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Dynamic Job-shop Scheduling Program (DJSP) Analysis for Preventive Military Helicopter Maintenance System (PMS)

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DYNAMIC JOB-SHOP SCHEDULING PROGRAM(DJSP) ANALYSIS FOR PREVENTIVE MILITARY HELICOPTER MAINTENANCE SYSTEM(PMS)

by

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A thesis submitted in partial fulfillment of the requirements
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Major Professor: Gene Lee

ABSTRACT

Republic of Korea Army(ROKA) has been founding new attack helicopter troops since last year by adopting US main attack helicopter, AH-64E Apache, and peripheral system like pilots and mechanics training systems and their organization. The AH-64E Apache is a major attack helicopter of the US Army and all of its systems are verified in terms of the effectiveness in real operations for several decades. However, ROKA still needs their own version of systems including tactics, template, and maintenance which are suitable for Korean terrain, climate, personnel, and so on. At least ROKA needs to have a chance to verify that the adopted system is working well with different circumstances, especially with a different maintenance system.

As basic characteristics, routine maintenance and management are essential for accident prevention for a helicopter, there are specially formalized maintenance systems for every kind of helicopter respectively. It was established by a manufacturer in maintenance manuals and can be modified and integrated by users and operators. Apache also has its own maintenance schedule and system including 25-hour, 50-hour, 125-hour, and 250-hour maintenance and inspections which are implemented according to the operation hours. Those schedules are done by a task force or temporary maintenance team which is led by one or two inspectors and supported by 3~4 mechanics.

Maintenance troops restrict the number of aircraft to get in the process by managing the flight hours considering the limit of manpower and equipment so that the operation rate stays above at least 80%. It is important to stipulate their capacity in need and max capacity with given personnel and facility for newly founding military troops. Especially since ROKA aviation branch is applying a more strict maintenance process, it might cause insufficiency of resources if organized by same template and procedure with the US Army.

The goal of this study is to verify if existing personnel organization is affordable for new maintenance system of AH-64 Apache helicopters. As a further step ahead, this research found the most critical personnel pool and their relationship by sensitivity analysis.

This research specified actual maintenance procedure and restrictions on computer and simulated virtually. During the repetition of the test, existing organization was found inadequate to satisfy all restrictions and requirements. Test pilot and inspector pool are critical to secure the successful maintenance support and to prepare for contingency. Also, there were interesting relationships between the mechanics groups. They are in supplemental relationships with each other because of the condition of one pool affects the other.

This work is dedicated to my wife and son

Without their support, this work would have not been possible.

ACKNOWLEDGMENTS

I would like to express my profound gratitude to my supervisor Professor. Gene Lee for the guidance and support I received. At every stage help was available to deal with obstacles both large and small. Appreciation is also extended to my thesis committee, Ahmad Elshennawy and Luis Rabelo for their valuable time and contributions.

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CHAPTER 1: **INTRODUCTION**

1.1 Background

These days, the role of helicopter as a transportation is not restricted to leisure and personal transportation like ‘Grand Canyon sky tour’ but extends to rescue missions, goods transportation and so on. Especially in military, helicopters are the essential factors in ground mission because of their high maneuverability and less terrain restriction. Their ability to overcome ground obstacles is outstanding in the Korean Peninsula, not only for commercial purposes, but also for military because it is hard to have multiple airports and stable road conditions due to mountainous terrain with a lot of rivers. For this reason, the Republic of Korea Army is operating more than six hundred attack and utility helicopters maintaining 4th firepower in the world following US, Russia, and China(Ministry of National Defense, 2014)

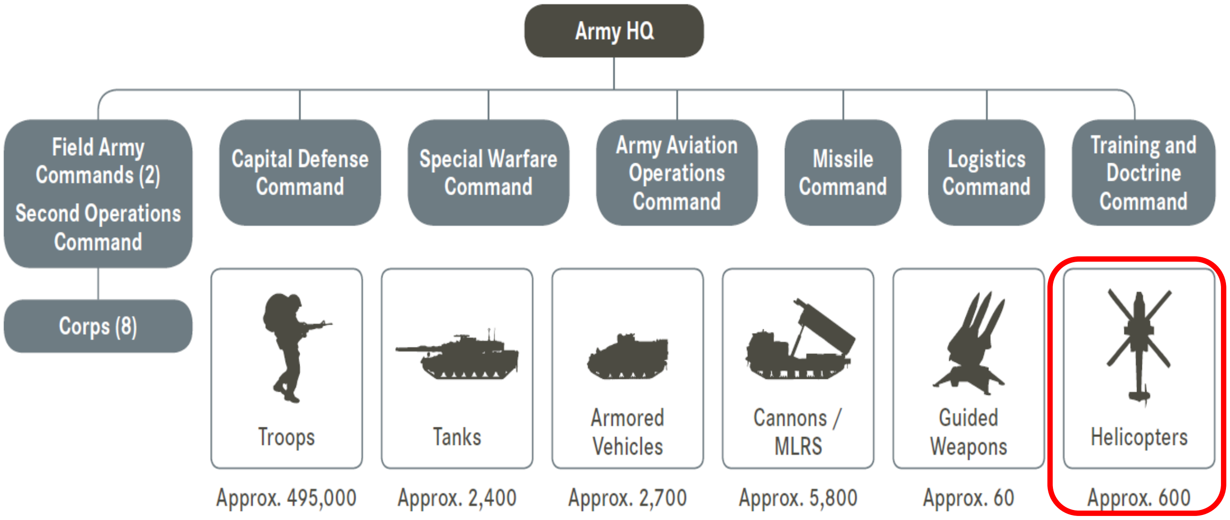


Figure 1-1. Main ground forces in ROKA

However, malfunction in flight threaten passenger’s lives with high probability, and they are mostly fatal. It is because it cannot pull over whenever driver wants like car. Especially, seasonal high temperature fluctuation, harsh weather conditions, and steep terrain differential in the Korean Peninsula are imposing more burdens to engines and fuselages increasing the possibility of a crash. There have been 85 helicopter crashes from 1977 to 2013 and seven technical failures are included among them (Choi, 2013).

For preventing these tragedies, the Republic of Korea Army (ROKA) is highlighting the importance of maintenance and applying a more strict maintenance system on top of manufacturers' recommendations. All helicopter aviation battalions have a maintenance company as a subordinate performing organizational maintenance (OM) and its composition of organizations vary depending on its maintenance systems. 500MD - Military version of commercial MD500 helicopter, AH-1S Cobra, UH-1Huey, and UH-60 Black Hawk, are the main attack and utility helicopters in ROKA and they have different maintenance systems respectively. However, it has been more than 25 years since their introduction, so it can be said that the maintenance systems are verified to satisfy all of safety requirements efficiently. However, ROKA has been founding AH-64 Apache helicopter troops since 2016 and has not had sufficient time to check supportability of its maintenance company. Because even they have more burdens to do special check up on top of regular maintenance schedule, apparent investigation is needed before implementing the main missions.

In this research we are going to, first, verify if existing personnel can keep maintenance and checkup schedule while supporting fight preparation and administrative work using Dynamic Job-shop Scheduling Problem(DJSP). Secondly, we will move on to find optimal personnel templates depending on their position: inspectors, mechanics, and a test pilot.

1.2 Problem Statement

The existing AH-64E Apache maintenance system composes of 25 flight-hour, 50 flight-hour, 125 flight-hour, and 250 flight-hour maintenance. Flight hour consumption is various depending on missions and weather conditions, and required maintenance personnel combination. And human-hour has also variance depending on their skill level and fuselage condition. 125 and 250flight-hour maintenance include a test flight step as a post checkup process, which require additional personnel and their human-hours.

We know that flight is vulnerable to weather like rain and fog. The average raining and foggy day in the area the apache troops are located in was 60days and 35days respectively. And when we consider fog doesn’t occur when it's raining and it disappears, within morning time, we can guess only 288days(79%) are affordable for flight. It affects the required test flight human-hours stochastically.

As a special case, military troops must maintain minimum operations readiness rate and it is 80% for helicopter troops. Helicopters in maintenance process or waiting in queue are not counted as ‘active duty’. It means only 4helicopters out of 18 are allowed to be in process or waiting in at the same time. This would restrict the capacity of the system.

With those several restrictions and duties, it is suspected that existing personnel resources cannot take care of all requirements because the organization is originated from US military template while ROKA conducts extra checkups on top of scheduled maintenance.

1.3 Research Objectives

AH-64 Apache troops are newly created with extra missions. And they will consume more flight hours for training their pilots and practicing the mission they are assigned. It is very reasonable to expect that there is a higher incident possibility in the initial couple of years because less educated pilots will be flying helicopters maintained by less mastered mechanics.

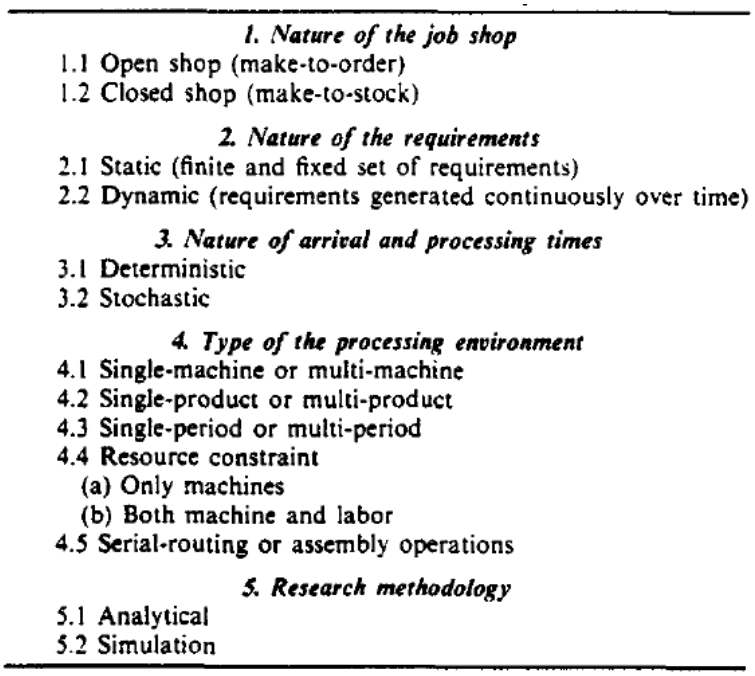
This research is focusing on verification of supportability of existing maintenance personnel for predictable maintenance demands using computer simulation to suggest better or essential number of personnel for mission and requirements. The sub-objectives of this research are:

- To model the existing maintenance system, called PMS, on a computer and simulate in order to verify if existing personnel pool and maintenance system are suitable to deal with all maintenance demands.
- To find the importance of each personnel pool and their relationships by sensitivity analysis.

