A SYSTEM FRAMEWORK FOR DESIGN ROBUSTNESS ANALYSIS OF HELICOPTER MID-LIFE UPGRADES

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Abstract

The global budget climate has laid restrictions on the design and development of new military aircraft to meet the demands of enhanced mission capabilities. To enhance mission capabilities, mid-life upgrade of in-service aircraft, with state-of-the-art mission systems onboard, is acknowledged as a cost-effective option. To facilitate the mid-life upgrade process, a "Decision Support System" is required to identify the state-of-the-art mission systems that will provide the enhanced mission capabilities. In this paper, a brief outline of An "Integrated Decision Support System" (IDSS) framework developed by a systems approach to identify mission systems is presented initially, followed by a detailed discussion on the development of 'Design Robustness Analysis' (DRA) sub-model. The DRA sub-model automates the robustness analysis of aircraft upgrade design against 'temporal uncertainties factors'.

Introduction

During the service life of military aircraft, mission systems onboard undergo major technological advancements (Ref 1). These advanced mission systems are designed to enahance mission capability of the aircraft (Ref 2 & 3). As the design of a new aircraft with the advanced systems onboard to enhance mission capability is a costly venture, mid-life upgrade of in-service aircraft with these advanced systems is the preferred option (Ref 4).

Sinha et al. (Ref 5 - 8) adopted a system approach to develop a 'Mid-life Upgrade System' (MLUS) to facilitate the mid-life upgrade process. The MLUS was conceptualised in an 'input-process-output' configuration (Ref 9). The approach considered the operational needs and the environmental conditions of the aircraft as the key 'inputs'. The 'process' identified the advanced systems for aircraft upgrade; and the 'outputs' were the mission capabilities derived from the system. The identified mission systems were then considered from an upgrade design perspective. The upgrade design was conceptualised as a 'system of systems methodologies' (Ref 9) to evaluate the following design parameters on which the upgrade design decision were dependent: (a) mission capability derived; (b) flight performance drop; (c) system reliability; (d) system maintainability; and (e) upgrade cost.

The generic methodology developed by Sinha et al. (Ref 5 - 8) for upgrade design decision was further explored for automation by Kusumo et al. (Ref 10 - 16) to provide time-based "mission system analysis" and upgrade design decision. A framework of an automated "Integrated Decision Support System" (IDSS) was formulated to address mid-life upgrade of maritime helicopters. The IDSS framework comprised of a series of sub-models, synergistically integrated to facilitate user-system interaction and mission system analysis. The IDSS sub-models were the following: (a) Man Machine Interface; (b) Mission System Identification; (c) Mission Payload Design; (d) Database; (e) Multi-Parameter Analysis; (f) Upgrade Decision Support; and (g) Design Robustness Analysis.

In this paper the overview of IDSS is presented, followed by detailed discussion on the development of 'Design Robustness Analysis' (DRA) sub-model. The DRA sub-model is designed to evaluate the robustness of the optimum upgrade design, by considering the severity of temporal uncertainty effects towards its system effectiveness. The results of the analysis provides the base for design acceptability.

Integrated Decision Support System

System Methodology

The generic system methodology for mid-life upgrade of aircraft, developed by Sinha et al. (Ref 7) was configured in a conventional input-process-output configuration (Ref 9), as a platform to structure a "Mid-Life Upgrade System" (MLUS). The system configuration for the development of the MLUS structure is presented in Figure 1. The operational needs and the operational environment were studied to identify the mission requirements and also the mission capabilities to be derived from the

MLUS, as outputs of the system (Table 1). The MLUS structure identified the following system elements: (a) components; (b) attributes; and (c) relationships. The MLUS structure is presented in Figure 2. The MLUS comprises of three components – Armed; Attack; and Utility. The attributes assigned to the components were based on the mission requirements of MLUS. The relationships identified were inter and intra – components and components; components and attributes; and attributes and attributes.

