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OPTIMIZING BASE CAMP RESOURCE EFFICIENCY THROUGH SYSTEMS ENGINEERING

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ABSTRACT

The Product Director for Contingency Base Infrastructure (PD CBI) is chartered to bring a system-of-systems approach to contingency basing. PD CBI has four major lines of effort to accomplish the mission. This paper briefly touches on the Strategic Recommendations, Analytical Support, and Stakeholder Collaboration and Integration lines of effort and focuses on the Contingency Basing Interface to the Warfighter line of effort. The paper outlines the Model-Based Systems Engineering (MBSE) approach employed by the CBI team, detailing the application of a common set of tools to address each part of the problem. The paper also addresses the use of existing models and simulations, modifying them for use with base infrastructure materiel, and developing new tools as needed, to conduct analyses treating a contingency base as a system of systems (similar to a ground vehicle system). The results of the analyses will provide the Army with materiel investment recommendations for decision makers, optimized base infrastructure-materiel set recommendations, and resource-efficient camp designs. Issues addressed include determining what capabilities the Army should invest in to increase operational/mission effectiveness, reduce risk, and increase operational reach. The analytical results will help identify the optimal mix of capabilities and standardized base camp configurations, cost/benefit in terms of dollars, manpower, resource impacts, etc. The MBSE approach demonstrates the power of bringing together key organizations and mature analytic methods and tools to characterize and quantify critical mission requirements.

INTRODUCTION

The U.S. Army Audit Agency published a report titled *Army Strategy for Establishing, Sustaining, and Transitioning Non-Traditional Installations* in May 2010, identifying systemic issues with base design and master planning. As a result, the audit reported camp designers did not consider scalability, waste management, or power generation in their designs, leading to excessive cost and inefficiencies in resources used at these camps. In March 2012, the Program Executive Officer, Combat Support and Combat Service Support (PEO CS&CSS) established the Contingency Basing Developmental Planning Team, which became the Product Director for Contingency Base Infrastructure (PD CBI) in July 2013, to bring a “holistic Systems Engineering” approach to base camp design.

PD CBI is addressing key issues facing the United States Forces resulting from the ad hoc nature of planning/designing base camps. The current ad hoc approach generally creates inefficiencies impacting mission effectiveness; increases costs because of the lack of informed decisions; and lacks a holistic approach to ensure efficient and repeatable planning and design, construction, operations, management, and closure/transfer of base camps. Through base camp resource optimization, PD CBI is recommending contingency base bills of material (BOM) and layouts that reduce operations and maintenance costs while potentially saving lives by reducing the number of vehicles in resupply convoys.

LINES OF EFFORT

Addressing the numerous issues facing contingency bases, PD CBI developed four lines of effort (LOE) to help frame the problem. The LOEs appear in Figure 1. The first three LOEs, Contingency Basing Interface to the Warfighter (CBIWar), Strategic Recommendations, and Analytical Support, use the CBI Model-Based Systems Engineering (MBSE) process described in the next section to provide recommended solutions within each LOE.

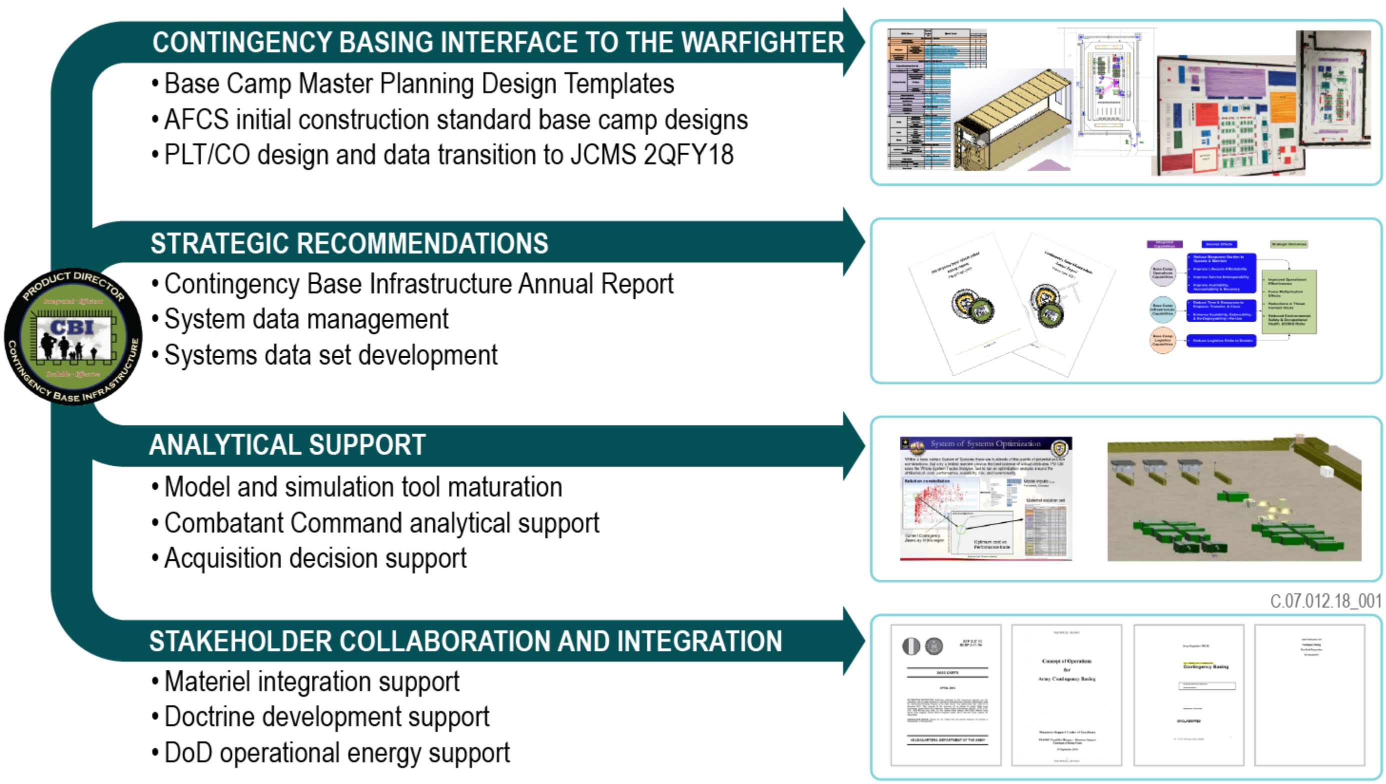

Figure 1: PD CBI Lines of Effort

Contingency Basing Interface to the Warfighter

The CBIWar LOE seeks to provide base camp planners at all levels with resource-optimized BOMs and initial camp layouts meeting specific population, unit, mission, and climate requirements. CBI accomplishes this LOE in two separate ways. First, CBI partners with the Army Facilities Component System (AFCS) to provide standard, initial construction standard, resource-optimized BOMs and layouts for inclusion in the

