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

Jonnalagadda S.[1], Sinha A.K.[1], Hoffmann P.[1], Schauenburg A.[1]
Schrage D. P.[2]

[1] The Sir Lawrence Wackett Centre for Aerospace Design Technology
Royal Melbourne Institute of Technology
GPO Box 2476V, Melbourne, Victoria, 3001, Australia
e-mail: arvind.sinha@rmit.edu.au

[2] School of Aerospace Engineering
Georgia Institute of Technology, Atlanta,
GA 30332-0150, USA
e-mail: daniel.schrage@aerospace.gatech.edu

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Abstract: Mission systems on-board military helicopters govern the anti-submarine mission capabilities. The global budget restricts the design and development of new maritime helicopter with state-of-the-art mission systems to enhance mission capabilities. A mid-life upgrade of helicopters in service with new on-board mission systems is a viable and cost-effective option. The identification of the alternative mission system payload through an major analytical process involving prioritisation of identified mission systems based on contribution and relative dependency presents an avenue for mission capability analysis. 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 a "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 and a mission capability analysis, to evaluate the degree to which the mission capability is enhanced by the upgrade design.

1 INTRODUCTION

The anti-submarine warfare (ASW) mission effectiveness is mainly governed by the operational capabilities provided by the mission systems on-board military helicopters [1]. Significant advancements in helicopter mission systems, due to improved materials, capable electronics and enhanced methods of fabrication, outpace the service life of helicopters. Littoral airborne ASW operations have widened the threat dimensions, demanding state-of-the-art helicopter borne ASW mission systems to enhance operational capabilities. The global budget climate restricts purchasing of new helicopters with these state-of the-art mission systems [10]. A mid-life upgrade of existing helicopters with new on-board mission systems is a viable and cost-effective option to enhance mission effectiveness and overcome technology upgrade demands [11].

Research on “Upgrade Analysis for Design Decision” by Sinha et al [15, 16, 17, 18] adopted a systems approach considering operational and environmental needs to identify state-of-the-art mission systems for aircraft upgrade. The result was a formulation of a generic “Mid-Life Upgrade System (MLUS)”. Kusumo et al [6, 7, 8] developed an automation framework for the design of an “Integrated Decision Support System”, simulating the MLUS to provide time-based analysis. Jonnalagadda et al [3, 4, 5] revisited the automation framework and presented a 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 ensues speed and accuracy while providing access to the system from remote locations for various users.

The design of a ASW mission payload is complex and a major analytical and iterative process. The importance of the mission systems in the payload and the attributes associated to these mission systems can be approximated by AHP using pair wise comparisons [14].

This paper presents the detailed description of the Mission Payload Design (MPD) sub-module which incorporates the AHP by [13, 14] with a following mission capability analysis, to investigate the degree to which the mission capabilities are fulfilled. The “Tactical Offensive ASW” mission as performed by the Seahawk (S-70B-2) helicopter is demonstrating its functionality.

2 INTELLIGENT DECISION SUPPORT SYSTEM FRAMEWORK

The generic system methodology for mid-life upgrade of aircraft, developed by Sinha et al [15, 16, 17, 18], was formulated with the conventional input-process-output configuration [3] 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 [6, 7, 8] further explored the possibility to prioritise and rank the mission systems and the attributes that offer these mission systems for various missions. The AHP concept of pair wise comparison provided the basis to rank the importance of components in specific mission and is presented in (Tab. 1 and Tab. 2).

