MODELLING UPGRADE DESIGN ANALYSIS OF MARITIME HELICOPTERS FOR ANTI-SUBMARINE MISSIONS – MISSION PAYLOAD DESIGN

Srinivas Jonnalagadda Arvind. K. Sinha Peter Hoffmann
The Sir Lawrence Wackett Centre for Aerospace Design Technology
School of Aerospace Mechanical and Manufacturing Engineering
Royal Melbourne Institute of Technology
GPO Box 2476V, Melbourne, Victoria, 3001, Australia
(Email: s3060523@student.rmit.edu.au, arvind.sinha@rmit.edu.au, hoffmann@rmit.edu.au)

Daniel. P. Schrage
Director CERT and CASA
School of Aerospace Engineering
Georgia Institute of Technology, Atlanta,
GA 30332-0150, USA
(Email: daniel.schrage@aerospace.gatech.edu)

Abstract

Mission systems aboard the military helicopter govern anti-submarine mission capabilities. The global budget restricted the design and development of new maritime helicopter with state-of-the-art mission systems aboard enhancing mission capabilities. A mid-life upgrade of existing helicopter with new on board mission systems is the only viable and cost-effective option. The determination of which alternative mission system payload is significantly better overall than the payload aboard is a major analytical process and involves prioritisation of identified mission systems based on contribution and relative dependency. A "Decision Support System" is required to identify and prioritise state-of-the-art mission systems providing enhanced mission capabilities. An "Intelligent Decision Support System (IDSS)" is being developed to simulate the mid-life upgrade process. The IDSS consists of "Mission Payload Design (MPD)" sub-module that follows the "Analytic Hierarchy Process (AHP)" for prioritisation and formulation of alternative mission system payloads. This paper presents a detailed discussion of the MPD.

Introduction

The anti-submarine warfare (ASW) mission effectiveness is mainly governed by the operational capabilities provided by the mission systems aboard the military helicopter (**Ref 2**). The significant advancements in helicopter mission systems, due to improved material, capable electronics and enhanced methods of fabrication outpace the service life of the helicopter. Though the littoral airborne ASW operations have widened the threat dimensions demanding the state-of-the-art helicopter borne ASW mission systems to enhance operational capabilities the global budget climate restricts purchase of new helicopter with these state-of the-art mission systems (**Ref 11**). A mid-life upgrade of existing helicopter with new on board mission systems is the only viable and cost-effective option to enhance mission effectiveness and overcome the technology upgrade demand **(Ref 12)**.

A research on "upgrade analysis for design decision" by Sinha et al **(Ref 16, 17, 18 & 19)** adopted a system approach considering operational and environmental needs to identify state-of-the-art mission systems for aircraft upgrade. The result was formulation of a generic "Mid-Life Upgrade System (MLUS)". Kusumo et al **(Ref 7, 8 & 9)** developed an automation framework for the design of an "Integrated Decision Support System" that simulated the MLUS to provide time-based analysis. Jonnalagadda et al **(Ref 4, 5 & 6)** revisited the automation framework and presented the framework for the "Intelligent Decision Support System (IDSS)" representing a collaborative design analysis environment to consider the following multi-dimensional aspects: a) complete spectrum of operational needs and operational environment for the; b) state-of-the-art mission systems; c) cost of ownership; and d) effective implementation of the mid-life upgrade program. The IDSS that caters the automation of mid-life upgrade process will ensue speed and accuracy with different users being able to access the system from remote locations.

The design of payload with mission systems identified that are specific to ASW is complex being a major analytical and iterative process. The importance of the mission systems in the payload and the attributes that offer these mission systems could be approximated by the AHP using pair wise comparisons (**Ref 15**).

This paper, presents the detailed description of the Mission Payload Design (MPD) sub-module which incorporates the AHP by (**Ref 14 & 15**). The "Tactical Offensive ASW" mission as applied to the Seahawk (S-70-B-2) helicopter is considered to demonstrate its functionality.

Intelligent Decision Support System Framework

The generic system methodology for mid-life upgrade of aircraft, developed by Sinha et al (**Ref 16, 17, 18 & 19**) was formulated with the conventional input-process-output configuration (**Ref 4**), as a platform to structure a MLUS. The mission systems for capability enhancement were identified with the development of a "System Hierarchy" (**Fig 3**). The missions were classified as offensive, defensive and logistic.

