

INTEGRATED RISK MANAGEMENT PROCESS TO ADDRESS THE PROBLEM OF ASSIGNING PILOT MISSIONS TO KOREAN ARMY HELICOPTER UNITS

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The pilot mission assignment problem is addressed to improve mission efficiency, with low level of accident risk. In this paper, an integrated framework for the risk management of pilot mission assignment is presented, which can be applied in Korean army helicopter units, using the IDEA (Imprecise Data Envelopment Analysis) method. The risks due to pilots, missions and helicopters are evaluated based on imprecise data, and the assignment of pilots to missions and helicopters is performed using goal programming with risk scores. The process is designed to obtain smaller variances in the risk evaluation based on the interval bounded data so that it can be combined with the AHP (Analytic Hierarchy Process). These numerical experiments provide reasonable solutions to the problem of risk management of pilot mission assignment.

Significance: The suggested framework provides an efficient risk management as applied in the resource allocation in consideration of the risk expectation and variance as well. It is expected that this robust procedure for the resource allocation using the mathematical optimization may provide more confident to the customer during its application in the area of risk management. The approach addressed in the paper is new and sophisticated in the sense that the risk evaluation and risk based allocation adopted the IDEA method and mathematical programming using history data.

Keywords: Risk management; IDEA; risk evaluation; assignment problem; variance value

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1. INTRODUCTION

The rapid changes that are occurring in the current security environment and the recent efforts to improve defense reforms have made it clear that an effective risk management plan is required, although the plan must be within the limited resources of the defense military. Maintaining high levels of both productivity and safety is an essential objective of the defense military field. The use of a risk management procedure is not a new concept for military missions as they are consistently vulnerable to a variety of hazards, and risk management is an intuitive part of a successful survival strategy. Such a strategy is also crucial to the pilot who wishes to control flights with maximal operational capability and minimal breakdowns, acting to prevent accidents caused by engine obsolescence or mission complexities. Safety can be defined as the freedom from unacceptable risk, and accident avoidance and high productivity are tightly linked with one another. Flight operations are generally performed under tight resource constraints, and operators are often faced with tradeoffs between productivity and safety. Since military operations involve both long and short term risk situations, it is necessary to treat these problems with an objective to minimize risk.

The General Assignment Problem (GAP) involves optimally matching the elements of two or more sets in order to determine a one-to-many matching between n tasks and m agents under the capacity constraints, with the overall objective of minimizing the total cost of the assignment. However both the cost and the risk have to be considered when addressing pilot mission assignment, since flight accidents may result in death. Military helicopter units, known as a company, are the core operational units that perform various missions such as surveillance, search, and transport operations. Since knowledge of these flight operations are critical to aviation command and pilots, the planning process is important so that to achieve minimized risk under an appropriate level of productivity. The risk management process is an activity that identifies existing risks, evaluates their impacts and takes appropriate measures to reduce or avoid the risks (Michael et al., 2001). The most critical issue that every decision maker needs to face is the risk in association with the decisions to be finalized and the actions to be taken (Lee et al., 2010). One of the difficulties in the risk management process is the proper evaluation of the risk when limited data is available. The DEA (Data Envelopment Analysis) is known as a method to appropriately evaluate the risk (Nurhan and Lerzan, 2005, Wang et al., 2008). The IDEA (Imprecise Data Envelopment Analysis), which is one type of DEA, may be able to deal with imprecise data. In this paper, interval bounded risk scores are designed using the IDEA, which transforms the imprecise data so that it can be used to represent risk. The risk-based assignment model takes into account multiple objectives during goal programming by: minimizing the risk, balancing in the pilot's mission load and maximizing the reliability of the bounded data. The risk-based assignment model also allows for the identification

of the risk range of the assignment results. Risk range results are valuable as they determine the actual possibility of an accident occurring. Another contribution of this paper is that a mathematical procedure was developed for use in goal programming in combination with AHP (Analytic Hierarchy Process) and a smaller variance value. A computational test was performed to evaluate the suggested frameworks using practical data obtained in one of the military units. The paper is organized as follows. In section 2, the literature review of risk management-based pilot mission assignment is discussed. In section 3, the new risk management process is suggested. In section 4, the results of the computational experiments are analyzed and discussed. Industry application is discussed in section 5, and the last section contains the concluding remarks.

