it is assessed if a part is needed. It will next be necessary to determine whether or not the part is available onboard. If not onboard, the part must be ordered through the supply system and delivered to the ship. If all required materials are present (a part is not needed, a part is needed but onboard, or a part is ordered and received), then the repair attempt is made on the system and operationally tested. Upon completion of the operational test, the system is assessed as fixed or not fixed. If the problem is fixed then the flow ends with a resolved issue. If the issue is assessed as not fixed, the RMC may or may not re-attempt repair of the issue. If re-attempt is decided, RMC diagnostics is restarted. If re-attempt is considered beyond the ability of the RMC, then the issue is elevated to the ISEA.

In the decisional flow model, the ISEA represents a second level of the Intermediate-Level Maintenance. The ISEA receives a failure notification and performs diagnostics on the system. If it is within the ISEA's DS ability, it will attempt repair of the system. If the ISEA feels the problem is beyond repair through DS, the problem is immediately elevated to onboard support, referred to as a Flyaway Team. It consists of the same members as the ISEA but is specific to hands-on the system. If repair is attempted by the ISEA, it is assessed if a part is needed. It will next be necessary to determine whether or not the part is available onboard. If not onboard, the part must be ordered through the supply system or borrowed from resources available to the ISEA, such as from test sites, borrowed from other assets not currently in need of them, such as those in refurbishment, high-value spares, or loaned from production material, and delivered to the ship. If all required materials are present (a part is not needed, a part is needed but onboard, or a part is ordered and received), then the repair attempt is made on the system and operationally tested. Upon completion of the operational test, the system is assessed as fixed or not fixed. If the problem is fixed then the flow ends with a resolved issue. If the issue is assessed as not fixed, the ISEA may or may not re-attempt repair of the issue remotely. If re-attempt is decided, ISEA remote diagnostics is begun again. If re-attempt is considered beyond the capability of affective DS, then the issue is elevated to the Flyaway Team.

The Flyaway Team represents the third level of the Intermediate-Level Maintenance and the final level of current DS. Depot Maintenance is not present for corrective maintenance in most current systems. If information is needed from the manufacturer, it is the ISEA's responsibility to acquire that information. For that reason, Depot Maintenance is not included in the Status Quo Distance Support flow chart. The flyaway team becomes aware of the problem through its own organization (the ISEA) and travels to the ship. The Flyaway Team performs diagnostics on the system. It is assessed if a part is needed. It will next be necessary to determine whether or not the part is available onboard. If not onboard, the part must be ordered through the supply system or borrowed from resources available to the ISEA and delivered to the ship. If all required materials are present (a part is not needed, a part is needed but onboard, or a part is ordered and received), then the repair attempt is made on the system and operationally tested. Upon completion of the operational test, the system is assessed as fixed or not fixed. If the problem is fixed then the flow ends with a resolved issue. If the issue is assessed as not fixed, the flyaway team must re-attempt repair until the issue is resolved.

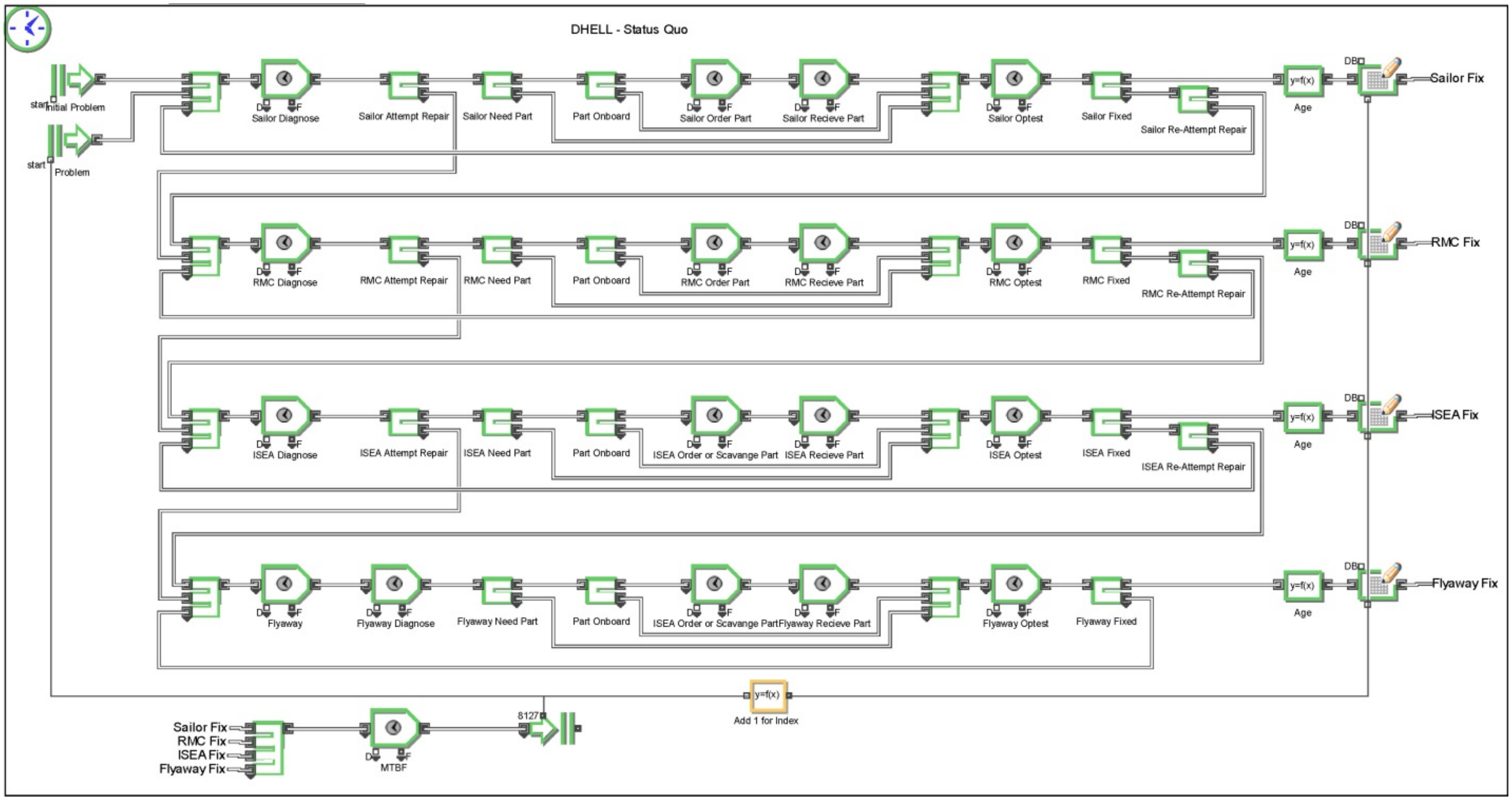

Figure 88. DSHEL—Status Quo Model

a. Organizational Level Repair

Organizational repair, as applied to USN DS and this model, refers to "Sailor" actions. The sailor is expected to follow a process to diagnose and attempt repair of the failed system to the best of his abilities. This procedure is the same for nearly every element of every combat system aboard ships. The sailor receives notification of the fault through automated monitoring of the system and daily operational tests. Diagnostics of the fault is then attempted using BIT and technical manuals. Depending on the training of the sailor, the severity of the apparent fault, and the resources available to attempt repair, the sailor can either attempt repair or defer the fault to the next level, which is the RMC. If repair is attempted at the organizational level, a part may or may not be needed; if it is needed, the part may or may not be onboard. If a part if needed and not onboard, it must be ordered through the supply system. After ordering, the part must be delivered to the ship. After receipt of the part, either through onboard spares or through the supply system, the part needs to be installed and operationally tested. After testing, the problem is either corrected or not. If the problem has not been corrected, the sailor may or may not re-attempt repair. If re-attempt is desired, re-diagnostics of the system is restarted. If re-attempt of repair is not sought, the problem is deferred to the next level of support.

b. Intermediate Level Repair

Intermediate repair, as applied to USN DS and this model, refers to RMC actions. The RMC follows a process to diagnose and attempt repair of the failed system to the best of its abilities. This procedure is the same for nearly every element of every combat system aboard ships. The RMC receives notification of the fault from the sailor by traditional methods such as phone and email. Diagnostics of the fault is then attempted using data provided from the sailor and technical manuals as well as lessons learned from repairing systems on other platforms. Depending on the severity of the apparent fault, and the resources available to attempt repair, the RMC can either attempt repair or defer the fault to the next level, which is the ISEA. If repair is attempted at the Intermediate Level, a part may or may not be needed; if it is needed, the part may or may not be onboard. If a part if needed and not onboard, it must be ordered through the supply system. After ordering, the part must be delivered to the ship. After receipt of the part, either through onboard spares or through the supply system, the part needs to be installed and operationally tested. After testing, the problem is either corrected or not. If the problem has not been corrected, the RMC may or may not re-attempt repair. If re-attempt is desired, re-diagnostics of the system is restarted. If re-attempt of repair is not sought, the problem is deferred to the next level of support.

c. ISEA Level Repair

ISEA Repair, as applied to USN DS and this model, refers to ISEA actions. Traditionally, depot maintenance is required after Intermediate Level Repair has failed or been deferred. However, because most ship systems cannot easily be removed and transported, the ISEA serves as the last two levels of repair for USN DS. In addition to having the maximum system documentation available for fault analysis, the ISEA has a direct relationship with the system manufacturer. The ISEA also witnesses and documents the most difficult system repairs across all platforms of which the system is installed.

The ISEA follows a process to diagnose and attempt repair of the failed system to the best of its abilities. This procedure is the same for nearly every element of every combat system aboard ships. The ISEA receives notification of the fault from both the RMC and Sailor by traditional methods such as phone and email. Diagnostics of the fault is then attempted using data provided from the sailor and technical manuals as well as lessons learned from repairing systems on other platforms. Depending on the severity of the apparent fault, and the resources available to attempt repair, the ISEA can either attempt repair or defer the fault to the next level, which is Flyaway Support. The support is performed by the ISEA in both cases. However, if enough information cannot be gleaned by remote reporting means, engineers and technicians from the ISEA may elect to travel to the ship for repair. Remote repair is attempted first in all but the most extreme cases. If repair is attempted at the ISEA Level, a part may or may not be needed; if it is needed, the part may or may not be onboard. If a part if needed and not onboard, it must be ordered through the supply system. However, the ISEA has several resources that all other entities do not. The ISEA, at its discretion, may scavenge parts from test systems or engineering models, loan parts from accumulated high-value spares, loan parts from future install allocations, and in extreme cases, borrow parts from the manufacturer. After ordering or scavenging,, the part must be delivered to the ship. The ISEA has at its discretion, overnight shipping. After receipt of the part, either through onboard spares or through the supply system, the part needs to be installed and operationally tested. After testing, the problem is either corrected or not. If the problem has not been corrected, the ISEA may or may not re-attempt repair by remote support. If re-attempt is desired, re-diagnostics of the system is begun. If re-attempt of repair is not sought, the problem is deferred to the next level of support which is flyaway support by the ISEA.

d. Flyaway Repair

Flyaway Repair, as applied to USN DS and this model, refers to ISEA actions as performed aboard ship. Traditionally, depot maintenance is required as the last level of repair when prior repair has failed or been deferred. However, because most ship systems cannot easily be removed and transported, the ISEA serves as the last two levels of repair for USN DS. In addition to having the maximum system documentation available for fault analysis, the ISEA has a direct relationship with the system manufacturer. The ISEA also witnesses and documents the most difficult system repairs across all platforms of which the system is installed. The ISEA can perform diagnostics with greater ease, speed, and accuracy than guiding a sailor in the actions. The ISEA also has specialized tools available to make diagnostics and repairs.

The ISEA flyaway team follows a process to diagnose and attempt repair of the failed system to the best of its abilities. This procedure is the same for nearly every element of every combat system aboard ships. The ISEA travels to the platform containing the system requiring repair. Diagnostics of the fault is then attempted using BIT and technical manuals as well as lessons learned from repairing systems on other platforms. All tests previously performed are re-run with new instrumentation. The ISEA must attempt repair and remain onboard until the problem is resolved. After diagnostics, a part may or may not be needed; if it is needed, the part may or may not be onboard. If a part if needed and not onboard, it must be ordered through the supply system. However, the ISEA has several resources that all other entities do not. The ISEA, at its discretion, may scavenge parts from test systems or engineering models, loan parts from accumulated high-value spares, loan parts from future install allocations, and in extreme cases, borrow parts from the manufacturer. After ordering or scavenging, the part must be delivered to the ship. The ISEA has at its discretion, overnight shipping. After receipt of the part, either through onboard spares or through the supply system, the part needs to be installed and operationally tested. After testing, the problem is either corrected or not. If the problem has not been corrected, the ISEA re-attempts repair until the problem is resolved.

2. Integrated Distance Support

The Integrated Distance Support Model represents the model that is proposed in the CONOPS of this effort. The model depicts a two-stage support model involving distance support level repair and flyaway repair. Figure 89 details the model logic and functional flow decision process which governs the simulation.

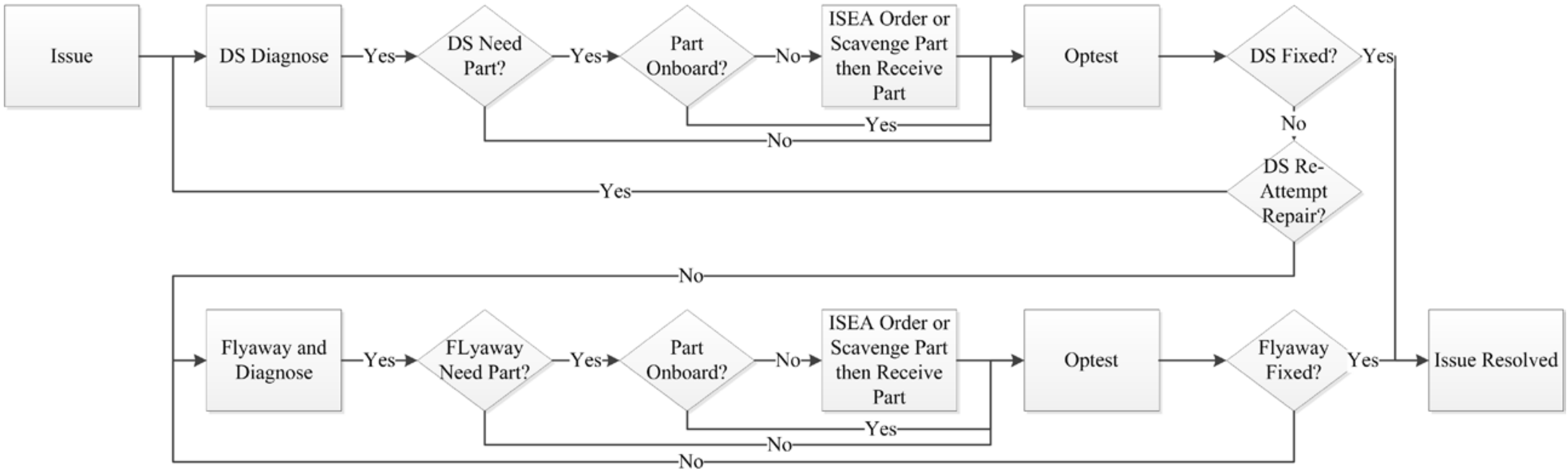

Figure 89. DSHEL - Integrated Distance Support Model Decisional Flow

The DSHEL—Integrated Distance Support Model Decisional Flow Diagram shows the decision path for system issue resolution in a theoretical future state as proposed by this effort. It represents a two-tier level of support structure that is an integration and evolution of the levels of support described in DODD 4151.18 (United States Department of Defense 2004). A basic depiction of the process can be seen in Figure 89 where many problems are encountered at the distance support level repair. Most are resolved and the rest are passed to the flyaway repair

In the decisional flow model, as compared to the Status Quo Model Decisional Flow Diagram, DS represents both the organizational-level maintenance and the first two levels of intermediate-level maintenance. The sailor recognizes the failure and connects with DS to perform diagnostics on the system. Remote diagnostics are conducted on the system and it is assessed if a part is needed. It will next be necessary to determine whether or not the part is available onboard. If not onboard, the part must be ordered through the supply system or borrowed from resources available to the ISEA and delivered to the ship. If all required materials are present (a part is not needed, a part is needed but onboard, or a part is ordered and received), then the repair attempt is made on the system and operationally tested. Upon completion of the operational test, the system is assessed as fixed or not fixed. If the problem is fixed then the flow ends with a resolved issue. If the issue is assessed as not fixed, the DS team may or may not re-attempt repair of the issue. If re-attempt is decided, DS diagnostics are restarted. If re-attempt is considered beyond the ability of DS, then the issue is elevated to the flyaway team.

The flyaway team represents the second and the final level of integrated distance support. Depot maintenance is not present for corrective maintenance in most current systems. If information is needed from the manufacturer, it is the ISEA's responsibility to acquire that information. For that reason, depot maintenance is not included in the Status Quo Distance Support flow chart. The flyaway team becomes aware of the problem though its own organization (the DS team) and travels to the ship. The flyaway team performs diagnostics on the system. It is assessed if a part is needed. It will next be necessary to determine whether or not the part is available onboard. If not onboard, the part must be ordered through the supply system or borrowed from resources available to the ISEA and delivered to the ship. If all required materials are present (a part is not needed, a part is needed but onboard, or a part is ordered and received), then the repair attempt is made on the system and operationally tested. Upon completion of the operational test, the system is assessed as fixed or not fixed. If the problem is fixed then the flow ends with a resolved issue. If the issue is assessed as not fixed, the flyaway team must re-attempt repair until the issue is resolved.

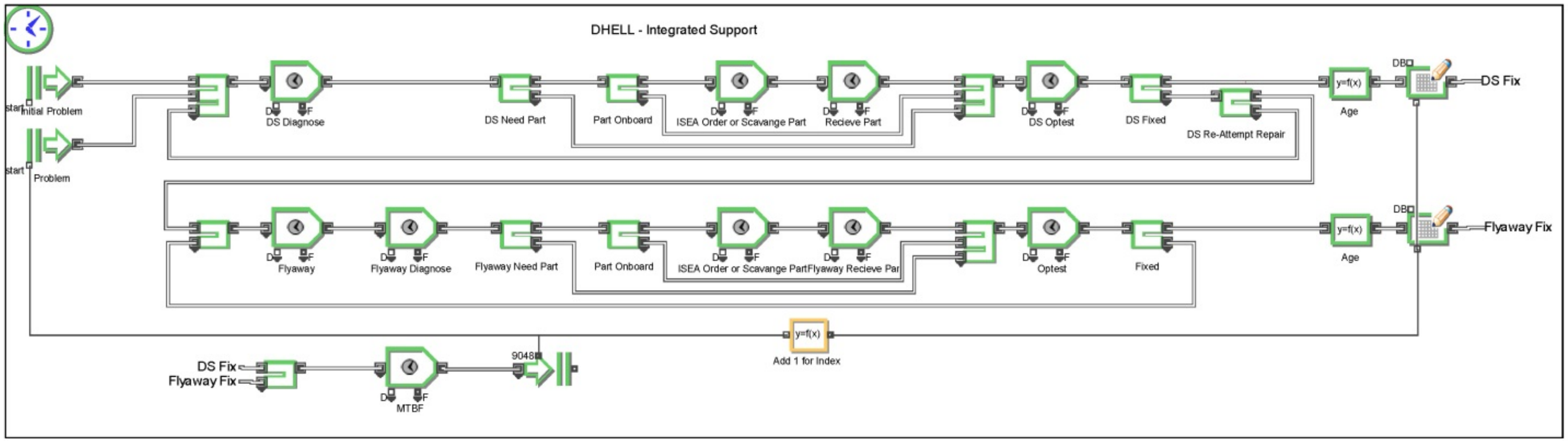

Figure 90. DSHEL - Integrated Distance Support Model

a. Distance Support Level Repair

Distance Support Repair, as applied to USN DS and this model is referred to in terms of sailor, RMC, and ISEA actions performed concurrently. The DS elements follow a process to diagnose and attempt repair of the failed system to the best of its abilities. This procedure is theoretical but is designed for nearly every element of every combat system aboard ships. The ISEA receives notification of the fault by an automated system, soon after the fault is detected onboard. Details of the fault and self-tests, as well as historical system health becomes available on a secure server for analysis. Secure chat is established with the ship if the shore-side support is not notified that the fault is inadvertent, such as due to power loss or cycling the system. Assuming the fault detected is a true fault, diagnostics of the fault is then attempted using data provided from the system, sailor, automated fault lookup, and technical manuals as well as lessons learned from repairing systems on other platforms. The CONOPS for this methodology requires that remote support always be attempted before the only other level of support, which is flyaway support. Diagnostics are performed between all parties on the integrated support system. A part may or may not be needed; if it is needed, the part may or may not be onboard. If a part is needed and not onboard, it must be ordered through the supply system. However, the ISEA has several resources that all other entities do not. The ISEA, at its discretion, may scavenge parts from test systems or engineering models, loan parts from accumulated high-value spares, loan parts from future install allocations, and in extreme cases, borrow parts from the manufacturer. After ordering or scavenging, the part must be delivered to the ship. The ISEA has at its discretion, overnight shipping. After receipt of the part, either through onboard spares or through the supply system, the part needs to be installed and operationally tested. Testing is performed with the DS system reporting results back to the integrated support team, after testing the problem is either corrected or not. If the problem has not been corrected, re-attempt of repair by remote support will almost always be attempted. If re-attempt is desired, re-diagnostics of the system is restarted. If re-attempt of repair is not sought, the problem is deferred to the next level of support which is flyaway team support by the ISEA.

b. Flyaway Repair

Flyaway Repair, as applied to USN DS and this model, refers to ISEA actions, as performed aboard ship. Traditionally, depot maintenance is required as the last level of repair if previous repair attempts have failed or been deferred. However, because most ship systems cannot easily be removed and transported, the ISEA serves as the last level of repair for USN DS. In addition to having the maximum system documentation available for fault analysis, the ISEA has a direct relationship with the system manufacturer. The ISEA also witnesses and documents the most difficult system repairs across all platforms that the system is installed on. The ISEA can perform diagnostics with greater ease, speed, and accuracy than guiding a sailor in the actions. The ISEA also has specialized tools available to make diagnostics and repairs.

The ISEA flyaway team follows a process to diagnose and attempt repair of the failed system to the best of its abilities. This procedure is the same for nearly every element of every combat system aboard ships. The ISEA travels to the platform containing the system requiring repair. Diagnostics of the fault is then attempted using BIT and technical manuals as well as lessons learned from repairing systems on other platforms. All tests previously performed are re-run with new instrumentation. The ISEA must attempt repair and remain onboard until the problem is resolved. After diagnostics, a part may or may not be needed; if it is needed, the part may or may not be onboard. If a part if needed and not onboard, it must be ordered through the supply system. However, the ISEA has several resources that all other entities do not. The ISEA, at its discretion, may scavenge parts from test systems or engineering models, loan parts from accumulated high-value spares, loan parts from future install allocations, and in extreme cases, borrow parts from the manufacturer. After ordering or scavenging, the part must be delivered to the ship. The ISEA has at its discretion, overnight shipping. After receipt of the part, either through onboard spares or through the supply system, the part needs to be installed and operationally tested. After testing, the problem is either corrected or not. If the problem has not been corrected, the ISEA re-attempts repair until the problem is resolved.

3. No Distance Support

The No Distance Support Model is a two level support model that consists only of sailor actions and contractor, in-port support. The model depicts a two-stage support model involving organizational level repair and contractor repair. Figure 92 details the model logic and functional flow decision process which governs the simulation. A basic depiction of the process can be seen in Figure 91 where many problems are encountered at the Organizational Level. Some are resolved, but most are passed to the next level of repair, to be performed by a contractor, when the ship is in port. The actual ExtendSim model used for simulation is shown as Figure 93.

Figure 91. Levels of Repair—No Distance Support

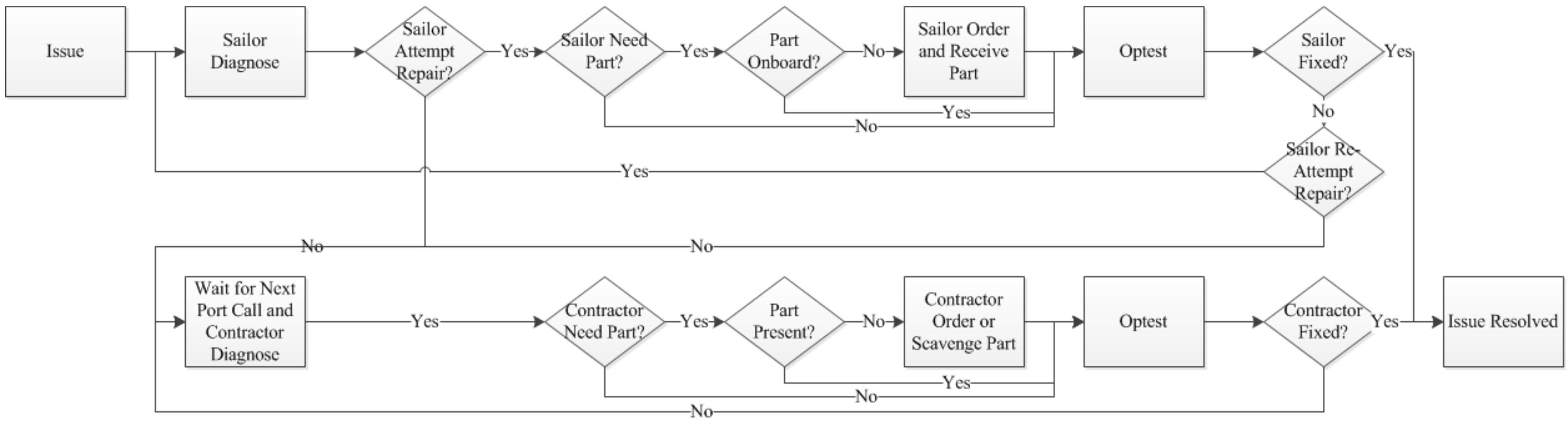

Figure 92. DSHEL—No Distance Support Model Decisional Flow

Figure 92 shows the decision path for system issue resolution in a theoretical current state in which DS is eliminated. It represents a major departure from the multi-tier level of support structure as described in DODD 4151.18. Instead it relies on only organizational-level maintenance and depot maintenance.

In the decisional flow model, the sailor represents the organizational-level maintenance. The sailor recognizes the failure and performs diagnostics on the system. If it is within the sailor's ability, he will attempt repair of the system. If the sailor exercises all known tech manual procedures assigned to their level of maintenance and the problem still exists, it is then elevated to contractor support and the system is left broken until the ship returns to port. If repair is attempted by the sailor, it is assessed if a part is needed. It will next be necessary to determine whether or not the part is available onboard. If not onboard, the part must be ordered through the supply system and delivered to the ship. If all required materials are present (a part is not needed, a part is needed but onboard, or a part is ordered and received), then the repair attempt is made on the system and operationally tested. Upon completion of the operational test, the system is assessed as fixed or not fixed. If the problem is fixed then the flow ends with a resolved issue. If the issue is assessed as not fixed, the sailor may or may not re-attempt repair of the issue. If re-attempt is decided, sailor diagnostics is restarted. If re-attempt is considered beyond the ability of the sailor, then the issue is elevated to contractor support.

In relation to DODD 4151.18, in the decisional flow model, the contractor represents the depot maintenance. The contractor receives a failure notification from the sailor and meets the ship when it returns to port. The contractor performs diagnostics on the system. It is assessed if a part is needed. It will next be necessary to determine whether or not the part is available onboard. If not onboard, the part must be ordered through the supply system or borrowed from resources available to the contractor and delivered to the ship. If all required materials are present (a part is not needed, a part is needed but onboard, or a part is ordered and received), then the repair attempt is made on the system and operationally tested. Upon completion of the operational test, the system is assessed as fixed or not fixed. If the problem is fixed then the flow ends with a resolved issue. If the issue is assessed as not fixed, the contractor must re-attempt repair until the issue is resolved. The ExtendSim model used for simulation is shown as Figure 93

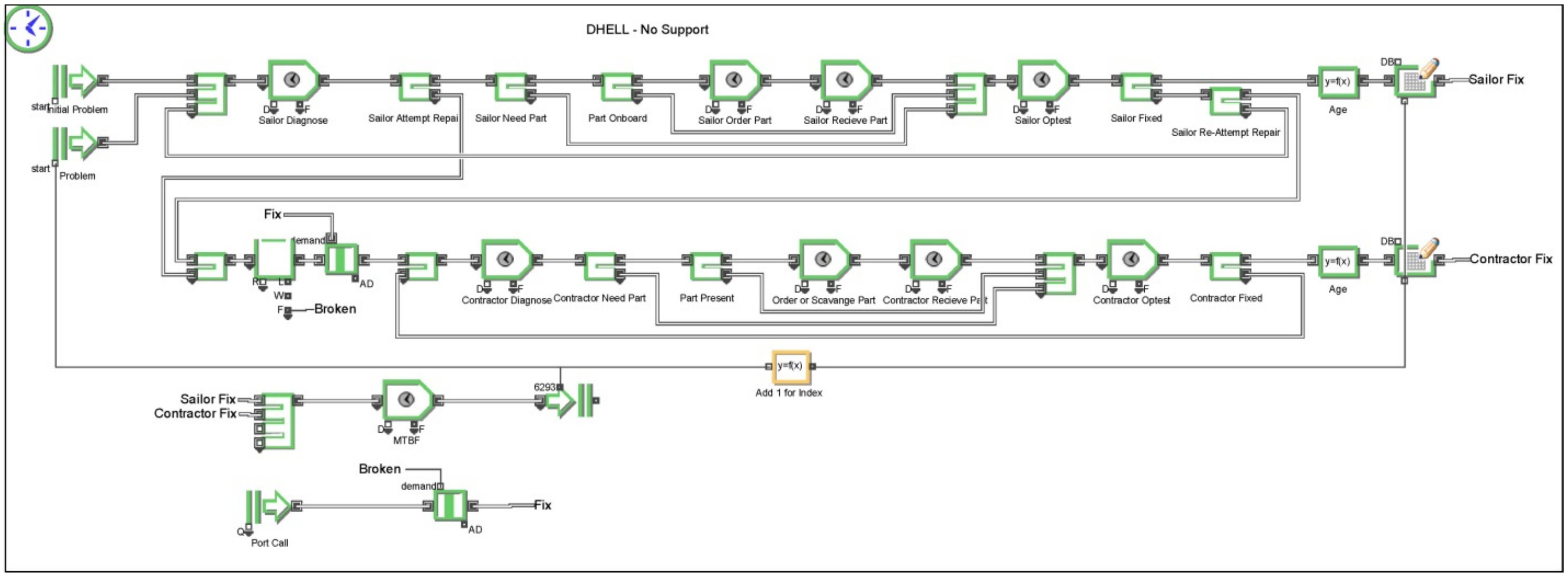

Figure 93. DSHEL—No Distance Support Model

a. Organizational Level Repair

Organizational Repair, as applied to USN DS and this model is referred to in terms of "Sailor" actions. The sailor is expected to follow a process to diagnose and attempt repair of the failed system to the best of his or her abilities. This procedure is the same for nearly every element of every combat system aboard ships. The sailor receives notification of the fault through automated monitoring of the system and daily operational tests. Diagnostics of the fault is then attempted using BIT and technical manuals. Depending on the training of the sailor, the severity of the apparent fault, and the resources available to attempt repair, the sailor can either attempt repair or defer the fault to the next level. If repair is attempted at the organizational level, a part may or may not be needed; if it is needed, the part may or may not be onboard. If a part if needed and not onboard, it must be ordered through the supply system. After ordering, the part must be delivered to the ship. After receipt of the part, either through onboard spares or through the supply system, the part needs to be installed and operationally tested. After testing, the problem is either corrected or not. If the problem has not been corrected, the sailor may or may not re-attempt repair. If re-attempt is desired, re-diagnostics of the system is restarted. If re-attempt of repair is not sought, the problem is deferred to the next level of support.

b. Contractor Repair

Contractor repair, as applied to USN DS and this model is referred to in terms of contractor actions, as performed aboard ship, in port. Traditionally, depot maintenance is required as the last level of repair has failed or been deferred. However, the No Support distance support model requires the manufacturer representatives to travel to the ship to diagnose and repair systems as the only level of support available after organizational level repair efforts.

The contractor team follows a process to diagnose and attempt repair of the failed system to the best of its abilities. This procedure is theoretical and is modeled to be generally applied. While content would be varying depending on the manufacturer and combat system element, the procedure should be delivered within the specification written in the contract deliverables. It is assumed that the contractor travels to the platform containing the system requiring repair in order to meet the ship upon arrival in port. Diagnostics of the fault is then attempted using BIT and technical manuals as well as lessons learned from repairing systems on other platforms. After diagnostics, a part may or may not be needed; if it is needed, the part may or may not be onboard. If a part is needed and not onboard, it must be ordered through the supply system. However, the contractor has several resources that all other entities do not. The contractor may scavenge parts from engineering models, loan parts from future install allocations, and in extreme cases, manufacturer new parts. After ordering or scavenging, the part must be delivered to the ship. The contractor has at its discretion, overnight shipping. However, systems supported in this manner may not have parts available in-country and are likely subject to contracting activities to provide the parts. After receipt of the part, either through onboard spares or through the supply system, the part needs to be installed and operationally tested. After testing, the problem is either corrected or not. If the problem has not been corrected, the contractor re-attempts repair until the problem is resolved.

D. MODEL INPUT

The following section defines the input parameters to the models. Additionally, bounds and assumptions of the model are disclosed.

1. Model Setup

As illustrated in Figure 88, Figure 90, and Figure 93, the system fault is initialized by an “Initial Problem” block. This block generates a system problem at time zero. The problem then progresses through the model. When the issue is resolved, the age of the problem is calculated and recorded in a database at line one, the default line for the simulation. The problem is then delayed by a probability distribution represented by the MTBM, detailed further in this section, and exited from the simulation logic. The exit of the item causes the exit counter to increment by one. The counter is used to trigger the next problem to be created in the simulation. Additionally, the counter represents the current line of the database entry. So, one is added to the counter value to set the database line location for entry of the next problem resolution.

The simulation is configured to run to represent 30 systems operating for 20 years each. Simulations are run sequentially for ease of data collection but represent the same outcome as if they were run in parallel. The simulation is set to run for 600 system-years which equates to 5,259,600 hours shown in Table 12. A key consideration is that simulations with lower times to repair will have a greater number of failures over a 20-year system life, as the system spends more time operational and subject to the MTBM.

Table 12. Time Bases Model Time Parameter

	Hours/Year	Systems/Ship	Ships	Years	Total
HEL	8766	1	30	20	5,259,600 HEL Systems Hours

2. Data Validation and Parameter Restriction Due to Classification

The USN has many inconsistent sources of reliability data that is reported aggregated to the technical community. Detailed probability distributions of each process, as needed for the model, are not currently available. System performance parameters such as MTBF/MTBM, Ao, and mean time to repair (MTTR) are designated for official use only (FOUO) and above. For this reason, the models were built using aggregate knowledge and estimations across multiple established systems. The authors of this effort are self-sources for releasable estimates of distance support times and probability distributions for relevant USN weapon systems. In this way, no FOUO or above performance information is needed from any fielded systems. By drawing parallels across models, the differences can be studied without the need for un-releasable data. It is suggested as a follow-on effort to review and update USN reliability reporting to include detailed probability distributions for all sub-categorized resolution activities to assist in validating this and future DS models.

3. Model Parameters and Assumptions

Parameters of the models are detailed in the following sections: time scale, general assumptions, mean time between maintenance, mean time between failure, and status quo distance support values, integrated distance support values, no distance support values, integrated distance support evolution from status quo distance support, and no distance support evolution from status quo distance support.

a. Time Scale

All time parameters are in hours. Because operations of a ship are day and night and not subject to office working hours, support and repair are to be measured the same. Hours in the model are assumed to be true day hours, twenty-four in a day.

b. General Assumptions

Values entered into this model are publically releasable. No value is representative of any single fielded system. These are an aggregate of multiple system broad estimates in order to avoid classification restrictions. When appropriate, values and distributions are the same across all three models in order to minimize unintended variation.

The models depict the vast majority of repair attempts made to fielded systems and to theoretical systems. However, it does not cover all cases. It is believed that a large enough portion of all cases follow the models' paths to deliver useful results. A suggestion for future work is to expand the model to include obscure case paths.

c. Mean Time between Maintenance

In the model, MTBF is substituted for MTBM and the terms are used interchangeably. The assumption is made that no preventative maintenance will be performed unless all supplies and tools are available to perform the prescribed maintenance. Also, it is assumed that all preventative maintenance shall take no more than two hours. Given the duration necessary to perform preventative maintenance is so small, a separate parameter was not created and the two hour duration lumped in with the total MTBM parameter. For clarity, the more common term of MTBF is used through the model.

d. Mean Time between Failure

MTBF is assumed to be 500 Hours. It is also assumed that the time between failures follows a normal distribution. This is the same for all three models.

e. Status Quo Distance Support Values

Table 13. Model Parameters—Status Quo Distance Support Values

Parameter	Line	Block	Distribution	Mean (Hours)	SD (Hours)	% Yes
MTBF	*	268	Normal	500	100	
Sailor Diagnose	1	2	Normal	24	12	
Sailor Attempt Repair?		3	Percentage			80
Sailor Need Part?		4	Percentage			80
Part Onboard?		5	Percentage			20
Sailor Order Part		6	Lognormal	24	12	
Sailor Receive Part		7	Lognormal	72	24	
Sailor Optest		8	Normal	12	6	
Sailor Fixed?		9	Percentage			70
Sailor Re-Attempt Repair?		37	Percentage			10
RMC Diagnose	2	48	Normal	48	24	
RMC Attempt Repair?		49	Percentage			80
RMC Need Part?		50	Percentage			90
Part Onboard?		51	Percentage			20
RMC Order Part		52	Lognormal	24	12	
RMC Receive Part		53	Lognormal	72	24	
RMC Optest		54	Normal	12	6	
RMC Fixed?		55	Percentage			80
RMC Re-Attempt Repair?		83	Percentage			10
ISEA Diagnose	3	104	Normal	48	24	
ISEA Attempt Repair?		105	Percentage			95
ISEA Need Part?		106	Percentage			90
Part Onboard?		107	Percentage			20
ISEA Order or Scavenge		108	Lognormal	12	6	
ISEA Receive Part		109	Lognormal	24	6	
ISEA Optest		110	Normal	12	6	
ISEA Fixed?		111	Percentage			90
ISEA Re-Attempt Repair?		139	Percentage			80
Flyaway	4	187	Normal	48	24	
Flyaway Diagnose		156	Normal	24	12	
Flyaway Need Part?		158	Percentage			90
Part Onboard?		159	Percentage			20
ISEA Order or Scavenge		160	Lognormal	12	6	

Parameter	Line	Block	Distribution	Mean (Hours)	SD (Hours)	% Yes
Flyaway Receive part		161	Lognormal	24	6	
Flyaway Optest		162	Normal	6	3	
Flyaway Fixed?		201	Percentage			95

f. Integrated Distance Support Values

Table 14. Model Parameters—Integrated Distance Support Values

Parameter	Line	Block	Distribution	Mean (Hours)	SD (Hours)	% Yes
MTBF	*	63	Normal	500	100	
DS Diagnose	1	2	Normal	24	12	
DS Need Part?		4	Percentage			80
Part Onboard?		5	Percentage			20
ISEA Order or Scavenge		6	Lognormal	12	6	
Sailor Receive Part		7	Lognormal	48	12	
DS Optest		8	Normal	12	6	
DS Fixed?		9	Percentage			90
DS Re-Attempt Repair?		37	Percentage			90
Flyaway	2	187	Normal	48	24	
Flyaway Diagnose		156	Normal	24	12	
Flyaway Need Part?		158	Percentage			90
Part Onboard?		159	Percentage			20
ISEA Order or Scavenge		160	Lognormal	12	6	
Flyaway Receive Part		161	Lognormal	24	6	
Flyaway Optest		162	Normal	6	3	
Flyaway Fixed?		201	Percentage			95

g. *No Distance Support Values*

Table 15. Model Parameters—No Distance Support Values

Parameter	Line	Block	Distribution	Mean (Hours)	SD (Hours)	% Yes
MTBF	*	268	Normal	500	100	
Sailor Diagnose	1	2	Normal	24	12	
Sailor Attempt Repair?		3	Percentage			80
Sailor Need Part?		4	Percentage			80
Part Onboard?		5	Percentage			5
Sailor Order Part		6	Lognormal	24	12	
Sailor Receive Part		7	Lognormal	168	48	
Sailor Optest		8	Normal	12	6	
Sailor Fixed?		9	Percentage			20
Sailor Re-Attempt		37	Percentage			50
Port Call	2	78	Lognormal	720	120	
Contractor Diagnose		48	Normal	24	12	
Contractor Need Part?		50	Percentage			90
Part Present?		51	Percentage			20
Order or Scavenge Part		52	Lognormal	24	12	
Contractor Receive part		53	Lognormal	96	48	
Contractor Optest		54	Normal	12	6	

h. *Integrated Distance Support Evolution from Status Quo Distance Support*

Table 16 depicts the differences between the Status Quo Distance Support Model and the Integrated Distance Support Model as well as explanations for the value differences. Positive impacts on repair time are denoted in green and negative impacts are denoted in red.

Table 16. Integrated Distance Support Evolution from Status Quo Distance Support

Status Quo							Integrated Support							Justification
Parameter	Line	Block	Distribution	Mean (Hours)	SD (Hours)	% Yes	Parameter	Line	Block	Distribution	Mean (Hours)	SD (Hours)	% Yes	
MTBF	*	268	Normal	500	100		MTBF	*	63	Normal	500	100		
Sailor Diagnose		2	Normal	24	12		DS Diagnose	1	2	Normal	24	12		Constrained by Sailor and Ship Operations Schedule
Sailor Attempt Repair?		3	Percentage			80								
Sailor Need Part?		4	Percentage			80	DS Need Part?		4	Percentage			80	
Part Onboard?		5	Percentage			20	Part Onboard?		5	Percentage			20	
Sailor Order Part		6	Lognormal	24	12		ISEA Order or Scavenge Part		6	Lognormal	12	6		ISEA has part loaning and scavenging available at its discretion
Sailor Receive Part	1	7	Lognormal	72	24		Sailor Receive Part		7	Lognormal	48	12		ISEA has overnight shipping available for scavenged part
Sailor Optest		8	Normal	12	6		DS Optest	1	8	Normal	12	6		
Sailor Fixed?		9	Percentage			70	DS Fixed?		9	Percentage			90	ISEA assistance through DS is expected to significantly improve probability of fault resolution
Sailor Re-Attempt Repair?		37	Percentage			10	DS Re-Attempt Repair?		37	Percentage			90	Status Quo culture dictates passing up to the next level of repair With DS, ISEA assistance is already retained So, re-attempt by remote is highly likely
RMC Diagnose		48	Normal	48	24									
RMC Attempt Repair?		49	Percentage			80								
RMC Need Part?		50	Percentage			90								
Part Onboard?		51	Percentage			20								
RMC Order Part	2	52	Lognormal	24	12									
RMC Receive Part		53	Lognormal	72	24									
RMC Optest		54	Normal	12	6									
RMC Fixed?		55	Percentage			80								
RMC Re-Attempt Repair?		83	Percentage			10								
ISEA Diagnose		104	Normal	48	24									
ISEA Attempt Repair?		105	Percentage			95								
ISEA Need Part?		106	Percentage			90								
Part Onboard?		107	Percentage			20								
ISEA Order or Scavenge Part	3	108	Lognormal	12	6									
ISEA Receive Part		109	Lognormal	24	6									
ISEA Optest		110	Normal	12	6									
ISEA Fixed?		111	Percentage			90								
ISEA Re-Attempt Repair?		139	Percentage			80								
Flyaway		187	Normal	48	24		Flyaway		187	Normal	48	24		
Flyaway Diagnose		156	Normal	24	12		Flyaway Diagnose		156	Normal	24	12		
Flyaway Need Part?		158	Percentage			90	Flyaway Need Part?		158	Percentage			90	
Part Onboard?	4	159	Percentage			20	Part Onboard?	2	159	Percentage			20	
ISEA Order or Scavenge Part		160	Lognormal	12	6		ISEA Order or Scavenge Part		160	Lognormal	12	6		
Flyaway Receive part		161	Lognormal	24	6		Flyaway Receive part		161	Lognormal	24	6		
Flyaway Optest		162	Normal	6	3		Flyaway Optest		162	Normal	6	3		
Flyaway Fixed?		201	Percentage			95	Flyaway Fixed?		201	Percentage			95	

Table 17. No Distance Support Evolution from Status Quo Distance Support

Status Quo							**No Support**							**Justification**
Parameter	Line	Block	Distribution	Mean (Hours)	SD (Hours)	% Yes	Parameter	Line	Block	Distribution	Mean (Hours)	SD (Hours)	% Yes	
MTBF	*	268	Normal	500	100		MTBF	*	268	Normal	500	100		
Sailor Diagnose		2	Normal	24	12		Sailor Diagnose		2	Normal	24	12		
Sailor Attempt Repair?		3	Percentage			80	Sailor Attempt Repair?		3	Percentage			80	
Sailor Need Part?		4	Percentage			80	Sailor Need Part?		4	Percentage			80	
Part Onboard?		5	Percentage			20	Part Onboard?		5	Percentage			5	Minimal to no spares onboard
Sailor Order Part	1	6	Lognormal	24	12		Sailor Order Part	1	6	Lognormal	24	12		
Sailor Receive Part		7	Lognormal	72	24		Sailor Receive Part		7	Lognormal	168	48		Lack of a robust supply system support, dependence on contractor
Sailor Optest		8	Normal	12	6		Sailor Optest		8	Normal	12	6		
Sailor Fixed?		9	Percentage			70	Sailor Fixed?		9	Percentage			20	Lack of training due to dependence on contractor support
Sailor Re-Attempt Repair?		37	Percentage			10	Sailor Re-Attempt Repai		37	Percentage			50	No help is available until port re-attempt is significantly more likely
RMC Diagnose		48	Normal	48	24									
RMC Attempt Repair?		49	Percentage			80								
RMC Need Part?		50	Percentage			90								
Part Onboard?		51	Percentage			20								
RMC Order Part	2	52	Lognormal	24	12									
RMC Receive Part		53	Lognormal	72	24									
RMC Optest		54	Normal	12	6									
RMC Fixed?		55	Percentage			80								
RMC Re-Attempt Repair?		83	Percentage			10								
ISEA Diagnose		104	Normal	48	24									
ISEA Attempt Repair?		105	Percentage			95								
ISEA Need Part?		106	Percentage			90								
Part Onboard?		107	Percentage			20								
ISEA Order or Scavenge Part	3	108	Lognormal	12	6									
ISEA Receive Part		109	Lognormal	24	6									
ISEA Optest		110	Normal	12	6									
ISEA Fixed?		111	Percentage			90								
ISEA Re-Attempt Repair?		139	Percentage			80								
							Port Call	*	78	Lognormal	720	120		No support method is based on leaving systems broken until the ship
Flyaway		187	Normal	48	24									It is assumed that the contractor will be remotely notified and flyout to meet the ship
Flyaway Diagnose		156	Normal	24	12		Contractor Diagnose		48	Normal	24	12		
Flyaway Need Part?		158	Percentage			90	Contractor Need Part?		50	Percentage			90	
Part Onboard?	4	159	Percentage			20	Part Present?	2	51	Percentage			20	
ISEA Order or Scavenge Part		160	Lognormal	12	6		Order or Scavenge Part		52	Lognormal	24	12		Less spares available than a robust ISEA and supply system
Flyaway Receive part		161	Lognormal	24	6		Contractor Receive part		53	Lognormal	96	48		Parts may be located out of country or endure contractual issues for
Flyaway Optest		162	Normal	6	3		Contractor Optest		54	Normal	12	6		Ship's attention is divided in port
Flyaway Fixed?		201	Percentage			95	Contractor Fixed?		201	Percentage			90	

i. No Distance Support Evolution from Status Quo Distance Support

Table 17 depicts the differences between the Status Quo Distance Support Model and the No Distance Support Model as well as explanations for the value differences. Positive impacts on repair time are denoted in green and negative impacts are denoted in red.

E. SUMMARY

The following sections summarize the results of the M&S Effort. Details of the Frequency and Time Models are presented below.

1. Frequency Models

The results of the Frequency Models below provide a high-level analysis on MDT and A_o as single values. The Integrated Distance Support Model shows significant improvement over the Status Quo Distance Support Model, increasing A_o from 77.6% to 85.6% without modifying the system to improve MTBM.

