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Next Generation Logistics Ship Automation and Uncrewed Underway Replenishment

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Abstract

The objective of this research is to analyze and propose comprehensive, adaptive, reusable, and innovative modeling processes to assist the U.S. Navy (USN) and Department of Defense (DoD) with Next Generation Logistics Ship (NGLS) automation for estimating and modeling underway replenishment (UNREP). The processes aim to assist in calculating, modeling, valuing, and optimizing a framework for estimating and modeling the UNREP equipment and emergency breakaway investigations. With a heightened strategic focus on distributed maritime and expeditionary advanced operations, this research suggests advanced technological research and development of unmanned UNREP equipment and support systems focused on uncrewed or minimally crewed combat logistics support operations.

The considerable rise in unmanned surface vessels, as well as automated and uncrewed UNREP research, demands the exploration of fueling and storage replenishment at sea, cargo stowage, and handling for unmanned or minimally staffed UNREP equipment operation. Technology development durations, investment costs, and benefits are calculated via this research, and ways to identify and execute emergency breakaway uncrewed or minimally crewed approaches are proposed. This research uses advanced analytical integrated risk management methodologies such as Monte Carlo simulation, stochastic forecasting for uncertainty modeling, knowledge value add analysis, portfolio optimization, prototype strategic flexibility alternatives, technology development durations, and investment options. Based on the results, the research anticipates substantial performance improvements alongside the UNREP processes category, aided by potential new automation.

This research proposes possible paths for advanced technology research and development of unmanned UNREP equipment and support systems, using advanced analytical techniques for technology development timelines estimations, investment analysis, and portfolio optimization. By outlining various strategies and options for identifying situations that warrant standard or emergency procedures, this research informs decision-makers on optimal conditions for UNREP using appropriate technology options that would minimize cost and maximize the efficiency and effectiveness of uncrewed or minimally crewed operations.

Introduction

Research by Koteskey (2020) highlighted the significant portion of refueling time that in-port refueling takes up for U.S. naval surface combatants, despite the Navy consistently deploying around 100 ships post–Cold War. In a major conflict, the inability to access conventional supply ports may make underway replenishment (UNREP) crucial for delivering necessary equipment, supplies, and forces during initial operational phases. To address this need, the research proposes exploring automated and uncrewed UNREP options, particularly with the emergence of unmanned surface vessels (Military Analysis Network, 1999). The study aims to identify potential approaches for unmanned or minimally staffed operation of UNREP equipment, such as fueling and storing replenishment at sea, cargo stowage, and handling. It also outlines paths for advanced technology research and development of unmanned UNREP equipment and support systems, estimating technology development timelines, required investments, and potential benefits.

Additionally, the investigation focuses on emergency procedures for UNREP, including emergency breakaways, and identify approaches for identifying situations warranting emergency breakaways and executing them using uncrewed or minimally crewed methods. The research estimates technology development timelines and required investments for these emergency protocols. Furthermore, the project aims to enhance decision-making processes by introducing advanced analytically based methods of integrated risk management, such as Monte Carlo simulation, stochastic forecasting, portfolio optimization, and strategic flexibility options for prototypes. These methodologies are crucial for avoiding costly disasters in system development and will be instrumental in assessing risks and uncertainties associated with UNREP operations. Moreover, the research project analyzes the application of Integrated Risk Management methodology for decision support, incorporating real options valuation methodology. This approach, successfully used in commercial industries and Navy shipbuilding, assesses the total future value of decisions made under high uncertainty. It includes options like waiting, switching, expanding, sequential development, and prototyping to make informed decisions in uncertain environments.

Research Objective

The Next Generation Logistics Ship (NGLS) analysis of alternatives (AOA) guidance directs the Navy to explore a purpose-built uncrewed or optionally crewed solution for NGLS. Across the Department of Defense (DoD), interest remains strong for uncrewed capabilities, with a heightened focus on uncrewed or minimally crewed solutions for the Combat Logistics Force based on the support of Distributed Maritime Operations (DMO) and Expeditionary Advance Base Operations (EABO) requirements. The Navy's study team is developing concepts to support this AOA alternative (DoN, 2001). This task should explore the systems and technologies required to significantly reduce, if not eliminate, the personnel required to conduct UNREP of U.S. Navy ships using U.S. Naval Auxiliary CLF ships.

Literature Survey

Miller et al. (1987) explained UNREP, which is the safe delivery of maximum cargo in the shortest time. The U.S. Navy operates an unusual cargo ship fleet that must unload goods in motion and transfer them to combatant ships only 150 feet apart. The current system is a combination of seamanship and engineering, with the modern UNREP fleet spanning from small breakbulk cargo ships to big, fast, technologically advanced vessels that can concurrently transfer fuel, ammunition, and supplies day or night, in good or bad weather.

The contents of Naval Warfare Publication 4-01.4, *Underway Replenishment*, are intended to prepare both the replenishment ship and the clientship for a replenishment evolution. Specific criteria are created for all replenishment elements at sea, including rig composition, required equipment, and standard operating procedures. UNREP transfers fuel, ammunition, supplies, and troops from one ship to another while the ships are in motion. There are two primary types of UNREP: linked (CONREP) and vertical (VERTREP), and they may be used separately or simultaneously. In connected replenishment, two or more ships steam alongside one another as hoses and lines transfer fuel, ammunition, supplies, and troops (Chen & Fang, 2001).

Several variables favor ship-to-ship refueling over replenishing at a distance. Refueling alongside allows the oiler or other auxiliary ship to simultaneously service two ships, each with several replenishment stations. Additionally, replenishing alongside allows the entire formation of ships to sustain a higher speed (up to 16 knots instead of the 7 to 8 knot maximum for astern refueling). With new innovative technologies, replenishment processes at sea continue to develop. The Standard Tensioned Replenishment Alongside Method (STREAM) is used in both replenishment at sea (RAS) and fueling at sea (FAS) evolutions and is favored over other connected techniques because it allows for greater ship separation. Hewgley and Yakimenko

(2009) examined more unorthodox UNREP techniques, such as precision-guided airdrops, which deliver autonomous cargo packages that guide themselves to a precise landing spot by controlling an attached aerodynamic decelerator (parafoil or parachute). The study highlighted the difficulty of resupplying navy warships at sea and the potential benefits of precision airdrop application.

Analyzing UNREP Processes

Curtin's 2001 study developed a conceptual model that combines current UNREP processes with operational scenarios, including Operational Maneuver From the Sea (OMFTS) and Sea Based Logistics (SBL). The model was modified to estimate UNREP cycle times under different conditions. Experiments showed that increasing helicopter lift capacity significantly reduced cycle time, particularly UNREP cycle time. The simulation model also detected constraining resources on crucial operations paths. The findings contribute to the future configuration of amphibious ships for SBL. The study concluded with the following recommendations:

(i) Increasing the lift capacity of the helicopter conducting the UNREP in our model significantly reduced the total cycle time and UNREP cycle time of the inter/intra ship materiel movement process.

