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Feasibility analysis of UAV technology to improve tactical surveillance in South Korea's rear area operations

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THESIS

FEASIBILITY ANALYSIS OF UAV TECHNOLOGY TO IMPROVE TACTICAL SURVEILLANCE IN SOUTH KOREA'S REAR AREA OPERATIONS

by

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March 2017

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This thesis examines the feasibility of introducing battalion-level unmanned aerial vehicles as a countermeasure to solve the problems in the Korean rear area operations caused by the Republic of Korea's military structure reform. This feasibility analysis allows the Republic of Korea to determine the optimum required operational capability of the unmanned aerial vehicles to support Korean rear area operations. We use Map Aware Non-Uniform Automata, an agent-based simulation software platform for computational experiments. The study models a scenario involving North Korea's provocation against a terminal high-altitude area defense battery and measures the unit's ability to detect infiltrators. The deployment of Remoeye-002Bs to rear area forces results in significant improvements on rear area operations. However, its capabilities are insufficient to support Korean rear area operations. Through further experimentations and analyses, we were able to find the optimum characteristics of an improved unmanned aerial vehicle that can cost-effectively achieve the unit's operational goals.

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FEASIBILITY ANALYSIS OF UAV TECHNOLOGY TO IMPROVE TACTICAL SURVEILLANCE IN SOUTH KOREA'S REAR AREA OPERATIONS

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Submitted in partial fulfillment of the
requirements for the degree of

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ABSTRACT

This thesis examines the feasibility of introducing battalion-level unmanned aerial vehicles as a countermeasure to solve the problems in the Korean rear area operations caused by the Republic of Korea's military structure reform. This feasibility analysis allows the Republic of Korea to determine the optimum required operational capability of the unmanned aerial vehicles to support Korean rear area operations. We use Map Aware Non-Uniform Automata, an agent-based simulation software platform for computational experiments. The study models a scenario involving North Korea's provocation against a terminal high-altitude area defense battery and measures the unit's ability to detect infiltrators. The deployment of Remoeye-002Bs to rear area forces results in significant improvements on rear area operations. However, its capabilities are insufficient to support Korean rear area operations. Through further experimentations and analyses, we were able to find the optimum characteristics of an improved unmanned aerial vehicle that can cost-effectively achieve the unit's operational goals.

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytic Hierarchy Process
AOR	area of responsibility
CI	confidence interval
DOE	design of experiments
DP	design point
DRP	Defense Reform Plan
ISR	intelligence, surveillance, and reconnaissance
KMND	Korea Ministry of National Defense
KRA	Korean rear area
MANA	Map Aware, Non-uniform, Automata
MOE	measures of effectiveness
NOLH	nearly orthogonal Latin hypercube
NPS	Naval Postgraduate School
NK	North Korea
RAO	rear area operations
ROC	required operational capability
ROK	Republic of Korea
ROKA	Republic of Korea Army
RSO&I	reception, staging, onward movement, and integration
SOF	special operation forces
SROKA	Second Republic of Korea Army
SUAV	small unmanned aerial vehicle
THAAD	terminal high altitude area defense
UAV	unmanned aerial vehicle
UAS	unmanned aircraft system

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EXECUTIVE SUMMARY

The Republic of Korea's (ROK) Defense Reform Plan addressed the transformation of the ROK military structure by a significant military personnel reduction (Bennett, 2006, iii). The decreased number of forces in the ROK Army (ROKA) will cause significant issues in covering the force's area of responsibility. In particular, the ROK rear area forces will have more difficulties in carrying out ROKA's rear area operations (RAO). As part of the efforts to address these problems, the Korea Ministry of National Defense decided to strengthen the battlefield visualization capability of each echelon by distributing the new hand-launched Remoeye-002B to battalion-level units and division-level KUS-9 to division-level units. However, the distribution of these unmanned aerial vehicles (UAV) are limited to the frontline forces, the distribution to the rear area forces has still not been achieved due to the Korea military's budget constraints.

This thesis examines the feasibility of introducing battalion-level UAV as a countermeasure to solve the problems in RAO caused by the Republic of Korea's (ROK) military structure reform. This feasibility analysis allows the ROK to determine the optimum required operational capability (ROC) of the UAVs for the Korean RAO. Since there is an insufficient amount of information and studies related to the utilization of UAVs in the ROK military, insights from this study will serve as a guide to acquisition strategies of future UAVs for supporting Korean RAO.

In order to get the proper ROC, this thesis uses Map Aware Non-Uniform Automata (MANA), an agent-based simulation software platform. It first examines the effects of deploying Remoeye-002B at the battalion level in the Korean rear area. Applying computer experimentation in a terminal high altitude area defense (THAAD) scenario provides insights to the intelligence, surveillance, and reconnaissance (ISR) capabilities that the force requires. Advanced experimental designs efficiently explore single and combined characteristics of a UAV that can best improve the surveillance mission. Regression analysis and partitioning tree analysis assist in examining 260 options. In addition, a relative cost analysis identifies the most cost-effective design option.

The simulation results of the scenario with no UAVs show that there is a need to strengthen the ISR capabilities of the ROKA rear area forces. The deployment of Remoeye-002Bs to rear area forces results in significant improvements on RAO, but Remoeye-002B capabilities are insufficient to support Korean RAO. Thus, we found the need for procuring a more capable UAV than Remoeye-002B. To get the proper ROC, we analyzed more computer experimentation results. The linear regression indicated the number of UAV sets has the largest impact on the Korean RAO. The contour plot showed that purchasing just one set of UAVs with a higher sensor capability could result in the same performance as two or more sets of UAVs with lower sensor capabilities. The partition tree analysis identifies that there are six design options, which meet the operational goals by using a single UAV set. In addition, we perform the cost estimation on the total price of the system represented for all 260 options. A relative cost analysis found that these six design options are the most cost effective options. Among them, design point (DP) 58 is the cheapest at $592,524. It also has high mission success probability of 98.8%. Therefore, we can conclude that DP 58 is the best design option for rear area forces (Figure 1 and Figure 2).

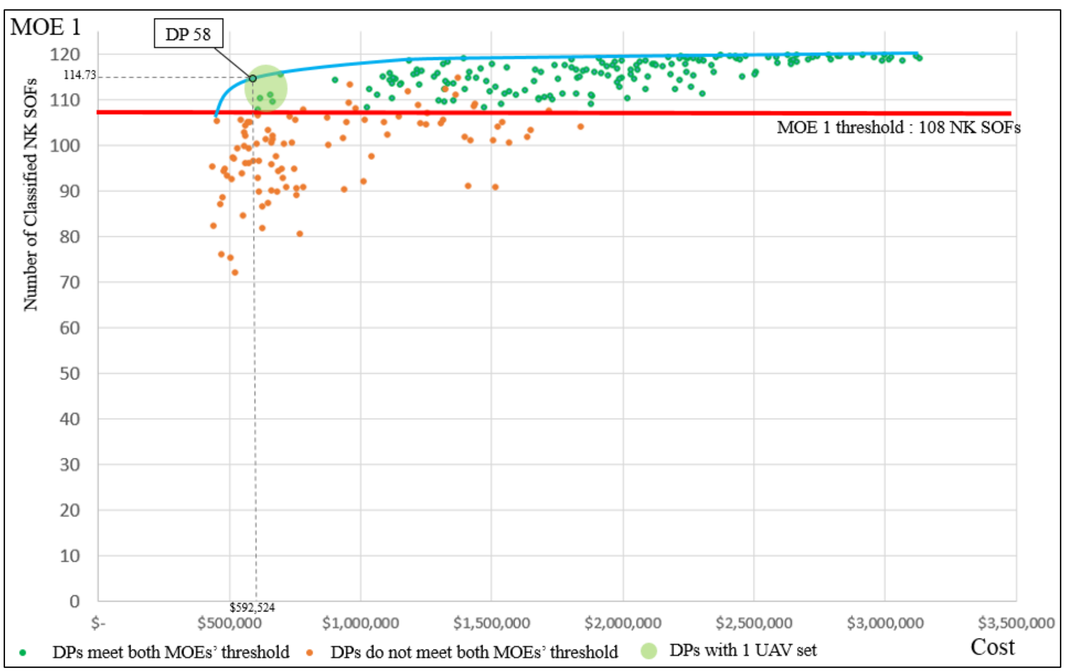

Figure 1. Relative Efficiency Frontier (for Measures of Effectiveness 1).

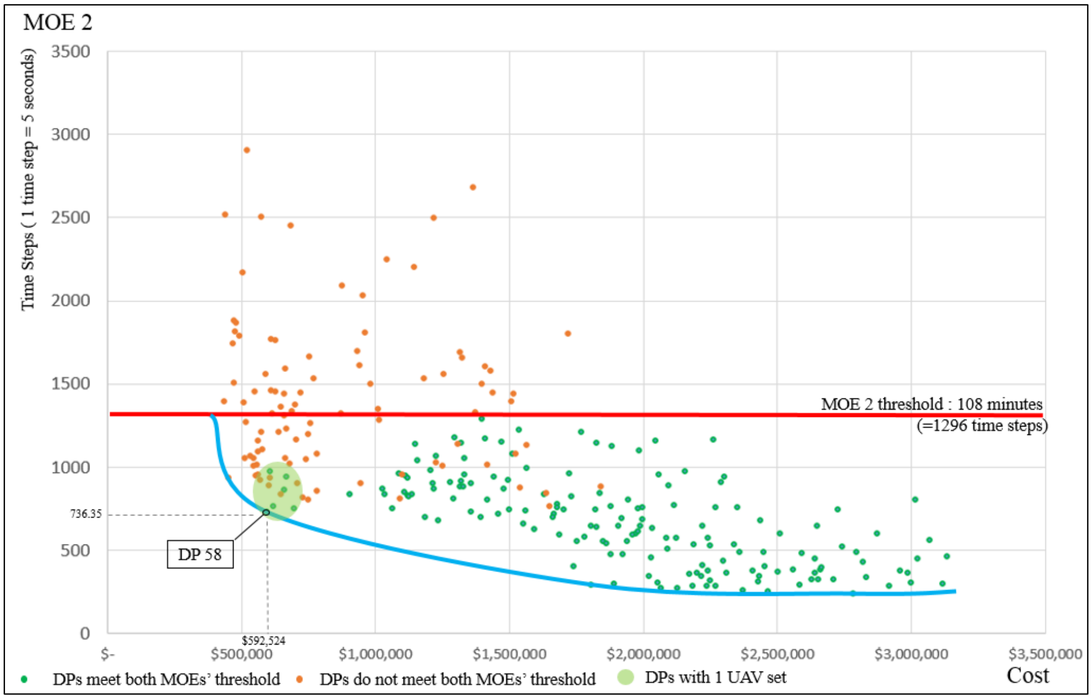

Figure 2. Relative Efficiency Frontier (for Measures of Effectiveness 2).

The best option establishes the required characteristics for future UAVs that Korean leadership may wish to consider to support Korean RAO. The optimum UAV capabilities for battalion units in the future Korean RAO are as follows: Probability of classification at 0.27, aperture angle width with 162 degrees, classification max range of 5,320 m, speed default of 181 kph, speed at enemy contact of 31 kph, time in refueling of 33 minutes, and endurance of 3.25 hours. A similar capability model to the DP 58, among the current U.S. Army UAV models in operation, is RQ-7B Shadow.

Reference

Bennett, Bruce W. 2006. *A Brief Analysis of the Republic of Korea's Defense Reform Plan.* Santa Monica, CA: RAND. http://www.rand.org/content/dam/rand/pubs/occasional_papers/2006/RAND_OP165.pdf.

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I. INTRODUCTION

In December 2005, the Korea Ministry of National Defense (KMND) created a Defense Reform Plan (DRP) to enhance the quality of the Republic of Korea's (ROK) military (Bennett, 2006). The DRP was ostensibly focused on "modernizing the ROK military equipment" and "achieving a higher level of professional military personnel," but the actual DRP transformation of the ROK military structure was through a significant military personnel reduction (Bennett, 2006, iii). The KMND established this DRP because the number of eligible draftees will decrease as a result of the ROK's declining birth rate (KMND, 2014). The Korean DRP highlighted that the Army accounts for most of the personnel reductions in the entire military (KMND, 2006).

The decreased number of forces in the ROK Army (ROKA) will cause significant issues in covering the force's area of responsibility (AOR). In particular, the ROK rear area forces will have more difficulties in carrying out ROKA's rear area operations (RAO). According to Joint Doctrine, the definition of rear area operations (RAO) follows:

> Rear area operations protect assets in the rear area to support the force. Rear area operations encompass more than just rear area security. While rear area operations provide security for personnel, materiel, and facilities in the rear area, their sole purpose is to provide uninterrupted support to the force as a whole. Rear area operations enhance a force's freedom of action while it is involved in the close and deep fight and extend the force's operational reach. (Joint Doctrine for Rear Area Operations, 1996)

There are a number of challenges for conducting RAO. First, the number of rear area personnel is smaller than the frontline forces. Second, the rear area forces cover 70% of the Korean theater (Bennett, 2006). Third, rear area forces are using legacy and obsolete systems relative to the frontline area forces. Fourth, the defense budget leans heavily toward frontline needs, thereby negating equipment upgrades to rear area forces.

As part of the efforts to address force deficiency problems, the KMND decided to strengthen the battlefield visualization capability of each echelon. In conjunction with this policy, the ROKA decided to use battalion-level reconnaissance UAVs in the solution space. In September 2015, ROKA started to use the small UAV (SUAV), RemoEye-002B, but it was insufficient. In fact, the distribution of Remoeye-002B is limited to the ROKA's frontline units. Currently, there are no plans for future UAV distribution in the Korean rear area (KRA).

A. PROBLEM STATEMENT

There is an insufficient amount of information and studies related to the utilization of UAVs in the ROK military. This thesis will provide the basis for using UAV technology for RAO to mitigate the significant reduction of forces in the Korean military. It will examine the feasibility of using battalion-level UAVs to enhance the ROKA battlefield awareness in the rear area. In addition, this study derives a suitable required operational capability (ROC) for future UAVs for the KRA forces.

B. BACKGROUND

This background section will provide a better understanding about the problems in the KRA. It discusses the ROKA's force structure changes and effects on RAO. This chapter explains RAO as it pertains to South Korea and the North Korean threats. It concludes with the problem definition for this thesis.

1. ROKA's Structural Changes and Impacts on the Rear Area Operations

This thesis will focus on South Korea's Defense Reform Plan, 2006–2020 (DRP 2020). This plan provides details to transform the "manpower-oriented quantitative military structure into an information- and knowledge-oriented qualitative military structure" (KMND, 2014, 82). The DRP 2020 ostensibly focused on modernizing "the ROK military equipment" (Bennett, 2006, iii). The motivation for DRP 2020 was the perceived reduction of available manpower (Bennett, 2006). Figure 1 shows that the ROK military would be reduced from 681,000 to 500,000 by 2020 (KMND, 2014). This would decrease the number of divisions from 47 to 24 (Bennett, 2006).

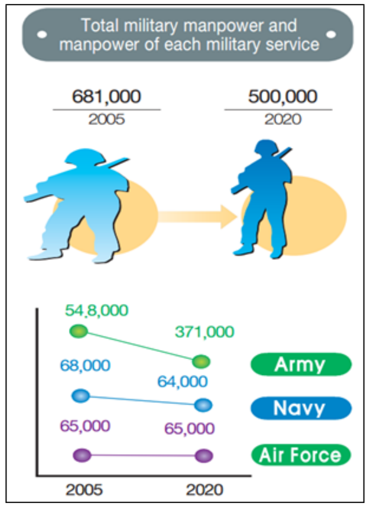


Figure 1. Reducing Forces in the ROK Military. Source: KMND (2006).

Figure 2 demonstrates a drastic change in the ROKA structure. In particular, it shows that, in 2004, the rear ground forces consisted of seven Homeland Reserve Divisions, three Mobilization Reserve Divisions, and three Commando Brigades. By 2020, rear area forces will consist of only six Homeland Reserve Divisions and one Commando Brigade. The decreased number of forces in the ROKA will cause an expansion of each unit's AOR. To reduce the impact of these profound structural changes in the army, the ROKA must increase its military budget (Paek, 2009). However, the ROK military budget is decreasing. Amid these budget constraints, the ROK rear forces must finds ways to effectively cover its increased operating areas.

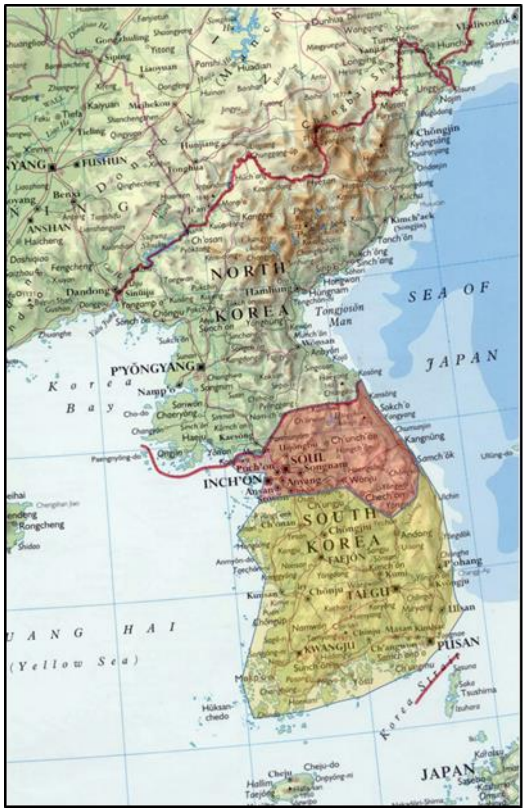
		2020 Force; Equipment	
Force Type	2004	Reduced	Sustained
Army active-duty personnel	560,000	370,000	390,000–400,000?
Forward ground forces			
Top echelons	2 armies, 8 corps	1 command, 6 corps	
Active divisions	5 mechanized, 17 infantry	3 mechanized, 10 motorized	5 mechanized, 8 motorized
Reserve divisions	6 HRDs, 9 MRDs	5 HRDs [+4 MRDs]	
Heavy brigades	4 armor	3 armor, 1 mechanized	
Light brigades	3 infantry	4 security	
Rear ground forces			
Divisions	7 HRDs, 3 MRDs	6 HRDs	
Brigades	3 commandos	1 commando	
Reserve personnel	3,000,000	1,500,000	

Figure 2. Comparison of the ROKA 2004 versus 2020. Source: Bennett (2006).

Within the next three years, the ROKA plans to make many improvements in its situational awareness and tactical surveillance capability. Battalion-level reconnaissance UAVs are means to enhance battlefield visualization. However, the distribution of these UAVs is limited to the frontline force.

2. Rear Area Operations in the South Korean Theater

The ROK and U.S. Combined Forces Command consider South Korean RAO to be very important for defending against North Korea (NK) aggression. The KRA contains important infrastructure facilities, including nuclear power plants, shipping ports, and airports. The Second Operations Command, or the Second Republic of Korea Army (SROKA), is responsible for the KRA (Globalsecurity, 2016). SROKA's role is to deter war and maintain stability on the Korean peninsula (Girard, 2000). SROKA's mission includes wartime host nation support, reception, staging, onward movement, and integration (RSO&I), and noncombatant evacuation operations (Girard, 2000). The SROKA's AOR consists of six southern provinces and extends from the rear edge of the front corps area to the 3,276-mile coastline. The size of the AOR is 70,000 square kilometers (㎢), which is 70% of South Korea's entire territory. The space is difficult to surveil with the current size of the ROKA. Normally, a ROKA infantry battalion in the frontline area reaches 400 to 500 men, but a rear area unit has only 250 soldiers. Reduction will make it even more difficult. Figure 3 shows the ROKA's AORs.



Red shaded area is the frontline area, and yellow shaded area is the rear area.

Figure 3. SROKA's AOR. Modified from Maps of the World (2016).

Many military experts warn about the ongoing threat from NK. According to Bennett (2006), "The resulting defense against special operation forces (SOF) and terrorists could be quite thin, suggesting a high risk" due to the result of DRP (15). The major threat is NK, which can use SOF to threaten and carry out attacks against the SROKA area. NK SOF's likely targets are infrastructure and key ROK military facilities in the rear area (Bennett, 2006).

Comparing the capabilities of the old ROKA with the current ROKA, rifles and communications equipment have improved, but there has been no major improvement in the observation equipment for situational awareness. In addition, the DRP impacts further increase the AOR of the rear area forces. Without the improvement of situational awareness, there is still the possibility that the case of Ulchin–Samcheok Landings in 1968 and Gangneung submarine infiltration incident in 1996 will happen again in the coming future. Consequently, the ROKA must now focus on mitigating the weaknesses in the KRA.

C. RESEARCH QUESTION

This thesis will answer these research questions.

How can the Republic of Korea's current and planned family of unmanned aerial vehicles (UAV) improve the security of its rear area operations?

- To what degree can the deployment of the current model of Remoeye-002B improve the effectiveness of a ROKA battalion to surveil the expanded area of operation in the KRA?
- What employment options should the ROK battalion use to obtain the most effective support from the Remoeye-002B UAV?
- What single and combined characteristics of a UAV can effectively support defense of the KRA against infiltration by North Korea's special operation forces?
- How many UAV systems are needed for the ROK battalion to successfully defend the KRA?