AFCS repository for use in the Joint Construction Management System (JCMS). Once in the JCMS library, base camp planners can pull the layouts and associated BOM as a starting point for new base camps. Once the Virtual Forward Operating Base (VFOB) software, currently in development by the Engineer Research Development Center—Construction Engineering Research Lab (ERDC-CERL), is fully merged into JCMS, planners will be able to site adapt the CBI layouts to the exact terrain allocated for the base camp.

The second way CBI accomplishes the CBIWar LOE is by working directly with a customer to develop a BOM and layout meeting the customer's specific requirements. PD CBI used this avenue to develop a life support area BOM and layout for Air Forces Africa (AFAF) in Niger. [1]

Strategic Recommendations

Under this LOE, PD CBI uses systems engineering processes and procedures to conduct analyses, resulting in recommendations for Project Managers and Product Managers on how best to invest their scarce resources for optimal benefit to the Army. One activity under this LOE was the PD CBI analysis to determine the effectiveness of the Shower Water Reuse System (SWRS) on reducing the amount of potable water a base required trucked in by convoy. The analysis shows that over a 2-year period adding the SWRS to a company size (300 personnel) in a desert environment has the potential to save $60.1 million and to remove 1,906 water trucks from convoys. [2]

Analytical Support

The PD CBI third LOE provides decision support analyses to acquisition Project Managers, Product Managers, and external customers (Combatant Commands, Service Component Commands, etc.) for base infrastructure technologies. The analysis PD CBI conducted for Product Manager Force Sustainment Systems (PM FSS) to verify Force Provider met the Energy Key Performance Parameter (KPP) of the Force Provider Capabilities Production Document (CPD) falls within this LOE. PD CBI used the Desktop Analysis Tool to analyze the baseline 600-person Force Provider set. PD CBI then analyzed the updated Force Provider configuration set under the new CPD, consisting of four 150-person Force Provider Expeditionary sets. Comparing the outputs of the baseline configuration and updated configuration analyses showed the new Force Provider configuration exceeded the Energy KPP requirement for a 30% energy reduction. The Army Test and Evaluation Center accepted the results as proof of meeting the Energy KPP. [3]

Stakeholder Collaboration and Integration

The final PD CBI LOE consists of the support provided to the requirements development community, the Army Deputy Chief of Staff G-4, the Deputy Assistant Secretary of Defense (Operational Energy), the Joint Staff J-4, and other organizations for non-analytical efforts. Under this LOE, PD CBI assisted in the development of Army Techniques Publication (ATP) 3-37.10 *Base Camps*, the *Concept of Operations for Army Contingency Basing*, Army Regulation 7XX-XX Contingency Basing (still under development), Joint Publication 4-04 Contingency Basing, the Base Camp Management System Capabilities Development Document (CDD) (out for worldwide staffing), and the Base Camp Facilities CDD (under development).

SYSTEMS ENGINEERING PROCESS

Bringing a holistic system-of-systems approach to contingency basing necessitated the development of an MBSE process for the analysis of the base camps and base camp clusters. Figure 2 depicts an overview of the CBI MBSE process. The foundation of the process is three collections of data around which inputs to each analytical model center: Requirements Data, Architecture Development, and Source Data. A robust configuration management process ensures the integrity of the data.