(ii) Increasing the number of helicopters used to conduct UNREP operations in our model only marginally decreased the total cycle time. This suggested that the cargo elevators were a bottleneck and could not move the pallets to their final destination at the same rate they received on the LHD.

(iii) Simulation models are used to understand how systems behave. This is especially useful because any "what-if" type experiments can be performed to gain insight into the future system's performance (Kyrkjebø et al., 2004).

UNREP Process

Rowling et al. (2019) developed a scheduling model for indefinitely replenishing a naval task group by UNREP vessels, which had to travel back and forth to a distant port. Constrained optimization can be applied to optimize various measures of effectiveness, such as the amount of slack time a replenishment ship is not needed and the maximum distance offshore a combination of replenishment ships can support naval and joint operations. Dun (1992) examined situations where operational requirements limit the time spent conducting replenishment, focusing on the time needed to transit between ships and the combat value added to the battle group by replenishment. However, the UNREP process has significant risks, including hydrodynamic problems between two moving ships in waves and interaction disturbances in surface vessel maneuvering and position tracking that often require high-precision controllers (Fu & Haddad, 2003). The baseline procedure for the overall UNREP process is enumerated in more detail, providing context for the more general subprocesses described in the Knowledge Value Added (KVA) analysis.

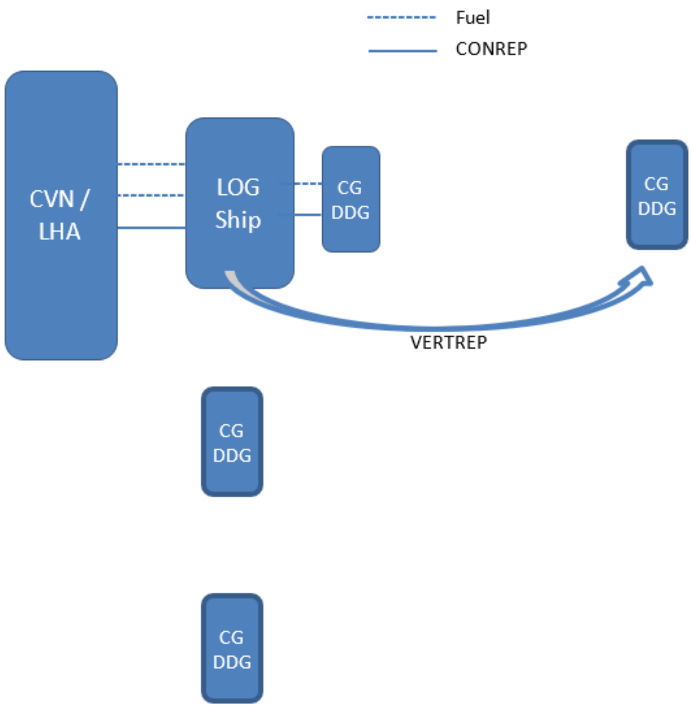


Figure 1. Underway Replenishment

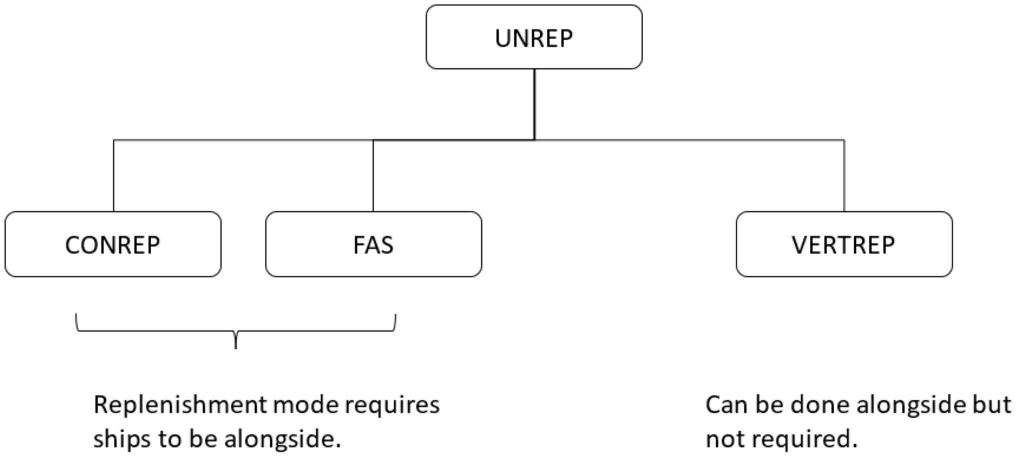
Baseline Procedures

UNREP is broken down into the following modes:

- CONREP
    - Palletized cargo transfer via span wire
    - Personnel transfer via span wire
- FAS
    - Liquid fuel transfer via span wire
- VERTREP
    - Cargo and personnel transfer via helicopter

CONREP and FAS are similar in processes. VERTREP has its own process.

- When we UNREP a carrier strike group (CSG) or amphibious ready group (ARG), we generally work in the formation depicted in Figure 1. A large deck comes alongside the port first, and then a CG/DDG comes alongside the starboard of the LOG. We can do 4 to 5 CG/DDG simultaneously with the large deck.
- When a CG/DDG is complete, they push out to starboard, and we continue to send cargo via helo until complete. The next CG/DDG drifts out to line up for the approach to starboard and then runs the approach. Once the CG/DDG is complete with UNREP, the tactical command (OTC) officer maneuvers them to a screen position.



Replenishment mode requires ships to be alongside.