The No Distance Support Model shows significant diminishment with respect to the Status Quo Distance Support Model, decreasing A_o from 77.6% to 61.6% without modifying the system to affect MTBM. Key results are denoted in bold in Table 18.

Table 18. Frequency Models

Parameter	Status Quo DS	Integrated Distance Support	No Distance Support	Units
Mean Time Between Maintenance (MTBM)	500	500	500	Hours
Mean Down Time (MDT) = M_{bar} + MLDT + MAdmDT	**144**	**84**	**312**	**Hours**
Mean Active Maintenance Time (Mbar)	48	24	96	Hours
Mean Logistics Delay Time (MLDT)	48	36	168	Hours

Parameter	Status Quo DS	Integrated Distance Support	No Distance Support	Units
Mean Administrative Delay Time	48	24	48	Hours
Operational Availability (A_o) = MTBM/(MDT + M_{bar})	**0.776**	**0.856**	**0.616**	

2. Time Models

The results of the Time Models below provide a detailed analysis on MDT and A_o as probability distributions.

a. Time Model—Status Quo Distance Support Results

As illustrated in Figure 94, the Status Quo Distance Support Model results show two distinct areas of repair times. The shorter time window is believed to be a distorted normal distribution representing system problems fixed in one attempt, without outside assistance. The second window of repair times is believed to be a distorted Normal distribution representing multiple repair attempts and multiple repair entities participating. Remaining values, in excess of 200 hours are believed to be associated with required flyaway support and multiple rounds of re-attempted repair of the system by the same repair entity.

The MDT for the Status Quo Distance Support Model is 149.0 Hours with a standard deviation of 91.5 Hours. The corresponding A_o is 0.770. These results are believed to be consistent with an aggregation of considered fielded systems. Results are summarized in Table 19.

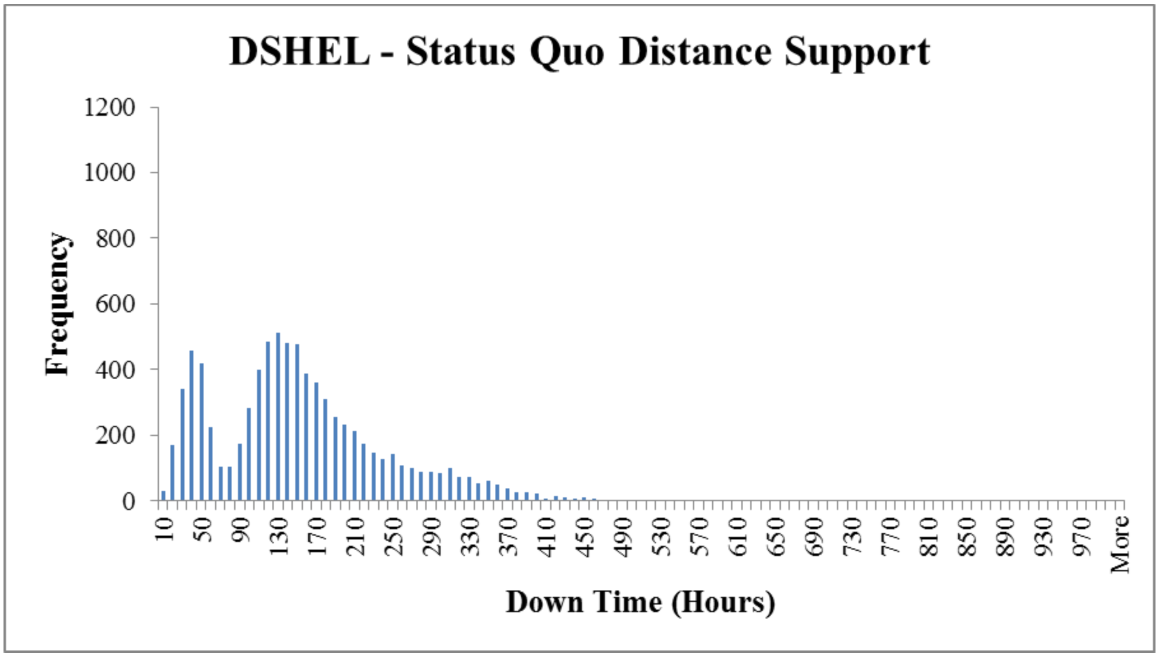

Figure 94. Status Quo Distance Support—Down Time

b. Time Model—Integrated Distance Support Results

As illustrated in Figure 95, the Integrated Distance Support Model results show two distinct areas of repair times. The shorter time window is believed to be a distorted Normal distribution representing system problems fixed in one attempt. The second window of repair times is believed to be a distorted normal distribution representing multiple repair attempts. Remaining values, in excess of 140 hours are believed to be associated with required flyaway support and multiple rounds of re-attempted repair of the system.

The MDT for the Status Distance Support Model is 83.8 Hours with a standard deviation of 44.9 Hours. The corresponding A_o is 0.856. These results are derived from status quo values, only modified for differences in the support methodologies, and accepted as reasonable. Results are summarized in Table 19.

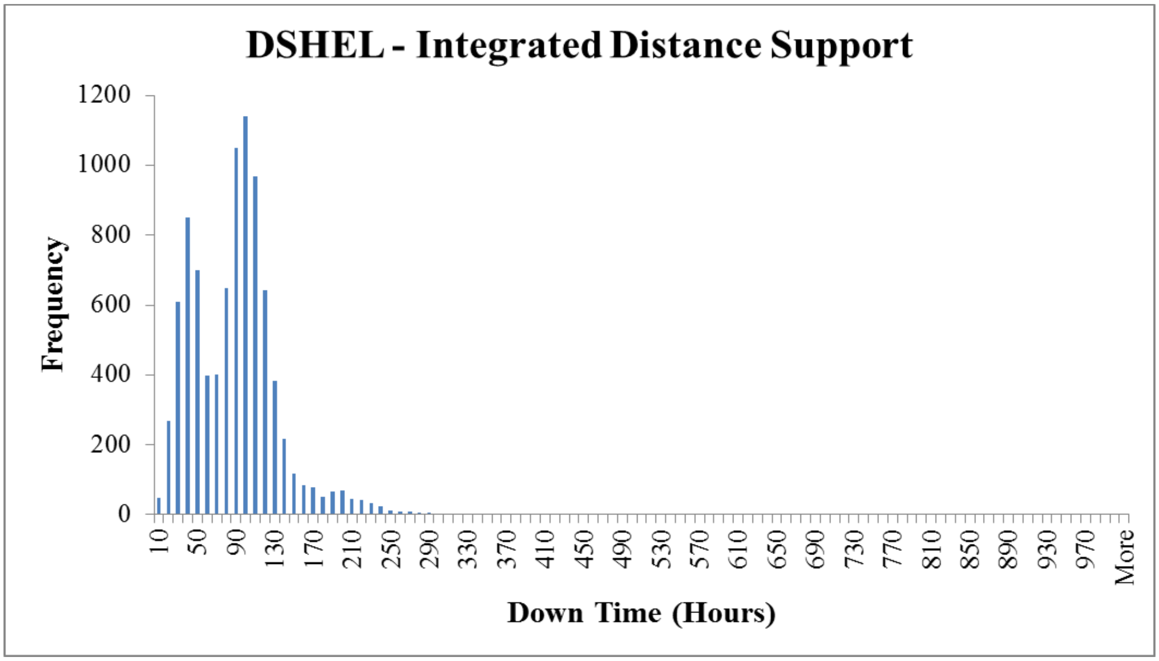

Figure 95. Integrated Distance Support—Down Time

c. Time Model—No Distance Support Results

As illustrated in Figure 96, the No Distance Support Model results show two distinct areas of repair times. The shorter time window is believed to be an approximate Normal distribution representing system problems fixed by the sailor, onboard, without assistance. The second window of repair times represents multiple repair attempts by the sailor or waiting for contractor support when the ship returns to port.

The MDT for the No Distance Support Model is 335.1 Hours with a standard deviation of 210.5 Hours. The corresponding A_o is 0.559. These results are derived from status quo values, only modified for differences in the support methodologies, and accepted as reasonable. Results are summarized in Table 19.

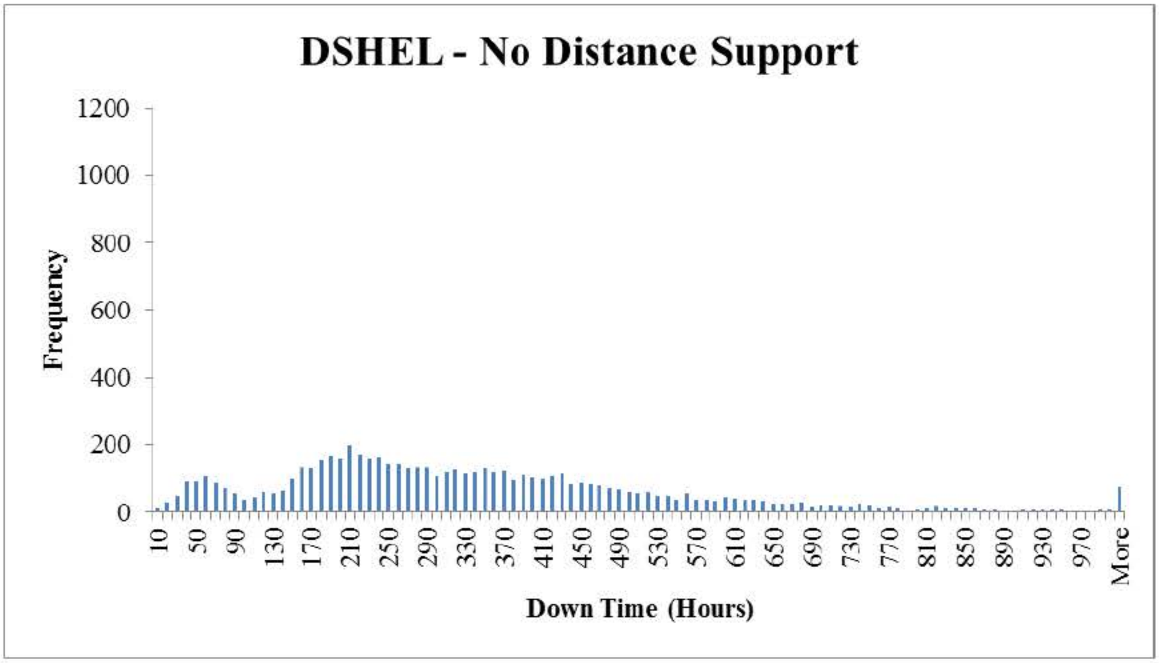

Figure 96. No Distance Support—Down Time

d. *Time Model—Summary Distance Support Results*

Table 19 is a summary of all three Time Model Results. The results below are denoted best to worst by green, yellow, and red, respectively. All model files are available upon request from The SE Department of NPS.

Table 19. Time Models Summary Results

Parameter	Status Quo Distance Support	Integrated Distance Support	No Distance Support	Units
Mean Down Time (MDT)	148.97	83.79	335.05	Hours
Down Time (SD)	91.45	44.86	210.50	Hours
Operational Availability (A_o)	0.770	0.856	0.599	

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VI. COST AND RISK ANALYSIS

This chapter explores, estimates, and provides in-depth analysis regarding the various costs and risks associated with the realization of DSHEL. Recommendations for the best path forward are summarized in each of the analysis results.

A. COST ANALYSIS APPROACH

The following section addresses the various SE methodologies and estimation techniques for analyzing the cost impact of DSHEL.

1. Systems Engineering

The initial SE efforts during the acquisition phase of development contribute to a considerable amount of effort in terms of labor. This ranges from the acquisition, supply, technical management, system design, product realization, to the test and evaluation type activities which span from concept realization to operational transition. The accepted approach for estimating the cost of these SE activities is the Constructive Systems Engineering Model (COSYSMO) as leveraged in this chapter. The assumptions driving the COSYSMO input variables of the cost estimation model were leveraged from material already covered in this report, e.g., number of requirements, interfaces, and diversity of installation platforms. Once obtained, these values were used as the system size and system cost driver attributes in the NPS COSYSMO Systems Engineering Cost Model Advisor software tool to compute an estimate of SE cost (Madachy, COCOMO Suite of Constructive Cost Models 2014).

2. Software Engineering

The Constructive Cost Model II (COCOMO II) is widely used, thoroughly documented, and calibrated software cost model. COCOMO II provides a methodology similar to COSYSMO where the model offers insight into the root cause of cost variations. The overall effort is provided in person-months to help the project lead create an accurate schedule. One of the key inputs of this tool is the logical Source Lines of Code (SLOC). To obtain this, research was performed weighing the needs of DSHEL's functional requirements against available software applications. Once an application was selected as a candidate for estimation, a functional SLOC count was performed. To perform this SLOC count, a tool was leveraged from the University of Southern California (USC) Center for Systems and Software Engineering (CSSE), known as the Unified Code Count (UCC) (University of Southern California 2014). CSSE provides the raw open source code of UCC. This source code was compiled by the team using the GNU Compiler Collection G++ application under the Fedora Operating System. This tool was used to analyze the application candidate source code to produce SLOC metrics as a COCOMO II input parameter. Following this, the constructive analysis of software input parameters based on earlier research in this report, alongside given assumptions, were used to produce an overall estimate of the software engineering activities during the acquisition phase of DSHEL.

3. Hardware Engineering

Hardware cost estimates for a subsystem are unique when it comes to selecting a methodology. Traditionally, the Advanced Mission Cost Model (AMCM) is used for SE project estimations. However, that particular model is slated for large scale projects such as ships, tanks, and complete weapon systems. In the case of DSHEL being a small component, it was the recommendation of NPS Professor Raymond Madachy to cost out and compute directly, given that AMCM does not scale down for estimates this small in project size. Therefore, the proposed methodology was to perform market research of common naval computing equipment already used in the shipboard enterprise, select and compile the costs, and then multiply by the estimated number of shipboard installations of HEL to determine the material cost of the proposed DSHEL subsystem.

4. Sustainment Engineering

Sustainment engineering refers to the costs incurred by the program necessary for the ISEA community to sustain DSHEL once it is operational. This involves a variety of factors, however, the basic methodology tailored for DSHEL will include the hardware, software, and logistical support. For hardware, an assumption has been made regarding the necessary obsolescence management for the two major DSHEL components.

diminishing manufacturing sources and material shortages (DMSMS) processes manage the obsolescence of the hardware. The hardware will therefore follow the standard five year technical refresh model as dictated by USN ISEAs. The initial sparing cost will also be included. Software sustainment costs follow a similar methodology, however, leveraging the extension of software license management. The software process is computed by the annual cost of licenses multiplied by the number of shipboard installations of HEL. Both endeavors include the addition of: SE efforts, hardware engineering efforts, regression testing, and logistical efforts for engineering change proposal review and configuration management.

5. Life-Cycle Cost Benefit Analysis

To perform the cost benefit analysis, the entire life-cycle cost of DS must be taken into account. This includes the cost of acquisition systems, software, hardware, and sustainment engineering in addition to the cost per technical assistance in supporting the Fleet. The methodology for estimating this cost is calculated by taking the summation of all acquisition and sustainment costs and dividing by the expected service life. This results in the annual cost for DS. By taking known costs of technical assistance to the Fleet with and without DS, the annual cost of DSHEL can be added to the effort per each tech assist and plotted against the cost of no DS. In turn, the point at which the lines intersect is the breakeven point. This is where DSHEL begins to "pay for itself" and reduces life-cycle cost to the HEL program.

B. COST ANALYSIS AND RESULTS

The following section shall present the application results from the aforementioned SE methodologies and estimation techniques used in analyzing the cost impact of DSHEL.

1. Systems Engineering

The system size and system cost driver attributes of the COSYSMO estimation methodology required numerous variables be explored and defined. This section iteratively explored each such variable, its relation to DSHEL based on the research provided thus far in this report, and a rationale as to the selection for its attribute ranking based on accepted disposition definitions from the SE Cost Estimation Workbook (Madachy, Systems Engineering Cost Estimation Workbook 2014).

The number of DSHEL specific “system requirements” was based on the quantity of those related to engineering the system interfaces, system specific algorithms, and operational scenarios. While these may be grouped as functional, performance, or service oriented, they are counted once decomposed to the lowest work breakdown structure allocation to avoid duplication of effort. Based on the results of the Requirements Analysis chapter, DSHEL had a total of 19 high level requirements. All 19 were determined to be difficult, given they were complex to engineer or implement, hard to trace to the source, contained a high degree of overlap, and required further decomposition from the USN Distance Support Handbook.

The number of “system interfaces” was based on the quantity of internally shared physical and logical boundaries between DSHEL components and functions, as well as those external to the system. Formally, these can be defined by ISO/IEC 15288 defined system elements. Based on the results of Chapter IV, DSHEL has a total of 32 interfaces. Of those, 21 were determined to be easy based on the interface providing transport of simple uncoupled messages, being well behaved, and having strong consensus. The count of 21 resulted from the three interface types of keyboard, video, and mouse interfacing across seven main components of the platform of interest. Eleven were determined to be nominal given moderate complexity of the protocols, being loosely coupled, having moderate consensus, and predictable behavior. Among the sensor suite, beam former, optical bench, storage, power, and DSHEL server, none were determined to be difficult, composed of highly coupled or complex protocols.

The number of “System Algorithms” was based on newly defined or altered reuse functions, which require mathematical functions to be created in order to meet system performance requirements. Given the focus of DSHEL in this report is scoped to the initial four pillars of DS, the number of algorithms are minimal given that the final two pillars of ePrognostics and Self Repair were slated for future work. Remote Monitoring involves an algebraic filter, which would send the appropriate system status results of health, sensor, and BIT passively to the shore. Alongside these are also the network infrastructure status between the DSHEL system and the ship's router, an external health status message to the system necessary for having situational awareness of the environment while troubleshooting. Given this is straightforward, algebraic, and a simple data type, the number of easy algorithms was determined to be four; whereas the number of nominal and difficult algorithms was determined to be zero.

The number of "operational scenarios" was based on the normal stimulus-response based operations alongside the malfunctioning scenarios in which DSHEL cannot operate properly (e.g., unavailable external systems, network connections or other interfaces, and invalid data). Given the focus of DSHEL in this report is scoped to the initial four pillars of DS; the normal operation count was determined to be four nominal scenarios. Given the areas where exception handling of HEL to DSHEL communication, bad data, infrastructure downtime, and satellite link malfunctions being non-normal operating conditions, the scenarios were determined to be two difficult and two nominal. The aggregate inputs for operational scenarios were then determined to be zero easy, six nominal, and two difficult.

"Requirements understanding" encompasses the overall comprehension of system requirements by all stakeholders. While this report presents the DSHEL requirements and decomposes to a reasonable level, some areas were already determined to require further analysis given the HEL systems currently in the USN are in test bed status and not fully realized as a program of record (PoR). Until a final system architecture and design has been selected by ONR as a formal PoR, the Requirements Understanding of DSHEL shall remain nominal, translating to being reasonably understood with some undefined areas.

"Architecture Understanding" relates to the difficulty in determining and managing the system architecture in terms of the platform, components, standards, and infrastructure. Similar to Requirements Understanding, this report presents the DSHEL architecture and decomposes to a reasonable level. The various shipboard platforms were addressed as various candidates, given their unique infrastructures alongside the standard design framework of a SSL. While the test bed has not been fully realized as a PoR, there is still a strong understanding of the various architectures, GOTS systems, and few unfamiliar areas. The architecture understanding was determined to be high.

"Level of Service" requirements defines the criticality and difficulty of satisfying KPPs, security, response time, safety, and other type "-ility" characteristics of the system. Given the performance and suitability requirements for DSHEL alongside the recent DOD memorandum of procedures for operational test and evaluation (OT&E) of Cybersecurity in Acquisition programs, core defense performance metrics in support of cyber reciprocity for HEL (via DSHEL) drive the Level of Service to be high given how coupled these parameters are and the impact of not meeting minimum threshold.

"Migration Complexity" refers to the difficulty and extent which legacy systems can be reused, e.g., components, databases, workflows. While the DSHEL concept focuses on commercial and other "bolt on" distance support technologies, there exists limited to no legacy DS systems for reuse alongside the HEL. Merely business processes, lessons learned, studies, and the research from this capstone report serves as the basis for migration of DS into integration, development, architecture and design. Therefore, the migration complexity was determined to be very high.

The overall "Technology Risk" of the system refers to the maturity, readiness, and obsolescence of the technology being implemented. In terms of DOD systems, there is a direct correlation to the Technology Readiness Level (TRL) which is used to assess maturity of evolving technologies during their development and early operations. Providing a few comparisons, a TRL of 7 describes readiness of a prototype where there exists a demonstration of the system in an operational environment. A TRL of 8 would describe readiness where an actual system has been completed and qualified through T&E and is ready for widespread adoption, and a TRL of 9 would describe readiness where the system has been proven through many operational missions. Using the aforementioned descriptions, DSHEL would have between a TRL of 8 and 9. Since it does not fully meet the readiness of TRL 9, the resulting assessment is that of TRL 8. This is due to the fact that distance support in the USN has already been proven through T&E and limited use in existing tactical systems. While not the standard in weapon or combat systems, it is qualified and ready for widespread use. Therefore, the technology risk was determined to be low.

Logistics artifacts such as documentation, formality, and necessary detail required for delivery of the DHSEL component, must be considered when taking the life-cycle support into account. While standard NAVSEA Logistics Center requirements mandate rigorous, strict standards and requirements, the detail necessary to guide the users through DS processes, must also leverage large amounts of documentation which are more rigorous relative to the life-cycle needs. This is due to the cybersecurity concerns and adherence to process compliance for necessary man-in-the-loop operations of DS. In turn, this leads the documentation assessment to be very high.

As a subsystem component of HEL, DSHEL would then be installed upon the various afloat platforms targeted for directed energy mission employment. Per the focus of this capstone report and other studies performed by the ONR, this is to focus on destroyers and cruisers with an ISNS configuration and Littoral Combat Ships with a Total Ship Computing Environment. The number of install configurations is estimated to be at least three. However, all would be using industry standard protocol on a shipboard network. The operating environment would also meet all known operational requirements as shipboard data rooms are environmentally controlled for information systems. The diversity of "Installation Platforms was therefore determined to be high.

The DSHEL "Recursive Levels of Design" span not only vertical and horizontal coordination between subsystem components, but also relate more complex interdependencies to coordinate the tradeoff analysis when determining which HEL components to monitor. Based on the architecture views previously created alongside the DS framework methodology, the recursive levels point to a nominal assessment.

"Stakeholder Team Cohesion" defines how well a team collaborates. Future inputs to stakeholder team cohesion will most likely consist of NAVSEA, SPAWAR, ONR, and industry partners. The team is composed of personnel from similar organizations, share project culture, compatible organizational objectives, and clear roles and responsibilities as defined by the warfare center technical capabilities. Therefore, cohesion was determined to be nominal.

The “Team Capability” best describes the intellectual capacity and execution ability to analyze complex problems and manifest solutions, compared to the national pool of SE’s. Given that the field of DS, infrastructure, and naval engineering is proficient with SE, this was determined to be at least in the 75th percentile, leading to an assessment of high.

“Personnel Experience and Continuity” relate to the applicability and consistency of the staff at the initial stage of the project, with respect to the system domain, customer, user, and technology. Given the pool of naval IT, infrastructure, and systems engineers who have already been in the test bed development stage of HEL, alongside the existence functional resources within the warfare centers, it is assumed there would at least be three years continuous experience available on average, and a turnover of less than 12%. The continuity was therefore determined to be nominal.

The “Process Capability” describes the consistency and effectiveness of the project team performing the SE processes. Given the current industry and government HEL teams have defined SE processes, activities driven by benefit to the project, a process approach driven by the organizations involved, as well as a Capability Maturity Model Index (CMMI) assessment level of 3, this is synonymous with a high process capability per the Cost Estimation Workbook.

“Multisite Coordination” on a USN project is an area that covers the location of stakeholders, team members, resources, and corporate collaboration barriers. Given the naval warfare centers, research labs, program offices, and test sites span the reaches of the country this leads to a team which is remotely collaborating at times. However, given criteria defined by the Cost Estimation Workbook as usage of wideband electronic communication, Internet based teleconference, and interactive development environments which employ collaborative tools and processes in place to mitigate these barriers; the coordination effort averages out to an assessment of high.

Considering the "Tool Support" coverage, integration, and maturity of toolsets in the naval SE environment is readily available, mature, and integrated with other disciplines, it is assumed these same resources will also be available to the DHSEL project team. The tool support was then assessed to be high.

For consistency of other DS cost benefit studies performed, the labor rate was assumed to be burdened at approximately $10,000 per person month. This assumption was made for the reuse of Fleet technical assistance data and describes the average cost of technical assistance with and without distance support thereby normalizing the person hours used between the DSHEL estimates and existing Fleet data.

Table 20 summarizes the input variables determined from the former analysis and was used as input to the COSYSMO tool, as well as the resulting estimation output in Figure 97 and Figure 98.

Table 20. COSYSMO Tool Input Data

Methodology Variable	Value
System Size - # of System Requirements (Easy)	0
System Size - # of System Requirements (Nominal)	0
System Size - # of System Requirements (Difficult)	19
System Size - # of System Interfaces (Easy)	21
System Size - # of System Interfaces (Nominal)	11
System Size - # of System Interfaces (Difficult)	0
System Size - # of Algorithms (Easy)	4
System Size - # of Algorithms (Nominal)	0
System Size - # of Algorithms (Difficult)	0
System Size - # of Operational Scenarios (Easy)	0
System Size - # of Operational Scenarios (Nominal)	6
System Size - # of Operational Scenarios (Difficult)	2

Methodology Variable	Value
System Cost Drivers - Requirements Understanding	NOMINAL
System Cost Drivers - Architecture Understanding	HIGH
System Cost Drivers - Level of Service Requirements	HIGH
System Cost Drivers - Migration Complexity	VERY HIGH
System Cost Drivers - Technology Risk	LOW
System Cost Drivers - Documentation	VERY HIGH
System Cost Drivers - # and Diversity of Installations/Platforms	HIGH
System Cost Drivers - # of Recursive Levels in the Design	NOMINAL
System Cost Drivers - Stakeholder Team Cohesion	NOMINAL
System Cost Drivers - Personnel/Team Capability	HIGH
System Cost Drivers - Personnel Experience/Continuity	NOMINAL
System Cost Drivers - Process Capability	HIGH
System Cost Drivers - Multisite Coordination	HIGH
System Cost Drivers - Tool Support	HIGH
Maintenance	Off
System Labor Rates	$10000 / Month

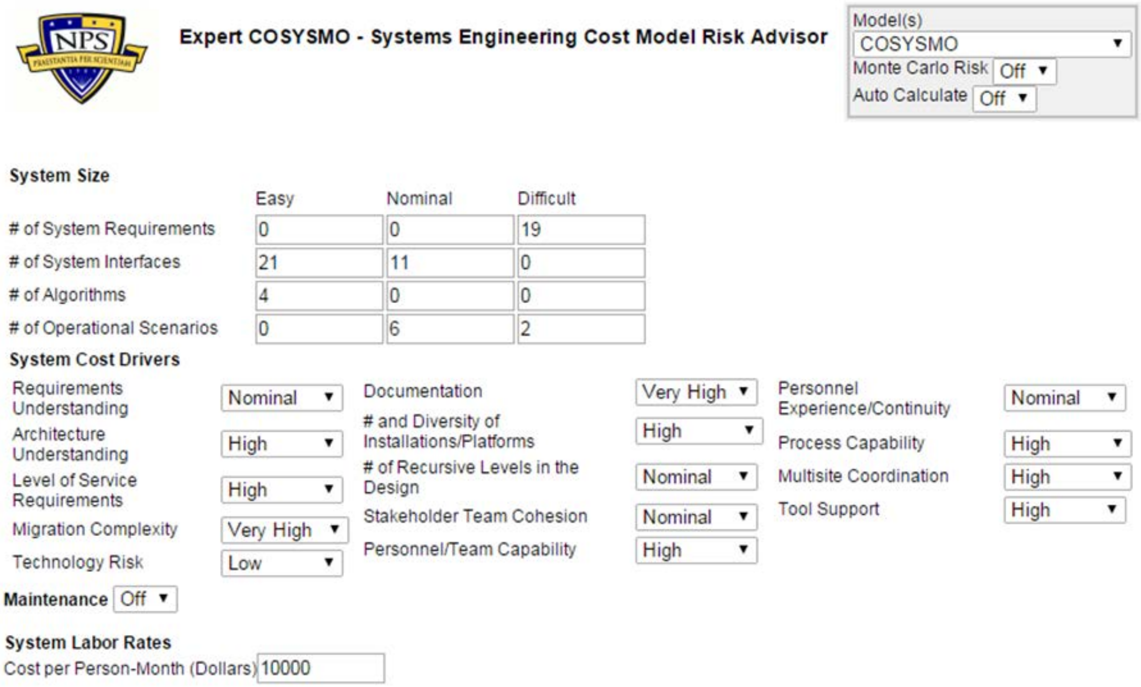


Figure 97. COSYSMO Data Input

Results

Cost and Schedule

Effort =129 Person-months
Schedule = 7 Months
Cost = $1290569

Effort Distribution (Person-Months)

Phase / Activity	Conceptualize	Develop	Operational Test and Evaluation	Transition to Operation
Acquisition and Supply	2.5	4.6	1.2	0.7
Technical Management	4.8	8.3	5.5	3.3
System Design	13.2	15.5	6.6	3.5
Product Realization	2.5	5.8	6.2	4.8
Product Evaluation	7.2	10.8	16.0	6.0

Figure 98. COSYSMO Analysis Results

Based on the resulting analysis, it can be estimated the total SE effort during acquisition would be 129 person months effort over a duration of seven months, totaling $1,290,569.

2. Software Engineering

The "System Size" and "System Cost Driver" attributes of the COCOMO II estimation methodology required numerous variables be explored and defined. This section iteratively explored each variable, its relation to DSHEL, and each rationale as to the selection for its attribute ranking based on the accepted disposition definitions from the SE Cost Estimation Workbook (Madachy, Systems Engineering Cost Estimation Workbook 2014).

A candidate for software use, based on the functional requirements of DSHEL, was performed assessing the ability to satisfy the needs of the four pillars of DS under evaluation. In accordance with the DOD Memorandum regarding free open source software (FOSS) (Department of Defense Chief Information Officer 2009), FOSS solutions were initially evaluated over COTS solutions, as mandated by this memo. The fundamental functions used in the private sector when evaluating this type of software falls into the realm of information technology (IT) system monitoring tools. This is an important factor to recognize that DSHEL, can be met with the 100% reuse of existing COTS or FOSS simply by providing the data in industry standard formats (e.g. SNMPv3, IPMI, etc.). Closed source COTS solutions, such as Splunk Enterprise (Splunk Inc.) or Solarwinds (Solarwinds Inc.), provide this functionality for service engineers to remotely monitor data centers, computing equipment, and environmental controls. After performing an AoA, FOSS alternative solutions were determined to be feasible: Nagios (Nagios Organization), Spiceworks (Spiceworks Inc.), and Zabbix (Zabbix Inc.). The needs of this COCOMO II estimate required ease of access to source code for analysis alongside little to no engineering integration involved (for the purposes of SLOC count). Nagios was chosen as the candidate for analysis. This was due to it having the highest adoption for use by the open source community, available documentation, and the source code for its core application and plugins were available without need to manually integrate. The latter options, Spiceworks and Zabbix, had drawbacks in that Spiceworks was recently acquired by a private company; thereby ending its continued development and the availability of usage. The documentation for Zabbix was limited. The UCC tool (v2013.4) was then used to perform an analysis on the Nagios Core application v4.0.8

and the Nagios Plugins v2.0.3 source code. The results are displayed in Table 22 and Table 23.

Table 21. UCC Analysis Output for Nagios Core v4.0.8

Language Name	Number of Files	Physical SLOC	Logical SLOC
Bash	3	4767	3835
C_CPP	188	93681	72257
CSS	35	1273	3252
JavaScript	2	529	514
Makefile	1	5	5
Perl	16	1586	1417
Ruby	1	95	76
PHP	12	815	632
HTML	7	600	340
Total	**265**	**103351**	**82328**

Table 22. UCC Analysis Output for Nagios Plugins v2.0.3

Language Name	Number of Files	Physical SLOC	Logical SLOC
Bash	4	7319	5919
C_CPP	222	59702	37841
Makefile	2	1400	1247
Perl	13	3013	2207
Total	**241**	**71434**	**47214**

The tool output categorized the various software languages used in the source code and provided metrics on actual number of files, alongside physical and logical SLOC. For the purposes of this analysis, Physical SLOC can be ignored as it is not used in the COCOMO II methodology; it applies only to traditional COCOMO where programmer comments, blank lines, and white spaces are counted. These provide no functional value to code execution; therefore, the improvements of COCOMO II only logical SLOC (lines of code executed by the computer) were counted for this this cost estimation in accordance with the guidelines set by the Software Engineering Institute (SEI). Adding the resulting logical SLOC analysis results together, gave a reuse estimate of 129,542 source lines of code.

The “Integration Required” refers to the amount of effort necessary to adapt the DSHEL software into its environment and test the product compared to the normal amount of integration and test effort for software of a comparable size. Given the application chosen not only meets the requirements of DSHEL, but has very few additional features not required in the plugins package, the amount of integration and test is comparable to a full IT monitoring suite. Given the available plugins with Nagios and the ones selected for DSHEL implementation, the Integration Required was estimated to be 90%.

The reuse “Assessment and Assimilation” refers to the effort required when determining if a fully reused DSHEL software merits use to the application and if it is required to integrate its description into the overall HEL product description. Given there would be considerable module test and evaluation alongside additional documentation to adapt to HEL, the assessment and assimilation effort was rated at 6%.

The “Precedentness” of the software describes the degree to which past experience applies for project execution, coupled with the relative age of the system. While the software chosen is widely used in the private sector and years of experience exist with IT System monitoring applications, the application to naval weapon systems is only generally familiar given the usage of DS. Given this is familiar to several previously developed naval PoRs, there is little need for the development of processing algorithms, and there exists a large organizational understanding of the DS objectives in the USN enterprise. The precedentedness was determined to be high.

“Development Flexibility” is the need for the software to conform to specific requirements. Since the external interfaces specifications are modeled on known open standards such as TCP/IP and SNMPv3 for modern IEEE reporting standards, alongside the complete reuse of the application where only network configuration is necessary for basic interface, the Development Flexibility was determined to be extra high.

"Architecture and Risk Resolution" covers the degree of design thoroughness and risk elimination. Given this study has provided the DS framework, initial design, risk identification and mitigation paths for the identified 2–4 critical risk items, as well as a strong familiarity of the shipboard architecture; the rating was determined to be nominal.

"Stakeholder Team Cohesion" defines how well a team collaborates. Future inputs to stakeholder team cohesion will most likely consist of NAVSEA, SPAWAR, ONR, and industry partners. The team is composed of personnel from similar organizations, share project culture, compatible organizational objectives, and clear roles and responsibilities as defined by the warfare center technical capabilities. Therefore, cohesion was determined to be nominal.

The "Process Maturity" describes the consistency and effectiveness of the project team performing the SE processes. Given the current industry and government HEL teams have defined SE processes, activities driven by benefit to the project, a process approach driven by the organizations involved, as well as a CMMI assessment level of 3, this is synonymous with a high process capability per the Cost Estimation Workbook.

The "Required Software Reliability" refers to the extent at which it must perform its intended DS function over time and the impact to operations and safety, if a failure occurs. DSHEL is a maintenance IT System supporting HEL. The event of DSHEL system failure would cause a person technical assistance to recover however the HEL would continue to operate. While this has a financial impact from in person travel, the loss is only moderate easily recoverable. Therefore, the required software reliability was determined to be nominal.

The "Data Base Size" is an important factor to consider when performing a cost estimate for an application such as DSHEL. The rating is a logical comparison of the potential data base size to the existing SLOC count. This mainly focuses and drives the cost of test and evaluation, given the effort to generate the test data to exercise DSHEL and save results. Given the data base would have simulated input alongside the saved sensor, health status, and maintenance results of HEL, the data base would be quite large in bytes. Given an average data base record with twelve fields results in a storage size of

50 bytes, alongside a typical Navy Core Test (NCT) stress test scenario with 5000 simulated inputs, the estimated data base size would then be: 3 data types (sensor, health, maintenance) * 5000 input records * 50 bytes/record + 3 data types * 5000 result records * 50 bytes/record = 1.5 Megabytes of data. The ratio of bytes in the database to SLOC is then 1,500,000 / 129,542 resulting in a ratio factor of approximately 12. By the COCOMO II assessment scale, this resulted in a data base size rating of nominal.

The "Product Complexity" of DSHEL was assessed across five main areas: control operations, computational operations, device dependent operations, and user interface management options. Since the code is 100% reuse, the complexity of development, aligns with control operations having straight line code with few non-nested operations. The device dependent operations have status checking of the HEL components, with moderately complex database operations for database queries and the user interface management options are provided with pre built dashboards with the option of using simple graphical user interface builders. The Product Complexity, given a variety across the main areas of assessment, therefore was determined to be low.

"Development for Reuse" cost drivers account for the additional effort during acquisition such that DSHEL can be reused across other HEL platforms. Given the software itself is fully reused from another project, the effort is inherently low. However, careful design in architecture must be observed such that the DSHEL subsystem itself can be reused in future mods or HEL baselines. The reusability aspect was determined to be nominal, as the reuse design architecture was inherent from the initial components of DSHEL.

Logistics artifacts such as documentation, formality, and necessary detail required for delivery of the DHSEL component, must be considered when taking the life-cycle support into account. While standard NAVSEA Logistics Center requirements mandate rigorous, strict standards and requirements, the detail necessary to guide the users through DS processes, must also leverage large amounts of documentation which are more rigorous relative to the life-cycle needs. This is due to the cybersecurity concerns and adherence to process compliance for necessary man-in-the-loop operations of DS. In turn, this leads the documentation assessment to be very high

“Analysts Capability” refers to those personnel responsible for requirements, high level design, and detail design. This has overlap with the SE capability also performing very similar efforts. Given that the field of DS, infrastructure, and naval engineering is competent with SE, this was determined to be at least in the 75th percentile, leading to an assessment of high.

The “Programmer Capability” describes the ability, efficiency, and thoroughness of the software engineering alongside communication and cooperation skillsets. Given the code is reused, Nagios is widely known and used by the IT Administrator community, and the software only required modification to the configuration of the HEL system for SNMP traps alongside the shipboard infrastructure configuration for email and chat server IP addresses, the assessment rating was determined to be in the 90th percentile at very high.

“Personnel Continuity” relate to the applicability and consistency of the staff at the initial stage of the project, with respect to the system domain, customer, user, and technology. Given the pool of naval IT, infrastructure, and systems engineers who have already been in the test bed development stage of HEL, alongside the existence functional resources within the warfare centers, it is assumed there would at least be three years continuous experience available on average, and a turnover of less than 12%. Therefore, the continuity was determined to be nominal.

“Application Experience” relates to the level of experience of the team developing, or in the case of DSHEL software reuse, application configuration and installation in terms of the software subsystem. Given the DSHEL personnel requirements for cybersecurity workforce and information technology engineers, the team can assume to have application experience of at least three years to meet the project needs, which led to an application experience of high.

“Platform Experience” relates to the applicability and consistency of the staff at the initial stage of the project, with respect to the system domain, customer, user, and technology. Given the pool of DE and naval systems engineers who have already been involved on the development stage of maritime HEL systems would also be involved in the development of the DSHEL component, it is estimated by the time DSHEL would be integrated there would at least be three years continuous experience available on average, leading to an assessment of high.

"Language and Toolset Experience" describes the measure of the software application experience of the team developing the DSHEL subsystem. It includes the use of tools that perform requirements and design representation and analysis, configuration management, document extraction, library management, program style and formatting, consistency checking, planning and control. Given these type of system design tools and remote monitoring applications common to those within the naval software engineering community and IT infrastructure domain, the language and toolset experience was assessed to be very high.

The execution "Time Constraint" refers to the measure of limitation imposed on the reactiveness and execution of the software application. Given this is a system status and maintenance reporting system, not affecting the performance of the HEL, the execution Time Constraint was assessed to be nominal given neither real time nor near-real time execution is required for DSHEL.

The "Storage Constraint" parameter describes the limits on storage of data in memory or hard drive of the system. Given the cost of storage has dropped dramatically to where a stock computing storage device measured in multiples of terabytes costs less than $100 in FY14, alongside the already estimated database size of storing records being far less, the main Storage Constraint was conservatively estimated to be less than 70% usage of the available storage leading to an assessment of high.

The "Platform Volatility" of DSHEL, in terms of software, refers to the relative frequency of change with respect to operating system, computing hardware, and HEL system under monitoring. Given the acquisition focus of naval weapons is to develop and freeze a baseline for multiple years in terms of system stability, the amount of change is measured to be greater than a major change every year with a minor change monthly. At most, the Platform Volatility in terms of the COCOMO II time constraints was assessed to be low.

The “Use of Software Tools” for DSHEL development describes the rating of simple tools for purposes of simple edits to coding and life-cycle management tools. Given the tools for editing the selected FOSS are readily available (e.g. Eclipse integrated development environment and subversion (SVN) configuration management version control software) and are well integrated with controlled processes and methods, the use of software tools was assessed to be very high.

“Multisite Coordination” on a USN project is an area that covers the location of stakeholders, team members, resources, and corporate collaboration barriers. Given the naval warfare centers, research labs, program offices, and test sites span the reaches of the country this leads to a team which is remotely collaborating at times. However, given criteria defined by the Cost Estimation Workbook as usage of wideband electronic communication, Internet based teleconference, and interactive development environments which employ collaborative tools and processes in place to mitigate these barriers, the coordination effort averages out to an assessment of high.

The “Required Development Schedule” constraint refers to the measure of limitation imposed on the development of the software application. It is a percentage ratio of schedule with respect to the nominal project length, or rather the available schedule to the nominal schedule. Given the initial PoR fielding aims to the FY18 timeframe and the DSHEL software reuse efforts are relatively executable in the next four years (FY14-FY18), the normal execution of this effort would only take 1–2 person years at most. This is approximately 130–150% of the available execution time is estimated to be needed for completion before HEL is fielded. The execution time constraint was assessed to be high.

For consistency of other distance support cost benefit studies performed, the labor rate was assumed to be burdened approximately $10,000 per person month. This assumption was made for the reuse of Fleet technical assistance data and describes the average cost of technical assistance with and without distance support, thereby normalizing the person hours used between this DSHEL estimates and existing Fleet data.

Table 23 summarizes the input variables determined from the former analysis and was used as input to the COCOMO II tool, as well as the resulting estimation output in Figure 99 and Figure 100.

Table 23. COCOMO II Tool Input Data

Methodology Variable	Value
Software Size - New Source Lines of Code (SLOC)	0
Software Size - Modified Source Lines of Code (SLOC)	0
Software Size - Reused Source Lines of Code (SLOC)	129,542
Software Size - Reused % Integration Required	90%
Software Size - Reused Assessment and Assimilation	6%
Software Scale Drivers - Precedentedness	HIGH
Software Scale Drivers - Development Flexibility	EXTRA HIGH
Software Scale Drivers - Architecture / Risk Resolution	NOMINAL
Software Scale Drivers - Team Cohesion	NOMINAL
Software Scale Drivers - Process Maturity	HIGH
Software Cost Drivers Product - Required Software Reliability	NOMINAL
Software Cost Drivers Product - Database Size	NOMINAL
Software Cost Drivers Product - Product Complexity	LOW
Software Cost Drivers Product - Developed for Reusability	NOMINAL
Software Cost Drivers Product - Documentation to Life-cycle Needs	VERY HIGH
Software Cost Drivers Personnel - Analyst Capability	HIGH
Software Cost Drivers Personnel - Programmer Capability	VERY HIGH
Software Cost Drivers Personnel - Personnel Continuity	NOMINAL
Software Cost Drivers Personnel - Application Experience	HIGH
Software Cost Drivers Personnel - Platform Experience	HIGH

Methodology Variable	Value
Software Cost Drivers Personnel - Language and Toolset Experience	VERY HIGH
Software Cost Drivers Platform - Time Constraint	NOMINAL
Software Cost Drivers Platform - Storage Constraint	HIGH
Software Cost Drivers Platform - Platform Volatility	LOW
Software Cost Drivers Project - Use of Software Tools	VERY HIGH
Software Cost Drivers Project - Multi Site Development	HIGH
Software Cost Drivers Project - Required Development Schedule	HIGH
System Labor Rates	$10000 / Month

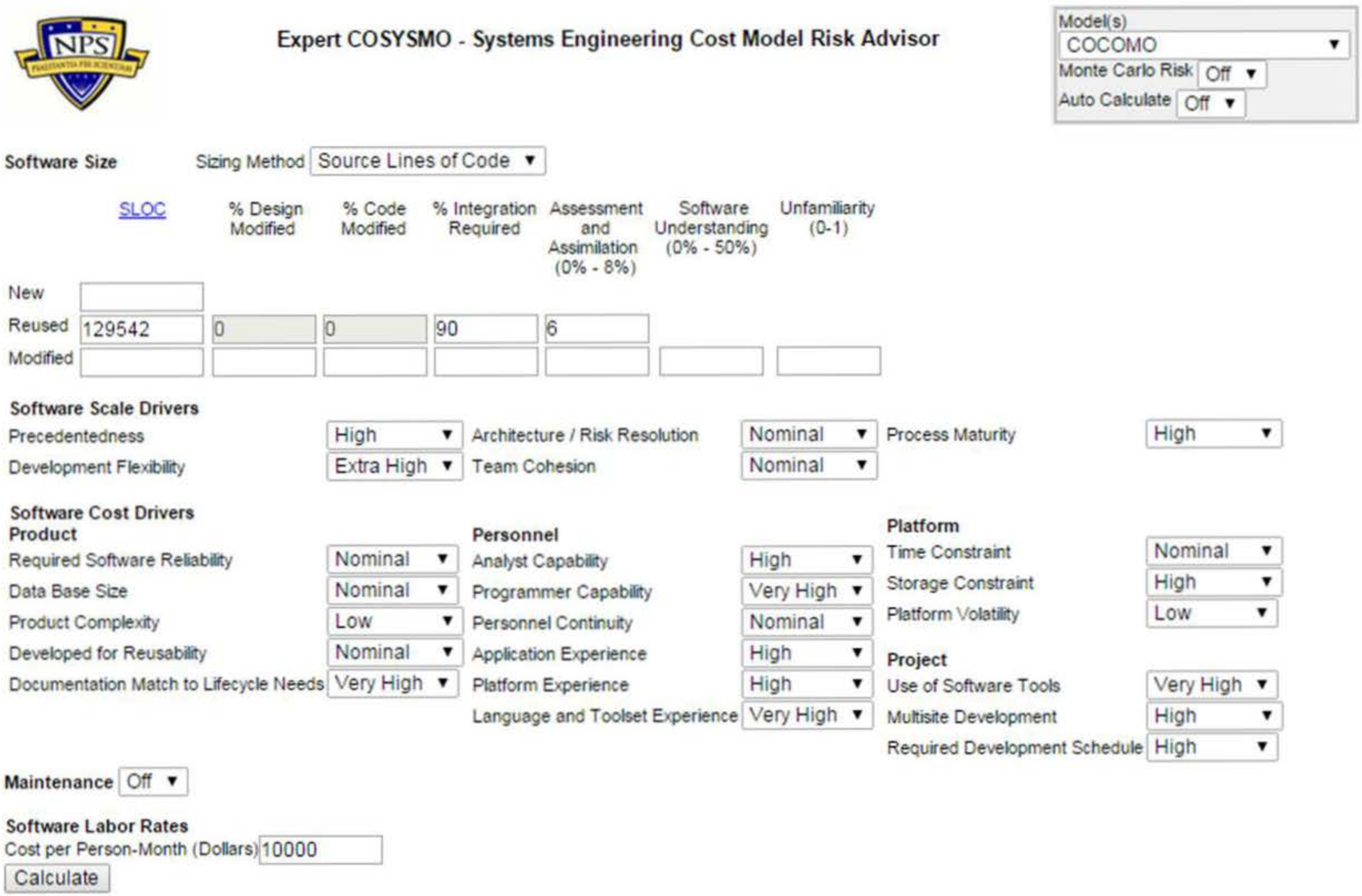


Figure 99. COCOMO II Data Input

Results

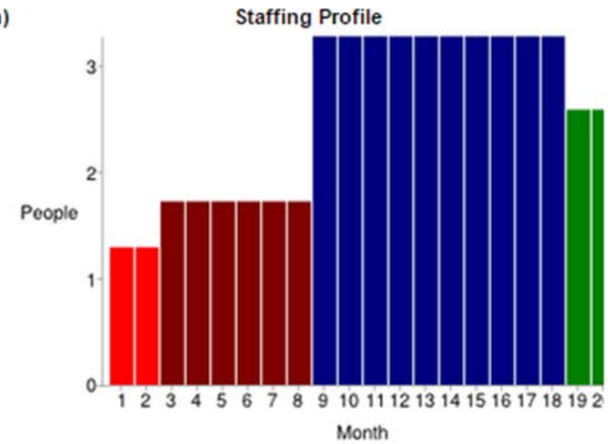
Software Development (Elaboration and Construction)

Effort = 45.2 Person-months
Schedule = 16.8 Months
Cost = $452246

Total Equivalent Size = 42748 SLOC

Acquisition Phase Distribution

Phase	Effort (Person-months)	Schedule (Months)	Average Staff	Cost (Dollars)
Inception	2.7	2.1	1.3	$27135
Elaboration	10.9	6.3	1.7	$108539
Construction	34.4	10.5	3.3	$343707
Transition	5.4	2.1	2.6	$54270



Software Activity Distribution (Person-Months)

Phase/Activity	Inception	Elaboration	Construction	Transition
Management	0.4	1.3	3.4	0.8
Environment/CM	0.3	0.9	1.7	0.3
Requirements	1.0	2.0	2.7	0.2
Design	0.5	3.9	5.5	0.2
Implementation	0.2	1.4	11.7	1.0
Assessment	0.2	1.1	8.2	1.3
Deployment	0.1	0.3	1.0	1.6

Figure 100. COCOMO II Data Analysis Results

Based on the resulting analysis, it was estimated that the total Software Engineering effort during acquisition would be 45.2 person months effort over a duration of 16.8 months, totaling $452,246.