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 1: Vector of Priorities [8]

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	

Table 2: Overall Vector of Priorities for components [8]

As most other existing design environments, the automation framework by Kusumo et al [6, 7, 8] 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 [1, 2, 3] is conceptualised as a multi-agent system. It 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 a 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 needs;
- 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 while 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):

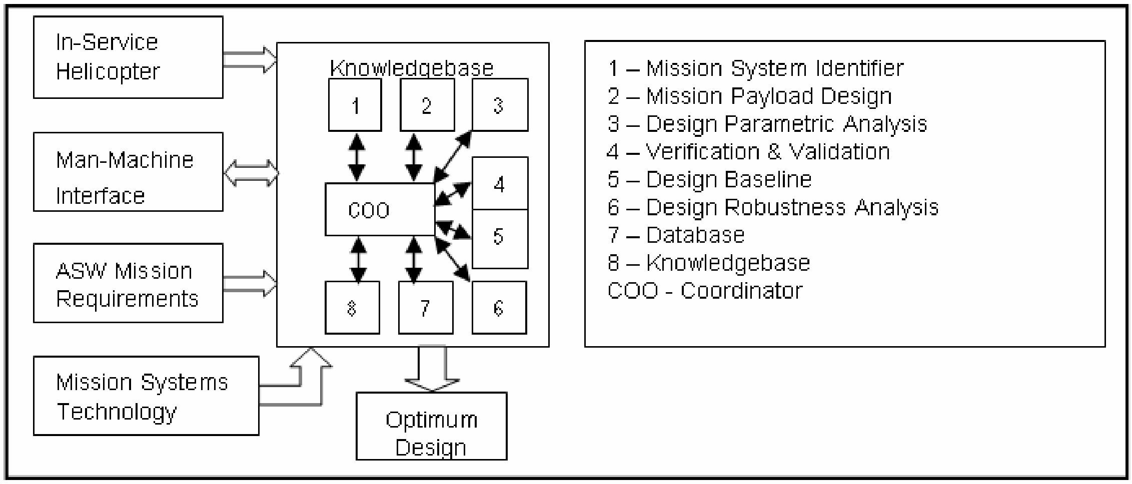

Figure 1: Intelligent Decision Support System for Upgrade Design Analysis of Anti-Submarine Maritime Helicopters.

- **In-Service Helicopter**: Contains the design details of the helicopter subjected to the upgrade design analysis including the on-board mission systems;
- **Man-Machine Interface**: To facilitate user-system interaction for input and view the output of the upgrade design analysis;
- **Anti-Submarine Mission Requirements**: Contains the anti-submarine mission requirements based on operational and environmental needs;
- **Mission Systems Technology**: Functional details of mission systems that provide enhanced anti-submarine mission capability; and
- **Knowledgebase**: 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;
  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 a collection of rules / methodologies 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; and

i) **<u>Design Baseline</u>**: Maintain a baseline of the optimised configuration for future upgrades.

3 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 can be formulated to design alternative mission payloads for further analysis by the “Design Parametric Analysis” (DPA) sub-module. The MPD receives identified mission systems from the MSI sub-module with stored attributes for the particular mission from the database sub-module. The MPD sub-module follows the AHP by [13, 14]. 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.

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

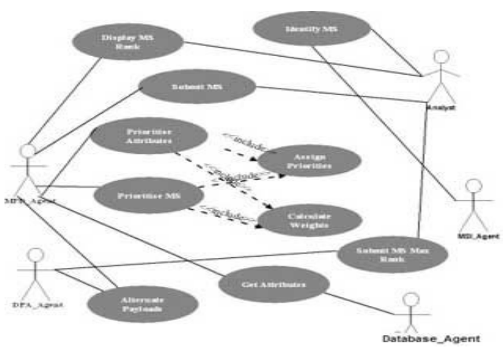

Figure 2: Use-Case Diagram for Mission Payload - Sub-module

3.1 High-Level Qualitative Analysis for Mission System Ranking

The first step is to decide on the relative importance of the attributes. A decision is taken which attributes are used to evaluate the overall quality of each mission system, to provide a mission systems ranking. Following, each attribute is composed into sub attributes. The result is the development of an “Attribute Hierarchy” for a specific ASW mission. The decomposition technique is conducted for each sub attribute again into sub-sub attributes, and so forth. At the lowest level of the hierarchy are the components required to fulfill the next higher level of the “Attribute Hierarchy”. As a general rule, only top-level attributes and between two and five sub attributes are considered [11].

An offensive tactical ASW mission consists of the following attributes: 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 I. The “Attribute Hierarchy” for the example mission is presented in Fig. 3.