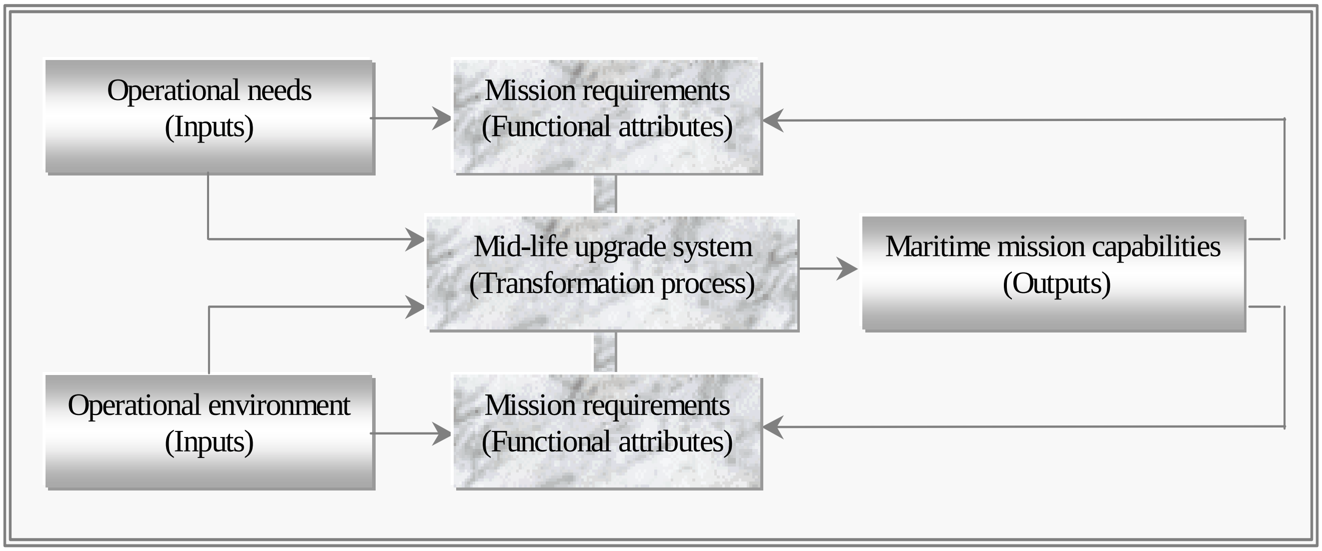

Figure 1. Mid-life Upgrade System Configuration

Table 1. Mid-life Upgrade System: Input, Attributes and Outputs

Operational needs (Inputs)	Mission requirements (Attributes)	Mission capabilities (Outputs)	
Offensive	Fire power	Offensive warfare sub-mission capabilities	Maritime Mission capability
	Tactical flying		
	Communicating		
	Operator activity		
Defensive	Fire power	Defensive Warfare sub-mission capabilities	
	Reconnaissance & Surveillance		
	Aerial assault & extraction		
	Tactical flying		
	Communicating		
	Operator activity		
Logistics	Search	Utility support sub-mission capabilities	
	Aerial replenishment		
	Transportation		
	Aid civil authorities		
	Evacuation		
	Tactical flying		
	Communicating		
	Operator activity		

The mission systems for capability enhancement of the aircraft through upgrade, were identified by a systematic development of the “System Hierarchy” (SH). The partial SH of the MLUS formulated by Sinha et al. (Ref 7 & 8), for maritime missions is presented in Figure 3. The appropriate mission systems for upgrade were identified at the last level of SH – Level IV.

