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Increasing Asset In-Transit Visibility at Fort Bragg, North Carolina

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Abstract: The U.S. Army maintains a ready-to-deploy unit at Fort Bragg, North Carolina that is known as the Immediate Response Force (IRF) which consists of more than 3,000 soldiers and hundreds of pieces of equipment. When given the order to deploy, the IRF must rapidly prepare its equipment to be loaded onto aircraft and shipped overseas. Currently, these assets (containers, vehicles, pallets, etc.) are tracked manually as they move through the various steps of the deployment sequence. This process involves soldiers visually identifying assets and then reporting this information to a central location that tracks the movement of all equipment, thereby giving the unit commander an understanding of where their equipment is in the deployment process. Unfortunately, this method has significant shortcomings. It only provides commanders the last known position of assets rather than real-time locations. This method also consumes time and manpower, the two most valuable and finite resources the commander has. Because unit leaders are unable to know the precise location of their assets, their ability to allocate resources effectively is decreased significantly. This paper researches potential solutions to increase commanders' in-transit visibility of deploying assets. Technologies such as radio-frequency identification (RFID), global positioning systems (GPS), and long-range wide area network (LoRaWAN) will be discussed in terms of their required infrastructure, implementation feasibility, the benefits produced by each alternative, the tradeoffs to consider with each solution's implementation, and the validation procedures used to ensure proper functioning of each technology's tracking system solution. A value-focused systems engineering decision process is applied to generate and evaluate each alternative solution for meeting the needs of commanders at Fort Bragg. The presented solutions show how incorporating new technologies and automating aspects of the current process can improve commanders' visibility of critical assets and increase their ability to make more informed decisions.

Keywords: In-Transit Visibility, Deployment Process, RFID, GPS, LoRaWAN, Tracking Equipment

1. Background

1.1 Deployment of the Immediate Response Force

During the IRF's deployment process at Fort Bragg, Army assets, to include vehicles, shipping containers, and cargo pallets, pass through various stations (stages) as they make their way towards being loaded onto U.S. Air Force or civilian contracted cargo aircraft. The Army dictates that the IRF be able to accomplish the entire deployment preparation process in 18 hours for a battalion-sized element (750 soldiers) or 96 hours for the entire brigade (3,000+ soldiers). To help manage this process, the Army currently positions soldiers equipped with radios at each of these stages. When equipment arrives to their assigned stage, the soldier will record each equipment's serial number and report the information via radio to the tactical operations center (TOC). For commanders and their staffs positioned at the TOC, collecting and organizing the information of every asset is time consuming and inefficient. The outload of equipment is just one part of the deployment process that requires the attention of commanders, hence the desire to develop a more efficient system. The inefficiency of the current system raises questions about the different asset tracking alternatives currently used by other organizations. Such alternatives include the use of radio-frequency identification (RFID), global positioning systems (GPS), and long-range wide area network (LoRaWAN) technologies.

1.2 Existing Technologies

An RFID tracking configuration consists of RFID tags, antennas, readers, and a network that connects the readers (Garfinkel and Holtzman, 16). Tags are attached to each asset and contain an antenna, radio receiver, radio modulator, a small amount of memory, and a power system (Garfinkel and Holtzman, 17). The radio receiver receives incoming radio frequency (RF) signals produced by RFID readers, and the radio modulator emits a returning signal from the tag containing the tag's serial number and other information back to the RFID reader (Garfinkel and Holtzman, 17). Readers are positioned at various locations where a system's operator desires to know the location of assets (Reckeweg et al., 1). The readers, like the tags, contain antennas and communication between the tags and the readers occurs between the antennas on each component (Garfinkel and Holtzman, 17). The network connects the readers and, depending on the type of network and user interface setup, the network consolidates tag location information from the readers (Garfinkel and Holtzman, 22).

Tags take one of two forms: active or passive (Reckeweg et al., 1). The primary difference between the two is the tag's power source. An active tag is powered by its own battery, whereas a passive tag receives its power from an incoming RF signal emitted by a reader (Garfinkel and Holtzman, 17). In an RFID system with active tags, the tags emit a signal that contains their identification information (atlasrfidstore.com). When an active tag enters the reading vicinity of a reader, the reader identifies the tag's emitted signal (Garfinkel and Holtzman, 17). With a passive tag, the tag receives a signal from a reader and uses the signal to power itself and respond with its own signal that contains its information (Garfinkel and Holtzman, 17). This requires the passive tag to be near the reader, usually 3 feet (rfidjournal.com).