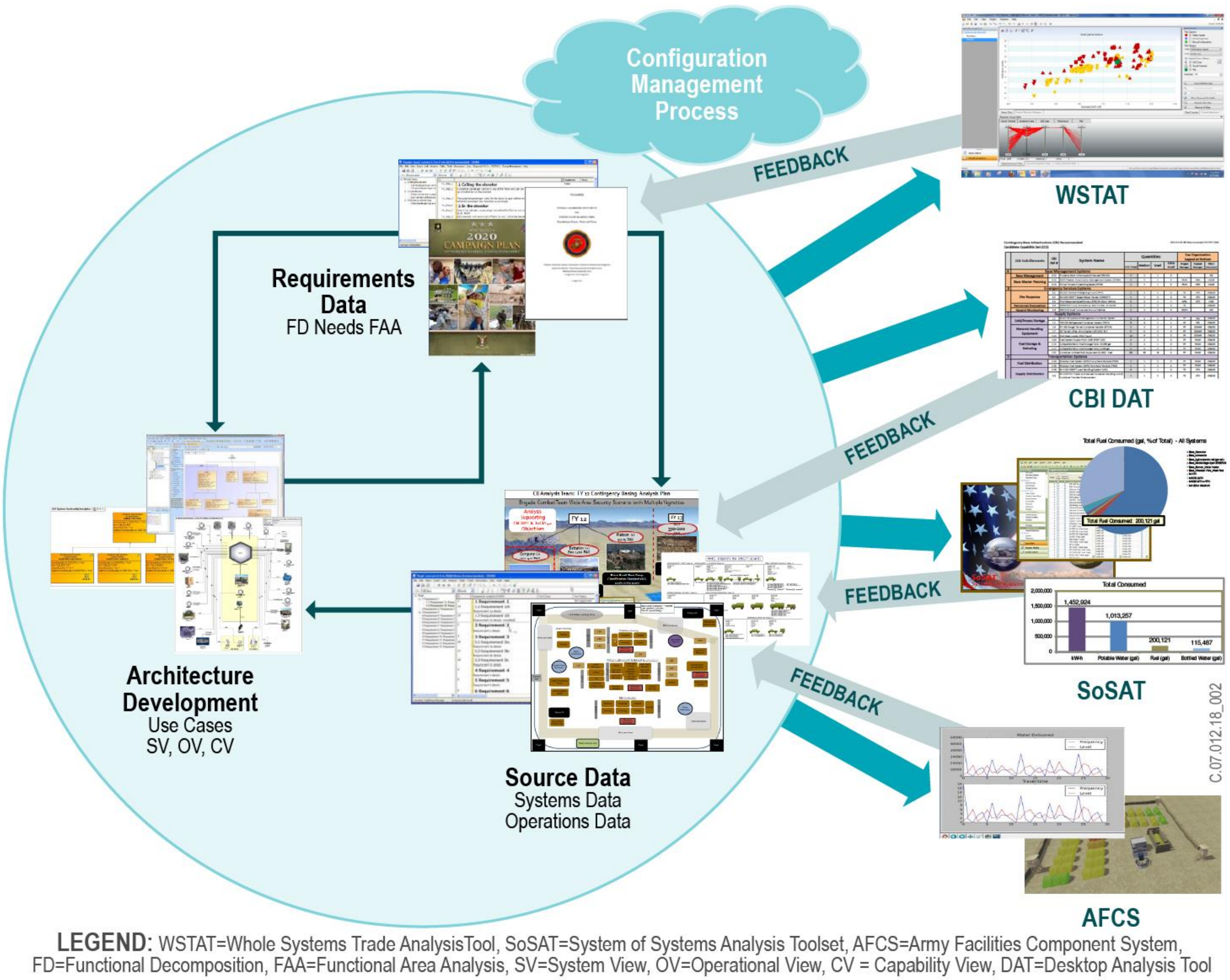

Figure 2: PD CBI MBSE Process Overview

Requirements Data

The requirement to improve the resource efficiency of contingency bases stems from several foundation documents—*United States Army Functional Area Assessment: Base Camps For Full Spectrum Operations (2015–2024)*, published in March 2010; an Army Audit Agency Report: *Army Strategy for Establishing, Sustaining, and Transitioning Non-Traditional Installations*, published in May 2010; and the Initial Capabilities Document for Contingency Basing (Joint Requirements Oversight Council Memorandum [JROCM] 116-12), approved in August 2012. To begin addressing the shortfalls and gaps presented in these documents, the Contingency Basing Developmental Planning Team (precursor to PD CBI) needed to understand the purpose and functions of contingency bases. The team conducted an exhaustive search of existing Army documentation and through a panel of subject matter experts developed an extensive functional decomposition for a contingency base. The resulting document is a 1,200+ line decomposition detailing functions down to seven levels for a contingency base. Figure 3 shows an excerpt from the functional decomposition. Reviewing the base infrastructure functions of the base camp led to grouping the tasks into essential activities required on every base camp. These activities became the basis for the Logical Systems Architecture (LSA) shown in Figure 4. The “buckets” in the LSA serve as a checklist to ensure the camp designers address all of the major base camp activities as the design matures.

Once the team understood the functions necessary for a contingency base, the team began searching for requirements for designing/building a camp. The result of this document search is the Planning Factors Database. The Planning Factors Database contains information such as the minimum distance between billeting structures, the number of gallons of water per Soldier per day, the number of Soldiers per shower head, the minimum square feet of living space per Soldier, the distance between guard towers, lighting requirements, ammunition storage safety requirements, etc. The Planning Factors Database is stored in the Dynamic Object-Oriented Requirements System (DOORS) environment. Figure 5 shows an excerpt from the Planning Factors Database.

Object Number	Object Heading	Object Text	Input Functions	Output Functions
1.2.1.3.8	Identify Hazards	Using sensed or collected data, ascertain and characterize the nature of hazards (fires, trip, electrical, critters, waste water backup, etc. within the base) with ever increasing fidelity and specificity.	Distribute Electrical Power Internal to the Base	Track Hazards Analyze Mission and Current Situation Predict Changes in Operating Environment
1.2.1.3.9	Identify Environmental Threat	Using sensed or collected data, ascertain and characterize the nature of environmental threats (flood, earthquake, sand storm, extreme temperatures, etc.) with ever increasing fidelity and specificity.	Distribute Electrical Power Internal to the Base	
1.2.1.3.10	Identify Insider Threat	Using sensed or collected data, ascertain and characterize the nature of Insider threats with ever increasing fidelity and specificity. This activity is specifically related to monitoring mental health of base occupants for potential threats.		Track Insider Threat Analyze Mission and Current Situation Predict Changes in Operating Environment
1.2.1.4	Locate Threat	Determine the position of a threat on the battlefield. Target location can be expressed, for example, as a six-digit grid coordinate. Also, to determine the position of targets during surveillance and reconnaissance in the defined target area of interest in sufficient detail to permit effective employment of weapons		
1.2.1.4.5	Report Threat Position	Convert to appropriate format (new grid-grid-coordinate systems if required) and communicate threat position to intended recipient.		