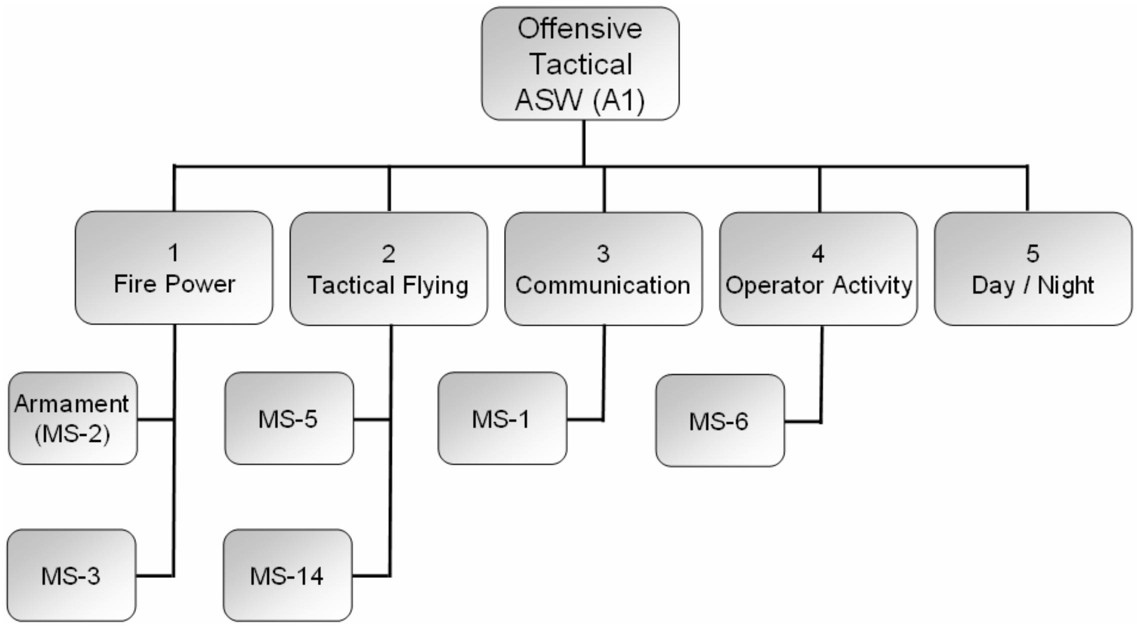

Figure 3: Partial Attribute Hierarchy Diagram for Offensive Tactical ASW Mission

The second step is to prioritise the high-level attributes and to obtain the overall vector of priorities for the attributes considered. The attributes are prioritised following the AHP concept of pair wise comparison [13]. In the offensive tactical ASW example the Level II attributes follow the pair wise comparison concept and is presented in Tab. 3. A loose interpretation was made that in an offensive tactical ASW mission, fire power is the most important attribute and is given the highest value of five. The comparison values should be interpreted as shown in Tab. 4.

Attributes	1	2	3	4	Total	Average
1	1	5.00	5.00	5.00	16.00	4.00
2	0.20	1	3.00	3.00	7.20	1.80
3	0.20	0.33	1	2.00	3.53	0.882
4	0.20	0.33	0.50	1	2.03	0.507

Table 3: Attribute comparison for offensive tactical ASW mission

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

Table 4: Comparison Values

After the relative importance values are assigned for each attribute, attribute weights are established and presented in Tab. 5. The largest value results in the highest ranking and hence priority in the upgrade design. To calculate the weights, each entry is divided by the sum of the row it appears in [20].

Calculated Weights

Attributes	1	2	3	4	Total	Average
1	0.062	0.312	0.312	0.312	0.998	0.250
2	0.028	0.139	0.417	0.417	1.001	0.250
3	0.057	0.093	0.283	0.567	1.000	0.250
4	0.099	0.163	0.246	0.493	1.001	0.250
Total	**0.246**	**0.707**	**1.258**	**1.789**	**4**	
Average	**0.062**	**0.177**	**0.314**	**0.447**	**1**	

Table 5: Attribute Comparison for Offensive Tactical ASW Mission – Calculated Weights

The third step in the high-level analysis is to prioritise the sub-attributes. Each attribute in the higher level becomes the attribute of interest. The overall vector of priorities for the calculated weights in this process is shown in Tab. 6.