Currently, the Army uses active tags within an intercontinental RFID system to track assets as they move throughout the world via air and sea. As part of the IRF's deployment sequence at Fort Bragg, the tags are attached at the end of the outload process just prior to loading the assets onto an aircraft, train, or line-haul truck. This system only gives commanders the ability to view the last known location of an asset. Specifically, a commander would only know which reader an asset was most recently tracked at. For example, if a unit from Fort Bragg deploys to Kuwait and the unit's equipment is scheduled to be transported first to Ramstein Air Force Base in Germany and then to Kuwait, a unit using RFID would be able to determine when each asset departed Fort Bragg, entered Ramstein AFB, departed Ramstein AFB, and arrived in Kuwait, so long as there are RFID readers at each location. During the equipment's journey, RFID readers positioned at Fort Bragg, Ramstein AFB, and Kuwait would detect the individual signals emitted from the tags when assets enter the vicinity of the readers.

Long-range wide area network technology is relatively new in the world of asset-tracking and logistics. LoRaWAN is a communication protocol standardized by the LoRa Alliance, a nonprofit association comprised of more than 500 members involved in the implementation of low power wide area network (LPWAN) technology (lora-alliance.org). A LoRaWAN tracking system uses a concept known as time difference of arrival (TDOA) to geolocate assets (LoRa Alliance Strategy Committee, 2). Like an RFID system, sensors are attached to each asset, and each sensor contains a small amount of memory with a serial number and other information. Gateways are positioned at various locations around an area of interest. An asset's sensor emits a signal which is received by the gateways (LoRa Alliance Strategy Committee, 3). The difference in time the signal reaches each gateway is used to calculate the asset's location (True Position Inc, 00:00:53 – 00:01:06). A major difference between a LoRaWAN system and an RFID system, however, is that a user can determine the location of assets anywhere in the area of interest rather than only their last known location. With a LoRaWAN system, the range capability is typically 2 to 3 kilometers in congested areas and 5 to 7 kilometers in open areas (Chauhan and Lee).

GPS technology is also used in asset-tracking applications throughout the world. A GPS asset-tracking system, like other systems, involves the use of tags attached to each asset. Instead of gateways or readers, however, a GPS system relies on orbiting satellites to identify asset locations (True Position Inc, 00:00:30 - 00:00:55). In a GPS system, a tag receives signals from multiple satellites and determines the distance to each satellite (True Position Inc, 00:00:30 - 00:00:55). The distances are then used to calculate the position of the tag (True Position Inc, 00:00:30 - 00:00:55). GPS devices have known disadvantages, however, including limited battery life and the frequent blocking of signals due to buildings and other objects in the vicinity of the reading range (IMUA.org).

2. Methodology

2.1 Functional Analysis

A value-focused systems engineering process was applied to generate and evaluate possible alternatives to increase commander's in-transit visibility of assets during the deployment process. Preliminary research into the aforementioned tracking technologies, combined with input received from engineers of the 82nd Airborne Division, yielded potential solutions which were evaluated for their feasibility. This systems engineering process involved the generation of a value hierarchy, creation of value functions, alternative generation using a morphological box, assignment of swing weights to each value measure, value scoring to compare each alternative solution, sensitivity analysis, and a comparison of cost to value for each alternative.

The process began with the generation of a value hierarchy. Stakeholder input from Fort Bragg along with background research into current asset tracking technologies yielded the fundamental objective, the functions the system should perform, the objectives of the system, and the value measures used to evaluate the feasibility of each generated alternative in the value scoring stage of the process.