3. Hardware Engineering

The hardware engineering material cost was a straightforward identification of computing resources necessary to meet shipboard environment and DSHEL functional requirements.

The main host of the DSHEL, an 86x64 bit architecture computer, was evaluated in comparison to existing AEGIS Combat System, DDG and CG ISNS, and Littoral Combat Ship Total Ship Computing Environment (TSCE) computing systems. The basic server meeting the shipboard grade B environmental shock and computing resource requirements for Red Hat Enterprise Linux, as well as the associate IT monitoring application software, was identified as a Hewlett Packard HPDL320. The assumption to use existing COTS already in use on USN PoRs is that the platform is already proven viable in the operational environment as well as to minimize developmental logistics costs of the USN supply system, provisioning, tech manuals, etc. Based on market cost of the USN supply system, a standard configuration of the HPDL320 had an average cost in FY15 dollars of $1,500.

The secondary human systems integration interface, which remotely extends the maintenance console of the afloat HEL, via DSHEL, to the ashore support engineer is an Internet protocol based keyboard video and mouse switch (iKVM). When access is permitted by the shipboard operators, iKVM works by taking the digital signals used from operator input and provide a secure encrypted TCP/IP interface via the GIG such that an operator can remotely login and troubleshoot a system. An evaluation of iKVMs in comparison to existing USN KVM switches in the supply system was made. The basic iKVM meets security and functional requirements of DSHEL as identified by Raritan Dominion KX III. The same assumption was used by existing COTS equipment in use on USN PoRs. These platforms have already proven viable in the operational environment as well as to minimize developmental logistics costs of the USN supply system, provisioning, and tech manuals. Based on market cost of the USN supply system, a standard configuration of the iKVM had an average cost in FY15 dollars of $2,000.

The amount of data collected regarding sensors, system health, and BIT results require a large supply of available data storage. A typical configuration for this is a set of hard drives using a Redundant Array of Independent Disks (RAID) configuration. RAID is a technology which provides extended reliability, availability, and maintainability for IT systems by independently creating backups of data stored across multiple hard drives. In essence, failures can occur without impact to operations or loss of data. Technology such as RAID bundled in a network storage device is known as Network Attached Storage (NAS). COTS NAS devices exist in common use across the USN enterprise and a component common to naval weapon and combat systems is the Hewlett Packard Store Easy 1600 NAS. Based on market cost of the USN supply system, a standard configuration of the HP NAS had an average cost in FY15 dollars of $10,000.

Given the current test bed application of HEL has yet to reach program of record status or develop a HEL fielding plan, an assumption was made for producing the a cost estimate in terms of DSHEL development. The DDG, CG, and LCS platforms have been identified for future HEL employment. Therefore, a conservative estimate of 10 HEL per ship, resulting in 10 DSHEL per ship, alongside an additional system at the HEL land based test site was assumed. An estimate of miscellaneous parts necessary for installation (e.g., bracketing, cables, screws) was estimated at $2,000. To overcome defective units which fail prior to their MTBF, an initial sparing of 20% of the total 30 DSHEL was assumed, acquiring an additional six units. No spare units were assumed to be procured for the land based test site as this is normal practice given the negligible impact to shipboard operations. As with the production of any system, hardware costs diminish with a marginal benefit per unit produced and this should be taken into account when an actual fielding plan exists for HEL. The hardware cost estimate is indicated in Table 24 and Table 25.

Table 24. DSHEL Hardware Parts Breakdown Estimate

DSHEL Components	**Cost**	**Quantity**	**Total Cost Per HEL**
Computer Server	$1,500	1	$1,500
Network Attached Storage	$10,000	1	$10,000
iKVM	$2,000	1	$2,000
Install Misc (brackets, cables)	$2,000.00	1	$2,000
			$15,500

Table 25. DSHEL Total Estimate Based on Number of HEL Sites and Spares

Ship Platform Types	HEL Quantity	Initial Sparing (20%)	Total DSHEL	Total DSHEL HW Cost
DDG	10	2	12	$186,000
CG	10	2	12	$186,000
LCS	10	2	12	$186,000
Land Based Test Site	1	0.2	1	$15,500
				$573,500

Based on the resulting analysis, it is estimated the total DSHEL COTS Hardware Engineering effort during acquisition would be a material cost of $573,500.

4. Sustainment Engineering

For estimating the hardware cost, the aforementioned sustainment methodology was applied taking in to account obsolescence management, engineering analysis, as well as logistics efforts. The cost of the replacement parts was assumed to be equivalent given COTS successors are relatively the same as the original unit. The engineering analysis effort was assumed to be two person-months at the standard labor rate of $10,000 per month. The effort to perform regression testing, logistics artifact updates, and change control review with configuration management were also assumed to be a person-month equally. Given the cost analysis only focuses on the DSHEL component of HEL, it can be assumed similar obsolescence management efforts are occurring in parallel with HEL; thereby leveraging the shipboard hardware installation and checkout activities as a sunk cost which occurs with or without the presence of DSHEL. The assumed service life of HEL was also assumed to be consistent with the normal 20 year system life span; life-cycle occurrences of this effort are the number of times the event would occur between transition and retirement. The hardware sustainment cost estimate is shown in Table 26.

Table 26. DSHEL Sustainment Hardware Estimate

Hardware	Cost	Qty.	Life-cycle Occurrences	Total
Computer Server Obsolescence	$1,500	37	3	$166,500
NAS Spares and Obsolescence	$10,000	37	3	$1,110,000
iKVM Switch Obsolescence	$2,000	37	3	$222,000
HW Obsolescence Analysis Effort	$20,000	1	3	$60,000
HW Regression Testing	$10,000	1	3	$30,000
HW ILS Artifact Updates	$10,000	1	3	$30,000
HW ECP Review and Configuration Mgmt.	$10,000	1	3	$30,000
				$1,648,500

For estimating the software cost, the aforementioned sustainment methodology was applied, taking in to account the software license management efforts of the operating system, engineering analysis, regression testing, as well as logistics efforts. Given the FOSS application chosen, Nagios, is native to the Linux platform, Red Hat Enterprise Linux (RHEL) was assumed as the operating system employed on DSHEL as is standard with most Linux based USN PoRs. The software license is a one time or recurring usage fee for OSs and applications. RHEL uses a subscription based license for expedited security and functional system patches. RHEL is open source to use given it is FOSS. The subscription is paying for support which is mandated in order to maintain a security accreditation. The annual price assumed was that of the commercial sector for extended support, $1,300 a year per installation (shipboard and lab). It is fair to note government pricing and volume purchases decrease the price; however, that is a contractual agreement between the government and Red Hat, beyond the scope and distribution disclosure of this paper. Therefore, the flat private sector price was assumed for input. Similarly, for the VMWare virtualization platform ESXi hypervisor, the licensing costs are determined per version per core of the HPDL320 server. Given the HPDL320 has four cores, at a licensing cost of $2000 per core; the cost per DSHEL is $8,000. Regression testing, engineering change proposal development and review, alongside configuration management and logistics processes necessary, were all assumed to be a person-month each. It was assumed that since the ship platforms with the ISNS, CANES, and TSCE infrastructures already provide workstations to enable email and chat, that DSHEL would inherit this infrastructure service and not have to additionally install Microsoft Windows to satisfy these requirements. The cost was then applied towards the 30 shipboard installations of DSHEL and the single land based test site. It was assumed that modern web based patch distribution via the GIG shall be leveraged for DSHEL patch installation and update. Sailor 2.0, a system managed by SPAWAR Systems Center (SSC) Pacific, is used for many applications in which patches are downloaded and installed by the shipboard crew Information Technology Chief (ITC) or Fire Controlman Chief (FCC) to avoid physical visits by the ISEA or SSA for installation. The assumed service life of HEL was also assumed to be consistent with the normal 20-year system life span. Life-cycle occurrences of this effort are life span driven by the necessary annual renewal of licenses or required patch update periodicity. The periodicity of life-cycle occurrences for software differs from hardware, in that software licenses occur annually and patching occurs semi-annually. Therefore, the quantity represents how many times a year the event occurs, not including the initial year which transitions to operation or the disposal year. While RHEL OS licensing costs occur annually resulting in 18 life-cycle occurrences, the VMWare ESXi licenses are perpetual until a major version upgrade. The assumed software tech insertion refresh is then once every year for VMWare, resulting in six life-cycle occurrences. The software sustainment cost estimate is shown in Table 27.

Table 27. DSHEL Sustainment Software Estimate

Software	Cost	Qty.	Life-cycle Occurrences	Total
Red Hat Linux Software License and Patches	$1,300	31	18	$806,000
VMWare eSXI License and Patches	$8,000	31	6	$1,488,000
SW Update/Patch Regression Testing	$10,000	2	18	$400,000
SW Update/Patch ILS Artifact Updates	$10,000	2	18	$400,000
SW ECP Review and Configuration Mgmt	$10,000	2	18	$400,000
				$3,293,400

In summary, the total hardware sustainment costs of $1,648,500 and software sustainment costs of $3,293,400 result in an aggregate DSHEL sustainment cost of $4,941,900 over the 20-year service life, captured in FY15 dollars.

5. Life-Cycle Cost Benefit Analysis

Tying together the aforementioned estimates, the purpose of this section is to summarize the costs associated with the acquisition and sustainment of DSHEL. This estimate describes the DSHEL life-cycle cost to the HEL program and determines the breakeven point in which DSHEL "pays for itself."

Incorporating the previous results from modeling and simulation, it was determined that the average downtime of a system with no distance support, the "status quo" methodology, was six days. Downtime associated with the use of a DSHEL component resulted in an estimate of two days. Using the cost estimates associated with technical assistance, an approximation can be made on the cost per event. The status quo methodology uses common DOD budgeting place holders for $5,000 per person, per week for OCONUS travel to account for airfare and hotel. A normal work day of eight person hours can be assumed during each day of system downtime. On average, two in service engineering agents are sent on site to provide assistance, typically a hardware and software subject matter expert. By multiplying the number of days of downtime, by eight hours per day, by the number of people, and finally adding the travel cost per person, an estimate per cost of technical assistance can be made. This estimate was then performed on the modeling and simulation results in Table 28.

Table 28. M&S Downtime Cost per Technical Assistance Estimate

Tech Assist Type	Downtime (Days)	Downtime (Work Hours)	People	Travel Cost	Rate ($/hr)	Total
M&S with DSHEL	10.47375	83.79	1	$0	$60	$5,027
M&S with Status Quo	18.62125	148.97	2	$10,000	$60	$18,938

Refining the above estimate, studies on mature legacy naval weapon systems have been performed by PEO IWS in relation to DS and the cost of technical assistance. The cost savings of execution effort provided by DS provided by this external study (Smith, Leonard and Jones 2012) showed cost savings where the average cost of per technical assistance event is $1,140 when integrated DS is employed and $15,390 with status quo assistance. The average cost was based on a labor rate of a $10,000 person month (approx. $60 per hour) burdened labor rate of onsite technicians and in service engineers, including travel. This data, while only applicable to legacy weapons systems, is being included for comparison as the M&S results are applied to DSHEL with the HEL POI. While the PEO IWS study provides valuable data, it was performed on legacy weapons systems, with a large SME support base, for systems which have been deployed in the Fleet for decades. The M&S was tailored towards HEL, which is a first of its kind weapon system and a smaller SME support base for the USN.

Table 29 summarizes the life-cycle costs under analysis for determining when the amount of technical assistance requests reaches a point when DSHEL begins to pay for itself, also known as the "breakeven" point.

Table 29. DSHEL Life-Cycle Cost with Downtime Estimate

Cost Type	Total
DSHEL Acquisition Systems Engineering	$1,290,569
DSHEL Acquisition Software Engineering	$452,246
DSHEL Acquisition Hardware Engineering	$573,500
DSHEL Total Acquisition Cost	$2,316,315
DSHEL Sustainment Engineering (SE/SW/HW)	$4,941,900
DSHEL Total Life-cycle Cost	$7,258,215
DSHEL Service Life (Years)	20
Average DSHEL Life-cycle Cost per Year	$362,911
M&S DSHEL Cost per Technical Assistance	$5,027
M&S Status Quo Cost per Technical Assistance	$18,938
Legacy DSHEL Cost per Technical Assistance	$1,140
Legacy Status Quo Cost per Technical Assistance	$15,390

By using the known cost of technical assistance with and without distance support from the M&S results in this capstone, as well as the legacy PEO IWS study costs for comparison, the average DSHEL life-cycle cost per year can then be combined into a linear formula for predicting cost based on the number of technical assistance requests by the Fleet. These results are illustrated in Figure 101 and Figure 102.

$$M\&S\ Status\ Quo\ DS\ Cost\ (\#\ Tech\ Assists)\ = \$18{,}938\ *\ (\#\ Tech\ Assists)$$

$$M\&S\ DSHEL\ Cost\ (\#\ Tech\ Assists)\ = \$5{,}027\ *\ (\#\ Tech\ Assists)\ +\ \$362{,}911$$

$$Legacy\ Status\ Quo\ DS\ Cost\ (\#\ Tech\ Assists)\ = \$15{,}390\ *\ (\#\ Tech\ Assists)$$

$$Legacy\ DSHEL\ Cost\ (\#\ Tech\ Assist) = \$1{,}140\ *\ (\#\ Tech\ Assists)\ + \$362{,}911$$

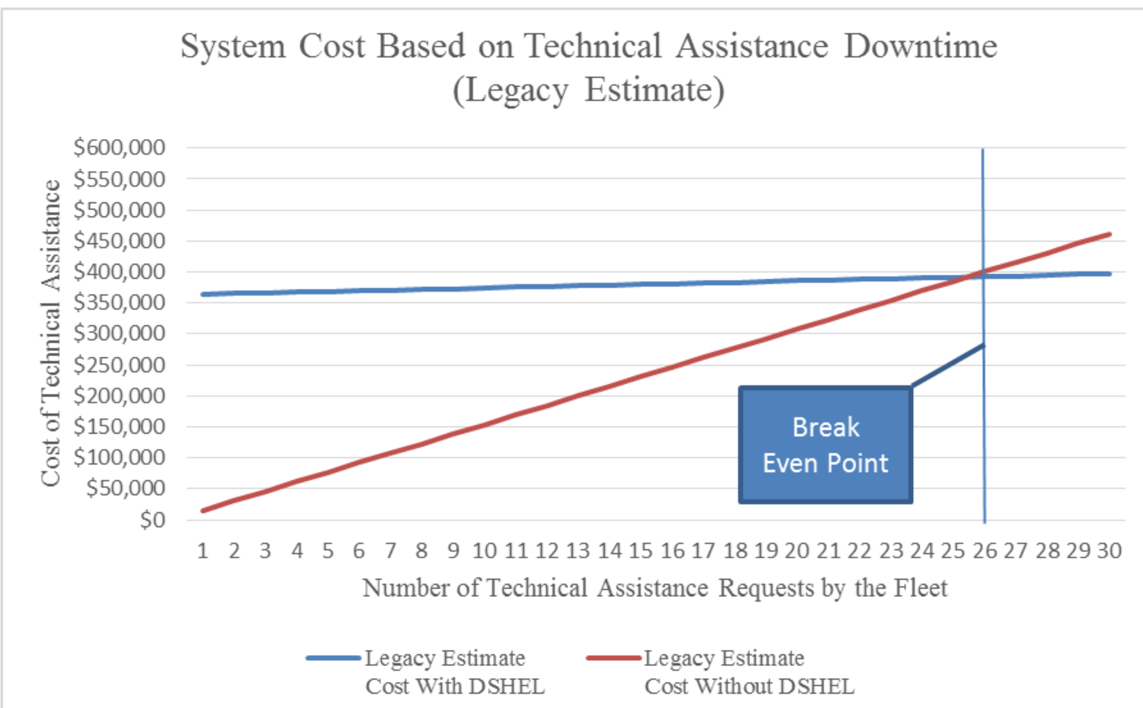


Figure 101. Annual Cost of Technical Assistance with Legacy Estimate

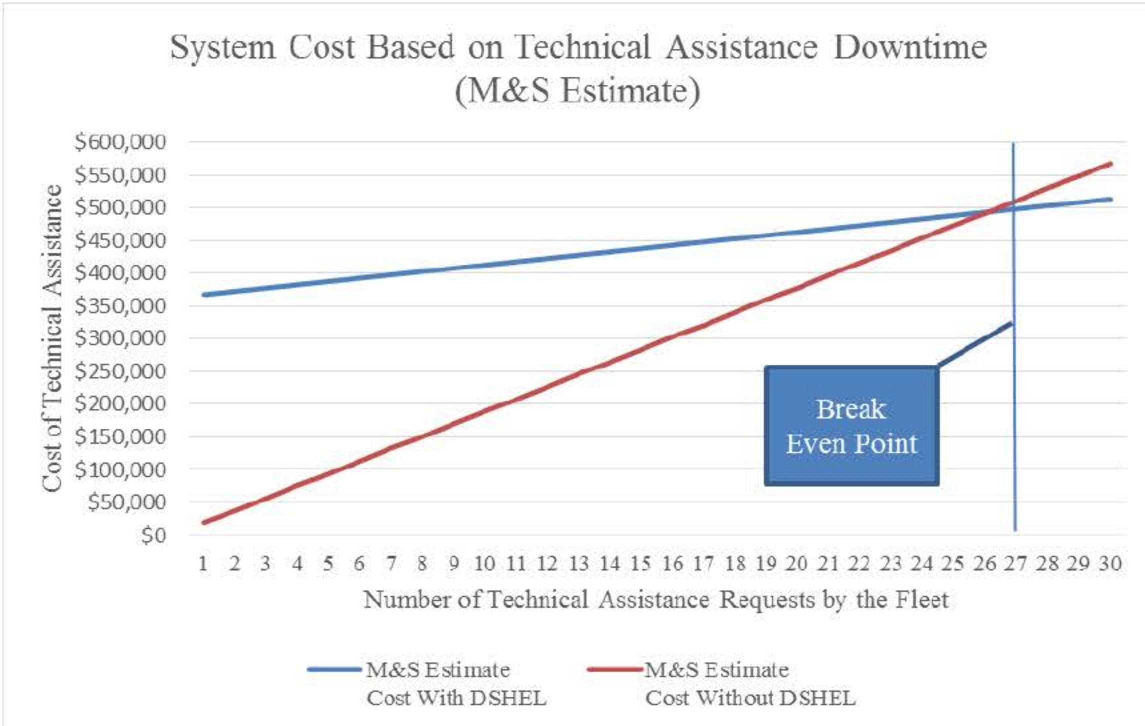


Figure 102. Annual Cost of Technical Assistance with M&S Estimate

Table 30. Annual Cost of Technical Assistance

# Tech Assists	Legacy Cost w/ DSHEL	Legacy Cost w/out DSHEL	M&S Cost w/ DSHEL	M&S Cost w/out DSHEL
1	$364,051	$15,390	$367,938	$18,938
2	$365,191	$30,780	$372,966	$37,876
3	$366,331	$46,170	$377,993	$56,815
4	$367,471	$61,560	$383,020	$75,753
5	$368,611	$76,950	$388,048	$94,691
6	$369,751	$92,340	$393,075	$113,629
7	$370,891	$107,730	$398,103	$132,567
8	$372,031	$123,120	$403,130	$151,506
9	$373,171	$138,510	$408,157	$170,444
10	$374,311	$153,900	$413,185	$189,382
11	$375,451	$169,290	$418,212	$208,320
12	$376,591	$184,680	$423,240	$227,258
13	$377,731	$200,070	$428,267	$246,197

# Tech Assists	Legacy Cost w/ DSHEL	Legacy Cost w/out DSHEL	M&S Cost w/ DSHEL	M&S Cost w/out DSHEL
14	$378,871	$215,460	$433,294	$265,135
15	$380,011	$230,850	$438,322	$284,073
16	$381,151	$246,240	$443,349	$303,011
17	$382,291	$261,630	$448,377	$321,949
18	$383,431	$277,020	$453,404	$340,888
19	$384,571	$292,410	$458,431	$359,826
20	$385,711	$307,800	$463,459	$378,764
21	$386,851	$323,190	$468,486	$397,702
22	$387,991	$338,580	$473,514	$416,640
23	$389,131	$353,970	$478,541	$435,579
24	$390,271	$369,360	$483,568	$454,517
25	$391,411	$384,750	$488,596	$473,455
26	**$392,551**	**$400,140**	$493,623	$492,393
27	$393,691	$415,530	**$498,651**	**$511,331**
28	$394,831	$430,920	$503,678	$530,270
29	$395,971	$446,310	$508,705	$549,208
30	$397,111	$461,700	$513,733	$568,146

Initially, it can be seen that the cost of no development or inclusion of a DSHEL is far cheaper when the Fleet has very few technical assistance requests to support HEL. However, as the number of tech assists per year grows, the breakeven point becomes apparent (highlighted in Table 30). More specifically, 26 technical assistance requests in a year is the breakeven point in which DSHEL begins to "pay for itself" based on the legacy average cost of technical assistance study. However, given HEL is an immature weapon system compared to legacy systems, comparatively the tailored M&S results determined the breakeven point to be 27 technical assistance requests. While the plots intersect at a point in between 26 and 27 technical assistance requests, the breakeven point is rounded up to account for the fact that it is impossible to have a fraction of technical assistance.

The model not only provided additional validation to studies performed by an external organization, but provided validation that the relevancy and accuracy of the estimate is on par with the assumptions made in this cost analysis. It must be noted that this cost estimate was based on a limited number of ships with HEL actually employed, leveraging a DSHEL subsystem to enable distance support. Further expanding on the results from the legacy estimate, given the number of ships with HEL in this model was assumed to be 30, the likelihood of 27 technical assistance request per year is quite probable given the severe complexity of the HEL system and its introduction to the Fleet as a never before seen weapon system type. Future work to refine this model is necessary once a PoR configuration of HEL has been identified to identify a fielding plan for number of shipboard installations. However, even in the current legacy cost model, if every ship with HEL in this analysis at least submitted one help ticket request for their system per year, the comparison for supporting 30 technical assistance requests with DSHEL had an annual estimate of $513,733 compared to supporting requests without DSHEL at an estimate of $568,146. That result is an annual labor and travel cost savings of $54,413 per year, or more importantly $1.09M over the 20-year life cycle. In addition to the increased issue resolution and overall Ao to perform the mission, this cost benefit analysis has shown the significant financial savings DSHEL would provide to USN. As a reminder, this cost benefit is limited to the labor and travel associated with technical assistance. Future work involving ePrognostics and Self Repair and Healing (the latter two pillars of DS) is expected to reveal even greater cost savings in the failure prevention of expensive HEL subsystem components.

C. RISK ANALYSIS APPROACH

This section aimed to objectively present the findings of research theories, processes, DOD mandates, stakeholder requirements, and methodologies applicable to the risk management of the DSHEL subsystem.

Risk is inherent to any engineering or management effort. Overall, it is the probability that given a series of one or more events, something with a negative outcome will occur. There are many ways to categorize types of risk, but for the purposes of this capstone report focusing on SE of a defense program, those categories were stated in terms of cost, schedule, and technical performance. Cost risk is the probability which the allocated budget of the project will be exceeded in some manner. Schedule risk is the probability which the project will fail to meet key dates or milestones by a specified duration. Technical performance risk is the probability which the key performance parameters of the system are negatively affected. Regardless of the risk type, there needs to exist a formalized process to identify, assess, and prioritize each risk; this is known as risk management.

The practice of risk management is broken down into an iterative process which extends the life of the program from cradle to grave. Blanchard and Fabrycky describe this process as follows (Blanchard and Fabrycky 2011, 692):

1. Risk planning—includes the development of a risk management plan or a given program.

2. Risk identification—includes the screening of all cost, schedule, and technical performance requirements and to identify which of those are likely not to be met.

3. Risk assessment—pertains to determining the probability of failure to meet a specified requirement and the possible consequences of not meeting the requirement.

4. Risk analysis—is accomplished to determine the way in which the risk can be eliminated or minimized (if the risk cannot be eliminated altogether).

5. Risk handling—includes the activities associated with the incorporation of changes to business process or system modification which are recommended as a solution to the identified problem.

While the aforementioned steps are specific in high level guidance, different methodologies exist for tailoring the process to best fit the project. The remaining sections explored a few of these methodologies, their capabilities and limitations, for the identification of stakeholder requirements and management of risk to DSHEL.

1. DOD Risk Management Guide

The Department of Defense Risk Management Guide (Department of Defense 2006) exists to assist DOD and contractor Program Managers (PMs), Program Offices, and integrated product teams (IPTs) to effectively manage risks during the life cycle of a program. It provides a standard framework and methodology of assessment and presentation which is common to all branches of DOD. By using this framework to manage risk, a format which is common to program managers and officers of the DOD, the methodology of status reporting can be normalized for the program. The RMG dictates that every program shall create a risk management plan specifically tailoring the individuals responsible for the integrated product teams, those accountable, and responsible for the process of risk management.

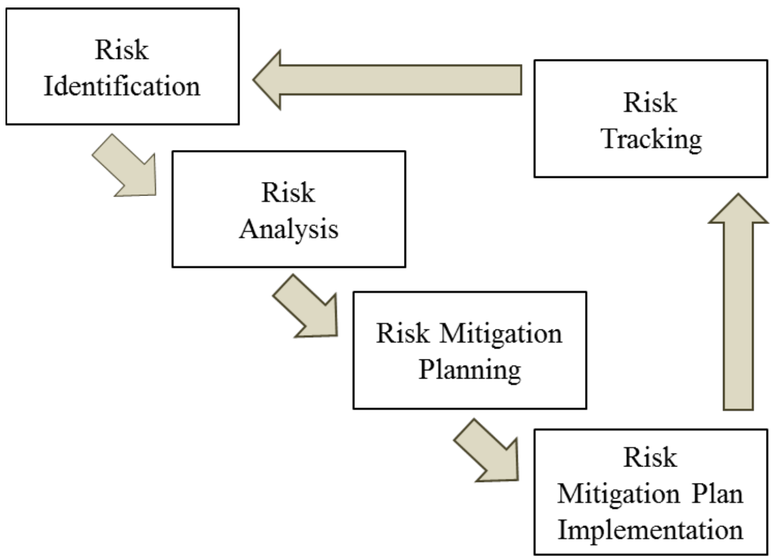


Figure 103. DOD Risk Management Process (after Department of Defense 2006)

While the plan is tailored via the SE process to best fit the need of the program, the general process described in the Figure 103. When risks are identified, they shall be expeditiously entered in to the risk management process where an IPT will assess their impact. Assessment is performed during the analysis phases where a number of criteria based on cost, schedule, and technical performance are used to determine the Likelihood and Consequence of occurrence. Table 31 displays the standard nomenclature for translating probability of occurrence to the wording of a given likelihood. This is to be used when another standard doesn't already exist to refine and supersede the assessment criteria presented in the RMG. For the purposes of DSHEL, the team also included

NAVSEAINST 9410.2A for Warfare System Certification or MILSTD-882G for Safety assessments to better refine the risk model.

Table 31. Risk Analysis for Levels of Likelihood (from Department of Defense 2006)

	Level	Likelihood	Probability of Occurrence
Likelihood	1	Not Likely	~10%
	2	Low Likelihood	~30%
	3	Likely	~50%
	4	Highly Likely	~70%
	5	Near Certainty	~90%

Consequence assessment, however, is more involved as it is assessing the impact in relationship to cost, schedule, and performance. Cost and schedule are based upon known quantities of the project and how a risk could impact a given percentage of the budgeted resource. Those details are outlined in the risk management plan when such project details are known; however, this capstone will later identify and refine risks following methodology assessments based on the cost analysis and projection scale. Technical performance impact requires a breadth of technical knowledge of the system risk being analyzed to properly categorize impact. However, just as with the likelihood criteria, the RMG provides a boilerplate guideline which is allowed to be superseded when other DOD instructions exist, which refine or tailor the process. For the purposes of DSHEL, the team also included the DOD Information Assurance Risk Management Framework for Cybersecurity. An example consequence table from RMG is illustrated in Table 32.

Table 32. DOD Levels and Type of Consequence Criteria (Department of Defense 2006)

Level	Technical Performance	Schedule	Cost
1	Minimal or no consequences to technical performance	Minimal or no impact	Minimal or no impact
2	Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program	Able to meet key dates Slip < * day(s)	Budget increase or unit production cost increases < ** (1% of Budget)
3	Moderate reduction in technical performance or supportability with limited impact on program objectives	Minor schedule slip. Able to meet key milestones with no schedule float Slip < * day(s) Sub-system slip > * day(s) plus available float	Budget increase or unit production cost increases < ** (5% of Budget)
4	Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success	Program critical path affected Slip < * days	Budget increase or unit production cost increase < ** (10% of Budget)
5	Severe degradation in technical performance; cannot meet KPP or key technical/supportability threshold; supportability; will jeopardize program success	Cannot meet key program milestones Slip > * days	Exceeds APB threshold > ** (10% of Budget)

Following analysis, the risk mitigation path is equally as involved and important. This is where the IPT decides the best path forward to manage the risk before it occurs (or mitigate the issue if it has already manifested itself). This kicks off an iterative process of planning, executing, and status reporting until the risk can be minimized or eliminated altogether. The status is tracked and continuously reported out to the Project Manager by the systems engineer. A feedback loop exists in the process for refinement.

An example of a risk status reporting matrix can be seen in Figure 104 showing a "stoplight" assessment where the likelihood and consequence results fall into a risk area of high (red), medium (yellow), or low (green).

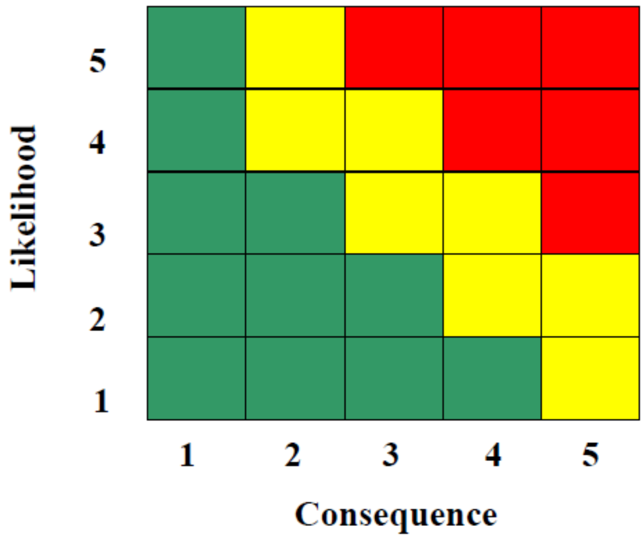


Figure 104. Example Risk Matrix

Overall, the DOD RMG provides the necessary framework to facilitate effective communication of DSHEL risk in a manner which is familiar to programmatic stakeholders. It is the recommended methodology by DOD to formalize risk management into the process familiar to the organization such that the IPTs can focus their energy more on managing risk rather than explaining a unique unfamiliarity.

2. DOD Risk Management Framework

The DOD Information Assurance Risk Management Framework (RMF) ties together the aforementioned topics of cybersecurity and risk management. This process is meant to better refine the technical impact of risk when it relates to information assurance. The overall instruction derives from the National Institute of Standards and Technology (NIST) 800–53 and better aligns the DOD with the rest of the Federal government in how it shall identify, assess, manage, and report cybersecurity risk. While the specific implementation of the Naval Instruction tailoring for DON has not been released at the time of this writing, it shall align with the RMF. Therefore, this capstone report focused on the instruction set forth by DOD with the caveat that when creating a DSHEL further refinement and tailoring for the USN RMF process. DOD is not requiring immediate transition to the RMF upon release in order to allow time for critical supporting guidance, automated tool updates, and training from DOD and the components to be developed and released. By FY15, the DON chief information officer (DON CIO) will release policy addressing component specific guidance regarding transition of all DON information systems and platform IT systems to the RMF in accordance with the DOD timelines (Department of Navy 2014).

Where the RMF specifically aligns with the DOD RMG, is in the assessment portion of the risk management process. During development of a system, for purposes of accreditation, the information technology system shall be identified as an information system, platform information technology, IT services, or IT products as indicated in Figure 105.

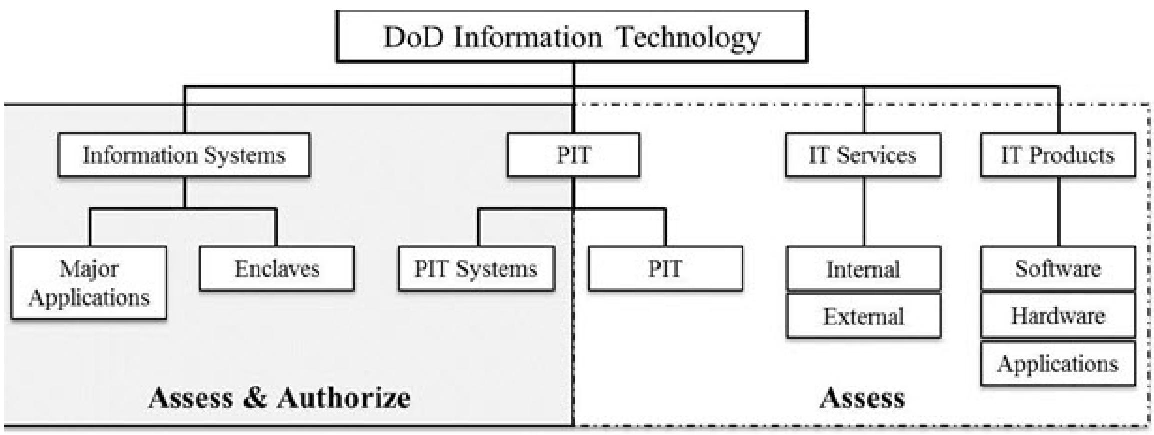


Figure 105. DOD Information Technology Categorization for RMF (from Department of Defense 2014)

Based on a system's required functionality and capabilities, once it is categorized, the RMF provides a set of cybersecurity requirements alongside STIGs as well as whether or not the system requires an authorization in addition to risk assessment. Not all requirements can be 100% implemented as it would degrade performance of the system from executing some functions. RMF dictates that as many of the requirements as feasible shall be implemented until required functionality or technical performance is impacted and design cannot be mitigated to accommodate the security control. At this point whatever security vulnerabilities are left open must be identified as known risks to the system and can be assessed for consequence in accordance with the Committee of National Security Systems Instruction CNSSI-1253. Cybersecurity has created its own sub framework for risk management, it is the amount a risk the program office, customer, and certification officials are willing to accept based on required functionality therewith the mitigation of security vulnerabilities which remain.

The RMF process shows the certification and authorization procedures necessary for IA. The assessment step, the fourth box, can directly correlate and report out to the overall risk management process for conveying risk to the project sponsor. In tandem, it provides a dual feedback loop where the sponsor can be informed of overall programmatic risk. While specific to cybersecurity, the risk can be conveyed to the designation officials determining if the system is secure enough to obtain certification. The RMF consists of the steps depicted in Figure 106. This process parallels the system life cycle with the RMF activities being initiated (a program or system inception, i.e., documented during capabilities identification or at the implementation of a major system modification). Per the updated instruction, "failure to initiate the RMF at system or program inception is not a justification for ignoring or not complying with the RMF" (Department of Defense 2014, 27). While the full details are contained in the instruction itself, this necessity is not to be taken lightly. The proper management of cybersecurity in accordance with RMF is the responsibility of all programs in DOD. Passive stakeholder requirements will need to be captured in any project's risk management plan such that in addition to cost, schedule, and technical performance, cybersecurity becomes a technical subset of the performance categorization.

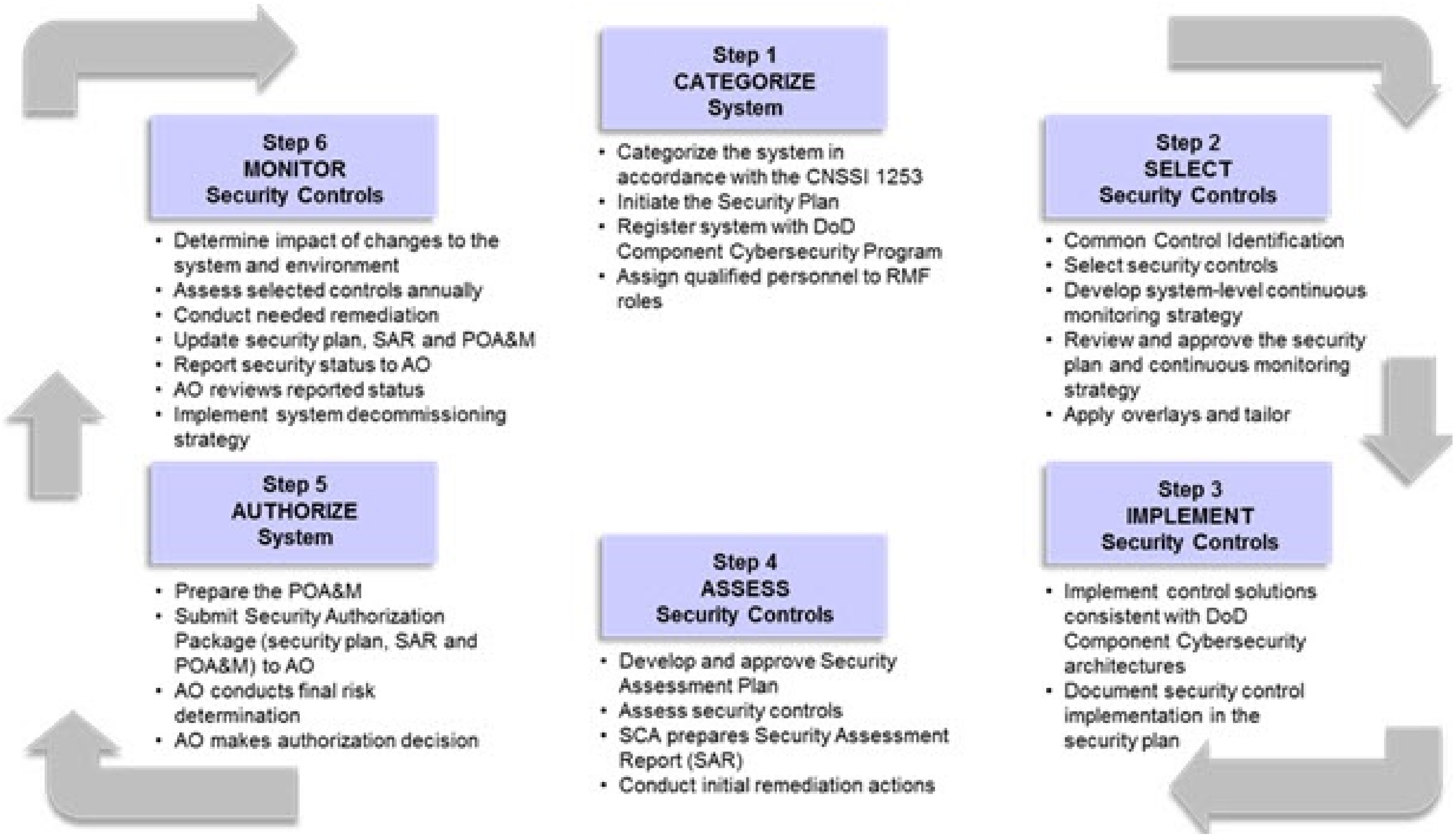


Figure 106. RMF for Information Systems and PIT Systems (from Department of Defense 2014)

In accordance with the NAVSEA Warfare System Certification criteria defined in NAVSEAINST 9410.2A, the following risk assessment priorities have been defined with respect to IA and the impacts to certification and systems performance. It must be noted, that unlike the DOD RMG which assess risk with Consequence 1 being the best case and Consequence 5 being the worst, the rating factor is switched where there worst case is Consequence 1 and best case is Consequence 5. The worst case, Consequence 1, defines risk as a “Problem that negatively impacts information systems security posture and results in the loss of authority to operate (ATO)” (Naval Sea Systems Command 2012). Consequence 2 defines risk as a “Problem (that) degrades / adversely affects information security posture and results in a reduced set of capabilities.” Consequence 3 defines risk as a “Problem that degrades/adversely affects information systems security posture but allows an interim authority to operate (IATO).” Consequences 4 and 5 do not provide any definitions to assess information assurance related risk, as beyond level three they do not impact certification. At this point, the consequence can be treated generically as any other technical impact, where a Consequence 4 “Problem results in user/operator inconvenience or annoyance and does not affect required operational or mission essential capability (or) results in a minor system degradation that does not prevent ownership accomplishment of an operational or mission critical/essential function and/or ship operations.” Consequence 5 defines risk as “An error that does not affect the system or operator from accomplishing a function in accordance with system requirements; a specification error that does not affect the software; an error that does not affect warfare systems operations.”

3. Tailored Risk Management Methodology

By leveraging the aforementioned guidance on cybersecurity, warfare systems certification, and resulting cost analysis, the DOD RMG table for assessing risk consequence was tailored for DSHEL technical performance, schedule, and cost. With regards to cybersecurity, the risk assessment relating to warfare systems certification shall be included into the appropriate technical performance areas; their consequences obviously being switched to align properly given the assessment scale for RMG goes from 1 to 5, and warfare systems certification goes from 5 to 1, describing best to worst case. Schedule was leveraged from the COSYSMO and COCOMO II estimates, with initial SE efforts supporting Software in parallel with an estimate of 16.8 person months (67 person weeks). Given the development of a detailed project schedule is beyond the scope of this study, the higher level COCOMO schedule was used to identify key periods and milestones: 2.1 months for the inception phase, 6.3 months for the elaboration phase, 10.5 months for construction, and 2.1 months for transition to operation. The individual phases will be used to assess duration impact to meet key dates, with the assumption that 25–30% float exists to accommodate a schedule slip within an individual phase. Given the project's critical elaboration phase has only 6.3 months (25.2 weeks) for execution, these estimates approximately 7.5 weeks of slippage until the critical path is affected. The resulting schedule impacts were then assessed proportionately. Finally, with respect to Cost, the total budget for DSHEL acquisition was estimated to be $2,316,315, whereas 1% impact would be $23,163, 5% would be $115,816, and 10% would be $231,632 respectively. Table 33shows the resulting risk management assessment criteria, tailored for the specifics of DSHEL.

Table 33. DSHEL Tailored Risk Management Assessment Criteria (after Department of Defense 2006)

Level	Technical Performance	Schedule	Cost
1	Minimal or no consequences to technical performance	Minimal or no impact	Minimal or no impact
2	Minor reduction in technical performance or supportability, can be tolerated with little or no impact on program	Able to meet key dates Slip < 2 Weeks	Budget increase or unit production cost increases < $23,163

Level	Technical Performance	Schedule	Cost
3	Moderate reduction in technical performance or supportability with limited impact on program objectives Problem that degrades/adversely affects information systems security posture but allows an Interim Authority to Operate (IATO)	Minor schedule slip. Able to meet key milestones with no schedule float Slip < 3.25 Weeks Sub-system slip > 3.25 Weeks plus available float	Budget increase or unit production cost increases < $115,816
4	Significant degradation in technical performance or major shortfall in supportability; may jeopardize program success Problem degrades / adversely affects information security posture and results in a reduced set of capabilities	Program critical path affected Slip < 7.5 Weeks	Budget increase or unit production cost increase < $231,632
5	Severe degradation in technical performance; Cannot meet KPP or key technical/supportability threshold; supportability; will jeopardize program success Problem that negatively impacts information systems security posture and results in the loss of ATO	Cannot meet key program milestones Slip > 7.5 Weeks	Exceeds APB threshold > $231,632

D. RISK ANALYSIS AND RESULTS

The following section applies the tailored risk management assessment criteria to risks identified during the research of DSHEL. This included assessments of likelihood and consequence, alongside recommended mitigations.

1. Risk 1—Maturity of RMA Data

Accurate data of a system regarding its components reliability, maintainability, and availability presents a complex issue when planning for DS. Real world data is needed for refined results that represent an operational maritime environment; however, this is not readily available for a first of its kind system such as HEL. Not knowing the true reliability of these laser components leads to the possibility of over monitoring HEL components or not monitoring the correct ones. Fortunately, many of the HEL components require system monitoring for normal operations to compute battle damage assessment as well as determining ready to fire status. The critical components will most likely be monitored and their status made available for DSHEL to pull. However, the risk exists that without operationally RMA data, it is unknown exactly which HEL components merit monitoring in a maritime environment and a critical component may not be monitored.

- Risk Nomenclature: (R1) Maturity of RMA Data
- Consequence: Moderate reduction in technical performance or supportability with limited impact on program objectives
- Likelihood: Likely ~ 50%
- Recommended Mitigation: Directed Energy SME analysis is necessary in tandem with logistical efforts to create Failure Mode, Effects, and Criticality Analysis (FMECA) to predict and identify critical parts for sensorization. FMECA is a required logistics artifact necessary as entrance criteria to present at Milestone B, finalized by Milestone C. By leveraging this data, an educated prediction can be made with respect to monitor the correct parts and refined over time as the system operates and real world data is collected.

The R1 risk assessment is determined to be (Consequence = 3, Likelihood = 3).

2. Risk 2— Common USN Data Format

The USN has moved away from MILSTD type requirements for transmitting and reporting system status, leaning more towards the recommendation that a program will use open standards. While this gives flexibility to the contractors, it results in a wide diversity in data reporting formats across all USN systems, resulting in not having a single program of record software application which can read and reuse this data. To minimize the cost of DS by reuse of existing COTS/FOSS software applications, it is imperative that a standardized open format is chosen for use, and that HEL reports its data in this format to DSHEL. The data format requirement from DSHEL recommends a common industry standard reporting format on HEL to help mitigate this, such as simple network management protocol version 3 (SNMPv3). Without doing this, the risk is that DSHEL will not be able to integrate, read, and report status ashore to meet its mission requirements. It is not likely that this would happen as HEL is early in the development cycle and this requirement is being proposed early on for the inclusion of DSHEL.

- Risk Nomenclature: (R2) Common USN Data Format not defined
- Consequence: Cannot meet key technical/supportability threshold and will jeopardize program success
- Likelihood: Near Certainty ~ 90%
- Recommended Mitigation: Require use of industry standard IEEE defined data formats for HEL sensorization, health monitoring, and test results (SNMPv3) such that FOSS can be leveraged for software functionality.

The R2 risk assessment is determined to be (Consequence = 5, Likelihood = 5).

3. Risk 3—Classification of HEL Data

The classification of weapon system data, specifically HEL, drives the cybersecurity requirements and controls necessary to obtain an ATO. HEL is unique in its application, as it is a ship self-defense weapon and an extremely accurate long range optical sight which could be used as an ancillary shipboard sensor. The former use, as ship self-defense, is typically unclassified. However, shipboard sensors and optical sights typically have a classified data set as they provide unique information used to create tracks managed by the ship's combat system. The risk is that an assumption is made to use DSHEL with an unclassified data set when in the future the classification of HEL could be escalated given an ancillary use, thereby invalidating the existing DSHEL cybersecurity accreditation.