Figure 3: Functional Decomposition Excerpt

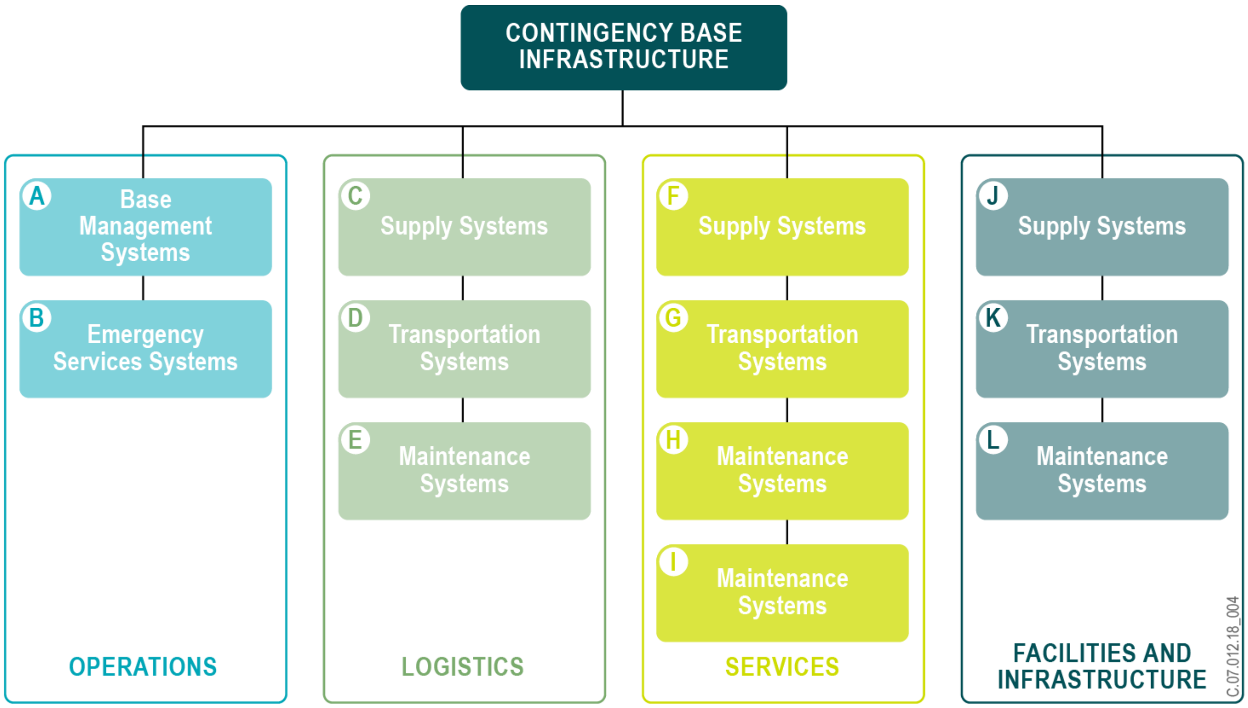

Figure 4: Logical Systems Architecture

Requirement	Source	Rationale	Source Date	Source Page	Source Paragraph	Source Text
The base camp shall provide a facility for baking that is 0.6 square feet per person supported.	FM 34.400			E-4		Table E-6 Troop Support Facilities
The base camp shall provide 110 square feet of living space per officer.	FM 34.400			E-5		Table E-10 Troop Housing.
The base camp shall provide 72 square feet of living space per enlisted personnel.	FM 34.400			E-5		Table E-10 Troop Housing.
The base camp shall be capable of providing 1.6 kW per hospital bed.	FM 34.400			E-6		Table E-14 General Planning Factors for electrical power and distribution requirements.
The base camp shall provide a maximum of 90 net square feet of open office space per enlisted personnel at the E-7 rank.	ATP 3-37.10		4/26/13	C-11		Table C-8 Planning Factors for Office Space
The base camp shall provide a maximum of 90 net square feet of open office space per civilian personnel at the GS-07 grade.	ATP 3-37.10		4/26/13	C-11		Table C-8 Planning Factors for Office Space
The base camp shall provide a maximum of 60 net square feet of open office space per stenographic and clerical positions.	ATP 3-37.10		4/26/13	C-11		Table C-8 Planning Factors for Office Space
The base camp shall provide 1.66 lbs. per person per day of Class II supply.	OPLOG Planner Supply Rates Doc	Supply Rate assumptions used in the OPLOG planner	3/27/14			
The base camp shall provide 3.32 lbs. per person per day of Class IV supply construction material.	OPLOG Planner Supply Rates Doc	Supply Rate assumptions used in the OPLOG planner	3/27/14			
The base camp shall provide 1.66 lbs. per person per day of Class IV supply barrier and fortification material.	OPLOG Planner Supply Rates Doc	Supply Rate assumptions used in the OPLOG planner	3/27/14			
The base camp shall provide 0.336 lbs. per person per day of Class VI basic stockage items.	OPLOG Planner Supply Rates Doc	Supply Rate assumptions used in the OPLOG planner	3/27/14			