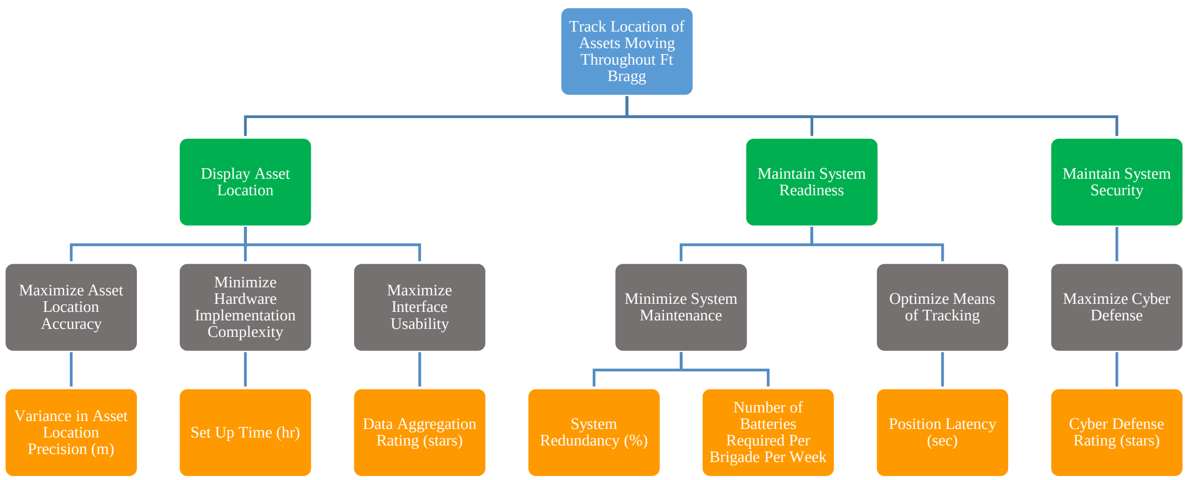

Figure 1. Value Hierarchy

In figure 1, the value measures are shown in orange. Variance in Asset Location Precision, Set Up Time, and Data Aggregation Rating measure how effective the system can be in displaying the location of assets as they move throughout Fort Bragg. Variance in Asset Location Precision refers to the amount of error that can occur in pinpointing the exact locations of assets. Set Up Time refers to the amount of time required to set up the system, including the attachment of all tracking tags to a brigade's worth of assets, the construction of gateway readers for each stage, and a check to ensure proper system functioning. Data Aggregation Rating deals with how well the system can condense the numerous serial numbers and location information of each asset and display this information on a user-friendly interface. It was found that evaluating the data aggregation was beyond the scope of this project, however directing effort into finding a suitable user interface is something that can be pursued in future research. System Redundancy, Number of Batteries Required Per Brigade Per Week, and Position Latency seek to maintain the readiness of the system. System Redundancy refers to additional infrastructure components that provide backup services if primary components fail or require maintenance. Number of Batteries Required Per Brigade Per Week covers how frequently tags attached to assets require battery changes. Position Latency refers to the delay, if any, that occurs in receiving the location information of every asset. Finally, the value measure Cyber Defense Rating measures the strength of the system in defending itself from external cyber threats.