CHAPTER 2: **LITERATURE REVIEW**

2.1 Job-shop Scheduling Problem(JSP)

Classical job-shop Scheduling Problem(JSP) is defined as an effort to find an optimal solution for output, scheduling rules, and/or behaviors with one or more deterministic input(s) and several deterministic sequential processes (Applegate & Cook, 1991). It may possibly be proved with analytic techniques in a very restricted situation. However, Dynamic Job-shop Scheduling Problems, known as nondeterministic polynomial time(NP)-complete, typically has multiple stochastic inputs, multiple stochastic, parallel processes with heuristic limitations. The difference between classical and dynamic JSP is shown in Figure 2-1(Ramasesh, 1990). This system embraces a reflection of real life problems like assembly process, machine breakdown, batch by batch inputs made by make-by-order, and so on. An analytical approach on DJSP has proven to be extremely difficult, even with several limiting assumptions (Law, 2015). As computers were getting common and their ability getting revolutionized, researchers in this area have relied on computer simulation because they could get a near-optimal solution with heuristic repetition in simulation. Additionally, computer simulation is becoming the only technique available to get the answer from the case in which mathematical models are either intractable or probably insoluble (Axtell, 2000).



1. Nature of the job shop

1.1 Open shop (make-to-order)
1.2 Closed shop (make-to-stock)

2. Nature of the requirements

2.1 Static (finite and fixed set of requirements)
2.2 Dynamic (requirements generated continuously over time)

3. Nature of arrival and processing times

3.1 Deterministic
3.2 Stochastic

4. Type of the processing environment

4.1 Single-machine or multi-machine
4.2 Single-product or multi-product
4.3 Single-period or multi-period
4.4 Resource constraint
  (a) Only machines
  (b) Both machine and labor
4.5 Serial-routing or assembly operations

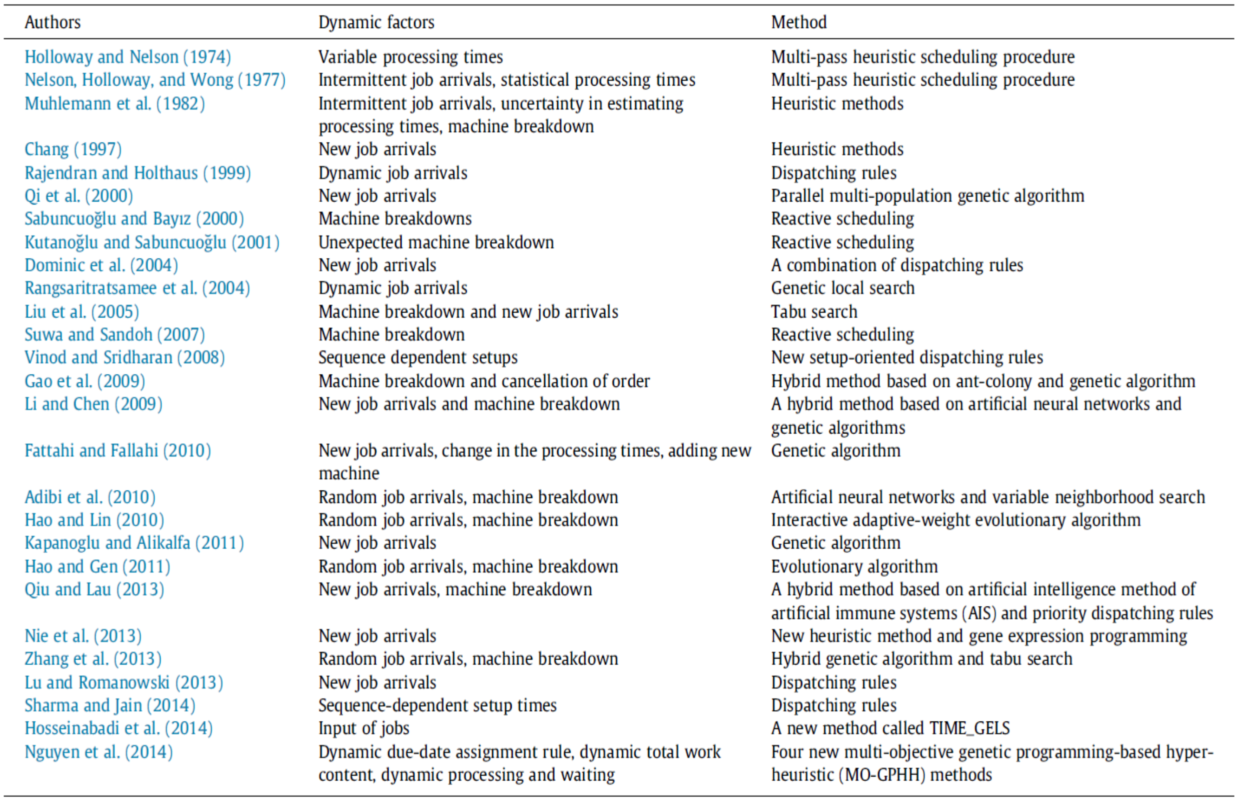
5. Research methodology

5.1 Analytical
5.2 Simulation

Figure 2-1. Classification of Scheduling Research

Table 2-1Table 2-1 is a summary of dynamic job shop scheduling applications by Kundakci & Kulak(2016). So far, DJSP research was usually focused on dynamic job arrival such as intermittent and batch-by-batch, machine breakdown, using the heuristic method until 2010. After that, researchers studied on interrelated machine work. Xiong et al(2017) formulized four extended technical precedence constraints such as ‘A only can start after B ended, A can start only B starts, A can be completed only B starts, A can be completed only B completed’. Also Mattias Thurer and Mark Stevenson(2016) suggested a new model for re-entrant flows. This model breaks one of the rules of JSP-“A job does not visit the same machines twice”- established by Cheng et al(1996).

Table 2-1. Field Study of PMS system



Authors	Dynamic factors	Method
Holloway and Nelson (1974)	Variable processing times	Multi-pass heuristic scheduling procedure
Nelson, Holloway, and Wong (1977)	Intermittent job arrivals, statistical processing times	Multi-pass heuristic scheduling procedure
Muhlemann et al. (1982)	Intermittent job arrivals, uncertainty in estimating processing times, machine breakdown	Heuristic methods
Chang (1997)	New job arrivals	Heuristic methods
Rajendran and Holthaus (1999)	Dynamic job arrivals	Dispatching rules
Qi et al. (2000)	New job arrivals	Parallel multi-population genetic algorithm
Sabuncuoğlu and Bayız (2000)	Machine breakdowns	Reactive scheduling
Kutanoğlu and Sabuncuoğlu (2001)	Unexpected machine breakdown	Reactive scheduling
Dominic et al. (2004)	New job arrivals	A combination of dispatching rules
Rangsaritratsamee et al. (2004)	Dynamic job arrivals	Genetic local search
Liu et al. (2005)	Machine breakdown and new job arrivals	Tabu search
Suwa and Sandoh (2007)	Machine breakdown	Reactive scheduling
Vinod and Sridharan (2008)	Sequence dependent setups	New setup-oriented dispatching rules
Gao et al. (2009)	Machine breakdown and cancellation of order	Hybrid method based on ant-colony and genetic algorithm
Li and Chen (2009)	New job arrivals and machine breakdown	A hybrid method based on artificial neural networks and genetic algorithms
Fattahi and Fallahi (2010)	New job arrivals, change in the processing times, adding new machine	Genetic algorithm
Adibi et al. (2010)	Random job arrivals, machine breakdown	Artificial neural networks and variable neighborhood search
Hao and Lin (2010)	Random job arrivals, machine breakdown	Interactive adaptive-weight evolutionary algorithm
Kapanoglu and Alikalfa (2011)	New job arrivals	Genetic algorithm
Hao and Gen (2011)	Random job arrivals, machine breakdown	Evolutionary algorithm
Qiu and Lau (2013)	New job arrivals, machine breakdown	A hybrid method based on artificial intelligence method of artificial immune systems (AIS) and priority dispatching rules
Nie et al. (2013)	New job arrivals	New heuristic method and gene expression programming
Zhang et al. (2013)	Random job arrivals, machine breakdown	Hybrid genetic algorithm and tabu search
Lu and Romanowski (2013)	New job arrivals	Dispatching rules
Sharma and Jain (2014)	Sequence-dependent setup times	Dispatching rules
Hosseinabadi et al. (2014)	Input of jobs	A new method called TIME_GELS
Nguyen et al. (2014)	Dynamic due-date assignment rule, dynamic total work content, dynamic processing and waiting	Four new multi-objective genetic programming-based hyper-heuristic (MO-GPHH) methods

Actually, military maintenance company investigated perform-ability themselves analytically comparing human-hour required versus human-hour available derived from the number of personnel, workdays, and skill level. And they decided ‘it is possible’. However this data on which decision was based on had elementary errors so that it is not proper to say it is accurate verification. There are several reasons following.

First, maintenance is implemented by a team and it may cause waste of human-hour. For example, let’s say that there is 25flight-hour maintenance on the queue and it requires 25human-hour with one B-grade and C-grade mechanics respectively. As a team they can deal with 1.25human-hour work per an hour. This job causes them to work 9hours using 11.25 human-hours to finish. In this case, 0.25human-hours were wasted.

Second, mechanics and pilots can have up to 21days off. It may prevent others forming a team for a new job or stop the process he/she used to do within the team.

Third, even though all other factors are available, weather condition affects the test flight decisively. A helicopter flight is restricted by rain, storm, and fog innately, and especially test flight which is for verifying its perfection, is banned in bad weather. It incurs time waste and can be a big obstacle to achieve minimum readiness rate.

That is, analytical calculation embraces those contingency errors. This research simulates problems in conservative conditions considering weather, day off, characteristics of team based maintenance with general restrictions and requirements.

The organization of the remaining sections of this paper is as follows; in Section 3, the conceptual model of DJSP of PMS system is described in detail. Also this section includes some reasonable assumptions and simplifications for the model to explain the gap with real world job and secure reliability and creditability of the computational model. Section 4 shows the computational model and its result analysis using 100times replications. Section 5 is intended to enhance the simulation analysis with sensitivity analysis of personnel pool differences. Importantly, this section highlights the most critical kinds of resources and interrelationships with different resource pool. Finally, concluding remarks and directions for future work are given out in Section 6.

CHAPTER 3: **CONCEPTUAL MODEL**

3.1 Introduction

This section describes conceptual design in detail. This model is made with multiple resources and processes. Four kinds of human resources integrate for each four kinds of maintenance processes with different combinations. Also, there are multiple restrictions and conditions. To abide by the minimum operation readiness posture, the number of fuselages under the processes or queue is restricted to 4. Weather is a critical condition for testing flight. rain data in 2016 and fog data from 1997~2006 was applied as the restriction for it. Each personnel may have days off in addition to weekends and holidays. Those will affect availability of personnel resources.