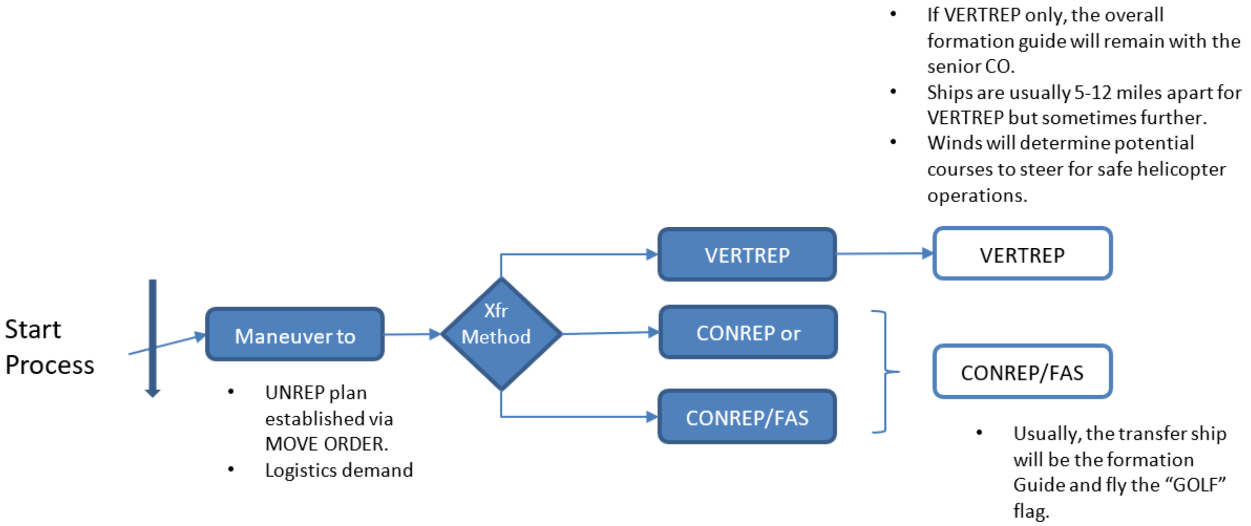
Can be done alongside but not required.

Figure 2. Subprocesses in UNREP

Ships logistic demand signal is sent via the following:

1. **OPSTAT RASREQ:** signals RAS requirements to the OTC and/or the CLF ship
2. **OPTASK RAS:** the OTC/URG commander’s or replenishment ship’s confirmation message containing details of the UNREP event
3. **OPSTAT RAS:** UNREP ship provides details of rigs and stations
4. **OPSTAT CARGO:** CLF ship report of major cargo remaining after UNREP

Provisions (all but Class III and V supplies, in slide notes [United States Department of the Army, 2008], see appendix) are procured, packed, and palletized at logistics centers via the Naval Sustainment System-Supply (NSS-S). Pallets are sent to sea via single-product ships (oilers [T-AO], dry cargo, and ammo transports [T-AKE]). Cargo is sometimes consolidated into a multiproduct ship (oiler/ammo/dry cargo), which are fast combat logistics ships (T-AOE) that can keep up with the speed of the CSG.

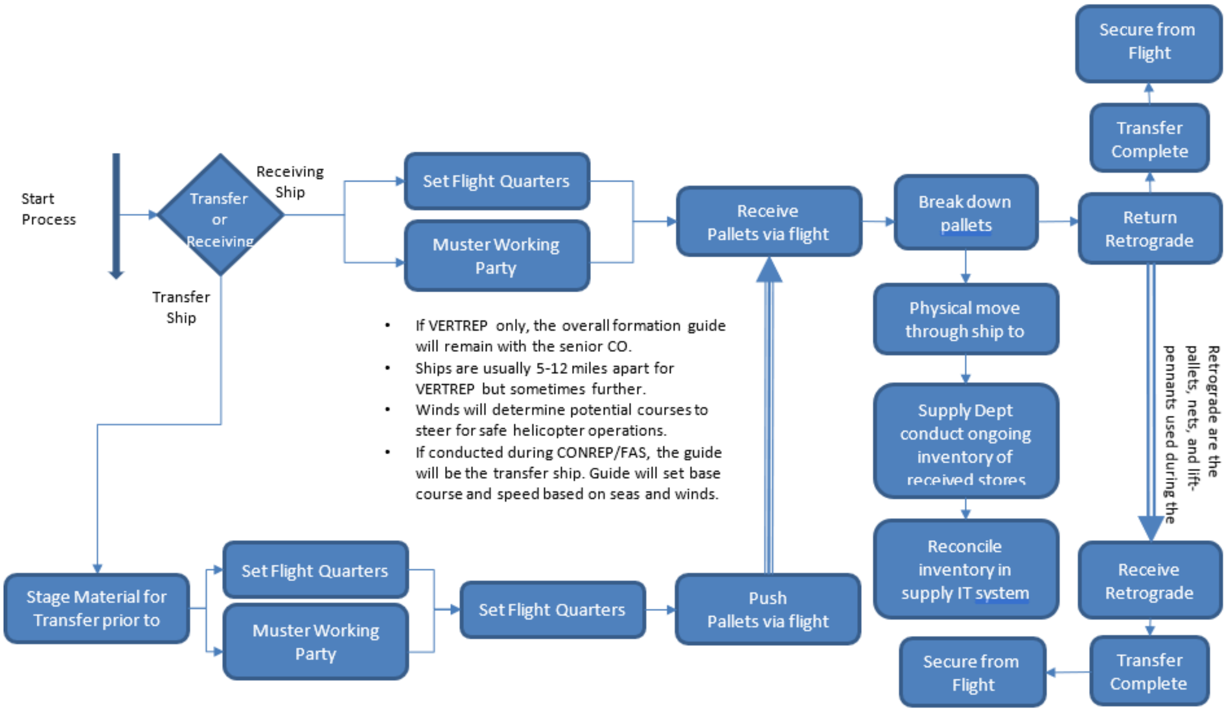


- If VERTREP only, the overall formation guide will remain with the senior CO.
- Ships are usually 5-12 miles apart for VERTREP but sometimes further.
- Winds will determine potential courses to steer for safe helicopter operations.