2. LITERATURE REVIEW

Assignment problems and risk management cases are studied so that they can be applied in the military field. To address a military assignment problem, Lee and Kim (2004) suggested a scheduling method to address the military training-based assignment problem whose iteratively solved assignment method can balance instructor loads. Korkmaz et al. (2008) proposed the use of the AHP and the decision support system to address the problem of military personnel assignment. Using both quantitative and qualitative methods together may result in more efficient solutions. Dupont et al. (2009) considered a frequency assignment problem that was occurring in a military dynamic dimension, in which the assignment results were calculated quickly by using the heuristic method. To address a military risk management, Unione et al. (1996) applied a risk management strategy to military ordinance safety that accounted for the manufacturer, storage conditions and loading method. Brooks (2005) suggested the use of the military Operational Risk Management (ORM) process as a decision-making tool. The military ORM process includes hazard detection, risk implementation and risk control monitoring in order to effectively support the risk based decision-making process. Likewise, various military risk management and assignment problems have been researched, although they have been applied independent of one another. It is necessary to integrate the risk management process with pilot mission assignments, because pilots are under constant risk of life-threatening occurrences.

Risk evaluation has to be preferentially carried out in the risk management process. In most cases, the situational risk can be approximated by the standard deviation, a measure on how spread a distribution is. The VaR (Value at Risk) method functions best under uncertainty, which is very common in financial risk evaluations. In other areas, there are many different types of evaluation and ranking methods (Dragan et al., 2010). DEA is known a non-parametric method for evaluating the relative risk score of a decision making unit (DMU) on the basis of multiple data inputs and outputs. Joseph et al. (2004) applied the DEA method to credit risk evaluation since it can take into account all of the dimensions of corporate activity, by simultaneously handling the multiple inputs and outputs without making judgments on their relative importance. Nurhan and Lerzan (2005) used the DEA method to evaluate the risk of an audited firm. The risk evaluation results could be imposed to determine the ranking of the audited firms. Wang et al. (2008) presented an integrated AHP-DEA method for bridge risk assessment, in which the AHP is used to determine the weights of the criteria, and the DEA is used to determine the risk values of each type of bridge structure. To our knowledge, risk evaluation based only on imprecise data has not yet been addressed. An imprecise data set is one in which some of the data to address pilot mission assignment is bounded with a lower and upper limit. The IDEA method is used to evaluate risks involving bounded data.

3. RISK MANAGEMENT PROCESS

In this section, the risk management process is developed so that it can be applied for use by Korean army aviation unit. The risk management process involves risk evaluation using imprecise data and the pilot assignment based on the evaluated risk.

3.1 Risk evaluation modeling

Risk evaluation method: IDEA

Risk evaluation is used to make decisions based on the significance of the risk to the organization. Values indicating risks and their implications are arguably subjective but, nonetheless, important for risk assessment. The original DEA method is an approach to evaluate the relative efficiency of the DMUs using multiple inputs in order to produce multiple outputs. The DEA method assumes that all of the data can be represented by specific numerical values (Cooper et al., 1999). When addressing pilot mission assignment, however, the risk of pilots, missions and helicopters, *i.e.*, each DMU, can be represented better as a range with upper and lower limits than in a specified single value. For example, the risk of the pilot of the Korean army has been evaluated based on two different output criteria; the deterministic value of aviation hours and the range of fighting power scores. The risks of missions and helicopters, which are similar to the risk of pilots, are also measured in a range type data. The IDEA method may broaden the scope of applications to determine efficiency based on imprecise information, which implies various possible forms for the bounded data (Park, 2010). In this paper, the risk evaluation method is comprised of the IDEA models in two ways; IDEA model (1) and (2). IDEA model (1) provides an

upper bound risk score and deals with the exact data, where the output levels are adjusted in favor of the evaluated DMU_{j_o} and aggressively against the other DMUs, while IDEA model (2) provides a lower bounded risk score for the DMU_{j_o} . IDEA model (1), the upper bound risk model, is formulated as follows:

Indices

- j : index for DMU ($j = 1, \dots, J$)
- r : index for evaluation criterion ($r = 1, \dots, R$)

Decision variables

- u_{rj} : weight of DMU_j in evaluation criterion r

Data

- y_{rj}^U : upper value of DMU_j in evaluation criterion r
- y_{rj}^L : lower value of DMU_j in evaluation criterion r
- ε : non-archimedean infinitesimal