- Risk Nomenclature: (R3) Classification of HEL Data
- Consequence: Problem that negatively impacts information systems security posture and results in the loss or inability to obtain ATO
- Likelihood: Not Likely ~ 10%
- Recommended Mitigation: Assume worst case that HEL data is classified and structure security posture to satisfy these controls with the RMF confidentiality rating of high

The R3 risk assessment is determined to be (Consequence = 5, Likelihood = 1).

4. Risk 4—Hardware Processing Drives Software Licensing Costs

The use of COTS/FOSS software comes with OEM license agreements for operational usage and support in the form of patches and updates. Regardless of the operational usage or performance requirements, licensing is sometimes based on the number of processing cores on the computer's central processing unit (CPU). Given that the cost of CPU performance is relatively cheap, hardware engineers have the risk of "gold plating" their choice of computing servers and using processors which are above and beyond what is necessary. The software operating platform was chosen to run virtualized on top of VMWare ESXi to minimize risk of future hardware technology refresh. Virtualization adds an abstraction layer between the operating system and computing hardware, thereby making the hardware appear static to the operating system no matter what the choice of hardware is. This incurs an upfront cost of software licensing to minimize the risk of integration efforts further on in the life cycle when hardware driver issues or software library compatibility typically has issues with hardware upgrades. The overall risk is that given this choice of architecture, choosing a server which has hardware performance above what is required would drive software licensing costs.

- Risk Nomenclature: (R4) Hardware Processing Drives Software Licensing Costs
- Consequence: Exceeds APB threshold > $231,632
- Likelihood: Low Likelihood ~ 30%
- Recommended Mitigation: SE must enable and manage communication between hardware and software engineering teams that “gold plating” of a computer server processor impacts software licensing costs, set objective and threshold requirements for processor cores.

The R4 risk assessment is determined to be (Consequence = 5, Likelihood = 2).

5. Risk 5—Training

The shipboard process of enabling distance support for active methods, such as remote repair or remote technical assistance, mandates a “man in the loop” philosophy to ensure the oversight, control, and operational security necessary to protect the system. Given active DS methodologies are not common or organic to naval weapon systems, it is imperative that detail standard operating procedures, technical manuals, and training are present to ensure process is adhered to in the interest of cybersecurity and mission success. The risk of not following process would delay the responsiveness of DS and increase system downtime.

- Risk Nomenclature: (R5) Training
- Consequence: Moderate reduction in supportability with limited impact on program objectives.
- Likelihood: Low Likelihood ~ 30%
- Recommended Mitigation: Detailed documentation and hands on sailor training at ISEA Laboratory to ensure the user is familiar with DSHEL usage and DS process adherence.

The R5 risk assessment is determined to be (Consequence = 3, Likelihood = 2).

6. Risk 6—Integration

As the HEL is being developed, components and their internal level of integration are in flux. DSHEL depends on known interfaces and message types to enable mission success. As the HEL progresses to a mature program of record, the risk of change impacts integration efforts, causing setbacks to reconfigure DSHEL to monitor the appropriate components. While there is an expected common message type, the HEL architecture and its interfaces must be relatively static to complete successful integration efforts.

- Risk Nomenclature: (R6) Integration
- Consequence: Minor schedule slip, able to meet key milestones, slip < 3.25 Weeks
- Likelihood: Highly Likely ~ 70%
- Recommended Mitigation: HEL engineering changes during development shall identify impacted interfaces, physical and logical. These interfaces shall be captured in a detailed interface control document and specification. A change to any HEL interface will trigger review by the DSHEL team for integration impact.

The R6 risk assessment is determined to be (Consequence = 3, Likelihood = 4).

E. SUMMARY

The following risk matrix, shown in Figure 107, is an aggregate rollup of all risks identified with the SE efforts associated with DSHEL. While a majority of the risk is medium (yellow), the mitigation paths presented can effectively prevent or mitigate this risk from occurring to achieve successful realization of DSHEL.

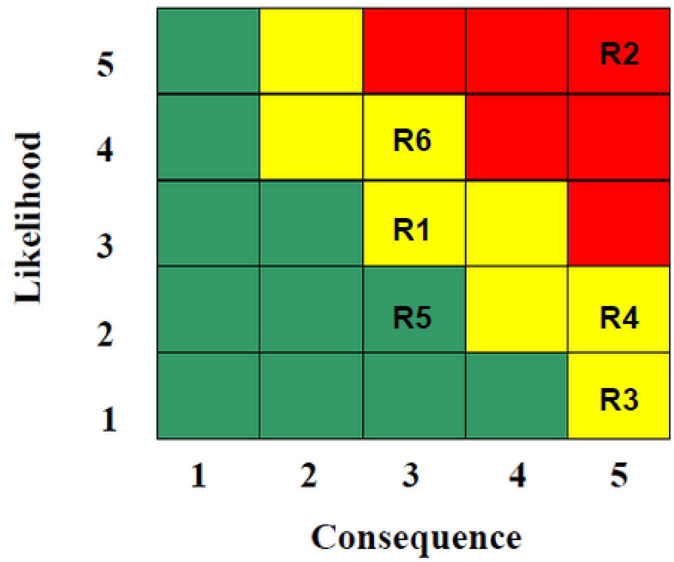


Figure 107. DSHEL Risk Matrix

- Risk Matrix Key

  R1 = Maturity of RMA Data

  R2 = Common USN Data Format

  R3 = Classification of HEL Data

  R4 = Hardware Processing Drives Software Licensing Costs

  R5 = Training

  R6 = Integration

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VII. CAPSTONE SUMMARY

A. TECHNICAL OUTCOMES

The first section of Technical Outcomes covers the development of the distance support decision process, which gave the support provider the ability to determine how much distance support is required and to what level the system might be sensorized. The second section discusses the modeling and simulation findings derived from an existing distance support process. The last section details the findings related to the cost analysis that was performed for the DSHEL system.

1. Distance Support Decision Process

In determining how much DS is required and to what level a system must be sensorized, an analysis of the POI as well as the PSP culture and strategy must be conducted. The PSP culture and strategy must first be understood in order to know what type of DS is needed. This raised the question of whether DS was a product or a service. This is dependent on PSP culture and how execution of DS is delivered. However, the PSP strategy must also be taken into account, as an organization will evolve over time. Providing quality DS is the progressive evolution of a PSP creating an environment in which they are no longer involved.

DS for a POI begins with the understanding of the POI's environment and interface interactions. A holistic systems view must be taken. DS is not isolated to one DS element: PSP, ESI, or POI. DS is the effective collaboration of these elements through SLAs and OLAs within the enterprise ecosystem. Only when these interactions and business process flows are understood, can an analysis of the POI begin. The POI must be classified as an "independent platform" or as a "guest platform contained within a host platform." This classification offers insight into the next decision, DSX configuration. The multiple DSX configurations (integrated – single-point all inclusive, encompassing – single-point semi inclusive, distributed – multipoint all inclusive, distributed – multipoint semi inclusive) offer the PSP flexibility in terms of POI life-cycle phase, cost, capability, scalability, and complexity. These are used to meet the minimum data picture completeness threshold to provide meaningful I2DF in delivering quality DS.

The level of sensorization and sensor collection network topology chosen by the PSP for the POI is highly dependent on the minimum data picture completeness threshold set by the PSP. Once the above steps are met, the PSP executes a POI system decomposition to an acceptable level where the I2DF set is adequately detailed. These components are then analyzed for inherent sensor capabilities and are either sensorized or added to the sensor collection network with characteristics as defined by the POI SMEs.

2. Modeling Distance Support

Through the employment of modeling and simulation tools, the effects of three types (no DS, status quo DS, integrated DS) of distance support were analyzed. The time-based analysis showed significant reduction in mean down time (MDT) for integrated distance support while it significantly increased for no distance support in relation to the status quo. Reduction in MDT, ceteris paribus, causes improvement in Ao. The baseline status quo distance support model indicated a MDT of 149.0 hours, a standard deviation of 91.5 hours, with a resulting Ao of 0.770. Integrated distance support showed significant improvement with a MDT of 83.8 hours, a standard deviation of 44.9 hours, with a resulting Ao of 0.856. Conversely, elimination of distance support was detrimental to reliability with a mean downtime of 335.1 hours, a standard deviation of 210.5 hours, and Ao of 0.559. The M&S portion of this study details the simulated downtime distributions that are suggested for use in future distance support decision making as related to HEL and other USN systems.

3. Cost Analysis

By applying the high-level requirements set, which drove the DS framework, architecture interfaces, and M&S results to standard systems engineering cost estimation methodologies based on COSYSMO and COCOMO II, cost savings were shown over the life cycle of HEL. This analysis, based on a 20 year life cycle of HEL installed on 30 shipboard platforms, resulted in an estimate of $7,258,215 for the addition of a DSHEL component, an average of $362,911 a year. The cost of a system, throughout its life cycle, is thereby shown to grow based on how much support it requires and cost per technical assistance. By incorporating the estimated DSHEL life-cycle cost with the M&S results for estimated downtime, a cost per technical assistance was determined to show the eventual breakeven point in which a distance support subsystem, such as DSHEL, would pay for itself. Given 30 HEL platforms, the integrated results from M&S have shown that DSHEL would begin to show a return on investment once 27 technical assistance requests have occurred as shown in Figure 108. This accounts for the fact that a fractional technical assistance request is impossible and that it must round up to the next technical assistance request to cross the break-even point.

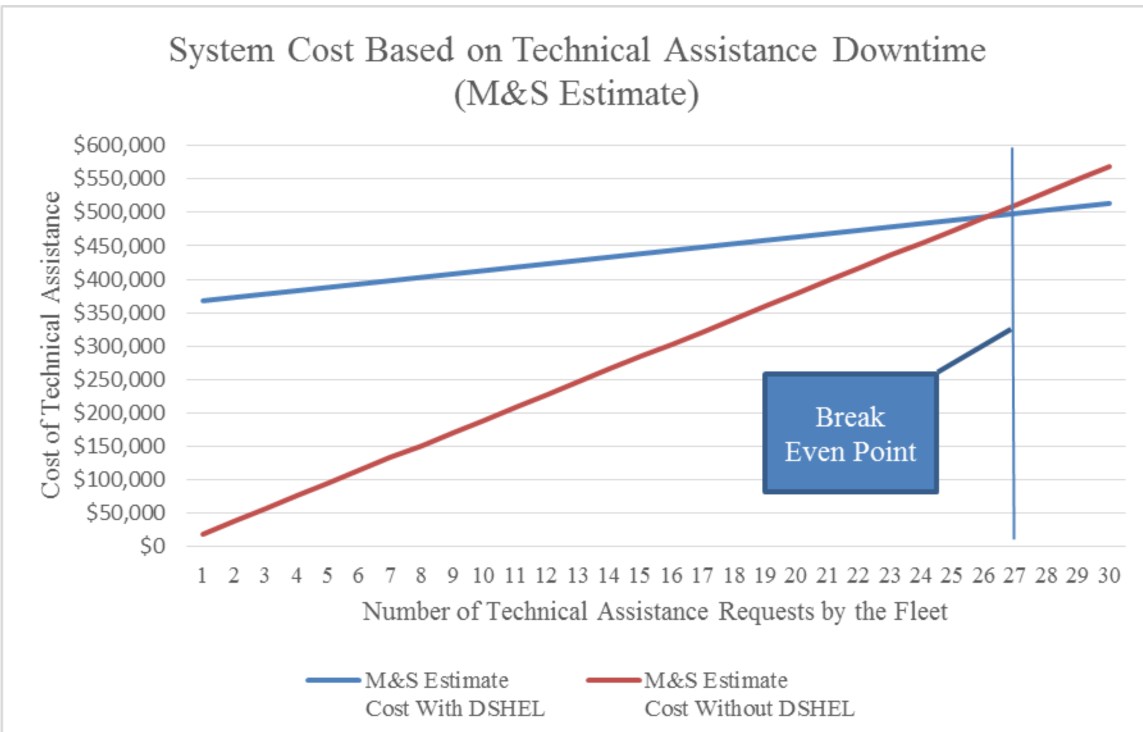

Figure 108. Annual Cost of Technical Assistance

Overall, given the complexity of a system such as HEL being first of its kind in the Fleet, it is reasonable to assume at least 27 technical assistance requests a year are resolved by distance support, thereby alleviating unnecessary travel and labor associated with "boots on deck" support by an ISEA. The cost analysis has shown that DSHEL will eventually pay for itself and provide cost savings over the life cycle of the HEL platform.

4. Research Question Findings

The following research questions were answered by this capstone report:

- How will DS affect the overall cost and risk in HEL shipboard implementation?

  Over the life cycle of the HEL program, DSHEL will provide cost savings. An annual labor and travel reduction of $54,413 per year is realized. Resulting in $1.09M over a 20 year life cycle, spread across 30 ships. Aggregate risk was shown to be moderate with six risks identified: one low, four medium, and one high.

- What type of infrastructure is required to adequately perform DS for HEL?

  In analyzing only the POI: selected sensors (as detailed in Chapter III), single rack mount server, IP KVM, NAS, and system monitoring software.

- Are there any existing DS frameworks that can be applied to DSHEL?

  No existing DS framework could be applied to DSHEL. Other frameworks were analyzed for best practices and then tailored to fit generic edge/peripheral devices.

- Of the HEL components, which information is the most important to collect?
  - Total intensity over time
  - Total energy in pulse
  - Spectral content
  - Degree of polarization
  - Angular divergence
  - Intensity profile
  - System temperature

B. CONTRIBUTION TO BODY OF KNOWLEDGE

The contribution to the BoK consisted of three topic areas. The first section discusses the distance support framework. The next section covers the functional analysis that was completed to map the various distance support functions to system/subsystem components within DSHEL. The final section details the DS System design that was developed in Chapter IV.

1. Distance Support Framework

The USN has a very complex organizational structure as well as many systems at different phases within their life cycles. A robust framework was needed that could account for all USN products and services, while adhering to the many policies and regulations that affect (directly/indirectly) them. In order to complete this task, a systems view of the concept was taken and current architecture frameworks were analyzed for best practices. Ultimately, a DS framework had to be constructed from the ground up.

With the goal being to deliver quality DS from the information and data collected, DS was broken down into three basic elements: PSP, ESI, and POI. Each of these elements play an important role in this goal and interacts with one another through the use of SLAs. Each basic element can further be broken down into a subset of elements. These subsets of elements, which define a successful organization, are people, process, and technology. The internal interactions of these subset elements are governed by OLAs. Through the use of OLAs and SLAs, quality DS is provided through the evidence passed, generated, and shared that these DS elements, collect, verify, record, validate, store, process, filter, log, compress, and analyze. This is done in order to produce an I2DF set that meets the minimum data picture completeness threshold.

The framework offers multiple views that must be taken when providing DS. These views start with the POI interfaces and slowly expand the scope to POI interactions. This includes: POI classification (independent platform vs. guest platform contained within host platform), DSX configuration (integrated—single-point all inclusive, encompassing—single-point semi inclusive, distributed—multipoint all inclusive, distributed—multipoint semi inclusive), enterprise ecosystem entities, and global environment externalities.

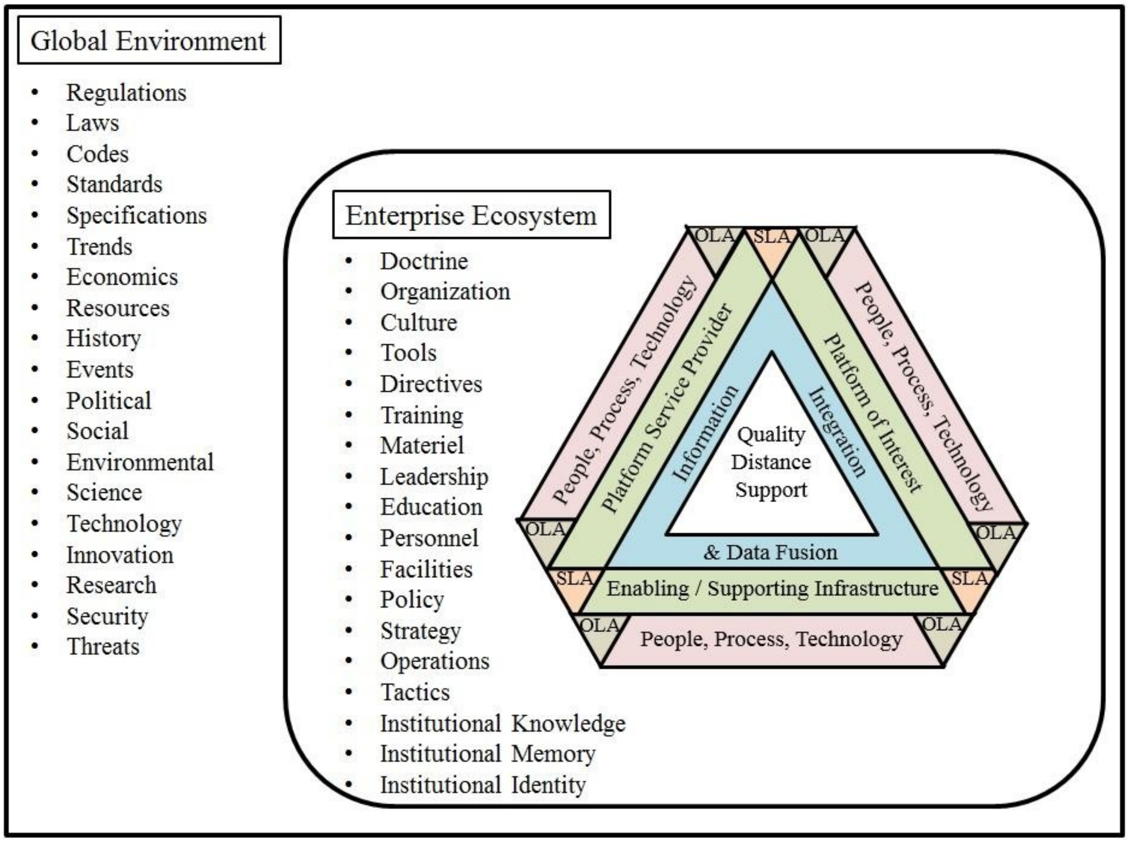

Figure 109. DS Application Context Diagram

2. Distance Support Functional Analysis

The functional analysis explored in chapter IV mapped four out of the six distance support pillars down to their most basic of functions. This was done using the IDEF0 modeling framework. The IDEF0 modeling framework shed light on the distance support pillars that the Navy has developed, namely that they might be structured improperly. When completing the functional analysis, the results indicated that although the Navy has broken out the distance support functions into six individual pillars, the Remote Diagnostics, Remote Repair and Validation, and Remote Monitoring pillars are a subset of the Remote Technical Assistance pillar.

This is the result of the way in which maintenance and repair is currently conducted in the USN. To date, the USN has been reluctant to allow remote connectivity and repair onboard ship due to the desire for human interface to ensure accountability. Much of the maintenance is driven through email or shore based databases that manage logistic functions for the ship. Verified in the IDEF0 diagrams in chapter four, all major outputs from the context diagram are outputs of the function performing remote technical assistance for the system. All other functions analyzed only provided outputs in the form of feedback to the function of providing remote technical assistance.

3. Distance Support System Design

In addition to the functional analysis that was accomplished in chapter four, the chapter also took on the task of creating a notional physical architecture for a generic DS system. The design analyzed both the hardware and software that could potentially be involved in developing the DS system. This allows system engineers to have a working prototype from which cost estimates and implementation strategies are developed. Although it is not advisable to develop a standalone system rather than integrating into the POI, it is useful for a program to know the TOC of a distance support capability.

C. RECOMMENDATIONS

The first section summarizes evidence from the capstone to support the need for distance support. This evidence is detailed further in Chapters V and VI of this capstone. The next section discusses the need for the establishment of detailed SLA/OLA's between organizations needing to develop a plan for distance support. The last section provides recommendations for developing the distance support functions.

1. Design-In Distance Support

Reiterating the findings from the HEL Master Plan, it was stated that there would be acquisition challenges in fielding a laser weapon, given the limited community of subject matter experts. Extending this original challenge of acquisition to in-service, it follows that the sustainment of a laser weapon has equal challenges given the few to many relationship of supporting these systems with a limited community of subject matter experts. Integrated distance support serves as a force multiplier and bridges the gap via service level agreements, to provide remote access and faster response time for issue resolution among the pool of support resources to the afloat HEL assets. Cost savings have been shown based on legacy and modeled technical assistance from the

Fleet in leveraging a knowledgebase of SME's ashore to resolve problems remotely. It was shown through modeling and simulation that system integrated distance support also has the potential to significantly decrease mean down time. By putting complete diagnostics data into the hands of the most experienced engineers and technicians at the onset of a system issue, problems are resolved faster. The reduction in mean down time dramatically increased Ao without modification to the host system. Given the results from M&S show a shorter duration in issue resolution time, alongside the reduction in travel and labor cost, it is the recommendation of this report to design in a distance support subsystem to the high energy laser.

2. Establish Service and Operational Level Agreements

Without communication and transmission of data, DSHEL would not function. DSHEL's entire layout and key principles were dependent upon the sharing and transmission of data between a PSP and a POI. As a result, SLAs and OLAs were paramount to establishing and maintaining the necessary communication paths for DS. SLAs and OLAs work together in order to facilitate agreements between service providers and end users (SLAs) and internal groups within an element (OLAs). This was the key description of the aforementioned PSP and POI sharing information and data. SLAs therefore proved essential to set up data transmission. These agreements are for products and services. In DSHEL's case, they were for the transmission, monitoring, and receipt of data as well as the implied sub categories and needs inherent to those functions. The number and type of SLA or OLA was dependent upon the portion of the platform in question that was under review. It is the recommendation that SLAs and OLAs are established in order to accomplish the internal and external communication essential to DS.

3. Redefine Distance Support for the U.S. Navy

Previously completed analysis indicates that the current DS efforts in use by the USN lack certain key qualities. The preconceived notion was that DS was composed of Six Pillars. This belief leads to the misconception that all pillars are equal in weight and importance and that they evenly share responsibility. However, choosing to separate DS into several pillars creates a fractured environment and is not cohesive. Also, the belief that each successive pillar is just as important as the last adds instability to the DS environment. DS is not a set of pillars that can be segregated; rather, it is a Service Oriented Architecture that takes into account (Service Oriented Architecture Organization 2013):

- business value over technical strategy
- strategic goals over project-specific benefits
- intrinsic interoperability over custom integration
- shared services over specific-purpose implementations
- flexibility over optimization
- evolutionary refinement over pursuit of initial perfection

This capstone has developed a DS framework that elevates the discussion of how best to apply Distance Support for a specific POI. This framework takes into account not just what is needed for the POI, but also what is needed for the ESI, and PSP. This encompassing approach to the application of DS as a service is a more comprehensive solution to the larger USN life-cycle support philosophy. It is the recommendation of this capstone that the USN redefine their current DS methods and adopt the DS framework outlined in this capstone.

D. FUTURE EXPLORATIONS

The following section describes areas of future work, which is outside the scope of this research, as well as areas, which could be refined by further analysis. The first section discusses the need for mapping the current DS pillar structure into the DS framework. The next section brings to light the benefits of using real world data to support the modeling and simulation and the cost analysis for a DS system. The last section calls attention to further research that could be done to explore the USN big data problem.

1. ePrognostics, and Self Repair and Healing

The focus of this capstone was on the application of the first four pillars of distance support to HEL. By expanding the initial focus to include the latter two pillars, ePrognostics and Self Repair & Healing, is expected to reveal even greater cost savings. Given the current cost analysis was only capturing the reduction of onsite travel and labor, inclusion of the last two pillars would result in the failure prevention of expensive HEL subsystem components, thereby adding additional material cost savings and increased uptime. Subsequent updates to system requirements, functional analysis, M&S, and risk analysis should be investigated.

2. Vetted Parameters as Inputs to Modeling and Cost Analysis

A challenge faced in this study was the immaturity of existing HEL systems and real world in service engineering and maintenance data. This was overcome by the use of M&S, as well as comparative and composite inputs for response times and costs from legacy PEO IWS studies for other weapon systems. As the HEL goes from a test bed status into a full-fledged Program of Record (PoR), the opportunity will exist to refine the models and estimates in this capstone with real world data. These sources will be contained in the Navy-311 Help Desk database, Command Issue Manager (CIM), and Maintenance Figure of Merit (MFOM) AWN system. The methodologies in this report were presented in a flexible and transparent manner, such that the variables could be updated for future studies. As it was necessary to use composite estimates as input parameters due to classification restrictions, it is suggested that the mean down time models be modified and analyzed for current fielded systems to assess potential impact of integrated distance support. It is the recommendation that as DSHEL is fielded and sustained, these simulations and analyses be performed annually and tailored by the program systems engineer to include the operational failure and response time data. This will enable the PEO and in-service community to make HEL system sustainment and modernization decisions based on data which includes the distance support methodologies.

3. DS Framework Expansion

The DS framework focused on the POI; follow-on work to expand and analyze the PSP and ESI in depth is needed. Within the PSP element, attention is needed in developing the proper resources requirements, infrastructure, manning levels, associated training programs, knowledge management tools, and product/service feedback improvement. The ESI element would benefit from future research and development into information transport mediums and infrastructure, cybersecurity challenges, and signal reconstruction/acquisition techniques.

4. U.S. Navy's Big Data Problem

In Chapter I, the amount of data generated by a typical Boeing 737 engine was extrapolated to a USN Arleigh Burke Class Guided Missile Destroyer (gas turbine engines only) and then compared to all the total amount of information contained within the Library of Congress. It was surmised that a typical deployment of a single ship lasting six months would generate 438 times more data than that of the entirety of the Library of Congress. This amount of data only accounts for the gas turbine engines alone and does not include the rest of the systems on board of the ship (radar, communication, weapons, mechanical, network, etc.). While data filtering can account for 80% data reduction (Porsche, Wilson, Johnson, Tierney, and Saltzman 2014), this would still leave 87 Library of Congress' worth of relevant data to be analyzed and transported.

As the USN becomes more networked, the Internet of Things (IoT) concept may be adopted by the USN and become, in the case of surface combatants, a Ship of Things (SoT). Research and development in the area of big data and data science needs to be increased to keep the USN from drowning in a flood of its own data.

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APPENDIX A. KPP, KSA, MOP, AND MOE

A. KPP AND KSA

KPPs are defined as “Performance attributes of a system considered critical to the development of an effective military capability. A KPP normally has a threshold representing the minimum acceptable value achievable at low-to-moderate risk, and an objective, representing the desired operational goal but at higher risk in cost, schedule, and performance (Defense Acqusition University 2014).”

KPPs are not to be confused with KSAs. KSAs, “A Key System Attribute (KSA) is a system capability considered crucial in support of achieving a balanced solution/approach to a system, but not critical enough to be designated a KPP (Defense Acqusition University 2014).”

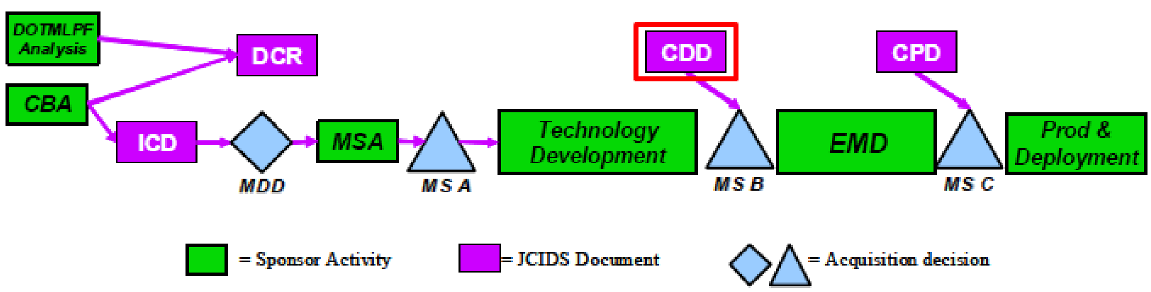


Figure 110. “CDD in the Acquisition/JCIDS Process” (from ACQNotes 2014)

KSAs, and KPPs, are developed and described in the CDD (Capability Development Document). This document is developed in coordination with the system’s development. In Figure 109, the general process for the development of this and other components of the acquisition process is displayed. However, it was necessary to consider the standard KPPs and KSAs as laid out by the JCIDS. These KPPs and KSAs and how they were applicable to DSHEL are listed below:

1. Mandatory KPP—Force Protection

For this particular KPP, it would not be applicable to the DSHEL system. "The intent of the FP KPP is to address protection of the system operator or other personnel rather than protection of the system itself (Survivability)." (Department of Defense 2012, B-A-2) In order for this official call to be made it would be necessary for, "the Protection FCB will assess the FP KPP, or Sponsor justification of why the FP KPP is not applicable, for any document with a JSD of JROC or JCB Interest (Department of Defense 2012, B-A-2)." Considering that DSHEL is a monitoring and reporting system, it was considered unlikely that force protection would be part of DSHEL.

2. Mandatory KPP—Survivability

Survivability, which deals with the ability of a system to maintain working status while under attack, is not applicable to DSHEL. "The intent of the Survivability KPP includes reducing a system's likelihood of being engaged by hostile fire, through attributes such as speed, maneuverability, detectability, and countermeasures; reducing the system's vulnerability if hit by hostile fire, through attributes such as armor and redundancy of critical components; and allowing the system to survive and continue to operate in a chemical, biological, radioactive, and nuclear (CBRN) environment, if required." (Department of Defense 2012, B-A-2) The individual monitored components that compose DSHEL require this KPP; however, DSHEL itself would not. Individual components reporting to HEL have potential to be "engaged by hostile fire;" however, DSHEL as a monitoring and reporting system, would not.

3. Mandatory KPP—Net-Ready

The Net-Ready KPP referred to "The NR-KPP is applicable to all documents addressing IS and National Security Systems (NSS) used in the automated acquisition, storage, manipulation, management, movement, control, display, switching, interchange, transmission, or reception of DOD data or information regardless of classification or sensitivity (Department of Defense 2012, B-A-3)." This KPP was directly related to DSHEL. One of the primary functions of DSHEL was the transmission of information between the POI and an off-site facility. Therefore, it was necessary to ensure the Net-Ready KPP was included.

4. Mandatory KPP—Sustainment

Sustainment KPPs were defined as, "The Sustainment KPP and two supporting KSAs (Reliability, Operation and Support (O&S) Cost) are applicable to all documents addressing potential acquisition category (ACAT) I programs. The intent of the Sustainment KPP is to JCIDS Manual 19 Jan 2012 B-A-3 Appendix A Enclosure B ensure that sustainment planning "upfront" enables the requirements and acquisition communities to provide a system with optimal availability and reliability to the warfighter at an affordable cost" (Department of Defense 2012, B-A-2). Since HEL could potentially become an ACAT I program and DSHEL is a subsystem component of HEL, there exists the possibility that DSHEL would then inherit the Sustainment KPP.

5. Mandatory KPP—Availability

According to JCIDS, the Availability KPP gets divided into Material Availability and Ao.

a. Mandatory KPP Subset—Materiel Availability

For the Materiel Availability portion, "Materiel Availability is the measure of the percentage of the total inventory of a system operationally capable, based on materiel condition, of performing an assigned mission. This can be expressed mathematically as the number of operationally available end items/total population. The total population of operational end items includes those in training, attrition reserve, pre-positioned, and temporarily in a non-operational materiel condition, such as for depot-level maintenance, shipyard repair, etc. Materiel Availability covers the total life-cycle timeframe, from placement into operational service through the planned end of service life" (Department of Defense 2012, B-E-3). DSHEL would be concerned with "Ao" and operational statuses so considered this to be an applicable KPP. DSHEL required the monitoring of various components of the HEL system and as a result, cared about the status of "materiel condition" of HEL components.

b. Mandatory KPP Subset—Operational Availability

Operational Capability is the second component of the Availability KPP and included, "Operational availability is the measure of the percentage of time that a system or group of systems within a unit are operationally capable of performing an assigned mission and can be expressed as (uptime/(uptime + downtime))." (Department of Defense 2012, B-E-3) As with the Material Availability, DSHEL was concerned with the Ao of the HEL system. This KPP subset represented the connection between availability of the system and the more specific concern of the availability of system components and their status, which was considered to be a key component to DS.

6. Selectively Applied KPP—System Training

The Training KPP encompassed, "The Training KPP is applicable to all documents addressing potential ACAT I programs. The intent of the Training KPP is to ensure that training requirements are properly addressed from the beginning of the acquisition process, in parallel with the planning and material development, and updated throughout the program's Acquisition Life-Cycle." (Department of Defense 2012, B-E-3) As stated previously in the Sustainment KPP, if DSHEL were to be considered an ACAT I program, this KPP would be necessary. Training should be considered to be a potential requirement for the DSHEL users.

7. Selectively Applied KPP—Energy Efficiency

The Energy KPP includes, "The Energy KPP is applicable to all documents addressing systems where the provision of energy, including both fuel and electric power, to the system impacts operational reach, or requires protection of energy infrastructure or energy resources in the logistics supply chain." (Department of Defense 2012, B-A-3). This particular KPP was not considered to be important to include in DSHEL because from the perspective of power usage, DSHEL is not a major component.

8. Mandatory KSA—Reliability

The Reliability KSA states that, “Reliability is a measure of the probability that the system will perform without failure over a specific interval, under specified conditions. Reliability shall be sufficient to support the warfighting capability requirements, within expected operating environments. Considerations of reliability must support both availability metrics.” (Department of Defense 2012, B-E-3). This particular KSA was applicable to DSHEL as it was a general, all-encompassing statement of the need for any system to perform the way in which it is designed to, whenever called upon to do so.

9. Mandatory KSA—Operations and Support Cost

The Operations and Support Cost KSA was described as, “O&S Cost metrics provide balance to the sustainment solution by ensuring that the O&S costs associated with availability and reliability are considered in making decisions.” (Department of Defense 2012, B-E-3) As well as, “Costs are to be included regardless of funding source or management control. The O&S value should cover the planned life cycle timeframe, consistent with the timeframe and system population identified in the Materiel Availability metric.” (Department of Defense 2012, B-E-3) Operations and Support costs were considered to be inherent to establishing a new system, including DSHEL. DSHEL’s constant monitoring and data transmission would add to the need for this KSA. Costs from data storage, transmission, SME representatives, and facilities would all contribute to this KSA.

B. MOP AND MOE

MOEs, are defined as “the data used to measure the military effect (mission accomplishment) that comes from the use of the system in its expected environment. That environment includes the system under test and all interrelated systems, that is, the planned or expected environment in terms of weapons, sensors, command and control, and platforms, as appropriate, needed to accomplish an end-to-end mission in combat” (Defense Acqusition University 2012). Therefore, the MOEs would be the resultant data from the testing of the DS system with respect to the HEL platform. Suggested data collection included: thermal testing, vibrations testing, Kbps and data size data, SME access and availability data, and frequency of data transmission. MOPs are defined as "System-particular performance parameters such as speed, payload, range, time-on-station, frequency, or other distinctly quantifiable performance features. Several MOPs may be related to the achievement of a particular Measure of Effectiveness (MOE)." MOPs would be reflective of the performance requirements (Defense Acquisition University 2012). As a result, based on the suggestions made for performance requirements above, MOPs would focus on data transfer as well as the POI. MOPs would be focused on the actual frequencies, temperatures, Bps, that would be again linked to the MOEs for data collection. As an example of a MOE and a MOP being part of the KPP, and developmental process, the following example from JCIDS was considered (Table 34 courtesy of JCIDS table B-F-1, "NR-KPP Development"):

Table 34. "NR-KPP Development" (from Department of Defense 2012, B-F-1)

NR-KPP Development Step	NR-KPP Attribute	Attribute Details	Measures	Sample Data Sources	MOE/MOP
Mission Analysis	Support to Military Operations	Military Operation (e.g., mission areas or mission threads)	MOEs used to determine the success of the military operation	JMETL, JMT, UJTL, and METL	MOE
			Conditions under which the military operations must be executed		
		Operational tasks required by the military	MOPs used to determine activity performance	JMETL, JMT, UJTL, and	MOP

NR-KPP Development Step	NR-KPP Attribute	Attribute Details	Measures	Sample Data Sources	MOE/MOP
		operations	Conditions under which the activity must be performed	METL	

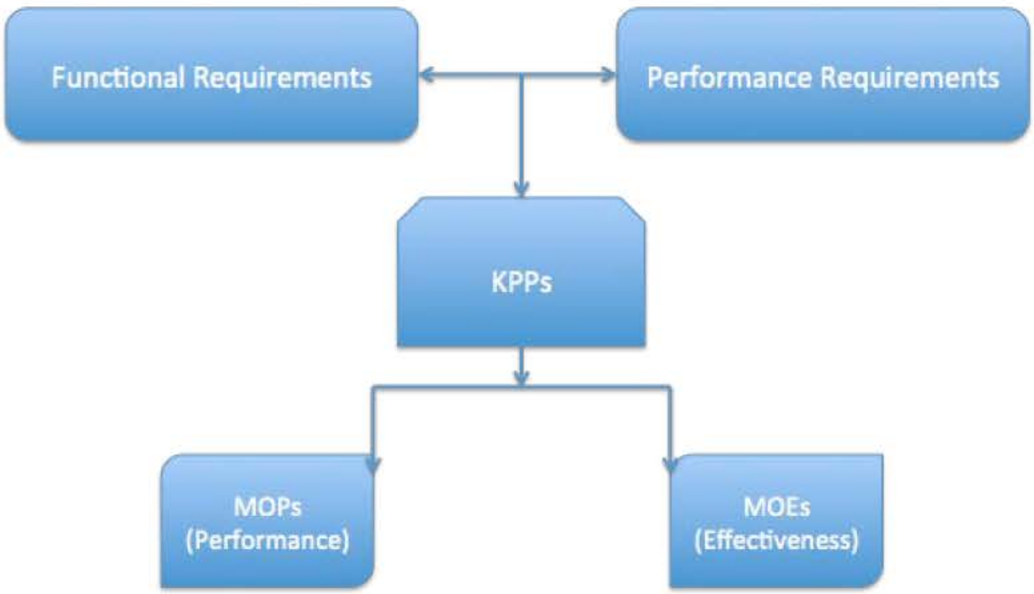


Figure 111. Relationships between Requirements, KPPs, MOPs, and MOEs

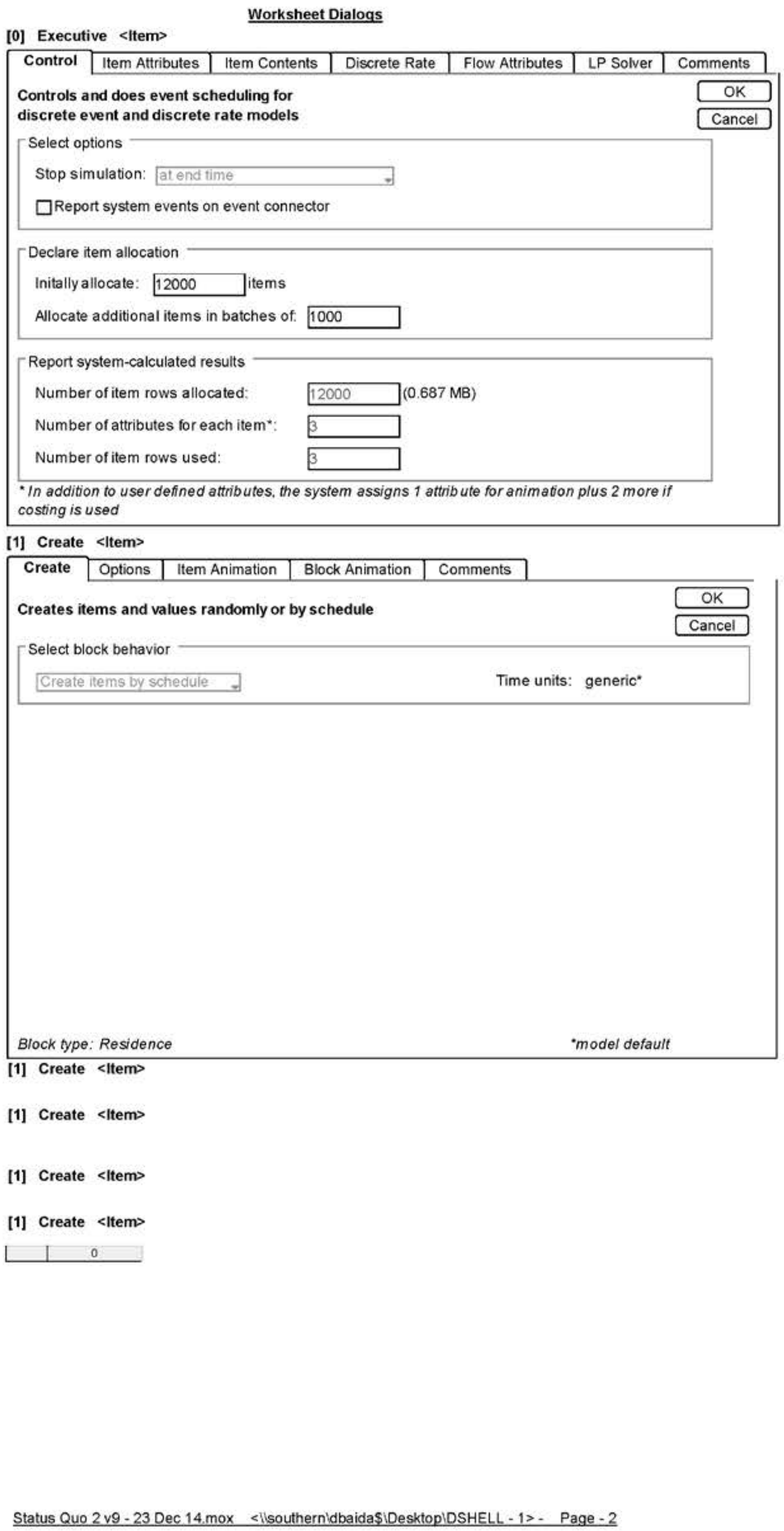
Table 34 and Figure 110 gave an example of how requirements and KPPs are linked to MOEs and MOPs. The KPP stood as the main need for the system, while the MOE and MOP gave support to and classification or credence to the existence of the KPP. As the Key Performance Parameter would be representative of "attributes of a system considered critical," (Department of Defense 2012, B-F-1), the diagram above emphasizes the connection between what the focus of the functional and performance requirements would be, and how the KPPs would logically reflect the same areas. These figures detailed the domino effect of requirements writing. The functional requirements are linked to the performance requirements. These requirements dictate and influence the

KPPs which then are verified and measured by the MOEs and MOPs. These figures underlined the importance for clarity and carefully worded language that was detailed previously in this chapter. Keeping requirements clear has a ripple effect on the subsequent KPPs, KSAs, MOEs and MOPs. Requirements, KPPs, KSAs, MOEs, and MOPs work in a linked process that requires balance and systematic collaboration.

APPENDIX B. MODEL PARAMETERS

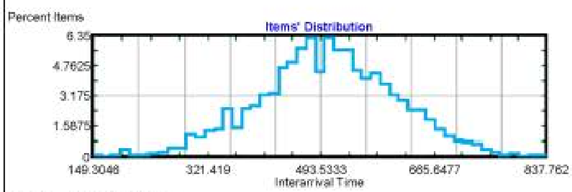
The following data is representative of the modeling and simulation effort performed as part of this effort. The included data tables directly exported from ExtendSim for each of the three models. While the model, in its most flexible form, is available from the SE Department at the Naval Postgraduate School, this data collection shall serve as a backup for the data, should the original files be lost.