3.2 Maintenance Process

As stated, the inputs are dynamic and stochastic because maintenance needs arise depending on the flight hours accrued and this occurs stochastically.

There are 5 different flight cycles in which scheduled maintenance is required. Daily maintenance and time based checkups will be disregarded because they are deterministic and the required time can be deducted from the daily available time for mechanics.

So, this system will be composed of 4 kinds of inputs. Each sort of maintenance requires different stochastic human-hour and personnel combinations depending on fuselage conditions. Additionally, 125 flight-hour and 250 flight-hour maintenance need a test flight prior to the completion of maintenance. Those stochastic characteristics of inputs may incur bottle neck of needs.

Table 3-1. Type of PMS maintenance

Cycle	Human-hour required	Required personnel	Test flight	Cycle	Human-hour required	Required personnel	Test flight
Daily	1.5h±20%	Anyone	×	125Flight hours	56h±20%	1I+2B+2C	O
25Flight hours	12h±20%	1I+4C or 1I+1B+3C	×	250Flight hours	96h±20%	2I+2B+1C or 2I+3B	O
50Flight hours	15h±20%	1I+4C or 1I+1B+3C	×	Test Flight	5h±20%	1I+1P	

I: Inspector, B: B class Mechanics, C: C class Mechanics, P: Test Pilot

Test flights are essential to check whether all procedures are done right and the object is ready to go after 125 and 250 flight-hour based maintenances. The reason that test flight is implemented only for two is because they include main rotor blade disassembly step for non-destructive inspections and position rotations. It may cause unexpected vibration and uneven tracks of each blade which incur massive stress for other parts and low controllability. One inspector and test pilot ride the helicopter and test vibration, track of blades, engine power and controllability in simulated emergency such as engine failure.

Since all processes would be done in flight, weather is one of the key factors to decide to ‘Go / No-Go’. As mentioned, The precipitation records of I-Chon area in 2016(Table 3-3) where ROKA Aviation Command is located in, and average foggy days per year from 1997 to 2006 in South Korea were applied. 63days had rain less than 5mm and 34days was more than or equal to 5mm out of 366days last year. It is assumed that less than 5mm rain affects half of a day and more than or equal to 5mm rain stops the flight all day. On the other hand, fog was generated

31.9days a year and it lasted 5hours and 15minutes in average. (How do the loads react to fog?, 2008) And, as a common sense, it is assumed that fog and rain don’t occur at the same time. After all of those considerations, 0.7823 was applied as a probability of good weather of a test flight(Table 3-2). The test flight would be delayed or stopped whenever bad weather occurs and it also may generate a bottle neck even though there are enough personnel to work.

Table 3-2. Simulation time calculation

	Days	Workdays	Workhours
Total of the Year	366	248	1,116
No Precipitation	269	182.273224	820.23
Rain less than or equal to 5mm*	63	42.68852459	96.05
Rain greater than 5mm**	34	23.03825137	103.67
Fog***	31.9	21.61530055	43.23
Ratio of Flight-affordable time	0.78	0.78	0.78
*: affect half of a day, **: affect whole day, ***: affect half of a day			

Table 3-3. Precipitation record in 2016

	Precipitation											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st	0	0	0	0	0	0	40.8	0	0.1	0	0	0
2nd	0	0	0	0	10.1	0	0.7	0	3.5	6.7	0	0
3rd	0	0	0	0	26.6	0	0	0	0.7	11	0.1	0
4th	0	0	0	0	0	0	82.2	0	0	0	0	0
5th	0	0	56.3	0	0.9	0	31.8	0	0	9.5	0	0.1
6th	0	0	0	2.7	0.4	0	1.5	0	0	0	0	0
7th	0	0	0	14.4	0	0	0	0	1.6	5.8	3	0.1
8th	0	0.8	0	0	0	0	0	0	0	6.6	0.3	1.8
9th	0	0	0	0	0	0	0	0	0	0	0	1.4

	Precipitation											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
10th	0	0	0	0	15.5	0	0	0	0	0	3.9	0
11th	0	0.2	0	0	0	0	0.1	0	0	0	3.2	0
12th	0	15	0	0	0	0.1	12.6	0	0	0	0	0
13th	1.2	16.2	0	4.7	0	0	0	0	0	0	1.8	0
14th	0.5	0.3	0	0	0	0	0	2.9	0	0	0.2	0.7
15th	1.1	0	0	0	17.5	2.1	1.1	0	0	0	0	0
16th	0	0.9	0	28.6	3.5	0	74.9	0	0	2.2	0	0
17th	0	0	0	15.1	0	0	2.1	0	34.6	0.3	0	0
18th	0.2	0.1	0	4	0	0	0	0	0	0	2.7	0
19th	0	0	0	0	0	0	0	0	0	0	0	0.5
20th	0	0	0	0.9	0	0	0	0	0	0	0	0
21st	0	0	0	15.8	0	0	0	0	0	0	0	34.1
22nd	0	0	0	0	0	0.7	0	0	0	0	0.2	18.2
23rd	0	0.3	0	0	0	0.5	0	0	0	3.6	0	0.5
24th	0	0	0	0	23.4	15.5	0.3	0	0	0	0	0
25th	0	0	0	0	0	0	0	0.2	0	43.1	0	0
26th	0.6	0.5	0	0	0	0	0	26	0	0	2	1.1
27th	0	8.9	0	0.5	0	0	0	0	0.6	0	0	0.5
28th	0	9	0	0	0	0	0	11.4	0	2	0	0
29th	0	0	0	0	0	0	17	0	0	0	0	0.2
30th	0		0	0	0	0	16.2	0	0	0	0.4	0
31st	0		0		0		1.7	19.4		0		0

3.3 Human Resources

There are three kinds of human resources: inspectors, mechanics, and a test flight pilot. They work as a five-person team for maintenance and the combination varies on the situation and level of work. All inspectors have the highest skill grade, while ordinal mechanics are divided into B and C grades. Each grade represents how much they can take care of the work per an hour. That means team ability also varies depending on the composition. The information in detail is summarized on Table 3-4.

Table 3-4. The number and ability of personnel resources

Type	Skill Grade	#	Maintenance Ability
Test Flight Pilot	-	1	-
Inspector	A	4	1hour workload / real hour
Mechanics	B	7	0.75 hour workload / real hour
	C	15	0.5 hour workload / real hour

The inspector is a key of maintenance because they lead a team for maintenance and perform flight test with a pilot. While B and C mechanics substitute each other in the case that resource pool is in shortage, the inspector(s) is needed in any case.

In this model, each agent has 21 days off maximum per year in total. It might be 1 or 2days off per a chance but they cannot have off while they are participating in a maintenance team. This assumption is very similar with the way to choose their day off in military and usually they cannot use all of granted days off in this model and real world because of their existing duty.

Surely, they have breaks for holidays and weekends. In this model, the calendar of last year (2016) was applied. There was 13holidays and 53weekends. After adding all consideration, they worked 248days last year. The formal work hours, according to the formal working schedule in ROKA, is 8hours a day including 1-hour breaks for lunch and workout respectively. Also additional 3.5hours from formal working hours (8hours) was subtracted for daily administrative works like meetings, paperwork, flight preparedness, and so on. To conclude, they devoted 1,116hours only for maintenance.

3.4 Symbolic Model

Figure 3-1 is the symbolic model of system. To review this system, there are 4 inputs and 4 kinds of personnel pools. Inputs have different workloads in need based on fuselage conditions up to 20% from average in the manual. All kinds of maintenance are done by a team of five and it essentially includes one inspector as a leader in the team. The combination of the team varies depending on availability of personnel and level of maintenance. They have annual days off up to 21days and it may cause delay of work. After a maintenance process is done, an additional test flight is needed for 125 and 250 flight-hour maintenance. It needs one test pilot and inspector consuming 5±1hours. The test flight is vulnerable against bad weather, and it would be delayed or stopped during fog or rain.

The total number of fuselage in this system is restricted by four out of eighteen helicopters for maintaining 80% of the minimum operations readiness posture.

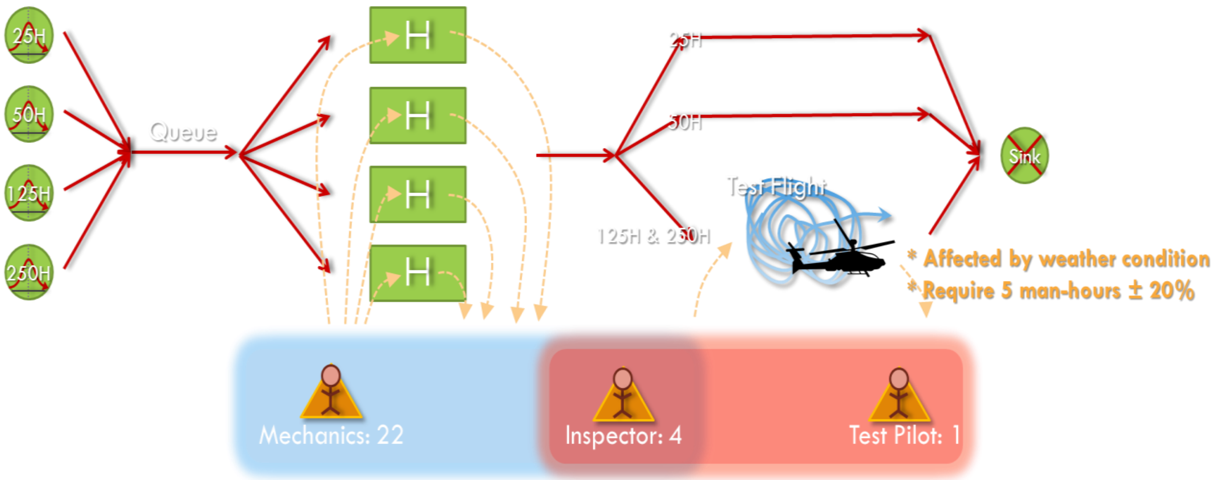


Figure 3-1. Symbolic model of PMS

3.5 Assumption

For this complicated model, we set some assumptions for simplification like below.

- All helicopters in the queue, maintenance, and test flight are unusable for military missions.
- Daily hour available per personnel: 4.5 hours
  - All personnel consume 3.5 hours for administrative work and flight preparation out of 8hours.
  - Daily maintenance and special check-ups are included in administrative hours
  - 1hour break for lunch is secured
- Teams are reorganized every time a new job is arriving and they have no preference
- Workload variance in need for maintenance follows 20% triangular distribution
- Weather conditions affect only test flight

CHAPTER 4: **COMPUTATIONAL MODEL**

4.1 Introduction

This system has a lot of things to consider stochastically. Various inputs with different demands, maintenance team with different combinations and work efficiency, and sudden day off and weather conditions do not allow to calculate the answer by hand. This is the one of main purposes of computational simulation because it is too complicated to find optimal answer manually.