D. SCOPE

This thesis examines distribution of UAVs for the KRA as a countermeasure against AOR expansion caused by DRP 2020. This thesis focuses on the intelligence, surveillance, and reconnaissance (ISR) capability of ROKA battalion-level units. Thus, only the ROKA's capability to detect and classify the enemy is examined in the simulation model. Combat between friendly forces and enemy is not included. This thesis includes the topographical characteristics of the KRA in the model and derives the optimum ROC of future Korean UAV for the KRA.

Since the ROK military has a lot of budget constraints and the defense budget leans heavily toward frontline needs, the UAV type could be supplied to the KRA in the future is inexpensive UAVs. Therefore, this thesis focuses on Group 1 to Group 3 UAV (i.e., relatively lower performance; see section II.A) that is suitable for the battalion level units in the KRA.

E. BENEFITS OF THE STUDY

This feasibility analysis allows the ROK to determine the optimum ROC of UAVs for the Korean RAO. Insights from this study will serve as a guide to acquisition strategies for future UAVs to support Korean RAO. In addition, this thesis provides decision makers with additional information to enable them to reduce the cost and time of such an acquisition project while they examine the ROC of the UAVs for the RAO. This paper will answer the military decision makers' questions regarding whether the deployment of the current model of Remoeye-002B is effective in the Korean RAO.

F. THESIS ORGANIZATION

Chapter II contains background information about the unmanned air vehicle UAV types and categories with highlights on the definitions and design factors that will used later for the analysis. Chapter II is the literature review of related studies that forms the academic context and identifies the knowledge gap. Chapter III explains the development of the simulation model and experiments, including the operational scenario used in the model. This thesis uses the Map Aware Non-Uniform Automata (MANA) as its primary simulation model to address the research questions. Chapter IV is the analysis of experiment results. Examination of the data will derive a suitable required operational capability for future UAVs for the KRA forces. We analyze each design options using the measures of effectiveness (MOE) as the basis. Chapter V is conclusion and recommendations for the future research.

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II. LITERATURE REVIEW

This chapter first introduces the UAV models currently used in Korea. It next discusses UAV-related research conducted in Korea. These research efforts include research on technical aspects related to commercial UAV sub-component development. However, there are relatively few studies that discuss military use of UAVs. The Naval Postgraduate School (NPS) has conducted numerous UAV studies. The author has found several approaches and modeling techniques from these studies that have been valuable.

A. UAV MODELS CURRENTLY IN USE IN KOREA

The ROKA currently uses several types of UAV in the frontline area, with various performance levels. The U.S. Army Unmanned Aircraft Systems (UAS) Roadmap 2010–2035 presents a classification criterion that classifies UAVs in five groups: Low performance as Group 1 and UAVs with high performance as Group 5. Table 1 depicts details for each group. Since 2002, the ROKA has operated UAVs in the frontline area; examples include the Israeli UAV Searcher and the homegrown RQ-101, Songgolmae. According Table 1, these UAVs belong to Group 3. However, these have been used in corps-level forces.

Table 1. UAS Current System. Adapted from U.S. Army (2010).

<table>
<tr><th>UAS Category</th><th>Max Gross Takeoff Weight</th><th>Normal Operating Altitude (Ft)</th><th>Airspeed</th><th>Current Army UAS in Operation</th></tr>
<tr><td>Group 1</td><td>< 20 pounds</td><td>< 1200 above ground level (AGL)</td><td>< 100 Knots</td><td>RQ-11B Raven</td></tr>
<tr><td>Group 2</td><td>21-55 pounds</td><td>< 3500 AGL</td><td rowspan="2">< 250 Knots</td><td>No current system</td></tr>
<tr><td>Group 3</td><td>< 1320 pounds</td><td rowspan="2">< 18,000 mean sea level (MSL)</td><td>RQ-7B Shadow</td></tr>
<tr><td>Group 4</td><td rowspan="2">> 1320 pounds</td><td rowspan="2">Any Airspeed</td><td>MQ-5B, MQ-1C</td></tr>
<tr><td>Group 5</td><td>> 18,000 MSL</td><td>No current system</td></tr>
</table>

To address issues resulting from a reduction in ROKA force levels, the Army has begun to distribute Group 1 and 3 UAVs to its frontline units. In September 2015, the

ROKA distributed the new hand-launched Group 1 UAV, Remoeye-002B (Table 2, Figure 4), to front-line infantry battalion-level units and Marine Corps troops in stages.

Table 2. Remoeye-002B Specifications. Adapted from Uconsystem (2016).

System	Remoeye-002B
Set-up time	Within 5 minutes
Launch	Automatic hand-off launch
Payload	Stabilize Gimbal with EO or IR thermal imager
Guidance/Tracking	Fully autonomous, preprogrammed mission flight with GPS navigation and inflight mission change in real time
Features	1~2 operator/image stabilization Flight modes changeable during mission flight Real time target position displayed on video screen Target hold (camera with two-axis scanning) Integrated logistics support (ILS)
Dimensions	Wingspan 1.80 m, Length (overall) 1.44 m
Max Take Off Weight (MTOW)	3.4 kg/empty weight (1.3 kg), max payload (0.17 kg)
Max Speed	Max 80 km per hour 50 ~ 70 kph
Operational Altitude	300 ~ 500 m above ground level
Operational Range (Mission Radius)	Over 10 km
Endurance	Over 60 minutes
Power plant	12V DC, battery-powered electric motor, two-blade pusher propeller
System Components	4 fuselages, 1 charger, 1 GCS, 4 image receiving headsets (option)

Figure 4. Remoeye-002B. Source: Uconsystem (2016).

The ROKA has also deployed about 30 units of KUS-9 (Figure 5) to its divisions since 2016 to enhance their ISR capabilities. The KUS-9 can be classified as a Group 3 UAV with "an endurance of six hours and a maximum range for communications of 60 kilometers" (Mortimer, 2010). Since the Group 3 level UAVs have been used only for corps-level units, deployment of the KUS-9 to the division-level units is expected to significantly improve the ROKA's ISR capability.

Figure 5. Korean Division-Level UAV, KUS-9. Source: Korean Air (2016).

B. RESEARCH IN KOREA

1. Korean Study on UAVs for Battalion-Level Units

Korea's research related to the use of UAVs at an infantry battalion level is limited. The single study describes how to effectively utilize the man-portable SUAVs of the ROKA infantry battalion. This document is authored by Lieutenant Colonel Lee, ROK Army. Lee took part in verifying the operational effectiveness of the Remoeye-002B at the time when SUAV was considered as an alternative to the ROKA's situational awareness enhancement project (Lee, 2015). It is the ROK Army's only available publication that deals with the use of SUAVs in ROK military. However, Lee's use of personal intuition in his analysis and conclusion is insufficient to support the use of UAVs in RAO.

Lee wrote the paper based on his experience in 2009 as an infantry battalion commander, operating Remoeye-002B, at Hoguk Training, an operational command-level field training exercise. He noted that the Korean battlefield environment is predominantly mountainous, and pointed out the target acquisition equipment currently possessed by an infantry battalion has limitations in obtaining accurate targets (2015). He also noted that the SUAV training provided him with great help in overcoming these limitations (2015). In addition, he gave several suggestions on SUAV utilization at the battalion level: 1) a SUAV shall be operated and controlled directly by infantry battalions, 2) a real-time striking system shall be established in conjunction with a fire support unit to strike a target that is detected and classified through the SUAV, and 3) the SUAV shall be able to overcome the topographic features of Korean terrain and characteristics. This thesis applies his suggestions for developing the military operational environment in the simulation model used in this study.

2. Studies Using Map Aware Non-Uniform Automata (MANA)

A number of studies that have used MANA provide insights for modeling the scenario of this study. Several provide background for modeling the factors and collecting data against MOE. Other papers direct how to use values that are more representative of reality in the model.

Oh Kyungtack from the University of Texas at Austin (2010) wrote a paper using the MANA program and covering the ROKA infantry problem. Similar to this thesis, Oh Kyungtack focuses on ROKA border security and models a complicated Korean border situation in a MANA scenario. However, Oh does adopt UAVs in his scenario, but his explanations of building a MANA model are valuable to this thesis. His paper recognizes that research regarding the impact of UAVs in ROKA operations is now needed. In particular, it identifies RAO as a separate study.

There are a few studies that use computer simulation for the ROKA. Chung Youngho (2008) examines the NK artillery threat to the ROKA. Chung developed a model in MANA to measure the effectiveness of using UAVs to overcome NK's capability to fire scatterable mines. His study introduces computer modeling and simulation to the ROKA artillery research about NK's mine artillery threat, whereas previous efforts had been mostly qualitative analyses. He used more capable UAVs such as the Predator (Group 5 UAV). Chung's research is meaningful because it involves the ROKA using UAVs to detect the enemy. However, it departs from the direction of this thesis because the objective was to detect NK artillery, not personnel.

Kim Se-yong's paper (2008) is quite similar to Chung's work. It focuses on how much a cannon's hit probability and UAV-based target acquisition contribute to the probability of striking a target. He did not present detailed values for other UAV performance levels such as altitude and sensor performance. Kim does fix the UAV's flight speed at 160 kph in the simulation. This thesis improves on Kim's fixed speed; it allows for changes in UAV speed for better detection when contacting the enemy.

C. RESEARCH AT NAVAL POSTGRADUATE SCHOOL

While there are few studies about the use of UAVs in the ROKA, NPS has conducted many studies to examine the impact of UAV capability factors on different operation, including ISR. This paper combines many of these approaches to leverage their advantages and reduce their shortcomings. The result is a simulation model that will address the research question in this thesis.

In his paper, James Williams (2014) explored the mathematical formulas that MANA uses. Williams supplements those that the MANA user manuals do not explain. His work is easily understood and a useful cipher to the information in MANA. William's work was particularly helpful for setting the UAV sensor value. His thesis was instrumental in designing a model that could better represent reality in MANA.

In 2013, a Turkish Air Force officer, LT Begum Ozcan, conducted a study focusing on the utility of UAVs in addressing Turkey's border security issues (Ozcan, 2013). Ozcan developed Turkey's operational environment in MANA. This thesis adopts Ozcan's approach for creating the KRA's topographical conditions in the model. Additionally, Ozcan's approach for solving her research questions was a good template. Adjusting to some of the unique conditions in South Korea, this study develops new ideas for finding solutions to its research objectives. For instance, Ozcan set the intervals between the minimum and maximum values of UAVs' capability factors for a much wider range of capabilities. South Korea will not have the same latitude, which will require a narrower range of values. These changes necessarily change the design of experiments (DOE) for the simulation.

German Army officer Tobias Treml used MANA to "provide a new specification development process for ground combat vehicles" (2013). Treml's paper did not focus on UAVs, but he incorporated a hand-launched UAV, RAVEN, into his simulation model. Treml used data for UAV sensors as detailed in Table 3. In light of few public sources for UAV sensor data, this thesis adopts Treml's input values.

Table 3. The Average Time between Detection and Classification Probabilities for the RAVEN Sensor. Source: Treml (2013).

Range	50	2000	4000	6000
Average time between detection	0	0	5	10
Probability of classification given detection	0.2	0.1	0.01	0.005

III. MODEL DEVELOPMENT AND SIMULATION EXPERIMENTS

We use modeling and simulation, experimentation, and simulation analysis to address the research questions in this thesis. This chapter first describes the simulation model used for the study. Next, it describes the scenario that is developed in the simulation model. Included in scenario development is an introduction to the simulation agents. This chapter discusses the power of computer experimentation to assign causality. The deliberate manipulation of input values for factors create the basis for analytically determining the degree of influence the factors have on a particular outcome. Lastly, we define the set of relevant MOEs, factors that may influence the MOEs, and the DOE that will explore the design space. The discussion also introduces nearly orthogonal Latin hypercube (NOLH) designs as an efficient DOE.

A. THE SIMULATION MODEL: MANA

This thesis uses MANA as its primary simulation model. MANA is easy to use; creating scenarios, modifying agent properties, and reviewing results are straightforward actions for the operator. MANA realistically models behavior and approximates physical effects of high-resolution agents. For the purpose of this study, MANA is the best fit. It has existing sample models, is available at NPS, and is easy to develop through program manuals. In particular, the NPS's Simulation Experiments and Efficient Design center supports scenario development and data analysis as result of MANA experiments. The utility of MANA to this research, combined with the internal structure to support it, makes it as an ideal tool for the thesis.

B. OPERATIONAL ENVIRONMENT FOR SCENARIO DEVELOPMENT

The scenario that this study develops in MANA is a fictional situation involving the U.S. military terminal high altitude area defense (THAAD) battery, which is a current political issue on the Korean peninsula. This scenario fits the objectives of this thesis; the THAAD battery would be located in the KRA and it can be a potential target for NK

SOF. The deployment of THAAD in ROK is a highly sensitive issue to NK. Therefore, dispatching NK SOF to eliminate THAAD is a very plausible scenario.

1. Background of the THAAD Deployment in Korean Rear Area

North Korea has carried out many provocations that show off its military strength. As Yoon (2016) has noted, "unrestrained by international sanctions based on United Nations Security Council Resolution 2270, North Korea continues to test intercontinental ballistic missiles and claims to have miniaturized its nuclear warheads" (1). Figure 6 illustrates the aggression, challenge and provocation of North Korea in the last seven years. The most recent of these occurred in 2016. Yoon (2016) also notes that to cope with NK's missile threat, "the South Korean government confirmed its intention to deploy the THAAD system."

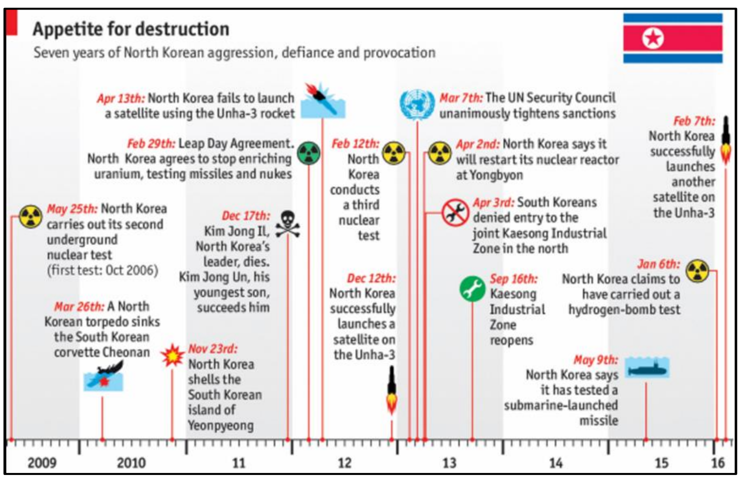


Figure 6. North Korea's Continuous Provocation. Source: *Economist* (2016).

Seongju County, North Gyeongsang Province, South Korea is the tentative location of the THAAD battery (Kim and Park, 2016). Locating the THAAD in the Seongju area is reasonable. It holds important national facilities such as nuclear reactors and oil storage facilities. In addition, most of the U.S. military bases and the ROK military headquarters are located within 200 km of Seongju (Figure 7). This geographic area will be the foundation of the operational environment in MANA.

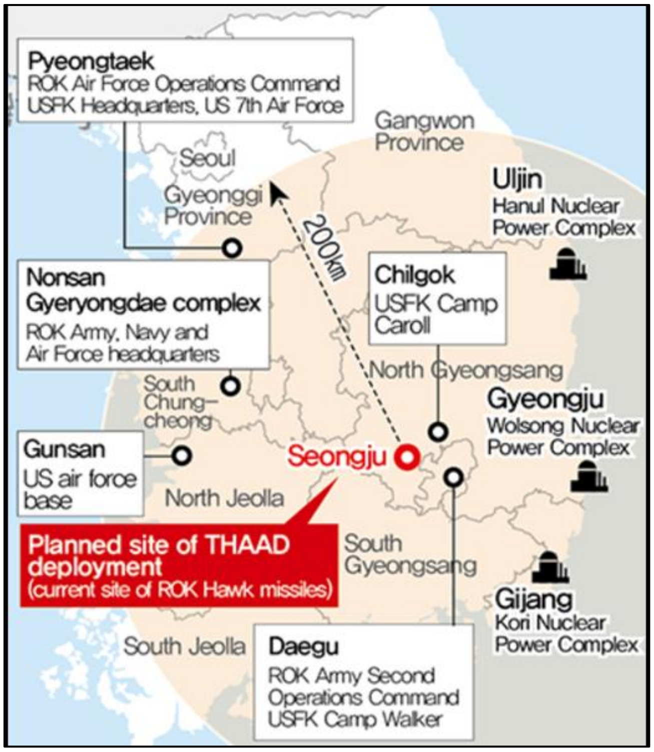


Figure 7. Scope of Defense for THAAD Deployment Site. Source: Park (2016).

2. Scenario Description—Conflict Situation

Kim Jong-un, NK's leader, aims to eliminate THAAD from the ROK. MANA will model 120 NK light infantry brigade soldiers that will attempt to infiltrate the South Korean rear area with the objective of neutralizing the THAAD.

The ROKA rear area forces in this scenario have two units. The first unit is the THAAD battery. While the battery has 200 soldiers assigned to it, they do not protect or carry out security missions in the battlefield in MANA. The THAAD will serve as the target in MANA. The second unit is an infantry battalion of 250 soldiers that is charged with the protection of the Seongju County. These soldiers patrol the THAAD area and can detect and intercept infiltrators.

C. SCENARIO DEVELOPMENT IN MANA

1. Baseline Scenario (Scenario One): No UAVs

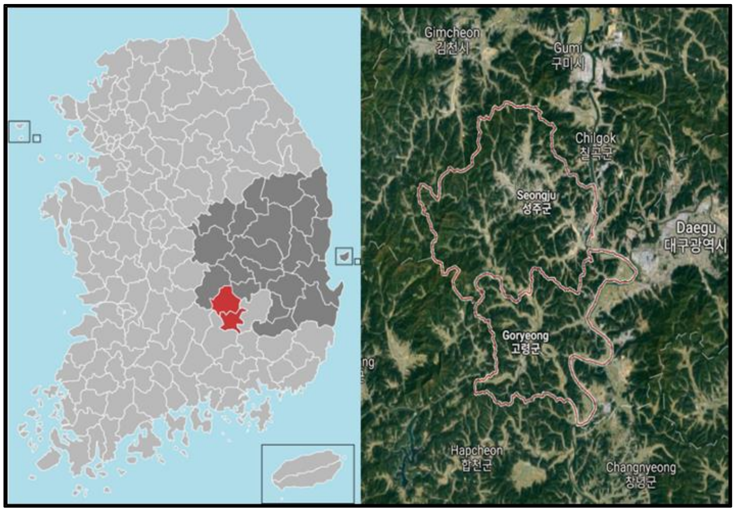
The Baseline Scenario is based on the fictional scenario explained earlier. One hundred twenty of NK's light infantry brigade soldiers (Red), divided in four groups each with thirty agents, try to infiltrate the ROK rear area and attack the THAAD battery. This scenario does not include UAVs. The ROK battalion of 250 soldiers (Blue) will be the only units available to detect Red forces. Combat between Blue forces and Red forces is beyond the scope of this study and is not included in any of the scenarios. Each simulation run is 18 hours of continuous operations. The results will serve as a baseline for comparison and analysis with the scenarios in which UAVs are introduced.

2. Scenario Two: Deployment of Remoeye-002B

Scenario Two deploys one set of the UAVs in the Baseline Scenario to support RAO. One set of UAVs consists of four UAVs. The UAV model for the simulation will have the capabilities of the Remoeye-002B. Scenario Two will be rerun when there are two, three, and four sets of UAVs deployed with rear area forces. Comparison with the Baseline Scenario results will provide an understanding of how UAV deployment can improve coverage of the ROKA's rear operational area.

3. Battlefield

Prior to force reductions each battalion must cover about 1000 ㎢. After DRP 2020 each battalion has expanded area of responsibility that is 1.67 time larger than its original area. As a result, MANA will use a 1670 ㎢ for the scenario (Figure 8).



Red shaded area to the left of the figure is Seongju and Goryeong County. The right side of the figure shows that most of Seongju and Goryeong are mountainous.

Figure 8. Seongju and Goryeong County, Korea. Adapted from Google Maps (2016).

Equally important to scenario development is Korea's topography. The UAV's detection depends heavily on the topographical characteristics of the search area. Even if the UAV sensor is highly capable, it will not be able to observe an object that is hidden in mountainous terrain. Figure 8 also shows the heavy vegetation in the Seongju area, as indicated by the green. Figure 9 presents elevation data.

Figure 9. South Korea Topography. Source: Wikimedia Commons (2016)

These topographical characteristics are applied in MANA. They affect the means that an agent can gain cover and concealment. Terrain types also have an effect on agent's speed of movement. It can affect the UAV sensor's line of sight, which may delay detection and classification of agents. MANA displays the effects of terrain features in Figure 10. Each colored area is associated with a multiplication factor that alters an agent's base speed.

	Going	Cover	Concealment	Color
Road	0.90	0.00	0.00	
Mountain	0.10	0.70	0.90	
Off_Road	0.60	0.40	0.80	

Figure 10. Terrain Map and Terrain Features. Adapted from Ozcan (2010).