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2.2 Value Modeling

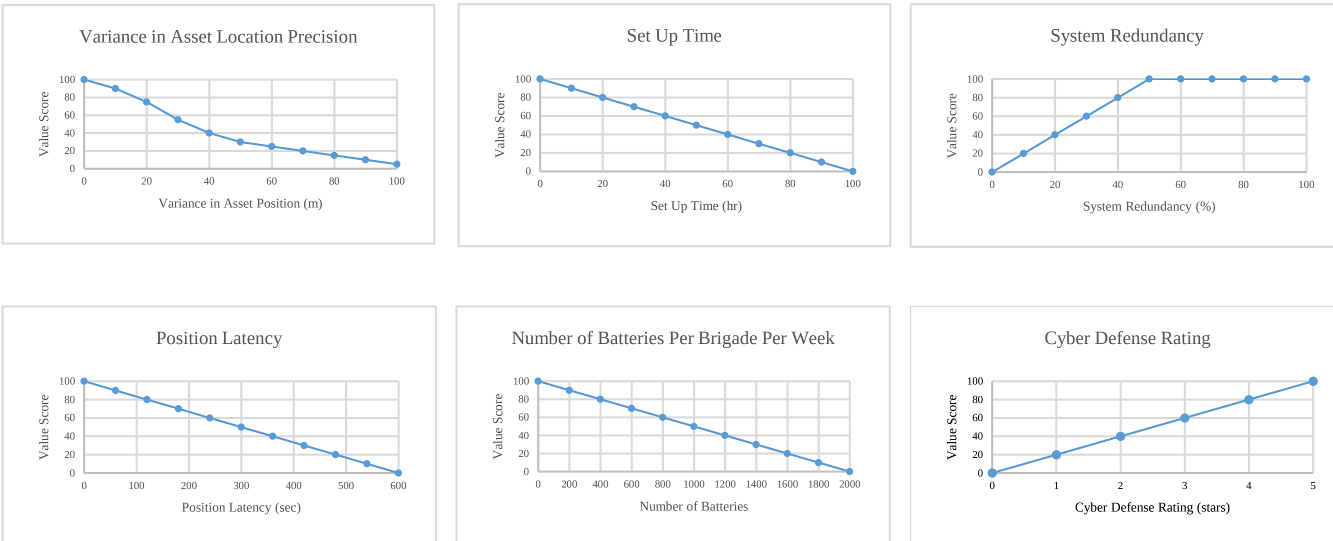

Exhibit 1. Value Functions

Exhibit 1 displays the value functions for each value measure. The value functions match specific values to a score ranging from 0 to 100 and are generated through discussion with the client. Using Set Up Time as an example, the shorter the time required to set up and test the system, the higher the value score. These functions are used to score each alternative in terms of overall value and are addressed further in section 2.4.

2.3 Alternative Generation

Table 1. Alternative Solutions

		Solution Design Parameters					
		Position Precision	**Gateways**	**Gateway Location**	**Batteries Required?**	**Position Status**	**Set Up Complexity**
Alternative Solutions	**Manual**	within 150 m	5 to 6	at each stage	No	Last known	Minimal
	RFID Traditional (active)	within 100 m	4 to 5	at each stage	Yes	Last known	Moderate
	RFID Plus (passive)	within 10 m	9 to 10	entrance and exit of each stage	No	Last known	Moderate
	Pure GPS	within 10 m	4	external	Yes	Current	Moderate
	Pure LoRaWAN	within 100 m	4 to 7	at each stage	Yes	Current	High
	LoRaWAN Plus	Greater than Pure LoRaWAN	8 to 10	varied across post and at each stage	Yes	Current	High

The generation of alternative solutions involved the creation of Table 1. The table displays six alternative solutions and their corresponding design parameters. The Manual alternative represents the current tracking system Fort Bragg uses, which involves soldiers visually identifying asset serial numbers and radioing this information to the tactical operations center. The RFID Traditional (active) alternative involves attaching active RFID tags that the Army currently uses at the beginning of the outload process (instead of the end of the process as is done currently). Readers would then be placed in the center of each outload stage to read incoming signals from an asset's tag as it moves through the deployment process. The RFID Plus (passive) alternative involves using passive RFID tags and placing readers at the entrance and exit of each stage of the deployment process. Passive tags do not require batteries and the readers would take the form of drive-over mats or drive-through interrogators. The Pure GPS alternative involves using GPS tags for tracking. The Pure LoRaWAN alternative involves attaching sensors to each asset and constructing gateways at each outload stage. This alternative would use the LoRaWAN protocol to track assets. The LoRaWAN Plus alternative would use the same hardware as the Pure LoRaWAN alternative, however additional gateways would be constructed to increase location accuracy.

		Level of Importance of the Value Measure		
		High	Medium	Low
Variation in measure ranges	High	Variance in Asset Location Precision 100	Number of Batteries Per Brigade Per Week 75	Set-Up Time 50
	Medium	Position Latency 80		
	Low	Cyber Defense Rating 65	System Redundancy 50	

Figure 2. Swing Weight Matrix

In order to conduct value scoring on the six alternative solutions, each value measure had to be assigned a swing weight ranging from 0 to 100. A value measure's level of importance and the variation in its measuring range are used to assign the swing weights. These weights represent the relative importance of the value measure to the stakeholders. For example, leadership at Fort Bragg determined that the precision of the asset's location was the most important measure and, thus, was assigned a value of 100. System Redundancy and Set Up Time were half as important to the stakeholders, and, therefore, given values of 50.