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

Table 6: Vector of Priorities for Attributes

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 mission systems were pooled together and are given marks. These values are presented in Tab. 7, and the calculated weights are presented in Tab. 8.

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	0.2	2	2	7.33	1.466
MS-2	0.33	5	1	5	5	16.33	3.266
MS-3	0.33	0.5	0.2	1	3	5.03	1.006
MS-5	0.33	0.5	0.2	0.33	1	2.36	0.472

Table 7: 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	1	3.0	3.0	3.0	3.0	13	2.6
MS-14	0.33	1	0.2	2	2	7.33	1.466
MS-2	0.33	5	1	5	5	16.33	3.266
MS-3	0.33	0.5	0.2	1	3	5.03	1.006
MS-5	0.33	0.5	0.2	0.33	1	2.36	0.472
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

Table 8: Mission System Comparison for Offensive Tactical ASW Mission – Calculated Weights

The final step is to combine the vector of priorities of both mission attributes and mission systems, which results in the overall normalised vector of priorities for each mission system. The mission system with the highest overall normalised vector automatically receives the highest rank. This mission system is the input for the DPA for further analysis. The ranking of mission systems in the "offensive tactical ASW" application is presented in Tab. 9.

Mission System	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**	

Table 9: Mission System Ranking for Offensive Tactical ASW Mission

The simulation software program for the "Intelligent Decision Support System" named "Intelligent Decision Support System Software" (IDSSS) is being developed. The software is entirely web-based, allowing several sources of input to participate in the upgrade design analysis process from remote locations. The man-machine interface was developed using ASP.NET®. The present version of the IDSSS runs on Internet Explorer ® Version 6.0 or above. The "Mission Payload Design" results are viewed on a standard web page. The database was built in Microsoft Access®. The selection and listing of the mission systems was accomplished through Structured Query Language (SQL) statements, retrieving 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 use-case diagram (Fig. 2) provides the base for the following sequence of interaction between the user and the system:

- The Analyst logs-in through the login screen or registers as an analyst.
- The Analyst views and selects the existing mission profile from the list or can create a dummy mission profile.

- Based on the mission profile the MSI_Agent generates lists of identified mission systems, on board mission systems and ideal mission systems by checking boxes (Fig. 4).
- The Analyst selects the mission systems of interest and hits the 'submit' button.
- The MSI_Agent redirects the mission systems selected to the MPD_Agent.
- The MPD_Agent retrieves the attributes for the specific mission profile from the database.
- The MPD_agent assigns the priorities to the attributes based on relative importance and dependency and displays the over overall vector of priorities for attributes.
- The MPD_agent assigns priorities for mission systems identified for each attribute and calculates the weights after pooling all the mission systems.
- The MPD_agent combines the attributes and mission systems to calculate the normalised overall vector of priorities and ranks the mission systems.
- The highest ranked mission system is the preferred candidate for the DPA_Agent for inclusion in further analysis.