4. Agent Descriptions

This section explains each agent type used for this study. Squads are central to developing a MANA scenario. A squad is a user-defined group of agents. Within a squad, agents share the same attributes set by the user. This study has 15 squads (Table 4). Table 4 also indicates on which side the agent is fighting, allegiance. The Blue force represents friendly forces with allegiance 1, the Red force represents enemy forces with allegiance 2, and Civilians are classified as neutral with allegiance 0.

Table 4. Agents and Features in Scenario. Adapted from Ozcan (2010).

Squad	Name	MANA Icon	Allegiance
1	Blue UAV1	Squad # 1 Blue_UAV1	1
2	Blue UAV2	Squad # 2 Blue_UAV2	1
3	Blue UAV3	Squad # 3 Blue_UAV3	1
4	Blue_UAV4	Squad # 4 Blue_UAV4	1
5	Blue Battalion 1	Squad # 5 Blue_Battalion_1	1

Squad	Name	MANA Icon	Allegiance
6	Blue Battalion 2	Squad # 6 Blue_Battalion_2	1
7	Blue Battalion 3	Squad # 7 Blue_Battalion_3	1
8	Blue Artillery	Squad # 8 Blue Artillery	1
9	Blue Targets	Squad # 9 Blue Targets	1
10	Red Team1	Squad # 10 Red_Team1	2
11	Red Team2	Squad # 11 Red_Team2	2
12	Red Team3	Squad # 12 Red_Team3	2
13	Red Team4	Squad # 13 Red_Team4	2
14	Red Scouts	Squad # 14 Red_Scouts	2
15	Civilians	Squad # 15 Civilians	0

Threat Level: 3 (High), 2 (Medium), 1 (Low), 0 (No threat)

Figure 11 shows the agent placement on the simulation model. The Red teams, divided into four teams, begin infiltration on the outskirts of the battle area. Red scouts are located in the infiltration route of the team. Red scouts are spread widely throughout the battle area to send information about the Blue UAVs to the Red team. Civilians are located around the battle area. The Blue UAVs will perform an aerial reconnaissance by equally dividing the battlefield according to the number of UAVs in operation.

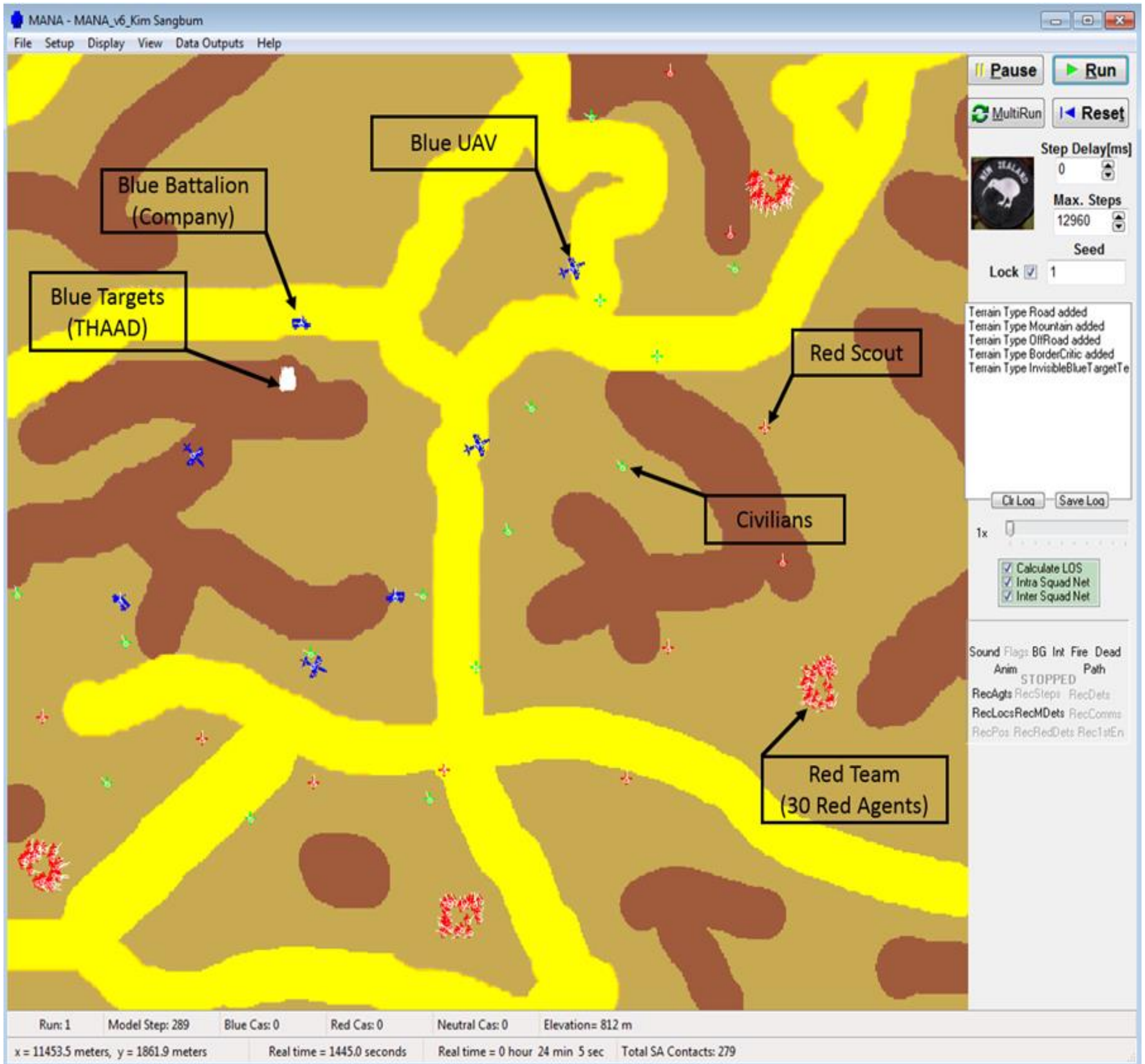


Figure 11. Overview of Battlefield in MANA Model.

a. *Blue UAVs*

The Blue UAVs are the most essential agents in this thesis. The Blue UAV is a reconnaissance UAV, which is capable of detecting personnel and vehicles and sending the information to a battalion command post in real-time. The capability of the Blue UAVs can vary based on 12 input factors.

The UAV follows a preset search path. When it detects activity, it veers and proceeds toward the activity to classify whether it is a Red agent or not. The UAV keeps track of the agent when it is classified as Red, and notifies the headquarters that requests the indirect fire support unit to kills the Red agent. The indirect fire unit has a 100% probability of kill. The UAV has a communication link with 100% reliability with the battalion headquarters. If the activity is not an enemy, the UAV will return to the preset path. The UAV stops detection activity if it begins to run low on fuel and returns to the starting point for refueling.

b. Blue Battalion

The Blue battalion is divided into three groups. A blue vehicle icon represents a company of the Blue battalion. The Blue battalion surveils with binoculars, which limits its line of sight to 1,000 m. Because the Blue battalion and UAV belong to the same allegiance, they share situation awareness.

c. Blue Artillery Unit (Invisible)

The Blue artillery unit is a modeling tool in scenarios that serves as a means to remove Red agents from game play during the simulation run. It prevents a double count of detection and classification of Red agents.

d. Blue Targets (Invisible)

Blue targets represent the THAAD battery. A number of Blue targets, equal to the number of Red agents, are placed as a waypoint for each Red agent. In essence, each invisible target provides a route for the Red agent. When the Red agent reaches the target, it will kill one Blue target with a pair of bullets that it owns, which counts as the Red agent has arrived at the target. The number of Blue targets killed is the number of Red agents that reach the target.

e. Red Teams

Red agents infiltrating the KRA are divided into four teams. They represent NK SOF. Each Red team follows its waypoint to the THAAD. The Red team tries to avoid UAVs and tries to conceal themselves when exposure is expected. Each of Red team is about 25 to 30 km away from the target. They travel at a speed of 3 kph to correspond with battlefield conditions and topography. Red agent cannot communicate with other agents. Red agents can only acquire information about the Blue UAV activities through the Red scouts. Red agents will not fire on a UAV during the infiltration to maintain its stealth. When a Red agent reach its destination, it kills the Blue target.

f. Red Scouts

There are 10 Red scouts are in the simulation model. Red scouts represent previous infiltrators. They are stationary and cannot be detected by Blue agents. Red scouts provide Red teams with terrain information or Blue force activities.

g. Civilians

Civilians distract UAVs. It is reasonable to assume that the battlefield will contain residents and the enemy. Requiring the UAV to classify the agent once it detects it is a realistic event that MANA models. Fifteen Civilians are distributed around the battlefield.

D. DESIGN OF EXPERIMENTS IN MANA

The DOE is a specified set of experimental runs in the simulation that systematically explores the design space. Each factor in a DOE is a variable that can assume a range of values. Analysts choose factors that they believe will have an impact on some measure of interest. Our implementation of DOE aims to identify factors that have significant influence on UAV performance. A DOE helps develop insights into about the design factors and isolates the effect of each individual factor on the measure of interest (SAS Institute, 2012). This thesis uses DOE for its variance reduction capabilities in developing estimates for UAV performance.

1. Measures of Effectiveness

This paper adopts two MOEs that quantify UAV performance. We also select thresholds for the MOEs that reflect the rear area force’s desired goal.

a. MOE #1: Total Number of Red Agents Classified

The most important MOE is the number of infiltrating enemy that UAV classifies. The UAV detects Red agents while the Red agent is attempting to attack the Blue target. The total number of Red agents that the Blue indirect unit attacks and renders inactive equals the total number of classified Red agents.

The threshold for MOE 1 is set at 90% of the total Red agents, which is 108 NK SOF. All commands wish for 100% success. However, a desired goal of 100% may be unrealistic. We therefore establish 90% as the threshold for MOE 1.

b. MOE #2: Time to Classify 10 Percent of Red Agents

Detecting the enemies in the early stages of the operation is also very important. Early detection enables ROK forces to react and repel infiltrators. During the Ulchin-Samcheok Landings in 1968, the ROK could not execute its initial course of action because there was not enough reaction time (National Archives of Korea, 2014). In this paper, the second MOE is the amount of time to detect 10% of the total number of possible infiltrators. The threshold for MOE 2 is set at 1.8 hours (108 minutes), which is 10% of the simulation run time.

2. Factors and Input Value Settings

There are numerous factors that can be investigated to determine the effect of using UAVs in the Korean RAO. Based on the two MOEs, we build the scenario to explore factors that may have the greatest influence on the RAO.

a. UAV Capability Factors

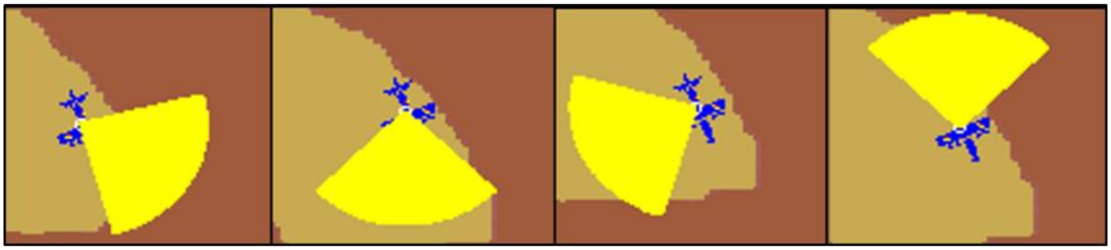
UAV capability factors are independent factors with input values that Blue players can actually manipulate. There are twelve factors that can affect UAV performance. Table 5 provides the factors used in the DOE and the range of input values.

Table 5. UAV Factors and Input Values for Experiments.

	FACTOR NAMES	REMOEYE	MIN	MAX	UNITS
1	NumUAVs	0~4	1	4	
2	Speed_Default	60	30	200	km/hr
3	Speed_EnContact	30	15	60	km/hr
4	Altitude_Default	400	150	5000	m
5	Altitude_EnContact	150	30	4000	m
6	EnduranceFuelLevel	3600	3600	21600	seconds
7	TimeInRefueling	900	900	3600	seconds
8	ClassRangeMax_Default	2000	2500	12000	m
9	PClassAtMax_Default	0.1	0.1	0.3	
10	TimeBtwDetAtMax_Default	0	0	20	seconds
11	SlewRate	90	90	360	degrees/sec
12	ApertureAngleWidth	90	90	180	degrees

Factors 1 through 7 are related to the flight performance of the UAV: speed, altitude, fuel level and refueling time of the UAV. Factors 8 to 12 represent the UAV's sensors. They consist of detection range, classification probability, detection interval, slew rate for gimbal camera sensor, and angular aperture of the sensor.

While some factors are self-explanatory, others require further description. For instance, TimeBtwDetAtMax_Default is the amount of time between "looks" at a search area as it slews the sensor. It affects how the UAV detects an object in the search area. The PClassAtMax_Default factor is the probability of classifying an observed object as an enemy. A detected object cannot be assumed as an enemy. The ability to successfully distinguish between enemy or not an enemy is not 100%. The slew rate (SlewRate) is the number of degrees that the UAV sensor can rotate per second. The sensor rotates 360 degrees, and the ApertureAngleWidth is the width that can be searched at each step of the rotation. Figure 12 shows a UAV in MANA. The yellow fan shape is a 90-degree aperture width.



To display the UAV's detectable range, DET LOS mode in MANA is used.

Figure 12. UAV Sensor's Slew Rate and Aperture Angle Width.

b. Input Value

(1) Factor Input Values

Assigning the appropriate minimum and maximum values to each of the factors is an essential step in creating a suitable DOE to obtain useful simulation results. This paper refers to Treml's input values for the UAV sensor (Treml, 2013). We also use the capability values for Remoeye-002B and KUS-9. We set the capability values for Remoeye-002B as the minimum value of factors, and KUS-9's as the maximum value of factors. By doing so, all our design options will be within the category of Group 1 and 3, which is relatively inexpensive type of UAV. These references establish the appropriate input value ranges for the DOE as indicated in Table 5.

(2) Enemy Settings in Simulation

This paper has determined factors that are closely related to the operation of the rear area in Korea, but which are not under the Korean military or UAV developer's control. Table 6 shows the settings of the Red scout, Red team, and civilians. We enter these values as fixed numbers for the experiment. Developing new enemy conditions is left for future research efforts.

Table 6. Enemy Settings in Simulation.

	FACTOR NAME	INPUT VALUES	UNITS
RED SCOUT	Red Scout Sensor Height	2	m
	Movement Speed	0	km/hr
	Detect Range	2000	m
	Intra-Squad Comms Delay	6	time step
RED TEAM	Red Team Sensor Height	2	m
	Movement Speed	3	km/hr
	Detect Range	3000	m
	Intra-Squad Comms Delay	6	time step
CIVILIAN	Red Team Sensor Height	2	m
	Detect Range	1000	m
	Intra-Squad Comms Delay	6	time step

3. Nearly Orthogonal Latin Hypercube Designs

The NOLH experimental designs were first developed by Cioppa (2002). Efficiently and simultaneously analyze the effects of factors. A NOLH reduces the number of simulation runs in experimental design to a fraction of full factorial designs. It is often impractical or impossible to run all possible combinations of factor values. Every combination of factor values is one design point (DP) in an experiment. The base experimental design for the experiments in this thesis would produce over 240 million DPs. A NOLH design is a powerful tool for examining interactions among factors and gaining insights to research questions with a minimal number of DPs

Using the NOLH design Excel spreadsheet (http://harvest.nps.edu) provides 65 DPs for the 11 UAV capability factors in this study (Appendix A). We cross these 65 DPs with the number of possible UAVs (1 to 4) that can be in the scenario, equating to 260 DPs = 4 * 65 DPs. The Baseline Scenario where a UAV is not used is another DP.

An additional four scenarios keep the UAV capabilities constant to match Remoeye-002B parameters, but examines results when the number of UAVs is increase from one to four. In total, we perform experiments on 265 DPs = 4 * 65 DPs + 1 DP + 4 DPs .

As an example, Figure 16 shows the two-dimensional, pairwise scatter plot for a NOLH with 65 DPs for twelve factors. Each dot represents a value combination of two factors. It present the NOLH design's good space-filling properties; uniform exploration of the design space. The max pairwise correlation of this design is 0.0249, and the mean correlation is 0.004804. Minimal correlation among the columns of the design matrix will isolate the effects of the factors on the measure of interest. Additionally, NOLH designs are capable of isolating the effects of two-way interactions (Cioppa, 2002).

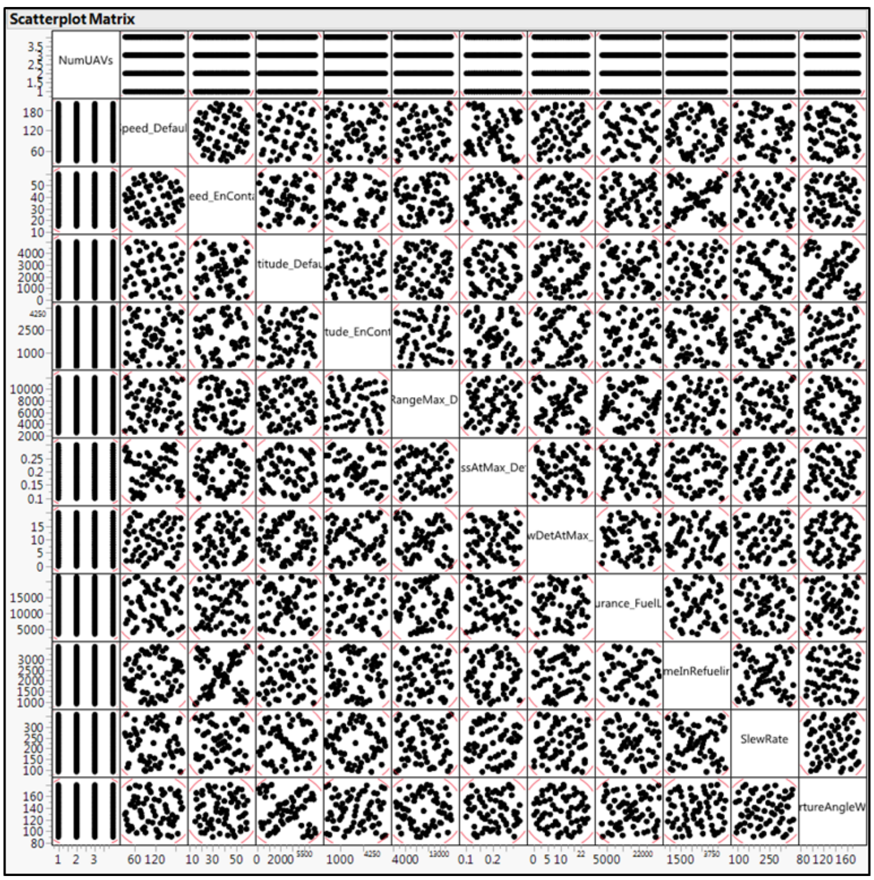


Figure 13. Scatterplot Matrix for Design Points.

4. Number of Replications Support Variance Reduction

Replications account for random errors in an experiment. We wish to replicate each DP such that the width for a 95% confidence interval on the estimated of the mean for MOE1 is less than 2. The equation to compute the number of replications, *n*, follows:

$$n = \left(\frac{\sigma(Z_\alpha + Z_\beta)}{(\mu_0 - \mu')}\right)^2$$

The result is 96 replications. Similarly, we compute the number of replications for an interval width of 30 minutes for MOE2. The required number of replications is 78 (Appendix B). Therefore, for our experiment, we determined to run each DP 100 times.

5. Execution of the simulation model

After these design of experiments, we managed the generation of scenario files for each design point using the experimental design sheet. We mapped the factor values of the design into the MANA scenario file, we run the all design options and finally got our experimental result. Each run requires 11.55 minutes, a total of 19.25 hours per DP, or 213 days for the entire experiment if utilizing a single processor. Using cluster technologies, the simulation experiment took approximately 2 days to complete.

IV. DATA ANALYSIS

This chapter analyzes our experimental results. Examination of the data will derive a suitable required operational capability for future UAVs for the KRA forces. We first explain the results of the Baseline scenario. The Baseline scenario results shows us what level of ISR capability the current ROKA has. The next step is a comparative analysis between the Baseline Scenario and scenarios in which UAVs are included. The analysis of the Scenario Two answers that what degree can the deployment of the current model of Remoeye-002B improve the ISR capability. We study the UAV capability factors that provide the best outcome of both MOEs. These results establish the desired characteristics of UAVs that support RAO. Finally, a relative cost-benefit analysis provides the most capable UAV for the least amount of expenditures.

A. RESULT OF SCENARIO ONE (BASELINE, NO UAVS)

1. BASELINE MOE #1: Total Number of Red Agents Classified

Results of the Baseline Scenario experiments indicate that rear area forces alone cannot achieve the desired threshold of MOE 1. Figure 14 shows the distribution of the number of Red agents detected and classified by the Blue battalion in the Baseline Scenario. The Blue battalion detected and classified a minimum of 14 Red agents and a maximum of 37 Red agents. The mean number of Red agents classified is 24.65 ± 1.02 at a 95% confidence interval (CI). It falls significantly short of the MOE 1 threshold of 108 Red agents. It is a clear signal for rear area forces to strengthen surveillance capabilities.

