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Cost Effective Maritime Surveillance

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Abstract: This paper discusses a comparative cost-based analysis approach for using manned and unmanned aerial platforms for maritime surveillance. The Department of Defense's (DOD) priority is developing innovative technology to keep up with or outpace U.S. adversaries. Emerging surveillance technology can be evaluated with comprehensive comparisons against programs of record. To make this evaluation, an Excel tool was created that will act as a commander's decision tool by providing cost estimates for various surveillance platforms. The tool examines large UASs and manned aircraft in the DOD inventory, as well as non-program of record systems, including new LOCUST (Low Cost Unmanned Aerial System (UAS) Swarming Technology) platforms. To use the tool, the user inputs parameters regarding the available aviation assets, the size of the search area, and the revisit time. Using the costs and capabilities of the various platforms, risk probabilities based on a changing state of military cooperation, competition, or conflict, and previously stated user operation parameters, the tool outputs a list of platforms and their associated costs. The paper analyzes the output of the tool to identify parameters which make the use of some systems advantageous and cost-effective over their counterparts. It also identifies trends where categories of platforms are the best choice in certain scenarios and not in the others.

Keywords: Cost Analysis, Unmanned Aerial System, Maritime Surveillance, Program of Record, LOCUST

1. Introduction

The MITRE Corporation requires a decision tool to provide the most cost-effective way to maintain aerial maritime surveillance for the United States Navy. The tool compares program of record surveillance aircraft (P-8A Poseidon, MH-60R Seahawk, MQ-4C Triton, MQ-8B Fire Scout) with new unmanned aerial systems (UASs) that are of interest to the Navy (Vanilla UAS, Altius-600 UAS, Coyote UAS). However, the tool is not constrained by these platforms. The ability to compare a different platform of interest is an option, given that appropriate platform parameters are known. The decision tool interface is user-friendly and provides the necessary information to make cost-effective operational surveillance decisions.

2. Context Analysis

2.1 Current Situation

The United States Navy currently uses platforms that are readily available in their area of operation to conduct maritime surveillance. This is often the P-8A Poseidon or other manned Intelligence, Surveillance, and Reconnaissance (ISR) capable platforms like the MH-60R Seahawk. Commanders have expert knowledge on how platforms excel in certain operational and atmospheric environments, but lack the tools to easily identify the cost-effectiveness of these platforms. DOD urgently desires to develop technology that outperforms, out-sustains, and out-budgets current surveillance platforms. An easy-to-use decision tool will help decision makers to evaluate the cost effectiveness of new unmanned platforms.

2.2 Objectives

The objective of this project is to create a user-friendly tool that is capable of accepting user inputs pertaining to specific missions, including but not limited to: the aircraft available, the size of and distance to the search area, duration of search, and range of military operation in the area. With these inputs, the tool delivers a cost per hour (CPH), cost per area (CPA), and a total estimated cost for operating each platform in the specified search area. The tool also calculates the cost and effectiveness of using platforms in tandem to provide surveillance over the area. These inputs are accompanied by an editable platform database. The tools database currently holds the data of seven maritime surveillance platforms: P-8A Poseidon, MH-60R Seahawk, MQ-4C Triton, MQ-8B Fire Scout, Vanilla UAS, Altius-600 UAS, and Coyote UAS. The tool is also capable of comparing additional aircraft that a user can incorporate, given they have the required data for that platform.

3. Terminology and Resources

Range of Military Operations (ROMO) is a concept outlined in Joint Publication (JP) 3-0. JP 3-0 defines main categories: "military engagement, security cooperation, and deterrence; crisis response and limited contingency operations; and large-scale combat operations." (United States Military, 2017, p. V-4) The three categories of ROMO are simplified to cooperation, competition, and conflict. These categories will be used in the model to dictate the magnitude of the probability of loss of aircraft. Different ROMO levels affect the probability of loss of the surveillance platform. In the tool, a state of "cooperation" yields a probability of loss of 0.001% which represents a loss of 1 aircraft for every 100,000 flight hours. This value from the Naval Safety Command is approximately the 10-year average (FY11-FY20) rate of Class A flight mishaps in the Navy. (Naval Safety Command, 2022, p. 1) The probability of loss value for "competition" and "conflict" are represented as 0.05% and 0.2% respectively. These probabilities are used as a baseline for the user for the purpose of comparison. The tool allows the user to override these values.