Also, the computational simulation allows the same work to be repeated without any complaint so that test feasibility of this system can be tested over and over. It will tell whether it is working or not with certain probability under the certain conditions which the modeler intended. This is the other important purpose of computational simulation, to save time and efforts while testing uneasy or even impossible works in real world. The only thing the tester does is clicking on ‘play’ button.

4.2 Software

The ‘AnyLogic’ simulation software was utilized for this study. This Java-based software is supporting discrete event, agent based, and system dynamics simulation like ‘Simio’. Its graphical interface, tools, and library objects allow users to model diverse areas quickly such as manufacturing and logistics, business processes, human resources, consumer and patient behavior. Also, it supports visual development environment including 3D visual simulation function(Figure 4-2). It makes easy to pass V&V intuitively while saving time and effort to build the model.

This software support real time resource availability and statistical analysis according to users’ setting(Figure 4-3). As we can see in Figure 4-1, it shows process flow and present resource status. When the screen was captured, three out of four inspectors were working on maintenance while the other was in idle.

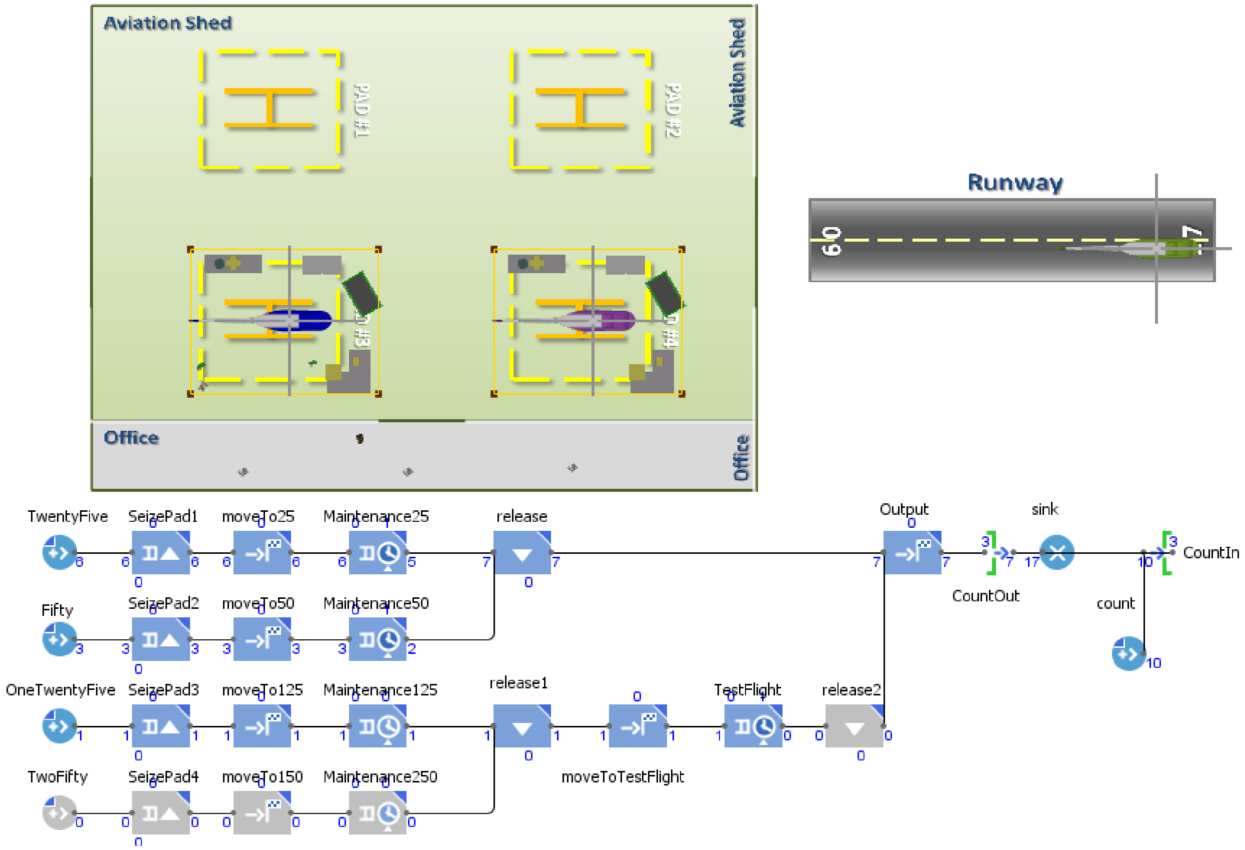


Figure 4-1. Computation model of PMS

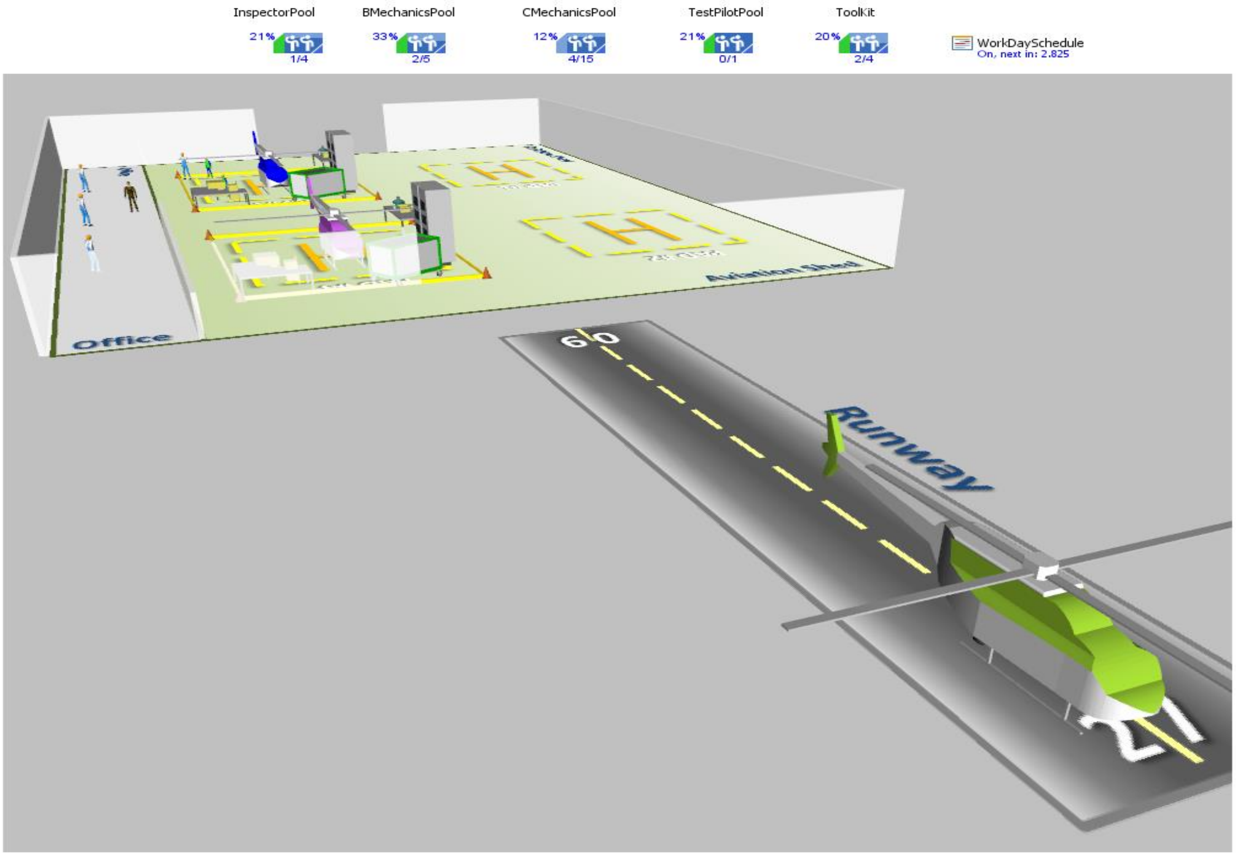
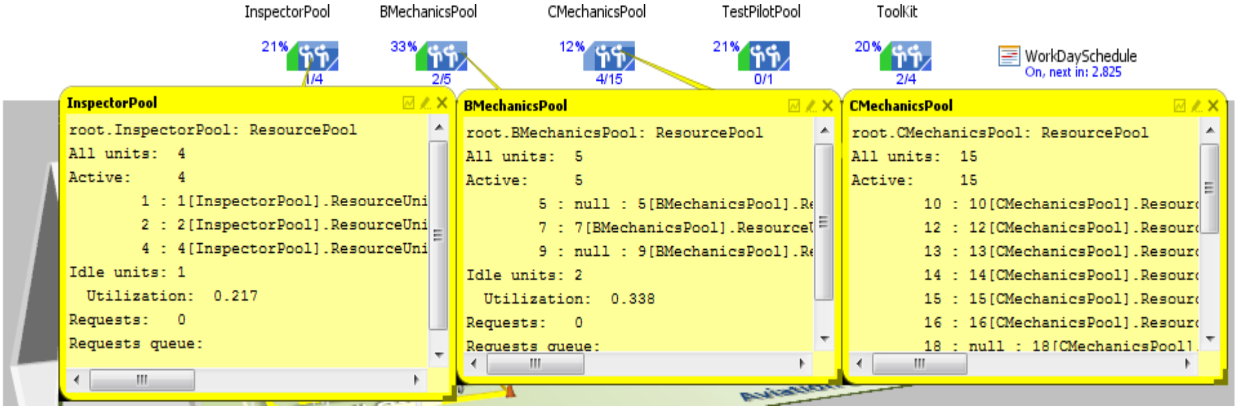


Figure 4-2. 3D Simulation of PMS



InspectorPool

```
root.InspectorPool: ResourcePool
All units:  4
Active:     4
        1 : 1[InspectorPool].ResourceUni
        2 : 2[InspectorPool].ResourceUni
        4 : 4[InspectorPool].ResourceUni
Idle units: 1
  Utilization:  0.217
Requests:   0
Requests queue:
```

BMechanicsPool

```
root.BMechanicsPool: ResourcePool
All units:  5
Active:     5
        5 : null : 5[BMechanicsPool].Re
        7 : 7[BMechanicsPool].Resource
        9 : null : 9[BMechanicsPool].Re
Idle units: 2
  Utilization:  0.338
Requests:   0
Requests queue:
```

CMechanicsPool

```
root.CMechanicsPool: ResourcePool
All units:  15
Active:     15
        10 : 10[CMechanicsPool].Resour
        12 : 12[CMechanicsPool].Resour
        13 : 13[CMechanicsPool].Resour
        14 : 14[CMechanicsPool].Resour
        15 : 15[CMechanicsPool].Resour
        16 : 16[CMechanicsPool].Resour
        18 : null : 18[CMechanicsPool].
```

Figure 4-3. Real-time resource data

4.3 Analysis

As shown in Table 4-1. Test data of feasibility , this stochastic system was repeated up to 100times and recorded the success or failure of test, utilization rates of each personnel resource at the end of trial. If failed, the reason was databased. It is considered success or passing the test if it doesn’t stop with any reasons till it reaches 1,116hours in the simulation. This means existing resources could deal with all of the maintenance workloads within restrictions during total workhours of last year.