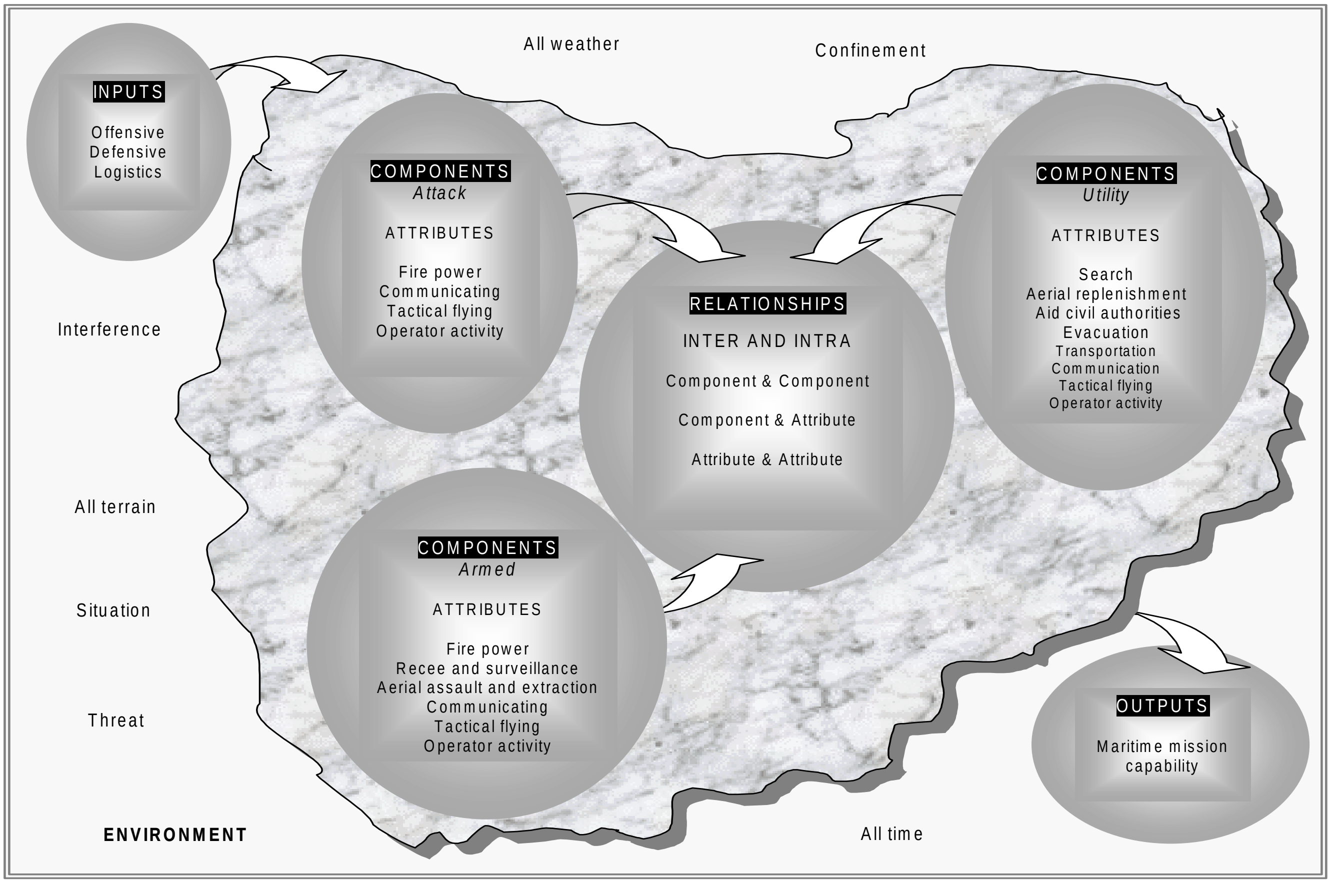

Figure 2. Mid-life Upgrade System Structure

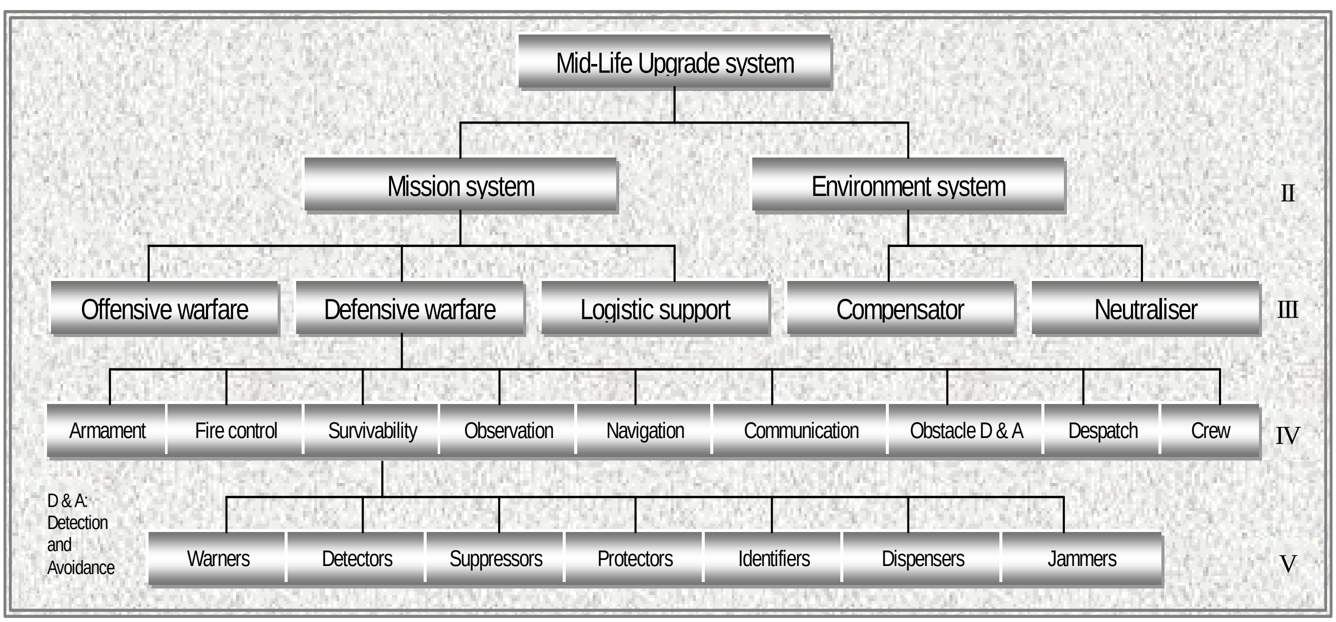

Figure 3. Partial System Hierarchy of Mid-life Upgrade System

The identified mission systems for upgrade were then considered from a design perspective to address the various design parameters for an optimum upgrade design. The design parameters considered were the following: (a) mission capability; (b) flight performance; (c) reliability; (d) maintainability; and (e) cost. The systems methodology summarising the design process as a 'system of systems methodologies' is presented in Figure 4.