IDEA model (1)

$$\text{Max} \quad H_{j_o}^U = \sum_r u_{rj_o} y_{rj_o}^U \quad \dots \quad (1)$$

$$\text{s.t.} \quad \sum_r u_{rj_o} y_{rj_o}^U \leq 1 \quad \dots \quad (2)$$

$$\sum_r u_{rj} y_{rj}^L \leq 1 \quad j = 1, \dots, n; \quad j \neq j_o \quad \dots \quad (3)$$

$$u_{rj} \geq \varepsilon \quad \forall r, j \quad \dots \quad (4)$$

For the evaluated DMU_{j_o} , the outputs are adjusted with respect to the upper bounds of the intervals. For the other DMUs, the outputs are contrarily adjusted with respect to their lower bounded values. The term $H_{j_o}^U$ denotes the risk score attained by DMU_{j_o} in IDEA model (1), for which, the upper bound risk score $H_{j_o}^U$ of each DMU_{j_o} can be generated with respect to the evaluation criterion (Despotis and Smirlis, 2002). The objective function (1) maximizes the total risk score of the DMU_{j_o} , and the constraint (2) imply that the relative risk score is less than or equal to one, where a risk score of one means that it is the most relatively risky DMU_{j_o} of the peer DMUs. For the other DMUs, the constraint (3) imply that all relative risk scores are less than or equal to one. Constraint (4) restricts the decision variable u_{rj} to a positive value. IDEA model (2) provides a lower bounded risk score for DMU_{j_o} .

IDEA model (2)

$$\text{Max} \quad H_{j_o}^L = \sum_r u_{rj_o} y_{rj_o}^L \quad \dots \quad (5)$$

$$\text{s.t.} \quad \sum_r u_{rj_o} y_{rj_o}^L \leq 1 \quad \dots \quad (6)$$

$$\sum_r u_{rj} y_{rj}^U \leq 1 \quad j = 1, \dots, n; \quad j \neq j_o \quad \dots \quad (7)$$

$$u_{rj} \geq \varepsilon \quad \forall r, j \quad \dots \quad (8)$$

Contrary to IDEA model (1), the levels of outputs are now adjusted unfavorably for the evaluated DMU_{j_0} and favorably for the other DMUs and, are adjusted with respect to their lower bounded values. For the other DMUs, the outputs are favorably adjusted with respect to their upper bounded values. In this manner, the evaluated DMU_{j_0} is in the worst possible position relative to the other units. The risk score ($H_{j_0}^L$), which is attained using the evaluated DMU_{j_0} in IDEA model (2), serves as the lower bound of the possible risk scores (Despotis and Smirlis, 2002). IDEA models (1) and (2) assign each DMUs a bounded interval risk scores $[H_{j_0}^L, H_{j_0}^U]$. Additionally, the mode risk scores ($H_{j_0}^M$) can be calculated using the traditional DEA method with the average values of the lower and upper values of the raw data. The traditional DEA method cannot handle bounded data. From a purely practical standpoint, the average method is simple and is used most frequently in processes that have of bounded data. In this paper, the mode risk score $[H_{j_0}^M]$ is calculated using the average value of the lower and upper bounds of the raw data.

Expected value

Risk measures evaluated from restricted data must be appropriately constructed in the risk-based assignment model. In this paper, the expected value is used to determine the interval bounded score because it can be interpreted as the expected value of the random variable as the long run average value (David et al., 2009). The expected value can be calculated using three values (min, mode and max) obtained from the IDEA models (1) and (2). Three point estimations can be produced using values: best-case estimate, most likely estimate and worst-case estimate. The triangular distribution is commonly used in these types of three-point estimations (Joo and Casella, 2001). The expected value of the triangular distribution differs from the other methods in its simple shape. Using the min, mode and max values, it is possible to calculate the expected value $E(x)$ and the variance value $V(x)$ in the triangular distribution using equations (9) and (10).

$$E(x) = (min + mode + max) / 3 \quad \dots \quad (9)$$

$$V(x) = (min^2 + mode^2 + max^2 - min \times mode - mode \times max - max \times min) / 18 \quad \dots \quad (10)$$

The expected value method based on the triangular distribution has some advantages for calculating the risk score. This method includes the natural characteristics of the bounded value; the minimum and maximum risk values, with the most likely estimation values. The average (mode value) method is frequently used in dealing with bounded data (Dodge, 2003), as it has practical uses for handling the bounded data.