It would be assumed that this system is working and existing personnel resources are enough to support the usual maintenance demands if the success rate is higher than or equal to 90%. This goal is not high because, first, there is no formal criterion of the mission success, and secondly, they may modify their schedule or do overtime in order to catch up with the demand temporarily. In truth, ROKA pays overtime up to 14 hours per a month and most of military personnel do more than maximum hours because of excessive workloads. So, 90% of success would be enough to say the existing military maintenance company template is proper or excessive when we consider there is more control and prediction for maintenance demand occurrence in the real world using flow charts. So, they consume or save the flight time of certain helicopter intentionally in order to prevent bottle-neck.

Table 4-1. Test data of feasibility analysis

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	0.6	790.49275	0.18	0.407701	0.01	0.41774	0	0.134577	0.34	0.48642
1	X	320.59	√	0.368		0.382		0.13		0.315
2	X	782.88	√	0.424		0.417		0.141	√	0.497
3	X	567.89	√	0.411		0.425		0.131	√	0.65
4	O			0.427		0.412		0.143		0.518
5	X	970.57		0.416		0.419		0.135	√	0.57
6	O			0.418		0.425		0.129		0.333
7	X	777.49	√	0.413		0.422		0.132	√	0.747
8	O			0.413		0.41		0.134		0.367
9	O			0.419		0.418		0.136		0.692
10	X	521.69		0.419		0.438		0.129	√	0.756
11	X	1006.3	√	0.421		0.42		0.128		0.6
12	X	775.23		0.409		0.425		0.124	√	0.713
13	O			0.418		0.401		0.144		0.335
14	X	833.55		0.419		0.42		0.134	√	0.81
15	X	1074.57		0.419	√	0.421		0.136	√	0.558
16	O			0.0424		0.41		0.14		0.344
17	O			0.429		0.415		0.141		0.336
18	X	1063.79	√	0.422		0.421		0.139		0.478
19	O			0.422		0.418		0.135		0.403
20	X	879.65	√	0.427		0.415		0.144	√	0.672
21	X	707.28	√	0.419		0.404		0.141	√	0.323
22	O			0.426		0.424		0.137		0.337
23	O			0.422		0.411		0.141		0.339
24	X	592.44	√	0.403		0.406		0.135	√	0.6
25	O			0.421		0.42		0.131		0.334
26	O			0.432		0.434		0.131		0.32
27	O			0.422		0.424		0.133		0.325
28	X	786.67		0.429		0.406		0.145	√	0.605
29	X	880.15		0.415		0.427		0.131	√	0.678
30	O			0.43		0.425		0.138		0.497
31	X	718.25		0.404		0.415		0.128	√	0.561
32	O			0.435		0.418		0.143		0.34
33	X	960.23	√	0.405		0.412		0.132	√	0.601
34	X	693.15	√	0.402		0.4		0.137	√	0.754
35	O			0.423		0.406		0.141		0.334
36	O			0.429		0.429		0.139		0.418
37	O			0.422		0.417		0.14		0.334

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	0.6	790.49275	0.18	0.407701	0.01	0.41774	0	0.134577	0.34	0.48642
38	O			0.421		0.425		0.132		0.343
39	X	677.47	√	0.415		0.395		0.144	√	0.645
40	O			0.432		0.422		0.143		0.337
41	O			0.427		0.432		0.134		0.343
42	O			0.417		0.413		0.136		0.337
43	O			0.42		0.422		0.132		0.326
44	O			0.415		0.413		0.136		0.36
45	O			0.43		0.426		0.138		0.337
46	O			0.426		0.431		0.13		0.34
47	O			0.427		0.433		0.134		0.413
48	X	563.55		0.396		0.424		0.121	√	0.628
49	O			0.429		0.429		0.136		0.348
50	O			0.427		0.436		0.132		0.34
51	O			0.418		0.421		0.132		0.671
52	X	114.83	√	0.361		0.378		0.12		0.256
53	X	804.98		0.41		0.421		0.131	√	0.75
54	O			0.431		0.431		0.137		0.347
55	O			0.413		0.406		0.139		0.457
56	O			0.427		0.423		0.135		0.401
57	O			0.427		0.411		0.141		0.39
58	O			0.0428		0.408		0.147		0.667
59	X	1090.22		0.425		0.428		0.132	√	0.568
60	O			0.422		0.418		0.135		0.327
61	O			0.0419		0.424		0.131		0.326
62	X	1019.48		0.427		0.412		0.143	√	0.507
63	X	813.1		0.419		0.416		0.137	√	0.722
64	X	654.93		0.417		0.425		0.133	√	0.686
65	O			0.418		0.413		0.136		0.336
66	X	821.75		0.426		0.432		0.136	√	0.774
67	O			0.418		0.413		0.137		0.332
68	O			0.42		0.426		0.131		0.42
69	O			0.427		0.423		0.137		0.332
70	O			0.421		0.421		0.133		0.461
71	O			0.431		0.428		0.0137		0.389
72	O			0.43		0.425		0.142		0.332
73	O			0.414		0.42		0.13		0.323
74	X	660.78		0.407		0.395		0.141	√	0.694
75	O			0.423		0.416		0.14		0.565
76	O			0.426		0.42		0.142		0.42

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	0.6	790.49275	0.18	0.407701	0.01	0.41774	0	0.134577	0.34	0.48642
77	X	1023.31		0.413		0.42		0.135	√	0.59
78	O			0.429		0.425		0.136		0.454
79	X	210.31	√	0.374		0.377		0.133		0.368
80	X	1092.42	√	0.42		0.415		0.137	√	0.536
81	O			0.409		0.416		0.131		0.331
82	O			0.424		0.424		0.133		0.349
83	O			0.424		0.415		0.14		0.61
84	X	709.81	√	0.409		0.432		0.128	√	0.59
85	X	1006.04		0.421		0.408		0.137	√	0.555
86	O			0.426		0.422		0.134		0.561
87	X	1112.25		0.43		0.423		0.142	√	0.629
88	X	786.31	√	0.428		0.42		0.139		0.714
89	O			0.427		0.41		0.142		0.329
90	X	1091.44	√	0.422		0.421		0.137	√	0.654
91	O			0.425		0.413		0.139		0.506
92	O			0.418		0.413		0.14		0.607
93	O			0.427		0.424		0.135		0.595
94	X	876.65		0.415		0.411		0.138	√	0.619
95	X	796.48		0.419		0.427		0.137	√	0.707
96	O			0.414		0.412		0.141		0.334
97	O			0.424		0.431		0.132		0.45
98	X	781.23		0.399		0.402		0.131	√	0.682
99	O			0.426		0.43		0.133		0.585
100	O			0.427		0.416		0.14		0.343

The results marked only 60% of success. That means personnel pool is too small to take care of all maintenance demands and may cause failure of maintaining the military readiness posture.

When looked at in detail, most of failure (97.5%) is by test pilot and inspectors like those shown in Figure 4-4. While B class mechanics are only involved in one case(case #15) and it was even with test pilot. C class mechanics looks have enough numbers because they never cause failure during 100times of repetition.

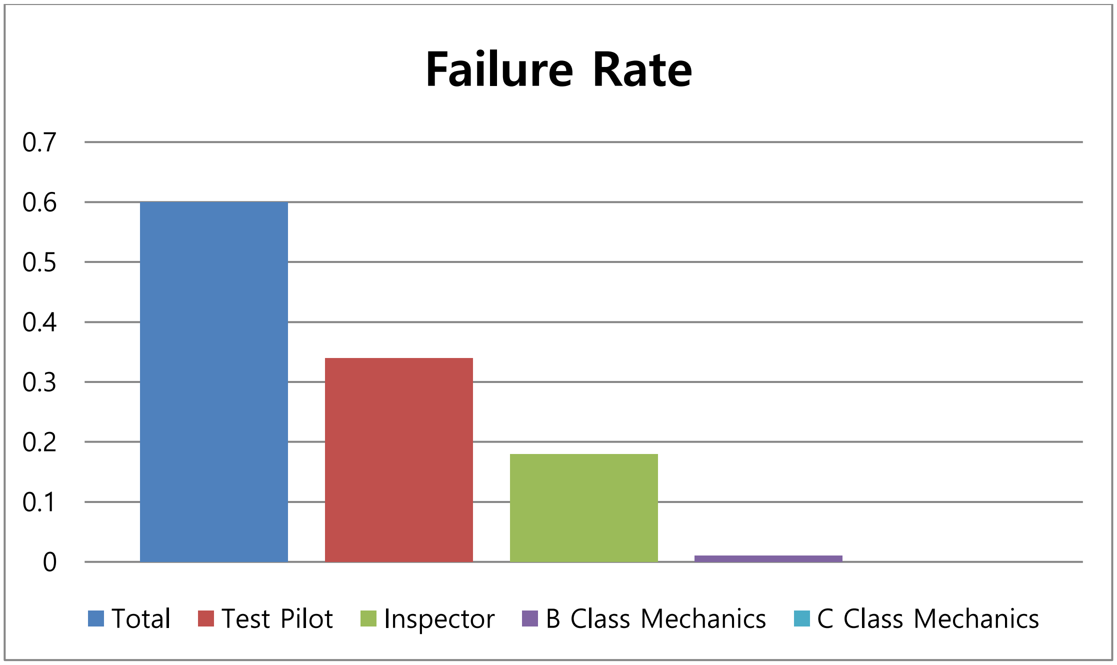


Figure 4-4. Reason of failure

The utilization rate graph tells more stories about the test pilot. It shows how busy each group was during the tests. It compares the time on the job with idle time. Delays due to the bad weather are included in 'Busy' while day off is excluded from statistics.

The test pilot category shows extremely large span of the variance compared to the other groups on Figure 4-5. The only different restriction on test pilot is weather conditions. And delay caused by bad weather is one of the factors that expand the gap. In addition, the test pilot pool is only one person. This also makes the variance big because there is no backup so weather condition affects utilization drastically. Table 4-2 and Figure 4-6 illustrate the guess with meaningful difference of utilization level between when test failed and when it succeeded. In other hand, inspector pool doesn't have same phenomena like shown on Figure 4-7. They show a small difference visually but cannot say it is meaningful with $\alpha = 0.05$ because the confidence interval of T-test result in Table 4-3 includes "0". This means inspectors are always busy regardless of result.