Kusumo et al (**Ref 7, 8 & 9**), further explored and the possibility to prioritise and rank the mission systems and the attributes that offer these mission systems for various mission. The AHP concept of pair wise comparison provided the basis to rank the importance of components in specific mission and is presented in (**Tab1 and Tab 2**).

Table 1: Vector of Priorities (Ref 9)

A1	A3	A4	A5	A11	A12	Vector of Priorities
A3	0.39	0.45	0.27	0.34	0.56	2.04
A4	0.13	0.15	0.16	0.23	0.10	0.77
A5	0.06	0.05	0.05	0.04	0.06	0.28
A11	0.13	0.07	0.16	0.11	0.10	0.58
A12	0.19	0.45	0.27	0.34	0.29	1.55

Table 2: Overall Vector of Priorities for components (Ref 9)

Components Prioritisation						NVP	RANK
C1	0.41	15.02	0.52			**0.07**	**6**
C2	15.02	0.52				**0.07**	**7**
C3	5.25	4.21	1.6	1.02		**0.06**	**8**
C4	2.90	15.02	0.25	9.42	14.69	**0.19**	**2**
C5	0.73	1.44	2.94			**0.02**	**9**
C6	1.41	28.66	0.8	1.59		**0.16**	**3**
C7	11.37	2.41	2.89			**0.08**	**5**
C9	5.86	0.98	2.41	9.42	4.78	**0.11**	**4**
C10	1.49	28.66	15.02	9.42		**0.25**	**1**
total						**1.00**	

As most other existing design environment the automation framework by Kusumo et al (**Ref 7, 8 & 9)** is built around the assumption that a single user will build and perform the engineering trade study. The automation framework developed by Jonnalagadda et al **(Ref 2, 3 & 4)** conceptualised as a multi-agent system identified the following functions for the IDSS designed for upgrade design analysis of anti-submarine maritime helicopters:

- Provide user input facility to different sources of data for the upgrade design analysis from remote locations;
- Integrate various ASW missions and provide a common tactical picture for specific helicopter model;
- Convert the operational and environmental data obtained from various sources or systems to operational and environmental needs;
- Derive the ASW mission requirements from operational and environment need;
- Identify state-of-the-art mission systems and their attributes to meet the derived ASW mission requirements;
- Evaluate the relative degree of contribution of the mission systems to the mission success;
- Design the mission payload based on aforementioned evaluation;
- Provide a holistic analysis of the ASW maritime helicopter upgrade options considering mission capability; flight performance; reliability; maintainability and cost as parameters;
- Integrate the results of the holistic analysis to verify and validate the system effectiveness of the upgrade option;
- Present the optimal design option for upgrade decision;
- Test the robustness of the upgrade decision; and
- Provide a baseline for future upgrade decisions.

Based on the functions identified for the IDSS the framework is divided into five modules. The complete automation framework is presented in (**Fig 1**):

- **Man-machine interface**: To facilitate user-system interaction for input and view the output of the upgrade design analysis;
- **In-service helicopter**: Contains the design details of the helicopter subjected to the upgrade design analysis including the on-board mission systems;
- **Anti-submarine mission requirements**: Contains the anti-submarine mission requirements based on the operational and environmental needs;
- **Mission systems technology**: Contains functional details of mission systems that provide enhanced anti-submarine mission capability; and

- **Knowledgebase**: Contains the computing methodology to integrate mission systems into the in-service helicopter, analyse and present an optimum upgrade design option for anti-submarine warfare. The sub modules for the "Knowledgebase" are listed below:
    a. **Mission systems identifier**: Identify the mission systems stored in the database that meet the defined ASW mission requirements also stored in the database;
    b. **Mission payload design**: Prioritise mission systems based on their relative dependency and degree of operational effectiveness;
    c. **Design parametric analysis**: Evaluates the degree to which ideal mission systems selected for upgrade meet the design parameters (mission capability, flight performance, maintainability, reliability, and cost);
    d. **Verification and Validation:** Evaluate the 'system effectiveness' through the integration of the design parameter analysis of the upgrade and select an optimal upgrade option;
    e. **Database:** Store and manage operational, mission requirements, mission systems and in-service helicopter data;
    f. **Knowledge Base**: Contains the collection of the rules or methodologies that are necessary for the upgrade design analysis;
    g. **Design robustness**: Test the robustness of the design decision against temporal uncertainties;
    h. **Coordinator**: Coordinate with various modules in the "Knowledgebase" for external interaction and perform upgrade design analysis; and missions,
    i. **Design baseline**: Maintain a baseline of the optimised configuration for future upgrades.