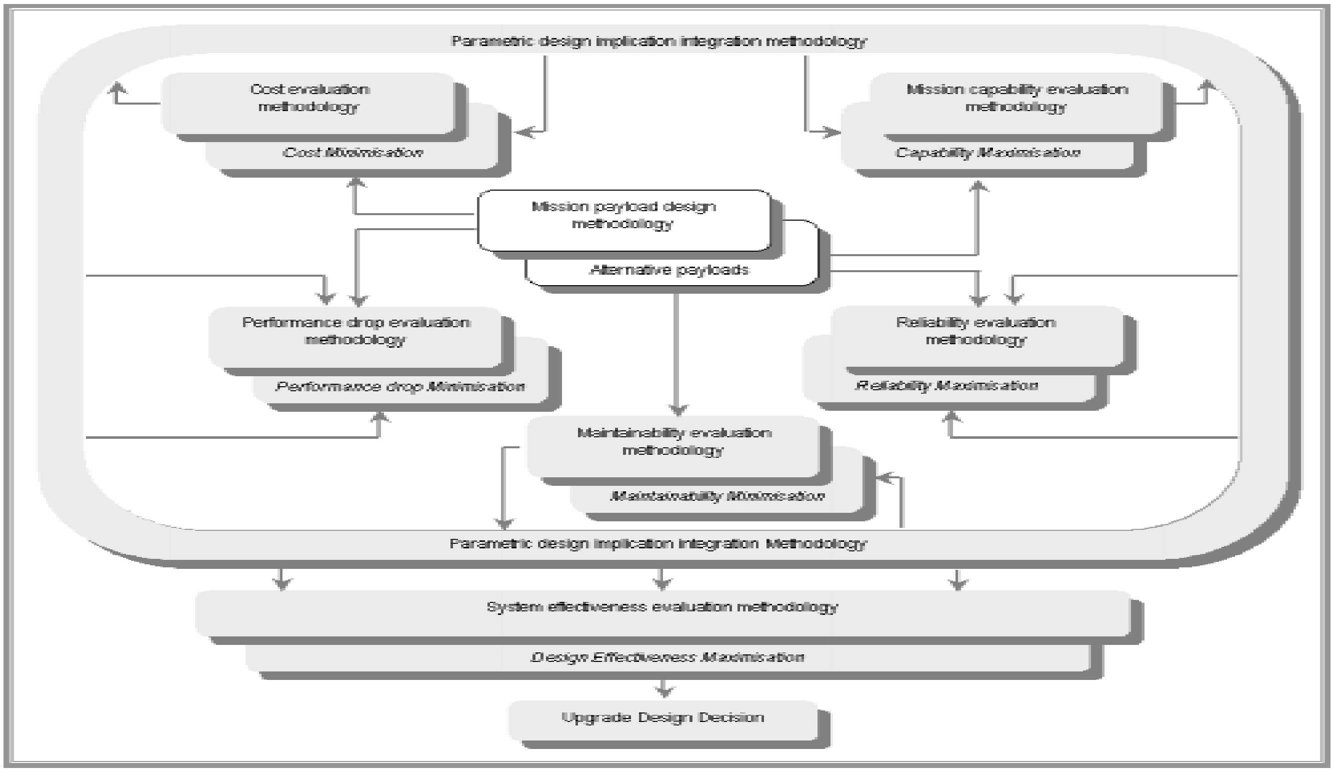

Figure 4. Systems of System Methodologies for Optimum Upgrade Design

Automation Methodology

To automate the system methodology developed by Sinha et al. (Ref 5 - 8), an ‘Integrated Decision Support System’ (IDSS) was formulated by Kusumo et al. (Ref 10 - 16). The IDSS consisted of three base-line sub-models with the following designated functions:

- **Man Machine Interface (MMI):** To provide user-system interaction;
- **Analysis, Synthesis and Decision Support System (ASDSS):** To identify state-of-the-art mission systems from defined operational and environmental needs and to evaluate system effectiveness of the upgraded helicopter for decision support; and
- **Database (DB):** To store and manage operational, mission systems and helicopter data.

The ASDSS base-line sub-model functions were defined to identify the sub-models required for automation of analysis to support decision. The sub-models of ASDSS and their slated functions were as follows:

- **Mission System Identification (MSI):** To translate operational and environmental needs to mission requirements, and identify state-of-the-art mission systems for upgrade;
- **Mission Payload Design (MPD):** To prioritise the mission systems based on their relative functional dependence and degree of contribution towards mission accomplishment. To provide upgrade options by composition of alternative ‘sets of mission systems’ (mission payload);
- **Multi-Parameter Analysis (MPA):** To evaluate the degree to which the system design parameters (mission capability, flight performance, reliability, maintainability and cost) are met by the alternative mission payloads;
- **Upgrade Decision Support (UDS):** To evaluate the system effectiveness of the upgrade options by considering the results of the MPA and to identify the optimal upgrade option, for design decision; and
- **Design Robustness Analysis (DRA):** To test the robustness of the design decision against temporal uncertainties and to validate the design.

The IDSS framework for automation of the system methodology for mid-life upgrade is presented in Figure 5. The framework represents the sub-models integrated accordingly to the stipulated functions and the inputs/output requirements.