Figure 5: Planning Factors Database Excerpt

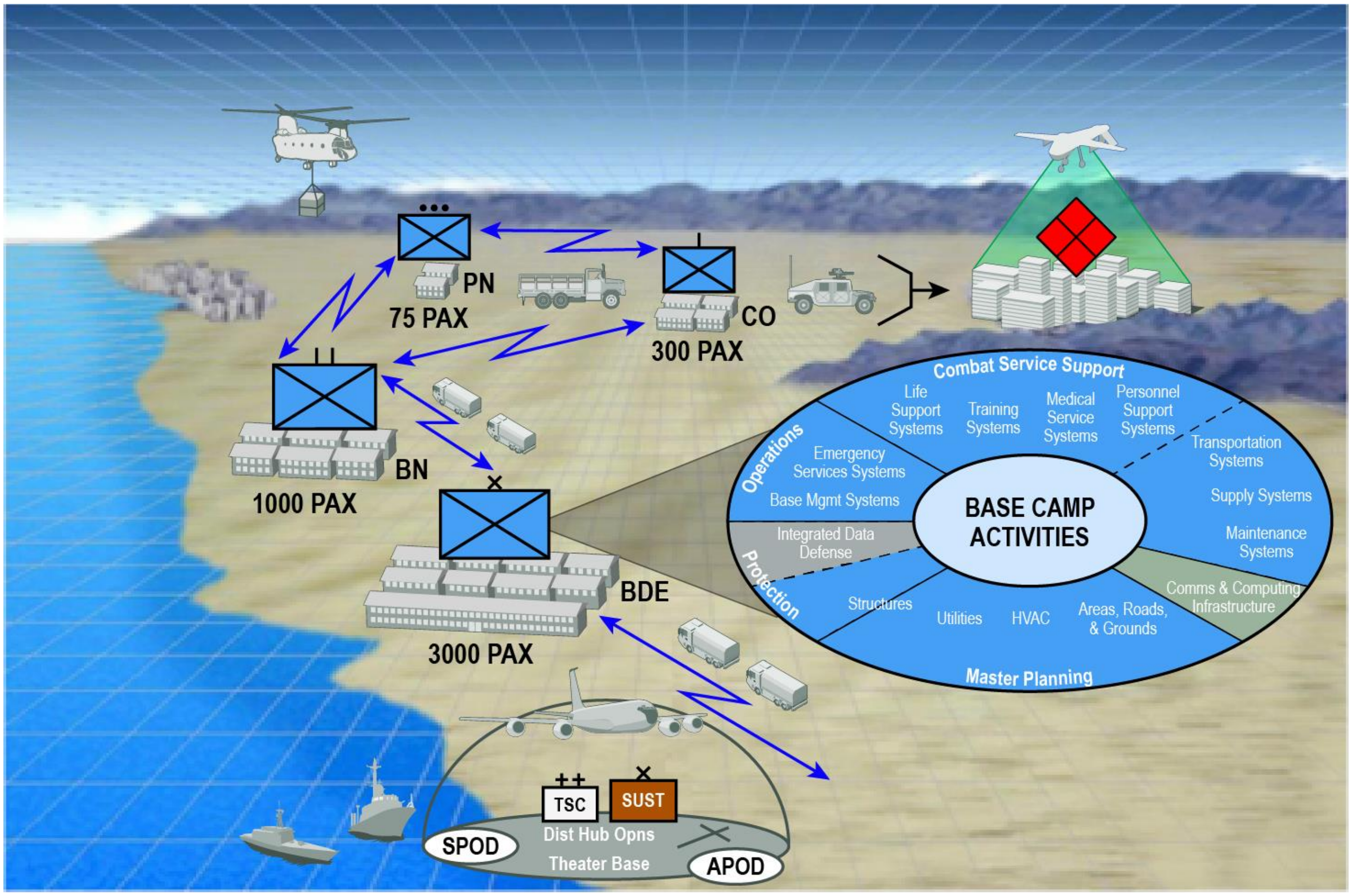

Figure 6: Operational Viewpoint-1

Architecture Development

PD CBI uses the Department of Defense Architecture Framework (DoDAF) Operational Viewpoint-1 (OV-1) to provide a graphical context for contingency bases in a theater of operations, showing the relationship between camps of the various sizes detailed in ATP 3-37.10 Base Camps. The current OV-1 is shown in Figure 6. Supplementing the OV-1, each designed camp has associated Systems Viewpoints -1 and -2 graphically representing the Systems Interface and Systems Resource Flow Descriptions. Figure 7 shows examples of these for fuel, power, and water. These views represent the way each resource should flow through the camp and help the planner ensure all systems connect to the proper inputs and outputs. [4]

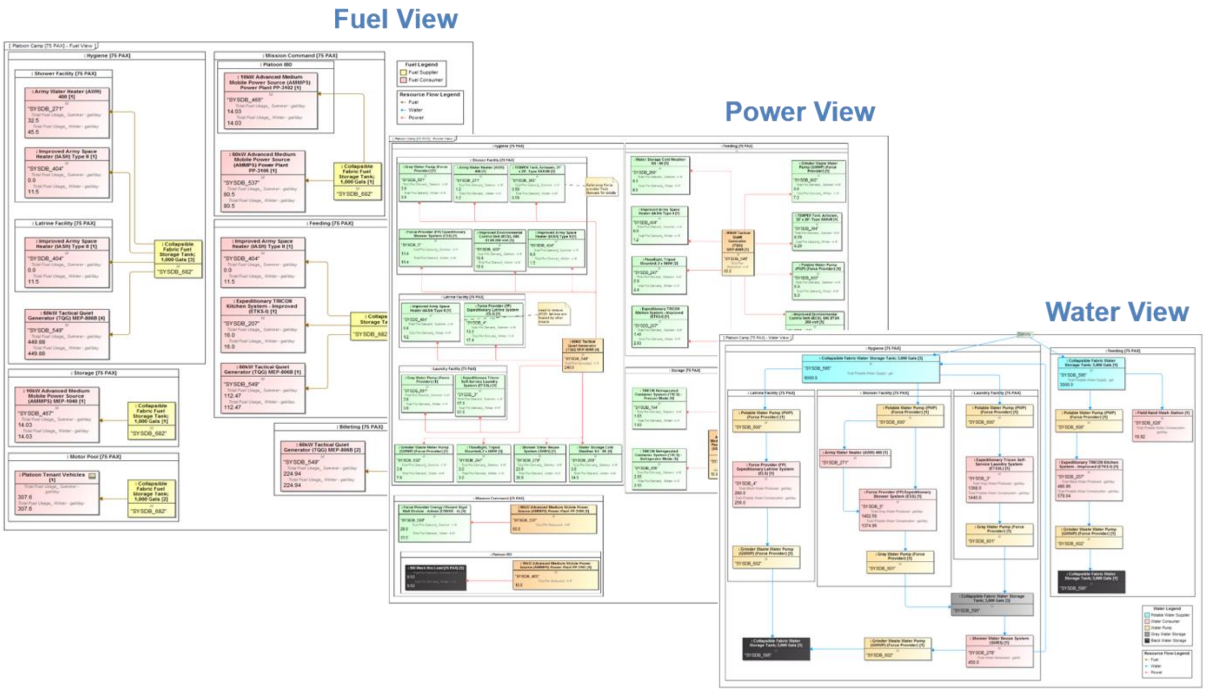

Figure 7: Systems Viewpoint 1 and 2 Example

Source Data

The requirements data and architecture development portions of the CBI MBSE process set the foundation for the resource optimization by setting forth the requirements and the "rules" necessary for a contingency base. To optimize the resources for the base camps, the models need to know the available systems and their resource demands. The other necessity is the operational scenario in which the camp will be operating. PD CBI handles the system information through the Systems Database. The current Systems Database houses information on more than 729 different base infrastructure systems, with the availability of 100 different attributes per system, although not all attributes apply to all systems. The systems in the database are mostly Army program of record (POR) systems; however, there are some science and technology programs, U.S. Air Force Basic Expeditionary Airfield Resource (BEAR) systems, and even some commercial systems included in the collection. PD CBI added the non-Army POR systems based on requests for analysis specifically asking they be included. Figure 8 shows an excerpt from the CBI Systems Database. Currently PD CBI updates the database by conducting data calls with the base infrastructure systems community. The accuracy of the data is dependent on the system owners providing correct and updated information.