Mission Payload Design

The "Mission Payload Design (MPD)" sub module priorities identified mission systems and provides ranking. Based on the ranking of the mission systems of the upgrade various sets of mission systems could be formulated to design alternative mission payloads for further analysis by the "Design Parametric Analysis (DPA)" sub-module. The MPD gets identified mission systems from the MSI sub-module and the stored attributes for that particular mission from the "Database" sub-module. The MPD sub-module follows the "Analytic Hierarchy Process (AHP)" by (**Ref 14 & 15**). The following functions are identified for the MPD:

- Enable to perform high-level quality analysis of mission systems identified by the MSI and provide the overall vector of priorities for the mission systems;
- Design alternative mission system payloads based on the quality; and
- Provide the alternative mission system payloads to the DPA sub-module for further analysis.

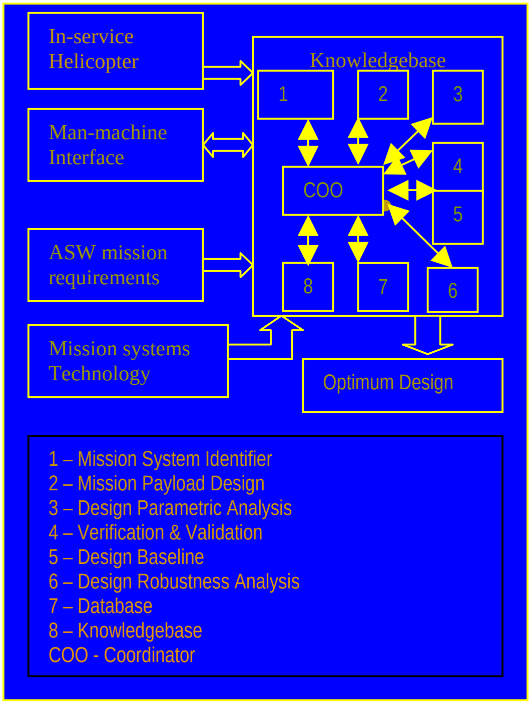

Figure 1: Intelligent Decision Support System for upgrade design analysis of anti-submarine maritime helicopter.

Based on the functions identified the MPD system has been developed. The following use case diagram (**Fig 2**) depicts the complete functionality of the MPD sub-module.

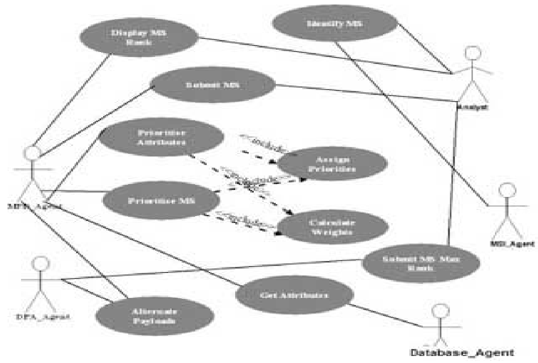

Figure 2: Use case Diagram for Mission Payload-Sub-module

High-level qualitative analysis for mission system ranking

The first step is to ignore the components (mission systems in case of upgrade design systems) and just decide the relative importance of the attributes. For this a decision must be taken on which attributes are used to evaluate the overall quality of each mission system so that the mission systems ranking can provided. Then, decompose each attribute into sub attributes. The result is development of an "Attribute Hierarchy" for a specific ASW mission. The decomposition technique is followed for each sub attributes into even smaller sub-sub attributes, and so forth. At the lowest level of the hierarchy are the components required to fulfill next higher level of the "Attribute Hierarchy". As a general rule, only top-level attributes and between two and five sub attributes are considered (**Ref 10**).

Consider the offensive tactical ASW mission. The mission profile which has been generated by the MSI sub-module and presented at the end of the paper (**Fig 9**) requires: Fire Power (1), Tactical flying (2), Communication (3), Operator Activity (4), Day/Night (5), All weather (6). These attributes form Level II of the hierarchy while the focus is set on offensive tactical ASW at Level 1. The "Attribute Hierarchy" for the example mission is presented in (**Fig 3**).