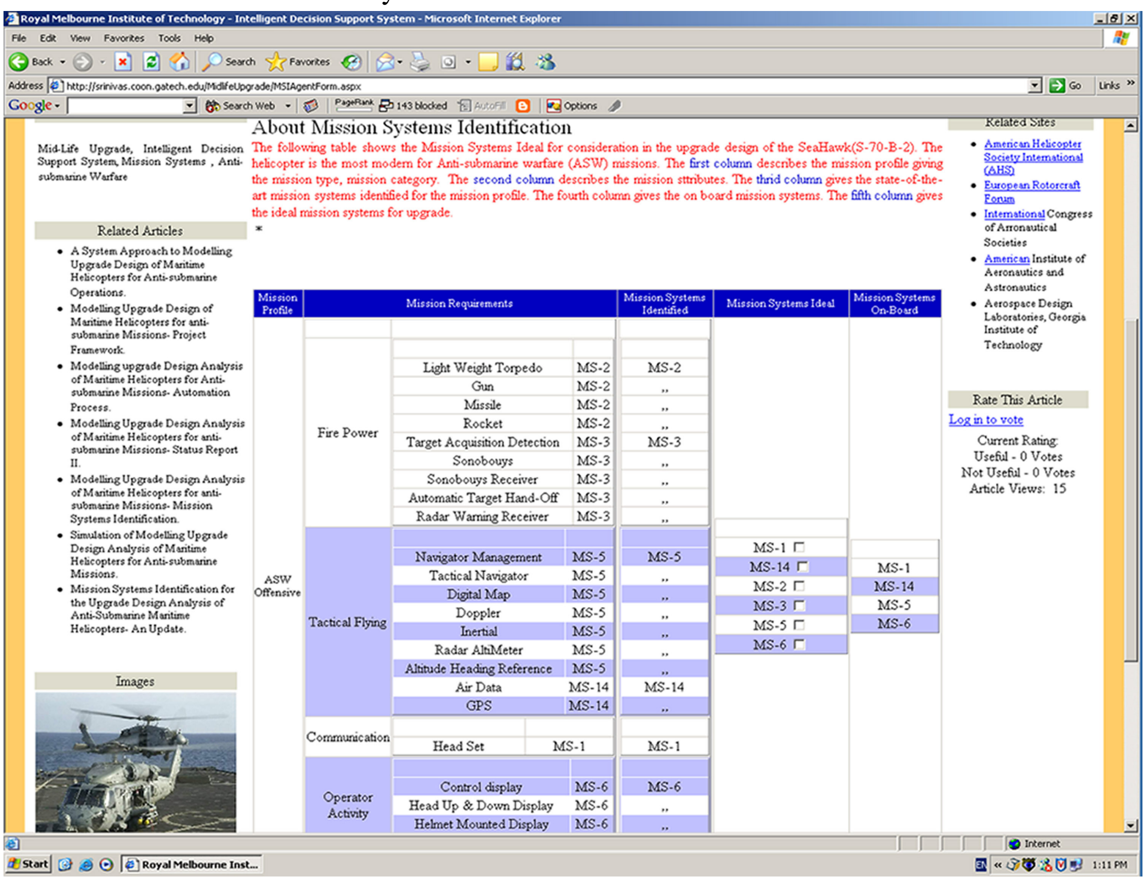

Figure 4: Snapshot of Results of Mission System Identifier Agent Listing Ideal Mission Systems for Upgrade

4 MISSION CAPABILITY ANALYSIS

The Design Paramteric Analysis (DPA) provides the basis for an evaluation of alternative mission payloads. The mission systems of interest are selected (Fig. 4.) and prioritised, forming the mission payload of identified missions. The slated systems are ranked according to their importance and grouped to sets of mission systems. To furhter investigate the sets of mission payloads and their capabilities, a mission capability analysis is conducted. The mission capabilities of the mission paylod design alternatives have to be investigated to provide an avenue to identifying the optimum upgrade design. The process can be automated by developing a Quantitative Mission Capability Analsysis (QMCA) process.

4.1 Quantitative Mission Capability Analysis

The functions of the QMCA process involves the study of derived and defined capabilities of the upgrade design. The capability is obtained by identifying the total number of mission systems and their attributes that constitute an 'ideal mission payload'. The derived capability is identified by comparing the number of missions systems and their attributes, forming the 'actual mission payload' against the number of mission systems and their attributes in the ideal mission payload. Having evaluated the derived capabilities, the mission capability achieved through the upgrade is evaulated as the mean of all dervived mission cabalities of the components. Furthermore a multi-mission capability of the mission payload design alternative is established. The multi-mission capability is computed to provide the basis for comparative analysis in a design decision support sub-model.

