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Maintaining an Inland Petroleum Distribution System

Steven Bushold, Matthew McCarthy, Lauren Muckey, Egbezien Obiomon, and LTC David Hughes

Department of Systems Engineering, United States Military Academy, West Point, NY 10996, USA

Corresponding author's Email: steven.bushold@usma.edu, matthew.mccarthy@usma.edu, lauren.muckey@usma.edu, egbezien.obiomon@usma.edu, david.hughes@usma.edu

Author Note: The cadets are all first-class cadets at the United States Military Academy (USMA) within the Department of Systems Engineering (DSE), advised by Lieutenant Colonel (LTC) David Hughes. Cadets Bushold, McCarthy, and Muckey are vying for a Bachelor of Science degree in the DSE. Cadet Obiomon is working for a Bachelor of Science in the Department of Mathematics.

Abstract: The Inland Petroleum Distribution System (IPDS) is a dynamic metasystem whose purpose is to transport bulk fuel to the front lines through pipelines fed from an offshore petroleum distribution system (OPDS). The IPDS is broken into three key components: the pipeline, pump station, and special assemblies. Each hose in the system is broken into five-mile sets with pump stations every fifteen miles depending on terrain. Currently, the United States Army lacks a viable solution for maintaining the IPDS. The purpose of the research is to conduct an analysis of alternatives to recommend methods for maintaining an IPDS in support of various operations. The solution recommended varies dependent on the environment in which the IPDS is operating. Maintaining the IPDS is critical; the disruptive shockwave of not having the system reduces the United States forces' capability to rapidly deploy, operate, and win conflicts around the world.

Keywords: IPDS, Petroleum Distribution, Security

1. Introduction

1.1 Background

The Inland Petroleum Distribution System (IPDS) transports bulk fuel products through pipelines fed from an offshore petroleum distribution system (OPDS) in theaters of operations allowing fuel to be supplied to the front lines in any environment. IPDS is broken into three main components: the pipeline, pump station, and special assemblies (FM 10-67-1, 1998). Each hose in the system is broken into five-mile sets with pump stations every fifteen miles depending on terrain (FM 10-67-1, 1998). Providing security for the IPDS is a concern for planners and logisticians. The initial problem posed by our client, the US Army Engineering Research and Development Center (ERDC), is how to secure the IPDS in different theaters of operation. To provide a comprehensive analysis of the factors contributing to the security concern, it is vital to interview subject matter experts in an attempt to gather critical information which will allow us to model the IPDS within any future battlefield area. The initial focus of this study is directed primarily on securing the pipeline during construction through the first two weeks of operation. An IPDS pump station is pictured below in Figure 1.

Figure 1. IPDS Pump Station

1.2 Problem Statement

Currently, U.S. Army forward maneuver forces lack a viable solution for effectively securing IPDS and oil pipelines being used in foreign theaters of operation. ERDC desires a solution to secure the IPDS from threats to the system, including both friendly damage and enemy destruction. However, through research and stakeholder analysis, it was determined friendly damage poses a significantly smaller threat to the ability to maintain IPDS. Friendly damage includes, but is not limited to, running over the pipeline, improper installation, and overall lack of knowledge and experience working with the IPDS. In order to address these issues, we revised our problem statement by shifting the focus from securing to maintaining the IPDS. The function of maintaining the IPDS addresses both friendly and enemy threats and encapsulates the fundamental objective of our system.

1.3 Proposed Work

This capstone team seeks to generate an analysis of alternatives that addresses the key considerations for a viable security plan for IPDS in order to ensure the system is maintained despite the myriad of threats the IPDS will face in various theaters of operation. The final end state of the capstone is to provide a recommendation to ERDC for a solution or family of solutions that provide protection to IPDS.