A. STATUS QUO DISTANCE SUPPORT



Worksheet Dialogs

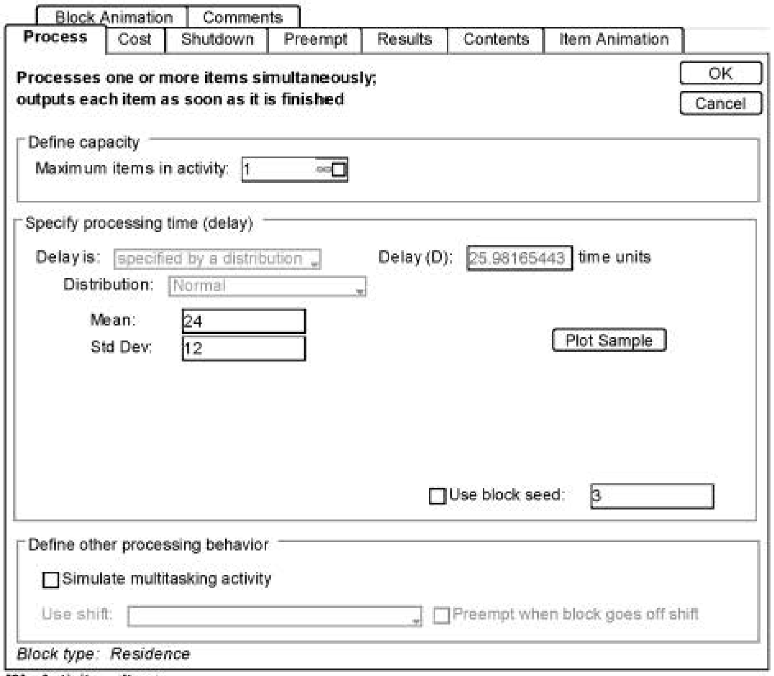
[1] Items' Distribution



[1] Items' Distribution

Interarrival Time	% Items
149.30464731	0.05
163.35479836	0
177.4049494	0.1
191.45510045	0.35
205.5052515	0.1
219.55540255	0.05
233.6055536	0.15
247.65570464	0.25
261.70585569	0.45
275.75600674	0.4
289.80615779	1.05
303.85630884	0.95
317.90645988	1.3
331.95661093	1.4
346.00676198	2.45
360.05691303	1.45
374.10706408	2.45
388.15721512	2.6
402.20736617	3.15
416.25751722	3.25
430.30766827	4.6
444.35781932	4.9
458.40797036	5.6
472.45812141	6.35
486.50827246	4.4
500.55842351	6.25
514.60857456	5.55
528.6587256	5.55
542.70887665	4.5
556.7590277	4.05
570.80917875	4.35
584.8593298	3.75
598.90948084	3.2
612.95963189	2.9
627.00978294	2.4
641.05993399	2.35
655.11008504	1.9
669.16023609	1.35
683.21038713	1
697.26053818	0.8
711.31068923	0.7
725.36084028	0.65
739.41099133	0.35
753.46114237	0.2
767.51129342	0.1
781.56144447	0.15
795.61159552	0
809.66174657	0.05
823.71189761	0.05
837.76204866	0.05

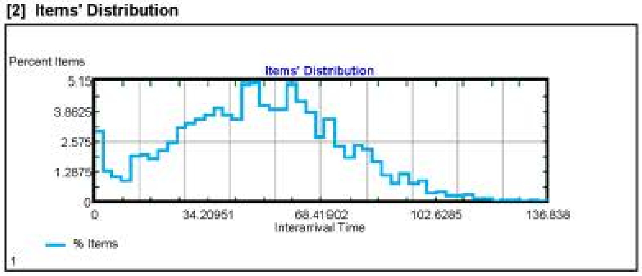
[2] Activity <Item>



[2] Activity <Item>

[2] Activity <Item>

[2] Items' Distribution

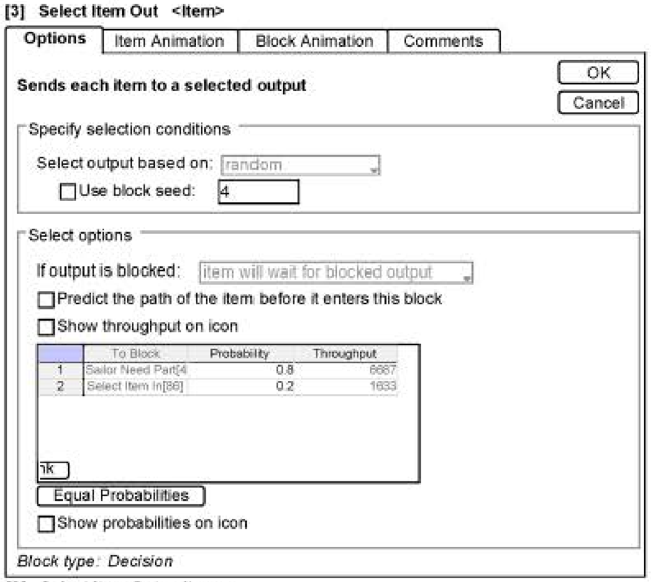


[2] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
0	3
2.7926130067	1.3
5.5852260135	1.05
8.3778390202	0.9
11.170452027	1.95
13.963065034	2
16.75567804	1.8
19.548291047	2.15
22.340904054	2.5
25.133517061	3.15
27.926130067	3.35
30.718743074	3.5
33.511356081	3.7
36.303969087	4
39.096582094	3.7
41.889195101	3.5
44.681808108	5
47.474421114	5.15
50.267034121	4.1
53.059647128	3.95
55.852260135	3.95
58.644873141	4.95
61.437486148	4.25
64.230099155	3.8
67.022712161	2.75
69.815325168	3.5
72.607938175	2.35
75.400551182	1.85
78.193164188	2.4
80.985777195	2.2
83.778390202	1.7
86.571003208	1.1
89.363616215	0.75
92.156229222	1.15
94.948842229	0.75
97.741455235	0.85
100.53406824	0.35
103.32668125	0.4
106.11929426	0.25
108.91190726	0.25
111.70452027	0.3
114.49713328	0.1
117.28974628	0.1
120.08235929	0
122.8749723	0.05
125.6675853	0.05
128.46019831	0
131.25281132	0.05
134.04542432	0
136.83803733	0.05

[3] Select Item Out <Item>



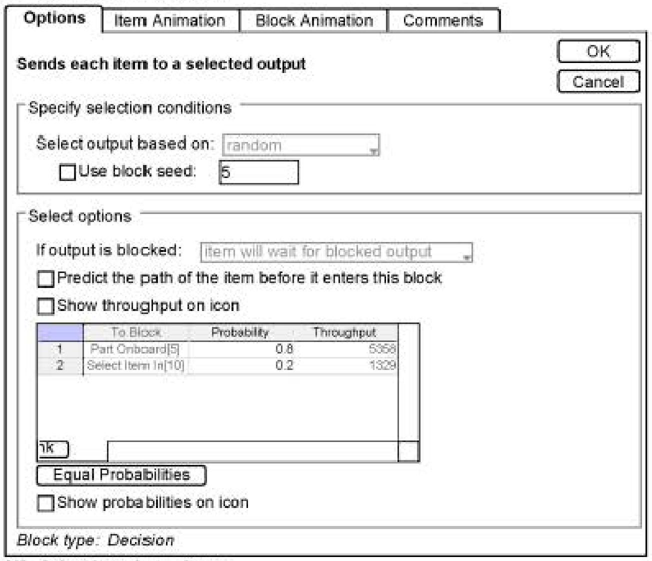
[3] Select Item Out <Item>

	To Block	Probability	Throughput
1	Sailor Need Part[4	0.8	6667
2	Select Item In[86]	0.2	1633

[3] Select Item Out <Item>

[3] Select Item Out <Item>

[4] Select Item Out <Item>



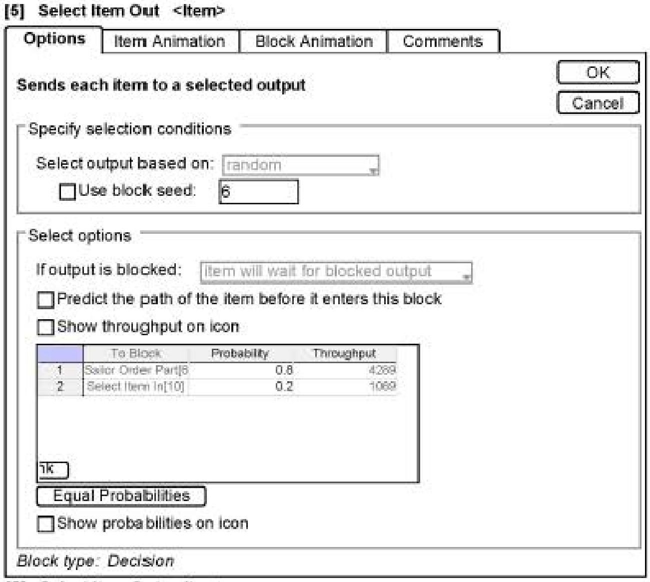
[4] Select Item Out <Item>

	To Block	Probability	Throughput
1	Part Onboard[5]	0.8	5358
2	Select Item In[10]	0.2	1329

[4] Select Item Out <Item>

[4] Select Item Out <Item>

[5] Select Item Out <Item>



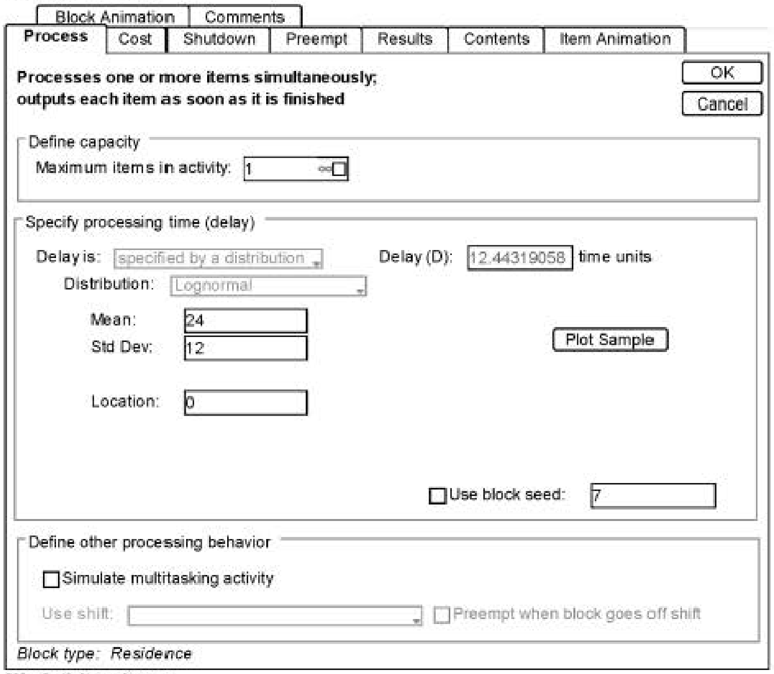
[5] Select Item Out <Item>

	To Block	Probability	Throughput
1	Sailor Order Part[6	0.8	4289
2	Select Item In[10]	0.2	1069

[5] Select Item Out <Item>

[5] Select Item Out <Item>

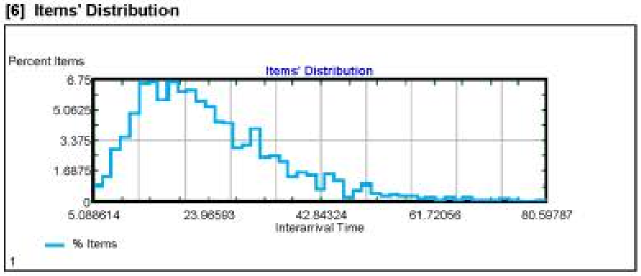
[6] Activity <Item>



[6] Activity <Item>

[6] Activity <Item>

[6] Items' Distribution

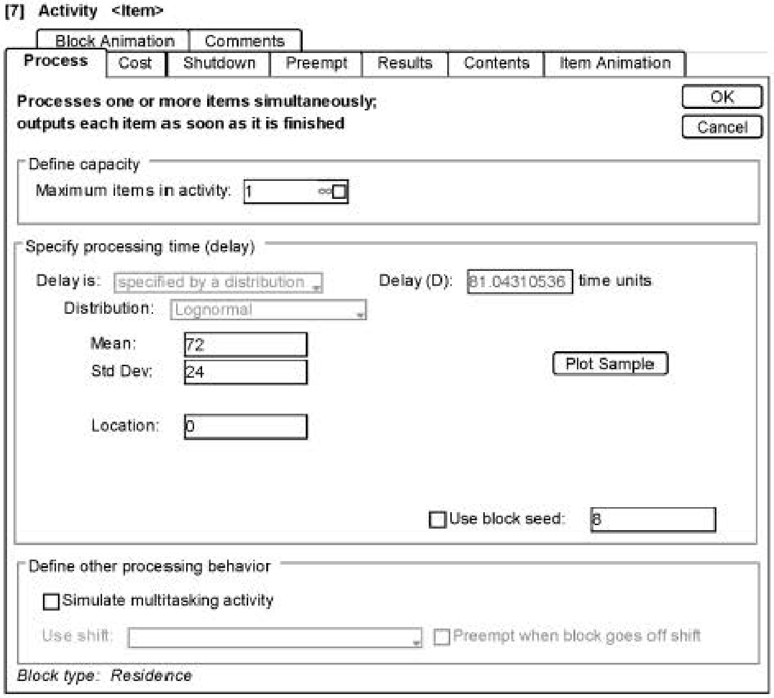


[6] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
5.0886142087	0.85
6.6296194357	1.3
8.1706246628	2.85
9.7116298899	3.5
11.252635117	4.85
12.793640344	6.5
14.334645571	6.75
15.875650798	5.8
17.416656025	6.6
18.957661252	6.05
20.498666479	6.15
22.039671706	5.5
23.580676933	5.25
25.12168216	4.4
26.662687388	4.3
28.203692615	2.9
29.744697842	3.1
31.285703069	4
32.826708296	2.4
34.367713523	2.45
35.90871875	2.15
37.449723977	1.3
38.990729204	1.55
40.531734431	1.4
42.072739658	0.7
43.613744885	1.45
45.154750112	1.05
46.695755339	0.25
48.236760566	0.65
49.777765793	0.9
51.31877102	0.45
52.859776248	0.3
54.400781475	0.4
55.941786702	0.3
57.482791929	0.3
59.023797156	0.15
60.564802383	0.25
62.10580761	0.1
63.646812837	0.2
65.187818064	0.05
66.728823291	0.2
68.269828518	0.1
69.810833745	0.1
71.351838972	0.05
72.892844199	0.15
74.433849426	0.1
75.974854653	0
77.51585988	0
79.056865108	0.05
80.597870335	0.05

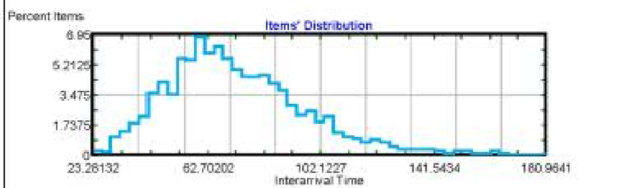
[7] Activity <Item>



[7] Activity <Item>

[7] Activity <Item>

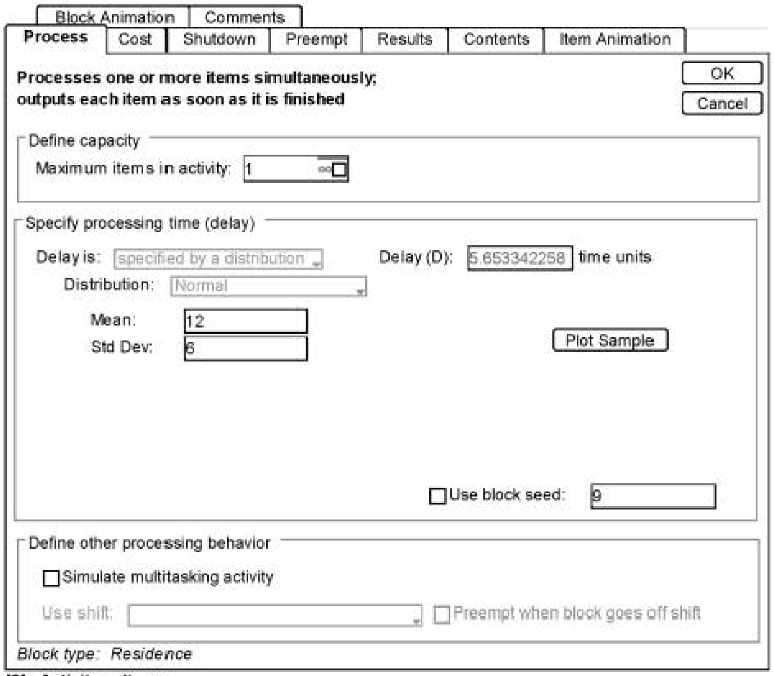
[7] Items' Distribution



[7] Items' Distribution

Interarrival Time	% Items
23.281324469	0.25
26.499340688	0.15
29.717356907	1
32.935373127	1.35
36.153389346	1.8
39.371405565	2.2
42.589421784	3.55
45.807438003	4.2
49.025454222	3.45
52.243470441	5.55
55.46148666	5.45
58.679502879	6.95
61.897519098	5.85
65.115535318	6.2
68.333551537	5.55
71.551567756	4.9
74.769583975	4.5
77.987600194	4.5
81.205616413	4.6
84.423632632	4.1
87.641648851	3.7
90.85966507	2.85
94.07768129	2.3
97.295697509	2.55
100.51371373	1.9
103.73172995	2.2
106.94974617	1.25
110.16776239	1
113.3857786	0.95
116.60379482	0.75
119.82181104	0.85
123.03982726	0.7
126.25784348	0.5
129.4758597	0.3
132.69387592	0.3
135.91189214	0.3
139.12990836	0.3
142.34792458	0.25
145.5659408	0.05
148.78395701	0.2
152.00197323	0.2
155.21998945	0.1
158.43800567	0.05
161.65602189	0.25
164.87403811	0.05
168.09205433	0
171.31007055	0
174.52808677	0
177.74610299	0
180.96411921	0.05

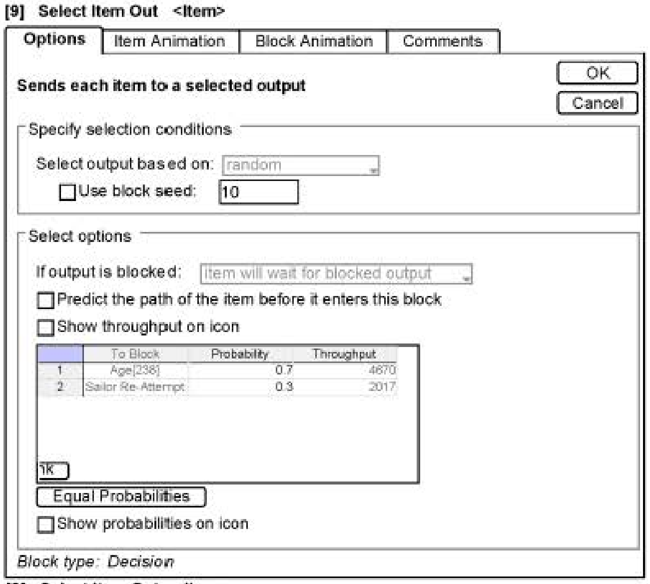
[8] Activity <Item>



[8] Activity <Item>

[8] Activity <Item>

[9] Select Item Out <Item>



[9] Select Item Out <Item>

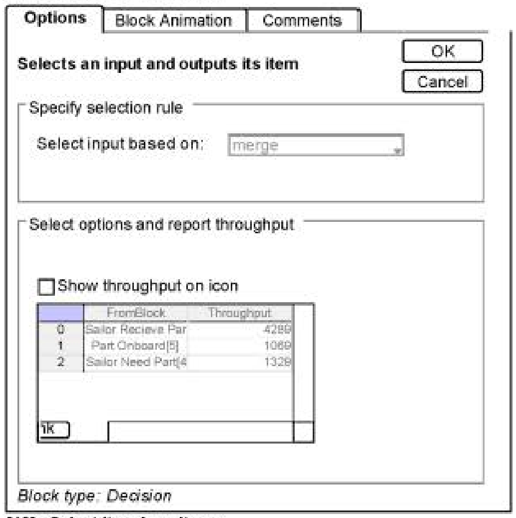
	To Block	Probability	Throughput
1	Age[238]	0.7	4670
2	Sailor Re-Attempt	0.3	2017

[9] Select Item Out <Item>

Worksheet Dialogs

[9] **Select Item Out <Item>**

[10] **Select Item In <Item>**

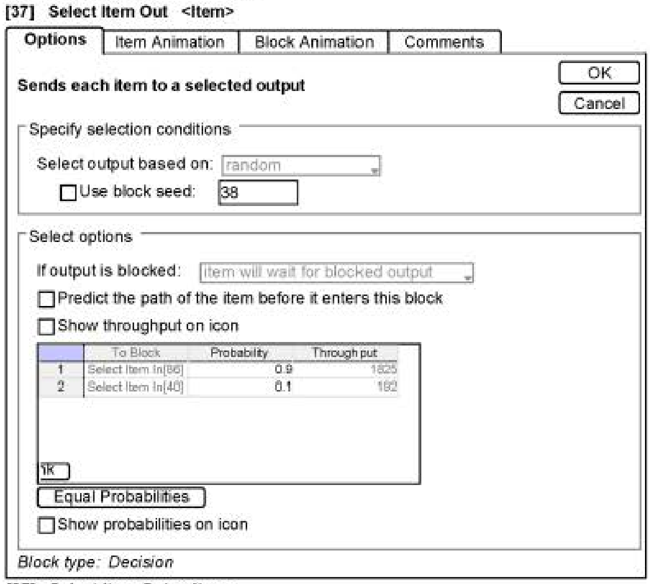


[10] **Select Item In <Item>**

[10] **Select Item In <Item>**

	FromBlock	Throughput
0	Sailor Recieve Par	4289
1	Part Onboard[5]	1069
2	Sailor Need Part[4	1329

[37] **Select Item Out <Item>**



[37] **Select Item Out <Item>**

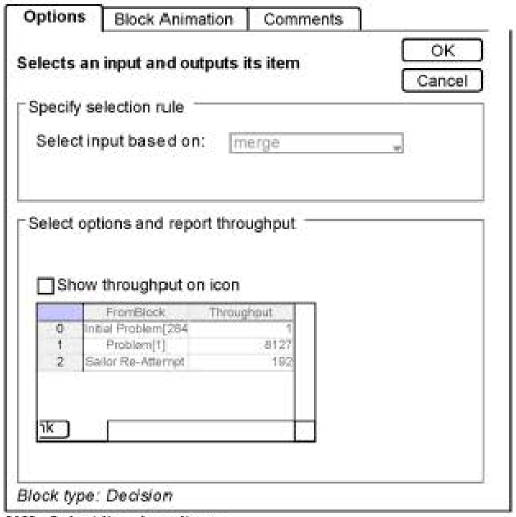
	To Block	Probability	Throughput
1	Select Item In[86]	0.9	1825
2	Select Item In[40]	0.1	192

[37] **Select Item Out <Item>**

[37] **Select Item Out <Item>**

Worksheet Dialogs

[40] Select Item In <Item>

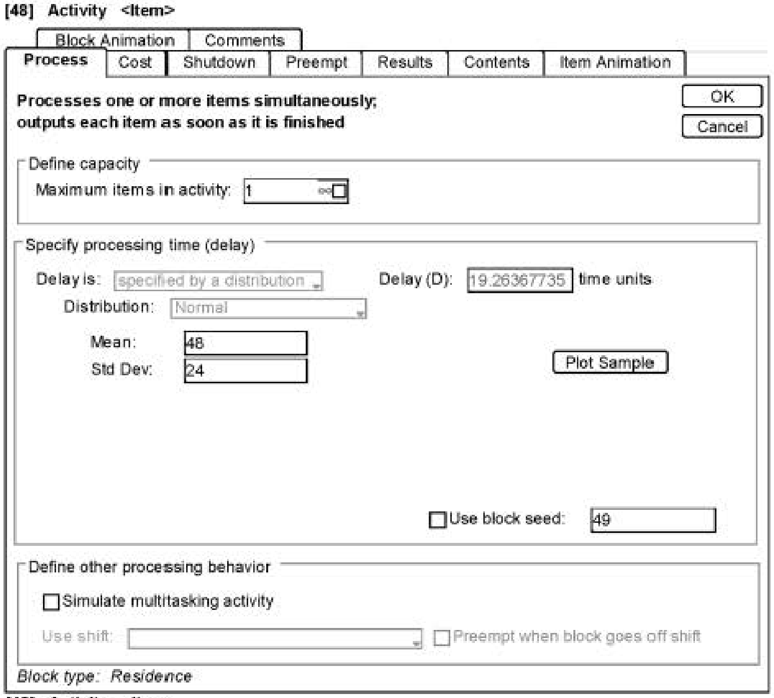


[40] Select Item In <Item>

[40] Select Item In <Item>

	FromBlock	Throughput
0	Initial Problem[284	1
1	Problem[1]	8127
2	Sailor Re-Attempt	192

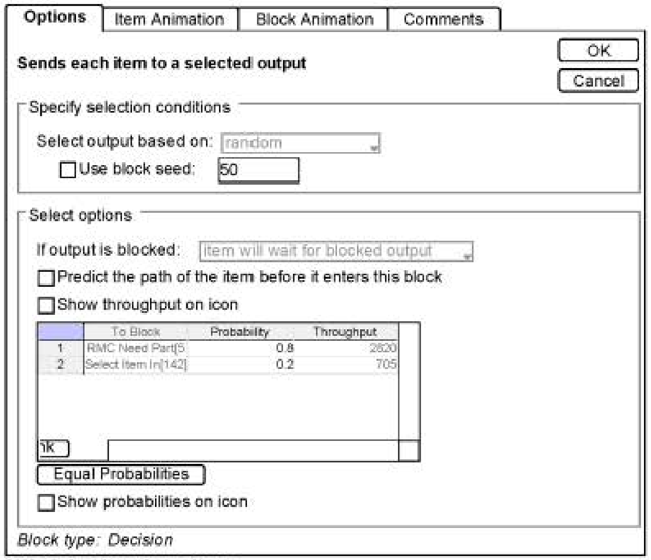
[48] Activity <Item>



[48] Activity <Item>

[48] Activity <Item>

[49] Select Item Out <Item>



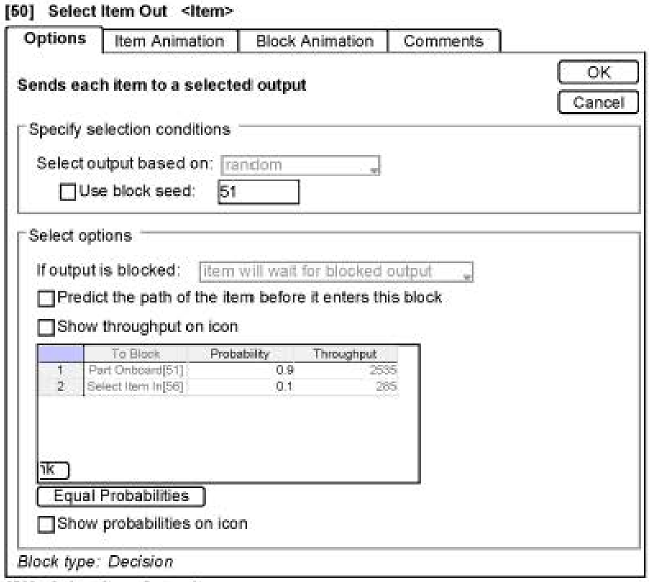
[49] Select Item Out <Item>

	To Block	Probability	Throughput
1	RMC Need Part[5	0.8	2820
2	Select Item In[142]	0.2	705

[49] Select Item Out <Item>

[49] Select Item Out <Item>

[50] Select Item Out <Item>



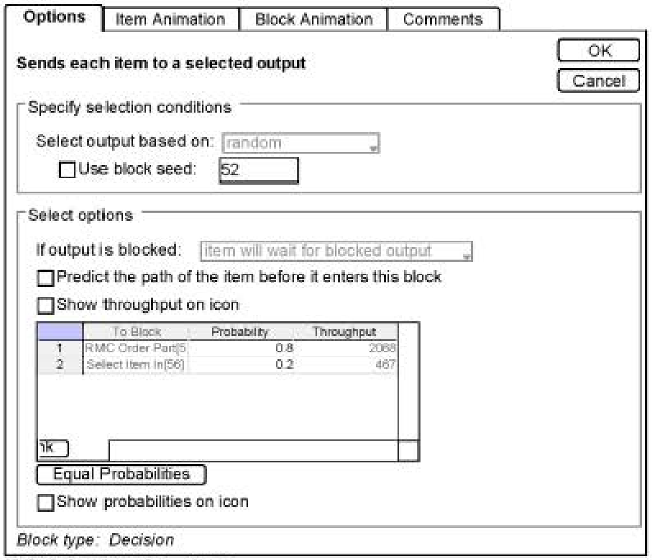
[50] Select Item Out <Item>

	To Block	Probability	Throughput
1	Part Onboard[51]	0.9	2535
2	Select Item In[56]	0.1	285

[50] Select Item Out <Item>

[50] Select Item Out <Item>

[51] Select Item Out <Item>



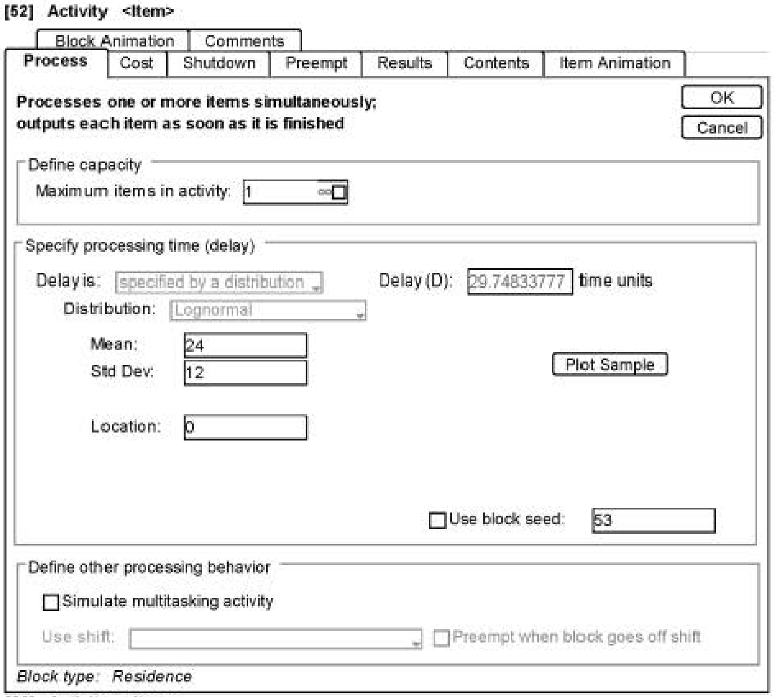
[51] Select Item Out <Item>

	To Block	Probability	Throughput
1	RMC Order Part[5	0.8	2068
2	Select Item In[56]	0.2	467

[51] Select Item Out <Item>

[51] Select Item Out <Item>

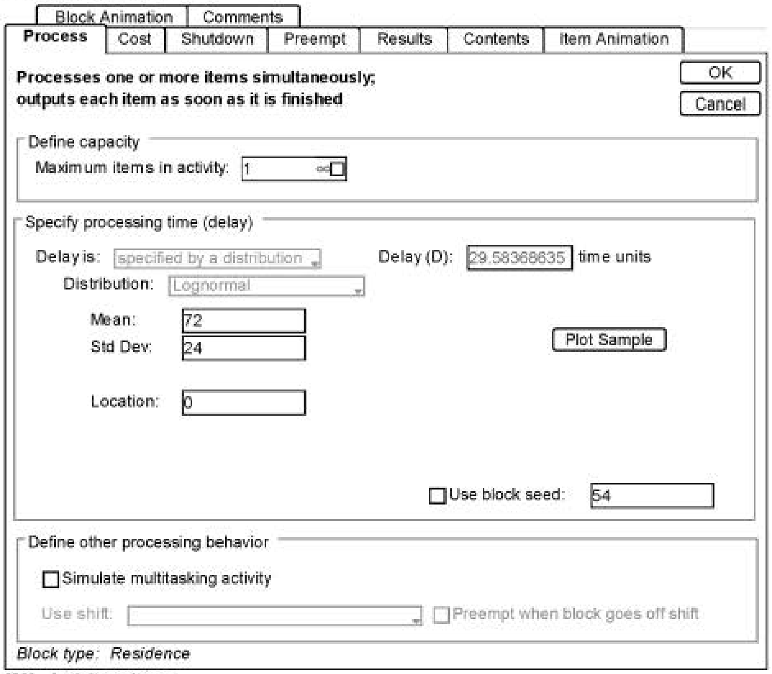
[52] Activity <Item>



[52] Activity <Item>

[52] Activity <Item>

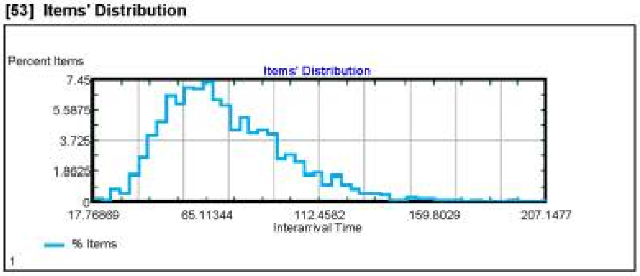
[53] Activity <Item>



[53] Activity <Item>

[53] Activity <Item>

[53] Items' Distribution

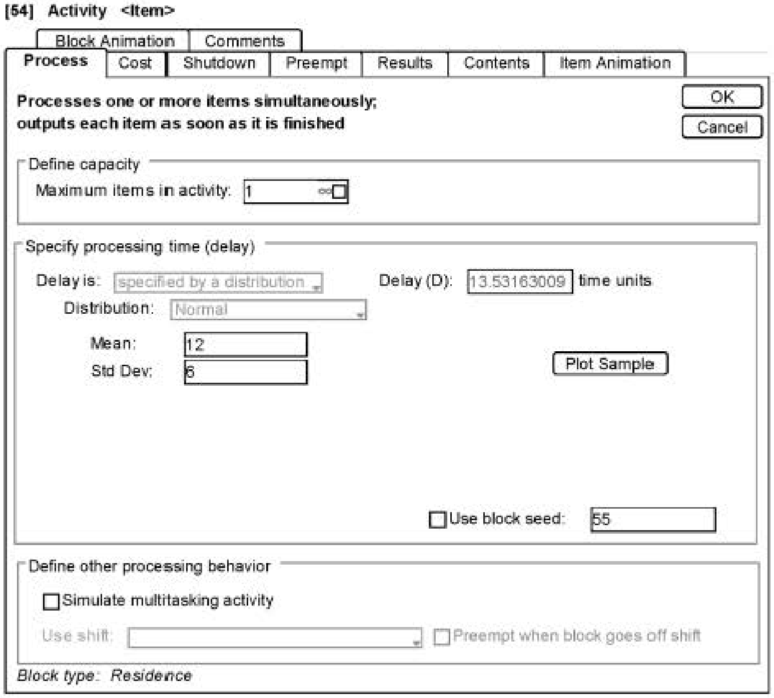


[53] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
17.768692468	0.15
21.633569552	0.05
25.498446635	0.8
29.363323719	0.55
33.228200802	1.65
37.093077886	2.65
40.957954969	3.95
44.822832053	4.85
48.687709137	6.4
52.55258622	5.9
56.417463304	6.9
60.282340387	6.85
64.147217471	7.45
68.012094554	6.15
71.876971638	5.85
75.741848721	4.3
79.606725805	5.1
83.471602888	4.15
87.336479972	4.3
91.201357056	4.1
95.066234139	2.5
98.931111223	2.8
102.79598831	2.35
106.66086539	1.65
110.52574247	1.7
114.39061956	1
118.25549664	1.5
122.12037372	1.05
125.98525081	0.8
129.85012789	0.5
133.71500497	0.5
137.57988206	0.4
141.44475914	0.1
145.30963623	0.05
149.17451331	0.25
153.03939039	0.2
156.90426748	0.15
160.76914456	0.05
164.63402164	0.05
168.49889873	0.1
172.36377581	0
176.22865289	0.1
180.09352998	0
183.95840706	0
187.82328414	0
191.68816123	0.05
195.55303831	0
199.41791539	0
203.28279248	0
207.14766956	0.05

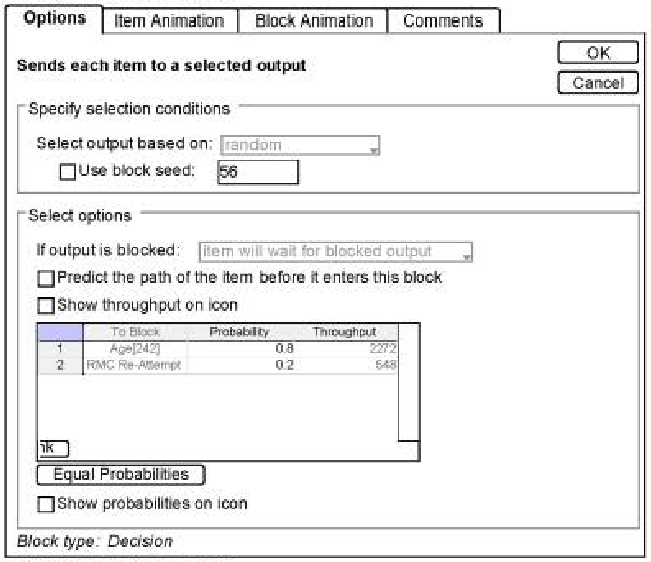
[54] Activity <Item>



[54] Activity <Item>

[54] Activity <Item>

[55] Select Item Out <Item>



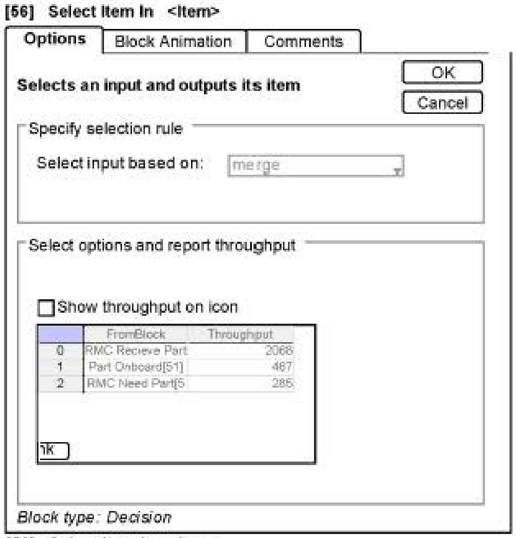
[55] Select Item Out <Item>

	To Block	Probability	Throughput
1	Age[242]	0.8	2272
2	RMC Re-Attempt	0.2	548

[55] Select Item Out <Item>

[55] Select Item Out <Item>

[56] Select Item In <Item>



[56] Select Item In <Item>

Worksheet Dialogs

[56] Select Item In <Item>

	FromBlock	Throughput
0	RMC Recieve Part	2068
1	Part Onboard[51]	467
2	RMC Need Part[5	285

[83] Select Item Out <Item>

Options | Item Animation | Block Animation | Comments

Sends each item to a selected output

OK

Cancel

Specify selection conditions

Select output based on: random

☐ Use block seed: 84

Select options

If output is blocked: item will wait for blocked output

☐ Predict the path of the item before it enters this block

☐ Show throughput on icon

	To Block	Probability	Throughput
1	Select Item In[142]	0.9	481
2	Select Item In[86]	0.1	67

1K

Equal Probabilities

☐ Show probabilities on icon

Block type: Decision

[83] Select Item Out <Item>

	To Block	Probability	Throughput
1	Select Item In[142]	0.9	481
2	Select Item In[86]	0.1	67

[83] Select Item Out <Item>

[83] Select Item Out <Item>

[86] Select Item In <Item>

Options | Block Animation | Comments

Selects an input and outputs its item

OK

Cancel

Specify selection rule

Select input based on: merge

Select options and report throughput

☐ Show throughput on icon

	FromBlock	Throughput
0	Sailor Re-Attempt	1825
1	Sailor Attempt Rep	1833
2	RMC Re-Attempt	67

1K

Block type: Decision

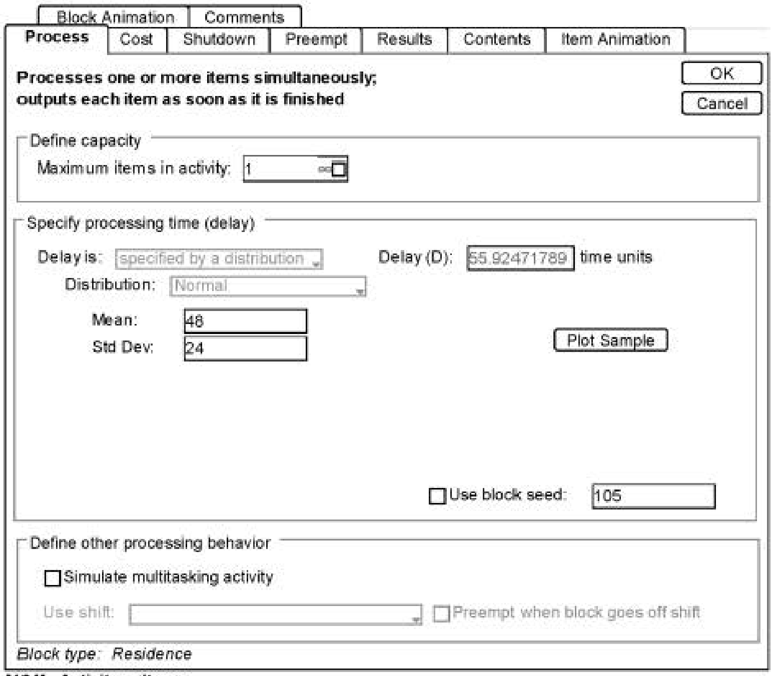
[86] Select Item In <Item>

[86] Select Item In <Item>

	FromBlock	Throughput
0	Sailor Re-Attempt	1825
1	Sailor Attempt Rep	1833
2	RMC Re-Attempt	67

Worksheet Dialogs

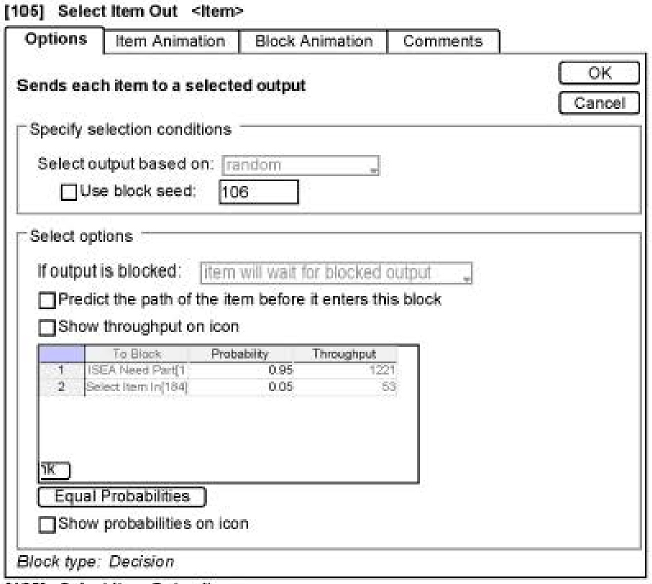
[104] Activity <Item>



[104] Activity <Item>

[104] Activity <Item>

[105] Select Item Out <Item>



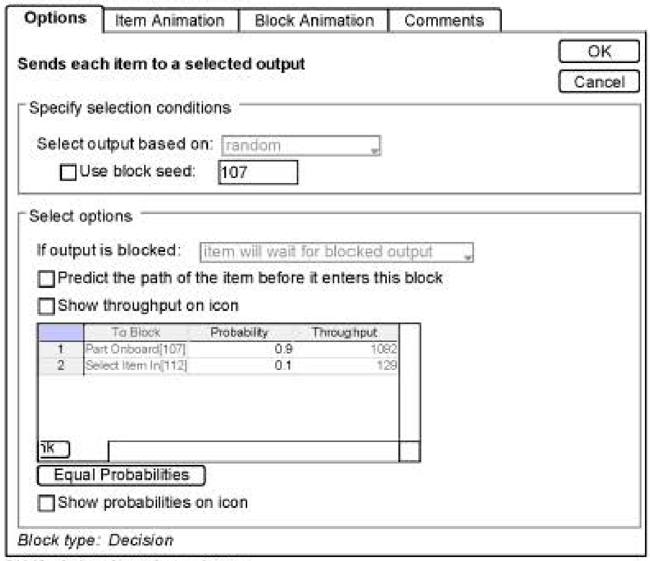
[105] Select Item Out <Item>

	To Block	Probability	Throughput
1	ISEA Need Part[1	0.95	1221
2	Select Item In[184]	0.05	53

[105] Select Item Out <Item>

[105] Select Item Out <Item>

[106] Select Item Out <Item>



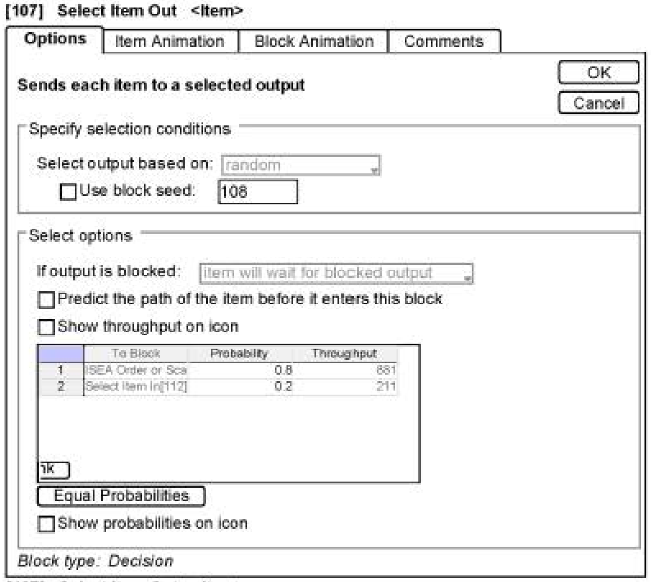
[106] Select Item Out <Item>

	To Block	Probability	Throughput
1	Part Onboard[107]	0.9	1092
2	Select Item In[112]	0.1	129

[106] Select Item Out <Item>

[106] Select Item Out <Item>

[107] Select Item Out <Item>



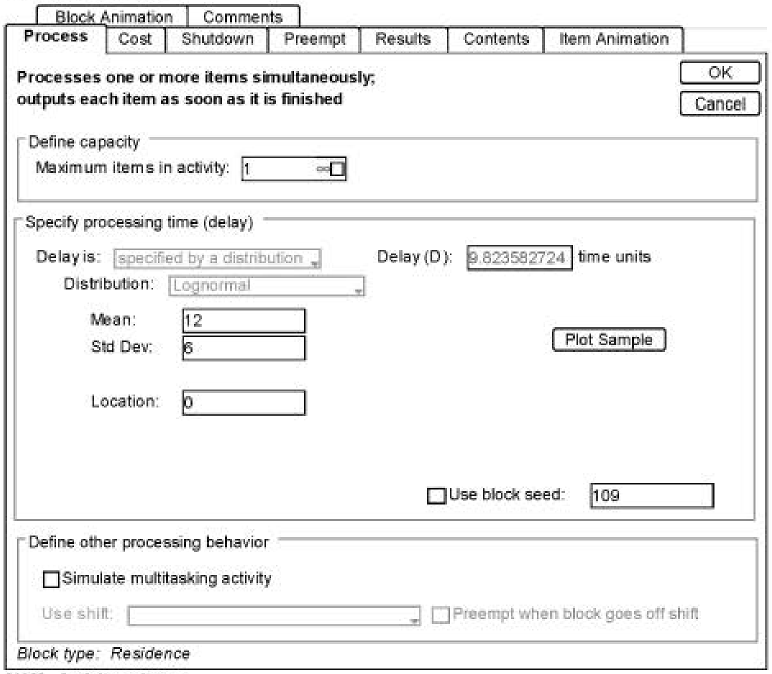
[107] Select Item Out <Item>

	To Block	Probability	Throughput
1	ISEA Order or Sca	0.8	881
2	Select Item In[112]	0.2	211

[107] Select Item Out <Item>

[107] Select Item Out <Item>

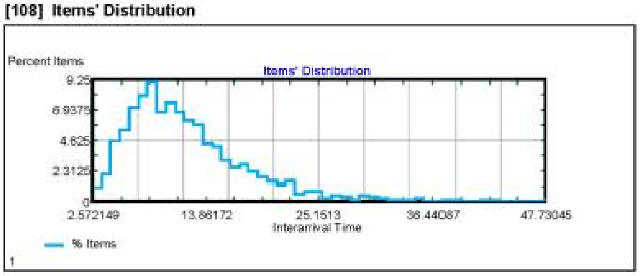
[108] Activity <Item>



[108] Activity <Item>

[108] Activity <Item>

[108] Items' Distribution

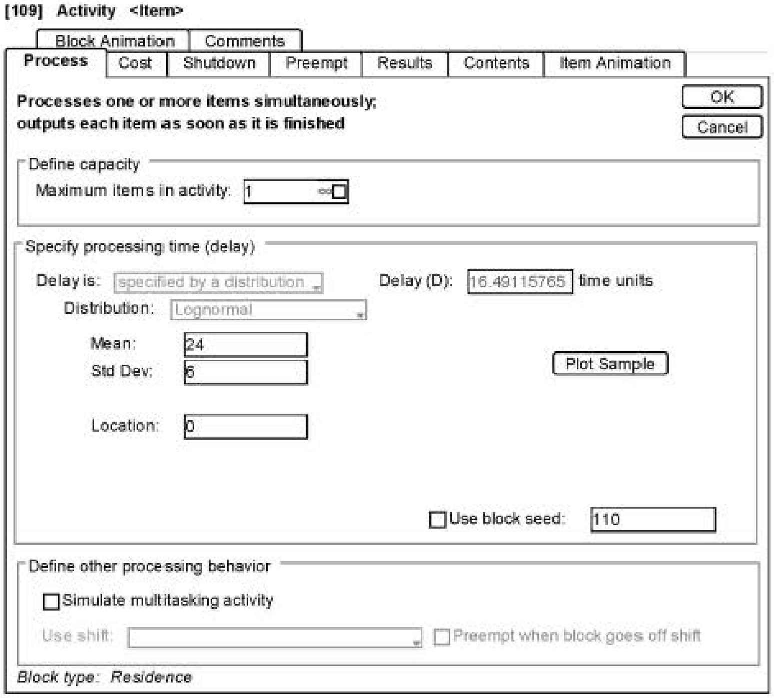


[108] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
2.5721488479	1.05
3.4937468155	2
4.4153447831	4.55
5.3369427507	5.35
6.2585407183	7
7.1801386859	8
8.1017366535	9.25
9.0233346211	8.7
9.9449325887	7.5
10.866530556	6.7
11.788128524	6.1
12.709726491	5.75
13.631324459	4.35
14.552922427	4.1
15.474520394	3.05
16.396118362	2.55
17.317716329	2.75
18.239314297	2.2
19.160912265	1.75
20.082510232	1.5
21.0041082	1.25
21.925706168	1.45
22.847304135	0.55
23.768902103	0.7
24.69050007	0.7
25.612098038	0.25
26.533696006	0.4
27.455293973	0.3
28.376891941	0.1
29.298489908	0.4
30.220087876	0.35
31.141685844	0.2
32.063283811	0.15
32.984881779	0.1
33.906479746	0.1
34.828077714	0.25
35.749675682	0
36.671273649	0
37.592871617	0.1
38.514469584	0.1
39.436067552	0
40.35766552	0
41.279263487	0.15
42.200861455	0.1
43.122459422	0
44.04405739	0
44.965655358	0
45.887253325	0
46.808851293	0
47.73044926	0.1

[109] Activity <Item>


Block Animation | Comments
Process | Cost | Shutdown | Preempt | Results | Contents | Item Animation

Processes one or more items simultaneously; outputs each item as soon as it is finished

OK
Cancel

Define capacity
Maximum items in activity: 1 ∞

Specify processing time (delay)
Delay is: specified by a distribution
Delay (D): 16.49115765 time units
Distribution: Lognormal
Mean: 24
Std Dev: 6
Plot Sample
Location: 0
Use block seed: 110

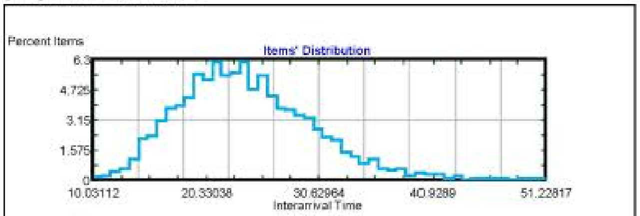
Define other processing behavior
Simulate multitasking activity
Use shift:
Preempt when block goes off shift