3.2 Risk-based assignment modeling

Risk policies can be categorized as risk avoidance, risk acceptance, risk compensation, risk transfer and risk reduction (Markus, 2004). Among these risk policies, risk reduction seeks to reduce the probability of an undesired event. One of the pilot mission assignment problems is that; entire missions must be completed under unavoidable undesirable circumstances. The best policy of helicopter units is to minimize the total risk score denoted by objective (1). However a military helicopter unit may have two or more objectives. Smaller variances are considered in order to obtain more reliable modeling results. If an assignment results in small variance, it is highly precise, and thus, regarded as a reliable assignment (Orhan et al., 2010). The risk-based assignment model selects the smaller variance value of the interval bounded risk scores denoted by objective (2). Another objective is to maintain impartiality for all of the pilots: objective (3) is designed to minimize the differences between the pilot mission loads. The risk-based assignment model is evaluated using these three objectives, which reflect the realistic requirements of helicopter units and maximize the reliability of using bounded data.

Goal programming can handle multiple conflicting objectives. In constructing the model, it is possible to identify objective (1) as having highest priority, although it is difficult to quantify its weight. The preemptive goal programming method is used to consider the priority of the objectives and to achieve the target value established by the decision maker. The preemptive goal programming method also considers the goals simultaneously and aims to satisfy all of the goals when possible by minimizing the sum of the deficiency variables. The assignment results were first obtained by focusing entirely on the risk target, even though this value violates both of the other objectives. Upon satisfactorily meeting the risk target, the second objective was considered to improve the variance value while continuing to achieve the risk target. The third objective was then considered after the second one. Additionally, the AHP method was used to determine appropriate weight of risk factors (Guneri et al., 2004). Assignment results were changed based on the weights of the pilot, mission and helicopter. For reliable results, appropriate weight of pilot, mission and helicopter were decided by AHP method. The risk-based assignment model is formulated as follows:

Indices

i : index for pilot ($i = 1, \dots, I$)

j : index for mission ($j = 1, \dots, J$)

k : index for helicopter ($k = 1, \dots, K$)

Decision variables

$X_{ijk} \begin{cases} 1, & \text{if pilot } i \text{ is assigned to mission } j \text{ in helicopter } k \\ 0, & \text{otherwise} \end{cases}$

$Y_{ijk} \begin{cases} 1, & \text{if a pilot } i \text{ is assigned to helicopter } k \\ 0, & \text{otherwise} \end{cases}$

DR_{ijk} : excess amount of targeted risk of pilot i assigned to mission j in helicopter k

DV_{ijk} : excess amount of targeted variance of pilot i assigned to mission j in helicopter k

DX_i^+ : excess amount of mission assignments for pilot i

DX_i^- : shortfall amount to pilot's mission assignment target number in pilot i

R_{ijk} : risk value of pilot i assigned to mission j in helicopter k

V_{ijk} : variance value of pilot i assigned to mission j in helicopter k

Data

w_p : weight of pilot (AHP)

w_m : weight of mission (AHP)

w_h : weight of helicopter (AHP)

P_i : expected value of pilot i

M_j : expected value of mission j

H_k : expected value of helicopter k

VP_i : variance value of pilot i

VM_j : variance value of mission j

VH_k : variance value of helicopter k

L_p : lower bound of pilot's mission load

U_p : upper bound of pilot's mission load

L_h : lower bound of helicopter's mission load

U_h : upper bound of pilot's mission load

T_r : risk score target (decision maker determined)

T_v : variance score target (decision maker determined)

T_x : mission load target (decision maker determined)

Risk-based assignment model

$$\text{Min} \quad \sum_i \sum_j \sum_k DR_{ijk} \quad \dots \quad (11)$$

$$\text{Min} \quad \sum_i \sum_j \sum_k DV_{ijk} \quad \dots \quad (12)$$

$$\text{Min} \quad \sum_i (DX_i^+ + DX_i^-) \quad \dots \quad (13)$$

$$\text{s.t.} \quad R_{ijk} = w_p P_i X_{ijk} + w_h H_k X_{ijk} + w_m M_j X_{ijk} \quad \forall i, j, k \quad \dots \quad (14)$$

$$R_{ijk} - DR_{ijk} \leq T_r \quad \forall i, j, k \quad \dots \quad (15)$$

$$V_{ijk} = w_p (X_{ijk})^2 VP_i + w_h (X_{ijk})^2 VH_k + w_m (X_{ijk})^2 VM_j \quad \forall i, j, k \quad \dots \quad (16)$$

$$V_{ijk} - DV_{ijk} \leq T_v \quad \forall i, j, k \quad \dots \quad (17)$$

$$\sum_j \sum_k X_{ijk} - DX_i^+ + DX_i^- = T_x \quad \forall i \quad \dots \quad (18)$$

$$L_p \leq \sum_j \sum_k X_{ijk} \leq U_p \quad \forall i \quad \dots \quad (19)$$