2. Literature Review

2.1 Security

Pump stations are the most critical aspects of the IPDS (Backus, 2017). An attack on one pump station could cripple the entire system and result in the system becoming inoperable. Since pump stations push the oil through the pipelines and damage has such a serious impact to the system itself, security at pump stations is critical. Pipelines are the most vulnerable aspects of the IPDS due to their linear structure (Backus, 2017). The pipeline itself is not hard to penetrate and the length of the pipeline makes it hard to defend. Another aspect that must be considered is the terrain of the environment (Race, 2017). The more grade change in the pipeline route will limit the range of the pump, thus more pump stations will be required to get the fuel to its destinations. Since the pump stations must be secured, more security is required if there is more elevation change. Due to the numerous factors, it is a challenge to effectively secure the IPDS from all threats.

2.2 Threats

A threat to the IPDS is anything that will hinder the movement of oil throughout the pipeline. It is clear that there are two main threats to the ability to maintain IPDS: enemy threats and friendly threats. Each source of threats has high and low levels of consequence to the maintenance of IPDS. Some of these threats are easier to mitigate than others; however, all threats to the system must be recognized in order to design a viable solution.

Enemy threats to IPDS range from a formal attack to siphoning for personal gain (Bond, 2017). Any threats to IPDS not posed by U.S. soldiers are deemed as enemy threats. There are common criminals who take oil from the pipeline for their own personal gain (Bond, 2017); this threat against IPDS cannot continue because it delays or prevents oil to the forward maneuver forces. Therefore, these threats against IPDS must be considered in addition to the formal attacking of the pipeline by armed individuals. Blowing up the pipeline is the worst kind of enemy attack against the system because it would halt its effectiveness and require the re-security of the area and the reinstallation of the system. For these reasons, it is deemed to be a high-level threat to the security of IPDS. The stealing of oil from the pipeline is also serious, but to a lesser degree. It is classified as a lower-level threat to the maintenance and security of IPDS.

Friendly threats include improper installation due to a lack of training or a vehicle running over the pipeline (De Simone and Gauthier, 2003). Better training and familiarization with the system needs to be made a priority for units who intend to work with IPDS. Currently, only the National Guard and Army Reserve forces are trained to install IPDS (Hook, 2013); soldiers who stay in theater to maintain IPDS should have training on the system itself. If this were not to change, reserve components must be called in to fix the system when something happens to it. This results in lost time and the inability to move necessary fuel across the battlefield. A faulty installation due to the lack of training in the system is a high-level threat, because if IPDS is installed wrong then it needs to be completely re-done. This avoidable outcome costs time and resources. An example of a lower-level friendly threat to IPDS is an accident which could occur during operation, such as a driver who runs over the pipeline. This would cause a delay because the system would need to be repaired; however, it is less serious than

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a bad installation because only one segment has to be fixed, as opposed to the entire pipeline having to be re-done. The lower-level threats are easier to avoid because only minor changes are needed to increase awareness, such as placing bright colors around the pipeline to make drivers aware of where it is. High-level friendly threats are not impossible to combat, however they will take more time because training forces is a lengthy process.

3. Methodology

3.1 Systems Decision Process

The Systems Decision Process (SDP) is a collaborative, iterative, and value-based decision process that was applied over the duration of the capstone project. We followed the four distinct phases of the SDP: Problem Definition, Solution Design, Decision Making, and Solution Implementation. The SDP can be seen in Figure 2.