ID	System Type	Nomenclature (System Name)	Model	LIN/ZLIN	NSN	System Description	System Cost ($K)	Total Systems Produced	Total Systems Fielded	Power Generated (kW)	Available Power (kW/Hz)	Noise
SYSDB_554	Structure	Containerized Chapel Complex	CCC	PC25A0	9925-01-592-9180 (Tan) 9925-01-592-9176 (Green)	Containerized Chapel (CC) provides the facilities & support for religious services at base camps for 600 Protestant, Catholic, Jewish, Muslim, and other faith group personnel. CC includes seating for 100 PAX and religious supplies. Includes vestments, altars, communion sets, ecclesiastical candelabra, chalices, patens, altar clothes, ecclesiastical statuary, sacramental wine.	281.4	0	0	0		
SYSDB_461	Generators	100kW Tactical Quiet Generator (TQG) MEP-807A	MEP-807A	G17596	6115-01-296-1463	The 100kW and 200kW Tactical Quiet Generator Sets, are the largest generator sets in the TQG family and come in two configurations, skid and trailer-mounted. The TQG sets are modernized, tactical, diesel fueled, lightweight, portable, reliable, ruggedized military power generation equipment for use in the most demanding military applications and extreme environmental conditions.	67	1061	1018	100	100kW skid	70/68 dBA @ 7 meters
SYSDB_462	Generators	100kW Tactical Quiet Generator (TQG) Power Unit PU-807A	PU-807A	G17528	6115-01-471-7088	The 100kW and 200kW Tactical Quiet Generator Sets, are the largest generator sets in the TQG family and come in two configurations, skid and trailer-mounted. The TQG sets are modernized, tactical, diesel fueled, lightweight, portable, reliable, ruggedized military power generation equipment for use in the most demanding military applications and extreme environmental conditions.	81.94	1061	1018	100	100kW/60Hz PU	70/68 dBA @ 7 meters
SYSDB_463	Generators	10kW Advanced Medium Mobile Power Source (AMMPS) Power Unit PU-2012	PU-2012	L84758	6115-01-562-3907	The AMMPS 10 kW PUs are trailer-mounted mobile suppliers of electrical energy to fielded equipment. The PU configuration consist of a one LTT trailer and one generator set. The trailer has been modified to accommodate the AMMPS 10-kilowatt generator set. Each generator set has a load capacity of 10 kW when operating at full load.	45.442	26	14	10	10kW 400Hz LTT	68 dBA @ 7 meters (23 feet)

Figure 8: Systems Database Excerpt

The operational scenario is important to the optimization of the base camp because the number and type of infrastructure equipment, the duty cycle, space requirements, number of personnel, type of unit, climate, and quality of life standard all impact the amount of resources necessary to operate the camp. PD CBI collects the operational scenario information from the requesting organization through a standard questionnaire developed for the purpose and refines the information through direct contact with the requestors. This information becomes inputs for the model setting the parameters for the optimization.

OPTIMIZATION MODELING

PD CBI employs three different models to meet the requirements of the four LOEs, the CBI Desktop Analysis Tool (often referred to as the Mini-model), the Whole System Trades Analysis Tool (WSTAT), and the System-of-Systems Analysis Toolset (SoSAT). However, only the WSTAT model is used for optimization. Sandia National Laboratory developed WSTAT as a decision support tool for use on vehicle systems. WSTAT integrates separate subsystem models into a holistic system view by mapping critical design choices to consequences relevant to stakeholders. PD CBI worked with Sandia National Lab to modify WSTAT to work with contingency bases. Contingency bases are complex systems with many interrelated subsystems producing more than 10^{150} potential combinations of equipment for a single base. WSTAT accomplishes this by looking at the design of a system, examining the millions of potential sets of equipment in an effort to satisfy multiple competing objectives. It uses a multi-objective genetic algorithm to find design "sweet spots" that balance the competing criteria, to produce a set of optimal alternatives to explore. PD CBI settled on five value dimensions to evaluate the potential base camps: performance, affordability, risk, scalability, and commonality.

The result of the model run is a Pareto curve of the 3,000–4,000 optimal solution sets out of the potential millions of equipment combinations. The default Pareto view displays the optimized solution set on a Performance versus Affordability graph. WSTAT can present the other value dimensions with markers on the individual points in the graph. Figure 9 shows a sample Pareto plot from a WSTAT run for a 300-person contingency base. The analysts can narrow the number of solutions by filtering the acceptable ranges of the value dimensions.