2.4 Value Scoring

Table 2. Raw Data Matrix

	Variance in Asset Location Precision (m)	Position Latency (sec)	Cyber Defense Rating (stars)	Number of Batteries Required Per Brigade Per Week	System Redundancy (%)	Set Up Time (hr)
Manual	100	5,400	5	0	50	0.50
RFID Traditional (active)	92	8	3	3.08	50	70
RFID Plus (passive)	1	160	4	0	50	70
Pure GPS	3	1	2	13,440	50	10
Pure LoRaWAN	70	1	4	6.15	50	70
LoRaWAN Plus	50	1	4	6.15	50	70

The value scoring procedure began with the collection of raw data for each alternative. Background research yielded the raw data in Table 2, however assumptions had to be made for certain values. It was assumed that 400 assets would be tracked for the IRF. For the Manual alternative, it was assumed that the Variance in Asset Location was 100 meters as commanders only know the stage in which assets are located, not the precise locations. The Manual alternative's values for Position Latency and Set Up Time were assumed to be 90 minutes (5,400 seconds) and 30 minutes, respectively, based on current operating procedures.

The Set Up Time values for the Pure GPS, Pure LoRaWAN, and LoRaWAN Plus alternatives also had to be assumed. With Pure GPS, it was assumed that it would take five minutes to attach a GPS tag to an asset, resulting in a total time of 10 hours. With the Pure LoRaWAN and LoRaWAN Plus alternatives, it was assumed that the setup times would mirror those for the RFID alternatives, two weeks, because the LoRaWAN and RFID alternatives use similar hardware (atlasrfidstore.com).

The Cyber Defense Rating for each alternative is based off a Likert scale. The Manual alternative received a 5-star rating because it would be immune to cyber threats. RFID systems are susceptible to numerous types of cyber-attacks, including eavesdropping, spoofing, and jamming attacks (Xiao et al., 5-6). Since active tags have wider read ranges, the RFID Traditional (active) alternative received a lower rating than the RFID Plus (passive) alternative based on the assumption that a wider read range would be more susceptible to outside threats (Xiao et al., 3). The GPS Plus alternative received a 2-star rating because GPS "…has a well-known signal structure, making it an easy target for jamming and denying accuracy" ("Supply Chain: Defeating the Security Watchdog," 1). Additionally, common jamming devices exist including small mobile short-range jammers, vehicle mounted short range jammers, and multi-signal jamming devices, to name a few ("Supply Chain: Defeating the Security Watchdog," 3-4). The two LoRaWAN alternatives received ratings of four stars because in the LoRaWAN protocol, data transmitted between end devices and the server is encrypted, which provides for confidentiality in messaging (Cerrudo et al., 7). Encryption does not necessarily indicate 100% security, however, as the possibility exists for hackers to extract encryption keys from devices through reverse engineering and other means (Cimpanu).

The next step in the value scoring process is to convert the raw data into value by using the functions created in section 2.2. Once all the raw data has been converted to normalized values, the swing weights must be used so that a total value score for each alternative can be calculated.

Table 3. Weighted Value Scores

	Variance in Asset Location Precision (m)	Position Latency (sec)	Cyber Defense Rating (stars)	Number of Batteries Required Per Brigade Per Week	System Redundancy (%)	Set Up Time (hr)	Total Value Score
Manual	0.00	0.00	15.48	17.86	2.98	11.85	48.15
RFID Traditional (active)	1.90	18.79	9.29	17.83	2.98	3.57	54.36
RFID Plus (passive)	23.81	13.97	12.38	17.86	2.98	3.57	74.56
Pure GPS	23.81	19.02	6.19	0.00	2.98	10.71	62.71
Pure LoRaWAN	5.36	19.02	12.38	17.80	2.98	3.57	61.10
LoRaWAN Plus	7.94	19.02	12.38	17.80	2.98	3.57	63.68
Ideal	23.81	19.05	15.48	17.86	11.90	11.90	100.00

In order to calculate the total value scores, global weights had to first be calculated from the predetermined swing weights. This was done by dividing each swing weight with the sum of all swing weights. The global weights were then multiplied by each value score to yield the weighted values for each alternative's value measures. By summing across each row in Table 3, the total value scores for each alternative were obtained.