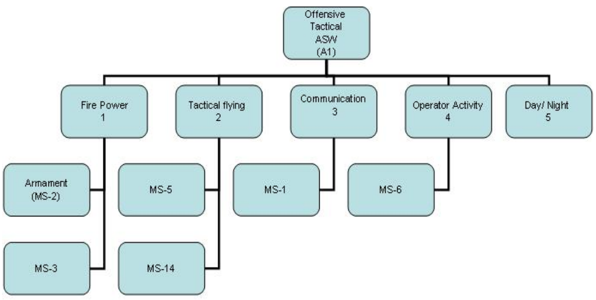

Figure 3: Partial Attribute Hierarchy Diagram for offensive tactical ASW mission

The second step is to prioritise the high-level attributes and get the overall vector of priorities for the attributes considered. The attributes are prioritized following the AHP concept of pair wise comparison (**Ref 14**) that compares two attributes at a time. In the offensive tactical ASW example the Level II attributes follow the pair wise comparison concept and is presented in (**Fig 4**). A loose interpretation has been made that in an offensive tactical ASW fire power is the most important and is given the highest value of 5. The comparison values should be interpreted as shown in (**Tab 3**).

Attributes	1	2	3	4	Total	Average
1	1	5.0	5.0	5.0	16	4
2	0.20	1	3.0	3.0	7.2	1.8
3	0.20	0.33	1	2.0	3.53	0.882
4	0.20	0.33	0.50	1	2.03	0.507

Figure 4: Attribute comparison for offensive tactical ASW mission

Table 3: Comparison Values

Relative Importance	Value
Equal importance	1
Somewhat more important/ better	3
Definitely more important/better	5
Intermediate value	2 and 4

Once the relative importance values are assigned for each attribute comparing with each other attribute weights are calculated and are presented in (**Fig 5**). The largest value has the highest ranking or priority in the upgrade design. The following rule is applied while calculating the weights (**Ref 21**):

Take each entry and divide by the sum of the row it appears in.

Calculated Weights

Attributes	1	2	3	4	Total	Average
1	0.062	0.312	0.312	0.312	0.998	0.2495
2	0.028	0.139	0.417	0.417	1.001	0.2502
3	0.057	0.093	0.283	0.567	1	0.25
4	0.099	0.163	0.246	0.493	1.001	0.2502
Total	0.246	0.707	1.258	1.789	4	
Average	0.062	0.177	0.314	0.447	1	

Figure 5: Attribute comparison for offensive tactical ASW mission – Calculated Weights

The third step in the high-level analysis is to prioritise the sub-attributes. For this each attribute in the higher level is taken as the attribute in focus. The overall vector of priorities for the calculated with this process is shown in (**Tab 4**).

Table 4: Vector of Priorities for Attributes

Offensive ASW	1	2	3	4	Vector of Priorities
1	0.062	0	0	0	0.062
2	0	0.177	0	0	0.177
3	0	0	0.314	0	0.314
4	0	0	0	0.447	0.447

The fourth step is to compare alternatives for each attribute. These are the mission systems identified from the mission profile by the MSI. While considering the prioritisation of alternatives all the mission systems have been pooled together and are given values. These values are presented in (**Fig 6**) and the calculated weights are presented in (**Fig 7**).

Mission System	MS-1	MS-14	MS-2	MS-3	MS-5	Total	Average
MS-1	1	3.0	3.0	3.0	3.0	13	2.6
MS-14	0.33	1	0.20	2.0	2.0	7.33	1.466
MS-2	0.33	5.0	1	5.0	5.0	16.33	3.266
MS-3	0.33	0.50	0.20	1	3.0	5.03	1.006
MS-5	0.33	0.50	0.20	0.33	1	2.36	0.472

Figure 6: Component comparison for offensive tactical ASW mission

Calculated Weights

Mission System	MS-1	MS-14	MS-2	MS-3	MS-5	Total	Average
MS-1	0.077	0.231	0.231	0.231	0.231	1.001	0.2
MS-14	0.045	0.136	0.027	0.273	0.273	0.754	0.151
MS-2	0.02	0.306	0.061	0.306	0.306	0.999	0.2
MS-3	0.066	0.099	0.04	0.199	0.596	1	0.2
MS-5	0.14	0.212	0.085	0.14	0.424	1.001	0.2
Total	0.348	0.984	0.444	1.149	1.83	4.755	
Average	0.07	0.197	0.089	0.23	0.366	0.951	

MS-1 – Communication
MS-14 – Network-enable
MS-2 – Armament
MS-5 – Navigation
MS-3 – Fire Control

Figure 7: Mission System comparison for offensive tactical ASW mission – Calculated Weights

The final step is to combine vector of priorities of both mission attributes and mission systems which results in overall normalised vector of priorities for each mission system. The mission system with the highest overall normalised vector gets the highest rank. This mission system is the input for the DPA for further analysis. The ranking of mission systems for the “offensive tactical ASW” is presented in (**Fig 8**).