Low-Cost UAS Swarming Technology (LOCUST) is a concept that encompasses the implementation of a swarm of UASs working together to accomplish a specific mission. In the scope of maritime surveillance, the cost of small UASs in a swarm to maintain maritime surveillance of an area will be determined and compared to the current manned and unmanned aerial surveillance platforms. The two LOCUST platforms that are evaluated by the tool are the Coyote UAS and Altius-600 UAS. It is important to note that these platforms must be tube launched. The modes of delivery that are included in the tool are P-8A and MH-60R sonobuoy tubes. The cost-based analysis of the LOCUST includes the costs of delivery methods.

Loss of Life - Peterson and Staley (2011) provides an analysis of air resupply platforms and estimates the cost of operating and supporting these platforms. The study makes a cost of life assumption based on life insurance, survivor benefits, loss of earnings, lost human capital, and welfare lost to society. The study estimates the cost of life at $6 million in 2006 U.S. dollars which inflates to approximately $8 million in 2021 dollars (value in tool). This cost is multiplied with crew size and probability of loss, then added to the hourly cost output for the manned aircraft as a cost penalty for losing a life.

Aircraft Data Collection - The database created for the tool uses data from *Command*, a wargaming and analysis tool which allows for full spectrum war simulation and modeling. The Command database gives access to all platforms and their aircraft data such as cruise speed, sensor capabilities, crew size, and lifespan. Data is also obtained from the *Jane's All the World's Aircraft* publication, Navy.mil, the official websites for the incorporated platforms, and various unclassified online resources. Additionally, information and estimates were obtained from subject matter experts (SMEs) at MITRE, USNA, and Platform Aerospace Corporation. For programs of record, cost data was obtained using the OP-20 and best estimates were made for the new UAS platforms.

Flight Hour Program (FHP) OP-20 Database is a Department of the Navy database published each year. It provides flying hour and cost data for every Navy platform of record by Type/Model/Series by aggregating data collected over several years. The OP-20 is used for fleet planning, budget designing, and platform analysis as used in this project. The OP-20 contains yearly costs, budget, budgeted hours, required (funded) hours, and actual hours for each platform. The platform costs include the contract, depot-level repairables (DLR), maintenance, and fuel costs. For the tool, the OP-20 budget cost (XB) for the P-8A, MH-60R, MQ-4C, and MQ-8B, along with their budget requirement hours (REQHRS) in order to compute a budgeted CPH value is used. This value is used along with other cost factors within the tool to obtain the comprehensive cost output. The OP-20 was provided via Commander of Naval Air Forces Force Readiness Analytics Group (CNAF FRAG). CNAF FRAG analysts provided accurate CPH.

4. Model Data and Design

4.1 Assumptions

The tool assumes that each platform is based on the fiscal year (FY) 2021 cost without inflation considered when considering future capabilities. This model also assumes that the platforms will only be detecting, classifying, and tracking; therefore, offensive combat capabilities are not considered. Additionally, the area of concern is a rectangular section of blue water some nautical mile (nm) distance away from where the platforms takeoff. With this assumption, it is up to the user to assess the environment (physiography and true area dimensions) and incorporate their knowledge on platform advantages in that environment. It is also assumed that the Altius-600 UAS and Coyote UAS are expendable and the Vanilla UAS is reusable. Lastly, the detection and classification ranges of sensors are based on unclassified open-source sensor capabilities and are made editable for the user. It is assumed that the platforms are carrying the most advanced maritime surveillance package and the range is based on detection and classification of a Navy patrol boat sized vessel.

4.2 Model Data

The model contains modifiable data from different manned and unmanned aircraft including cruise speed, endurance, sensor detection and classification range, sweep width, expendability, lifespan, crew size, manufacturing cost, and budgeted cost per flight hour. The spreadsheet currently includes data for the seven platforms (P-8A Poseidon, MH 60R Seahawk, MQ-4C Triton, MQ-8B Fire Scout, and the Vanilla, Altius, and Coyote UASs). These aircraft give the user a baseline for comparison and the ability to discover some cost trends amongst the different platforms. The tool also allows the user to add a platform by filling in the required columns of aircraft specifications. User inputs are calculated with the model data to output cost values and a comparison for each platform.