$$L_h \leq \sum_i \sum_j X_{ijk} \leq U_h \quad \forall k \quad \dots \quad (20)$$

$$\sum_i \sum_k X_{ijk} = 2 \quad \forall j \quad \dots \quad (21)$$

$$Y_{jk} \geq X_{ijk} \quad \forall i, j, k \quad \dots \quad (22)$$

$$2Y_{jk} \leq \sum_i X_{ijk} \leq 2 \quad \forall j, k \quad \dots \quad (23)$$

$$X_{ijk} \in \{0,1\} \quad \forall i, j, k \quad \dots \quad (24)$$

$$Y_{jk} \in \{0,1\} \quad \forall j, k \quad \dots \quad (25)$$

The objective functions (11) and (12) minimize the total deficiency value of the risk and the variance target, respectively, while objective function (13) minimizes the total deficiency value of the pilot’s mission load target amount. Constraint (14) implies that the risk score is calculated using the weighted sum of the pilot, mission and helicopter, reflecting its importance. Constraint (15) indicates that the risk cannot be greater than the target value. Constraint (16) implies that the variance score is calculated by the weighted sum of the pilot, mission and helicopter. Constraint (17) indicates that the variance score cannot be greater than the target value. Constraint (18) aims equally to allocate the mission workloads among the pilots. Constraint (19) imposes the lower and upper bounds of the mission load on each pilot. Constraint (20) allocates the lower and upper bounds of the mission load on each helicopter. Constraint (21) imposes that every mission requires only two pilots. Constraints (22) and (23) imply that one mission requires that all pilots operate identical helicopters. Constraints (24) and (25) are the binary variables.

4. EXPERIMENT RESULTS

For the experimental part of this study, the risks associated with accidents that have actually occurred in practice of a Korean army helicopter unit were investigated. Experimental data were taken from the 2009 Korean army investigation reports of helicopter accidents in order to evaluate the performance of the suggested process. The Korean army Headquarters analyzed and categorized the causes of helicopter accidents as pilot, helicopter or mission-related. Reports of 93 helicopter accidents that occurred between 1973 and 2008 were investigated.

4.1 Risk evaluation results

The Korean army helicopter company is usually composed of ten pilots, twelve missions and eight helicopters. The evaluation system of the Korean army has a decisive effect on the detailed output variables. IDEA models (1) and (2) both provide interval bounded risk scores $[H_{jo}^L, H_{jo}^U]$ for each of the DMUs, in which the possible risk scores are presented, from the worst to the best cases. The mode risk score $[H_{jo}^M]$ was calculated using the traditional DEA method, using the average value of the lower and upper bounds of the raw data. The interval bounded risk scores and the mode risk scores are shown in Table 1. A risk score of ‘1.0000’ indicates the DMU with the highest risk relative to its peer DMUs. The reality of the accident risk can be appreciated, for example, by comparing the risk scores of helicopters ‘1’ and ‘3’. The risk score of helicopter ‘1’ (0.3744-0.6245) identified it as the most safe helicopter relative to the other available helicopters due to its short flight time and lower maintenance costs. Meanwhile, the risk score of helicopter ‘3’ (1.0000-1.0000) is identified it as the most risky helicopter relative to all of the other helicopters. Additionally, the mode risk scores (H_{jo}^M) were not located in the middle of the interval bounded risk scores ranges $[H_{jo}^L, H_{jo}^U]$. The traditional DEA method may be practical for dealing with bounded data, but the IDEA method may have an advantage in the sense that it may reflect the characteristics of the bounded data. More closely, without adopting another single measure representing the multiple bounded data, the IDEA method may give a right decision on the allocation, in which the information residing in the bounded data can be lost otherwise. The end users can be more confident in decision with IDEA method.

The expected value must be appropriately considered in the assignment process, while the expected and variance values were used to address the interval bounded score. The equations (9) and (10) provide the expected and variance values for

each DMU, respectively. The risk score of helicopter ‘1’ (0.3744-0.5228-0.6245) was used to represent the expected value (0.5072). Through the expected values in Table 1, the risk scores can be simply identified. Hence, end users can easily use the information for risk allocation without misunderstanding of the bounded data. Additionally, comparing the variance values of pilots ‘3’ and ‘8’, it was possible to determine that the variance values were comparable to the bounded risk scores. The variance value of pilot ‘3’ (0.00556) was the highest (0.6357-1.0000), whereas that of pilot ‘8’ (0.00006) was the smallest (0.9650-1.0000). Comparing the variance values allowed for the determination of the most and least range of interval bounded risk score.