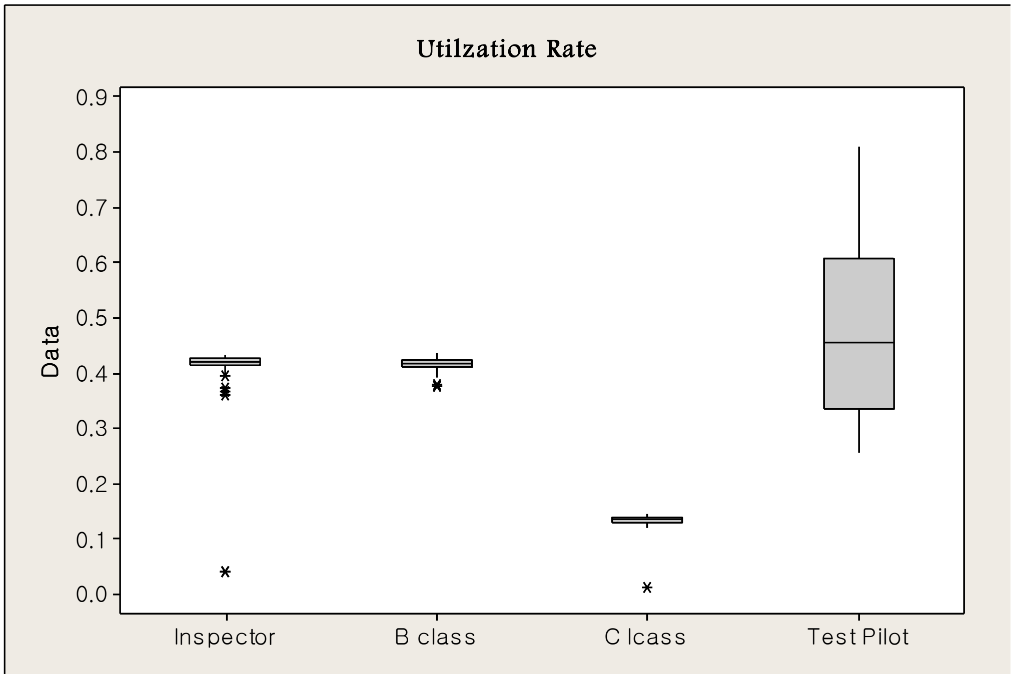


Figure 4-5. Utilization variance analysis

Table 4-2. Two-sample T test result for test pilot pool

Minitab Result

```
Two-sample T for Test-Critical vs Test-NonCritical
                          N      Mean     StDev   SE Mean
Test-Critical        34   0.6362   0.0973      0.017
Test-NonCritical   67     0.408      0.111       0.014

Difference = mu (Test-Critical) - mu (Test-NonCritical)
Estimate for difference:   0.2279
95% CI for difference:   (0.1851, 0.2707)
T-Test of difference = 0 (vs not =): T-Value = 10.61   P-Value = 0.000   DF = 74
```

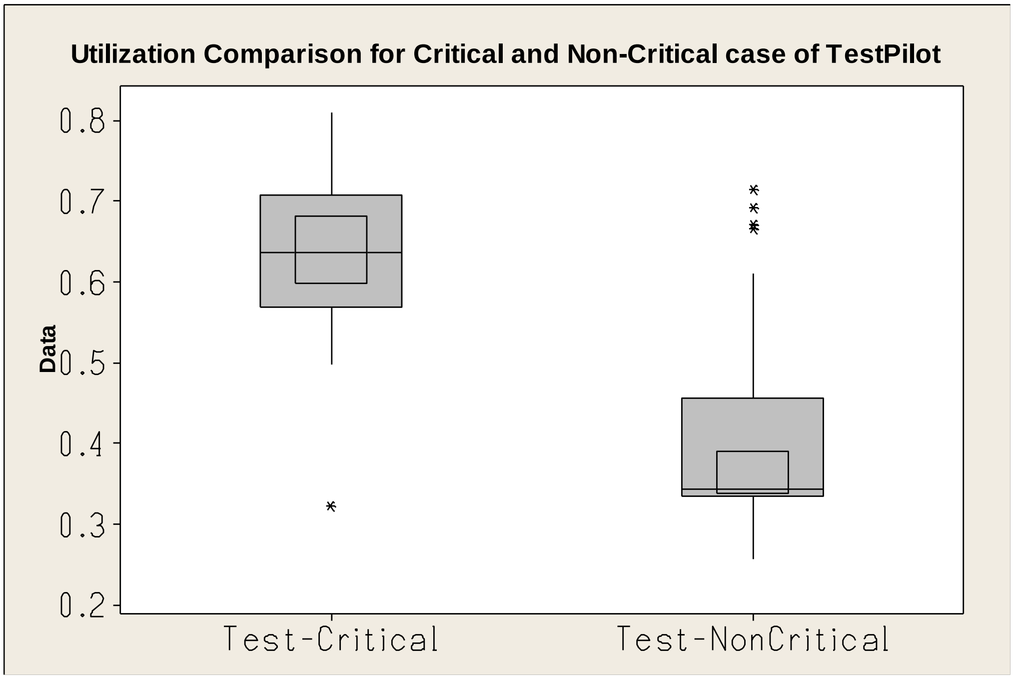


Figure 4-6. Utilization comparison for critical and non-critical case of test pilot

Table 4-3. Two-sample T test result for Inspector pool

Minitab Result

```
Two-sample T for Ins-Critical vs Ins-NonCritical
                          N       Mean      StDev    SE Mean
Ins-Critical          18    0.4080    0.0202      0.0048
Ins-NonCritical    82    0.4076    0.0720      0.0080

Difference = mu (Ins-Critical) - mu (Ins-NonCritical)
Estimate for difference:    0.00036
95% CI for difference:    (-0.01805, 0.01878)
T-Test of difference = 0 (vs not =): T-Value = 0.04    P-Value = 0.969    DF = 92
```

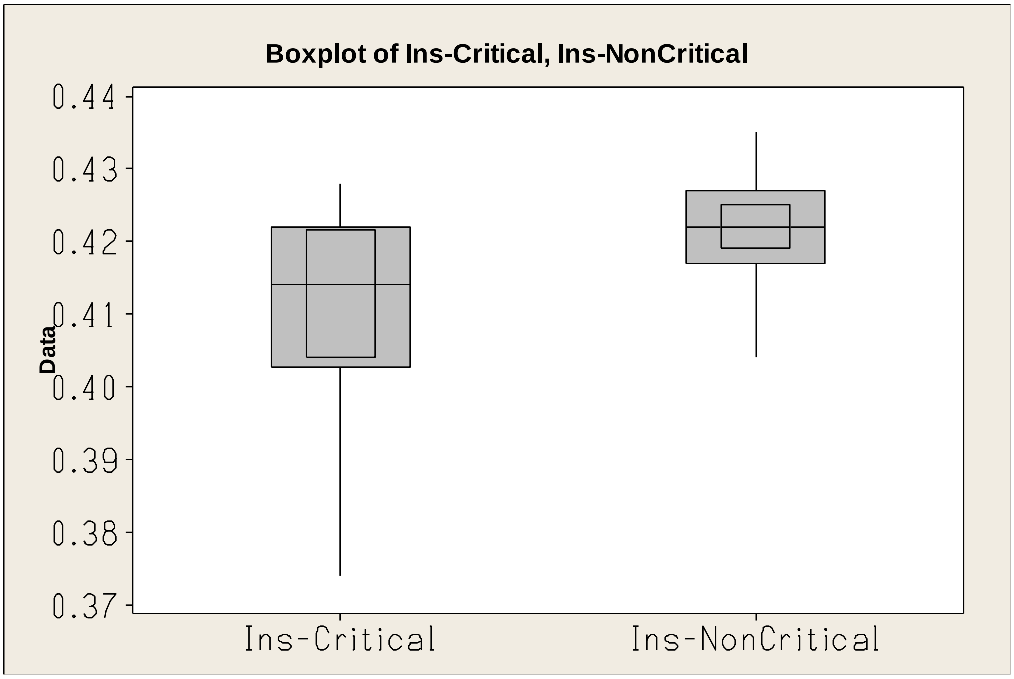


Figure 4-7. Utilization comparison for critical and non-critical case of inspector pool

4.4 Sensitivity analysis

As mentioned before, it is strongly suspected that test pilot and inspector pools are critical factors for this system because they incur most of failure (97.5%) alone or integrated each other. They have their own duties so they cannot have backup from others while B and C grade mechanics can substitute each other.

In this chapter, the sensitivity of the test pilot and inspector pool were tested by increasing and decreasing the number of units. Additionally the sensitivity analysis for B grade mechanics was implemented in order to look at the relationship with C grade. It is expected that the utilization of B and C grade mechanics would increase simultaneously when B grade mechanics is decreased because C grade would take the place of B grade mechanics.

It was simulated 50 times for each step of increase and decrease respectively following Table 4-4.

Table 4-4. Sensitivity analysis plan

Category	Test pilot	Inspector	B class mechanics
Test level	+1	+1	-1, -2

Test results for the test pilot (Table 4-5) shows remarkable decrease of failure. There was only one failure out of 50times of test and even it was because of inspectors. We can notice not only that the utilization is getting lower but also that error span became narrower than previous tests. This means more pilots are more stable to implement their duty and less vulnerable against exterior obstacles such as weather and day off like other personnel resource pools. The others show very narrow variance span regardless of conditions. With this test, a conclusion can be drawn that it is essential to have more than one test pilot in order to not only secure successful execution of duty, but also prepare for any urgent situations by having a more stable resources condition.