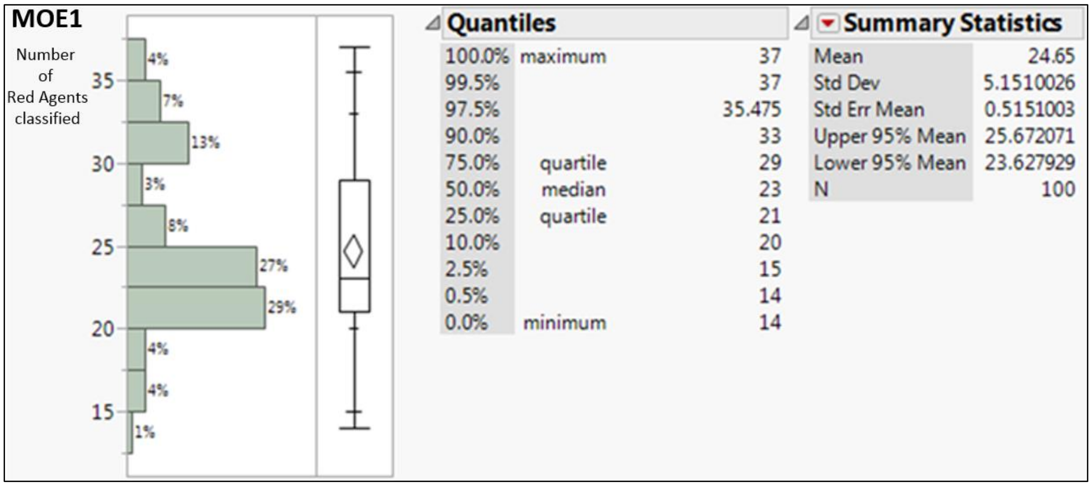
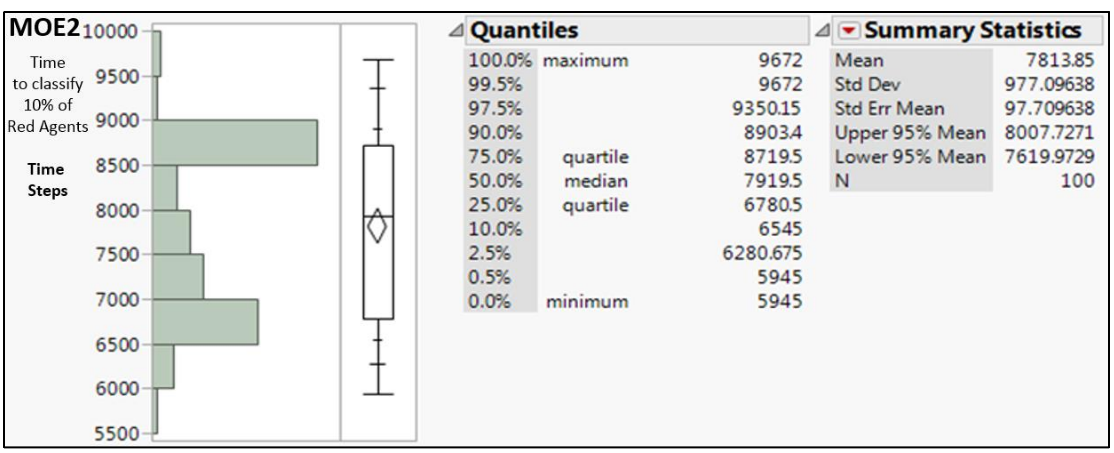


Figure 14. Distribution and Summary Statistics for Baseline Scenario (MOE 1).

2. BASELINE MOE #2: Time to Classify 10 Percent of Red Agents

Results of the Baseline Scenario experiments also show that rear area forces alone cannot achieve the desired threshold of MOE 2. It requires the Blue battalion to detect 10% of the total number of Red agents with an average of 651 minutes ± 16 minutes at a 95% CI. This time is over 60% of the total operational time in the simulation and is six times the MOE 2 threshold of 108 minutes. The failure to achieve early detection will place the Blue battalion and the ROKA at a great disadvantage in repelling NK forces.



1 Time Step = 5 seconds

Figure 15. Distribution and Summary Statistics for Baseline Scenario (MOE 2).

3. Conclusion for the Baseline Scenario

The Blue battalion cannot achieve the desired threshold of MOE 1 and 2. These results identify a considerable issue with the rear area force's ISR capabilities. The following experimental results evaluate the potential value of adding UAV capabilities to the rear area forces.

B. RESULT OF SCENARIO TWO (STATIC REMOEYE-002B CAPABILITIES)

1. MOE #1: Total Number of Red Agents Classified

Figure 16 shows the value changes of MOE 1 when one to four sets of Remoeye-002B are used. For comparison, we show the Baseline Scenario results on the far left. When one set of Remoeye-002B is deployed in the rear area of Korea, the MOE increases to 55.98 ± 1.516 at a 95% CI. This is about 31 more Red agents than the Baseline Scenario, a 200% increase.

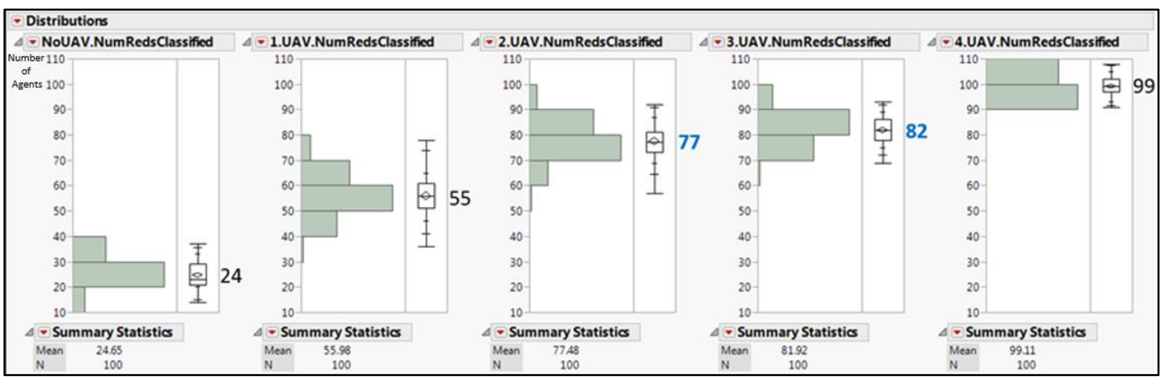
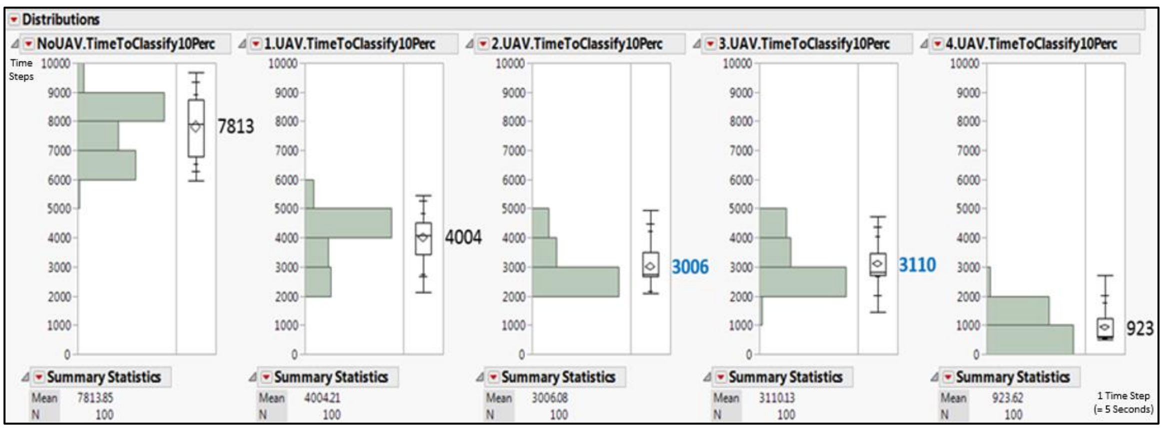


Figure 16. Distribution and Summary Statistics for Scenario Two (MOE 1).

The value of MOE 1 increases as the UAVs increase. MOE 1 increases from 55 to 77 when two UAV sets are used. Interestingly, the difference in MOE 1 values between two sets and three sets of UAVs is only five, but is still statistically significant. When three UAV sets increase to four sets, the difference in MOE 1 values is 17. Deployment of four sets of Remoeye-002B increases the Blue battalion's ability to classify enemy infiltrators by 400%. However, it still fails to meet the MOE 1 threshold.

2. MOE #2: Time to Classify 10 Percent of Red Agents

Figure 17 shows the value changes of MOE 2 as the sets of Remoeye-002B increases from one to four. Deploying one Remoeye-002B UAV decreases MOE 2 to 333 minutes ± 12 minutes at a 95% CI. It is a decrease of 317 minutes or over 5 hours from the Baseline Scenario's result. This represents a significant improvement in the effectiveness of the Korean RAO. It postures rear area forces to quickly react to enemy excursions, increasing the force's probability of mission success.



1 Time Step = 5 seconds

Figure 17. Distribution and Summary Statistics for Scenario Two (MOE 2).

Figure 17 also shows the decrease in MOE 2 as the number of Remoeye-002B UAVs increase. We note that the change from using two UAVs and three UAVs is not statistically significant. This result indicates that purchasing another set of Remoeye-002B would not improve the rear area force's capabilities in terms of MOE 2. Four sets of Remoeye-002B deployments reduced the time to classify 10% of the total Red agents to less than one eighth of the Baseline Scenario. With four sets, the average value of MOE was 77 minutes ± 8 minutes at a 95% CI, which achieves the MOE 2 threshold.

3. Conclusion for Scenario Two

While the deployment of Remoeye-002Bs to rear area forces results in significant improvements for achieving the MOE 1 threshold and does meet the MOE 2 threshold, it would mean a major monetary investment from the ROK military budget. To obtain these tremendous operational improvements required four sets of Remoeye-002B. We assert that fewer than four sets would be necessary if the ROK military procures a more capable UAV. The following sections examine different combinations of UAV capabilities that can meet and exceed the MOE thresholds.

C. EXAMINATION OF IMPROVED UAV CAPABILITIES

Remoeye-002B capabilities are insufficient to support Korean RAO. Therefore, this section shows the process of finding the optimal ROC that the ROK military can use to select a UAV. First, we investigate which UAV capability factors have the greatest impact on the RAO through regression analysis. Second, contour plots and a partition tree analysis identify the optimum design options for UAVs to support the Korean RAO. Third, a relative cost-benefit analysis provides the most capable UAV for the least amount of expenditures.

1. Factors Screening of UAV Capabilities

Screening identifies factors that significantly affect a measure of interest. It directs the analysts to focus on those factors for improving the UAV's performance in terms of MOE 1 and 2. Screening for the most significant factors also scopes the relevant options that the ROK military should consider. This study utilizes regression analysis to determine the significant factors.

a. Factors Screening on MOE 1

A linear regression model of all 12 factors on MOE 1 results in an adjusted R square value of approximately 0.70. It is indicates that the complete set of factors can adequately describe MOE 1. Therefore, regression analysis is an appropriate technique for examining the level that each factor contributes to describing MOE 1. We set the significance level to 0.05, which is the probability that will discount a factor when it actually contributes significantly to explaining the variance in MOE 1.

Figure 18 lists the 12 factors in order of the highest impact on MOE 1. The notable value in Figure 18 is the **t Ratio**. The t Ratio is the test statistic in a hypothesis test that evaluates if the estimated coefficient (**Estimate**) associated with the factor is appropriate, or if its actual value is zero. A large t Ratio results in a low probability that the actual value is zero. Therefore, the factor is significant. Seven factors are significant: Number of UAVs (NumUAVs), probability of classification (PClassAtMax_Default), aperture angle width (ApertureAngleWidth), classification maximum range (ClassRangeMax_Default), UAV default speed (Speed_Default), endurance (Endurance_FuelLevel), and refueling time (TimeInrefueling).

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
NumUAVs	6.5746308	0.310467	21.18	<.0001*
PClassAtMax_Default	44.369867	5.921928	7.49	<.0001*
ApertureAngleWidth	0.093162	0.013151	7.08	<.0001*
ClassRangeMax_Default	0.0004446	0.000125	3.57	0.0004*
Speed_Default	0.023097	0.00697	3.31	0.0011*
Endurance_FuelLevel	0.0002045	6.58e-5	3.11	0.0021*
TimeInRefueling	-0.001243	0.000439	-2.83	0.0050*
Speed_EnContact	0.0675402	0.026342	2.56	0.0109*
Altitude_Default	-0.000262	0.000244	-1.07	0.2838
Altitude_EnContact	-0.000287	0.000298	-0.96	0.3364
TimeBtwDetAtMax_Default	-0.035162	0.059233	-0.59	0.5533
SlewRate	0.0020108	0.004387	0.46	0.6471

Figure 18. Order of Factor Significance on MOE 1.

b. Factors Screening on MOE 2

A linear regression model of all 12 factors on MOE 2 also results in an adjusted R square value of approximately 0.70. Significance level of 0.05 is applied. Figure 19 lists the 12 factors in order of the highest impact on MOE 2. There are also seven factors that prove significant: Number of UAVs (NumUAVs), UAV default speed (Speed_Default), aperture angle width (ApertureAngleWidth), UAV speed at enemy contact (Speed_EnContact), classification maximum range (ClassRangeMax_Default), endurance (Endurance_FuelLevel), and probability of classification (PClassAtMax_Default).

Sorted Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
NumUAVs	-298.6854	15.09229	-19.79	<.0001*
Speed_Default	-4.625787	0.338819	-13.65	<.0001*
ApertureAngleWidth	-2.4899	0.639283	-3.89	0.0001*
Speed_EnContact	-3.806477	1.280511	-2.97	0.0032*
ClassRangeMax_Default	-0.017396	0.006059	-2.87	0.0044*
Endurance_FuelLevel	-0.009034	0.003199	-2.82	0.0051*
PClassAtMax_Default	-781.7502	287.8744	-2.72	0.0071*
TimeInRefueling	0.0167938	0.021324	0.79	0.4317
Altitude_Default	0.0021181	0.01187	0.18	0.8585
TimeBtwDetAtMax_Default	0.4048252	2.879419	0.14	0.8883
Altitude_EnContact	0.0007497	0.014499	0.05	0.9588
SlewRate	-0.008521	0.213248	-0.04	0.9682

Figure 19. Order of Factor Significance on MOE 2.

c. *Result of Factor Screening: Eight Significant Factors*

The union of all factors that are significant results in eight factors that significantly influence UAV performance. While six of the factors overlap, there was one factors that is unique for each MOE. Table 7 lists the eight factors.

Table 7. Significant Factors on Both MOEs

#	Factor Name	MOE 1	MOE 2
1	Num_UAVs	O	O
2	PClassAtMax_Default	O	O
3	ApertureAngleWidth	O	O
4	ClassRangeMax_Default	O	O
5	Speed_Default	O	O
6	Speed_EnContact		O
7	EnduranceFuelLevel	O	O
8	TimeInRefueling	O	

'**O**' has significant effect on MOE.

2. Exploring Factor Interactions with Contour Plots

Contour plots help visualize the interactions among factors (X variables) and their effects on the MOEs (Y variable). We present these plots as two-dimensional graphics. A contour line for a function of two variables is a curve connecting points where the function has the same MOE value. The contour plot provides some of the insights on

UAV capability factors' value that provide the best outcome of both MOEs. We show two examples in this discussion.

a. Contour Plot on MOE 1 – Example 1

The number of UAVs and probability of classification are the most significant factors on MOE 1. Figure 20 shows the contour plot of these two factors and MOE 1. The horizontal axis of the plot is the number of UAVs, and the vertical axis is the probability of classification. Each color is shown in the legend, indicating various MOE 1 values. In the legend, the second color from the bottom is the light green area, which represents the area greater than 108 (MOE 1 threshold) and less than or equal to 115. Different combinations of variable values can result in the same MOE 1 threshold. For instance, one UAV with a sensor capability that classifies the enemy with a probability of 0.20 can result in three UAVs with a lower sensor probability of classifying the enemy at a value of 0.10. Therefore, purchasing just one set of UAVs with a slightly higher sensor capability can result in the same performance as three sets of UAVs with lower sensor capabilities.

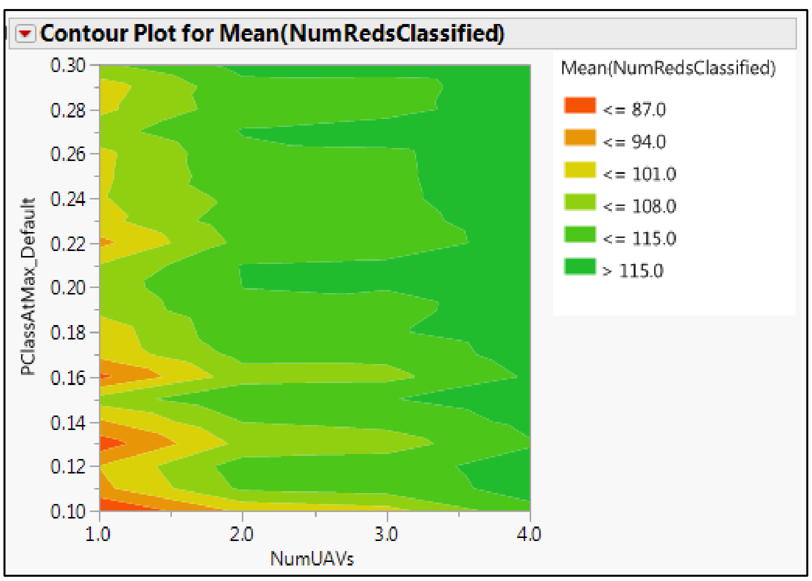


Figure 20. Contour Plot: Number of UAVs and Classification Probability.

b. Contour Plot on MOE 2 – Example 2

The number of UAVs and speed default are the most significant factors on MOE 2. Figure 21 shows the contour plot of these two factors and MOE 2. The horizontal axis of the plot is number of UAVs, and the vertical axis is speed default. As the number of UAVs increase and the speed is constant, we see an improvement in MOE2. Similarly, when the number of UAVs is constant and speed is increased, there is also marked improvement in MOE2. However, it is also clear that combinations of both variables have better results in MOE 2 when neither factor is at its maximum value. For instance, three UAVs with an average speed of 100 kph achieves the best MOE 2 value.

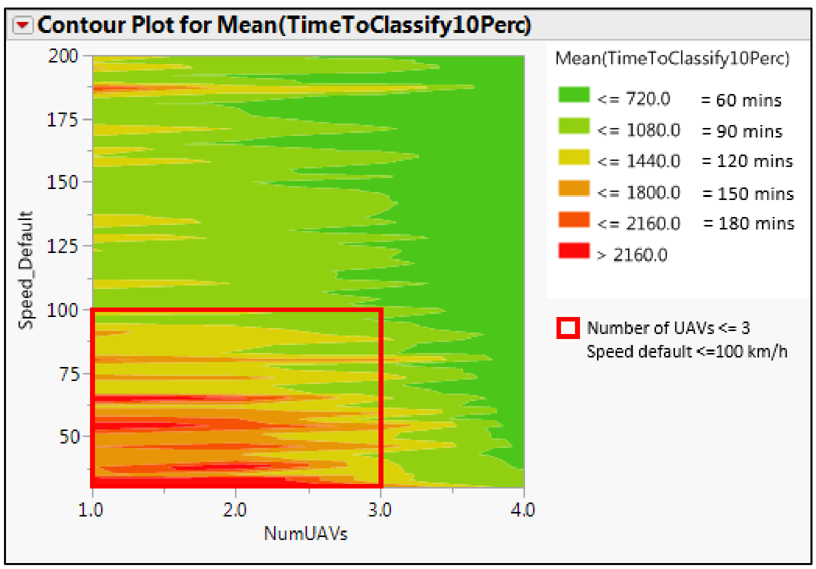


Figure 21. Contour Plot: Number of UAVs and Aperture Angle Width.

3. Conclusion for Contour Plots

Contour plots are useful for examining two-way interactions of factors. However, the influence of other factors is unseen in these plots. This complex problem involves many interactions. It is still unclear which factor should have what value level to get the best MOE result. Therefore, our next step is to use partition trees to find specific guidelines for establishing optimal UAV characteristics to help rear area forces.

4. Partition Tree Analysis: Discovering Optimum ROC for UAV

Partition tree analysis, or decision trees, finds groupings of X values that best predict a Y value. It does this by recursively searching all possible splits or groupings and then choosing the optimum splits from a large number of possible splits. Partition trees are particularly useful for exploring relationships within data, and make complicated problems easier to handle. For this thesis partition trees sort out the DPs based on the specific factor values to achieve the MOE threshold. We remind the reader that each DP is one combination of value levels for all factors, one option for UAV characteristics.

a. Partition Trees Analysis on MOE 1

The first partition tree analysis is based on the MOE 1's threshold, more than or equal to 108 NK SOF. Figure 22 shows the partition tree up to four splits. In the first box has 87 'No' and 173 'Yes'. This means that 173 DPs achieved the classification of more than or equal to 108 NK SOF. These results are also indicated as green and red bars, where green is 'Yes' and red means 'No'.