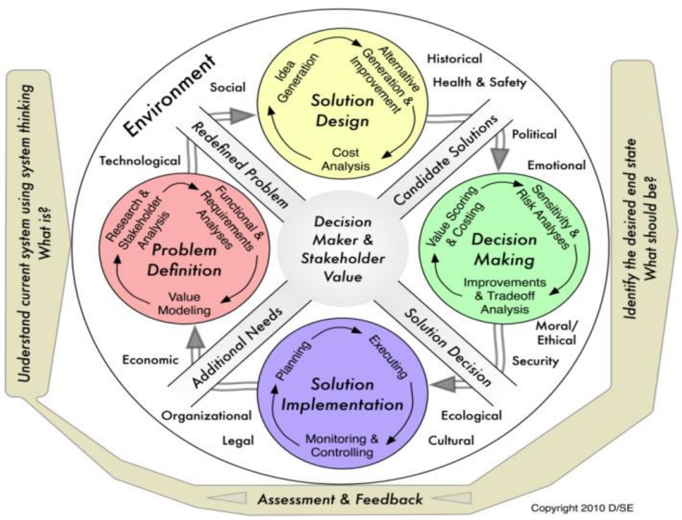

Figure 2. Systems Decision Process

3.2 Problem Definition

Problem definition is the first step of the SDP. It serves as the basis of understanding the client's desired end state. This is the most important step of the SDP because it is vital to solve the correct problem in order to provide an effective solution. To model the problem of maintaining the IPDS, it was necessary to develop a Value Hierarchy (see in Figure 3). Based on the main fundamental objective of maintaining the IPDS, there are three main functions: detect interruptions to IPDS, protect IPDS from potential attacks/threats, and maintain operation of the IPDS. Under each of these functions is an objective and the associated value measure. All of the value measures are direct and natural measures, except measure 2.1.2, titled the level of protection. In order to provide a quantifiable level of security, a Star Rating Chart was created for the Level of Protection value measure (seen in Figure 4) to determine how well solutions scored on a constructed scale. This scale is designed similarly to a crash test rating for a vehicle. The level 1 is the baseline that all IPDS will have in order to maintain the system. As the levels of protection increase, the security measures increase. A level 5 would be the most secure, but it may not be feasible due to cost and resource allocation. In some environments, such as low-threat or training environments, a level 5 would be excessive. The level of protection will change depending on the environment; therefore, the solution must be flexible in order to address the problem at hand.

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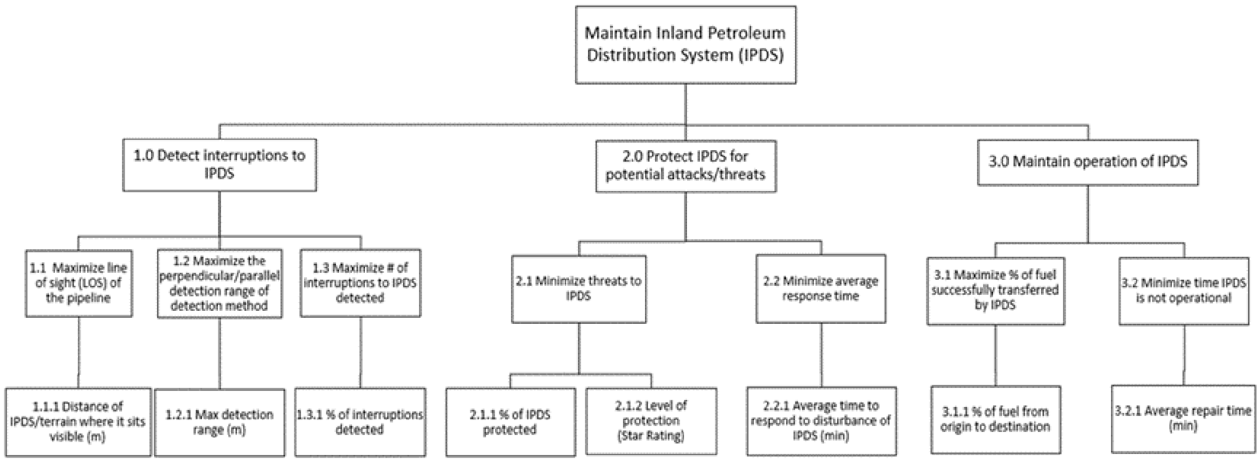