	1	2	3	4	Overall	Normalised overall	Rank
MS-1	0.000	0.000	0.314	0.000	0.314	0.590	1
MS-14	0.000	0.147	0.000	0.000	0.147	0.276	2
MS-2	0.015	0.000	0.000	0.000	0.015	0.028	5
MS-3	0.047	0.000	0.0004	0.000	0.047	0.088	3
MS-5	0.000	0.030	0.000	0.000	0.030	0.056	4
TOTAL					0.533	1.038	

Figure 8: Mission System ranking for offensive tactical ASW mission

Simulation

The simulation software program for the “Intelligent Decision Support System” named “Intelligent Decision Support System Software” (IDSSS) is being developed. The software is completely web-based allowing different sources of input to participate in the upgrade design analysis process from remote locations. The man-machine interface has been developed using ASP.NET®. The current version of the “IDSSS” works with Internet Explorer ® version 6.0 or above. Other browsers have not been tested. The “Mission Payload Design” results are viewed on a standard web page. This database has been built in Microsoft Access®. The selection and listing of the mission systems has been accomplished through simple Structured Query Language (SQL) statements, which retrieve data from the database. One or more of the ideal mission systems can be part of the mission systems payload already on the in-service helicopter for a particular mission. Algorithms were developed and have been ambitiously implemented in Visual C#® for Mission Profile, MSI and MPD modules. The following is the sequence of events that take place while the user is interacting with the system and is based on the use case diagram shown in (**Fig 2**):

1. The Analyst login thru the login screen or registers as an analyst.
2. The Analyst views and selects the existing mission profile from the list or can create a dummy mission profile.
3. Based on the mission profile the MSI_Agent generates list of identified mission systems, on board mission system and ideal mission systems with check boxes by the side of each ideal mission system (**Fig 9**).
4. The Analyst selects the interested mission systems and presses the submit button.
5. The MSI_Agent redirects the mission systems selected to the MPD_Agent.
6. The MPD_Agent then retrieves the attributes for that specific mission profile from the Database.
7. The MPD_agent then assigns the priorities to the attributes based on relative importance and dependency and displays the over overall vector of priorities for attributes.
8. The MPD_agent assigns priorities for mission system identified for each attribute and calculates the weights after pooling all the mission systems.
9. The MPD_agent then combines the attributes and mission systems to calculate the Normalised overall vector of priorities and ranks the mission systems.
10. The highest ranked mission system is the best candidate for the DPA_Agent for inclusion in further analysis.