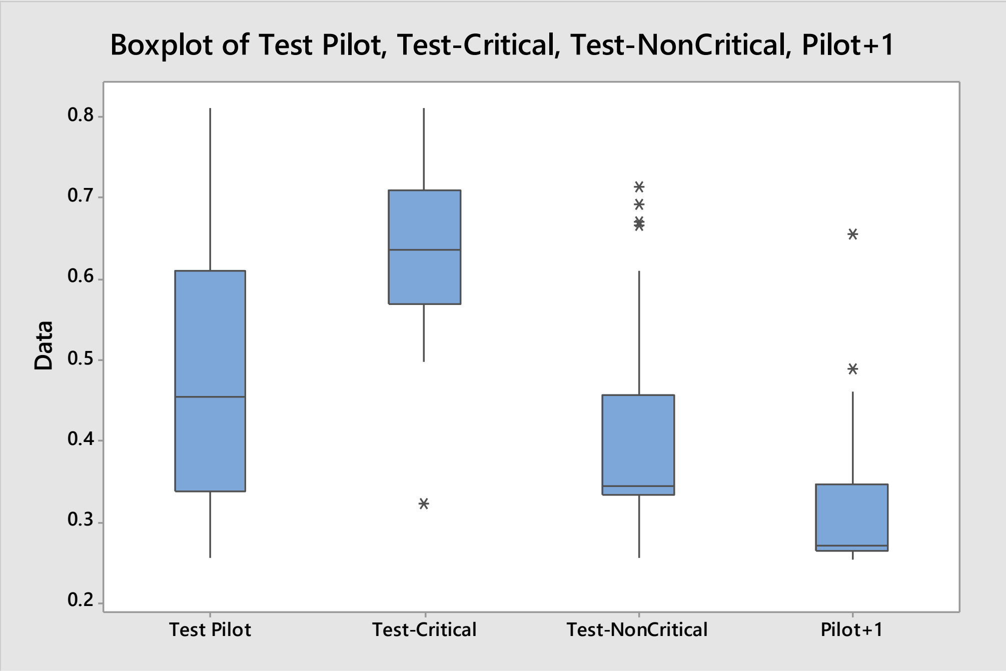


Figure 4-8. Utilization comparison for test pilot sensitivity analysis

Table 4-5. Test data of Sensitivity analysis for test pilot + 1

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	67	301.23	1	0.4082	0	0.4207	0	0.133966	0	0.33572
1	O			0.429		0.433		0.133		0.362
2	O			0.43		0.41		0.143		0.321
3	O			0.42		0.427		0.131		0.304
4	O			0.432		0.416		0.141		0.271
5	O			0.42		0.417		0.136		0.323
6	O			0.425		0.429		0.133		0.268
7	O			0.421		0.425		0.136		0.275

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	67	301.23	1	0.4082	0	0.4207	0	0.133966	0	0.33572
8	O			0.427		0.428		0.137		0.269
9	O			0.42		0.424		0.131		0.346
10	O			0.421		0.422		0.133		0.569
11	O			0.423		0.417		0.138		0.521
12	O			0.0418		0.41		0.136		0.264
13	O			0.421		0.42		0.135		0.282
14	O			0.414		0.417		0.136		0.146
15	O			0.423		0.425		0.137		0.443
16	O			0.436		0.433		0.138		0.348
17	O			0.423		0.431		0.131		0.262
18	O			0.421		0.429		0.13		0.431
19	O			0.42		0.416		0.137		0.262
20	O			0.425		0.417		0.136		0.264
21	O			0.417		0.417		0.137		0.298
22	O			0.43		0.427		0.137		0.592
23	O			0.421		0.429		0.134		0.47
24	O			0.434		0.423		0.142		0.264
25	O			0.416		0.419		0.132		0.26
26	O			0.431		0.428		0.139		0.382
27	O			0.418		0.419		0.133		0.453
28	O			0.413		0.421		0.0133		0.258
29	O			0.427		0.428		0.135		0.264
30	O			0.426		0.416		0.14		0.267
31	O			0.424		0.423		0.131		0.517
32	O			0.42		0.409		0.139		0.489
33	X	301.23	√	0.382		0.415		0.12		0.253
34	O			0.432		0.414		0.136		0.288
35	O			0.43		0.422		0.141		0.262
36	O			0.421		0.414		0.134		0.41
37	O			0.429		0.425		0.138		0.3
38	O			0.43		0.428		0.138		0.266
39	O			0.425		0.423		0.138		0.318
40	O			0.427		0.409		0.143		0.266
41	O			0.428		0.427		0.136		0.271
42	O			0.0417		0.424		0.133		0.324
43	O			0.404		0.406		0.137		0.655
44	O			0.437		0.422		0.145		0.264

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	67	301.23	1	0.4082	0	0.4207	0	0.133966	0	0.33572
45	O			0.423		0.42		0.138		0.268
46	O			0.429		0.424		0.138		0.346
47	O			0.431		0.43		0.138		0.461
48	O			0.42		0.412		0.138		0.262
49	O			0.425		0.407		0.144		0.265
50	O			0.425		0.408		0.143		0.262

Figure 4-9 and

Table 4-6 show the sensitivity test results for inspector increase. Twelve failures occurred out of fifty tests but only one case was related with the inspectors directly. With only single increase of number increase success rate to 0.76 from 0.6. When we consider only the failure cases related directly with inspector pools, it is 0.98 from 0.74. Also, variation span became narrower than before which means burden distribution is improved with a larger personnel pool. So, it can be said that this sensitivity analysis for the inspector is also showing strong evidence to have more inspectors than the present maximum number of personnel in order to secure reliable execution of duty and to cope with contingency.

Figure 4-9. Utilization comparison for inspector sensitivity analysis

Table 4-6. Test data of Sensitivity analysis for inspector + 1

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	38	823.070833	1	0.33676	1	0.41878	0	0.13586	9	0.45566
1	O			0.342		0.419		0.14		0.328
2	O			0.339		0.428		0.135		0.329
3	X	1057.4		0.328	√	0.413		0.133	√	0.663
4	O			0.341		0.425		0.137		0.322
5	O			0.343		0.415		0.142		0.344
6	X	346.59		0.33		0.409		0.138	√	0.6
7	O			0.343		0.432		0.136		0.335
8	X	496.37		0.319		0.415		0.122		0.675
9	O			0.337		0.416		0.134		0.327
10	O			0.337		0.412		0.139		0.328
11	X	959.24	√	0.335		0.421		0.133	√	0.559
12	X	982.42		0.33		0.42		0.135	√	0.547
13	O			0.341		0.422		0.138		0.475
14	O			0.346		0.434		0.138		0.332

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	38	823.070833	1	0.33676	1	0.41878	0	0.13586	9	0.45566
15	O			0.342		0.423		0.138		0.334
16	X	671.84		0.33		0.398		0.147	√	0.69
17	O			0.332		0.426		0.132		0.337
18	O			0.338		0.414		0.14		0.553
19	O			0.345		0.415		0.141		0.341
20	O			0.342		0.428		0.135		0.333
21	X	712.51		0.323		0.397		0.138	√	0.524
22	O			0.34		0.41		0.142		0.353
23	O			0.321		0.402		0.132		0.328
24	O			0.331		0.402		0.14		0.332
25	O			0.34		0.428		0.131		0.339
26	O			0.335		0.427		0.132		0.333
27	O			0.336		0.419		0.134		0.43
28	O			0.337		0.426		0.133		0.499
29	O			0.33		0.417		0.13		0.357
30	O			0.337		0.419		0.133		0.594
31	O			0.334		0.406		0.135		0.429
32	O			0.326		0.412		0.129		0.331
33	O			0.341		0.42		0.136		0.372
34	X	827.66		0.337		0.432		0.129	√	0.794
35	O			0.342		0.42		0.139		0.347
36	X	896.77		0.339		0.427		0.133	√	0.792
37	O			0.335		0.409		0.139		0.44
38	O			0.339		0.437		0.129		0.409
39	O			0.346		0.426		0.141		0.34
40	X	902.77		0.34		0.41		0.147		0.555
41	O			0.338		0.425		0.135		0.474
42	O			0.338		0.424		0.133		0.602
43	O			0.344		0.425		0.135		0.662
44	O			0.333		0.413		0.135		0.382
45	X	942.97		0.335		0.417		0.135		0.646
46	O			0.344		0.419		0.142		0.418
47	O			0.34		0.417		0.136		0.328
48	O			0.339		0.42		0.137		0.333
49	X	1080.31		0.342		0.425		0.139	√	0.508
50	O			0.336		0.423		0.131		0.78

The following is the sensitivity analysis for B class mechanics. It was repeated 50times for each reducing the number from 7 to 5 for the sensitivity analysis. As shown in

Table 4-7, there was no meaningful difference in terms of the failure rate with six B class mechanics. However it soared up to 22% when it was reduced to 5. The boxplot graph on Figure 4-10 shows that utilization has a trend to increase accordingly. The interesting part is the utilization of C class follows same trend as B class. Also both personnel pools became vulnerable toward the bottleneck, showing larger variance when the number went down to five. These results proved that two classes of mechanics have trade-off relationship so if one becomes busy, the other would substitute.

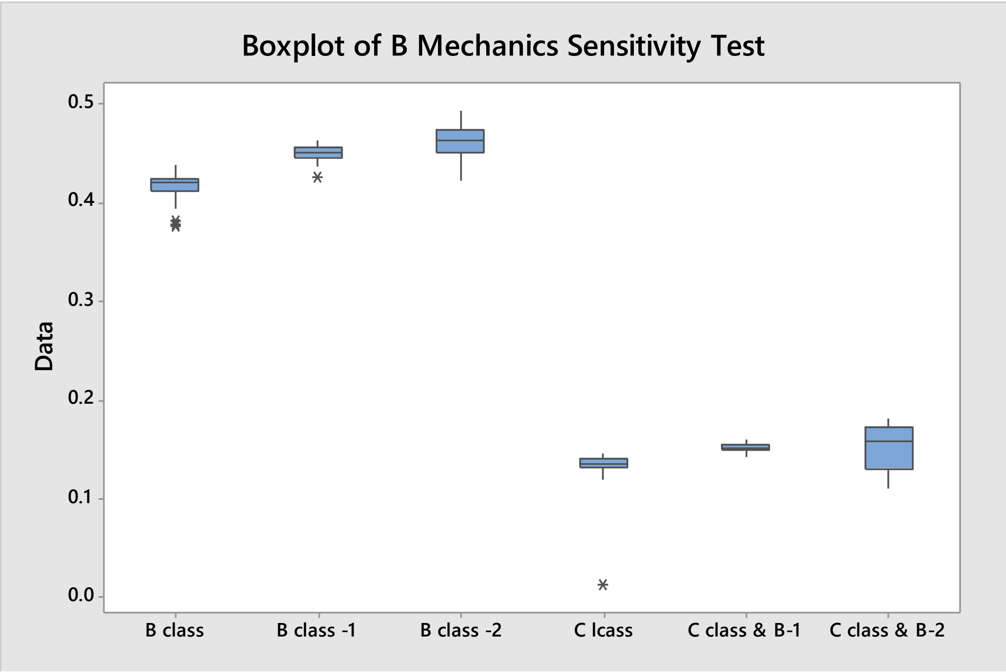


Figure 4-10. Utilization comparison for B class mechanics sensitivity analysis

Table 4-7. Test data of Sensitivity analysis for B class mechanics - 1

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	41	757.251111	5	0.42132	0	0.45008	0	0.15188	6	0.44226
1	O			0.425		0.46		0.151		0.525
2	X	566.37		0.394		0.436		0.142		0.694
3	O			0.423		0.446		0.153		0.334
4	O			0.415		0.436		0.154		0.4
5	O			0.435		0.447		0.157		0.343
6	O			0.404		0.448		0.143		0.696
7	O			0.42		0.442		0.151		0.334
8	O			0.43		0.458		0.156		0.335
9	O			0.417		0.455		0.149		0.324
10	O			0.419		0.451		0.152		0.389
11	O			0.424		0.458		0.152		0.582
12	O			0.425		0.458		0.151		0.374
13	O			0.426		0.458		0.149		0.33
14	O			0.428		0.451		0.156		0.337
15	O			0.43		0.446		0.16		0.488
16	X	758.76		0.413		0.45		0.149	√	0.613
17	X	779.94	√	0.411		0.446		0.148		0.554
18	O			0.426		0.449		0.154		0.326
19	O			0.429		0.464		0.149		0.46
20	O			0.414		0.448		0.146		0.333
21	O			0.429		0.461		0.151		0.338
22	X	809.24	√	0.42		0.451		0.152		0.504
23	O			0.433		0.454		0.159		0.424
24	O			0.427		0.451		0.152		0.666
25	O			0.424		0.449		0.152		0.42
26	O			0.434		0.452		0.159		0.56
27	O			0.407		0.453		0.144		0.325
28	X	849.88	√	0.41		0.45		0.149	√	0.492
29	O			0.416		0.456		0.148		0.563
30	O			0.417		0.452		0.152		0.54
31	X	1007.48	√	0.413		0.448		0.15	√	0.653
32	O			0.422		0.459		0.149		0.326
33	O			0.425		0.453		0.152		0.334
34	O			0.426		0.439		0.157		0.325
35	O			0.434		0.448		0.159		0.338
36	O			0.417		0.437		0.153		0.332