Figure 3. Value Hierarchy

Star Rating	
Level of Protection	**Protection Methods Utilized**
5	Everything from Level 2 and three of the following: 24hr patrols, 24hr UAV surveillance, guard towers that allow 100% line of sight (LOS) of IPDS, barbed wire fences along 100% of IPDS, large-sized QRF, and bury the enitre IPDS pipeline.
4	Everything from Level 2 and two of the following: 18hr patrol (4am-10pm), 18hr UAV surveillance, guard towers that allow 75% LOS of IPDS, barbed wire fences along 75% of the IPDS, medium-sized QRF, and culverts at road intersections
3	Everything from Level 2 and one of the following: 12hr patrol (6am-6pm), concertina wire (C-Wire) that covers 75% of IPDS, and bury pipeline at road intersections (culverts)
2	Everything from Level 1 and the following: cameras and small sized quick reaction force (QRF) (armed response team)
1	Pipeline entirely above ground, no regular patrols, sensors (motion dectectors) and accelerometers (vibration detectors)
*Assume Cameras, Sensors, and Accelerometers allow for detection along 100% of IPDS	

Figure 4. Star Rating Chart

3.3 Solution Design

Solution design is the second step in the SDP. This step allowed us to develop feasible candidate solutions. A major aspect of solution design is the development of an alternative generation table (Zwicky's Morphological Box). Four key parameters exist to maintain the IPDS (see in Figure 4). The key decisions were detection/deterrence method, threat mitigation before contact with the friendly or enemy, time between contact and investigation, and response method after contact. Once our possible alternatives were established, solutions were run through a feasibility screening matrix. The screening is based on the needs, wants, and desires of our clients. This is done to limit the possible pool of solutions to solutions that provide value to our clients.

Zwicky's Morphological Box gives an overview of all the possible decisions which could be implemented into a solution. In the case of IPDS, it was used to combine the possibilities into solutions that ranged from being the most proactive to the most reactive alternatives. The alternatives are depicted in Figure 5. When simulating the alternatives in iWARS, due to the complexity of the software, only the most proactive and most reactive alternatives were tested.

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Code Letter	Detection	Threat Mitigation (F/E)	Response Time	Response Method
a	Patrol	Bury Pipeline	0 mins	QRF
b	UAV	Barbed Wire Fences	10 mins	Electric Shock
c	Guard Tower	Above Ground	20 mins	Alarm
d	Cameras	Bury at Intersections	30 mins	Air Support (Apache/Jet)
e	Sensors	C-Wire	40 mins	UAV
f	UGV		50 mins	UGV
g	Air Support		60 mins	Indirect Fire
h	Accelerometers			Special Ops (75th)

Alternatives				
Most Reactive	e,h	c	g	c
Most Proactive	a, b, c, d, e, h	a, b, e	a	a, b
Middle	a, d, e, h	c, e	d	a
More Reactive	d, e, h	c	e,f	b, c
More Proactive	a, c, d, e,h	b, d	a, b, c	a, c

Figure 5. Alternative Generation Table

3.4 Model Simulation

The Infantry Warrior Simulation (iWARS) was used to model the current method used by the Army. This model consists of an enemy squad attacking a pipeline, with the friendly force consisting of a dismounted platoon size element patrolling with a UAV overwatch. Over 30 iterations, the enemy had a 40% success rate to disrupt the pipeline with an attack. We plan to run additional scenarios to see how they compare to the baseline method.

3.5 Decision Making

In order to make the best decision possible, the additive value model was utilized to rank order the value measures. See Equation 1 below. In order to make the best decision possible, a survey was sent out to subject matter experts to determine the importance of each function in the value hierarchy. In Figure 6 below, the weights used in the Additive Value Model (Equation 1) for Detect, Protect, and Maintain were .5, .3, and .2, respectively.[1] Figure 6 shows the results and their total scores out of 100.

$$v(x) = \sum_{i=1}^{n} w_i v_i(x_i) \tag{1}$$

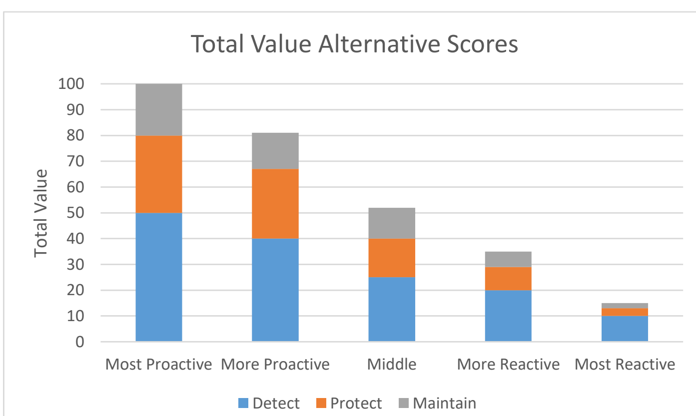

Figure 6. Stacked Bar Chart

[1] The weights were derived from the survey results from subject matter experts.