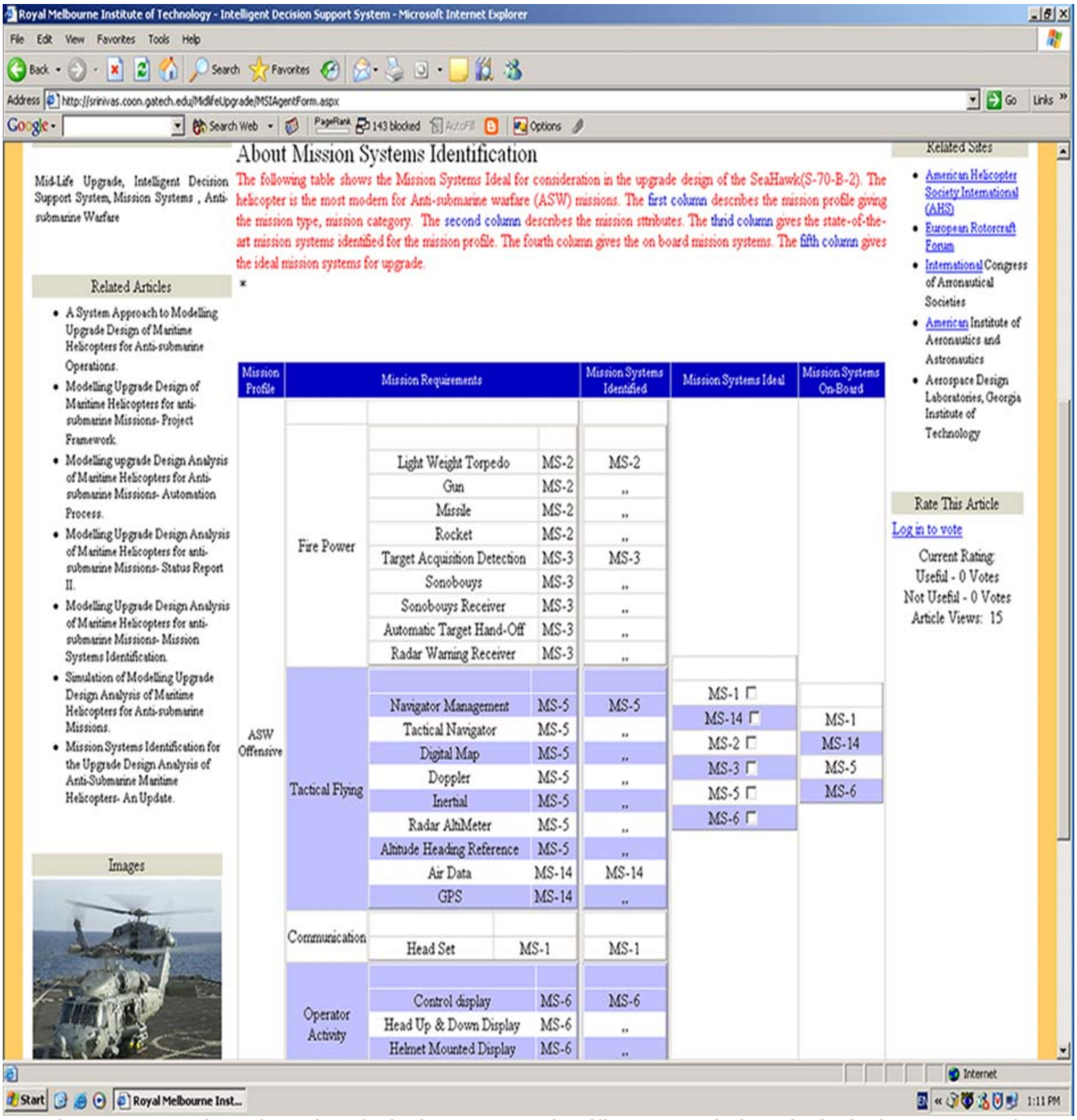

Figure 9: Snapshot of results of Mission System Identifier Agent Listing Ideal Mission Systems for Upgrade

Results and Discussion

The Analytic Hierarchy Process (AHP), formed the basis for mission systems ranking through high-level quality analysis for a specific ASW mission. In formalising the decision there were a limited number of choices (mission systems) but each has a number of attributes difficult to formalise.

The MPD provides ranking to any mission system selected from the ideal mission systems list of the MSI. In the example "Offensive Tactical ASW" mission considered only 5 systems (MS-1, MS-2, MS-3, MS-5, and MS-14) were considered by to demonstrate user/analyst's choice while formalising the ranking. For this reason MS-6 have been leftout of the ranking and its related attribute 4 display a value 0 in all its rows (**Fig 8**). Inclusion of MS-6 may provide a different ranking but makes the system dynamic.

The ranking of the mission systems and the ranking of the attributes that use these mission systems offer in various missions provide a platform to setup alternative mission payloads for further ugrade design analysis. The mission systems should be considered in the order they are ranked.

The muti-agent, web-based view of the IDSS to formalise and rank the mission systems resulted in the formulation of algorithms based on AHP and an ambitious implementation of the algorithms in a web environment to ensue speed and accuracy.

Future Work

The ranked mission systems being part of the various alternative mission payloads form the input to the Design Parametric Analysis (DPA) that involves mission capability, flight performance, maintainability, reliability, and cost analyses. Research is required to formulate a DPA system framework, algorithms and implementation of these algorithms in a web-based environment to form an IDSS.

Conclusion

The AHP used in a large number of applications and fields provides structure on a difficult decision making process such as mision system ranking where there are few mission systems but large number of attributes associated with each mission system. There have been few assumptions such as the fire power attribute being of the highest importance which make the process arbitrary. Despite these rather arbitrary aspects of the procedure, has been rigorous and hence solution to the mission payload design for ASW maritime helicopter upgrade problem considered to other multi-criteria analysis methods.

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