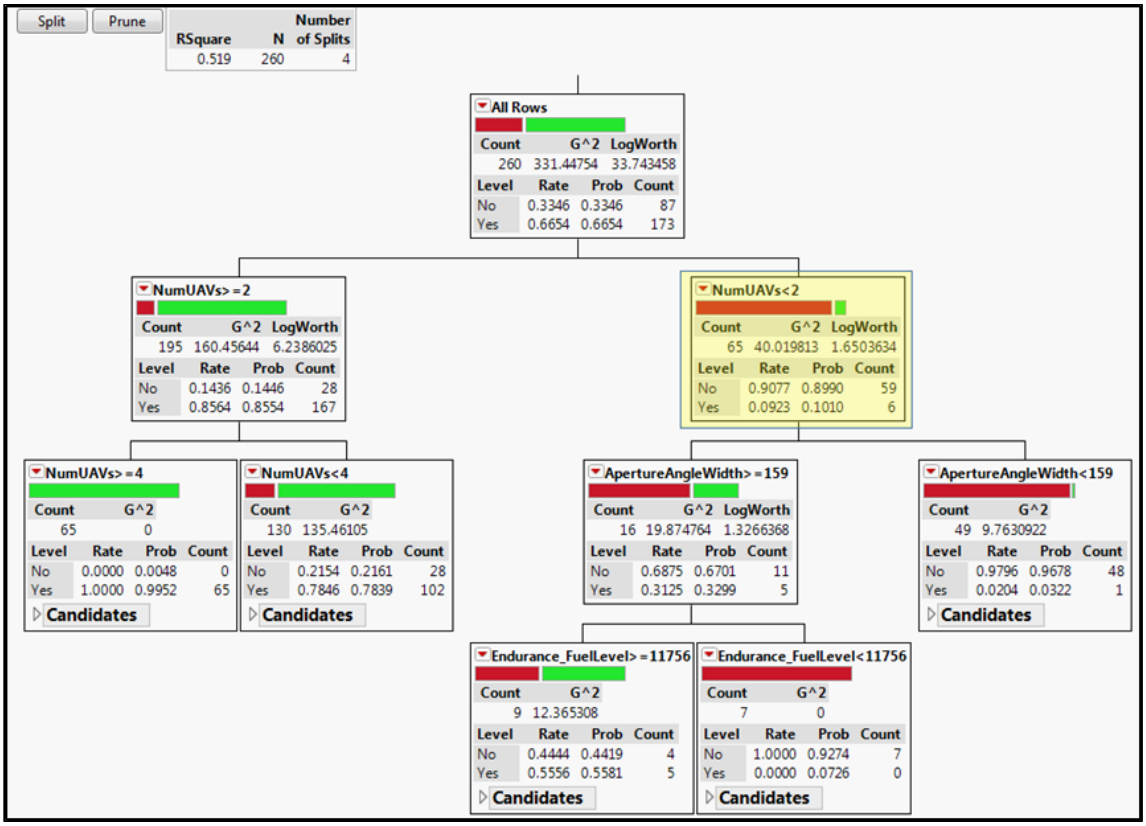


Figure 22. Partition Tree for MOE 1.

The first split is whether there are two or more sets of UAVs in the option. The box on the left side shows that 195 DPs have more than or equal to two UAVs among 260 DPs. It has 28 'No' and 167 'Yes'. This means that 85% of the 195 DPs with more than two UAVs succeeded in detecting more than 108 enemies, but 14% of the DPs failed. On the other hand, the yellow shaded box on the right represents the DPs for less than two UAV sets. It has 59 "No" and 6 "Yes." This indicates that only 10% of the 65 DPs with a single UAV set succeeded in classifying more than 108 enemies.

The second split threshold on the left side is whether there are four sets of UAVs. The box on the left side shows 65 DPs with four UAVs. All 65 DPs detect more than 108 enemies. Regardless of other performance characteristics, using four sets of UAVs can always detect more than 90% of the enemy. The box on the right of the split shows 130 DPs with two or three UAVs. There are 102 DPs that detect more than 90% of the enemy.

We can conclude that using two or more UAV sets is much more advantageous than using one UAV set to classify more than 90% of infiltrating enemies.

We focus on the right hand side of the first split; DPs with one set of UAVs. As previously stated there are six DPs containing one set of UAVs that can detect more than 90% of the enemy. With regard to the KMND's budgetary constraints, the KMND would regard the use of a single set of UAVs as more economically feasible. Therefore, we will focus more on this side of the splits to determine what capability combinations enable these DPs to achieve the MOE 1 threshold. The third split under the yellow shaded box is whether the UAV sensor's aperture angle width is greater than or equal to 159 degrees. When the aperture angle width is more than 159 degrees, five DPs out of these six DPs are in the green area. The fourth split is whether the UAV's endurance is greater than or equal to 11,756 seconds (3 hours 15 minutes). Five DPs are in the green area if the endurance is greater than 3.25 hours. This means that five DPs achieve the MOE 1 threshold if the UAV endurance is greater than 3.25 hours and the aperture angle width is greater than 159 degrees.

b. Partition Trees Analysis on MOE 2

Figure 23 shows the partition tree for MOE 2's threshold. On the left hand side of the first split, when more than two UAVs operate with speed default of above 83 kph, all DPs are able to achieve the threshold. On the right hand side of the first split, there are 28 DPs that achieve the MOE 2 threshold by using a single UAV with a speed greater than 94 kph and classification probability better than 0.18.

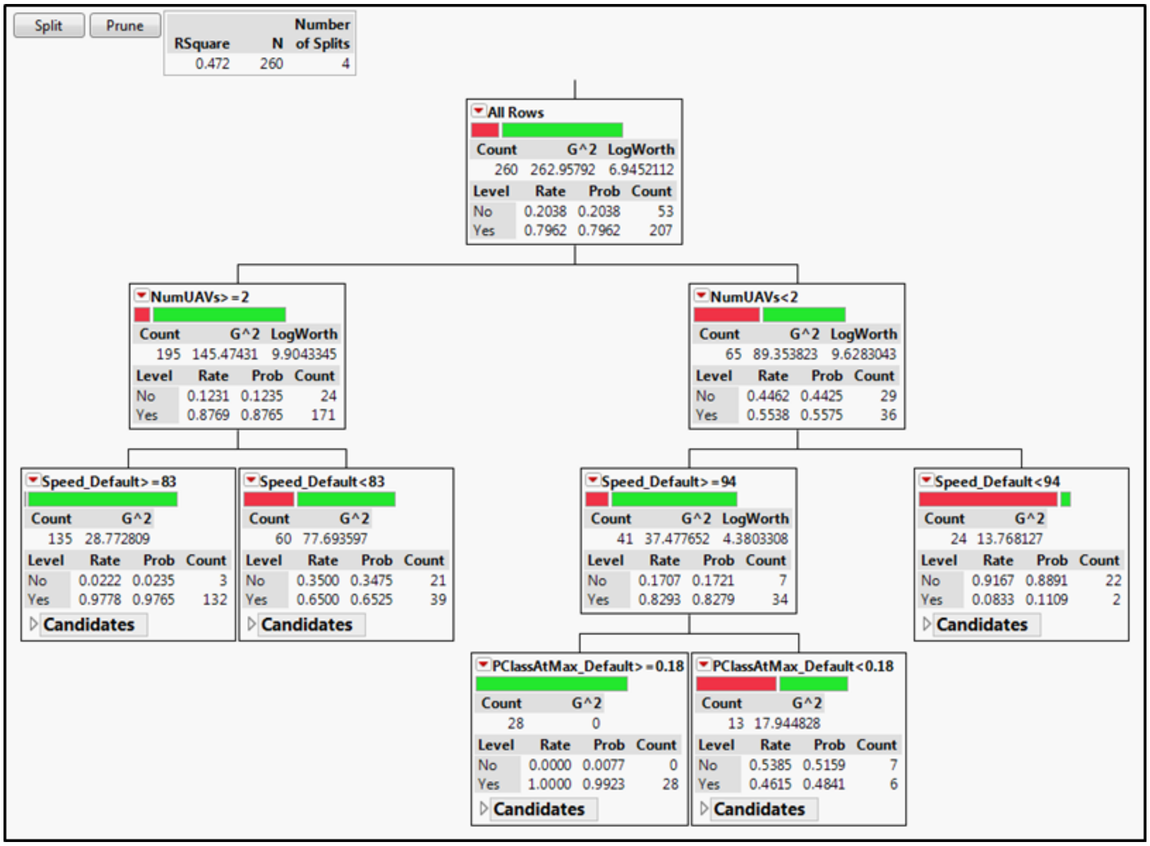


Figure 23. Partition Tree for MOE 2.

c. Partition Tree Analysis on Both MOEs

The KRA forces desire a UAV with ROC that meets both MOEs. Figure 24 shows the partition tree on both MOEs. Among 260 DPs, 163 DPs satisfy both MOEs' threshold. This analysis tells that it is advantageous to use two or more UAVs for classifying more than 90% of infiltrating enemies, and in most of these cases it is also possible to classify 10% of enemies infiltrating within 108 minutes.

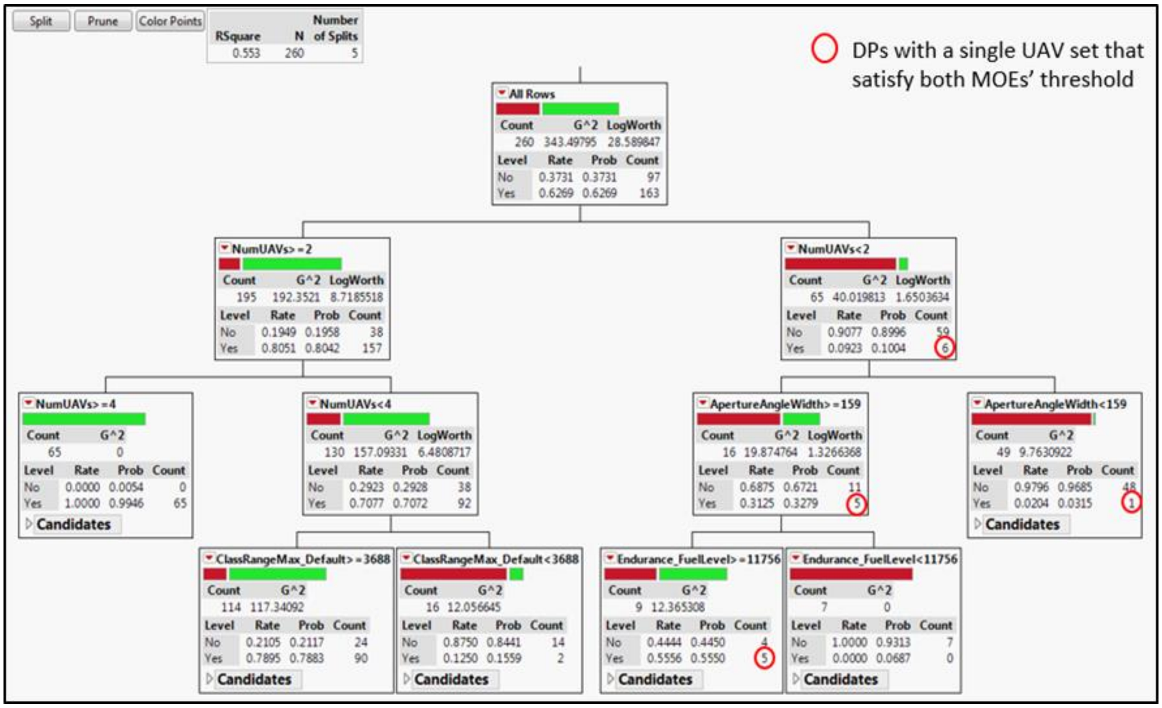


Figure 24. Partition Tree Model for Both MOEs (up to Five Splits).

The most important information that the partition tree analysis gives us is that there are six DPs, which meet both MOEs by using a single UAV set. Five DPs out of the six DPs are able to achieve both MOEs' threshold if the endurance is greater than 3.25 hours (11,756 seconds) and the aperture angle width is greater than 159 degrees. These six options shown in Table 8 are likely the most economical. However, it is difficult to ascertain the cost trade-offs in capabilities. Later in this chapter, we provide a relative cost analysis on all options to determine how these DPs fare in terms of cost and performance.

Table 8. Best Six Design Points with a Single UAV.

	Num_UAVs	EnduranceFuelLevel	ApertureAngleWidth	Speed_Default	Speed_EnContact	ClassRangeMax_Default	PClassAtMax_Default	TimeBtwDetAtMax_Default	TimeInRefueling	Altitude_Default	Altitude_EnContact	SlewRate	MOE 1	MOE 2
Remoeye-002b	**1**	**3600**	**90**	**60**	**30**	**2000**	**0.1**	**0**	**900**	**400**	**150**	**90**	**55**	**4004**
DP 26	**1**	**18506**	**176**	**96**	**27**	**6805**	**0.27**	**11**	**1406**	**832**	**3752**	**124**	**109.68**	**944.41**
DP 30	**1**	**16538**	**167**	**107**	**50**	**8289**	**0.2**	**16**	**1027**	**3409**	**1457**	**103**	**111.18**	**864.88**
DP 35	**1**	**19069**	**127**	**120**	**56**	**3984**	**0.23**	**3**	**3305**	**1287**	**1953**	**120**	**108.05**	**974.6**
DP 52	**1**	**19631**	**173**	**165**	**52**	**7398**	**0.24**	**10**	**1364**	**150**	**650**	**183**	**115.82**	**753.34**
DP 58	**1**	**11756**	**162**	**181**	**31**	**5320**	**0.27**	**3**	**1997**	**4773**	**898**	**246**	**114.73**	**736.35**
DP 62	**1**	**17100**	**159**	**192**	**47**	**5766**	**0.15**	**11**	**2841**	**680**	**1705**	**339**	**110.55**	**765.03**

5. Relative Cost Analysis for Capability Options

Because we have no available cost data for UAV components, we develop a relative cost scale in terms of user needs for each significant UAV capability. We compare the relative cost of each UAV design option and compare its performance with each MOE. A design option with a high MOE value and a low cost is the most desirable.

a. Cost of Remoeye-002B

The cost of Remoeye-002B is the basis for calculating the expected cost for each design option. We estimate the cost of Remoeye-002B based on a contract with the Defense Acquisition Program Administration of Uconsystem, the maker of Remoeye-002B. The cost of one set of Remoeye-002B UAVs is 350 million won (= 306,000 USD). The cost of one Remoeye-002B UAV is $43,500 USD. The cost of the GCS and other utilities is another $132,000 USD (Appendix C).

b. Cost per Each Factor of Remoeye-002B

To estimate the cost of each design option, we first have to calculate the cost assigned to the seven significant capability factors of Remoeye-002B. The number of UAVs is simply a multiplication factor for procuring the desired capability. Insignificant factors are not included in the cost estimate. They are constant values that do not play a role in the cost comparisons.

The author uses the Analytic Hierarchy Process (AHP) to calculate each of the seven significant factors' weights of Remoeye-002B. The weights of the seven factors are calculated through a pair comparison of which factors are more important in terms of UAV performance. This approach assumes that an important factor in UAV performance has a significant cost impact. Figure 25 illustrates the calculation of factors weight using an Excel template (SCB Associates, http://www.scbuk.com/ahp.html).

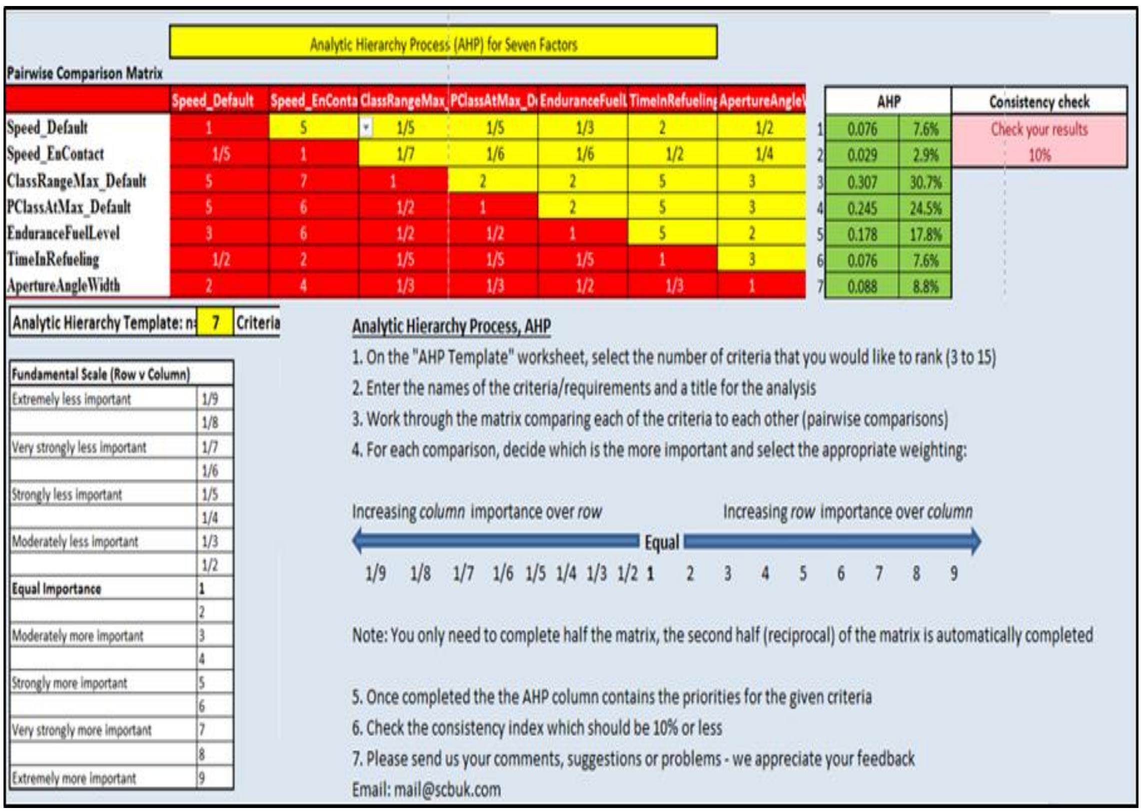


Figure 25. Weight of Seven Factors. Adapted from SCB Associates (2017).

The Excel template directs the user to list all factors on each row. It automatically populates the column headers. The subject matter expert then compares each factor with all other factors. The user assigns a score of 1 through 9 for the pairwise comparison. For example, if Row Factor A is more important than Column Factor B, then the score is an integer value of 2 through 9, say 9. A score of 1 means that the factors are of equal importance. However, if Row Factor A is less important than Column Factor B, then the user scores a fractional value, say 1/9. The resulting weight values are shown inside the AHP box, highlighted in green. A Consistency Ratio measures if the scoring is consistent. If the Consistency Ratio is less than or equal to 10%, we accept the weights (Teknomo, 2006). Our weight values are consistent. We calculate the relative costs to purchase the capability by multiplying the calculated weights by the cost of Remoeye-002B.

c. *Relative Cost for Each Design Options*

Table 9 shows the calculation of the single UAV cost of DP 35. The green cells show the cost of one Remoeye-002B UAV and the weights for each of the seven factors. The values in the gray cells are basic cost of the capability in accordance with the relative weight of the factor. The white cells are the basic Remoeye-002B capability values. The orange cells show new factor value for DP 35. The blue cells calculate the percent difference between the new and old factor values. This allows us to compute the additional costs to obtain the capability that DP 35 describes, as shown in yellow cells. Using the methodology, we calculate the new UAV in DP 35 will cost $118,719. We remind the reader that this relative cost estimation is not absolute cost.

Table 9. Relative Cost Calculation of Design Point 35.

1 RemoEye UAV $$	Speed _Default	Speed _EnContact	ClassRangeMax _Default	PClassAtMax _Default	Endurance FuelLevel	TimeIn Refueling	Aperture AngleWidth	Sum
$ 43,500	0.076	0.03	0.307	0.245	0.178	0.076	0.088	1.00
Cost per factor	$3,306	$ 1,305	$ 13,355	$ 10,658	$ 7,743	$ 3,306	$ 3,828	$ 43,500
Old Capability (Remoeye-002B)	60	30	2000	0.1	3600	900	90	
New Capability (DP 35)	120	56	3984	0.23	19069	3305	127	
% Improvement = |Old - New|/ Old	1.00	0.87	0.99	1.30	4.30	2.67	0.41	
% Improvement = Added $$	$3,306	$ 1,131	$ 13,248	$ 13,855	$ 33,271	$ 8,834	$ 1,574	$ 75,219
							Cost of 1 UAV	$118,719

We perform the same computations to estimate the total price of the system represented for all 260 options (Appendix D). The estimate accounts for four UAVs and one GCS in a UAV set.

In Figure 26, green dots represent DPs that meet two MOE thresholds, and orange dots represent DPs that do not. The red line represents the 108 NK SOF, the MOE 1 threshold. Therefore, we have to look at the green dots above the red line. The blue line connects DPs with the highest MOE 1 value for a specific price point. This relative efficiency frontier enables a cost-benefit comparison easy. We focus on the DPs that touch the blue frontier.