Block type: Residence

[109] Activity <Item>

[109] Activity <Item>

[109] Items' Distribution

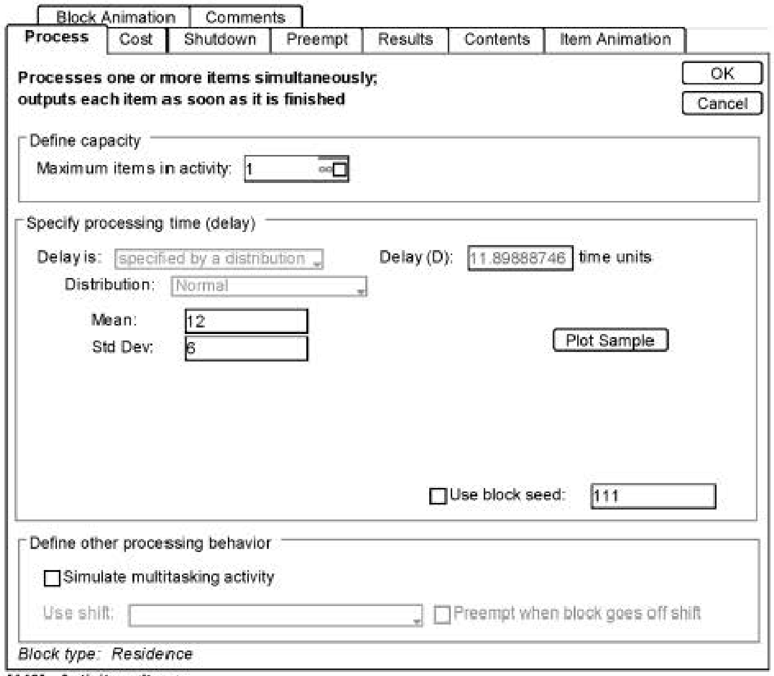


[109] Items' Distribution

Interarrival Time	% Items
10.031119972	0.15
10.871876007	0.25
11.712632042	0.45
12.553388077	0.6
13.394144112	1.1
14.234900147	2.15
15.075656181	2.3
15.916412216	3.1
16.757168251	3.7
17.597924286	3.9
18.438680321	4.3
19.279436356	5.5
20.12019239	5.25
20.960948425	6.15
21.80170446	5.45
22.642460495	5.55
23.48321653	6.3
24.323972565	4.7
25.164728599	5.45
26.005484634	4.35
26.846240669	3.75
27.686996704	3.65
28.527752739	3.35
29.368508774	3.2
30.209264809	2.65
31.050020843	2.25
31.890776878	2.1
32.731532913	1.4
33.572288948	1.25
34.413044983	0.85
35.253801018	1.05
36.094557052	0.6
36.935313087	0.5
37.776069122	0.6
38.616825157	0.2
39.457581192	0.35
40.298337227	0.3
41.139093261	0.3
41.979849296	0.1
42.820605331	0.25
43.661361366	0
44.502117401	0.1
45.342873436	0.1
46.18362947	0.1
47.024385505	0.05
47.86514154	0
48.705897575	0.05
49.54665361	0.05
50.387409645	0.1
51.22816568	0.05

Worksheet Dialogs

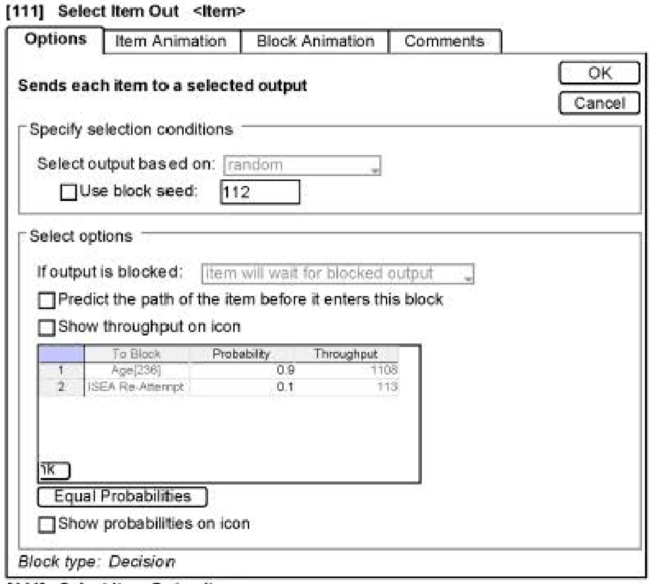
[110] Activity <Item>



[110] Activity <Item>

[110] Activity <Item>

[111] Select Item Out <Item>



[111] Select Item Out <Item>

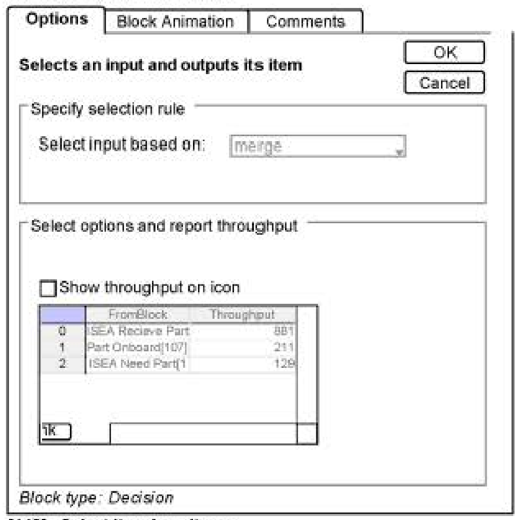
	To Block	Probability	Throughput
1	Age[236]	0.9	1108
2	ISEA Re-Attempt	0.1	113

[111] Select Item Out <Item>

Worksheet Dialogs

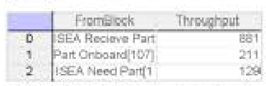
[111] Select Item Out <Item>

[112] Select Item In <Item>

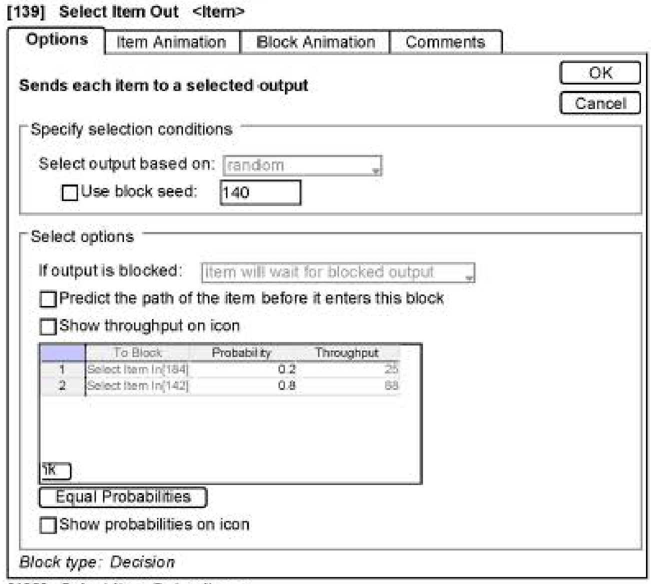


[112] Select Item In <Item>

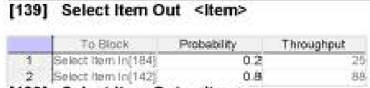
[112] Select Item In <Item>



[139] Select Item Out <Item>



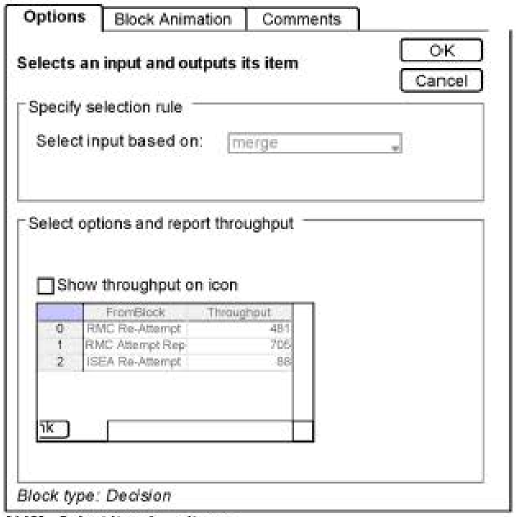
[139] Select Item Out <Item>



[139] Select Item Out <Item>

[139] Select Item Out <Item>

[142] Select Item In <Item>

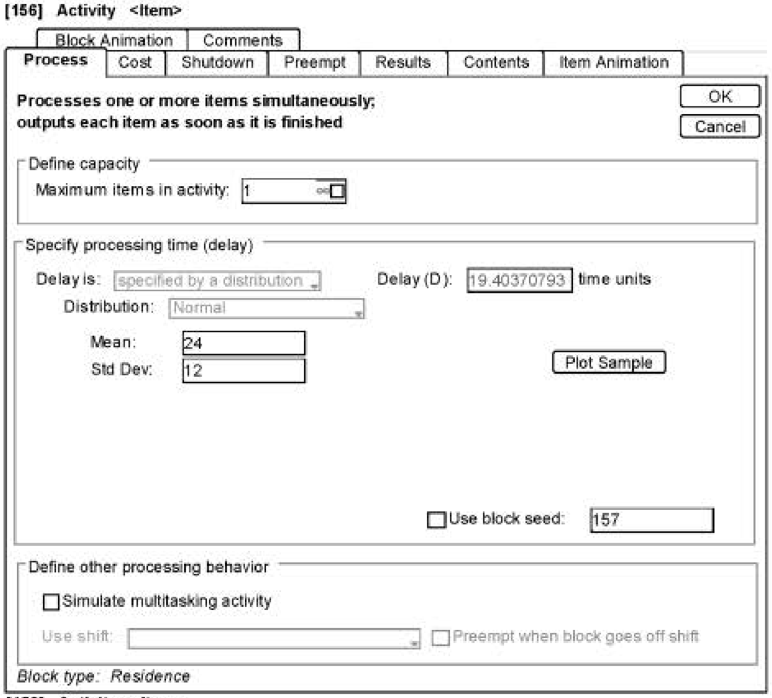


[142] Select Item In <Item>

[142] Select Item In <Item>

	FromBlock	Throughput
0	RMC Re-Attempt	481
1	RMC Attempt Rep	705
2	ISEA Re-Attempt	88

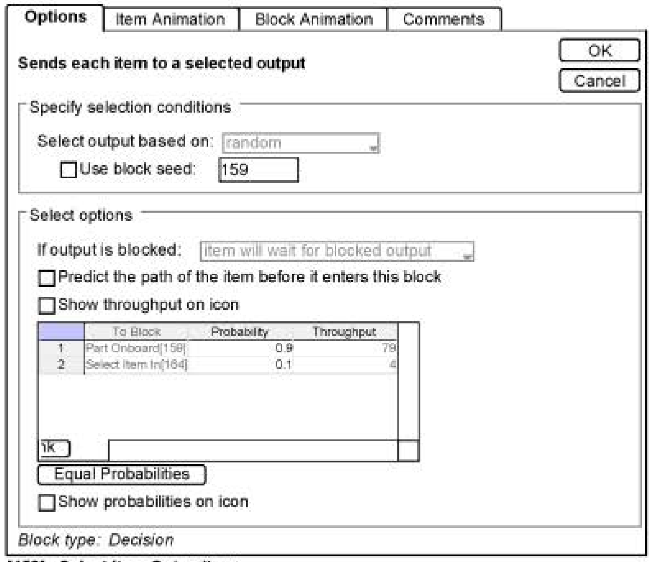
[156] Activity <Item>



[156] Activity <Item>

[156] Activity <Item>

[158] Select Item Out <Item>



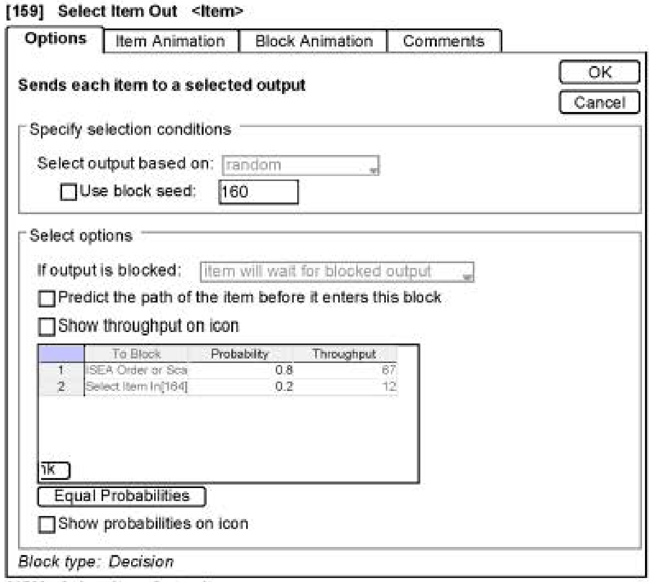
[158] Select Item Out <Item>

	To Block	Probability	Throughput
1	Part Onboard[159]	0.9	79
2	Select Item In[164]	0.1	4

[158] Select Item Out <Item>

[158] Select Item Out <Item>

[159] Select Item Out <Item>



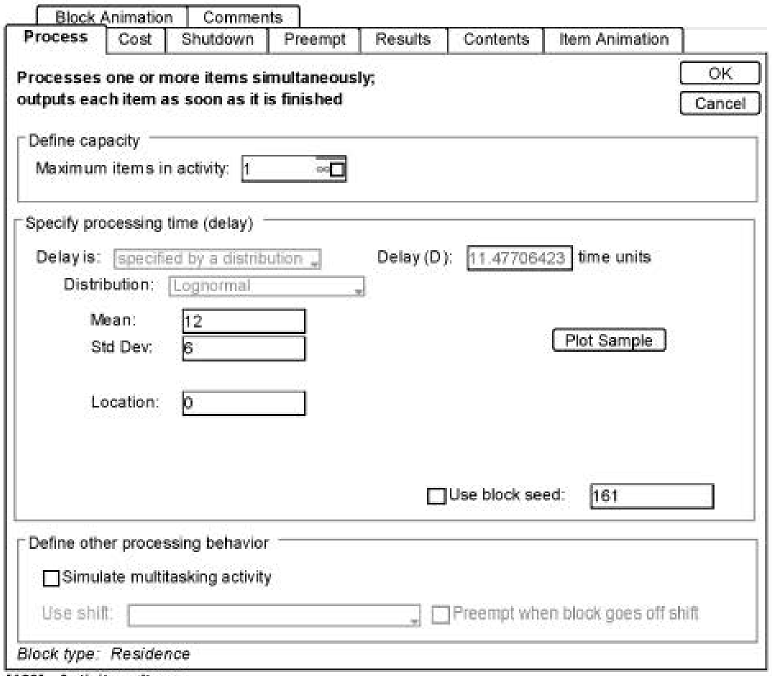
[159] Select Item Out <Item>

	To Block	Probability	Throughput
1	SEA Order or Sca	0.8	67
2	Select Item In[164]	0.2	12

[159] Select Item Out <Item>

[159] Select Item Out <Item>

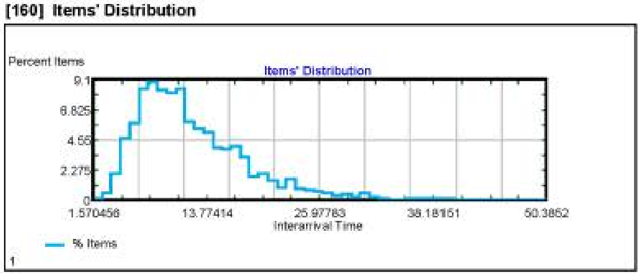
[160] Activity <Item>



[160] Activity <Item>

[160] Activity <Item>

[160] Items' Distribution

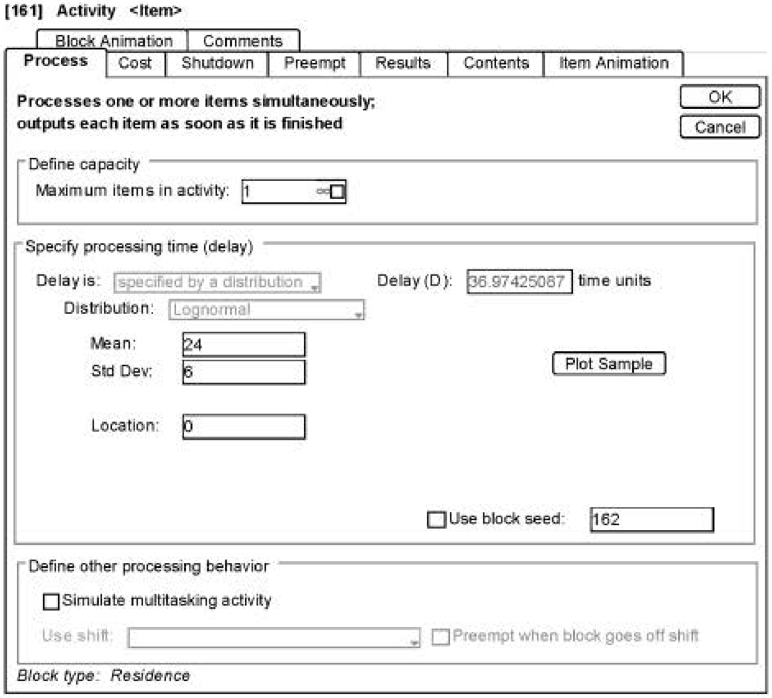


[160] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
1.5704555519	0.15
2.5666747721	0.55
3.5628939924	1.95
4.5591132126	4.65
5.5553324328	5.75
6.5515516531	8.4
7.5477708733	9.1
8.5439900935	8.3
9.5402093138	8.1
10.536428534	8.4
11.532647754	5.85
12.528866974	5.35
13.525086195	5.1
14.521305415	3.9
15.517524635	3.85
16.513743855	4.05
17.509963076	3.2
18.506182296	1.75
19.502401516	2
20.498620736	1.45
21.494839957	0.95
22.491059177	1.5
23.487278397	0.85
24.483497617	0.75
25.479716838	0.65
26.475936058	0.55
27.472155278	0.35
28.468374498	0.45
29.464593718	0.25
30.460812939	0.55
31.457032159	0.25
32.453251379	0.15
33.449470599	0.05
34.44568982	0.05
35.44190904	0.1
36.43812826	0.1
37.43434748	0.1
38.430566701	0.15
39.426785921	0.1
40.423005141	0.05
41.419224361	0.05
42.415443581	0
43.411662802	0
44.407882022	0.05
45.404101242	0.05
46.400320462	0
47.396539683	0
48.392758903	0
49.388978123	0
50.385197343	0.05

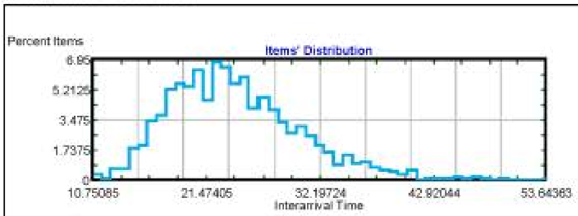
[161] Activity <Item>



[161] Activity <Item>

[161] Activity <Item>

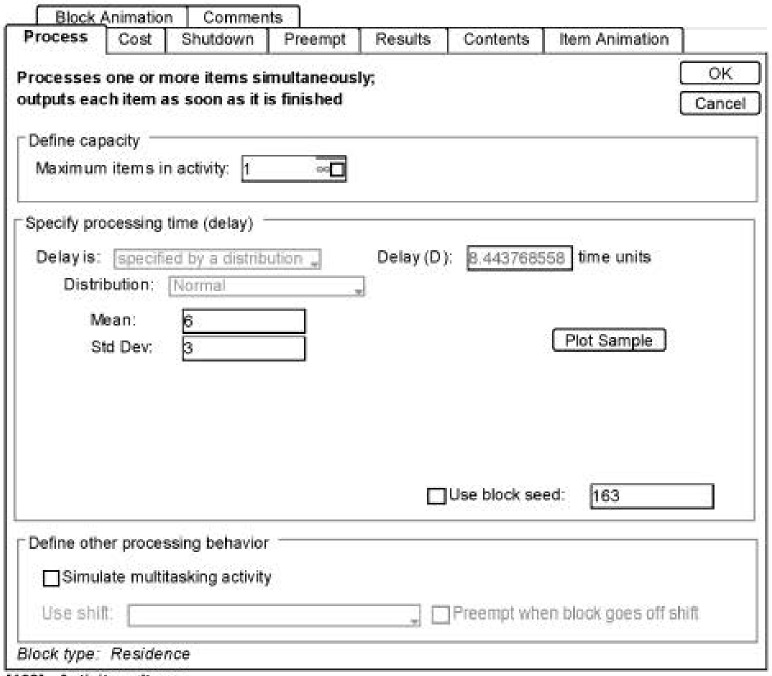
[161] Items' Distribution



[161] Items' Distribution

Interarrival Time	% Items
10.750851019	0.3
11.626213896	0.05
12.501576772	0.65
13.376939649	0.6
14.252302525	1.8
15.127665401	2
16.003028278	3.4
16.878391154	3.75
17.753754031	5.2
18.629116907	5.55
19.504479784	5.35
20.37984266	6.35
21.255205537	4.55
22.130568413	6.95
23.005931289	6.5
23.881294166	5.5
24.756657042	5.9
25.632019919	4.1
26.507382795	4.75
27.382745672	4
28.258108548	3.35
29.133471424	2.65
30.008834301	3.05
30.884197177	2.55
31.759560054	1.95
32.63492293	1.6
33.510285807	0.9
34.385648683	1.45
35.261011559	0.95
36.136374436	1.05
37.011737312	0.7
37.887100189	0.55
38.762463065	0.45
39.637825942	0.3
40.513188818	0.55
41.388551694	0
42.263914571	0.1
43.139277447	0.05
44.014640324	0.05
44.8900032	0.15
45.765366077	0.05
46.640728953	0.15
47.516091829	0.05
48.391454706	0
49.266817582	0.05
50.142180459	0
51.017543335	0
51.892906212	0
52.768269088	0
53.643631965	0.05

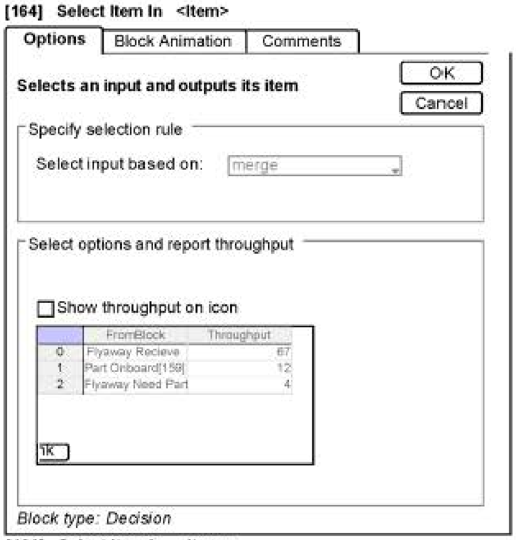
[162] Activity <Item>



[162] Activity <Item>

[162] Activity <Item>

[164] Select Item In <Item>



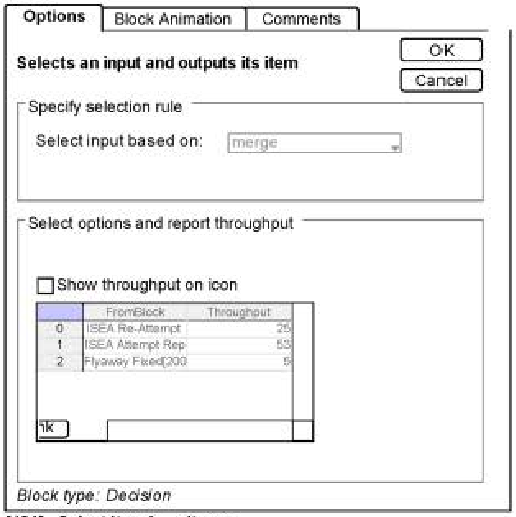
[164] Select Item In <Item>

[164] Select Item In <Item>

	FromBlock	Throughput
0	Flyaway Recieve	67
1	Part Onboard[159]	12
2	Flyaway Need Part	4

Worksheet Dialogs

[184] Select Item In <Item>

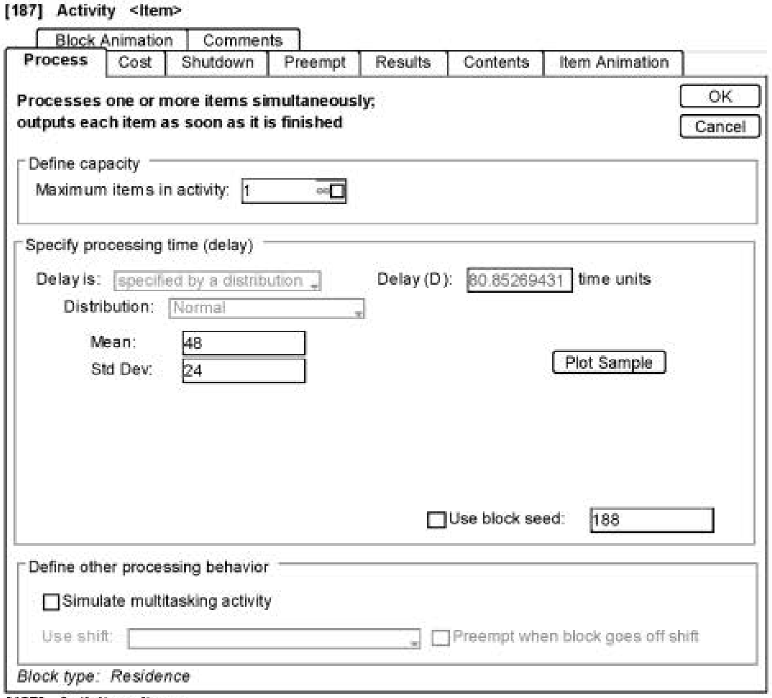


[184] Select Item In <Item>

[184] Select Item In <Item>

	FromBlock	Throughput
0	ISEA Re-Attempt	25
1	ISEA Attempt Rep	53
2	Flyaway Fixed[200	5

[187] Activity <Item>



[187] Activity <Item>

[187] Activity <Item>

[189] Equation <Value>

Equation | Options | Comments

Computes an equation and outputs the results

OK

Open Developer Reference

Cancel

Define input and output variables

Input Variables

	Variable Type	Variable Name	Variable Value
1	Connector 0	inCon0	8127

Output Variables (results)

	Variable Type	Variable Name	Variable Value
1	Connector 0	outCon0	8128

Enter the equation in the form "result = formula;"

```
outCon0 = inCon0 + 1;
```

Open / Close Equation Editor

☐ Enable Debugger

Set Breakpoints

Test Equation

☐ Use include files

[189] Equation <Value>

	Variable Type	Variable Name	Variable Value
1	Connector 0	inCon0	8127

[189] Equation <Value>

	Variable Type	Variable Name	Variable Value
1	Connector 0	outCon0	8128

[189] Equation <Value>

[200] Select Item Out <Item>

Options | Item Animation | Block Animation | Comments

Sends each item to a selected output

OK

Cancel

Specify selection conditions

Select output based on: random

☐ Use block seed: 201

Select options

If output is blocked: item will wait for blocked output

☐ Predict the path of the item before it enters this block

☐ Show throughput on icon

	To Block	Probability	Throughput
1	Age[248]	0.95	78
2	Select Item In[184]	0.05	5

nk

Equal Probabilities

☐ Show probabilities on icon

Block type: Decision

[200] Select Item Out <Item>

	To Block	Probability	Throughput
1	Age[248]	0.95	78
2	Select Item In[184]	0.05	5

Worksheet Dialogs

[200] Select Item Out <Item>

[200] Select Item Out <Item>

[211] Write(I) <Item>

Write Data | Options | Item Animation | Block Animation | Comments

OK

Cancel

Writes data to a database when an item arrives

Select database and define database coordinates

Database: Database 1

Open selected database

Open selected table

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}

Block type: Passing

[211] Write(I) <Item>

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source	Value Written
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}	261.6017568456

[225] Select Item In <Item>

Options | Block Animation | Comments

OK

Cancel

Selects an input and outputs its item

Specify selection rule

Select input based on: merge

Select options and report throughput

☐ Show throughput on icon

	FromBlock	Throughput
0	Sailor Fix[219]	4670
1	RMC Fix[220]	2272
2	ISEA Fix[221]	1108
3	Flyaway Fix[222]	78

1K

Block type: Decision

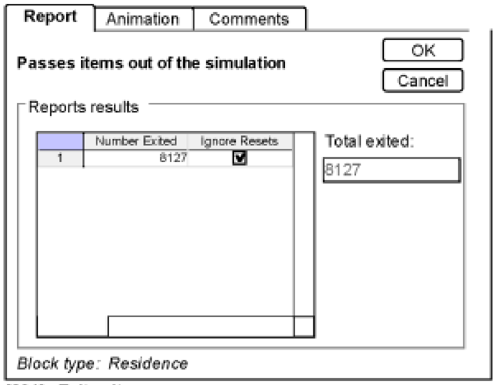
[225] Select Item In <Item>

[225] Select Item In <Item>

	FromBlock	Throughput
0	Sailor Fix[219]	4670
1	RMC Fix[220]	2272
2	ISEA Fix[221]	1108
3	Flyaway Fix[222]	78

Worksheet Dialogs

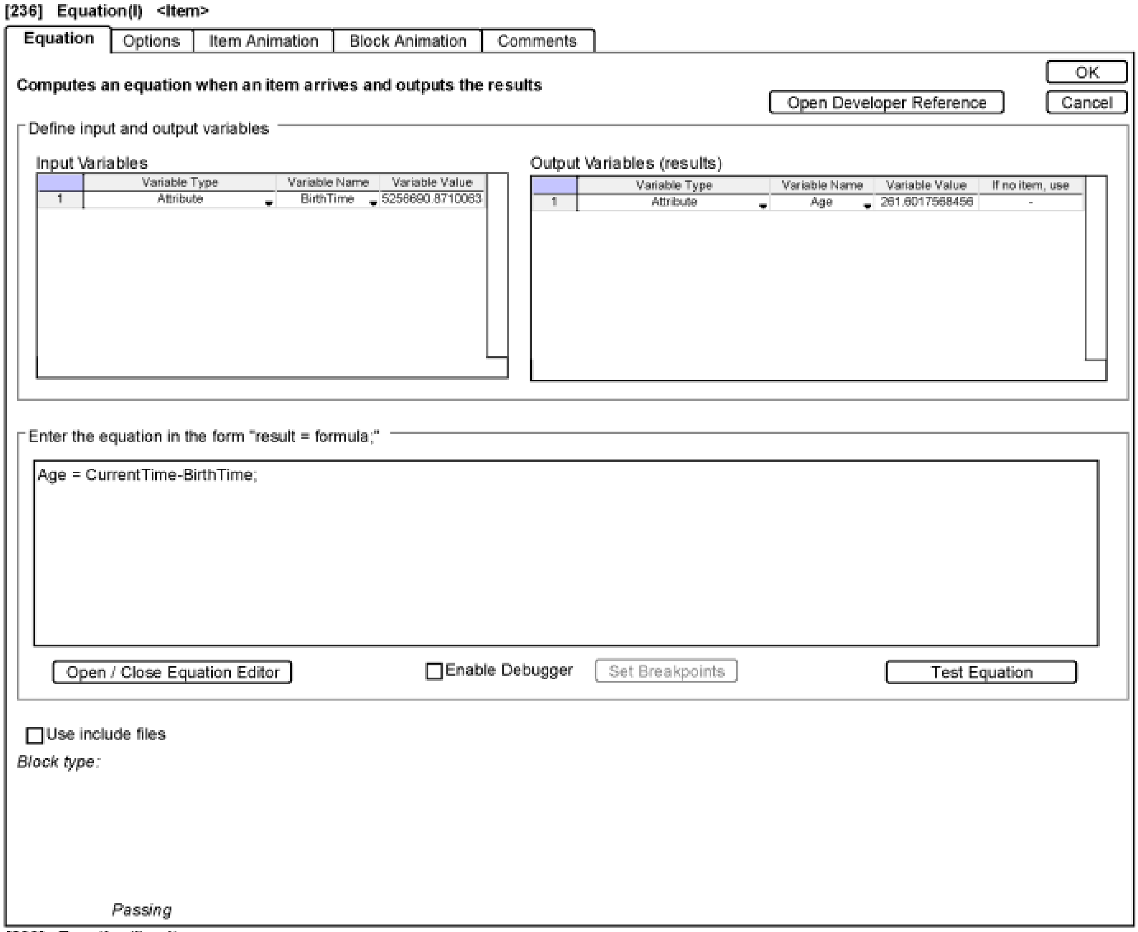
[231] Exit <Item>



[231] Exit <Item>

	Number Exited	Ignore Resets
1	8127	☑

[236] Equation(I) <Item>



[236] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5256690.8710063

[236] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	261.6017568456	-

[236] Equation(I) <Item>

Worksheet Dialogs

[237] Write(I) <Item>

Write Data | Options | Item Animation | Block Animation | Comments

Writes data to a database when an item arrives

OK

Cancel

Select database and define database coordinates

Database: Database 1

Open selected database

Open selected table

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}

Block type: Passing

[237] Write(I) <Item>

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source	Value Written
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	(Age)	45.213933054358

[238] Equation(I) <Item>

Equation | Options | Item Animation | Block Animation | Comments

Computes an equation when an item arrives and outputs the results

Open Developer Reference

OK

Cancel

Define input and output variables

Input Variables

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5258611.8671542

Output Variables (results)

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	45.213933054358	-

Enter the equation in the form "result = formula;"

```
Age = CurrentTime-BirthTime;
```

Open / Close Equation Editor

☐ Enable Debugger

Set Breakpoints

Test Equation

☐ Use include files

Block type:

Passing

[238] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5258611.8671542

Worksheet Dialogs

[238] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	45.213933064358	-

[238] Equation(I) <Item>

[241] Write(I) <Item>

Write Data | Options | Item Animation | Block Animation | Comments

OK

Cancel

Writes data to a database when an item arrives

Select database and define database coordinates

Database: Database 1

Open selected database

Open selected table

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}

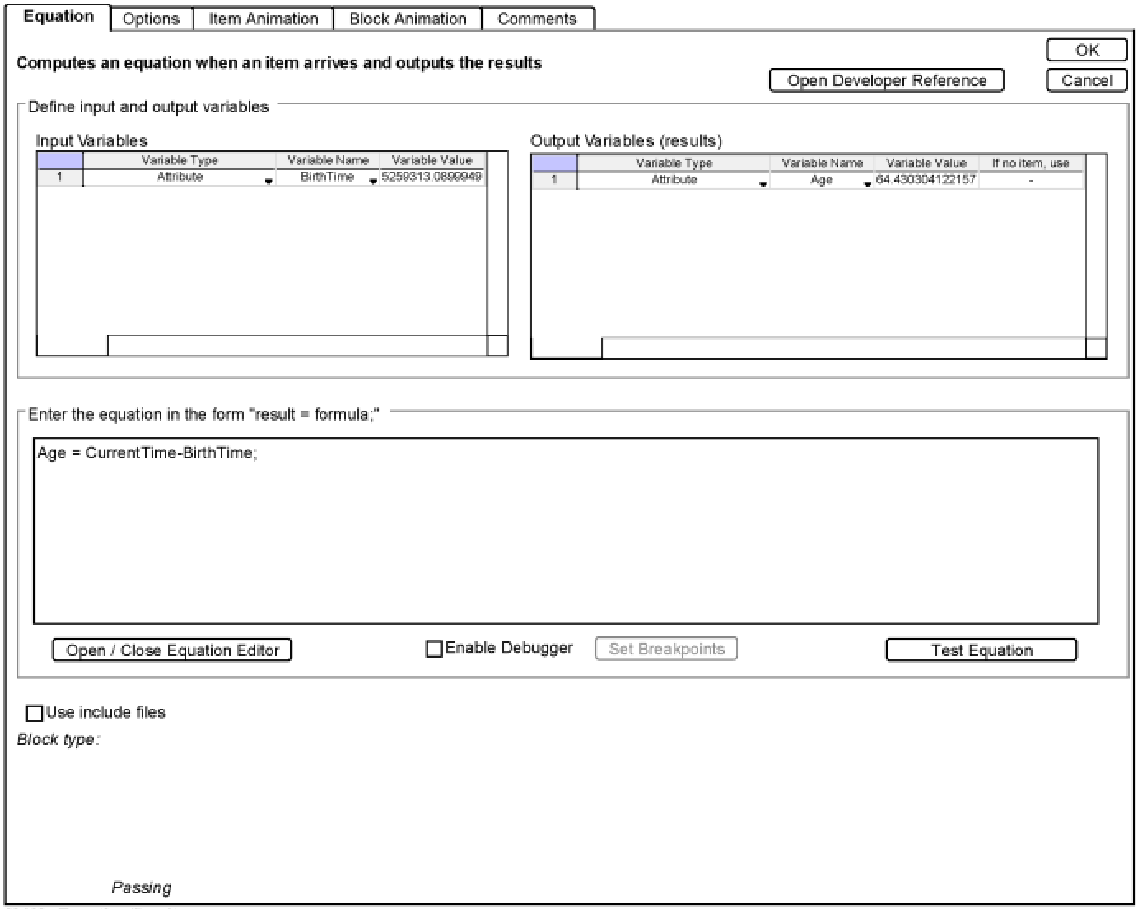
Block type: Passing

[241] Write(I) <Item>

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source	Value Written
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}	64.430304122157

Worksheet Dialogs

[242] Equation(I) <Item>



[242] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5259313.0899949

[242] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	64.430304122157	-

[242] Equation(I) <Item>

Worksheet Dialogs

[247] Write(I) <Item>

Write Data | Options | Item Animation | Block Animation | Comments

Writes data to a database when an item arrives

OK

Cancel

Select database and define database coordinates

Database: Database 1 | Open selected database | Open selected table

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}

Block type: Passing

[247] Write(I) <Item>

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source	Value Written
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}	527.80324519053

[248] Equation(I) <Item>

Equation | Options | Item Animation | Block Animation | Comments

Computes an equation when an item arrives and outputs the results

OK

Open Developer Reference | Cancel

Define input and output variables

Input Variables

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5230539.1309219

Output Variables (results)

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	527.80324519053	-

Enter the equation in the form "result = formula;"

```
Age = CurrentTime-BirthTime;
```

Open / Close Equation Editor | ☐ Enable Debugger | Set Breakpoints | Test Equation

☐ Use include files

Block type:

Passing

[248] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5230539.1309219

Worksheet Dialogs

[248] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	527.80324519053	-

[248] Equation(I) <Item>

[268] Activity <Item>

Block Animation | Comments
Process | Cost | Shutdown | Preempt | Results | Contents | Item Animation

Processes one or more items simultaneously; outputs each item as soon as it is finished

OK
Cancel

Define capacity
Maximum items in activity: 1 ∞

Specify processing time (delay)
Delay is: specified by a distribution   Delay (D): 596.6150679 time units
Distribution: Normal
Mean: 500
Std Dev: 100
Plot Sample
Use block seed: 269

Define other processing behavior
Simulate multitasking activity
Use shift: Preempt when block goes off shift

Block type: Residence

[268] Activity <Item>

[268] Activity <Item>

[284] Create <Item>

Create | Options | Item Animation | Block Animation | Comments

Creates items and values randomly or by schedule

OK
Cancel

Select block behavior
Create items by schedule   Time units: generic*

Enter a schedule of arrival times

	_Create Time	_Item Quantity	_Item Priority	None	None	None
1	0	1	1			

1K

Repeat the schedule every
Total cost: 0

Block type: Residence   **model default*

[284] Create <Item>

Worksheet Dialogs

[284] Create <Item>

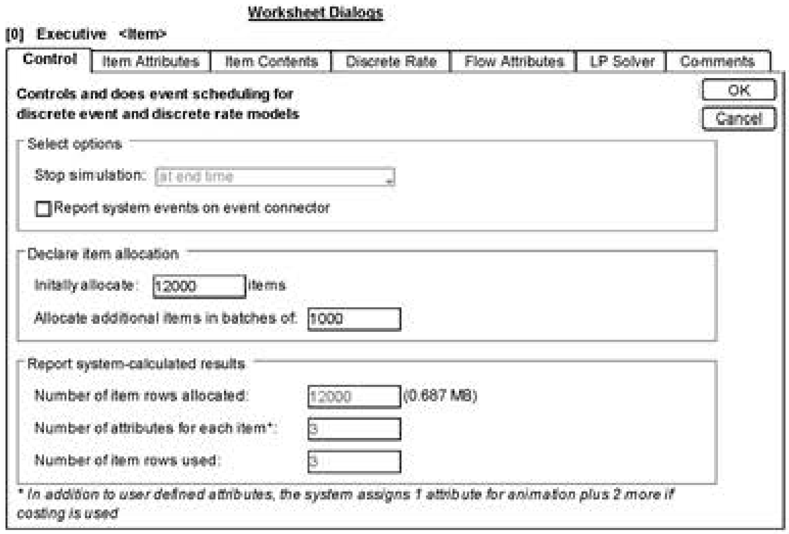
	_Create Time	_Item Quantity	_Item Priority	None	None	None
1	0	1	1			

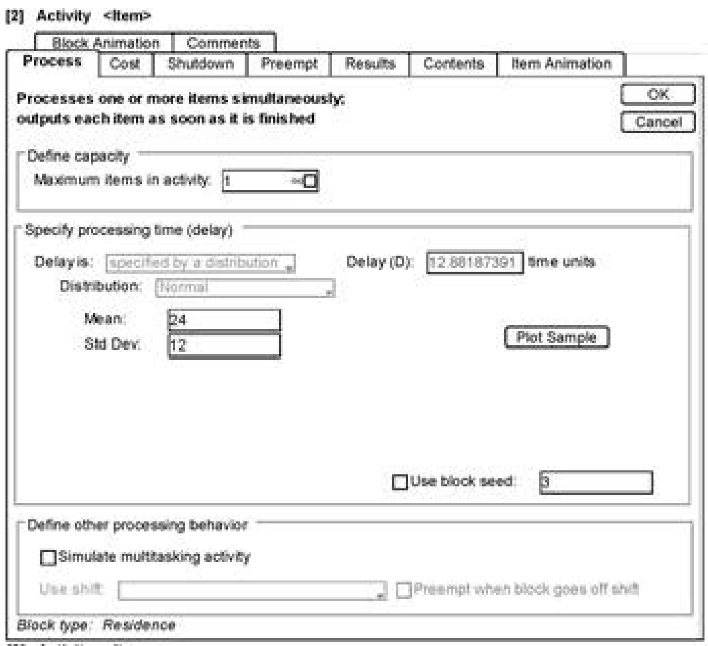
[284] Create <Item>

[284] Create <Item>

	0

B. INTEGRATED DISTANCE SUPPORT





[2] Activity <Item>

[2] Activity <Item>

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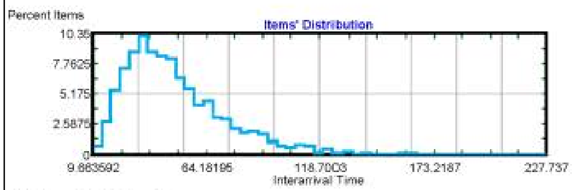
[2] Items' Distribution

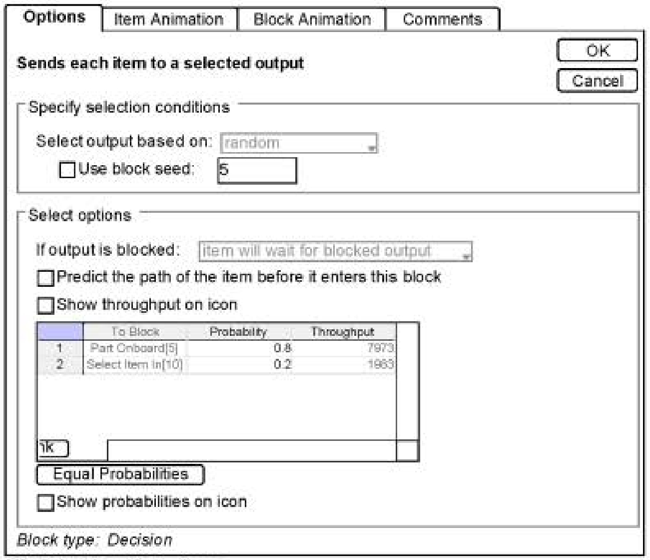


[2] Items' Distribution

Interarrival Time	% Items
9.6635916225	0.75
14.114069768	2.65
18.564547914	5.45
23.01502606	7.35
27.465504206	8.7
31.915982352	10.35
36.366460497	8.7
40.816938643	8.35
45.267416789	8.1
49.717894935	6.5
54.168373081	5.5
58.618851227	4.15
63.069329372	4.45
67.519807518	3
71.970285664	2.9
76.42076381	2.1
80.871241956	1.8
85.321720101	1.9
89.772198247	1.65
94.222676393	1
98.673154539	0.7
103.12363268	0.6
107.57411083	0.8
112.02458898	0.7
116.47506712	0.15
120.92554527	0.45
125.37602341	0.15
129.82650156	0.25
134.27697971	0.05
138.72745785	0.15
143.177936	0.05
147.62841414	0.05
152.07889229	0.05
156.52937043	0.15
160.97984858	0.1
165.43032673	0
169.88080487	0.05
174.33128302	0.05
178.78176116	0
183.23223931	0
187.68271746	0
192.1331956	0.05
196.58367375	0
201.03415189	0
205.48463004	0
209.93510818	0
214.38558633	0.05
218.83606448	0
223.28654262	0
227.73702077	0.05

Worksheet Dialogs

[4] Select Item Out <Item>



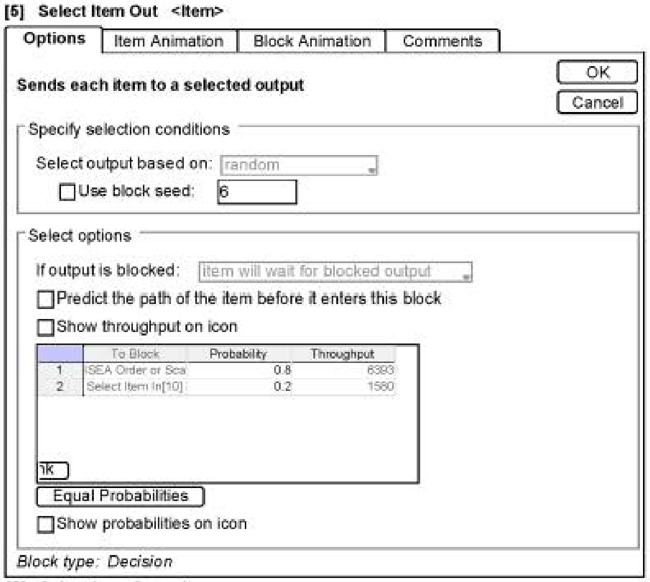
[4] Select Item Out <Item>

	To Block	Probability	Throughput
1	Part Onboard[5]	0.8	7973
2	Select Item In[10]	0.2	1983

[4] Select Item Out <Item>

[4] Select Item Out <Item>

[5] Select Item Out <Item>



[5] Select Item Out <Item>

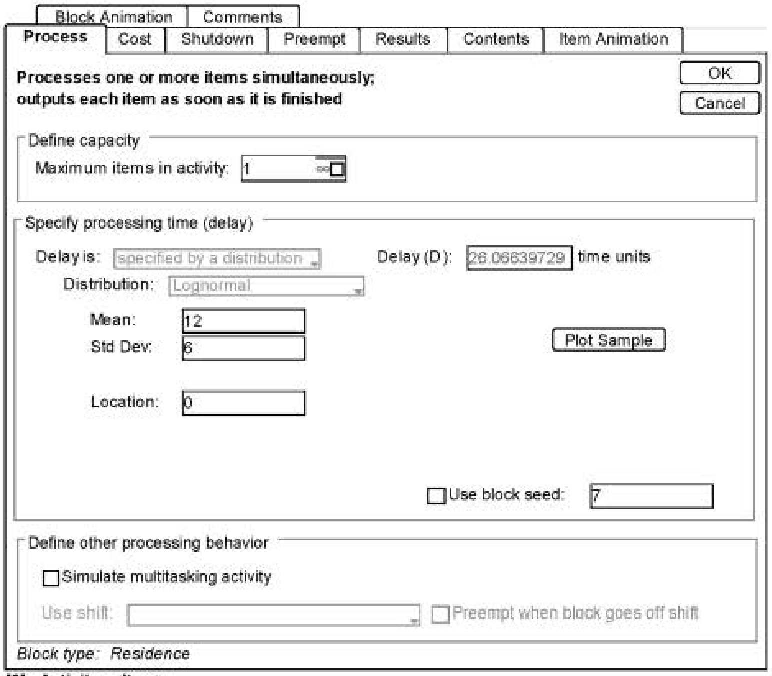
	To Block	Probability	Throughput
1	SEA Order or Sca	0.8	6393
2	Select Item In[10]	0.2	1580