- UNREP plan established via MOVE ORDER.
- Logistics demand

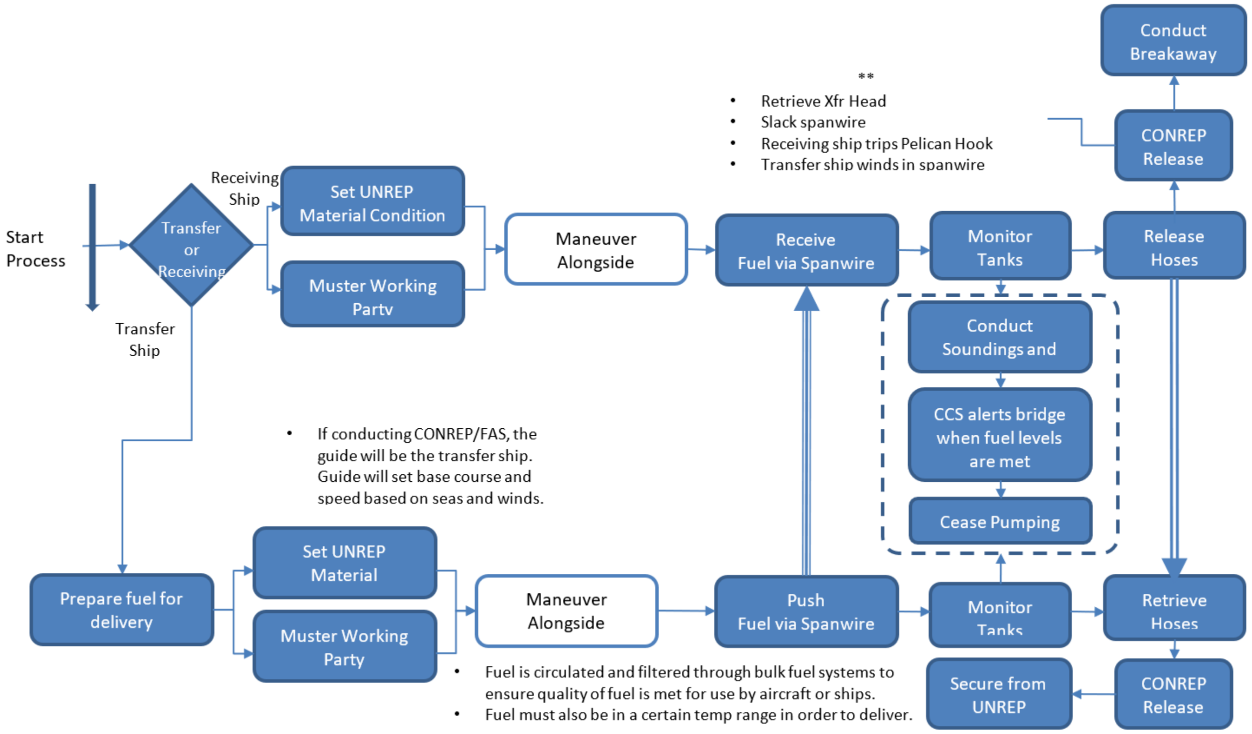
- Usually, the transfer ship will be the formation Guide and fly the “GOLF” flag.

Figure 3. Overall UNREP Process



- If VERTREP only, the overall formation guide will remain with the senior CO.
- Ships are usually 5-12 miles apart for VERTREP but sometimes further.
- Winds will determine potential courses to steer for safe helicopter operations.
- If conducted during CONREP/FAS, the guide will be the transfer ship. Guide will set base course and speed based on seas and winds.

Figure 4. VERTREP Subprocess



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- Retrieve Xfr Head
- Slack spanwire
- Receiving ship trips Pelican Hook
- Transfer ship winds in spanwire

- If conducting CONREP/FAS, the guide will be the transfer ship. Guide will set base course and speed based on seas and winds.

- Fuel is circulated and filtered through bulk fuel systems to ensure quality of fuel is met for use by aircraft or ships.
- Fuel must also be in a certain temp range in order to deliver.