Table 1. Risk evaluation results for pilots, missions and helicopters

Pilot number	Aviation hours	Fighting power score			Pilot risk score (bounded)			Expected value	Variance value
		lower	average	upper	$\min(H_{j_0}^L)$	$\text{mode}(H_{j_0}^M)$	$\max(H_{j_0}^U)$		
1	782	91	93	95	1.0000	1.0000	1.0000	1.0000	0.00000
2	1979	91	92	93	0.5384	0.6667	0.8181	0.6744	0.00326
3	1442	89	90.5	92	0.6357	0.7916	1.0000	0.8091	0.00556
4	1972	89	90	91	0.6923	0.8333	1.0000	0.8418	0.00395
5	958	92	93	94	0.8975	0.9087	0.9849	0.9304	0.00037
6	1244	91	92.5	94	0.7310	0.7801	0.8640	0.7917	0.00075
7	1715	88	89	90	0.7692	0.9166	1.0000	0.8952	0.00227
8	842	87	91	95	0.9650	1.0000	1.0000	0.9883	0.00006
9	1075	87	88	89	0.8580	1.0000	1.0000	0.9526	0.00111
10	1514	93	94	95	0.5739	0.6160	0.6767	0.6222	0.00044
Mission number	Difficult levels	Mission hours			Mission risk score (bounded)			Expected value	Variance value
		lower	average	upper	$\min(H_{j_0}^L)$	$\text{mode}(H_{j_0}^M)$	$\max(H_{j_0}^U)$		
1	0.4	2	3	4	0.4000	0.4000	0.4102	0.4034	0.00005
2	1.0	9	13	17	1.0000	1.0000	1.0000	1.0000	0.00000
3	0.6	10	12	14	0.6000	0.8571	1.0000	0.8190	0.00684
4	0.7	5	6.5	8	0.7000	0.7000	0.7435	0.7145	0.00010
5	0.4	9	11	13	0.5294	0.7857	1.0000	0.7717	0.00925
6	0.3	5	5.5	6	0.3000	0.3928	0.5000	0.3976	0.00166
7	0.3	6	7.5	9	0.3529	0.5357	0.7500	0.5462	0.00658
8	0.9	12	14	16	0.9000	1.0000	1.0000	0.9666	0.00055
9	0.2	6	7.5	9	0.3529	0.5357	0.7500	0.5462	0.00658
10	0.4	5	6.5	8	0.4000	0.4642	0.6667	0.5103	0.00322
11	0.5	10	11	12	0.5882	0.7857	1.0000	0.7913	0.00706
12	0.3	8	11	14	0.4705	0.7857	1.0000	0.7521	0.01181
Helicopter number	Aviation hours	Maintenance cost			Helicopter risk score (bounded)			Expected value	Variance value
		lower	average	upper	$\min(H_{j_0}^L)$	$\text{mode}(H_{j_0}^M)$	$\max(H_{j_0}^U)$		
1	278	702	743.5	785	0.3744	0.5228	0.6245	0.5072	0.00263
2	589	678	976	1274	0.3814	0.6863	1.0000	0.6892	0.01594
3	1568	1257	1422	1587	1.0000	1.0000	1.0000	1.0000	0.00000
4	1532	924	1399.5	1875	0.9770	0.9841	1.0000	0.9870	0.00002
5	512	806	866.5	927	0.4298	0.6093	0.7374	0.5922	0.00397
6	1245	998	1049.5	1101	0.7940	0.7940	0.8758	0.8213	0.00037
7	854	987	1120.5	1254	0.5533	0.7879	0.9976	0.7796	0.00823
8	785	992	989.5	987	0.5290	0.6958	0.7852	0.6701	0.00281

4.2 Risk-based assignment results

Setting appropriate weights: AHP

The AHP method provides comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. Once the

hierarchy has been constructed, the participants analyze it through a series of pair-wise comparisons that derive numerical scales of measurement for the nodes. Suppose that the pair-wise comparison matrix for the three assessment criteria (pilot, mission, and helicopter) provided by the decision maker (Korean army Headquarters) is as follows:

$$A = \begin{bmatrix} 1 & 3 & 2 \\ 1/3 & 1 & 1/2 \\ 1/2 & 2 & 1 \end{bmatrix}$$

Whose maximum eigen-value λ_{max} is = 3.0092 and whose corresponding normalized principal right eigen-vector is, (pilot, mission, helicopter) = (0.5389, 0.1638, 0.2973). The consistency index (CI) for the above paired comparison matrix is $CI = (\lambda_{max} - n)/(n - 1) = 0.0046$ and the corresponding consistency ratio (CR) is $CR = CI/0.58 = 0.0079$. Due to the fact that the $CR < 0.1$, the above pair-wise comparison matrix is considered to have an acceptable consistency, and its normalized principal right eigen-vector values can be used as the criteria weights. To obtain a more reliable modeling result, the AHP method is considered when performing the risk-based assignment model. The AHP method can be useful in implementation, especially when it is difficult to specify the proper weights of the component such as the pilot, mission and the helicopters in evaluation of the risk. For more reliable results, opinions of agencies and the official records can be considered in a systematic way.