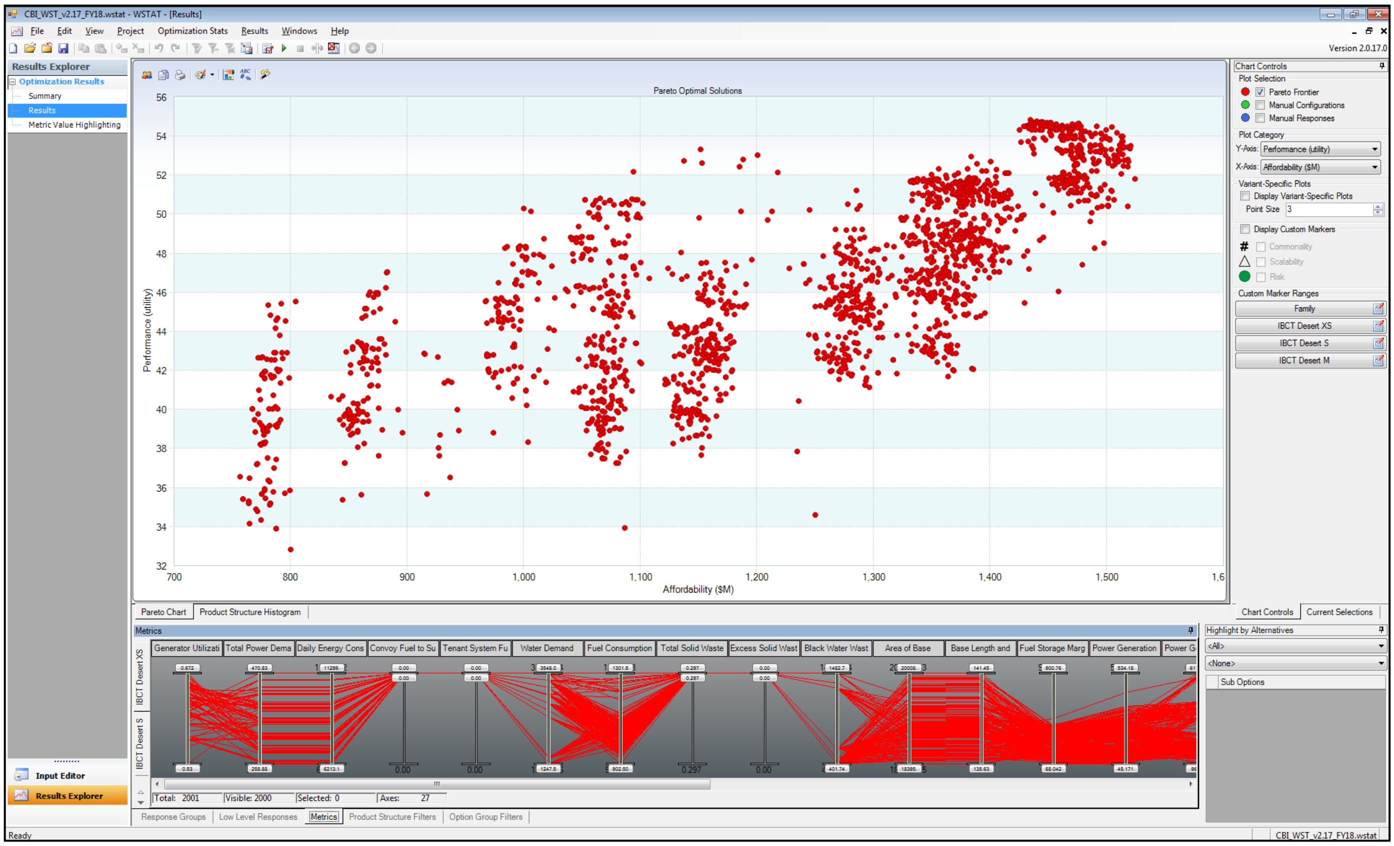

Figure 9: WSTAT Solution Pareto Example

Once the analysts determine a single solution for the customer, WSTAT will output a BOM for the selected base camp, similar to the one shown in Figure 10, arranged according to the CBI LSA, ensuring the solution addresses all the base camp activities. WSTAT will also produce a resource consumption table, similar to Figure 11, showing the resources the base consumes and generates daily; the manpower required to set up, operate, and maintain the base; and the various costs associated with establishing and operating the base.

Army Rigid Wall Course of Action					
	LSA Sub-Elements		**Ref. No.**	**Nomenclature (System Name)**	**QTY**
A	**Base Management Systems**				
B	**Emergency Services Systems**				
		First Response Vehicles	B.4	First Response Expeditionary (FRE) M-Gator Vehicle	1
C	**Supply Systems**				
			C.2	TRICON Refrigerated Container System (TRCS) - Freezer	4
			C.2	TRICON Refrigerated Container System (TRCS) - Refrigerator	17
	Material Handling Equipment (MHE)	Load Handling Systems	D.39	HEMTT Load Handling System (LHS)	1
		Fuel Storage	C.31	Container Unitized Bulk Equipment (CUBE)- Fuel	11
			C.17	Collapsible Fabric Fuel Storage Tank; 3,000 Gals	6
D	**Transportation Systems**				
	Fuel Distribution		D.2	M978 HEMTT Fuel Truck; 2,500 GAL	1
	Supply Distribution		C.20	Skid Steer Loader (SSL) Type II	2
E	**Maintenance Systems**				
	Vehicle Recovery		E.1	M984 HEMTT Wrecker	1
	Wash Rack		J.19	Engineering Mission Module Water Distributor (EMM WD)	1
F	**Life Support Systems**				
				Force Provider All Electric Kitchen	1
		Complete Dining System	F.53	Force Provider Rigid Wall Dining Shelter (FPRW-DS)	4
			F.11	Expeditionary Containerized Batch Laundry (ECBL) System	1
		Complete Hygiene Systems	F.47	Force Provider Rigid Wall Hygiene Center (FPRW-HC)	4
		Hand Washing Station		Field Hand Wash Station	3
	Billeting	Billeting System	F.28	Force Provider Rigid Wall Billeting Shelter (FPRW-BS)	42
G	**Medical Services Systems**				
H	**Personnel Support Systems**				
			H.2	Deployable Chapel - Sacred Space	1
	Morale, Welfare, & Recreation	MWR Kit	H.6	Force Provider MWR Kit	1
I	**Training Systems**				
J	**Areas, Roads & Grounds**				
			J.18	Floodlight, Tripod Mounted; 2 x 500W	32
				Floodlight Set (FLS)	10
		Perimeter Lighting	J.17	FLOODINATOR - FNS400SFQT/PCS	16
K	**Utilities**				
	Bulk Water Production & Purification	Well Systems	K.2	Water Well Drilling Rig (WWDR)	1

Figure 10: Bill of Material Example

Resource Consumption	Max Operating Power Demand - Summer (kW)	779.82
	Max Operating Power Demand - Winter (kW)	630.96
	Peak Fuel Usage - Summer (gal/day)	1,360.09
	Peak Fuel Usage - Winter (gal/day)	1,386.09
	Potable Water Consumption (gal/day)	9,824.70
	Mission Specific Requirements (Drinking Water)	0.00
	CCI Requirements	0.00
	IBD Requirements (BDOC + Guard Towers + ECPs)	0.00
	Totals From Facilities	9,824.70
	Bottled Water Consumption (gal/day)	337.23
	Gray Water Produced (gal/day)	7,859.40
	Gray Water Consumed (gal/day)	7,859.40
	Net Gray Water for Disposal (gal/day)	0.00
	Black Water Produced (gal/day)	4,034.05
	Black Water Consumed (gal/day)	0.00
	Net Black Water for Disposal (gal/day)	4,034.05
	Solid Waste Production (lbs/day)	1,800.00
	Solid Waste Consumed (lbs/day)	0.00
	Solid Waste for Disposal (lbs/day)	1,800.00
Resource Generation	Potable Water Generated by Wastewater Recycling (gal/day)	5,894.55
	Potable Water Generated by Well/Surface Source (gal/day)	0.00
	Potable Water Generated by Water From Air (gal/day)	0.00
	Potable Water Trucked in to Base (gal/day)	3,930.15
	Bottled Water Generated by Water Bottling (gal/day)	0.00
	Bottled Water Trucked in to Base (gal/day)	337.23
Manpower	# Maintainers Required	73
	# Operators Required	16
	Set-up Time (man-hrs)	106
Transportation	Twenty-Foot Equivalent Units (TEUs)	36.30
Area	Area(sq ft)	258,169.15
Cost	System Cost ($K)	$2,723.70
	Fully Burdened Cost of Transportation ($K)	$554.55
	Fully Burdened Cost of Fuel ($K/day)	$10.73
	Fully Burdened Cost of Bulk Water ($K/day)	$15.01
	Fully Burdened Cost of Bottled Water ($K/day)	$0.01
	Fully Burdened Cost to Dispose of Gray & Black Water ($K/day)	$48.41
	Fully Burdened Cost to Dispose of Solid Waste($K/day)	$0.44
	Total ($K)	$57,733.27