Figure 5. FAS Subprocess

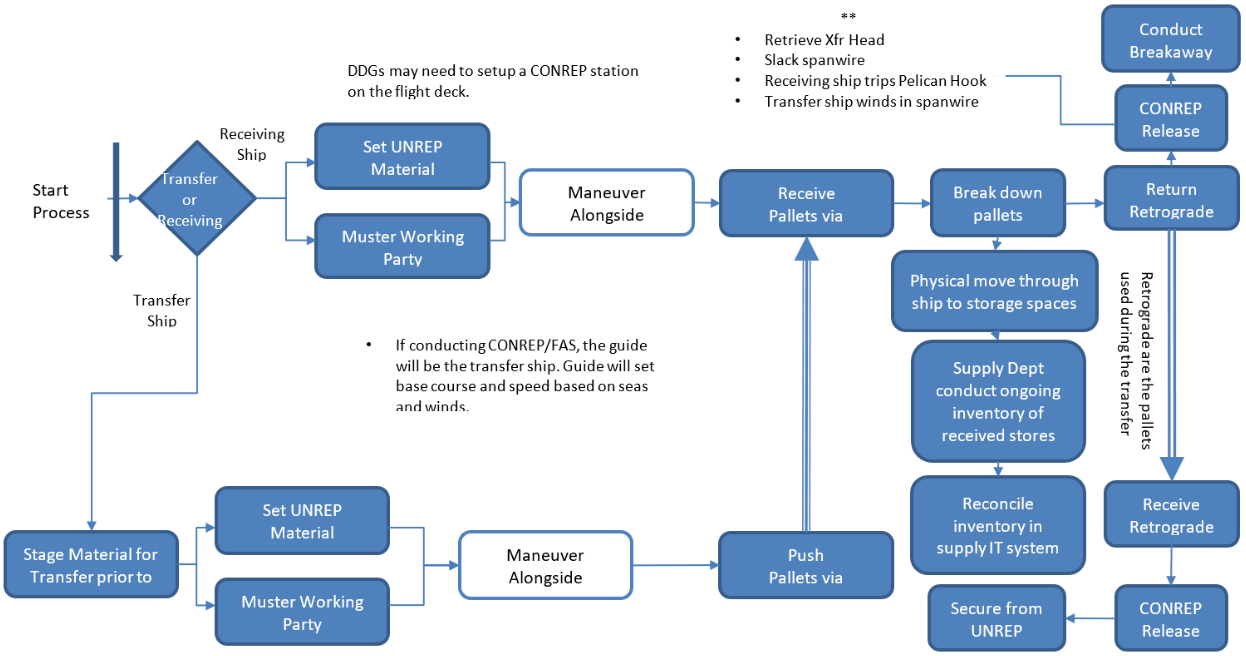

Figure 6. CONREP Subprocess

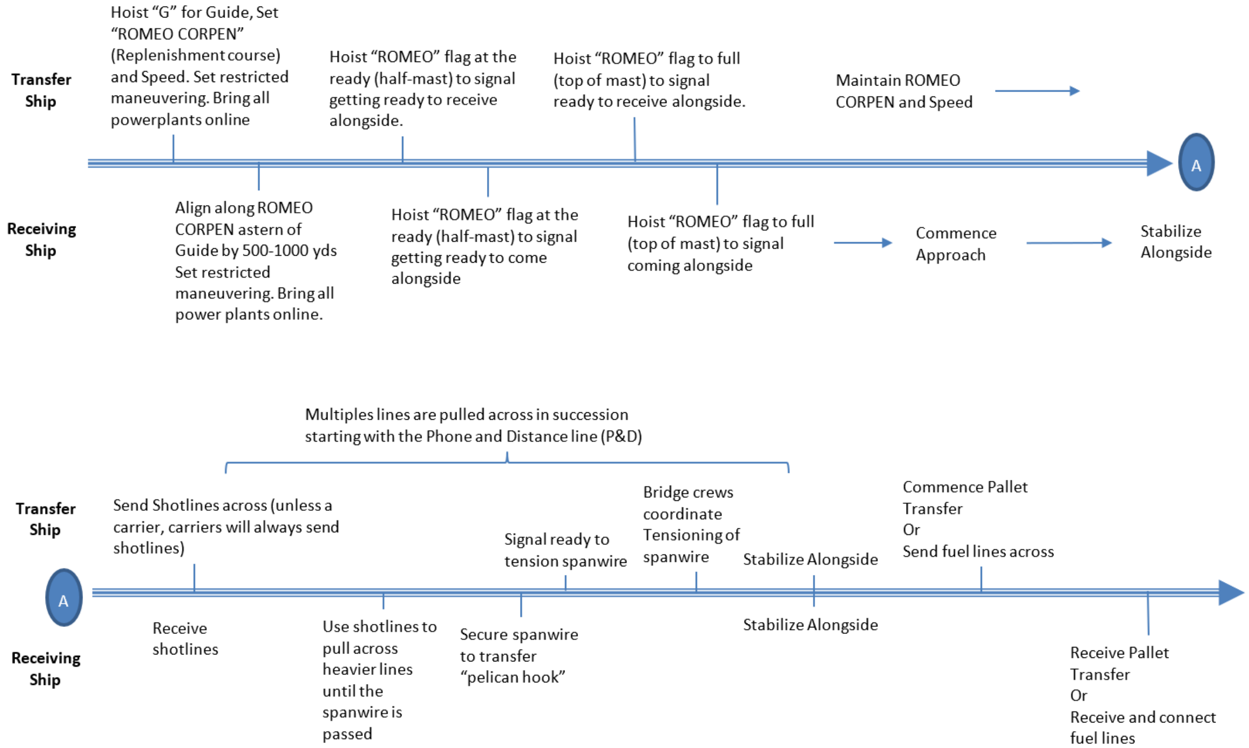

Figure 7. Maneuver Alongside Subprocess

Analysis of Alternatives: Technologies and Techniques

The Navy must adopt radical approaches to find alternatives to the current UNREP process, which relies heavily on legacy equipment. This includes the need to change significant UNREP equipment aboard ships, such as the CONREP station on the flight deck, and the need for special equipment to fuel large deck ships. This research proposes substituting new automation technology for existing “analog” processes such as the phone and distance communication lines. These could be replaced by laser rangefinders that display the distance between ships on large LED displays. This would eliminate 2 to 3 personnel on the transferring ship and eliminate the need for sound-powered phones or signals. The number of personnel required for the overall personnel alongside the UNREP process can be reduced by providing more automation and analog equipment, such as wheeled transfer rails. The potential risk is that these are another thing to pack for the future alongside UNREP and have been known to break.

KVA + Integrated Risk Management Analysis Description

The KVA method aims to capture the value information within each subprocess of the UNREP process, ensuring a reliable estimate of returns on investment (ROI) and return on knowledge (ROK). The KVA analysis involves comparing inputs from subject matter experts (SMEs) to create an accurate model of the process and its subprocesses. The utilization of the KVA method in analyzing the UNREP process, specifically focusing on the As-Is baseline and To-Be optimization analyses, provides an important consideration for this research.

The ROI ratio and ROK estimate are key components of the analysis, with the ROI ratio requiring a monetized numerator and denominator for revenue-cost/cost calculation, while the ROK estimate is revenue/cost, representing the monetized benefits to cost ratio. The KVA analysis allows for comparing subprocess performance, making the baseline information comparable and facilitating a defensible assessment of potential performance improvements in the To-Be model. Common units of output, representing the value produced by a process at a specific time, are used in the KVA method and monetized using the market comparables valuation technique. This technique enables the calculation of relative total revenue for each subprocess based on revenue per unit and the number of common output units. The resulting ROI information for each subprocess is crucial in modeling the effects of subprocess optimizations across the UNREP process, aiding in forecasting potential performance enhancements.

The KVA analysis results are presented in tables for the As-Is baseline and To-Be optimization analyses, which are then used in the Integrated Risk Management (IRM) method to determine each process optimization element’s forecasted real option value. These real options results are incorporated into portfolios, considering the level of risk associated with each real option. The combination of KVA and IRM methods has been employed for nearly 2 decades to optimize DoD and naval processes. Endnotes providing basic assumptions for the KVA analyses are included, and a more detailed description of the combined KVA+IRM method can be found in the report’s appendix. All KVA spreadsheets are available upon request, emphasizing transparency and accessibility of the analysis results.

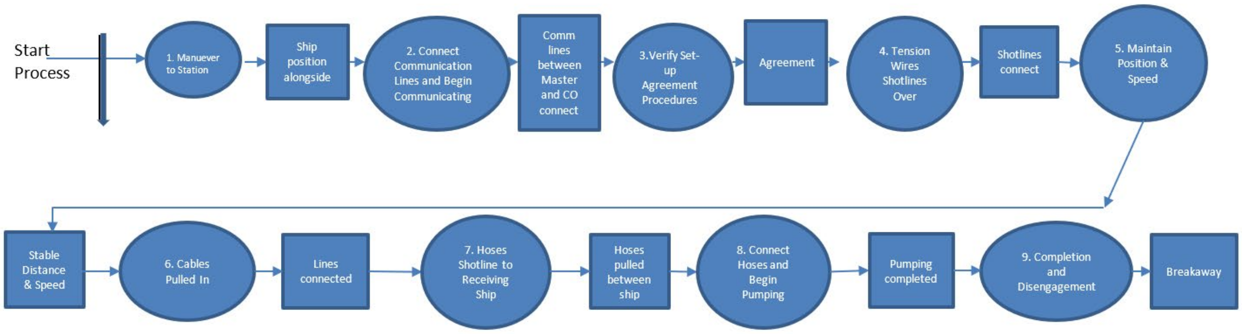

Figure 8. Along Side Process: As-Is Optimization

Table 1: Along Side UNREP KVA As-Is Analysis I

Process	TLT	Total K	Expenses	Revenues	Denominator	Numerator	ROK	ROI
1. Maneuvering to Station	26400.00	26400.00	$ 60,930	$ 242,789	$ 60,930	$ 242,789	398%	298%
2. Comm lines connected	5280.00	5280.00	$ 10,508	$ 48,558	$ 10,508	$ 48,558	462%	362%
3.Set-up Agreement Procedures	35200.00	35200.00	$ 23,654	$ 323,719	$ 23,654	$ 323,719	1369%	1269%
4.Tension lines received	17600.00	17600.00	$ 8,326	$ 161,859	$ 8,326	$ 161,859	1944%	1844%
5. Maintain Distance and Speed	35200.00	35200.00	$ 49,378	$ 323,719	$ 49,378	$ 323,719	656%	556%
6. Cable Pulled In	8800.00	8800.00	$ 9,433	$ 80,930	$ 9,433	$ 80,930	858%	758%
7. Hose Shotline Over	8800.00	8800.00	$ 26,940	$ 80,930	$ 26,940	$ 80,930	300%	200%
8. Connect Hoses	3520.00	3520.00	$ 8,478	$ 32,372	$ 8,478	$ 32,372	382%	282%
9. Completion and Disengagement (Breakaway)	32160.00	32160.00	$ 8,055	$ 295,761	$ 8,055	$ 295,761	3672%	3572%
Total	140800.00	172960.00	$197,647	$ 1,294,875	$ 197,647	$ 1,294,875	655%	555%