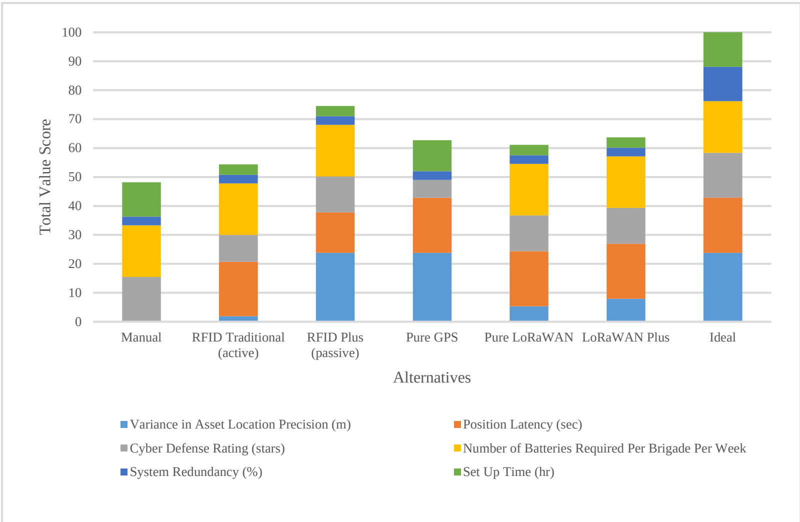

Figure 3. Value Stacked Bar Chart

Figure 3 displays a comparison of the total value scores for each alternative. The bar chart shows each alternative broken down into different colors representing the weighted values for each value measure. An Ideal solution is included in Figure 3 to show what a perfect solution would look like. This is helpful to visualize which specific value measures cause an alternative to have a lower (or higher) total value score. For example, RFID Plus (passive) has the highest total value score because its weighted values for Variance in Asset Precision Location and Number of Batteries Required Per Brigade Per Week are high compared to the other alternatives. In fact, the RFID Plus (passive) alternative maximizes those two value measures, as seen by comparing it to the Ideal solution.

2.5 Sensitivity Analysis

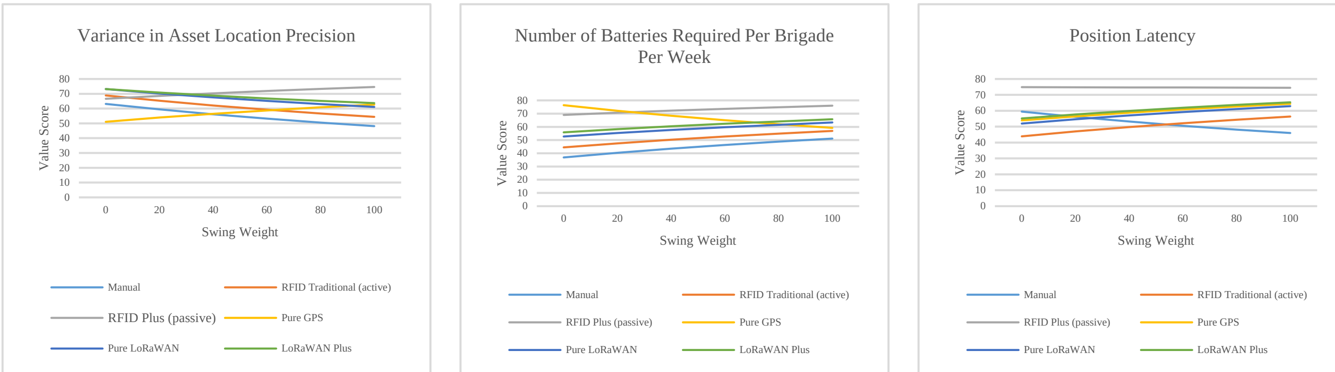

Exhibit 2. Sensitivity Graphs

Sensitivity analysis provides insight into the amount of variation in the ranges of assigned values. The creation of sensitivity graphs allows for the sensitivity of each value measure, with respect to changes in their assigned swing weights, to be analyzed. This allows stakeholders to understand whether the recommended solution changes if the assigned swing weight is altered. For example, the Number of Batteries Required Per Brigade Per Week value measure is considered sensitive because the recommended solution based on value score (the line highest on the y-axis) changes at a swing weight of approximately 25. Recall that the current swing weight for this value measure is 75, therefore the stakeholders would have to significantly change their opinion of the importance of batteries for the recommended solution to change.