4.3 Model Design

4.3.1 User Inputs

The tool's cost output is derived from the user inputs, aircraft and sensor specifications, and cost of surveillance calculations performed by the tool. Figure 1 shows the input tab of the Excel tool which allows the user to select the platforms they want to compare. The input tab also allows the user to define the scenario as well as to change the personnel cost and loss of life value. The input tab also allows the user to specify a surveillance strategy and get the cost of using platforms in tandem with each other. The right column in Figure 1 shows where the user can input the number of each platform that they would like to provide maritime surveillance over the specified area and time frame. E2-D is displayed in red in Figure 1 as it represents a new aircraft being added by the user. The user specifies the dimensions of the search area, travel distance from base to search area, required surveillance time duration, and revisit time (frequency of a full area sweep). The user also provides an estimate of the adversary intentions with the ROMO state of the search area. The user can add new aircrafts that are not the original seven platforms in the database. In Figure 1, the aircraft in red is an example of the aircraft that has been added that is not in the original group of seven.

Platform	Distance to Area	**Click to Compare** (Outputs a cost comparison and minimum number of each platform needed to achieve the specified surveillance parameters)	Or	**Number of each Platform in the Air** (Outputs total cost to achieve specified surveillance parameters given that there are X number of each platform in the air at a time. *Ignores Search Frequency, A18)
Coyote UAS	0	☑		
Altius-600 UAS	0	☑		12
		☐		
Vanilla UAS	0	☑		
P-8A Poseidon	0	☑		1
MH-60R Seahawk	0	☑		
MQ-8B Fire Scout	0	☑		
MQ-4C Triton	0	☑		
E-2	0	☑		
		☐		

Survey Area Width (nm)	110		
Survey Area Length (nm)	240		
Size of Survey Area	26400		
Surveillance Duration (hrs)	24		
Revisit Time (hrs)	1		*P_L Override (percentage per hr)
ROMO State (P_L per hr)	Cooperation (0.001%)	Or	
Mode of LOCUST Delivery	P-8		
Personnel Cost ($/hr)	$15		
Loss of Life $	$8,000,000		

Figure 1. User Input Tab

4.3.2 Aircraft Data

Once the user finishes the input tab, they will click on the next tab labeled "Aircraft Data " to check the prefilled values of the database and fill the boxes that are highlighted red if they are adding a new platform to be analyzed. They can also look through the database and make changes to the values. This tab contains the data that is needed to make the surveillance and cost calculations for the selected aircraft. Most columns are straight forward. The classification range represents the approximate unclassified range for the platform's sensors (TV Camera, (Forward Looking Infrared (FLIR), Inverse Synthetic Aperture Radar (SAR/ISAR)) to make a positive identification of a vessel the size of a Navy patrol boat (approx. 85 ft length). The budget costs and the REQHRS comes from the OP-20 report. These values will calculate the "Budgeted CPH" value. However, the user can approximate a CPH value that would account for the Contract, DLR, Fuel, and Maintenance costs of the platform if they do not have access to the OP-20 report. They can then fill that value into the far-right column shown in Figure 2.

Aircraft	Expendable?	Classification Range (nm) of "Patrol Boat Sized" Vessel	Cruise Speed (kts)	Endurance (hrs)	Lifespan (flight hrs)	Crew	Procurement Cost	2021 Contract Budget (XB)	2021 DLR Budget (XB)	2021 Fuel Budget (XB)	2021 Maintenence Budget (XB)	2021 Required Hours (ReqHrs)	2021 Budgeted CPH
Coyote UAS	Y	8	60	2	2	0	$20,000						$0
Altius-600 UAS	Y	8	100	4	4	0	$100,000						$0
Vanilla UAS	N	15	55	72	10000	0	$5,000,000						$600
P-8A Poseidon	N	18	440	10	30000	10	$150,000,000	$36,807,000	$87,140,000	$113,050,000	$32,276,000	58801	$4,579
MH-60R Seahawk	N	15	140	4	10000	4	$43,000,000	$25,094,000	$208,887,000	$19,280,000	$52,019,000	79476	$3,841
MQ-8B Fire Scout	N	12	105	8	10000	0	$27,500,000	$2,432,000	$5,395,000	$158,000	$1,993,000	2213	$4,509
MQ-4C Triton	N	18	250	24	30000	0	$100,000,000	$2,798,000	$560,000	$2,473,000	$9,348,000	5500	$2,760
Platform X													