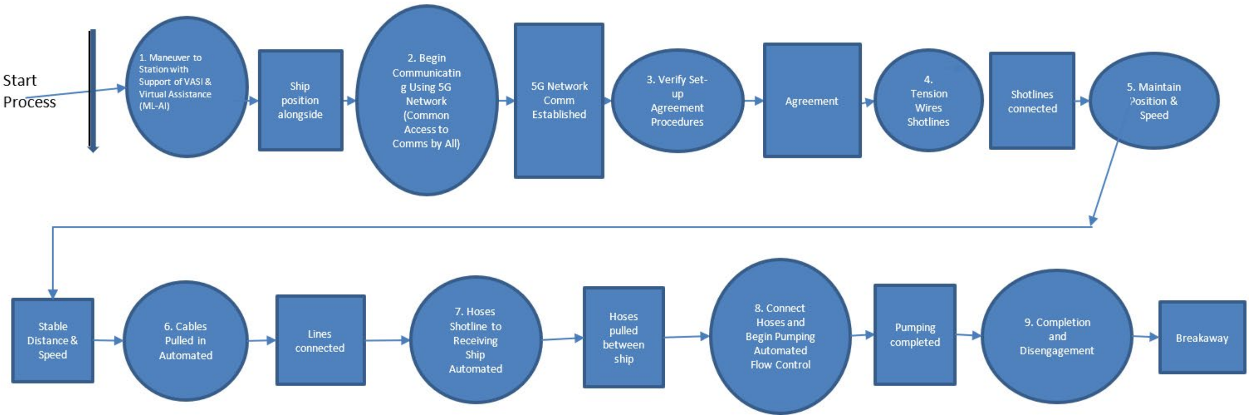

Figure 9. Along Side Process: To-Be Optimization

Table 2: Along Side Process To-Be Optimization II

Process	TLT	Total K	Expenses	Revenues	Denomiator	Numerator	ROK	ROI
1. Manuevering to Station	36000	36000	$ 16,489	$ 331,200	$ 16,489	$ 331,200	2009%	1909%
2. Comm lines connected	5280	5280	$ 8,631	$ 48,576	$ 8,631	$ 48,576	563%	463%
3.Set-up Agreement Procedures	35200	35200	$ 21,263	$ 323,840	$ 21,263	$ 323,840	1523%	1423%
4.Tension lines received	28800	28800	$ 311	$ 264,960	$ 311	$ 264,960	85236%	85136%
5. Maintain Distance and Speed	35200	35200	$ 16,459	$ 323,840	$ 16,459	$ 323,840	1968%	1868%
6. Cable Pulled In	8800	8800	$ 311	$ 80,960	$ 311	$ 80,960	26044%	25944%
7. Hose Shotline Over	8800	8800	$ 9,090	$ 80,960	$ 9,090	$ 80,960	891%	791%
8. Connect Hoses	6080	6080	$ 544	$ 55,936	$ 544	$ 55,936	10287%	10187%
9. Completion and Disengagement (Breakaway)	32160	32160	$ 5,155	$ 295,872	$ 5,155	$ 295,872	5739%	5639%
Total	164160	196320	$ 73,098	$ 1,510,272	$ 73,098	$ 1,510,272	2066%	1966%

Table 3. Assumptions and Analysis of the As-Is to To-Be Potential Optimizations

1. Maneuvering to Station: The 1611% net improvement in this subprocess is expected to be a result of implementing an automated approach system that provides an automated rudder and power setting to the receiving ship (comparable to an instrument landing system and autopilot to landing aircraft) which would increase speed of approach and decrease the need for constant bridge watch team having to monitor and correct the approach. This potential automation would increase this subprocess' information value and substantially reduce its cost.
2. Comm lines connected: There was no significant improvement, 101%, expected in this subprocess. There was a potential minor cost reduction as a result of implementing a 5G network for all watch standers.
3.Set-up Agreement Procedures: There was a minor improvement, 127%, expected in this subprocess as a result of implementing by completing this subprocess further in advance of the actual alongside UNREP. This potential optimization would provide an incremental cost reduction for this subprocess.
4.Tension lines received: Reengineering of this subprocess is expected to result in a substantial, 83292%, optimization as a result of implementing automated firing and receiving shot lines which would dramatically increase the information value and decrease the cost for this subprocess. The forecasted overall process optimization improvement was very sensitive to this potential subprocess reengineering.
5. Maintain Distance and Speed: The net improvement in this subprocess, 1312%, is expected to be a result of implementing automated helm and power settings of the receiving ship in this subprocess.
6. Tension Cable Pulled In: Reengineering of this subprocess is expected to result in a substantial, 25186% improvement in this subprocess as a result of implementing newly designed king post tensioning system either by moving king posts, i.e., in or out, or by varying king post height. This potential optimization is expected to provide a substantial cost reduction.
7. Hose Shotline for Fuel Hoses Over: The net improvement, 591%, in this subprocess is expected to be a result of implementing an automated shot line firing and recovering system. This would potentially increase the information value of this subprocess while also providing a substantial reduction in the cost.
8. Connect Hoses: Reengineering of this subprocess is expected to result in a substantial, 9905%, improvement in this subprocess as a result of implementing an automated system to extend hoses via the tension wires. This potential optimization would result in a substantial reduction in cost.
9. Completion and Disengagement (Breakaway): The potential net improvement, 2067%, in this subprocess is expected to be a result of implementing an automated low risk maneuvering capability. This optimization would substantially reduce the cost of this subprocess.