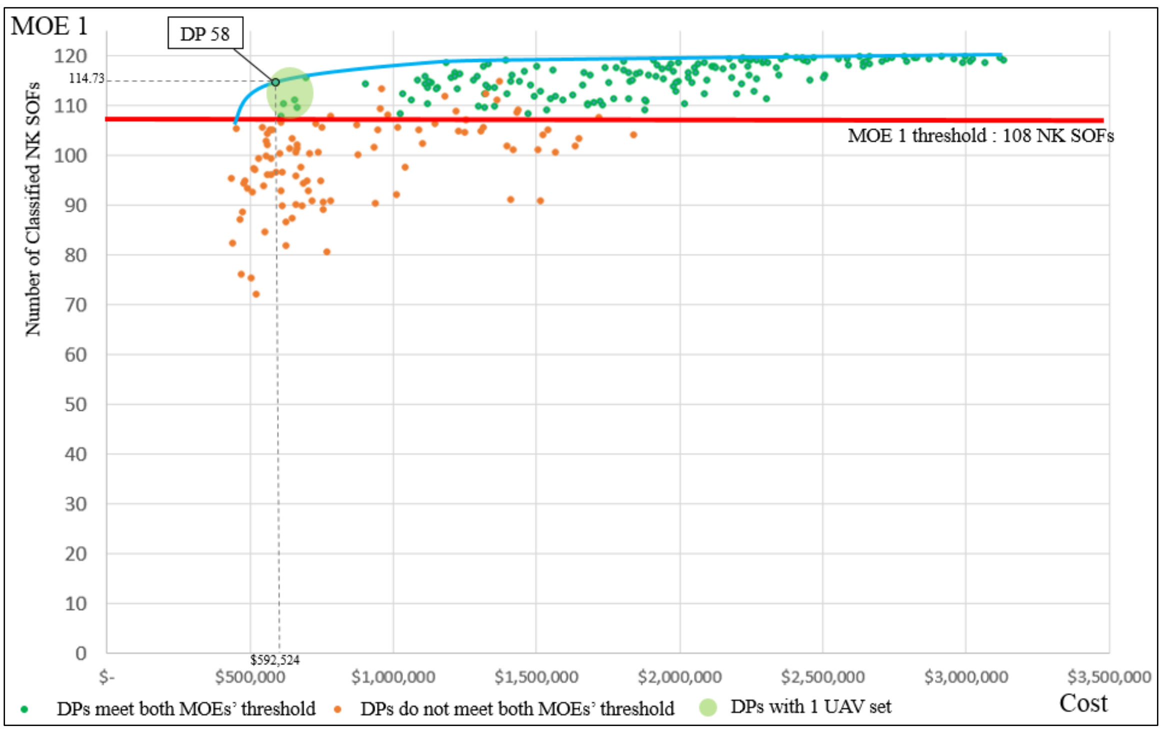


Figure 26. Relative Efficiency Frontier for MOE 1.

Figure 26 shows that DP 58 has the lowest relative cost of approximately $592,000 for meeting the MOE 1 threshold. The capability factor values for DP 58 are detailed in Table 8. On the other hand, there are DPs with 100% detection of NK SOF, but can cost over $3,000,000.

In Figure 27, the red line represents the MOE 2 threshold of 108 minutes. The blue frontier connects DPs with the lowest (best) MOE 2 value for a specific price point. Figure 27 shows that DP 58 has the lowest cost and MOE 2 value of 61 minutes. In comparison, there are DPs that can achieve an MOE 2 value of less than 30 minutes, but costs three times more than DP 58.

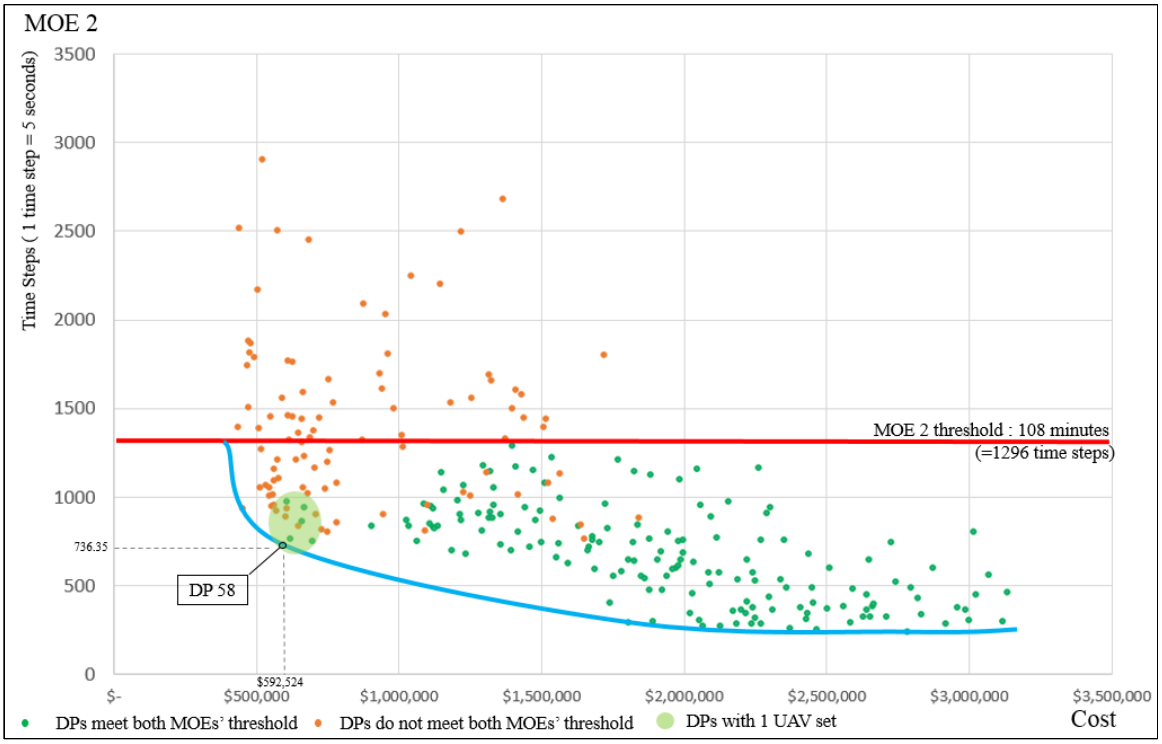


Figure 27. Relative Efficiency Frontier for MOE 2.

d. Selecting the Best among the Six Design Options

(1) Best Cost Effective Option

The DPs in the green area of both relative efficiency frontiers (Figure 27 and 28) are identical to the six DPs identified in the partition tree analysis. These DPs use only one UAV set. Table 10 shows the six DPs' data and their relative cost. In Table 10, the cost for each of the six DPs is about $600,000 to $700,000, which is twice as expensive as Remoeye-002B. However, we discover that Remoeye-002B is incapable of meeting neither of the MOE thresholds that rear area forces require. The ROK military must invest in greater capability.

Table 10. Six DPs Relative Cost and MOEs.

	Num_UAVs	EnduranceFuelLevel	ApertureAngleWidth	Speed_Default	Speed_EnContact	ClassRangeMax_Default	PClassAtMax_Default	TimeBtwDetAtMax_Default	TimeInRefueling	Altitude_Default	Altitude_EnContact	SlewRate	MOE 1	MOE 2	Cost
Remoeye-002b	1	3600	90	60	30	2000	0.1	0	900	400	150	90	55	4004	$ 306,000
DP 26	1	18506	176	96	27	6805	0.27	11	1406	832	3752	124	109.68	944.41	$ 665,572
DP 30	1	16538	167	107	50	8289	0.2	16	1027	3409	1457	103	111.18	864.88	$ 656,718
DP 35	1	19069	127	120	56	3984	0.23	3	3305	1287	1953	120	108.05	974.6	$ 606,875
DP 52	1	19631	173	165	52	7398	0.24	10	1364	150	650	183	115.82	753.34	$ 695,686
DP 58	1	11756	162	181	31	5320	0.27	3	1997	4773	898	246	114.73	736.35	$ 592,524
DP 62	1	17100	159	192	47	5766	0.15	11	2841	680	1705	339	110.55	765.03	$ 616,356

Among all options, DP 58 is the cheapest at $592,524, followed by DP 35 and DP 62. Figure 28 is an enlarged view for the highlighted DPs in the relative cost curves. While achieving the best values for MOEs 1 and 2, DP 58 also has the least cost. The highest value in MOE 1 is DP 52, differing from DP 58 by only one NK SOF soldier, but at a cost of another $103,162. Therefore, we can conclude that DP 58 is the best DP in terms of cost efficiency.

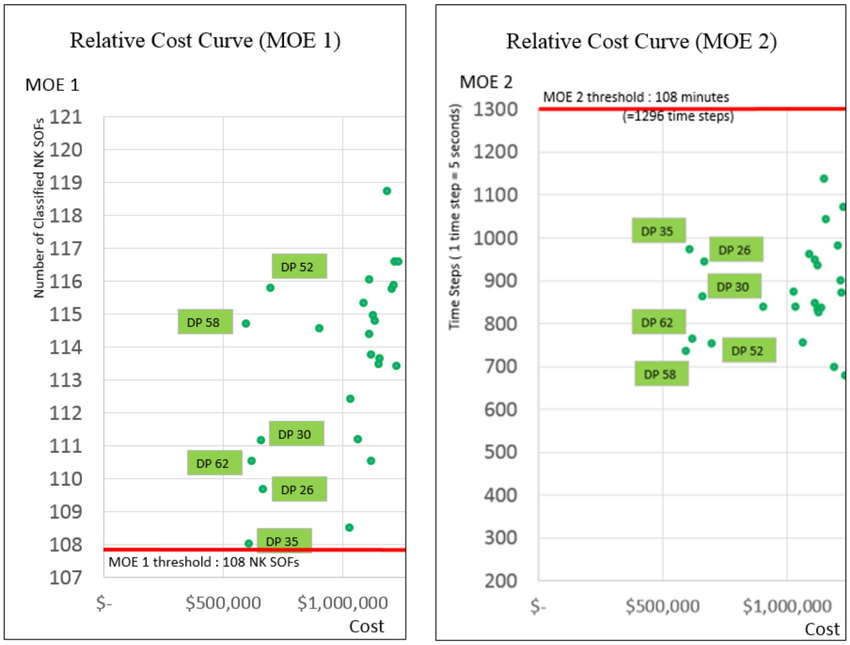


Figure 28. Enlarged Cost-Benefit Plots with Six Design Points.

(2) MOEs and Highest Probability of Mission Success

MOE 1 and MOE 2 values are obtained by averaging the results of 100 repetitions of each option. Since it is the averaged MOEs, it does not mean the six DPs can always get these MOEs values simultaneously when we repeat these simulation runs. These six DPs might be lucky enough to have good mean value of both MOEs over 100 repetitions. Thus, for each of the six best options in Table 10, we run 500 simulations. We determine whether, or not the run results in meeting both MOE thresholds. The percentage of runs that result in meeting both MOEs thresholds is the probability of mission success for that option. We computed the probability of mission success at a 95% CI, from the 500 simulation runs.

In Table 11, after repeating 500 simulation runs, DP 30 and 35 still have an average MOE 1 value that is higher than 108. However, DPs 26, 30 and 35 have low probability of mission success. This result is not surprising since their 95% CI lower endpoint values for MOE 1 values do not meet the MOE 1 threshold. It indicates that meeting an even harder criterion would result in a lower probability. Therefore, DPs 26, 30 and 35 are no longer acceptable DPs.

On the other hand, DPs 52, 58 and 62 are DPs whose worst value on a 95% CI still achieve both MOE thresholds. All three DPs have a probability of mission success that is 95% or greater. While DP 52 showed a 100% mission success rate it is at an increased costs of 17% more than DP 58, which achieves a 98.8% success rate. We conclude that DP 58 is the best design option for rear area forces.

Table 11. MOEs and Mission Success Probability of Best Six Design Points.

	DP #	MOE 1			MOE 2			Iterations			Probability
		Lower CI	Mean	Upper CI	Lower CI	Mean	Upper CI	Total	Yes	No	
1	DP 26	105.836	106.452	107.067	916.966	925.726	934.486	500	257	243	0.514
2	DP 30	107.753	108.14	108.526	894.783	905.98	917.177	500	282	218	0.564
3	DP 35	107.786	108.104	108.422	966.055	975.594	985.133	500	290	210	0.580
4	DP 52	115.681	115.858	116.034	726.467	733.968	741.469	500	500	0	1.000
5	DP 58	114.239	114.466	114.693	723.898	728.862	733.826	500	494	6	0.988
6	DP 62	111.697	111.924	112.151	750.501	757.29	764.078	500	475	25	0.950

95% of confidence interval on MOE 1 and MOE 2.

In Iterations, ‘Yes’ means the DP meets both MOEs threshold. ‘No’ do not meet the thresholds.

According to the U.S. Army UAS Roadmap 2010–2035, DP 58 characteristics can be classified as Group 3. The sensor-related factor values of the DP 58, which were derived through simulation, are difficult to directly compare with the existing UAV models. It is because published data on factor values such as the probability of classification are not available. Thus, we compared DP 58 with the current U.S. Army UAV model in terms of the UAV flight performance. We find that among the current U.S. Army UAV models in operation the RQ-7B Shadow is the most similar to DP 58.

Table 12. Comparison between Design Point 58 and RQ-7B Shadow.

UAV Model	Speed_Default	Altitude (Service Ceiling)	Endurance	System Cost
RQ-7B Shadow (Group 3)	Cruise: 167 kph Max: 203 kph	4572 m	6 hours	$ 15,500,000
DP 58	181 kph	4773 m	3.36 hours	$ 592,524

V. CONCLUSION

The purpose of this thesis is to examine the use of battalion-level UAVs as a countermeasure to address emerging problems in RAO caused by the ROK's military reform. This study derived a suitable required operational capability (ROC) for future UAVs for the KRA forces.

In order to get the proper ROC, we first examine the effects of deploying Remoeye-002B at the battalion level in the KRA. Applying computer experimentation in a THAAD scenario provides insights to the ISR capabilities that the force requires. Advanced experimental designs efficiently explore single and combined characteristics of a UAV that can best improve the surveillance mission. Regression analysis and partitioning tree analysis assist in examining 260 options. In addition, a relative cost analysis identifies the most cost-effective design option. The best option establishes the required characteristics for future UAVs that Korean leadership may wish to consider to support Korean RAO.

A. PRIMARY FINDINGS

- Without any UAVs, the ROKA battalion could classify only 20% of the total 120 NK SOF as enemies. On average, it required almost 11 hours to classify 12 NK soldiers. This indicates that there is a need to strengthen the ISR capabilities of the ROKA rear area forces.
- The deployment of Remoeye-002Bs to rear area forces results in significant improvements on RAO. The deployment of a single set of Remoeye-002B doubled the Blue battalion's ISR mission capability. It made a 200% increase on the classification of NK SOFs than the Scenario with no UAVs. It reduced the time for classifying the enemy to 333 minutes. It cut the time required by half compared to no UAV. Four sets of Remoeye-002B for a battalion unit gives further improvement on ISR mission capability.
- Despite running the four UAV sets of Remoeye-002B, the rear area force still failed to achieve operational goals of detecting more than 90% of enemies infiltrating during operating hours and detecting more than 10% of enemies in the early stages of operations. Small UAV, Remoeye-002B capabilities are insufficient to support Korean RAO.

- Four sets of Remoeye-002B for a battalion unit mean a massive monetary investment in Korea's military budget. If the ROK military procures a more capable UAV than Remoeye-002B, fewer than four sets would be necessary and it can be more cost effective.

B. ADDITIONAL FINDINGS

The linear regression identified factors that significantly affect a measure of interest. It indicates that the number of UAVs, probability of classification, aperture angle width, classification maximum range, speed default, refueling time, and endurance have some effect on the number of NK SOFs classified. It also shows that the number of UAVs, speed default, aperture angle width, speed at enemy contact, classification maximum range, endurance, and probability of classification have some effect on the time to classify 10% of the total number of enemies. It also indicates that the number of UAV sets has the largest impact on the Korean RAO.

- The contour plot showed that purchasing just one set of UAVs with a higher sensor capability could result in the same performance as two or more sets of UAVs with lower sensor capabilities.

- The partition tree analysis identifies that there are six design options, which meet the operational goals by using a single UAV set. Five of them have endurance of greater than 3.25 hours and the aperture angle width of greater than 159 degrees.

- The cost analysis found these six design options are the most cost effective options. Among them, DP 58 is the cheapest at $592,524. It also has high mission success probability of 98.8%. Therefore, DP 58 is the best design option for rear area forces.

- The optimum UAV capabilities for battalion units in the future Korean RAO are as follows: Probability of classification at 0.27, aperture angle width with 162 degrees, classification max range of 5,320 m, speed default of 181 kph, speed at enemy contact of 31 kph, time in refueling of 33 minutes, and endurance of 3.25 hours.

C. FUTURE RESEARCH

The following is a list of topics that could be examined:

- Include the combat between agents in the simulation model.

- Consider UAV vulnerability to small armaments of ground forces.

- Create algorithms that UAV can change paths efficiently in real-time situations.

- Use enemy settings that change in real-time, reflecting enemy’s tactics.
- Establish the UAV operational concept associated with current ROK military operations.
- Focus on employment options of UAVs corresponding to both topographic features of the KRA and the enemy’s infiltration behavior.
- Use detailed data for the cost estimation.

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APPENDIX A. 65 DESIGN POINTS

NumUAVs	Speed_Default	Speed_EnContact	Altitude_Default	Altitude_EnContact	ClassRangeMax_Default	PClassAtMax_Default	TimeBtwDetAtMax_Default	Endurance_FuelLevel	TimeInRefueling	SlewRate	ApertureAngleWidth
1	30	42	1135	3008	2797	0.28	6	19350	2081	271	129
1	33	37	1666	340	10367	0.29	13	6975	2756	259	132
1	35	29	2651	960	12000	0.24	2	14850	1786	360	120
1	38	28	4470	2325	8734	0.25	9	8100	1659	111	111
1	41	47	4394	1581	5914	0.26	12	20194	3009	128	101
1	43	39	4091	3938	11109	0.27	15	10631	1955	229	174
1	46	22	1969	712	3242	0.24	18	9788	1617	263	146
1	49	44	377	3132	9180	0.13	17	13444	2503	204	108
1	51	30	453	588	5172	0.17	2	9506	1828	195	105
1	54	40	3105	3504	5617	0.1	4	4163	2039	200	152
1	57	56	1363	836	6953	0.12	13	4444	1533	293	160
1	59	51	3030	3628	2648	0.23	20	8944	2798	335	142
1	62	26	529	2759	8438	0.12	6	21319	2925	276	179
1	65	23	5000	3380	7102	0.16	10	5569	3136	267	97
1	67	35	2954	464	9477	0.11	19	21600	2208	217	158
1	70	52	2423	3876	9625	0.23	2	14006	3178	242	149
1	73	32	4242	30	4727	0.26	7	15131	2588	238	177
1	75	42	2272	2821	4578	0.12	19	14288	2166	145	136
1	78	58	3257	2697	10813	0.15	4	12881	984	166	131
1	80	18	3333	1085	3539	0.1	13	12038	3431	149	125
1	83	59	4924	774	8141	0.18	12	19913	1448	280	104
1	86	34	2348	1147	10664	0.11	0	11475	2377	141	148
1	88	54	1590	1767	2945	0.22	5	7819	1111	98	107
1	91	20	1514	2201	11406	0.22	15	16819	3263	94	98
1	94	49	4545	1643	4281	0.15	1	18788	3347	318	156
1	96	27	832	3752	6805	0.27	11	18506	1406	124	176
1	99	15	984	2511	5469	0.19	8	17663	900	343	117
1	102	45	1211	216	7844	0.26	11	4725	3220	136	180
1	104	21	3712	2635	6508	0.21	3	7256	2630	162	170
1	107	50	3409	1457	8289	0.2	16	16538	1027	103	167
1	110	19	3863	2077	10516	0.17	17	6131	1195	330	143
1	112	59	302	1891	10070	0.21	14	9225	3558	297	115
1	115	38	2575	2015	7250	0.2	10	12600	2250	225	135
1	118	16	4848	2139	4430	0.19	6	15975	942	153	155
1	120	56	1287	1953	3984	0.23	3	19069	3305	120	127
1	123	25	1741	2573	6211	0.2	4	8663	3473	347	103
1	126	54	1438	1395	7992	0.19	17	17944	1870	288	100
1	128	30	3939	3814	6656	0.14	9	20475	1280	314	90
1	131	60	4166	1519	9031	0.21	12	7538	3600	107	153
1	134	48	4318	278	7695	0.13	9	6694	3094	326	94
1	136	26	605	2387	10219	0.25	19	6413	1153	132	114
1	139	55	3636	1829	3094	0.18	5	8381	1238	356	172
1	142	21	3560	2263	11555	0.18	15	17381	3389	352	163
1	144	41	2802	2883	3836	0.29	20	13725	2123	309	122
1	147	16	226	3256	6359	0.22	8	5288	3052	170	166
1	150	57	1817	2945	10961	0.3	7	13163	1069	301	145
1	152	17	1893	1333	3688	0.25	16	12319	3516	284	139
1	155	33	2878	1209	9922	0.28	1	10913	2334	305	134
1	158	43	908	4000	9773	0.14	13	10069	1913	212	93
1	160	23	2727	154	4875	0.17	18	11194	1322	208	121
1	163	40	2196	3566	5023	0.29	1	3600	2292	233	113
1	165	52	150	650	7398	0.24	10	19631	1364	183	173
1	168	49	4621	1271	6063	0.28	14	3881	1575	174	91
1	171	24	2120	402	11852	0.18	0	16256	1702	115	128
1	173	19	3788	3194	7547	0.28	7	20756	2967	158	110
1	176	35	2045	526	8883	0.3	16	21038	2461	250	118
1	179	45	4697	3442	9328	0.23	18	15694	2672	255	165
1	181	31	4773	898	5320	0.27	3	11756	1997	246	162
1	184	53	3181	3318	11258	0.16	3	15413	2883	187	124
1	187	36	1059	92	3391	0.13	5	14569	2545	221	96
1	189	28	756	2449	8586	0.14	8	5006	1491	322	169
1	192	47	680	1705	5766	0.15	11	17100	2841	339	159
1	195	46	2499	3070	2500	0.16	18	10350	2714	90	150
1	197	38	3484	3690	4133	0.11	8	18225	1744	191	138
1	200	33	4015	1023	11703	0.13	14	5850	2419	179	141

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APPENDIX B. CALCULATION ON REQUIRED RUNS

A. MOE 1

Calculate required runs by using hypothesis testing (to compare means)			
m0-m' (practical difference we want to detect)			2
sigma estimate (std dev)			6.040269
z value for power = .9		zsubBeta	1.28
z value for alpha = .05		zsubAlpha	1.96
	required sample size n=		96

B. MOE 2

Calculate sample size required for hypothesis testing (to compare means)			
m0-m' (practical difference we want to detect)		1800	=30 mins
sigma estimate (std dev)			4885.4819
z value for power = .9		zsubBeta	1.28
z value for alpha = .05		zsubAlpha	1.96
	required sample size n=		78

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APPENDIX C. REMOEYE-002B COST ESTIMATION

The cost of the Remoeye-002B single system is roughly estimated at 350 million won (= $306,000), but the details of the GCS price and the price of the four aircraft fuselages were not available to the public. Therefore, we refer to the price information of RQ-11 Raven in the United States, which has similar performance to the Remoeye-002B. RQ-11 Raven's single system consists of two GCSs and three aircraft fuselages.