Figure 11: Resource Consumption Example

Two-Dimensional Base Camp Layout

Once the analysts determine the optimal BOM for the contingency base, the PD CBI Program Implementation and Integration Team develops an AutoDesk AutoCAD representation of the base. The layout is a terrain-independent representation of the base, incorporating all the required planning factors based on the current doctrine, policies, and regulations governing construction in a contingency environment. The two-dimensional (2-D) layout provides the customer a starting point for an optimized resource-efficient base tailored to the operational scenario provided. The customer can then site adapt the layout to the actual terrain designated for the contingency base. Figure 12 shows an example 2-D company-size base camp.

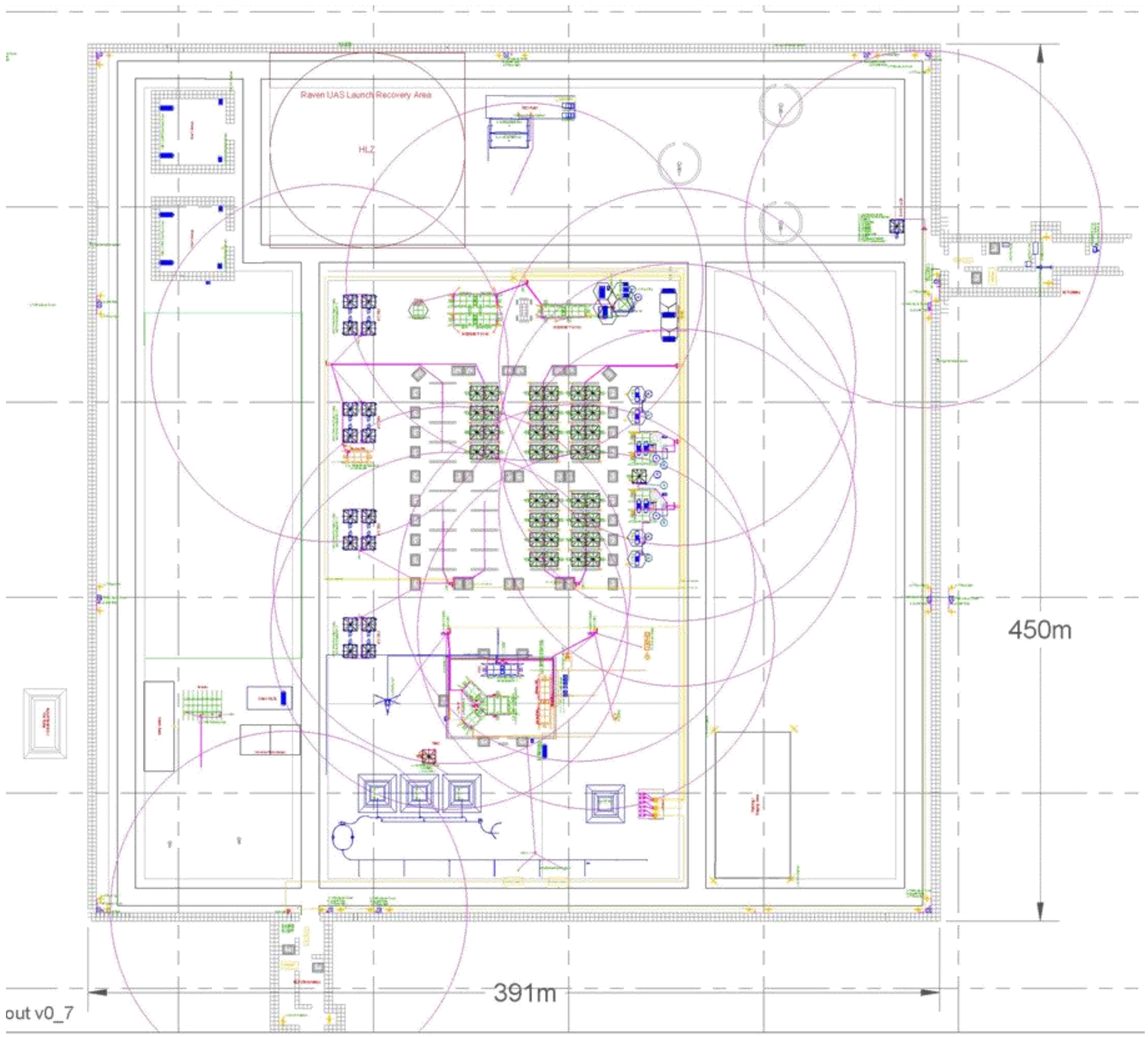

Figure 12: 2-D Company Camp Layout

CONCLUSION

The PD CBI uses an MBSE approach to view contingency bases as systems of systems. This approach allows PD CBI to analyze the bases for multiple purposes. It allows technology insertion and return on investment analyses to assist Product Managers in determining the most effective use of their available resources. Treating bases as systems of systems enables PD CBI to optimize the resources used on the contingency bases, reducing the manpower required to operate and maintain the base. It also reduces the number of trucks required to resupply fuel and water and to backhaul waste for disposal. Resource-optimized contingency bases have the potential to significantly reduce the cost to operate these bases and to save lives by reducing threat exposure time.

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