Results And Conclusions

The KVA analysis revealed a significant potential increase in ROI, primarily driven by cost optimizations in subprocesses and enhanced knowledge expertise from new automation. The analysis highlighted the value of knowledge embedded in automation and its impact on process optimization. The To-Be model's subprocess optimizations formed the basis for IRM analysis, which assessed the risks associated with each optimization option. The IRM results provided a more thorough estimate of potential values and aided sponsor leadership in investment decision-making by considering risk–reward benefits. The research proposed advanced analytical modeling processes integrating IRM and Strategic Real Options to quantify and optimize a framework for estimating and hedging prototyping uncertainty. Monte Carlo simulations were used to determine the Expected Value of Information and the value of prototyping, assisting decision-makers in understanding the criticality of prototyping. A tornado static sensitivity analysis identified critical success factors for ROI, leading to 100,000 Monte Carlo risk simulation trials comparing As-Is and To-Be models. The simulations showed a significant improvement in ROI with the To-Be model, indicating an average net ROI improvement of 843%. In most of the other subprocesses, the ROIs increased due to cost improvements.[1]

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[1] We did not incorporate the cost of the new automation as it has yet to be selected and it would have been spread like peanut butter across the entire process making it a constant. The team at Naval Warfare Center, Point Hueneme has been working on a

The KVA analysis demonstrated the potential for a substantial increase in ROI through cost optimizations and enhanced knowledge expertise from new automation. The analysis preserved the information value of subprocesses and quantified the value of knowledge embedded in automation. The To-Be model's subprocess optimizations formed the basis for IRM analysis, which assessed risks associated with each optimization option. The IRM results provided a more thorough estimate of potential values and aided sponsor leadership in investment decision-making by considering risk–reward benefits. The research proposed advanced analytical modeling processes integrating IRM and Strategic Real Options to quantify and optimize a framework for estimating and hedging prototyping uncertainty. Monte Carlo simulations were used to determine the Expected Value of Information and the value of prototyping, assisting decision-makers in understanding the criticality of prototyping.

A tornado static sensitivity analysis identified critical success factors for ROI, leading to 100,000 Monte Carlo risk simulation trials comparing As-Is and To-Be models. The simulations showed a significant improvement in ROI with the To-Be model, indicating an average net ROI improvement of 843%. For an As-Is and To-Be 90% confidence interval, the simulated Option ROI shows a 525% and 588% ROI on As-Is and a marked improvement to 1,059% and 1,782% ROI (Figure 11). The difference is an average net ROI improvement of 843% if the To-Be improvements are incorporated (Figure 12).

This risk–reward analysis was based on inputs from the process SMEs' inputs and may be subject to updates from the given priorities of the sponsor. There may also be further, more detailed inputs to the KVA+IRM analysis based on ongoing research at the Naval Warfare Center in Point Hueneme. Further research would be required to solicit and review these various input sources for our models. However, our estimates support the potential performance improvements alongside the UNREP process when aided by potential new automation.

Future Research and Limitations

The UNREP process involves various considerations, including conducting UNREP to service the fleet in a distributed force context, ensuring sufficient LOG ships, and considering possible formations and distributions of the fleet. Improvements in naval operational efficiency are being made, including fuel, personnel, hybrid systems, and automation. Including Allied capabilities is also important, as it is expected that we will need to rely more on allies' contributions in future naval combat scenarios. This could be achieved by providing host nations with smaller but quicker turn logistics support vessels, which can be used as refueling platforms. This would require optimizing fuel flow forward and rethinking CONOPS of potential daisy-chain operations. The study did not explicitly consider other technologies required to refine the coming alongside process. A two-dimensional version of the Instrument Landing System could be put onboard receiving ships to guide them more efficiently alongside UNREP. Another potential implementation is for the replenishment ship and receiving ship to be connected in an "auto-drive" capability, which could reduce danger and improve seakeeping in higher sea states.

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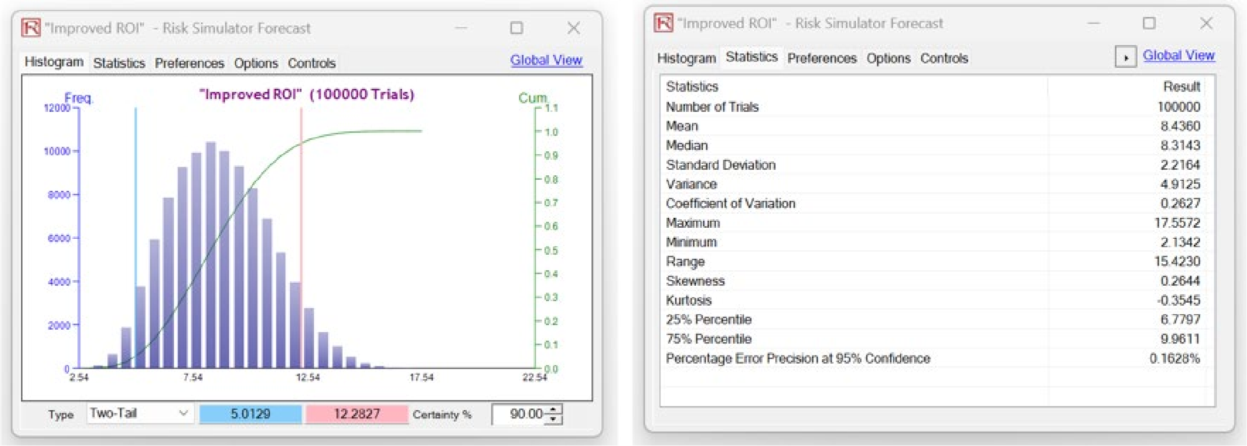
series of new automation capabilities for the alongside UNREP process, and when these trials are successfully completed, they estimated that the overall cost of the process would be halved (per their website information).

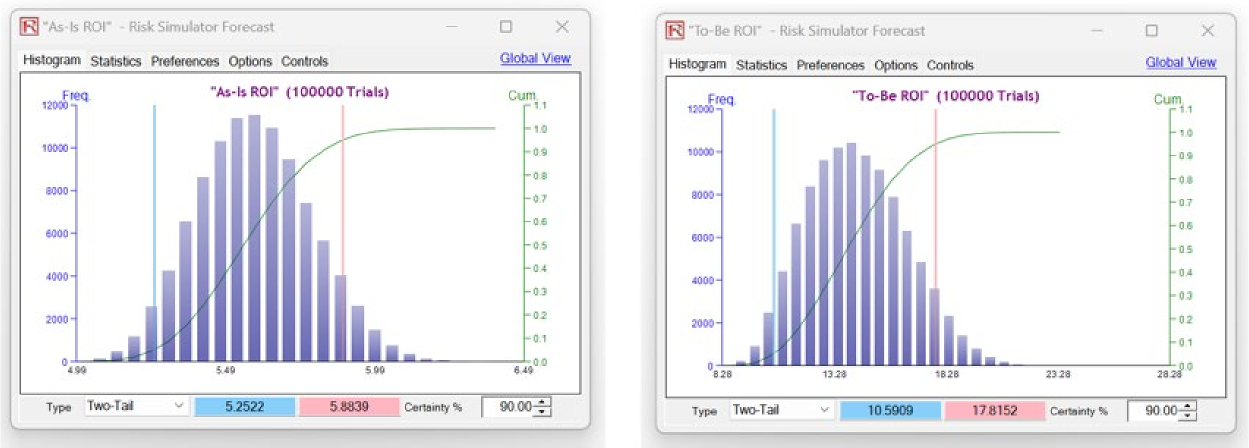


Type: Two-Tail 5.0129 12.2827 Certainty % 90.00

Statistics	Result
Number of Trials	100000
Mean	8.4360
Median	8.3143
Standard Deviation	2.2164
Variance	4.9125
Coefficient of Variation	0.2627
Maximum	17.5572
Minimum	2.1342
Range	15.4230
Skewness	0.2644
Kurtosis	-0.3545
25% Percentile	6.7797
75% Percentile	9.9611
Percentage Error Precision at 95% Confidence	0.1628%