[5] Select Item Out <Item>

[5] Select Item Out <Item>

Worksheet Dialogs

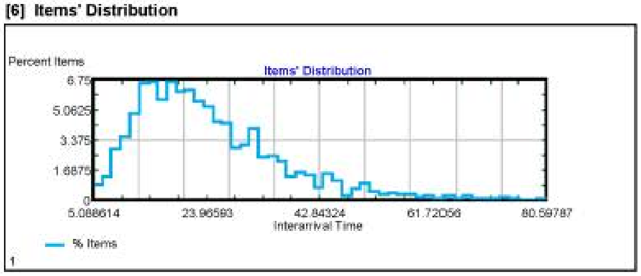
[6] Activity <Item>



[6] Activity <Item>

[6] Activity <Item>

[6] Items' Distribution

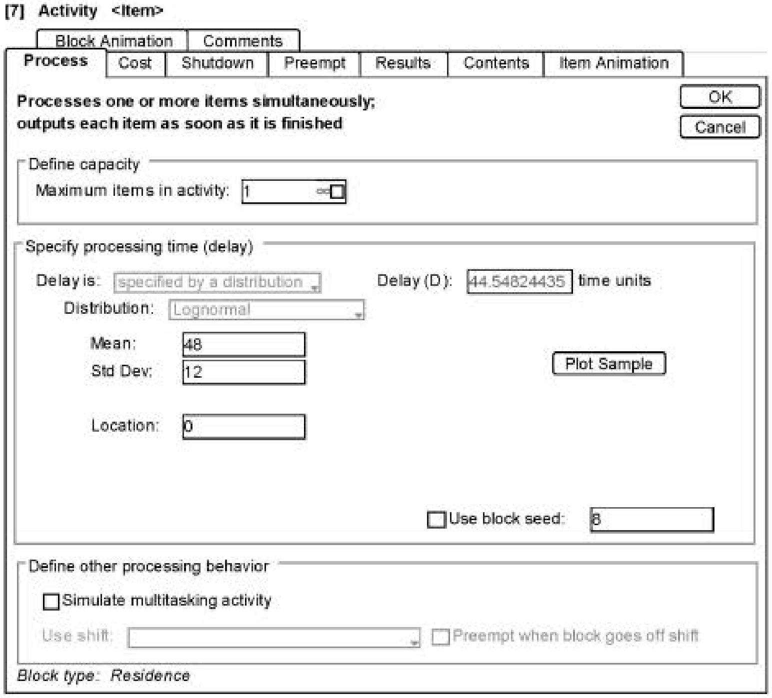


[6] Items Distribution

<u>**Worksheet Dialogs**</u>

Interarrival Time	% Items
5.0886142087	0.85
6.6296194357	1.3
8.1706246628	2.85
9.7116298899	3.5
11.252635117	4.85
12.793640344	6.5
14.334645571	6.75
15.875650798	5.6
17.416656025	6.6
18.957661252	6.05
20.498666479	6.15
22.039671706	5.5
23.580676933	5.25
25.12168216	4.4
26.662687388	4.3
28.203692615	2.9
29.744697842	3.1
31.285703069	4
32.826708296	2.4
34.367713523	2.45
35.90871875	2.15
37.449723977	1.3
38.990729204	1.55
40.531734431	1.4
42.072739658	0.7
43.613744885	1.45
45.154750112	1.05
46.695755339	0.25
48.236760566	0.65
49.777765793	0.9
51.31877102	0.45
52.859776248	0.3
54.400781475	0.4
55.941786702	0.3
57.482791929	0.3
59.023797156	0.15
60.564802383	0.25
62.10580761	0.1
63.646812837	0.2
65.187818064	0.05
66.728823291	0.2
68.269828518	0.1
69.810833745	0.1
71.351838972	0.05
72.892844199	0.15
74.433849426	0.1
75.974854653	0
77.51585988	0
79.056865108	0.05
80.597870335	0.05

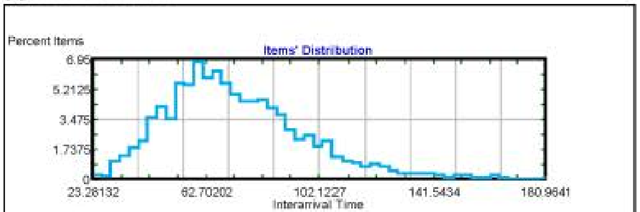
[7] Activity <Item>



[7] Activity <Item>

[7] Activity <Item>

[7] Items' Distribution

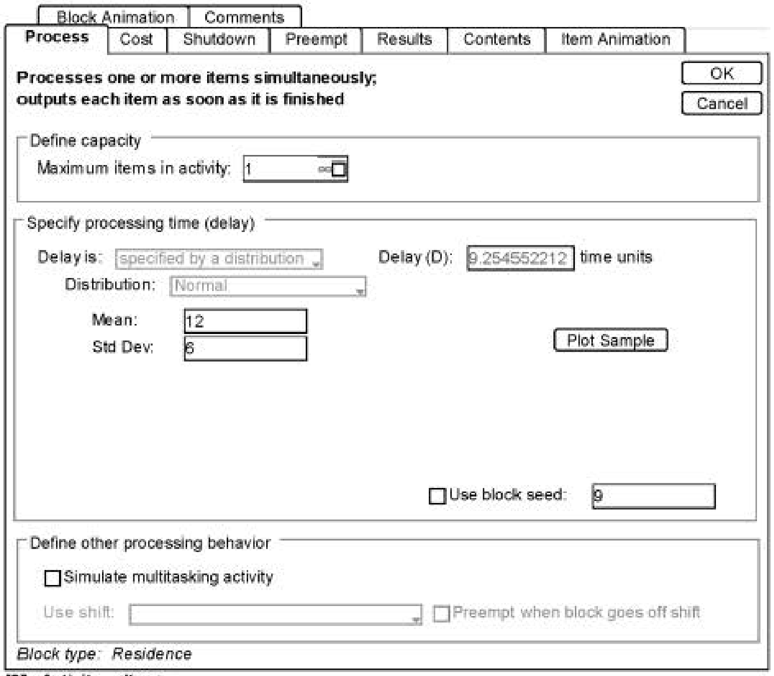


[7] Items' Distribution

Interarrival Time	% Items
23.281324469	0.25
26.499340688	0.15
29.717356907	1
32.935373127	1.35
36.153389346	1.8
39.371405565	2.2
42.589421784	3.55
45.807438003	4.2
49.025454222	3.45
52.243470441	5.55
55.46148666	5.45
58.679502879	6.95
61.897519098	5.85
65.115535318	6.2
68.333551537	5.55
71.551567756	4.9
74.769583975	4.5
77.987600194	4.5
81.205616413	4.6
84.423632632	4.1
87.641648851	3.7
90.85966507	2.85
94.07768129	2.3
97.295697509	2.55
100.51371373	1.9
103.73172995	2.2
106.94974617	1.25
110.16776239	1
113.3857786	0.95
116.60379482	0.75
119.82181104	0.85
123.03982726	0.7
126.25784348	0.5
129.4758597	0.3
132.69387592	0.3
135.91189214	0.3
139.12990836	0.3
142.34792458	0.25
145.5659408	0.05
148.78395701	0.2
152.00197323	0.2
155.21998945	0.1
158.43800567	0.05
161.65602189	0.25
164.87403811	0.05
168.09205433	0
171.31007055	0
174.52808677	0
177.74610299	0
180.96411921	0.05

Worksheet Dialogs

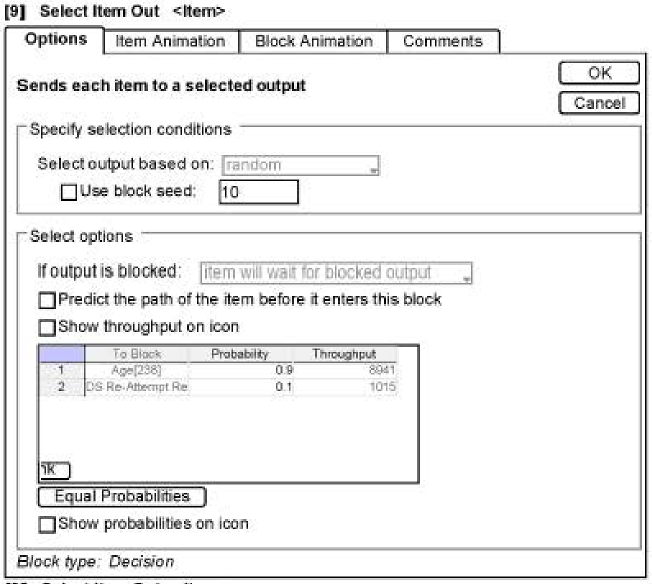
[8] Activity <Item>



[8] Activity <Item>

[8] Activity <Item>

[9] Select Item Out <Item>



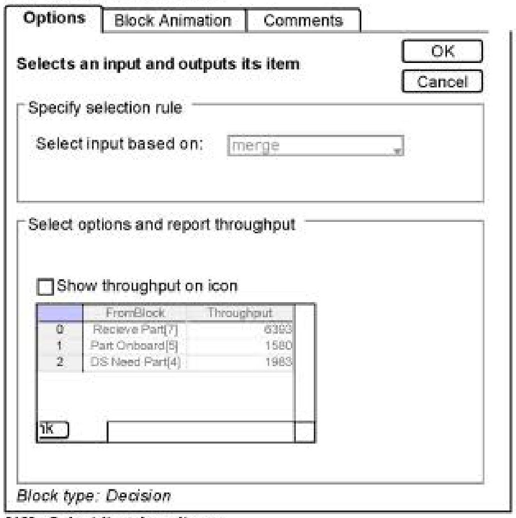
[9] Select Item Out <Item>

	To Block	Probability	Throughput
1	Age[238]	0.9	8941
2	DS Re-Attempt Re	0.1	1015

[9] Select Item Out <Item>

[9] Select Item Out <Item>

[10] Select Item In <Item>

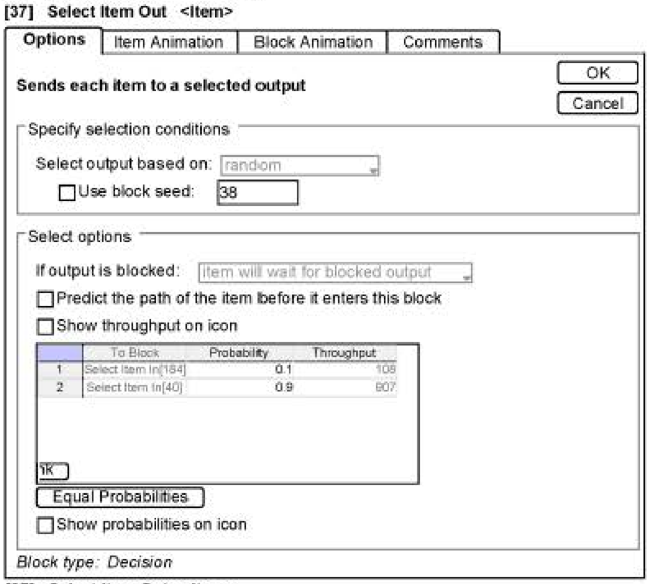


[10] Select Item In <Item>

[10] Select Item In <Item>

	FromBlock	Throughput
0	Recieve Part[7]	6393
1	Part Onboard[5]	1580
2	DS Need Part[4]	1983

[37] Select Item Out <Item>



[37] Select Item Out <Item>

	To Block	Probability	Throughput
1	Select Item In[184]	0.1	108
2	Select Item In[40]	0.9	907

[37] Select Item Out <Item>

[37] Select Item Out <Item>

Worksheet Dialogs

[40] Select Item In <Item>

Options | Block Animation | Comments

Selects an input and outputs its item

OK
Cancel

Specify selection rule

Select input based on: merge

Select options and report throughput

☐ Show throughput on icon

	FromBlock	Throughput
0	Initial Problem[88]	1
1	Problem[57]	9048
2	DS Re-Attempt Re	907

Block type: Decision

[40] Select Item In <Item>

[40] Select Item In <Item>

	FromBlock	Throughput
0	Initial Problem[88]	1
1	Problem[57]	9048
2	DS Re-Attempt Re	907

[57] Create <Item>

Create | Options | Item Animation | Block Animation | Comments

Creates items and values randomly or by schedule

OK
Cancel

Select block behavior

Create items by schedule   Time units: generic*

Enter a schedule of arrival times

	_Create Time	_Item Quantity	_Item Priority	None	None	None
1	0	1	1			

☐ Repeat the schedule every

Total cost: 0

Block type: Residence   **model default*

[57] Create <Item>

[57] Create <Item>

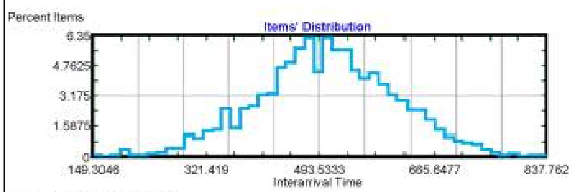
	_Create Time	_Item Quantity	_Item Priority	None	None	None
1	0	1	1			

[57] Create <Item>

[57] Create <Item>

	0

[57] Items' Distribution



[57] Items' Distribution

Interarrival Time	% Items
149.30464731	0.05
163.35479836	0
177.4049494	0.1
191.45510045	0.35
205.5052515	0.1
219.55540255	0.05
233.6055536	0.15
247.65570464	0.25
261.70585569	0.45
275.75600674	0.4
289.80615779	1.05
303.85630884	0.95
317.90645988	1.3
331.95661093	1.4
346.00676198	2.45
360.05691303	1.45
374.10706408	2.45
388.15721512	2.6
402.20736617	3.15
416.25751722	3.25
430.30766827	4.6
444.35781932	4.9
458.40797036	5.6
472.45812141	6.35
486.50827246	4.4
500.55842351	6.25
514.60857456	5.55
528.6587256	5.55
542.70887665	4.5
556.7590277	4.05
570.80917875	4.35
584.8593298	3.75
598.90948084	3.2
612.95963189	2.9
627.00978294	2.4
641.05993399	2.35
655.11008504	1.9
669.16023609	1.35
683.21038713	1
697.26053818	0.8
711.31068923	0.7
725.36084028	0.65
739.41099133	0.35
753.46114237	0.2
767.51129342	0.1
781.56144447	0.15
795.61159552	0
809.66174657	0.05
823.71189761	0.05
837.76204866	0.05

[61] Exit <Item>

Report | Animation | Comments

Passes items out of the simulation

OK
Cancel

Reports results

	Number Exited	Ignore Resets
1	9048	☑

Total exited: 9048

Block type: Residence

[61] Exit <Item>

	Number Exited	Ignore Resets
1	9048	☑

[156] Activity <Item>

Block Animation | Comments

Process | Cost | Shutdown | Preempt | Results | Contents | Item Animation

Processes one or more items simultaneously; outputs each item as soon as it is finished

OK
Cancel

Define capacity

Maximum items in activity: 1 ∞☐

Specify processing time (delay)

Delay is: specified by a distribution   Delay (D): 28.91921504 time units

Distribution: Normal

Mean: 24

Std Dev: 12

Plot Sample

☐ Use block seed: 157

Define other processing behavior

☐ Simulate multitasking activity

Use shift: ☐ Preempt when block goes off shift

Block type: Residence

[156] Activity <Item>

[156] Activity <Item>

[158] Select Item Out <Item>

Options | Item Animation | Block Animation | Comments

Sends each item to a selected output

OK
Cancel

Specify selection conditions

Select output based on: random

☐ Use block seed: 159

Select options

If output is blocked: item will wait for blocked output

☐ Predict the path of the item before it enters this block

☐ Show throughput on icon

	To Block	Probability	Throughput
1	Part Onboard[159]	0.9	100
2	Select Item In[164]	0.1	15

nk

Equal Probabilities

☐ Show probabilities on icon

Block type: Decision

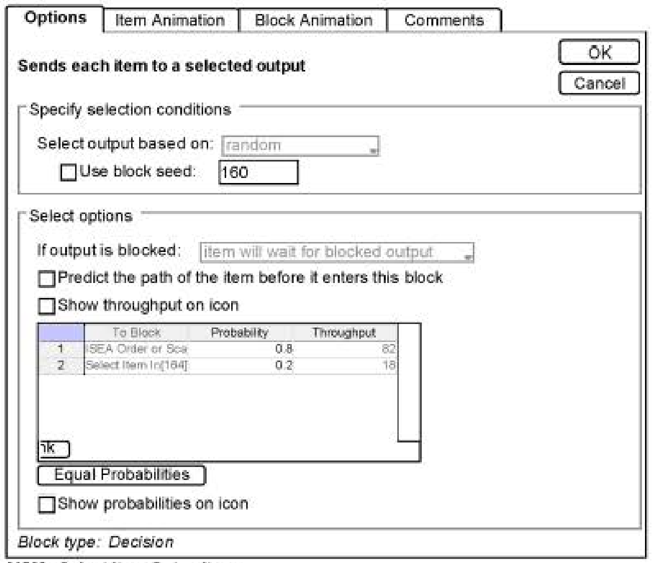
[158] Select Item Out <Item>

	To Block	Probability	Throughput
1	Part Onboard[159]	0.9	100
2	Select Item In[164]	0.1	15

[158] Select Item Out <Item>

[158] Select Item Out <Item>

[159] Select Item Out <Item>



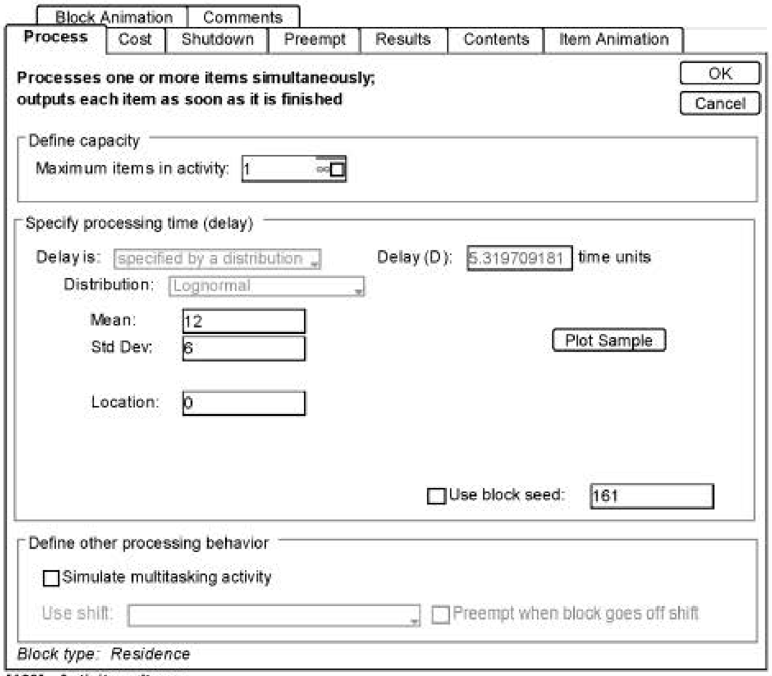
[159] Select Item Out <Item>

	To Block	Probability	Throughput
1	ISEA Order or Sca	0.8	82
2	Select Item In[164]	0.2	18

[159] Select Item Out <Item>

[159] Select Item Out <Item>

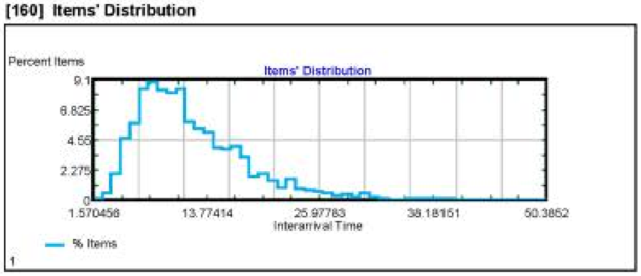
[160] Activity <Item>



[160] Activity <Item>

[160] Activity <Item>

[160] Items' Distribution



[160] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
1.5704555519	0.15
2.5666747721	0.55
3.5628939924	1.95
4.5591132126	4.65
5.5553324328	5.75
6.5515516531	8.4
7.5477708733	9.1
8.5439900935	8.3
9.5402093138	8.1
10.536428534	8.4
11.532647754	5.85
12.528866974	5.35
13.525086195	5.1
14.521305415	3.9
15.517524635	3.85
16.513743855	4.05
17.509963076	3.2
18.506182296	1.75
19.502401516	2
20.498620736	1.45
21.494839957	0.95
22.491059177	1.5
23.487278397	0.85
24.483497617	0.75
25.479716838	0.65
26.475936058	0.55
27.472155278	0.35
28.468374498	0.45
29.464593718	0.25
30.460812939	0.55
31.457032159	0.25
32.453251379	0.15
33.449470599	0.05
34.44568982	0.05
35.44190904	0.1
36.43812826	0.1
37.43434748	0.1
38.430566701	0.15
39.426785921	0.1
40.423005141	0.05
41.419224361	0.05
42.415443581	0
43.411662802	0
44.407882022	0.05
45.404101242	0.05
46.400320462	0
47.396539683	0
48.392758903	0
49.388978123	0
50.385197343	0.05

[161] Activity <Item>

Block Animation | Comments

Process | Cost | Shutdown | Preempt | Results | Contents | Item Animation

Processes one or more items simultaneously; outputs each item as soon as it is finished

OK | Cancel

Define capacity

Maximum items in activity: 1 ∞

Specify processing time (delay)

Delay is: specified by a distribution

Delay (D): 20.79539551 time units

Distribution: Lognormal

Mean: 24

Std Dev: 6

Plot Sample

Location: 0

☐ Use block seed: 162

Define other processing behavior

☐ Simulate multitasking activity

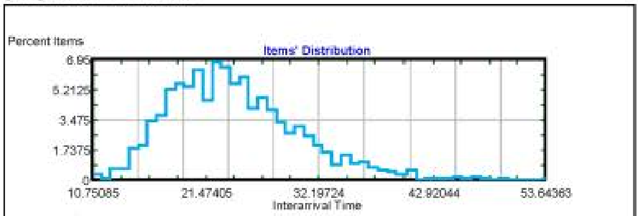
Use shift: ☐ Preempt when block goes off shift

Block type: Residence

[161] Activity <Item>

[161] Activity <Item>

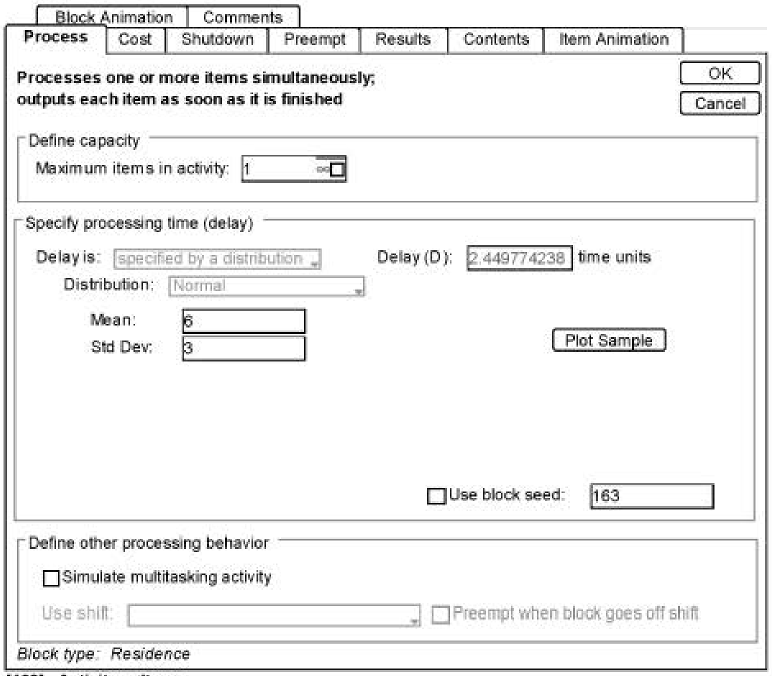
[161] Items' Distribution



[161] Items' Distribution

Interarrival Time	% Items
10.750851019	0.3
11.626213896	0.05
12.501576772	0.65
13.376939649	0.6
14.252302525	1.8
15.127665401	2
16.003028278	3.4
16.878391154	3.75
17.753754031	5.2
18.629116907	5.55
19.504479784	5.35
20.37984266	6.35
21.255205537	4.55
22.130568413	6.95
23.005931289	6.5
23.881294166	5.5
24.756657042	5.9
25.632019919	4.1
26.507382795	4.75
27.382745672	4
28.258108548	3.35
29.133471424	2.65
30.008834301	3.05
30.884197177	2.55
31.759560054	1.95
32.63492293	1.6
33.510285807	0.9
34.385648683	1.45
35.261011559	0.95
36.136374436	1.05
37.011737312	0.7
37.887100189	0.55
38.762463065	0.45
39.637825942	0.3
40.513188818	0.55
41.388551694	0
42.263914571	0.1
43.139277447	0.05
44.014640324	0.05
44.8900032	0.15
45.765366077	0.05
46.640728953	0.15
47.516091829	0.05
48.391454706	0
49.266817582	0.05
50.142180459	0
51.017543335	0
51.892906212	0
52.768269088	0
53.643631965	0.05

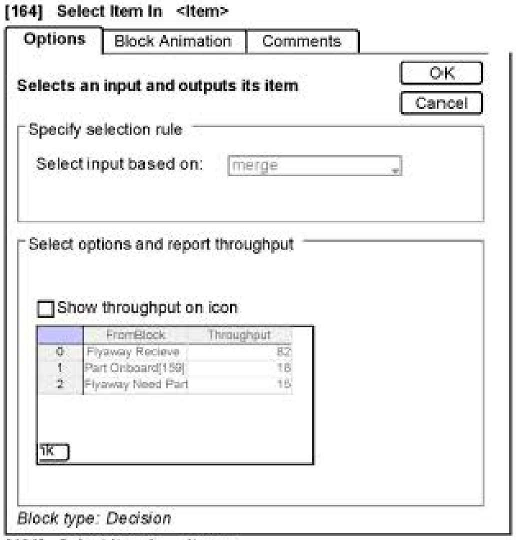
[162] Activity <Item>



[162] Activity <Item>

[162] Activity <Item>

[164] Select Item In <Item>



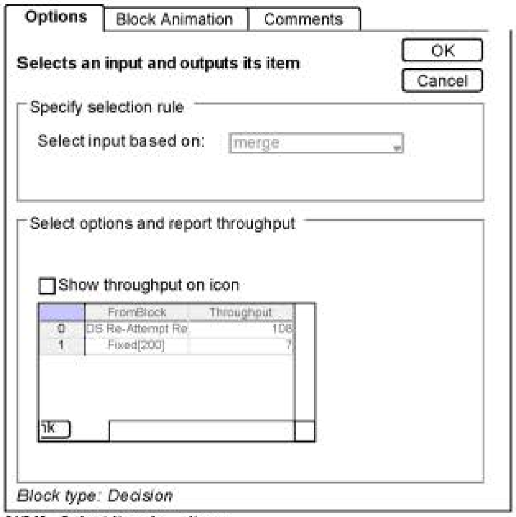
[164] Select Item In <Item>

[164] Select Item In <Item>

	FromBlock	Throughput
0	Flyaway Recieve	82
1	Part Onboard[159]	18
2	Flyaway Need Part	15

Worksheet Dialogs

[184] Select Item In <Item>

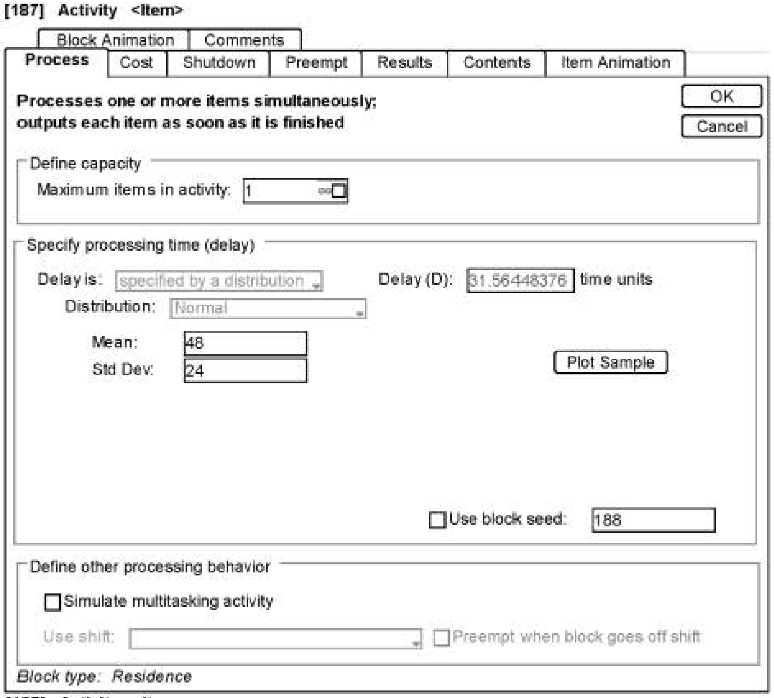


[184] Select Item In <Item>

[184] Select Item In <Item>

	FromBlock	Throughput
0	DS Re-Attempt Re	108
1	Fixed[200]	7

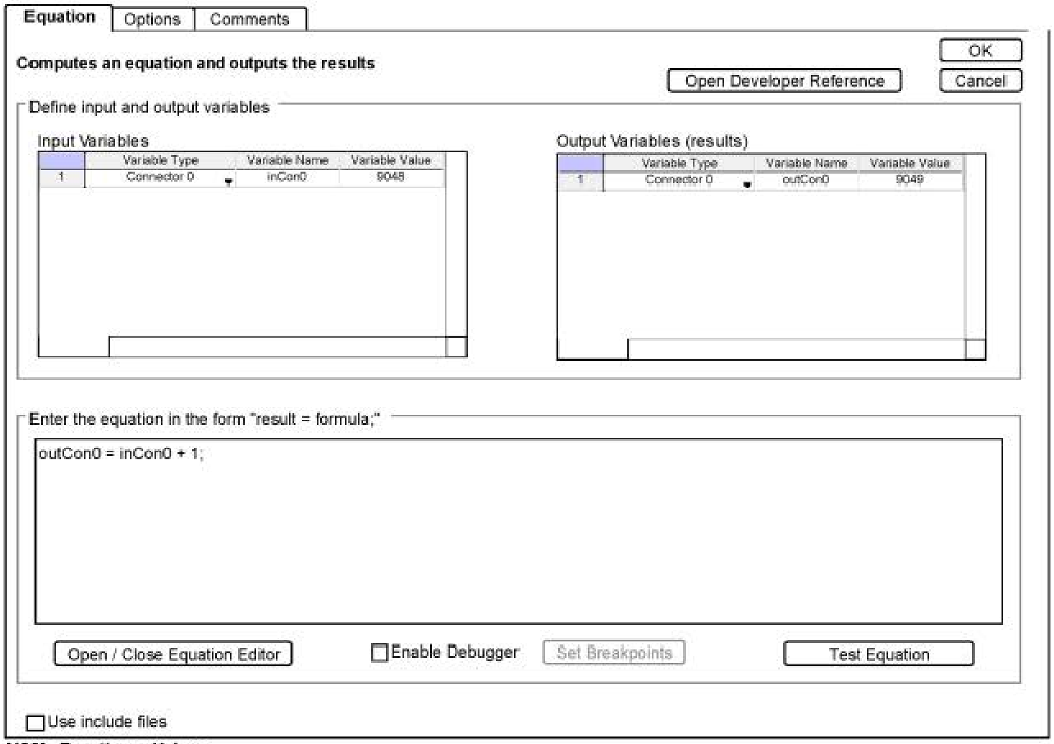
[187] Activity <Item>



[187] Activity <Item>

[187] Activity <Item>

[189] Equation <Value>



[189] Equation <Value>

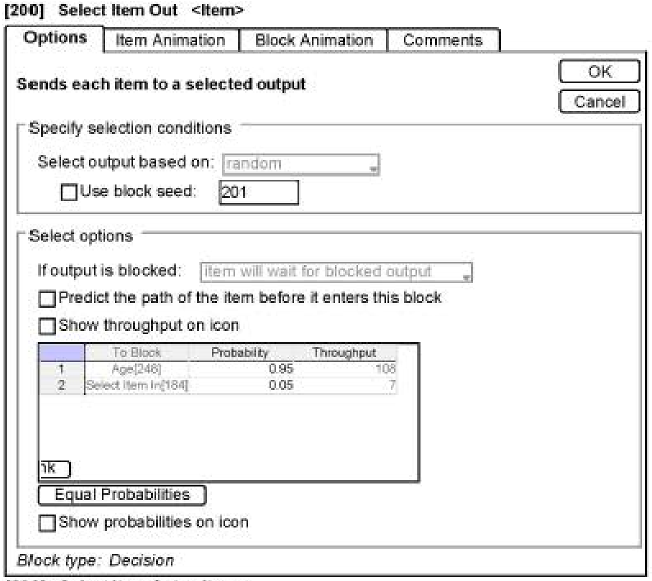
	Variable Type	Variable Name	Variable Value
1	Connector 0	inCon0	9048

[189] Equation <Value>

	Variable Type	Variable Name	Variable Value
1	Connector 0	outCon0	9049

[189] Equation <Value>

[200] Select Item Out <Item>



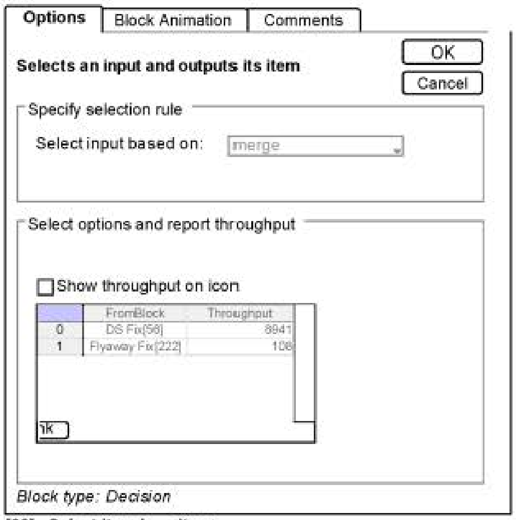
[200] Select Item Out <Item>

	To Block	Probability	Throughput
1	Age[248]	0.95	108
2	Select Item In[184]	0.05	7

[200] Select Item Out <Item>

[200] Select Item Out <Item>

[60] Select Item In <Item>

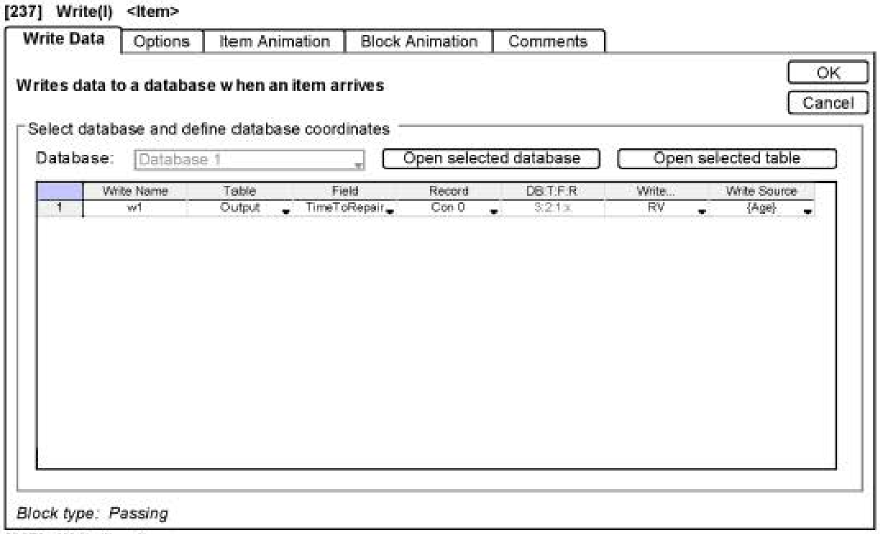


[60] Select Item In <Item>

[60] Select Item In <Item>

	FromBlock	Throughput
0	DS Fix[56]	8941
1	Flyaway Fix[222]	108

[237] Write(I) <Item>



[237] Write(I) <Item>

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source	Value Written
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}	92.751067758875

[238] Equation(I) <Item>

Equation | Options | Item Animation | Block Animation | Comments

Computes an equation when an item arrives and outputs the results

OK

Open Developer Reference

Cancel

Define input and output variables

Input Variables

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5259346.5703515

Output Variables (results)

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	92.751067756675	-

Enter the equation in the form "result = formula;"

```
Age = CurrentTime-BirthTime;
```

Open / Close Equation Editor

☐ Enable Debugger

Set Breakpoints

Test Equation

☐ Use include files

Block type:

Passing

[238] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5259346.5703515

[238] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	92.751067756675	-

[238] Equation(I) <Item>

Worksheet Dialogs

[247] Write(I) <Item>

Write Data | Options | Item Animation | Block Animation | Comments

Writes data to a database when an item arrives

OK

Cancel

Select database and define database coordinates

Database: Database 1

Open selected database

Open selected table

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}

Block type: Passing

[247] Write(I) <Item>

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source	Value Written
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}	188.18790249527

[248] Equation(I) <Item>

Equation | Options | Item Animation | Block Animation | Comments

Computes an equation when an item arrives and outputs the results

OK

Open Developer Reference

Cancel

Define input and output variables

Input Variables

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5172756.2011033

Output Variables (results)

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	188.18790249527	-

Enter the equation in the form "result = formula;"

```
Age = CurrentTime-BirthTime;
```

Open / Close Equation Editor

☐ Enable Debugger

Set Breakpoints

Test Equation

☐ Use include files

Block type:

Passing

[248] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5172756.2011033

Worksheet Dialogs

[248] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	188.18790249527	-

[248] Equation(I) <Item>

[63] Activity <Item>

Block Animation | Comments

Process | Cost | Shutdown | Preempt | Results | Contents | Item Animation

Processes one or more items simultaneously; outputs each item as soon as it is finished

OK
Cancel

Define capacity

Maximum items in activity: 1 ∞

Specify processing time (delay)

Delay is: specified by a distribution   Delay (D): 418.204248 time units

Distribution: Normal

Mean: 500

Std Dev: 100

Plot Sample

Use block seed: 64

Define other processing behavior

Simulate multitasking activity

Use shift: Preempt when block goes off shift

Block type: Residence

[63] Activity <Item>

[63] Activity <Item>

[68] Create <Item>

Create | Options | Item Animation | Block Animation | Comments

Creates items and values randomly or by schedule

OK
Cancel

Select block behavior

Create items by schedule   Time units: generic*

Enter a schedule of arrival times

	_Create Time	_Item Quantity	_Item Priority	None	None	None
1	0	1	1			

1k

Repeat the schedule every

Total cost: 0

Block type: Residence   **model default*

[68] Create <Item>

Worksheet Dialogs

[68] Create <Item>

	_Create Time	_Item Quantity	_Item Priority	None	None	None
1	0	1	1			

[68] Create <Item>

[68] Create <Item>

	0

C. NO DISTANCE SUPPORT

Worksheet Dialogs

[0] Executive <Item>

Control | Item Attributes | Item Contents | Discrete Rate | Flow Attributes | LP Solver | Comments

OK
Cancel

Controls and does event scheduling for discrete event and discrete rate models

Select options

Stop simulation: at end time

☐ Report system events on event connector

Declare item allocation

Initially allocate: 12000 items

Allocate additional items in batches of: 1000

Report system-calculated results

Number of item rows allocated: 12000 (0.687 MB)

Number of attributes for each item*: 3

Number of item rows used: 5

** In addition to user defined attributes, the system assigns 1 attribute for animation plus 2 more if costing is used*

[1] Create <Item>

Create | Options | Item Animation | Block Animation | Comments

OK
Cancel

Creates items and values randomly or by schedule

Select block behavior

Create items by schedule

Time units: generic*

Enter a schedule of arrival times

	Create Time	Item Quantity	Item Priority	None	None	None
1	0	1	1			

1K

☐ Repeat the schedule every

Total cost: 0

Block type: Residence **model default*

[1] Create <Item>

[1] Create <Item>

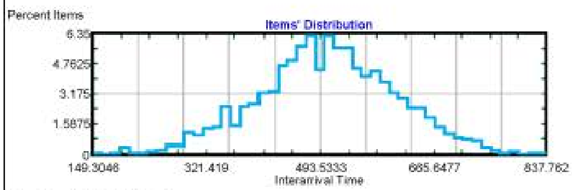
	Create Time	Item Quantity	Item Priority	None	None	None
1	0	1	1			

[1] Create <Item>

[1] Create <Item>

	0

[1] Items' Distribution

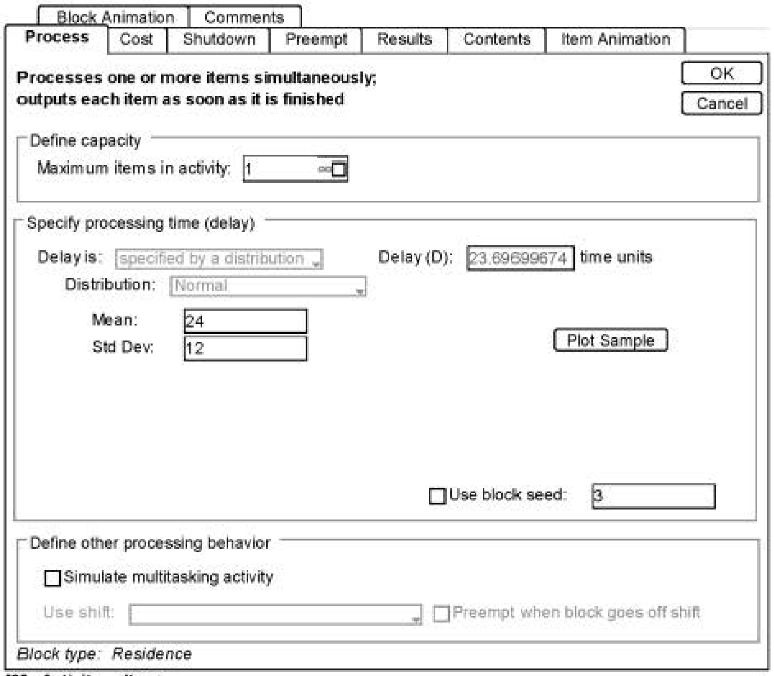


[1] Items' Distribution

Interarrival Time	% Items
149.30464731	0.05
163.35479836	0
177.4049494	0.1
191.45510045	0.35
205.5052515	0.1
219.55540255	0.05
233.6055536	0.15
247.65570464	0.25
261.70585569	0.45
275.75600674	0.4
289.80615779	1.05
303.85630884	0.95
317.90645988	1.3
331.95661093	1.4
346.00676198	2.45
360.05691303	1.45
374.10706408	2.45
388.15721512	2.6
402.20736617	3.15
416.25751722	3.25
430.30766827	4.6
444.35781932	4.9
458.40797036	5.6
472.45812141	6.35
486.50827246	4.4
500.55842351	6.25
514.60857456	5.55
528.6587256	5.55
542.70887665	4.5
556.7590277	4.05
570.80917875	4.35
584.8593298	3.75
598.90948084	3.2
612.95963189	2.9
627.00978294	2.4
641.05993399	2.35
655.11008504	1.9
669.16023609	1.35
683.21038713	1
697.26053818	0.8
711.31068923	0.7
725.36084028	0.65
739.41099133	0.35
753.46114237	0.2
767.51129342	0.1
781.56144447	0.15
795.61159552	0
809.66174657	0.05
823.71189761	0.05
837.76204866	0.05

<u>**Worksheet Dialogs**</u>

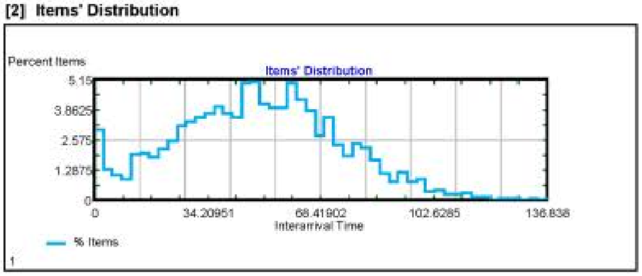
[2] Activity <Item>



[2] Activity <Item>

[2] Activity <Item>

[2] Items' Distribution



[2] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
0	3
2.7926130067	1.3
5.5852260135	1.05
8.3778390202	0.9
11.170452027	1.95
13.963065034	2
16.75567804	1.8
19.548291047	2.15
22.340904054	2.5
25.133517061	3.15
27.926130067	3.35
30.718743074	3.5
33.511356081	3.7
36.303969087	4
39.096582094	3.7
41.889195101	3.5
44.681808108	5
47.474421114	5.15
50.267034121	4.1
53.059647128	3.95
55.852260135	3.95
58.644873141	4.95
61.437486148	4.25
64.230099155	3.8
67.022712161	2.75
69.815325168	3.5
72.607938175	2.35
75.400551182	1.85
78.193164188	2.4
80.985777195	2.2
83.778390202	1.7
86.571003208	1.1
89.363616215	0.75
92.156229222	1.15
94.948842229	0.75
97.741455235	0.85
100.53406824	0.35
103.32668125	0.4
106.11929426	0.25
108.91190726	0.25
111.70452027	0.3
114.49713328	0.1
117.28974628	0.1
120.08235929	0
122.8749723	0.05
125.6675853	0.05
128.46019831	0
131.25281132	0.05
134.04542432	0
136.83803733	0.05

[3] Select Item Out <Item>

Options | Item Animation | Block Animation | Comments

Sends each item to a selected output

OK

Cancel

Specify selection conditions

Select output based on: random

Use block seed: 4

Select options

If output is blocked: item will wait for blocked output

Predict the path of the item before it enters this block

Show throughput on icon

	To Block	Probability	Throughput
1	Sailor Need Part[4	0.8	7405
2	Select Item In[86]	0.2	1861

Equal Probabilities

Show probabilities on icon

Block type: Decision

[3] Select Item Out <Item>

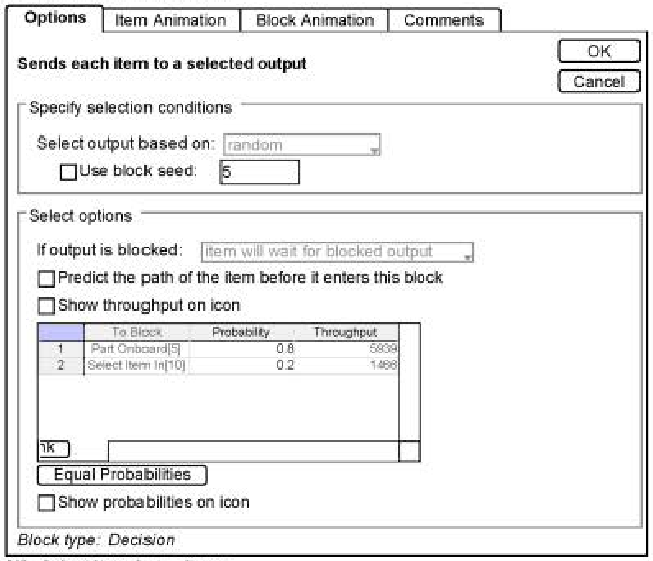
	To Block	Probability	Throughput
1	Sailor Need Part[4	0.8	7405
2	Select Item In[86]	0.2	1861

[3] Select Item Out <Item>

Worksheet Dialogs

[3] Select Item Out <Item>

[4] Select Item Out <Item>



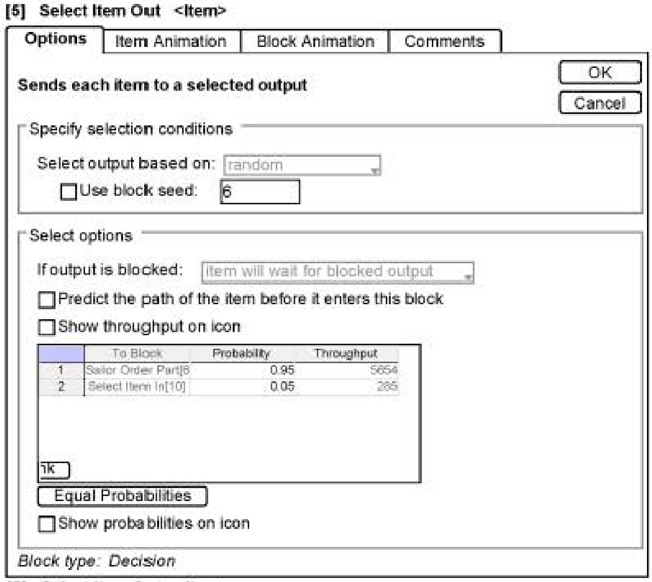
[4] Select Item Out <Item>

	To Block	Probability	Throughput
1	Part Onboard[5]	0.8	5939
2	Select Item In[10]	0.2	1468