Figure 2. Aircraft Data Tab

4.3.3 Calculations

While the user completes the "Aircraft Data" tab, the spreadsheet performs surveillance and cost calculations that are shown in Figure 3. These calculations go into the final cost outputs. The "Coverage Area Size" represents the size of the area that each platform can search within the specified search frequency (default - nm/hour.), depending on platform cruise speed and sweep width. The search and detection formula for the coverage area is shown in Equation (1). The "Number Flying Consecutively" is the amount of aircraft needed in the air to cover the entire specified region, while the "Missions Required" is the total number of launches for each platform to provide that level of coverage over the specified time span of the surveillance. "Delivery Missions Needed" as well as the "Delivery Cost" refers to the specified delivery system for the LOCUST platforms (P-8A or MH-60R).

$$\text{Coverage Area} = t * W * v + \pi \left(\frac{W}{2}\right)^2 \text{ where t = search frequency, v = cruise velocity, and W = sweep width} \quad (1)$$

The right side of Figure 3 shows the individual cost calculations that go into the final CPH value in the output. "2021 Budgeted CPH" comes directly from combining the aircraft database budget columns. "Lifespan CPH" represents the depreciation cost of each hour flown by using the manufacturing cost and expected aircraft lifespan. "Loss of Life CPH" and "Loss of Aircraft CPH" are calculated from the probability of loss (P_L) along with the loss of life and manufacturing costs.

Aircraft	Coverage / Sweep Width (nm)	Coverage Area Size (nm²/1 hr)	Time to Area (hrs)	Number Flying Consecutively	Missions Required to Maintain Surveillance	Delivery Missions Needed	P_L per hr	2021 Total Budget	2021 Budgeted CPH	Lifespan CPH	Personnel CPH	Loss of Life CPH	Loss of Aircraft CPH	Delivery Cost
Coyote UAS	16	1161	0.23	23	276	3	50.000%	$0	$0	$0	$0	$0	$10,000	$346,382
Altius-600 UAS	16	1801	0.23	15	90	3	25.000%	$0	$0	$0	$0	$0	$25,000	$346,382
Vanilla UAV	30	2357	1.82	12	12		0.050%	$0	$600	$67	$0	$0	$1,000	
P-8 Poseidon	36	16857	0.23	2	6		0.050%	$269,273,000	$4,579	$6,667	$300	$40,000	$100,000	
MH-60R Seahawk	30	4907	0.71	6	48		0.050%	$305,280,000	$3,841	$4,770	$360	$16,000	$23,850	
MQ-8B Fire Scout	24	2972	0.95	9	36		0.050%	$9,978,000	$4,509	$2,750	$0	$0	$13,750	
MQ-4C Triton	36	10017	0.40	3	6		0.050%	$15,179,000	$2,760	$6,000	$0	$0	$90,000	

Figure 3. Calculations Tab

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4.3.4 Output

The final output for the aircraft is in the Excel output tab. This tab includes the overall CPH and CPA for each aircraft, and the total cost to maintain surveillance over the specified area. The total cost can be interpreted as a relative cost to maintain a certain level of surveillance that fulfills the user-specified revisit time requirement, and the resulting revisit time (Default = 1 hour). The right column in Figure 4 is the resulting search frequency that would result from employing the surveillance strategy using the number of aircraft shown to the left. This number of aircraft is the minimum number needed to achieve the desired revisit time. Figure 5 shows the outputs for the surveillance strategy which employs platforms in tandem that the user specified in the input tab. Using all the aircraft provided, the tool calculates the resulting revisit time of that strategy along with its CPH and total cost. The user can use this to compare the costs of different configurations.

Platform	Number of Each Platform in the Air	Total CPH per Aircraft	Cost per Area per Aircraft ($/nm^2)	Total Cost to Maintain 24 hr Surveillance	Resulting Revisit Time (hrs)
Coyote UAS	23	$10,000	$8.61	$6,094,764	0.986
Altius-600 UAS	15	$25,000	$13.88	$9,287,382	0.974
Vanilla UAS	12	$1,150	$0.49	$331,200	0.905
P-8A Poseidon	2	$11,879	$0.70	$570,211	0.769
MH-60R Seahawk	6	$8,891	$1.81	$1,280,327	0.879
MQ-8B Fire Scout	9	$7,534	$2.53	$1,627,303	0.985
MQ-4C Triton	3	$7,093	$0.71	$510,707	0.865
E-2	3	$14,983	$1.46	$1,078,800	0.844
	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!