Remoeye-002B				RQ-11 Raven		
4 UAVs, 1 GCS				3 UAVs, 2 GCS, 1 RSTA, 1 FRK		
				GCS : Ground Control Stations		
				RSTA Kit : Reconnaissance, Surveillance and Target Acquisition kit		
120 systems contract				FRK : Field Repair Kit		
42000000000	KRW					
36700000	USD					
1 system	350000000	KRW		1 system	300000	USD
	306000	USD		1 UAV	34000	USD
4 UAVs	174000	USD		3 UAVs	102000	USD
1 GCS	66000	USD		2 GCS	132000	USD
1 RSTA	33000	USD		1 RSTA	33000	USD
1 FRK	33000	USD		1 FRK	33000	USD
Total	306000	USD		Total	300000	USD
Remoeye-002B				RQ-11 Raven		
1 system	306000	USD		1 system	300000	USD
1 UAV	43500	USD		1 UAV	34000	USD

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APPENDIX D. COST ESTIMATION FOR ALL DESIGN OPTIONS

	1 UAV Set Cost					Total System Cost
	1 Remoeye UAV $$	1 UAV Cost	4 UAVs Cost	GCS Cost	Subtotal	
DP 1	$ 43,500.00	$ 110,052.90	$ 440,211.60	$ 132,000.00	$ 572,211.60	$ 572,211.60
DP 2	$ 43,500.00	$ 137,273.17	$ 549,092.68	$ 132,000.00	$ 681,092.68	$ 681,092.68
DP 3	$ 43,500.00	$ 155,341.45	$ 621,365.79	$ 132,000.00	$ 753,365.79	$ 753,365.79
DP 4	$ 43,500.00	$ 119,110.06	$ 476,440.25	$ 132,000.00	$ 608,440.25	$ 608,440.25
DP 5	$ 43,500.00	$ 132,379.01	$ 529,516.05	$ 132,000.00	$ 661,516.05	$ 661,516.05
DP 6	$ 43,500.00	$ 146,339.70	$ 585,358.78	$ 132,000.00	$ 717,358.78	$ 717,358.78
DP 7	$ 43,500.00	$ 86,158.05	$ 344,632.19	$ 132,000.00	$ 476,632.19	$ 476,632.19
DP 8	$ 43,500.00	$ 123,681.76	$ 494,727.05	$ 132,000.00	$ 626,727.05	$ 626,727.05
DP 9	$ 43,500.00	$ 89,386.06	$ 357,544.25	$ 132,000.00	$ 489,544.25	$ 489,544.25
DP 10	$ 43,500.00	$ 76,449.13	$ 305,796.50	$ 132,000.00	$ 437,796.50	$ 437,796.50
DP 11	$ 43,500.00	$ 87,118.08	$ 348,472.30	$ 132,000.00	$ 480,472.30	$ 480,472.30
DP 12	$ 43,500.00	$ 83,327.98	$ 333,311.93	$ 132,000.00	$ 465,311.93	$ 465,311.93
DP 13	$ 43,500.00	$ 138,238.42	$ 552,953.67	$ 132,000.00	$ 684,953.67	$ 684,953.67
DP 14	$ 43,500.00	$ 97,288.13	$ 389,152.51	$ 132,000.00	$ 521,152.51	$ 521,152.51
DP 15	$ 43,500.00	$ 141,506.73	$ 566,026.94	$ 132,000.00	$ 698,026.94	$ 698,026.94
DP 16	$ 43,500.00	$ 143,035.67	$ 572,142.69	$ 132,000.00	$ 704,142.69	$ 704,142.69
DP 17	$ 43,500.00	$ 114,266.41	$ 457,065.63	$ 132,000.00	$ 589,065.63	$ 589,065.63
DP 18	$ 43,500.00	$ 93,789.03	$ 375,156.12	$ 132,000.00	$ 507,156.12	$ 507,156.12
DP 19	$ 43,500.00	$ 131,899.47	$ 527,597.86	$ 132,000.00	$ 659,597.86	$ 659,597.86
DP 20	$ 43,500.00	$ 84,334.89	$ 337,339.57	$ 132,000.00	$ 469,339.57	$ 469,339.57
DP 21	$ 43,500.00	$ 133,254.79	$ 533,019.16	$ 132,000.00	$ 665,019.16	$ 665,019.16
DP 22	$ 43,500.00	$ 128,854.30	$ 515,417.21	$ 132,000.00	$ 647,417.21	$ 647,417.21
DP 23	$ 43,500.00	$ 75,758.31	$ 303,033.23	$ 132,000.00	$ 435,033.23	$ 435,033.23
DP 24	$ 43,500.00	$ 158,690.53	$ 634,762.13	$ 132,000.00	$ 766,762.13	$ 766,762.13
DP 25	$ 43,500.00	$ 111,222.16	$ 444,888.64	$ 132,000.00	$ 576,888.64	$ 576,888.64
DP 26	$ 43,500.00	$ 133,392.93	$ 533,571.73	$ 132,000.00	$ 665,571.73	$ 665,571.73
DP 27	$ 43,500.00	$ 110,452.10	$ 441,808.40	$ 132,000.00	$ 573,808.40	$ 573,808.40
DP 28	$ 43,500.00	$ 117,310.37	$ 469,241.48	$ 132,000.00	$ 601,241.48	$ 601,241.48
DP 29	$ 43,500.00	$ 105,761.17	$ 423,044.69	$ 132,000.00	$ 555,044.69	$ 555,044.69
DP 30	$ 43,500.00	$ 131,179.49	$ 524,717.95	$ 132,000.00	$ 656,717.95	$ 656,717.95
DP 31	$ 43,500.00	$ 119,838.87	$ 479,355.48	$ 132,000.00	$ 611,355.48	$ 611,355.48
DP 32	$ 43,500.00	$ 136,160.85	$ 544,643.39	$ 132,000.00	$ 676,643.39	$ 676,643.39
DP 33	$ 43,500.00	$ 118,822.06	$ 475,288.25	$ 132,000.00	$ 607,288.25	$ 607,288.25
DP 34	$ 43,500.00	$ 102,657.78	$ 410,631.11	$ 132,000.00	$ 542,631.11	$ 542,631.11
DP 35	$ 43,500.00	$ 118,718.75	$ 474,875.02	$ 132,000.00	$ 606,875.02	$ 606,875.02
DP 36	$ 43,500.00	$ 106,858.29	$ 427,433.16	$ 132,000.00	$ 559,433.16	$ 559,433.16
DP 37	$ 43,500.00	$ 132,622.45	$ 530,489.81	$ 132,000.00	$ 662,489.81	$ 662,489.81
DP 38	$ 43,500.00	$ 120,290.26	$ 481,161.02	$ 132,000.00	$ 613,161.02	$ 613,161.02
DP 39	$ 43,500.00	$ 128,455.68	$ 513,822.71	$ 132,000.00	$ 645,822.71	$ 645,822.71
DP 40	$ 43,500.00	$ 104,468.69	$ 417,874.78	$ 132,000.00	$ 549,874.78	$ 549,874.78
DP 41	$ 43,500.00	$ 126,728.62	$ 506,914.46	$ 132,000.00	$ 638,914.46	$ 638,914.46
DP 42	$ 43,500.00	$ 79,783.77	$ 319,135.06	$ 132,000.00	$ 451,135.06	$ 451,135.06
DP 43	$ 43,500.00	$ 162,625.32	$ 650,501.27	$ 132,000.00	$ 782,501.27	$ 782,501.27
DP 44	$ 43,500.00	$ 108,746.32	$ 434,985.29	$ 132,000.00	$ 566,985.29	$ 566,985.29
DP 45	$ 43,500.00	$ 105,565.99	$ 422,263.94	$ 132,000.00	$ 554,263.94	$ 554,263.94
DP 46	$ 43,500.00	$ 154,311.88	$ 617,247.53	$ 132,000.00	$ 749,247.53	$ 749,247.53
DP 47	$ 43,500.00	$ 106,838.84	$ 427,355.35	$ 132,000.00	$ 559,355.35	$ 559,355.35
DP 48	$ 43,500.00	$ 143,813.75	$ 575,254.98	$ 132,000.00	$ 707,254.98	$ 707,254.98
DP 49	$ 43,500.00	$ 123,392.99	$ 493,571.97	$ 132,000.00	$ 625,571.97	$ 625,571.97
DP 50	$ 43,500.00	$ 95,173.95	$ 380,695.81	$ 132,000.00	$ 512,695.81	$ 512,695.81
DP 51	$ 43,500.00	$ 96,136.42	$ 384,545.69	$ 132,000.00	$ 516,545.69	$ 516,545.69
DP 52	$ 43,500.00	$ 140,921.50	$ 563,685.99	$ 132,000.00	$ 695,685.99	$ 695,685.99
DP 53	$ 43,500.00	$ 99,716.88	$ 398,867.54	$ 132,000.00	$ 530,867.54	$ 530,867.54
DP 54	$ 43,500.00	$ 155,970.59	$ 623,882.37	$ 132,000.00	$ 755,882.37	$ 755,882.37
DP 55	$ 43,500.00	$ 151,770.15	$ 607,080.60	$ 132,000.00	$ 739,080.60	$ 739,080.60
DP 56	$ 43,500.00	$ 161,814.85	$ 647,259.40	$ 132,000.00	$ 779,259.40	$ 779,259.40
DP 57	$ 43,500.00	$ 149,206.36	$ 596,825.45	$ 132,000.00	$ 728,825.45	$ 728,825.45
DP 58	$ 43,500.00	$ 115,131.06	$ 460,524.25	$ 132,000.00	$ 592,524.25	$ 592,524.25
DP 59	$ 43,500.00	$ 153,683.53	$ 614,734.11	$ 132,000.00	$ 746,734.11	$ 746,734.11
DP 60	$ 43,500.00	$ 93,134.33	$ 372,537.32	$ 132,000.00	$ 504,537.32	$ 504,537.32

	1 UAV Set Cost					Total System Cost
	1 Remoeye UAV $$	1 UAV Cost	4 UAVs Cost	GCS Cost	Subtotal	
DP 61	$ 43,500.00	$ 107,489.41	$ 429,957.65	$ 132,000.00	$ 561,957.65	$ 561,957.65
DP 62	$ 43,500.00	$ 121,088.96	$ 484,355.85	$ 132,000.00	$ 616,355.85	$ 616,355.85
DP 63	$ 43,500.00	$ 85,101.18	$ 340,404.71	$ 132,000.00	$ 472,404.71	$ 472,404.71
DP 64	$ 43,500.00	$ 103,302.86	$ 413,211.42	$ 132,000.00	$ 545,211.42	$ 545,211.42
DP 65	$ 43,500.00	$ 131,919.48	$ 527,677.90	$ 132,000.00	$ 659,677.90	$ 659,677.90
DP 66	$ 43,500.00	$ 110,052.90	$ 440,211.60	$ 132,000.00	$ 572,211.60	$ 1,144,423.20
DP 67	$ 43,500.00	$ 137,273.17	$ 549,092.68	$ 132,000.00	$ 681,092.68	$ 1,362,185.36
DP 68	$ 43,500.00	$ 155,341.45	$ 621,365.79	$ 132,000.00	$ 753,365.79	$ 1,506,731.59
DP 69	$ 43,500.00	$ 119,110.06	$ 476,440.25	$ 132,000.00	$ 608,440.25	$ 1,216,880.49
DP 70	$ 43,500.00	$ 132,379.01	$ 529,516.05	$ 132,000.00	$ 661,516.05	$ 1,323,032.09
DP 71	$ 43,500.00	$ 146,339.70	$ 585,358.78	$ 132,000.00	$ 717,358.78	$ 1,434,717.57
DP 72	$ 43,500.00	$ 86,158.05	$ 344,632.19	$ 132,000.00	$ 476,632.19	$ 953,264.38
DP 73	$ 43,500.00	$ 123,681.76	$ 494,727.05	$ 132,000.00	$ 626,727.05	$ 1,253,454.09
DP 74	$ 43,500.00	$ 89,386.06	$ 357,544.25	$ 132,000.00	$ 489,544.25	$ 979,088.50
DP 75	$ 43,500.00	$ 76,449.13	$ 305,796.50	$ 132,000.00	$ 437,796.50	$ 875,593.01
DP 76	$ 43,500.00	$ 87,118.08	$ 348,472.30	$ 132,000.00	$ 480,472.30	$ 960,944.61
DP 77	$ 43,500.00	$ 83,327.98	$ 333,311.93	$ 132,000.00	$ 465,311.93	$ 930,623.85
DP 78	$ 43,500.00	$ 138,238.42	$ 552,953.67	$ 132,000.00	$ 684,953.67	$ 1,369,907.34
DP 79	$ 43,500.00	$ 97,288.13	$ 389,152.51	$ 132,000.00	$ 521,152.51	$ 1,042,305.02
DP 80	$ 43,500.00	$ 141,506.73	$ 566,026.94	$ 132,000.00	$ 698,026.94	$ 1,396,053.88
DP 81	$ 43,500.00	$ 143,035.67	$ 572,142.69	$ 132,000.00	$ 704,142.69	$ 1,408,285.38
DP 82	$ 43,500.00	$ 114,266.41	$ 457,065.63	$ 132,000.00	$ 589,065.63	$ 1,178,131.25
DP 83	$ 43,500.00	$ 93,789.03	$ 375,156.12	$ 132,000.00	$ 507,156.12	$ 1,014,312.24
DP 84	$ 43,500.00	$ 131,899.47	$ 527,597.86	$ 132,000.00	$ 659,597.86	$ 1,319,195.72
DP 85	$ 43,500.00	$ 84,334.89	$ 337,339.57	$ 132,000.00	$ 469,339.57	$ 938,679.14
DP 86	$ 43,500.00	$ 133,254.79	$ 533,019.16	$ 132,000.00	$ 665,019.16	$ 1,330,038.32
DP 87	$ 43,500.00	$ 128,854.30	$ 515,417.21	$ 132,000.00	$ 647,417.21	$ 1,294,834.43
DP 88	$ 43,500.00	$ 75,758.31	$ 303,033.23	$ 132,000.00	$ 435,033.23	$ 870,066.46
DP 89	$ 43,500.00	$ 158,690.53	$ 634,762.13	$ 132,000.00	$ 766,762.13	$ 1,533,524.26
DP 90	$ 43,500.00	$ 111,222.16	$ 444,888.64	$ 132,000.00	$ 576,888.64	$ 1,153,777.28
DP 91	$ 43,500.00	$ 133,392.93	$ 533,571.73	$ 132,000.00	$ 665,571.73	$ 1,331,143.45
DP 92	$ 43,500.00	$ 110,452.10	$ 441,808.40	$ 132,000.00	$ 573,808.40	$ 1,147,616.80
DP 93	$ 43,500.00	$ 117,310.37	$ 469,241.48	$ 132,000.00	$ 601,241.48	$ 1,202,482.96
DP 94	$ 43,500.00	$ 105,761.17	$ 423,044.69	$ 132,000.00	$ 555,044.69	$ 1,110,089.38
DP 95	$ 43,500.00	$ 131,179.49	$ 524,717.95	$ 132,000.00	$ 656,717.95	$ 1,313,435.90
DP 96	$ 43,500.00	$ 119,838.87	$ 479,355.48	$ 132,000.00	$ 611,355.48	$ 1,222,710.96
DP 97	$ 43,500.00	$ 136,160.85	$ 544,643.39	$ 132,000.00	$ 676,643.39	$ 1,353,286.79
DP 98	$ 43,500.00	$ 118,822.06	$ 475,288.25	$ 132,000.00	$ 607,288.25	$ 1,214,576.50
DP 99	$ 43,500.00	$ 102,657.78	$ 410,631.11	$ 132,000.00	$ 542,631.11	$ 1,085,262.21
DP 100	$ 43,500.00	$ 118,718.75	$ 474,875.02	$ 132,000.00	$ 606,875.02	$ 1,213,750.04
DP 101	$ 43,500.00	$ 106,858.29	$ 427,433.16	$ 132,000.00	$ 559,433.16	$ 1,118,866.31
DP 102	$ 43,500.00	$ 132,622.45	$ 530,489.81	$ 132,000.00	$ 662,489.81	$ 1,324,979.62
DP 103	$ 43,500.00	$ 120,290.26	$ 481,161.02	$ 132,000.00	$ 613,161.02	$ 1,226,322.04
DP 104	$ 43,500.00	$ 128,455.68	$ 513,822.71	$ 132,000.00	$ 645,822.71	$ 1,291,645.41
DP 105	$ 43,500.00	$ 104,468.69	$ 417,874.78	$ 132,000.00	$ 549,874.78	$ 1,099,749.55
DP 106	$ 43,500.00	$ 126,728.62	$ 506,914.46	$ 132,000.00	$ 638,914.46	$ 1,277,828.92
DP 107	$ 43,500.00	$ 79,783.77	$ 319,135.06	$ 132,000.00	$ 451,135.06	$ 902,270.13
DP 108	$ 43,500.00	$ 162,625.32	$ 650,501.27	$ 132,000.00	$ 782,501.27	$ 1,565,002.54
DP 109	$ 43,500.00	$ 108,746.32	$ 434,985.29	$ 132,000.00	$ 566,985.29	$ 1,133,970.57
DP 110	$ 43,500.00	$ 105,565.99	$ 422,263.94	$ 132,000.00	$ 554,263.94	$ 1,108,527.89
DP 111	$ 43,500.00	$ 154,311.88	$ 617,247.53	$ 132,000.00	$ 749,247.53	$ 1,498,495.06
DP 112	$ 43,500.00	$ 106,838.84	$ 427,355.35	$ 132,000.00	$ 559,355.35	$ 1,118,710.70
DP 113	$ 43,500.00	$ 143,813.75	$ 575,254.98	$ 132,000.00	$ 707,254.98	$ 1,414,509.96
DP 114	$ 43,500.00	$ 123,392.99	$ 493,571.97	$ 132,000.00	$ 625,571.97	$ 1,251,143.93
DP 115	$ 43,500.00	$ 95,173.95	$ 380,695.81	$ 132,000.00	$ 512,695.81	$ 1,025,391.62
DP 116	$ 43,500.00	$ 96,136.42	$ 384,545.69	$ 132,000.00	$ 516,545.69	$ 1,033,091.39
DP 117	$ 43,500.00	$ 140,921.50	$ 563,685.99	$ 132,000.00	$ 695,685.99	$ 1,391,371.98
DP 118	$ 43,500.00	$ 99,716.88	$ 398,867.54	$ 132,000.00	$ 530,867.54	$ 1,061,735.07
DP 119	$ 43,500.00	$ 155,970.59	$ 623,882.37	$ 132,000.00	$ 755,882.37	$ 1,511,764.75
DP 120	$ 43,500.00	$ 151,770.15	$ 607,080.60	$ 132,000.00	$ 739,080.60	$ 1,478,161.19
DP 121	$ 43,500.00	$ 161,814.85	$ 647,259.40	$ 132,000.00	$ 779,259.40	$ 1,558,518.80
DP 122	$ 43,500.00	$ 149,206.36	$ 596,825.45	$ 132,000.00	$ 728,825.45	$ 1,457,650.90
DP 123	$ 43,500.00	$ 115,131.06	$ 460,524.25	$ 132,000.00	$ 592,524.25	$ 1,185,048.51
DP 124	$ 43,500.00	$ 153,683.53	$ 614,734.11	$ 132,000.00	$ 746,734.11	$ 1,493,468.22
DP 125	$ 43,500.00	$ 93,134.33	$ 372,537.32	$ 132,000.00	$ 504,537.32	$ 1,009,074.63
DP 126	$ 43,500.00	$ 107,489.41	$ 429,957.65	$ 132,000.00	$ 561,957.65	$ 1,123,915.31
DP 127	$ 43,500.00	$ 121,088.96	$ 484,355.85	$ 132,000.00	$ 616,355.85	$ 1,232,711.71
DP 128	$ 43,500.00	$ 85,101.18	$ 340,404.71	$ 132,000.00	$ 472,404.71	$ 944,809.41
DP 129	$ 43,500.00	$ 103,302.86	$ 413,211.42	$ 132,000.00	$ 545,211.42	$ 1,090,422.84
DP 130	$ 43,500.00	$ 131,919.48	$ 527,677.90	$ 132,000.00	$ 659,677.90	$ 1,319,355.80