Table 2. Assignment results of the risk-based assignment model

Solutions	Pilot	Mission	Helicopter	R_{ijk}	Risk range	DR_{ijk}	DV_{ijk}	DX_i
Set 1	1	9	1	0.7791	(0.7080-0.8474)	0.0091	-	0.4
Set 2	1	10	1	0.7732	(0.7157-0.8337)	0.0032	-	
Set 3	2	2	6	0.7714	(0.7633-0.8651)	0.0014	-	0.6
Set 4	2	5	4	0.7833	(0.7406-0.9020)	0.0133	0.0012	
Set 5	2	12	3	0.7839	(0.7378-0.9020)	0.0139	0.0016	
Set 6	3	3	2	0.7751	(0.6477-1.0000)	0.0051	0.0068	0.6
Set 7	3	8	5	0.7704	(0.7112-0.9219)	0.0004	0.0022	
Set 8	3	11	2	0.7705	(0.6477-1.0000)	0.0005	0.0068	
Set 9	4	1	7	0.7515	(0.6837-0.9026)	-	0.0025	0.4
Set 10	4	4	8	0.7699	(0.7256-0.8941)	-	0.0009	
Set 11	5	6	8	0.7657	(0.7078-0.8461)	-	-	0.4
Set 12	5	7	5	0.7669	(0.6871-0.8728)	-	0.0004	
Set 13	6	3	2	0.7657	(0.6383-0.9267)	-	0.0042	0.6
Set 14	6	8	5	0.7610	(0.7018-0.8487)	-	-	
Set 15	6	11	2	0.7612	(0.6364-0.9267)	-	0.0043	
Set 16	7	1	7	0.7803	(0.7124-0.9026)	0.0103	0.0016	0.4
Set 17	7	4	8	0.7987	(0.7544-0.8941)	0.0287	0.0001	
Set 18	8	9	1	0.7729	(0.7017-0.8474)	0.0029	-	0.4
Set 19	8	10	1	0.7670	(0.7094-0.8337)	-	-	
Set 20	9	6	8	0.7777	(0.7198-0.8542)	0.0077	-	0.4
Set 21	9	7	5	0.7789	(0.6990-0.8810)	0.0089	0.0008	
Set 22	10	2	6	0.7432	(0.7351-0.7888)	-	-	0.6
Set 23	10	5	4	0.7551	(0.7125-0.8257)	-	-	
Set 24	10	12	3	0.7558	(0.7097-0.8257)	-	0.0001	
Sum				18.4794	(16.9055-21.1441)	0.1059	0.0344	4.8

Pilots mission assignment results: goal programming

Computational experiments were conducted in order to test the practicality of the risk-based assignment model. The solutions were obtained using ILOG OPL studio 5.5. The decision maker determined the target values in the experiment to be risk target $T_r = 0.77$, variance target $T_v = 0.002$ and pilot’s mission load target $T_x = 2.4$. The results of the computational experiment are shown in Table 2. The solution of set 1 indicates, for example, pilot ‘1’, mission ‘9’ and helicopter ‘1’, with the risk score of 0.7791. The solutions of a total of 24 sets were obtained using risk-based assignment model with an assumption that one mission requires a main pilot and an assistant pilot (12 missions \times 2 pilots = 24 sets).

The decision maker can also determine the risk range of each possible solution, which can then be calculated with regard to either the worst or the best case scenario for each of the solution set. For example, the lower value of set 1, the best case,

was calculated using the minimum risk scores of pilot ‘1’, mission ‘9’ and helicopter ‘1’ in Table 1 ($0.7080 = 0.5389 \times 1.0000 + 0.1638 \times 0.875 + 0.2973 \times 0.3474$), and the upper value of set 1 (0.8474), the worst case, was calculated using the maximum risk scores. Comparing the risk score and the risk range results, the relative location of the risk score within the risk range is identified. This information is valuable to determine the actual risk range of certain occurrences. Using the risk range results, the decision maker can consider additional situations of various risk levels.