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	41	757.251111	5	0.42132	0	0.45008	0	0.15188	6	0.44226
37	O			0.421		0.451		0.149		0.429
38	O			0.428		0.459		0.15		0.393
39	O			0.427		0.46		0.152		0.335
40	O			0.424		0.444		0.153		0.391
41	O			0.427		0.448		0.155		0.667
42	X	925.69		0.423		0.45		0.157	√	0.613
43	X	579.52	√	0.404		0.441		0.146	√	0.619
44	O			0.421		0.453		0.153		0.327
45	O			0.426		0.46		0.151		0.333
46	O			0.419		0.437		0.152		0.338
47	O			0.426		0.445		0.155		0.34
48	X	538.38		0.403		0.426		0.151	√	0.743
49	O			0.426		0.45		0.157		0.336
50	O			0.429		0.46		0.153		0.338

Table 4-8. Test data of Sensitivity analysis for B class mechanics - 2

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	6	362.280682	30	0.37804	11	0.4614	0	0.15228	25	0.34836
1	X	789.58	√	0.431		0.493		0.172	√	0.322
2	X	123.57	√	0.354		0.472		0.141	√	0.24
3	X	116.12	√	0.307		0.448		0.11	√	0.231
4	X	306.03	√	0.392		0.443		0.161	√	0.327
5	X	479.42		0.391	√	0.444		0.159	√	0.623
6	X	122.41	√	0.312		0.435		0.138	√	0.241
7	X	1097.03		0.412	√	0.471		0.172		0.499
8	O			0.429		0.472		0.178		0.34
9	X	317.32	√	0.376		0.459		0.156	√	0.293
10	X	1039.49	√	0.411		0.454		0.179	√	0.616
11	X	599.23		0.441	√	0.465		0.172		0.313
12	X	598.74		0.409		0.453		0.178	√	0.755
13	X	216.64	√	0.382	√	0.454		0.156	√	0.295
14	X	387.83	√	0.411	√	0.461		0.171	√	0.319
15	X	120.91		0.346	√	0.465		0.126		0.273
16	X	116.39	√	0.339		0.436		0.129	√	0.301
17	X	604.74	√	0.418	√	0.47		0.173	√	0.316

Category	Total		Inspector		B class Mechanics		C class Mechanics		Test Pilot	
	O,X	Time to stop	Reason	%	Reason	%	Reason	%	Reason	%
Average	6	362.280682	30	0.37804	11	0.4614	0	0.15228	25	0.34836
18	X	301.97	√	0.396		0.481		0.158		0.299
19	X	325.08	√	0.397		0.457		0.16		0.287
20	X	114.49	√	0.321		0.438		0.129	√	0.214
21	X	222.03	√	0.364		0.466		0.147		0.269
22	X	851.19	√	0.424		0.476		0.173		0.323
23	X	642.91	√	0.408		0.474		0.167	√	0.334
24	X	408.75	√	0.403		0.48		0.159		0.617
25	X	112.91	√	0.295		0.445		0.111	√	0.209
26	O			0.419		0.473		0.174		0.504
27	X	838.16		0.427		0.487		0.169		0.548
28	X	117.53		0.313	√	0.452		0.116		0.273
29	O			0.43		0.474		0.18		0.34
30	X	120.25	√	0.344		0.463		0.13	√	0.373
31	X	131.39	√	0.293		0.446		0.112		0.217
32	X	511.82	√	0.415		0.481		0.166		0.321
33	X	318.9	√	0.391		0.451		0.163		0.323
34	X	216.02	√	0.372		0.473		0.145		0.285
35	X	117.77	√	0.344	√	0.474		0.131		0.266
36	X	742.72	√	0.428		0.488		0.174	√	0.537
37	X	124.22	√	0.306		0.45		0.118		0.236
38	X	122.56		0.349		0.483		0.13	√	0.263
39	X	107.28	√	0.307		0.423		0.129		0.226
40	X	112.85		0.303	√	0.435		0.11		0.232
41	O			0.415		0.453		0.181		0.472
42	X	770.18		0.427		0.471		0.177	√	0.588
43	X	214.99	√	0.36	√	0.451		0.147		0.311
44	O			0.425		0.463		0.182		0.344
45	X	125.14		0.341		0.455		0.129	√	0.312
46	X	314.44	√	0.399		0.445		0.171	√	0.299
47	X	669.07		0.433		0.469		0.182	√	0.49
48	X	125.94		0.332		0.478		0.117	√	0.233
49	X	124.34		0.343		0.452		0.134	√	0.235
50	O			0.417		0.468		0.172		0.334

CHAPTER 5: **CONCLUTIONS AND FUTURE WORK**

5.1 Conclusions and Recommendations

So far, characteristics of helicopter maintenance system in S.Korea military was reviewed. There are many considerations to manage maintenance schedule including timing of entering maintenance, days off and inevitable weather conditions. I believe the commander of the maintenance company have done a good job on his/her position. However, even with perfect management, it is not easy to cope with all the maintenance demands with inefficient personnel resources. In truth, most of the ROKA helicopter maintenance company have been suffering with excessive workloads and overtime work. Their fatigue and tight schedule may become critical reasons of imperfect maintenance and man-made disasters.

In this study, PMS which ROKA is applying for helicopter maintenance was modeled and simulated and a meaningful conclusion was drawn. Having additional one or more of test pilots and inspectors is essential. A test pilot is an especially critical factor for successful maintenance management because this resource is very vulnerable against weather condition and contingency.

5.2 Future work

To acquire more reliable analysis for personnel demand, future works need more accurate and sufficient data to obtain practical assumptions. The data of this study is largely based on expert's opinion. The representative example is workload variance of 20% and its distribution. There was no data except company commander and inspectors' comments. This is because Apache troops was newly founded and there was no time to accumulate enough data for objective variance and its distribution. And the information from military is very restrictive due to confidentiality. All information and data are only disclosed and utilized for military defense within authorized areas through complicated procedures. This was the limitation for this research.

Also, C class mechanics have less time to work for maintenance because they spend more time on fight and maintenance preparations. And certainly they have more small duties than higher ranks. This needs field research and surveys to get actual time ratio between maintenance and miscellaneous.

The maintenance company needs to secure more available helicopters and flight hours because troops practice war plan assuming all helicopters are available and it is not easy to do maintenance in open field. Usually the maintenance company has more burden and bottleneck to cope with imminent maintenance in order to secure enough flight times for exercise plan before it begins. Also, they encounter bottleneck after exercise because many of the helicopters use up their available flight hours. This important event for verification was out of consideration for this research due to lack of data.

Additionally, new maintenance system needs to be tested with same personnel pool. This research tested existing maintenance system for newly adopted helicopters. The results show less than 50% of utilization rate for the inspector pool. In other ward, even though there are many things to do, they are not so busy because of the inefficient working system. It can be explained by 5 person team based work system. If the system let them to work more flexible allowing to work with smaller or larger team, it can show different result.

In conclusion, first of all, future work needs to have more data in order to enhance the quality and reliability of result. Secondly, it needs to test different or more flexible maintenance system to find out if same personnel pool works more efficiently.

REFERENCES

Applegate, D., & Cook, W. (1991). A Computational Study of the Job-Shop Scheduling Problem. *ORSA Journal on Computing, 3*(2), 149-156.

Axtell, R. L. (2000). *WHY AGENTS? ON THE VARIED MOTIVATIONS FOR AGENT COMPUTING IN THE SOCIAL SCIENCES. Center on Social and Economic Dynamics.* Washington DC, Virginia, US: The Brookings Institution.

Cheng, R., Gen, M., & Tsujinura, Y. (1996). A TUTORIAL SURVEY OF JOB-SHOP SCHEDULING PROBLEMS USING GENETIC ALGORITHMS-I. REPRESENTATION. *Computers Industrial engineering, 30*(4), 983-997.

Kundakci, N., & kulak, O. (2016). Hybrid genetic algorithms for minimizing makespan in dynamic job shop scheduling problem. *Computer & Industrial Engineering, 96,* 31-51.

Law, A. M. (2015). *Simulation Modeling and Analysis* (Vol. 5th). New York, NY, US: McGraw-Hill Education.

Ministry of National Defense. (2014). *2014 Republic of Korea Defanse white Paper.* Seoul, Korea: Ministry of National Defense.

Ramasesh, R. (1990). Dynamic Job Shop Scheduling: A survey of Simulation Research. *OMEG International Journal of Management Science, 18*(1), 43-57.

Thurer, M., & Stevenson, M. (2016). Workload control in job shops with re-entrant flows: an assessment by simulation. *International Journal of Production Research, 54*(17), 5136-5150.

Xiong, H., Fan, F., Jiang, G., & Li, G. (2017). A simulation-based study of dispatching rules in a dynamic job shop scheduling problem with batch release and extended technical precedence constraints. *European Journal of Operational Research, 257*, 13-24.

Yunchul, C. (2013). *소형항공기(헬기) 안전개선대책 수립을 위한 정책연구*. Ministry of Land, 항공정책실 항공안전정책관 운항정책과. Seoul: 한서대학교 산학협력단. Retrieved Mar. 16, 2017, from http://www.prism.go.kr/homepage/entire/retrieveEntireDetail.do?pageIndex=1&research_id=1613000-201400009&leftMenuLevel=160&cond_research_name=%EC%86%8C%ED%98%95%ED%95%AD%EA%B3%B5%EA%B8%B0&cond_research_start_date=&cond_research_end_date=&pageUnit=10&cond_