	1 UAV Set Cost					Total System Cost
	1 Remoeye UAV $$	1 UAV Cost	4 UAVs Cost	GCS Cost	Subtotal	
DP 131	$ 43,500.00	$ 110,052.90	$ 440,211.60	$ 132,000.00	$ 572,211.60	$ 1,716,634.80
DP 132	$ 43,500.00	$ 137,273.17	$ 549,092.68	$ 132,000.00	$ 681,092.68	$ 2,043,278.04
DP 133	$ 43,500.00	$ 155,341.45	$ 621,365.79	$ 132,000.00	$ 753,365.79	$ 2,260,097.38
DP 134	$ 43,500.00	$ 119,110.06	$ 476,440.25	$ 132,000.00	$ 608,440.25	$ 1,825,320.74
DP 135	$ 43,500.00	$ 132,379.01	$ 529,516.05	$ 132,000.00	$ 661,516.05	$ 1,984,548.14
DP 136	$ 43,500.00	$ 146,339.70	$ 585,358.78	$ 132,000.00	$ 717,358.78	$ 2,152,076.35
DP 137	$ 43,500.00	$ 86,158.05	$ 344,632.19	$ 132,000.00	$ 476,632.19	$ 1,429,896.57
DP 138	$ 43,500.00	$ 123,681.76	$ 494,727.05	$ 132,000.00	$ 626,727.05	$ 1,880,181.14
DP 139	$ 43,500.00	$ 89,386.06	$ 357,544.25	$ 132,000.00	$ 489,544.25	$ 1,468,632.74
DP 140	$ 43,500.00	$ 76,449.13	$ 305,796.50	$ 132,000.00	$ 437,796.50	$ 1,313,389.51
DP 141	$ 43,500.00	$ 87,118.08	$ 348,472.30	$ 132,000.00	$ 480,472.30	$ 1,441,416.91
DP 142	$ 43,500.00	$ 83,327.98	$ 333,311.93	$ 132,000.00	$ 465,311.93	$ 1,395,935.78
DP 143	$ 43,500.00	$ 138,238.42	$ 552,953.67	$ 132,000.00	$ 684,953.67	$ 2,054,861.02
DP 144	$ 43,500.00	$ 97,288.13	$ 389,152.51	$ 132,000.00	$ 521,152.51	$ 1,563,457.52
DP 145	$ 43,500.00	$ 141,506.73	$ 566,026.94	$ 132,000.00	$ 698,026.94	$ 2,094,080.82
DP 146	$ 43,500.00	$ 143,035.67	$ 572,142.69	$ 132,000.00	$ 704,142.69	$ 2,112,428.08
DP 147	$ 43,500.00	$ 114,266.41	$ 457,065.63	$ 132,000.00	$ 589,065.63	$ 1,767,196.88
DP 148	$ 43,500.00	$ 93,789.03	$ 375,156.12	$ 132,000.00	$ 507,156.12	$ 1,521,468.37
DP 149	$ 43,500.00	$ 131,899.47	$ 527,597.86	$ 132,000.00	$ 659,597.86	$ 1,978,793.58
DP 150	$ 43,500.00	$ 84,334.89	$ 337,339.57	$ 132,000.00	$ 469,339.57	$ 1,408,018.71
DP 151	$ 43,500.00	$ 133,254.79	$ 533,019.16	$ 132,000.00	$ 665,019.16	$ 1,995,057.48
DP 152	$ 43,500.00	$ 128,854.30	$ 515,417.21	$ 132,000.00	$ 647,417.21	$ 1,942,251.64
DP 153	$ 43,500.00	$ 75,758.31	$ 303,033.23	$ 132,000.00	$ 435,033.23	$ 1,305,099.69
DP 154	$ 43,500.00	$ 158,690.53	$ 634,762.13	$ 132,000.00	$ 766,762.13	$ 2,300,286.39
DP 155	$ 43,500.00	$ 111,222.16	$ 444,888.64	$ 132,000.00	$ 576,888.64	$ 1,730,665.93
DP 156	$ 43,500.00	$ 133,392.93	$ 533,571.73	$ 132,000.00	$ 665,571.73	$ 1,996,715.18
DP 157	$ 43,500.00	$ 110,452.10	$ 441,808.40	$ 132,000.00	$ 573,808.40	$ 1,721,425.19
DP 158	$ 43,500.00	$ 117,310.37	$ 469,241.48	$ 132,000.00	$ 601,241.48	$ 1,803,724.44
DP 159	$ 43,500.00	$ 105,761.17	$ 423,044.69	$ 132,000.00	$ 555,044.69	$ 1,665,134.08
DP 160	$ 43,500.00	$ 131,179.49	$ 524,717.95	$ 132,000.00	$ 656,717.95	$ 1,970,153.84
DP 161	$ 43,500.00	$ 119,838.87	$ 479,355.48	$ 132,000.00	$ 611,355.48	$ 1,834,066.44
DP 162	$ 43,500.00	$ 136,160.85	$ 544,643.39	$ 132,000.00	$ 676,643.39	$ 2,029,930.18
DP 163	$ 43,500.00	$ 118,822.06	$ 475,288.25	$ 132,000.00	$ 607,288.25	$ 1,821,864.75
DP 164	$ 43,500.00	$ 102,657.78	$ 410,631.11	$ 132,000.00	$ 542,631.11	$ 1,627,893.32
DP 165	$ 43,500.00	$ 118,718.75	$ 474,875.02	$ 132,000.00	$ 606,875.02	$ 1,820,625.06
DP 166	$ 43,500.00	$ 106,858.29	$ 427,433.16	$ 132,000.00	$ 559,433.16	$ 1,678,299.47
DP 167	$ 43,500.00	$ 132,622.45	$ 530,489.81	$ 132,000.00	$ 662,489.81	$ 1,987,469.42
DP 168	$ 43,500.00	$ 120,290.26	$ 481,161.02	$ 132,000.00	$ 613,161.02	$ 1,839,483.06
DP 169	$ 43,500.00	$ 128,455.68	$ 513,822.71	$ 132,000.00	$ 645,822.71	$ 1,937,468.12
DP 170	$ 43,500.00	$ 104,468.69	$ 417,874.78	$ 132,000.00	$ 549,874.78	$ 1,649,624.33
DP 171	$ 43,500.00	$ 126,728.62	$ 506,914.46	$ 132,000.00	$ 638,914.46	$ 1,916,743.38
DP 172	$ 43,500.00	$ 79,783.77	$ 319,135.06	$ 132,000.00	$ 451,135.06	$ 1,353,405.19
DP 173	$ 43,500.00	$ 162,625.32	$ 650,501.27	$ 132,000.00	$ 782,501.27	$ 2,347,503.82
DP 174	$ 43,500.00	$ 108,746.32	$ 434,985.29	$ 132,000.00	$ 566,985.29	$ 1,700,955.86
DP 175	$ 43,500.00	$ 105,565.99	$ 422,263.94	$ 132,000.00	$ 554,263.94	$ 1,662,791.83
DP 176	$ 43,500.00	$ 154,311.88	$ 617,247.53	$ 132,000.00	$ 749,247.53	$ 2,247,742.60
DP 177	$ 43,500.00	$ 106,838.84	$ 427,355.35	$ 132,000.00	$ 559,355.35	$ 1,678,066.05
DP 178	$ 43,500.00	$ 143,813.75	$ 575,254.98	$ 132,000.00	$ 707,254.98	$ 2,121,764.94
DP 179	$ 43,500.00	$ 123,392.99	$ 493,571.97	$ 132,000.00	$ 625,571.97	$ 1,876,715.90
DP 180	$ 43,500.00	$ 95,173.95	$ 380,695.81	$ 132,000.00	$ 512,695.81	$ 1,538,087.43
DP 181	$ 43,500.00	$ 96,136.42	$ 384,545.69	$ 132,000.00	$ 516,545.69	$ 1,549,637.08
DP 182	$ 43,500.00	$ 140,921.50	$ 563,685.99	$ 132,000.00	$ 695,685.99	$ 2,087,057.98
DP 183	$ 43,500.00	$ 99,716.88	$ 398,867.54	$ 132,000.00	$ 530,867.54	$ 1,592,602.61
DP 184	$ 43,500.00	$ 155,970.59	$ 623,882.37	$ 132,000.00	$ 755,882.37	$ 2,267,647.12
DP 185	$ 43,500.00	$ 151,770.15	$ 607,080.60	$ 132,000.00	$ 739,080.60	$ 2,217,241.79
DP 186	$ 43,500.00	$ 161,814.85	$ 647,259.40	$ 132,000.00	$ 779,259.40	$ 2,337,778.20
DP 187	$ 43,500.00	$ 149,206.36	$ 596,825.45	$ 132,000.00	$ 728,825.45	$ 2,186,476.36
DP 188	$ 43,500.00	$ 115,131.06	$ 460,524.25	$ 132,000.00	$ 592,524.25	$ 1,777,572.76
DP 189	$ 43,500.00	$ 153,683.53	$ 614,734.11	$ 132,000.00	$ 746,734.11	$ 2,240,202.34
DP 190	$ 43,500.00	$ 93,134.33	$ 372,537.32	$ 132,000.00	$ 504,537.32	$ 1,513,611.95
DP 191	$ 43,500.00	$ 107,489.41	$ 429,957.65	$ 132,000.00	$ 561,957.65	$ 1,685,872.96
DP 192	$ 43,500.00	$ 121,088.96	$ 484,355.85	$ 132,000.00	$ 616,355.85	$ 1,849,067.56
DP 193	$ 43,500.00	$ 85,101.18	$ 340,404.71	$ 132,000.00	$ 472,404.71	$ 1,417,214.12
DP 194	$ 43,500.00	$ 103,302.86	$ 413,211.42	$ 132,000.00	$ 545,211.42	$ 1,635,634.26
DP 195	$ 43,500.00	$ 131,919.48	$ 527,677.90	$ 132,000.00	$ 659,677.90	$ 1,979,033.70
DP 196	$ 43,500.00	$ 110,052.90	$ 440,211.60	$ 132,000.00	$ 572,211.60	$ 2,288,846.40
DP 197	$ 43,500.00	$ 137,273.17	$ 549,092.68	$ 132,000.00	$ 681,092.68	$ 2,724,370.72
DP 198	$ 43,500.00	$ 155,341.45	$ 621,365.79	$ 132,000.00	$ 753,365.79	$ 3,013,463.17
DP 199	$ 43,500.00	$ 119,110.06	$ 476,440.25	$ 132,000.00	$ 608,440.25	$ 2,433,760.98
DP 200	$ 43,500.00	$ 132,379.01	$ 529,516.05	$ 132,000.00	$ 661,516.05	$ 2,646,064.18

	1 UAV Set Cost					Total System Cost
	1 Remoeye UAV $$	1 UAV Cost	4 UAVs Cost	GCS Cost	Subtotal	
DP 201	$ 43,500.00	$ 146,339.70	$ 585,358.78	$ 132,000.00	$ 717,358.78	$ 2,869,435.14
DP 202	$ 43,500.00	$ 86,158.05	$ 344,632.19	$ 132,000.00	$ 476,632.19	$ 1,906,528.77
DP 203	$ 43,500.00	$ 123,681.76	$ 494,727.05	$ 132,000.00	$ 626,727.05	$ 2,506,908.19
DP 204	$ 43,500.00	$ 89,386.06	$ 357,544.25	$ 132,000.00	$ 489,544.25	$ 1,958,176.99
DP 205	$ 43,500.00	$ 76,449.13	$ 305,796.50	$ 132,000.00	$ 437,796.50	$ 1,751,186.01
DP 206	$ 43,500.00	$ 87,118.08	$ 348,472.30	$ 132,000.00	$ 480,472.30	$ 1,921,889.21
DP 207	$ 43,500.00	$ 83,327.98	$ 333,311.93	$ 132,000.00	$ 465,311.93	$ 1,861,247.70
DP 208	$ 43,500.00	$ 138,238.42	$ 552,953.67	$ 132,000.00	$ 684,953.67	$ 2,739,814.69
DP 209	$ 43,500.00	$ 97,288.13	$ 389,152.51	$ 132,000.00	$ 521,152.51	$ 2,084,610.03
DP 210	$ 43,500.00	$ 141,506.73	$ 566,026.94	$ 132,000.00	$ 698,026.94	$ 2,792,107.76
DP 211	$ 43,500.00	$ 143,035.67	$ 572,142.69	$ 132,000.00	$ 704,142.69	$ 2,816,570.77
DP 212	$ 43,500.00	$ 114,266.41	$ 457,065.63	$ 132,000.00	$ 589,065.63	$ 2,356,262.51
DP 213	$ 43,500.00	$ 93,789.03	$ 375,156.12	$ 132,000.00	$ 507,156.12	$ 2,028,624.49
DP 214	$ 43,500.00	$ 131,899.47	$ 527,597.86	$ 132,000.00	$ 659,597.86	$ 2,638,391.44
DP 215	$ 43,500.00	$ 84,334.89	$ 337,339.57	$ 132,000.00	$ 469,339.57	$ 1,877,358.28
DP 216	$ 43,500.00	$ 133,254.79	$ 533,019.16	$ 132,000.00	$ 665,019.16	$ 2,660,076.64
DP 217	$ 43,500.00	$ 128,854.30	$ 515,417.21	$ 132,000.00	$ 647,417.21	$ 2,589,668.85
DP 218	$ 43,500.00	$ 75,758.31	$ 303,033.23	$ 132,000.00	$ 435,033.23	$ 1,740,132.91
DP 219	$ 43,500.00	$ 158,690.53	$ 634,762.13	$ 132,000.00	$ 766,762.13	$ 3,067,048.52
DP 220	$ 43,500.00	$ 111,222.16	$ 444,888.64	$ 132,000.00	$ 576,888.64	$ 2,307,554.57
DP 221	$ 43,500.00	$ 133,392.93	$ 533,571.73	$ 132,000.00	$ 665,571.73	$ 2,662,286.90
DP 222	$ 43,500.00	$ 110,452.10	$ 441,808.40	$ 132,000.00	$ 573,808.40	$ 2,295,233.59
DP 223	$ 43,500.00	$ 117,310.37	$ 469,241.48	$ 132,000.00	$ 601,241.48	$ 2,404,965.92
DP 224	$ 43,500.00	$ 105,761.17	$ 423,044.69	$ 132,000.00	$ 555,044.69	$ 2,220,178.77
DP 225	$ 43,500.00	$ 131,179.49	$ 524,717.95	$ 132,000.00	$ 656,717.95	$ 2,626,871.79
DP 226	$ 43,500.00	$ 119,838.87	$ 479,355.48	$ 132,000.00	$ 611,355.48	$ 2,445,421.92
DP 227	$ 43,500.00	$ 136,160.85	$ 544,643.39	$ 132,000.00	$ 676,643.39	$ 2,706,573.57
DP 228	$ 43,500.00	$ 118,822.06	$ 475,288.25	$ 132,000.00	$ 607,288.25	$ 2,429,153.00
DP 229	$ 43,500.00	$ 102,657.78	$ 410,631.11	$ 132,000.00	$ 542,631.11	$ 2,170,524.43
DP 230	$ 43,500.00	$ 118,718.75	$ 474,875.02	$ 132,000.00	$ 606,875.02	$ 2,427,500.08
DP 231	$ 43,500.00	$ 106,858.29	$ 427,433.16	$ 132,000.00	$ 559,433.16	$ 2,237,732.62
DP 232	$ 43,500.00	$ 132,622.45	$ 530,489.81	$ 132,000.00	$ 662,489.81	$ 2,649,959.23
DP 233	$ 43,500.00	$ 120,290.26	$ 481,161.02	$ 132,000.00	$ 613,161.02	$ 2,452,644.08
DP 234	$ 43,500.00	$ 128,455.68	$ 513,822.71	$ 132,000.00	$ 645,822.71	$ 2,583,290.82
DP 235	$ 43,500.00	$ 104,468.69	$ 417,874.78	$ 132,000.00	$ 549,874.78	$ 2,199,499.10
DP 236	$ 43,500.00	$ 126,728.62	$ 506,914.46	$ 132,000.00	$ 638,914.46	$ 2,555,657.84
DP 237	$ 43,500.00	$ 79,783.77	$ 319,135.06	$ 132,000.00	$ 451,135.06	$ 1,804,540.25
DP 238	$ 43,500.00	$ 162,625.32	$ 650,501.27	$ 132,000.00	$ 782,501.27	$ 3,130,005.09
DP 239	$ 43,500.00	$ 108,746.32	$ 434,985.29	$ 132,000.00	$ 566,985.29	$ 2,267,941.15
DP 240	$ 43,500.00	$ 105,565.99	$ 422,263.94	$ 132,000.00	$ 554,263.94	$ 2,217,055.78
DP 241	$ 43,500.00	$ 154,311.88	$ 617,247.53	$ 132,000.00	$ 749,247.53	$ 2,996,990.13
DP 242	$ 43,500.00	$ 106,838.84	$ 427,355.35	$ 132,000.00	$ 559,355.35	$ 2,237,421.39
DP 243	$ 43,500.00	$ 143,813.75	$ 575,254.98	$ 132,000.00	$ 707,254.98	$ 2,829,019.93
DP 244	$ 43,500.00	$ 123,392.99	$ 493,571.97	$ 132,000.00	$ 625,571.97	$ 2,502,287.87
DP 245	$ 43,500.00	$ 95,173.95	$ 380,695.81	$ 132,000.00	$ 512,695.81	$ 2,050,783.23
DP 246	$ 43,500.00	$ 96,136.42	$ 384,545.69	$ 132,000.00	$ 516,545.69	$ 2,066,182.77
DP 247	$ 43,500.00	$ 140,921.50	$ 563,685.99	$ 132,000.00	$ 695,685.99	$ 2,782,743.97
DP 248	$ 43,500.00	$ 99,716.88	$ 398,867.54	$ 132,000.00	$ 530,867.54	$ 2,123,470.15
DP 249	$ 43,500.00	$ 155,970.59	$ 623,882.37	$ 132,000.00	$ 755,882.37	$ 3,023,529.50
DP 250	$ 43,500.00	$ 151,770.15	$ 607,080.60	$ 132,000.00	$ 739,080.60	$ 2,956,322.39
DP 251	$ 43,500.00	$ 161,814.85	$ 647,259.40	$ 132,000.00	$ 779,259.40	$ 3,117,037.60
DP 252	$ 43,500.00	$ 149,206.36	$ 596,825.45	$ 132,000.00	$ 728,825.45	$ 2,915,301.81
DP 253	$ 43,500.00	$ 115,131.06	$ 460,524.25	$ 132,000.00	$ 592,524.25	$ 2,370,097.01
DP 254	$ 43,500.00	$ 153,683.53	$ 614,734.11	$ 132,000.00	$ 746,734.11	$ 2,986,936.45
DP 255	$ 43,500.00	$ 93,134.33	$ 372,537.32	$ 132,000.00	$ 504,537.32	$ 2,018,149.26
DP 256	$ 43,500.00	$ 107,489.41	$ 429,957.65	$ 132,000.00	$ 561,957.65	$ 2,247,830.62
DP 257	$ 43,500.00	$ 121,088.96	$ 484,355.85	$ 132,000.00	$ 616,355.85	$ 2,465,423.42
DP 258	$ 43,500.00	$ 85,101.18	$ 340,404.71	$ 132,000.00	$ 472,404.71	$ 1,889,618.83
DP 259	$ 43,500.00	$ 103,302.86	$ 413,211.42	$ 132,000.00	$ 545,211.42	$ 2,180,845.68
DP 260	$ 43,500.00	$ 131,919.48	$ 527,677.90	$ 132,000.00	$ 659,677.90	$ 2,638,711.60

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