4.2 Computerisation of Quantitative Mission Capability Analysis

The computational functions of the QMCA process can be translated into a software-based application, by the design of algorithms to simulate the required functions. The algorithms of the QMCA process begin by procuring the inputs. The inputs consist of mission categories and the derived mission requirements from a database sub-model; mission systems ideal from MSI sun-model; and the mission payload design from the MPD sub-model. Based on these inputs, the algorithms proceed to analyse the degree of offensive, defensive and logistic mission capabilities and subsequently the multi-mission capabilities, that can be achieved by the upgrade design alternatives. The algorithms for the QMCA process are presented in Fig. 5:

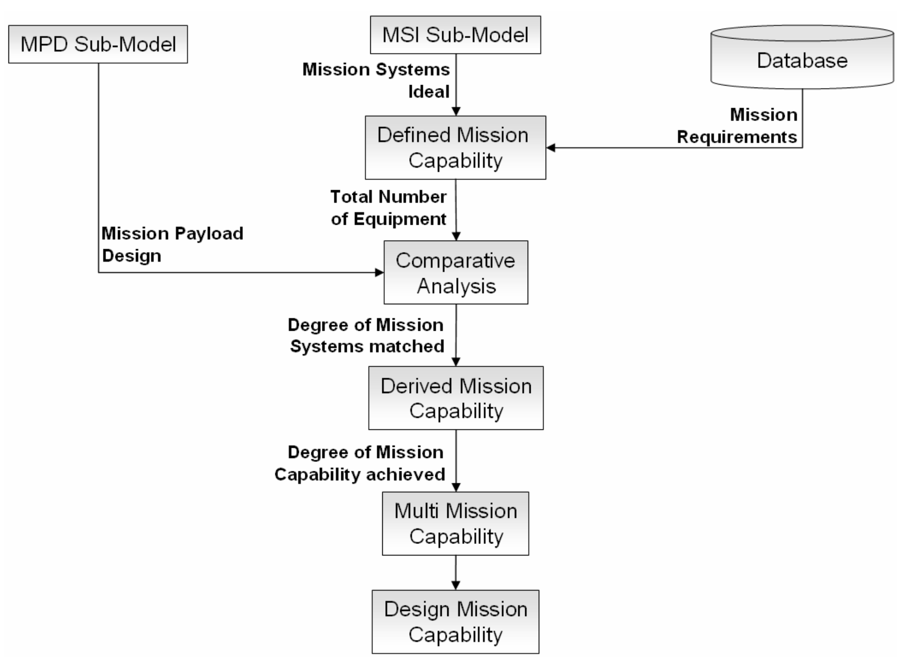

Figure 5: Algorithms to Automate the Quantitative Mission Capability Analysis

5 RESULTS AND DISCUSSION

The MPD provides a ranking to any mission system selected from the ideal mission systems list of the MSI. The example “Offensive Tactical ASW” mission considered only five systems (MS-1, MS-2, MS-3, MS-5, and MS-14) to demonstrate the user / analysts’ choice while formalising the ranking. For this reason, the MS-6 was ignored and its related attribute 4 displays a “0” in all its rows (Tab. 9). The inclusion of MS-6 may provide a different ranking but makes the system dynamic.

The ranking of the mission systems and attributes using these mission systems provide a platform to setup alternative mission payloads for further ugrade design analysis. The mission systems are 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 implementation of the algorithms in a web environment to ensue speed and accuracy.

The mission capability analysis involves a study of defined and derived capabilities, to evaluate the degree to which the mission capability is enhanced by the upgrade design. The defined capabilities are the capabilities required to meet the mission attributes, whilst the derived capabilities are the capabilities offered by the mission payloads. A comparative analysis of the capabilities in quantitative terms provides the degree to which the capabilities are met by the design.

6 FUTURE WORK

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

7 CONCLUSION

The AHP, used in a large number of applications and fields, provides the structure for a decision making process, such as the mission system ranking, with a few mission systems but a large number of attributes associated with each mission system. Limited assumptions in the process, such as the fire power attribute being of the highest importance, make the process arbitrary.

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