All of the risk scores of 24 sets in Table 2 ranged from 0.7432 to 0.7987. They were appropriately determined that the first objective of the risk-based assignment model was to achieve the decision maker’s target risk score of 0.77, while minimizing the total risk deficiency values. It is noticeable that the most declination result is 0.7987 away from 0.77. Most of the experimental results were located around the risk target (0.77) and had reasonable computational times (6 sec.). The second most important objective was to minimize the total variance in the deficiency values. Several cases ($10/24 = 41.67\%$) produced results that fell within the variance target range. Based on these results, it was concluded that the second objective was properly applied in the developed method to satisfy with target value and reduce the variance value. The process of determining the smallest variance value can improve reliability in cases involving interval-bounded data. The risk-based assignment model was used to calculate a solution that adhered to the third objective without deviating from either of the other two objectives. Using the results of Table 2, goal programming was identified as a useful method for achieving the decision maker’s target for obtaining reasonable assignment results.

The qualitative decision on the allocation can be applied in a different way. Although the decisions are made optimally for the given mathematical formulation, the measures for each allocation are much different from each other. All sets of solutions can be categorized into, three groups based on the data of DR_{ijk} and DV_{ijk} values; high, medium and low with respect to the fitness to the objective functions. High-satisfaction solutions have no DR_{ijk} and DV_{ijk} values, hence end users can regard high-satisfaction solution as a relatively safe solutions. Medium-satisfaction solutions have either DR_{ijk} and DV_{ijk} values. Low-satisfaction solutions simultaneously have DR_{ijk} and DV_{ijk} values. For example, low-satisfaction solutions can be categorized by solution sets 4, 5, 6, 7, 8, 16, 17 and 21. Additional cases can be given in a different level according to the groups. End users can pay more attentions to low-satisfaction solutions while operating the units, as its information may help to reduce the risk of accidents. Qualitative indicators can be influenced by the condition of the pilot, weather condition, recent issues and decision maker’s experiences, etc. Through the risk range results, end users can consider risk situations in a versatile manner. If end users have a pessimistic view in risk management, the worst case risk score is considered to with higher priority in operating the units.

5. INDUSTRY APPLICATION

Maintaining high levels of both productivity and safety are essential objectives for many industries, especially those that operate safety critical production systems such as nuclear power plants, offshore oil platforms, chemical plants and aviation transport system. Risk is a natural part of all industries landscape including the production system. The risk management procedure is necessary for all industries because an accident would be one of the biggest influences over the organization. For example, in chemical plants problem, accident would result in huge losses of both life and property. The risk factor of chemical accident can be considered as obsolescence of plant, difficulty of chemical mission and proficiency of workers. The current risk evaluation method can give the more reliable results in using the historical data including the imprecise data. The general allocation problems have been considered with the objective to minimize the total cost of the allocations, but some allocation problems can be considered both the cost and the risk. For example, in nuclear power plant allocation problem, from a corporate standpoint and short terms, minimizing of the allocation cost is the most important. But from long term standpoints, allocation results reflecting the risk management are the best solutions because nuclear power plant accidents may result in the form of ‘disaster’. The accident’s risk factor of nuclear power plant can be considered as technological level of workers, size of plants, difficulty of missions and resident population. The framework suggested in this paper can be applied appropriately with the imprecise data and multiple objectives.

6. CONCLUSION

In this paper, the pilot mission assignment problem was generalized for the introduction of risk management. Applying the risk management process is essential for the improvement of military aviation safety. Risks should be evaluated using a reliable method. The IDEA method, which deals with imprecise data, may be a practical tool for use in risk evaluation. The IDEA method can be used to, calculate the interval bounded risk scores, in which it is possible to represent the risk score as the unique and special characteristics of imprecise data, based on which the possible situations can be ranked. Additionally, it is possible to identify the risk range of the assignment results, valuable information in the determination of the actual risk of an accident. Another approach to risk management is to use the goal programming method, which can be used to obtain additional reasonable assignment results in order to satisfy the decision maker’s multi-objective target values, using the AHP and the variance values.

The Korean army aviation units have investigated the practices towards the prevention of accidents. Helicopter accidents, however, have occurred on average once a year because safety-related activities were delayed in order to meet production goals or deadlines. The presented framework provides one possible and effective risk management process for the prevention of helicopter accidents. This method also, infers a more practical interpretation of the risks. It is expected that the gap between the theoretical approach and the practical perspective of risk management can be diminished through the use of these new methods.

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BIOGRAPHICAL SKETCH



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