3. Results

3.1 Cost Analysis and Recommendation

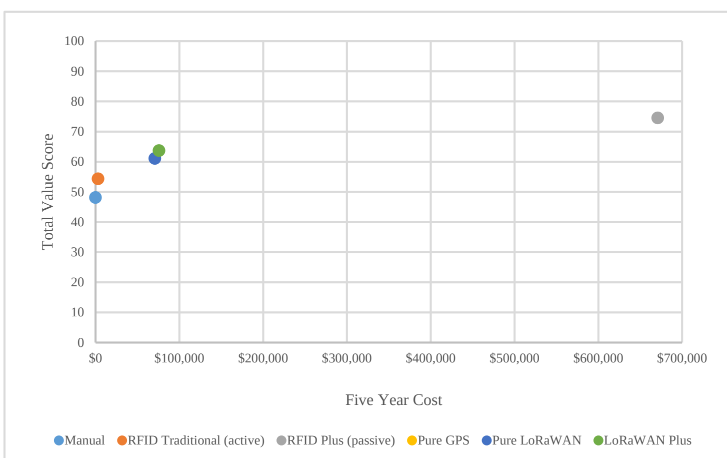

Figure 4. Cost vs. Value Graph

Figure 4 displays a comparison of each alternative's total value score to its cost over a period of five years. The minimum acceptable rate of return was assumed to be 5% per year for all cost calculations. The cost for the Manual alternative would be $0 since radios would be the only hardware involved and the Army already uses them. With the RFID Traditional (active) alternative, the cost would be approximately $2,941 based solely on battery cost. Each active tag uses one AA 3.6-volt battery which lasts 2.5 years and costs $2.65 each (RF-ITV Tracking Portal; batteryjunction.com). Employing this alternative would save costs to include the costs for the tags themselves, the RFID readers, and the RFID tracking software since this alternative would use current Army RFID hardware. With the RFID Plus (passive) alternative, the cost for five years would be about $671,000 based on the $3.50 cost of a passive tag designed for use on metal surfaces, $15,000 for the cost of a reader and its installation fee, and the $25 fee per tag per month for the RFID software ("The Recurring Costs of Passive RFID: Hidden Costs that Hurt Your Business and Your Budget" 1; Watson; Rowe). Since this alternative would involve positioning readers at the entrance and exit of each of the five primary outload stages, 10 readers would need to be purchased. With the Pure GPS alternative, the GPS tracking service would cost $25 per month, and this fee was assumed to be per tag (Shiner). The GPS tags are under $100 so it was assumed a tag would cost $80 ("How Long Does a GPS Tracker Battery Last?"). Each tag uses four C-sized batteries and a pack of two batteries has a cost of $3.50 ("Remora"; grandinroad.com). These costs result in a $5,846,660 five-year cost for the Pure GPS alternative. With the two LoRaWAN alternatives, gateways cost $1,000 each and a tag costs $159 ("The LoRaWAN as an IoT Network Solution - Wireless Solutions Part 1"; "Guppy LoRaWAN Tag & Asset Tracker"). Each tag uses two 1.5-volt AA batteries, and it is assumed the batteries would last 2.5 years like the battery life in the active tags of the RFID Traditional (active) alternative ("Guppy LoRaWAN Tag & Asset Tracker"). The cost for the service per tag is $0.95 per year ("Pricing - ResIOT LoRaWAN Network Server and IoT Platform"). The only difference between the Pure LoRaWAN and LoRaWAN Plus alternatives is the number of gateways. With these specs, the Pure LoRaWAN alternative with four gateways would cost about $70,170, and the LoRaWAN Plus alternative with nine gateways would cost about $75,710 for a five-year period.

These costs are compared with the total value scores shown in Table 3 and Figure 3. The Army would have to conduct a trade space analysis in order to evaluate the benefits of choosing an alternative of higher value for a greater total cost. Based on total value and cost, however, the LoRaWAN Plus alternative would be the option to recommend for implementation feasibility. Comparatively speaking, this alternative has a reasonable cost and would offer commanders superior value. In addition to the LoRAWAN Plus alternative, the RFID Traditional (active) alternative could be further explored due to its very low cost. The Army already uses this system on a much larger scale and could explore how it would perform in tracking assets within an Army installation. Additionally, experts within the Army understand the details of this system which would make implementation and validation easier compared to other alternatives.

3.2 Future Work

If the LoRaWAN Plus alternative were to be considered for implementation at Fort Bragg, a detailed design plan would need to be created outlining considerations such as the position of the readers, the connections to the readers, and the configuration of the LoRaWAN software to a user interface. Testing procedures would also have to be generated in order to validate the system for proper functionality. The same applies to the RFID Traditional (active) alternative, with the exception that a suitable user interface would need to be determined since the Army already uses one.

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