[4] Select Item Out <Item>

[4] Select Item Out <Item>

[5] Select Item Out <Item>



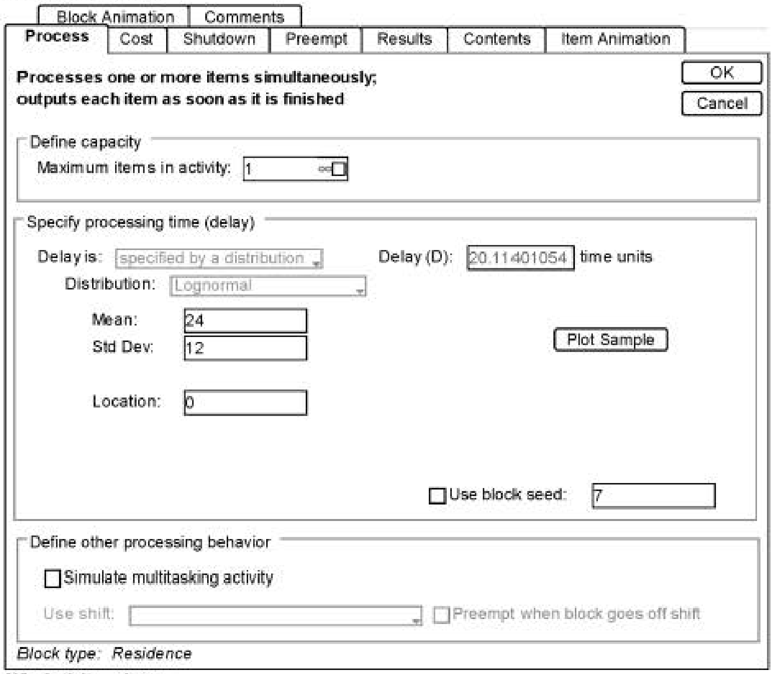
[5] Select Item Out <Item>

	To Block	Probability	Throughput
1	Sailor Order Part[6	0.95	5654
2	Select Item In[10]	0.05	285

[5] Select Item Out <Item>

[5] Select Item Out <Item>

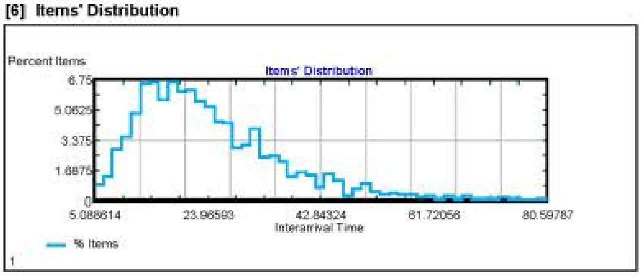
[6] Activity <Item>



[6] Activity <Item>

[6] Activity <Item>

[6] Items' Distribution

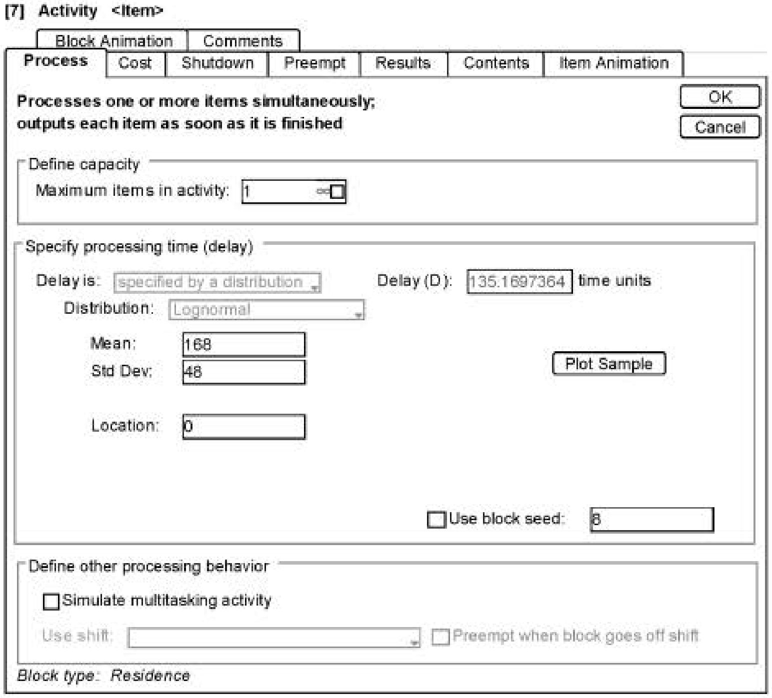


[6] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
5.0886142087	0.85
6.6296194357	1.3
8.1706246628	2.85
9.7116298899	3.5
11.252635117	4.85
12.793640344	6.5
14.334645571	6.75
15.875650798	5.6
17.416656025	6.6
18.957661252	6.05
20.498666479	6.15
22.039671706	5.5
23.580676933	5.25
25.12168216	4.4
26.662687388	4.3
28.203692615	2.9
29.744697842	3.1
31.285703069	4
32.826708296	2.4
34.367713523	2.45
35.90871875	2.15
37.449723977	1.3
38.990729204	1.55
40.531734431	1.4
42.072739658	0.7
43.613744885	1.45
45.154750112	1.05
46.695755339	0.25
48.236760566	0.65
49.777765793	0.9
51.31877102	0.45
52.859776248	0.3
54.400781475	0.4
55.941786702	0.3
57.482791929	0.3
59.023797156	0.15
60.564802383	0.25
62.10580761	0.1
63.646812837	0.2
65.187818064	0.05
66.728823291	0.2
68.269828518	0.1
69.810833745	0.1
71.351838972	0.05
72.892844199	0.15
74.433849426	0.1
75.974854653	0
77.51585988	0
79.056865108	0.05
80.597870335	0.05

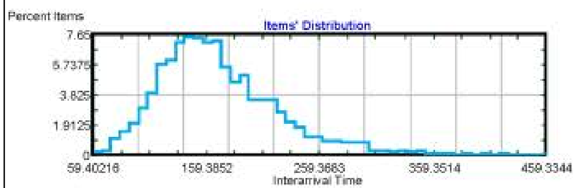
[7] Activity <Item>



[7] Activity <Item>

[7] Activity <Item>

[7] Items' Distribution

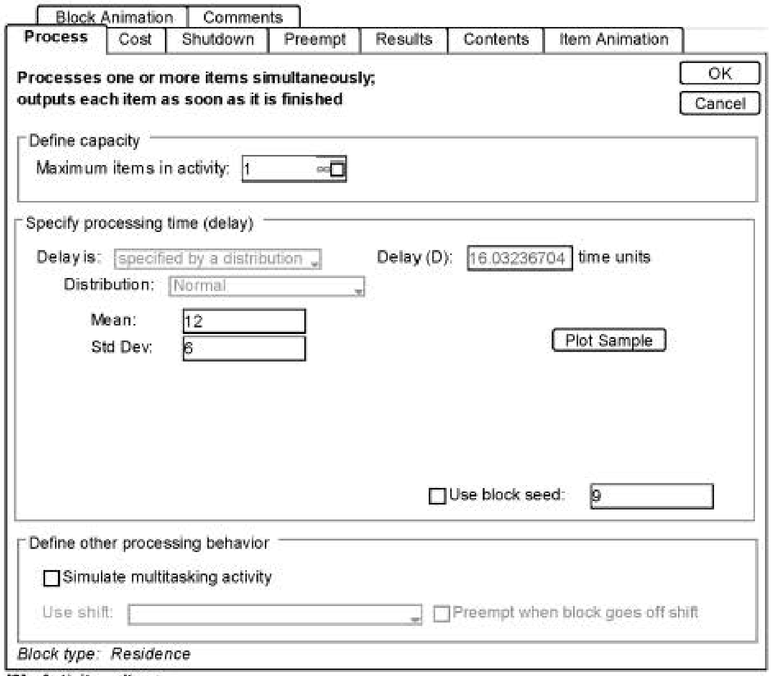


[7] Items' Distribution

Interarrival Time	% Items
59.402161561	0.2
67.564044847	0.25
75.725928133	1.05
83.887811418	1.5
92.049694704	2
100.21157799	2.95
108.37346128	3.9
116.53534456	5.7
124.69722785	6
132.85911113	7.1
141.02099442	7.65
149.1828777	7.35
157.34476099	7.1
165.50664428	7.25
173.66852756	5.55
181.83041085	4.6
189.99229413	5
198.15417742	3.45
206.31606071	3.45
214.47794399	3.45
222.63982728	2.7
230.80171056	2.1
238.96359385	1.75
247.12547713	1.1
255.28736042	1.15
263.44924371	0.9
271.61112699	0.85
279.77301028	0.75
287.93489356	0.75
296.09677685	0.75
304.25866013	0.25
312.42054342	0.25
320.58242671	0.15
328.74430999	0.25
336.90619328	0.2
345.06807656	0.25
353.22995985	0.05
361.39184314	0.05
369.55372642	0.05
377.71560971	0
385.87749299	0.05
394.03937628	0
402.20125956	0.05
410.36314285	0
418.52502614	0.05
426.68690942	0
434.84879271	0
443.01067599	0
451.17255928	0
459.33444256	0.05

Worksheet Dialogs

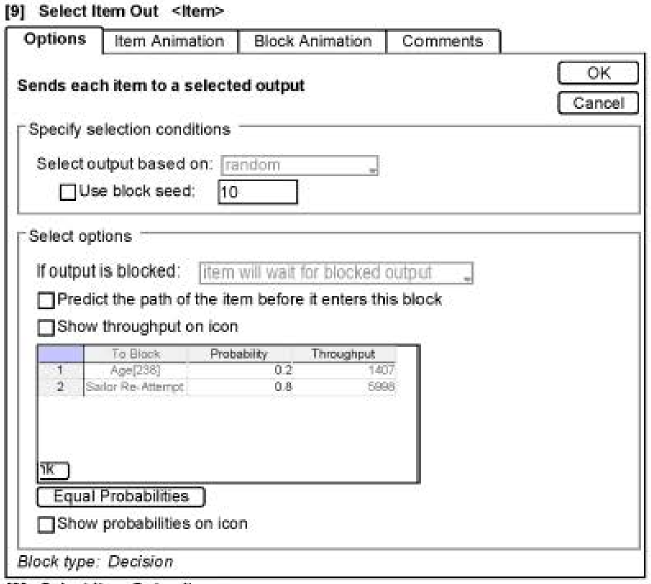
[8] Activity <Item>



[8] Activity <Item>

[8] Activity <Item>

[9] Select Item Out <Item>



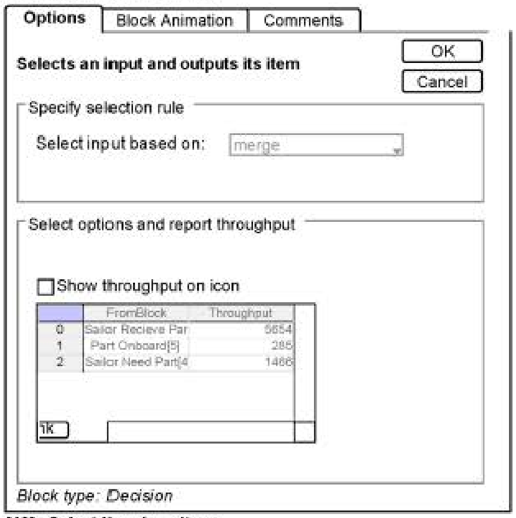
[9] Select Item Out <Item>

	To Block	Probability	Throughput
1	Age[238]	0.2	1407
2	Sailor Re-Attempt	0.8	5998

[9] Select Item Out <Item>

[9] **Select Item Out <Item>**

[10] **Select Item In <Item>**

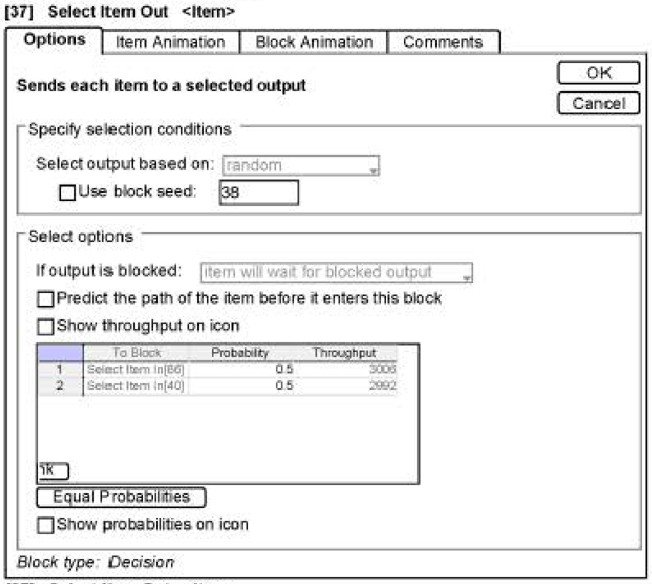


[10] **Select Item In <Item>**

[10] **Select Item In <Item>**

	FromBlock	Throughput
0	Sailor Recieve Par	5654
1	Part Onboard[5]	285
2	Sailor Need Part[4	1466

[37] **Select Item Out <Item>**



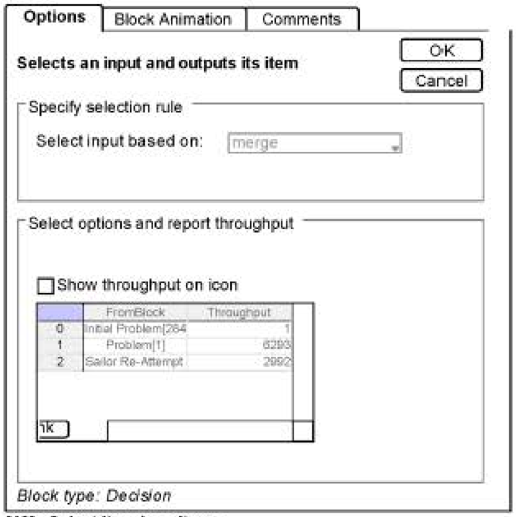
[37] **Select Item Out <Item>**

	To Block	Probability	Throughput
1	Select Item In[66]	0.5	3008
2	Select Item In[40]	0.5	2992

[37] **Select Item Out <Item>**

[37] **Select Item Out <Item>**

[40] Select Item In <Item>

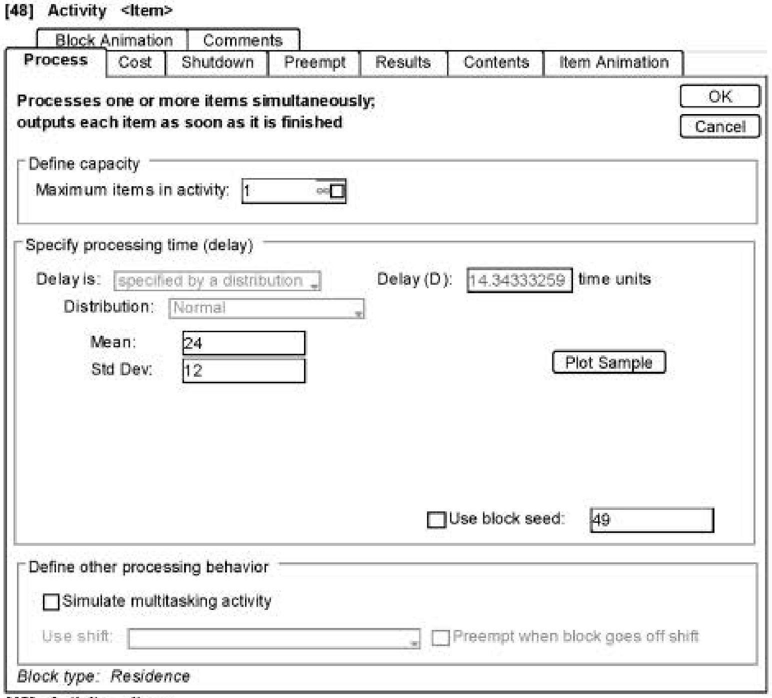


[40] Select Item In <Item>

[40] Select Item In <Item>

	FromBlock	Throughput
0	Initial Problem[284	1
1	Problem[1]	6293
2	Sailor Re-Attempt	2992

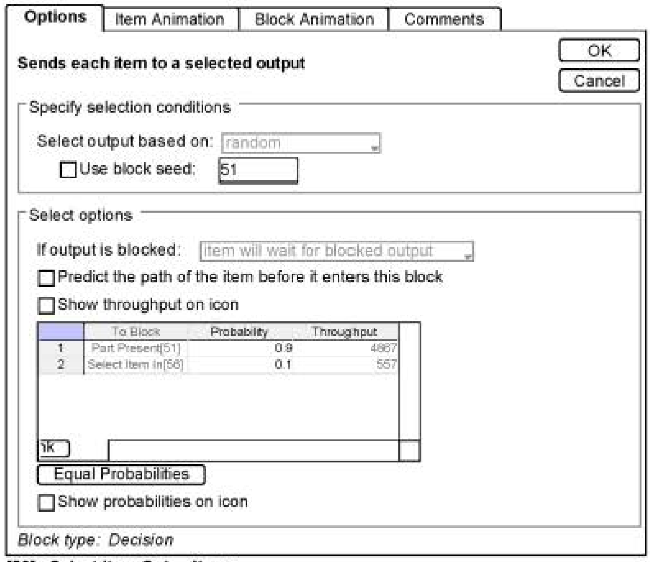
[48] Activity <Item>



[48] Activity <Item>

[48] Activity <Item>

[50] Select Item Out <Item>



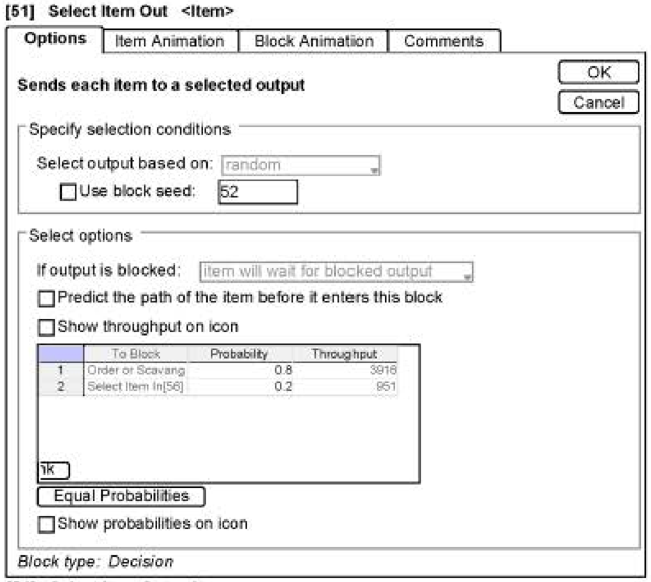
[50] Select Item Out <Item>

	To Block	Probability	Throughput
1	Part Present[51]	0.9	4867
2	Select Item In[56]	0.1	557

[50] Select Item Out <Item>

[50] Select Item Out <Item>

[51] Select Item Out <Item>



[51] Select Item Out <Item>

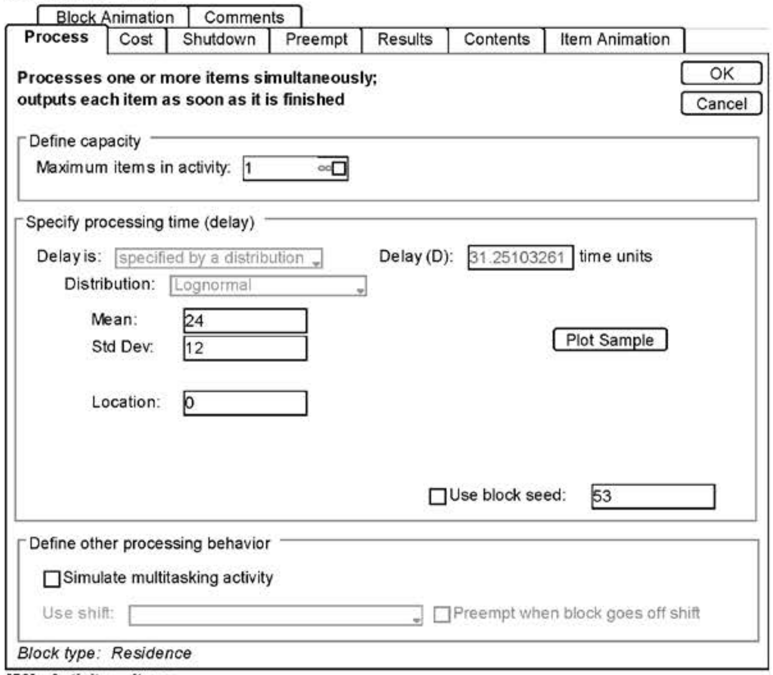
	To Block	Probability	Throughput
1	Order or Scavang	0.8	3916
2	Select Item In[56]	0.2	951

[51] Select Item Out <Item>

[51] Select Item Out <Item>

Worksheet Dialogs

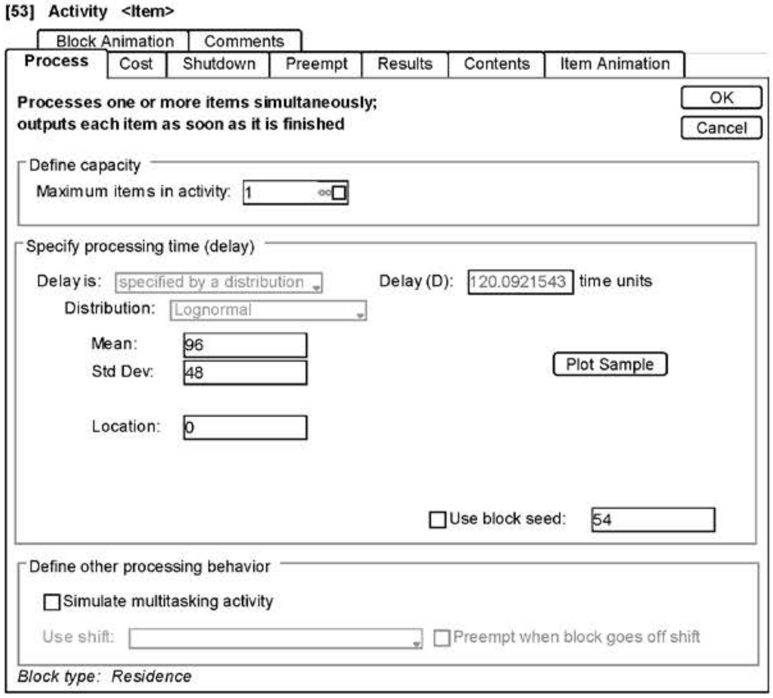
[52] Activity <Item>



[52] Activity <Item>

[52] Activity <Item>

[53] Activity <Item>

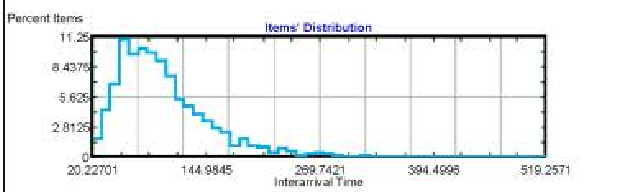


Worksheet Dialogs

[53] Activity <Item>

[53] Activity <Item>

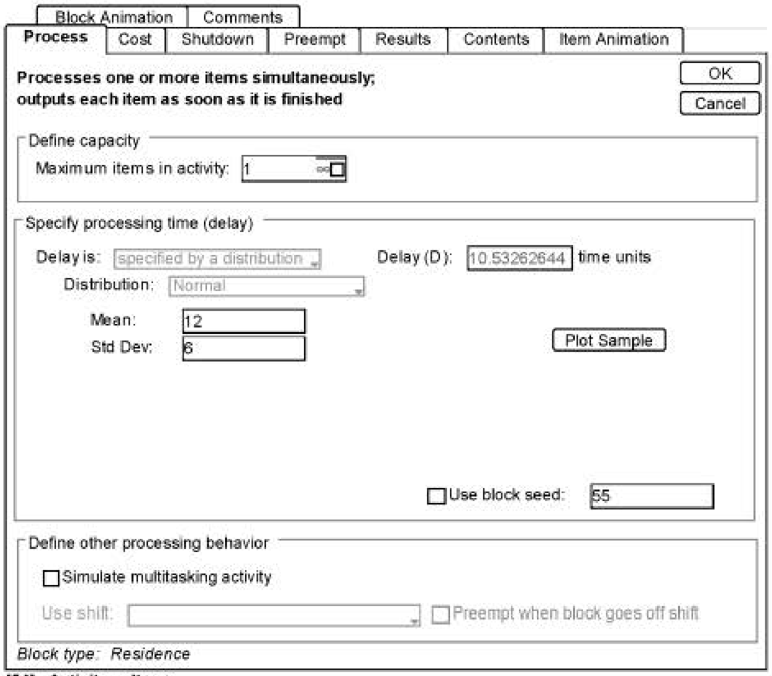
[53] Items' Distribution



[53] Items' Distribution

Interarrival Time	% Items
20.227009289	1.7
30.41129702	4.4
40.59558475	6.8
50.77987248	11.25
60.96416021	9.55
71.148447941	10.05
81.332735671	9.75
91.517023401	8.9
101.70131113	7.6
111.88559886	5.35
122.06988659	4.75
132.25417432	3.95
142.43846205	3.3
152.62274978	2.65
162.80703751	2.25
172.99132524	1
183.17561297	1.6
193.3599007	1.05
203.54418843	0.85
213.72847616	0.4
223.91276389	0.75
234.09705162	0.45
244.28133935	0.15
254.46562709	0.25
264.64991482	0.35
274.83420255	0.2
285.01849028	0.15
295.20277801	0.05
305.38706574	0.05
315.57135347	0.1
325.7556412	0.05
335.93992893	0
346.12421666	0.05
356.30850439	0.05
366.49279212	0
376.67707985	0
386.86136758	0
397.04565531	0.05
407.22994304	0
417.41423077	0.05
427.5985185	0
437.78280623	0
447.96709396	0
458.15138169	0
468.33566942	0.05
478.51995715	0
488.70424488	0
498.88853261	0
509.07282034	0
519.25710807	0.05

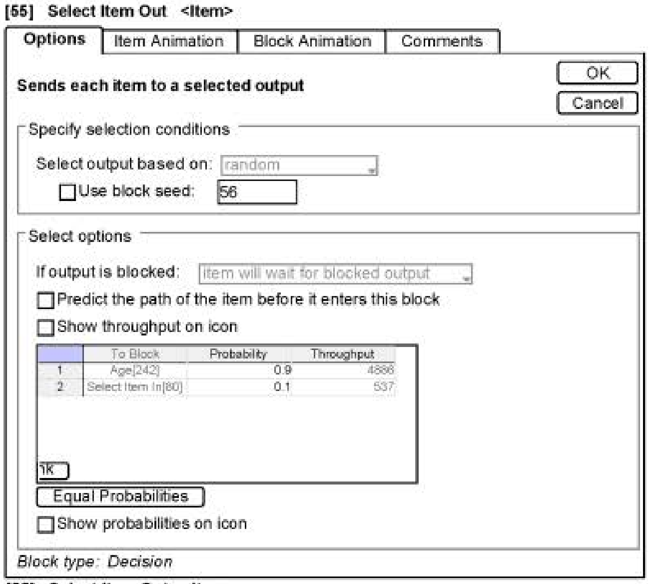
[54] Activity <Item>



[54] Activity <Item>

[54] Activity <Item>

[55] Select Item Out <Item>



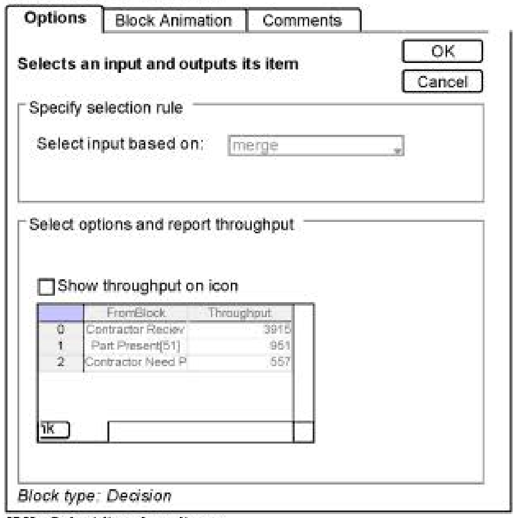
[55] Select Item Out <Item>

	To Block	Probability	Throughput
1	Age[242]	0.9	4888
2	Select Item In[80]	0.1	537

[55] Select Item Out <Item>

[55] Select Item Out <Item>

[56] Select Item In <Item>

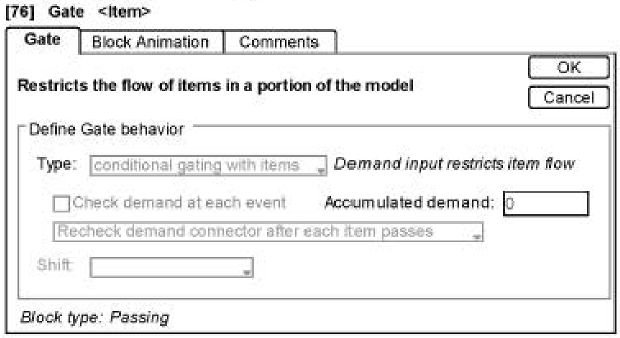


[56] Select Item In <Item>

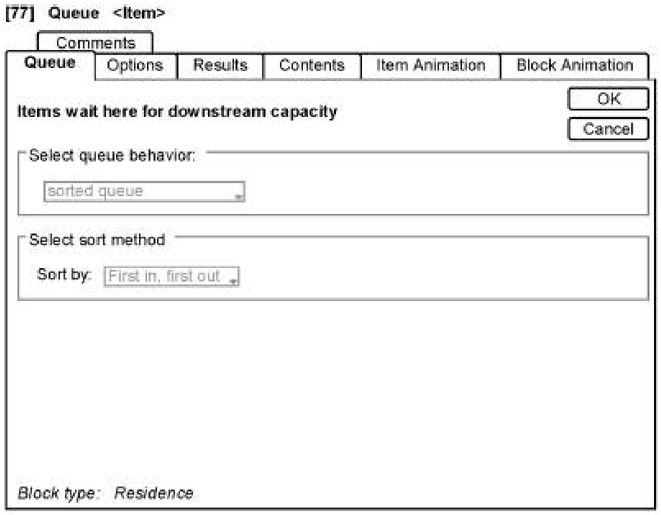
[56] Select Item In <Item>

	FromBlock	Throughput
0	Contractor Reciev	3915
1	Part Present[51]	951
2	Contractor Need P	557

[76] Gate <Item>

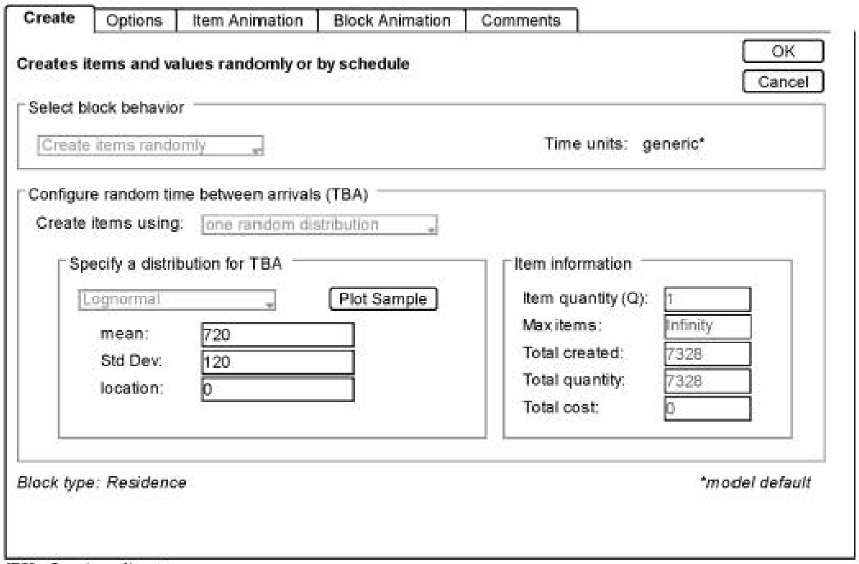


[77] Queue <Item>



[77] Queue <Item>

[78] Create <Item>



[78] Create <Item>

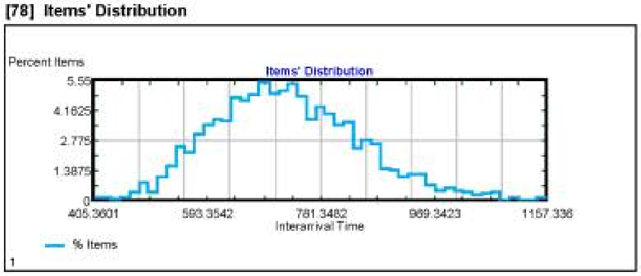
[78] Create <Item>

[78] Create <Item>

[78] Create <Item>

0

[78] Items' Distribution

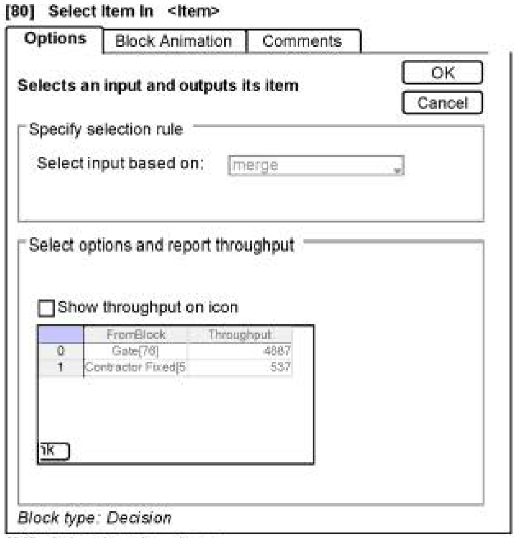


[78] Items Distribution

Worksheet Dialogs

Interarrival Time	% Items
405.36011657	0.1
420.70656954	0.1
436.0530225	0.05
451.39947547	0.15
466.74592844	0.4
482.09238141	0.85
497.43883438	0.4
512.78528734	1.1
528.13174031	1.6
543.47819328	2.45
558.82464625	2.2
574.17109922	3
589.51755218	3.5
604.86400515	3.7
620.21045812	3.65
635.55691109	4.75
650.90336406	4.6
666.24981702	4.85
681.59626999	5.55
696.94272296	4.9
712.28917593	5.05
727.6356289	5.35
742.98208186	4.8
758.32853483	3.7
773.6749878	4.3
789.02144077	4
804.36789374	3.5
819.7143467	3.6
835.06079967	2.4
850.40725264	2.75
865.75370561	2.6
881.10015858	1.45
896.44661154	1.4
911.79306451	1.1
927.13951748	1.2
942.48597045	1.2
957.83242342	0.7
973.17887638	0.45
988.52532935	0.55
1003.8717823	0.45
1019.2182353	0.35
1034.5646883	0.25
1049.9111412	0.3
1065.2575942	0.35
1080.6040472	0
1095.9505001	0.1
1111.2969531	0
1126.6434061	0
1141.989859	0.1
1157.336312	0.1

[80] Select Item In <Item>

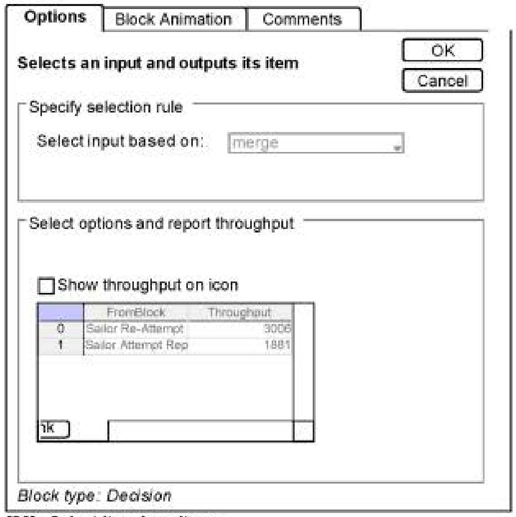


[80] Select Item In <Item>

[80] Select Item In <Item>

	FromBlock	Throughput
0	Gate[76]	4887
1	Contractor Fixed[5	537

[86] Select Item In <Item>

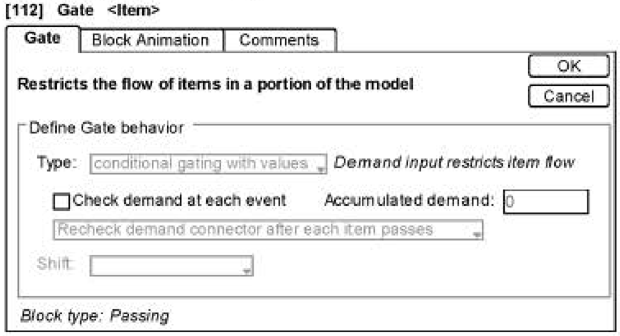


[86] Select Item In <Item>

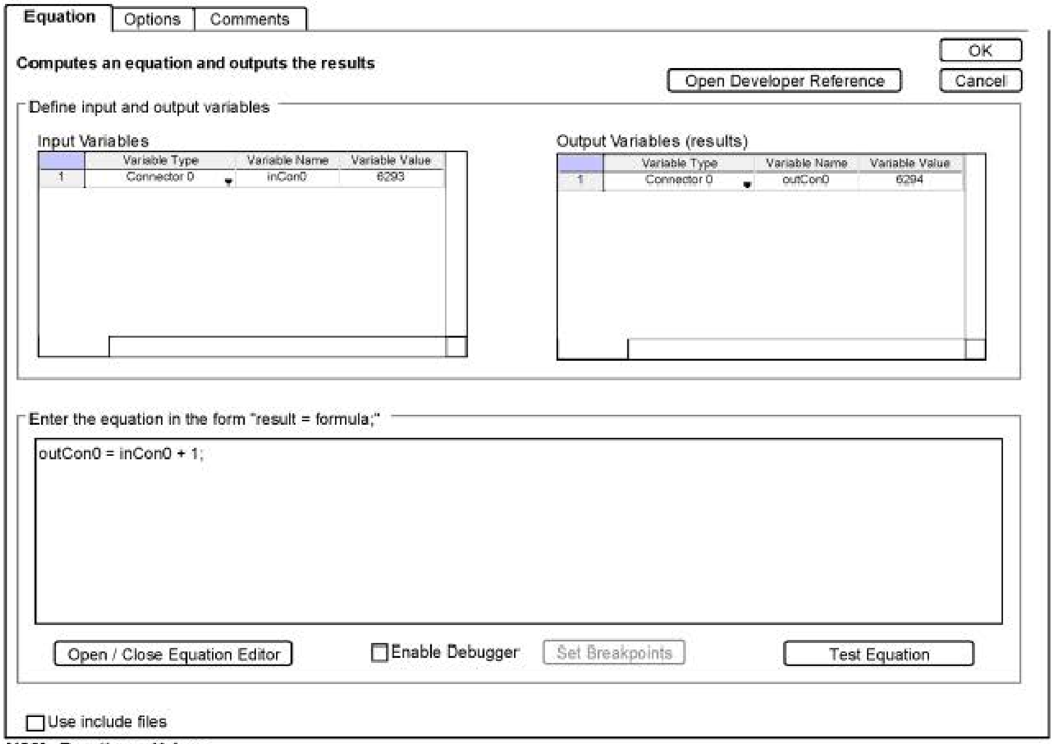
[86] Select Item In <Item>

	FromBlock	Throughput
0	Sailor Re-Attempt	3006
1	Sailor Attempt Rep	1881

[112] Gate <Item>



[189] Equation <Value>

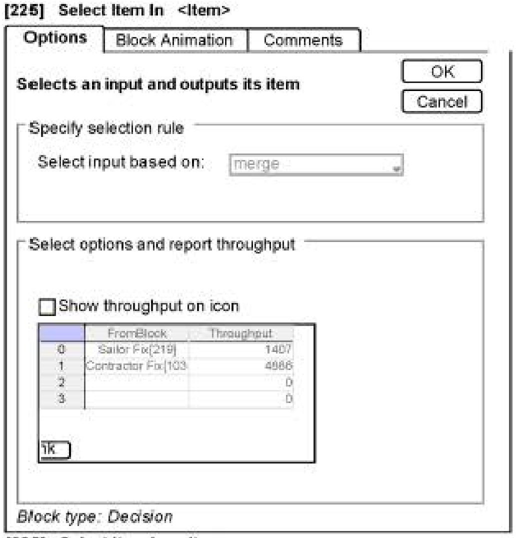


[189] Equation <Value>

[189] Equation <Value>

[189] Equation <Value>

[225] Select Item In <Item>



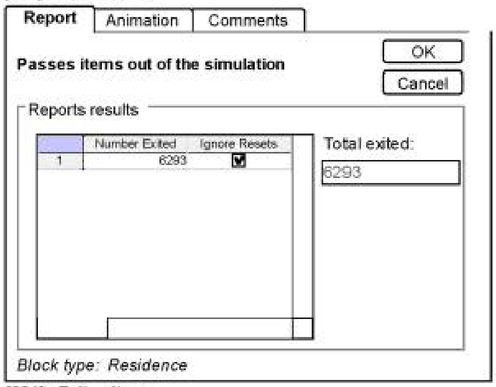
[225] Select Item In <Item>

Worksheet Dialogs

[225] Select Item In <Item>

	FromBlock	Throughput
0	Sailor Fix[219]	1407
1	Contractor Fix[103	4886
2		0
3		0

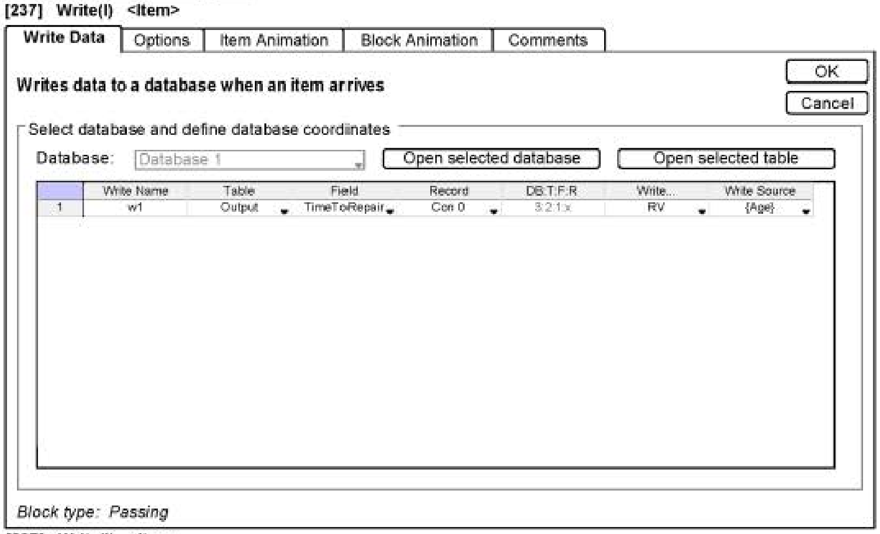
[231] Exit <Item>



[231] Exit <Item>

	Number Exited	Ignore Resets
1	6293	☑

[237] Write(I) <Item>



[237] Write(I) <Item>

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source	Value Written
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}	481.21617505234

Worksheet Dialogs

[238] Equation(I) <Item>

Equation | Options | Item Animation | Block Animation | Comments

OK

Computes an equation when an item arrives and outputs the results

Open Developer Reference | Cancel

Define input and output variables

Input Variables

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5244949.3054718

Output Variables (results)

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	481.21617505234	-

Enter the equation in the form "result = formula;"

```
Age = CurrentTime-BirthTime;
```

Open / Close Equation Editor | Enable Debugger | Set Breakpoints | Test Equation

Use include files

Block type:

Passing

[238] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5244949.3054718

[238] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	481.21617505234	-

[238] Equation(I) <Item>

Worksheet Dialogs

[241] Write(I) <Item>

Write Data | Options | Item Animation | Block Animation | Comments

Writes data to a database when an item arrives

OK

Cancel

Select database and define database coordinates

Database: Database 1 | Open selected database | Open selected table

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	{Age}

Block type: Passing

[241] Write(I) <Item>

	Write Name	Table	Field	Record	DB:T:F:R	Write...	Write Source	Value Written
1	w1	Output	TimeToRepair	Con 0	3:2:1:x	RV	(Age)	436.49836880434

[242] Equation(I) <Item>

Equation | Options | Item Animation | Block Animation | Comments

Computes an equation when an item arrives and outputs the results

OK

Open Developer Reference | Cancel

Define input and output variables

Input Variables

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5258528.3038382

Output Variables (results)

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	436.49836880434	-

Enter the equation in the form "result = formula;"

```
Age = CurrentTime-BirthTime;
```

Open / Close Equation Editor | ☐ Enable Debugger | Set Breakpoints | Test Equation

☐ Use include files

Block type:

Passing

[242] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value
1	Attribute	BirthTime	5258528.3038382

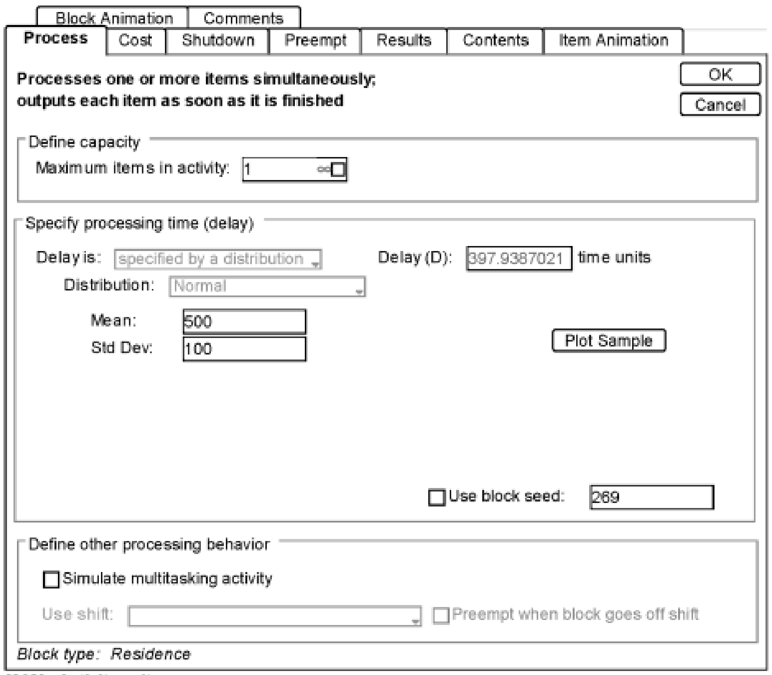
Worksheet Dialogs

[242] Equation(I) <Item>

	Variable Type	Variable Name	Variable Value	If no item, use
1	Attribute	Age	436.49836880434	-

[242] Equation(I) <Item>

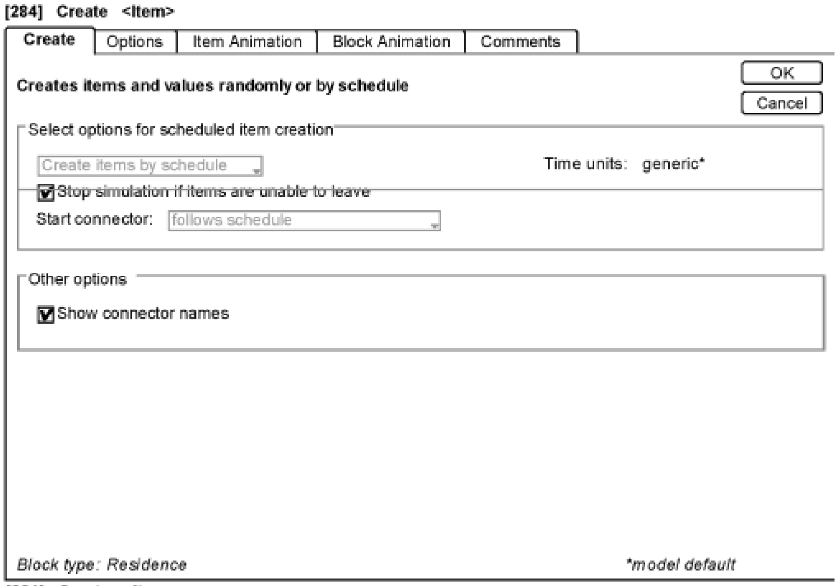
[268] Activity <Item>



[268] Activity <Item>

[268] Activity <Item>

[284] Create <Item>



[284] Create <Item>

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