Figure 4. Output #1

Platform	Number of each Platform in the Air	Platform Cost to Maintain Surveillance	Resulting Revisit Time (hrs)	Cost Per Hour	Total Cost of 24 hr Surveillance
Coyote UAS		$0	0.656	$311,879	$7,772,487
Altius-600 UAS	12	$7,487,382			
Vanilla UAS		$0			
P-8A Poseidon	1	$285,105			
MH-60R Seahawk		$0			
MQ-8B Fire Scout		$0			
MQ-4C Triton		$0			
E-2		$0			
		$0			

Figure 5. Output #2

5. Results

The decision tool allows a user to compare multiple aircraft at once. In a hypothetical scenario where the user is surveilling an area the size of the Taiwan Strait, the Vanilla UAS tends to be the cheapest solution across all ROMO states. However, it currently is not a program of record and additional cost to contract is not publicly available. If the Vanilla is not selected as a program of record, greater costs will be expected and other platforms must be considered. In the situation where Vanilla is not available, the ROMO state has a great impact on which platforms are the most cost-effective. Basic application of the tool shows that the unmanned platforms, more notably, the Coyote and the Altius, tend to have the lowest cost when in a conflict ROMO state with high probability of loss. This is due to no loss of human life and loss of expensive platforms which are significant costs with high probability of loss. The most cost-effective options in a competition ROMO state with lower probability of loss are the MQ-4C Triton and MQ-8B Fire Scout which have similar overall costs. In a cooperation ROMO state with loss due only to mishaps, manned aircraft become good cost options. The two best platforms in this state are the P-8A and the MQ-4C. Figure 6 shows the relationship between probability of loss and cost to search.

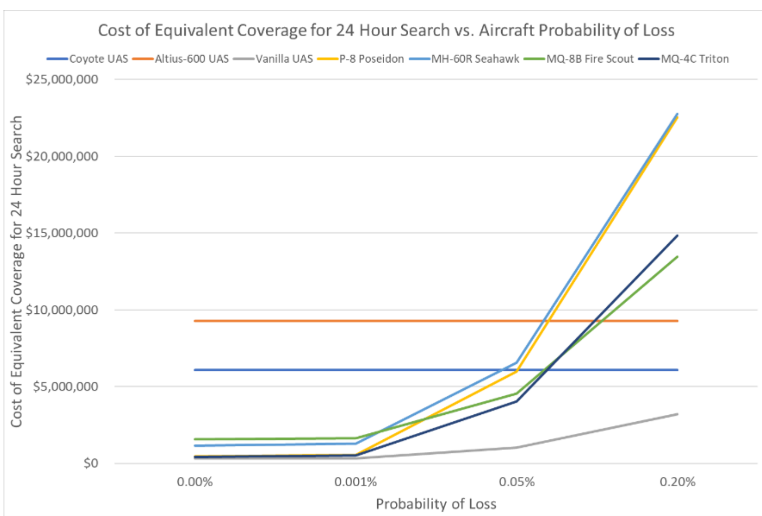

Figure 6. Probability of Loss vs. Cost to Search

Additional trends can be recognized as other parameters are changed, such as distance to search area and area size. As distance increases, platforms with longer endurance, such as the Vanilla and MQ-4C are cost-effective. With greater search area, faster and broader coverage platforms such as the P-8A are more cost-effective. The results provided by the tool are good estimates to aid in decision making and provide these trends for analysis. The tool allows for easy improvements and adjustments to take on more accurate and future data. Creating this tool in Microsoft Excel allows it to be transferable to the classified domain to implement more realistic values.

6. Conclusion

The user-friendly tool created in Microsoft Excel improves the process of finding the best choices of manned and unmanned aircraft to employ for maritime surveillance when cost is a concern. The tool is a commander's decision aid that cuts down the amount of time it takes to decide on platform usage with respect to relative cost. With the Navy moving towards the use of unmanned platforms, it is important to consider cost, platform capabilities and ROMO in the surveillance area to support this transition. This tool can aid in finding the most cost-effective surveillance platforms but with flexibility in the sense that multiple scenarios can be presented and the tool can determine the best resources to employ.

7. Future Work

This project will be improved upon next year. As this project is a decision-making tool, the basic framework is complete. Future students could work on the spreadsheet data by improving parameter estimates, such as sweep width sensor capabilities, and refining CPH to be more realistic, especially for non-program of record platforms. The probability of loss value estimates can change in every scenario, which makes it difficult to categorize into 3 ROMO states. More research should be done to examine probability of loss under ranges of military operations and environments. Finally, students could use tool outputs to find significant trends in cost-effectiveness for different scenarios. They could create interactive visuals of the trends to provide additional insight at how cost values curves change in a sensitivity analysis of the input parameters.

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