4. Conclusions and Future Work

In conclusion, the maintainability of IPDS starts with detection. Detection is the most important function to the system because detecting an enemy before they attack allows a unit to move from a reactive to a proactive posture. Having a better ability to detect an enemy attack allows a unit's posture to be more proactive.

Proactivity is important because it allows a unit to mitigate a threat before damage to the system is done. Currently, the enemy has a 40% success rate when attacking the IPDS. Being more proactive would decrease this success rate because a unit could intercept the threat before the enemy performs a successful attack. Therefore, the most important function of the IPDS is to detect the enemy. In a non-permissive environment, we recommend at least a three star protection rating because this is the first level of protection that takes proactive measures, such as adding a patrol. Protection levels will vary depending on the environment; however, we recommend that units in charge of maintaining the IPDS place their heaviest emphasis on detecting the enemy.

While detection is essential to maintaining the IPDS, it comes at a cost. A five star level of protection is not always essential or feasible due to resource and cost limitations. In the future, we recommend performing further research on the cost of the alternative methods to provide data necessary for a cost versus value analysis. This will determine which solution dominates other solutions, and could allow for a recommendation to be made across all environments. Additionally, more simulation models can be made and could provide results for each of the alternatives. From these results, realizing which specific elements within the solutions (such as adding C-wire, walls, etc) prevents a successful enemy attack could be crucial information for ground forces.

5. Citations and References

Bednar, A. E. (). Planning Logistics Analysis Network System (PLANS). N/A, 1. Department of Army (1998). FM 10-67-1 Chapter 7. *Field Manual*, N/A

Bednar, A., Dr, Cowan, M., White, B., Green, J. G., Hargis, B., Loney, D., Dr, . . . Boler, C. (2016). Logistics Planning in the A2AD Environment. Proceedings of the 2016 Industrial and Systems Engineering Research Conference. Retrieved September 8, 2017.

Blacketter, Derrick SPC (2014). Retrieved March 28, 2018, from https://www.dvidshub.net/video/327016/b-roll-army-reserve-soldiers-operate-inland-petroleum-distribution-system-ipds

Collier, S. J., & Lankoff A. (2008). The Vulnerability of Vital Systems: How "Critical Infrastructure" Became a Security Problem. 1-32. http://anthropos-lab.net/wp/publications/2008/01/collier-and-lakoff.pdf

De Simone, A., CPT, & Gauthier, N., MAJ. (2003). The Inland Petroleum Distribution System in Kuwait and Iraq. Engineer. Retrieved September 8, 2017.

Department of the Army. (2015). Petroleum Supply Operations. *Planning Considerations*. (DOA Publication No. 4-43). Washington, DC: U.S. Government Printing Office.

Hook, K. R. (2013). Balancing Petroleum Force Structure/Capabilities between Active and Reserve Components. USAWC Strategy Research Project, 1-21. http://www.dtic.mil/docs/citations/ADA589341

Interview with COL(R) Phillip Bond

Interview with LTC Paul Evangelista

Interview with COL Eric Backus

Interview with CPT Matthew Salyer

Parnell, Gregory S., Patrick J. Driscoll, and Dale L. Henderson. Decision Making in Systems Engineering and Management. Hoboken, NJ: Wiley, 2011.

Thoreson, M. D. (2013). Army Bulk Petroleum Current Force Structure Mix and its Implications. *Strategy Research Project*, 1-36. doi:10.21236/ada590233

Weaver, K. A. (2001.). The Inland Petroleum Distribution System (IPDS). *Can It Fuel The Force?* Published April 10, 2001. Accessed September 7, 2017.