Figure 10. Simulated Option Return on Investment for As-Is and To-Be

Figure 11. Tornado Static Sensitivity



Type Two-Tail 5.2522 5.8839 Certainty % 90.00

Type Two-Tail 10.5909 17.8152 Certainty % 90.00

Figure 12. Simulated Option Return on Investment Increment

Appendix A: Assumptions for To-Be Calculations

- All basic assumptions about potential optimizations of the subprocesses are based on SMEs estimates and can be updated over time as the alongside subprocess new automation and procedures are implemented.
- The cost of implementing new automation for the alongside UNREP process at Port Hueneme is expected to be spread out and amortized over a 10–15-year period. The team developing the automation was unable to provide cost estimates for the current automation being tested, likely due to ongoing testing. Future studies may provide more accurate cost data for the new automation.
- The market comps estimates for the ROI surrogate revenue values were based on a 1.7 acceleration for sailor salaries in addition to a 1.5 or 50% increase of the total price that the market would pay to obtain the same process outputs.
- A day is equal to 8 working hours; 40 working hours per week; 4 weeks per month; 365 days per year.
- Rank Order of Difficulty to learn has 8 as the most difficult to learn, and 1 is the least difficult to learn.
- There are 260 working days per year.
- Automation was treated as a constant of 10% for knowledge of how to use the basic MS Office suite.
- Hourly wage is calculated from the 2023 basic pay table provided by DFAS.
- Hourly Wage is equal to the Basic Pay divided by working days times the amount of hours worked in a day.
- The revenue numerator equals the ratio of knowledge of each process to total knowledge multiplied by the total revenue.
- Times used per year are based on the number of UNREPS.
- All sailors possess a minimum of a high school reading level and several years of experience.
- All sailors possess basic office suite knowledge (Outlook/Word/Excel/PowerPoint...)
- Hourly wages based on the basic pay rate without BAH.
- Infrastructural cost, i.e., the cost of ships, fuel, hoses, etc.**. This cost was considered as a constant for the average UNREP and was not included in the cost for an average UREP. The focus was on personnel and automation costs.
- Asked Subject Matter Experts to verify or change estimates.
- The price per unit of output, K-unit, remained constant while the cost per common unit of output varied. This information will be used for future research on portfolio optimization, focusing on

potential new automation like the UNREP process improvements developed by the Port Hueneme team. Learning time estimates are a combination of formal and OJT.

- The average learner has an OOD underway, a qualified bosun's mate, and a supply officer.
- Correlation Rank order = 93%
- To learn how to do the Replenishment process (hours) = Jr officer deck qual = 200; Officer of deck qual = 300 and Actual Average LT
- Underway replenishment JOOD = 100; qualified underway OOD = 50
- The ship Captain and XO costs are not part of the cost estimate.

Appendix B: Assumptions for As-Is calculations

- The market comps included a 1.7 acceleration for salary and a 1.5 or 50% increase of the total price that the market would pay to obtain the same outputs.
- A day is equal to 8 working hours; 40 working hours per week; 4 weeks per month; 365 days per year.
- Rank Order of Difficulty to learn has 8 as the most difficult to learn, and 1 is the least difficult to learn.
- There are 260 working days per year.
- Automation is a constant of 10% for knowledge of how to use the basic MS Office suite.
- Hourly wage is calculated from the 2023 basic pay table provided by DFAS.
- Hourly Wage is equal to the Basic Pay divided by working days times the amount of hours worked in a day.
- The revenue numerator is equal to the ratio of knowledge of each process to total knowledge multiplied by the total revenue.
- Times used per year are based on the number of UNREPs.
- All sailors possess a minimum of a high school reading level.
- All sailors possess basic office suite knowledge (Outlook/Word/Excel/PowerPoint...)
- Hourly wages based on the basic pay rate without BAH.
- Infrastructural cost, i.e., the cost of ships, fuel, hoses, etc.**. This cost was considered as a constant for the average UNREP and was not included in the cost for an average UNREP. The focus was on personnel and automation costs.
- Asked Subject Matter Experts to verify or change estimates.
- The price per unit of output, K unit, was constant because all the common output units were the same. However, the cost per common unit of output varied. These assumptions allow portfolio optimization of future real options for improving the UREP process.
- Learning time estimates are a combination of formal and OJT.
- The average learner has an OOD underway, a qualified bosun's mate, and a supply officer.
- Jr officer deck qual = 200; Officer of deck qual = 300
- To learn how to do Replenishment process (hours) = Underway replenishment JOOD = 100; qualified underway OOD = 50
- The ship Captain and XO costs are not part of the cost estimate.

Appendix C: U.S. Armed Forces classes of supply

Class I – Rations – Subsistence (food and drinking water), gratuitous (free) health and comfort items.

Class II – Clothing and Equipment – individual equipment, tentage, some aerial delivery equipment, organizational tool sets and kits, hand tools, unclassified maps, administrative and housekeeping supplies, and equipment.

Class III – POL – Petroleum, Oil and Lubricants (POL) (package and bulk): Petroleum, fuels, lubricants, hydraulic and insulating oils, preservatives, liquids and gases, bulk chemical products,

coolants, deicer and antifreeze compounds, components, and additives of petroleum and chemical products, and coal.
Class IV – Construction materials, including installed equipment and all fortification and barrier materials.
Class V – Ammunition of all types, bombs, explosives, mines, fuses, detonators, pyrotechnics, missiles, rockets, propellants, and associated items.
Class VI – Personal demand items (such as health and hygiene products, soaps and toothpaste, writing material, snack food, beverages, cigarettes, batteries, alcohol, and cameras—nonmilitary sales items).
Class VII – Major end items such as launchers, tanks, mobile machine shops, some parachute systems, and vehicles.
Class VIII – Medical material (equipment and consumables), including repair parts that are particular to medical equipment. (Class VIIIa – Medical consumable supplies not including blood & blood products; Class VIIIb – Blood & blood components (whole blood, platelets, plasma, packed red cells, etc.).
Class IX – Repair parts and components to include kits, assemblies, and subassemblies (repairable or non-repairable) required for maintenance support of all equipment.
Class X – Material to support nonmilitary programs such as agriculture and economic development (not included in Classes I through IX).
Miscellaneous – Water, salvage, and captured material. Source: (AR-710-2, 2008)

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