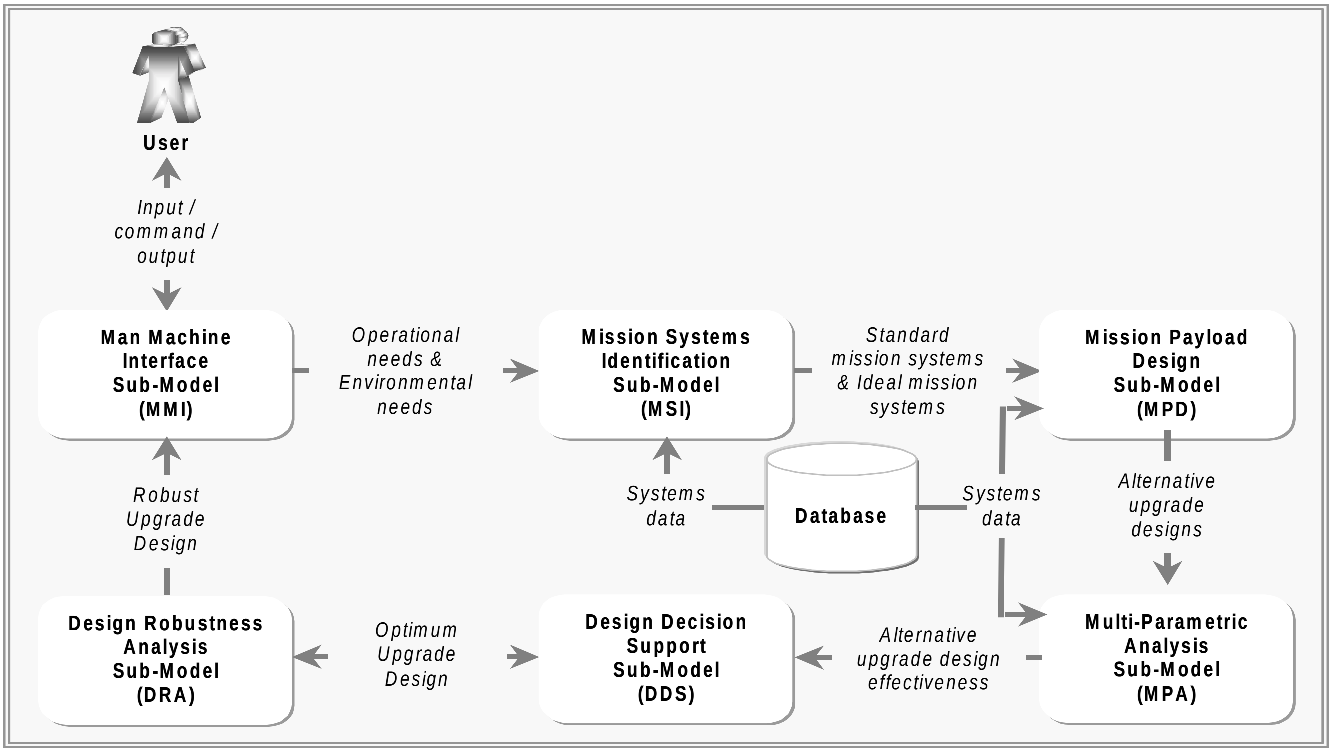

Figure 5. Framework of an Integrated Decision Support System for Automation of Systems Methodology for Mid-life Upgrade

<u>Design Robustness Analysis</u>

The alternative designs for mid-life upgrade were studied and analysed by Kusumo et al. (Ref 10 - 16) and analysed for their system effectiveness. The results of the system effectiveness analysis resulted in the identification of optimum upgrade design. Before the optimum design can be processed for decision, the robustness of the design against 'temporal uncertainty factors' (TUF) needs to be studied. TUFs are factors of design, operation and environment that fluctuate with time and have adverse effects on the upgrade design. A severe implication on the system effectiveness will ultimately effect the design optimisation process. To address TUF issues, the 'Design Robustness Analysis' (DRA) sub-model of IDSS needs to be developed. The DRA sub-model evaluates the robustness of the optimum upgrade design, by considering the severity of TUFs on system effectiveness. Having analysed the risks associated with potential degradation of system effectiveness, the DRA sub-model analyses the acceptability of the optimum upgrade design for decision support.

To facilitate automation, the DRA sub-model first procures inputs consisting of identified optimum design from the DDS sub-model; and information on TUF that is stored in Database sub-model. The TUF information consists of a list of identified factors and their severity of effects that are quantitatively assessed based on experts and domain knowledge. To transform the inputs into outputs, the DRA sub-model initially analyses the relationships between TUF and the design parameters used in system effectiveness analysis. Based on the relationships, the severity of effects towards system design effectiveness, which are introduced by the TUF is analysed. The results of the severity analysis allows the DRA sub-model to prioritise the TUF and identify the most susceptible design parameter. Subsequently, the DRA sub-model analyses the risks of potential degradation in system effectiveness of the optimum upgrade design. The process of the DRA sub-model is to result in the determination of optimum design acceptability and the transfer of this information to MMI sub-model.

Having identified the inputs, process and outputs, the system structure of the DRA sub-model can be developed to identify the system elements. To facilitate the function in the DRA sub-model, the system elements and their functions are as follows:

- **Analyser:** To identify the causal relationship between TUF and slated design parameters; implications on system effectiveness; risk of potential degradation in system effectiveness; and acceptability of upgrade design; and

- **Identifier:** To identify the most influential TUF and the most susceptible design parameters.

The visual representation of system structure of DRA sub-model is presented in Figure 6.

degree of potential degradation in upgrade design due to temporal uncertainty factors;

- **Risk analysis:** To evaluate the potential design risk introduced by the degradation; and

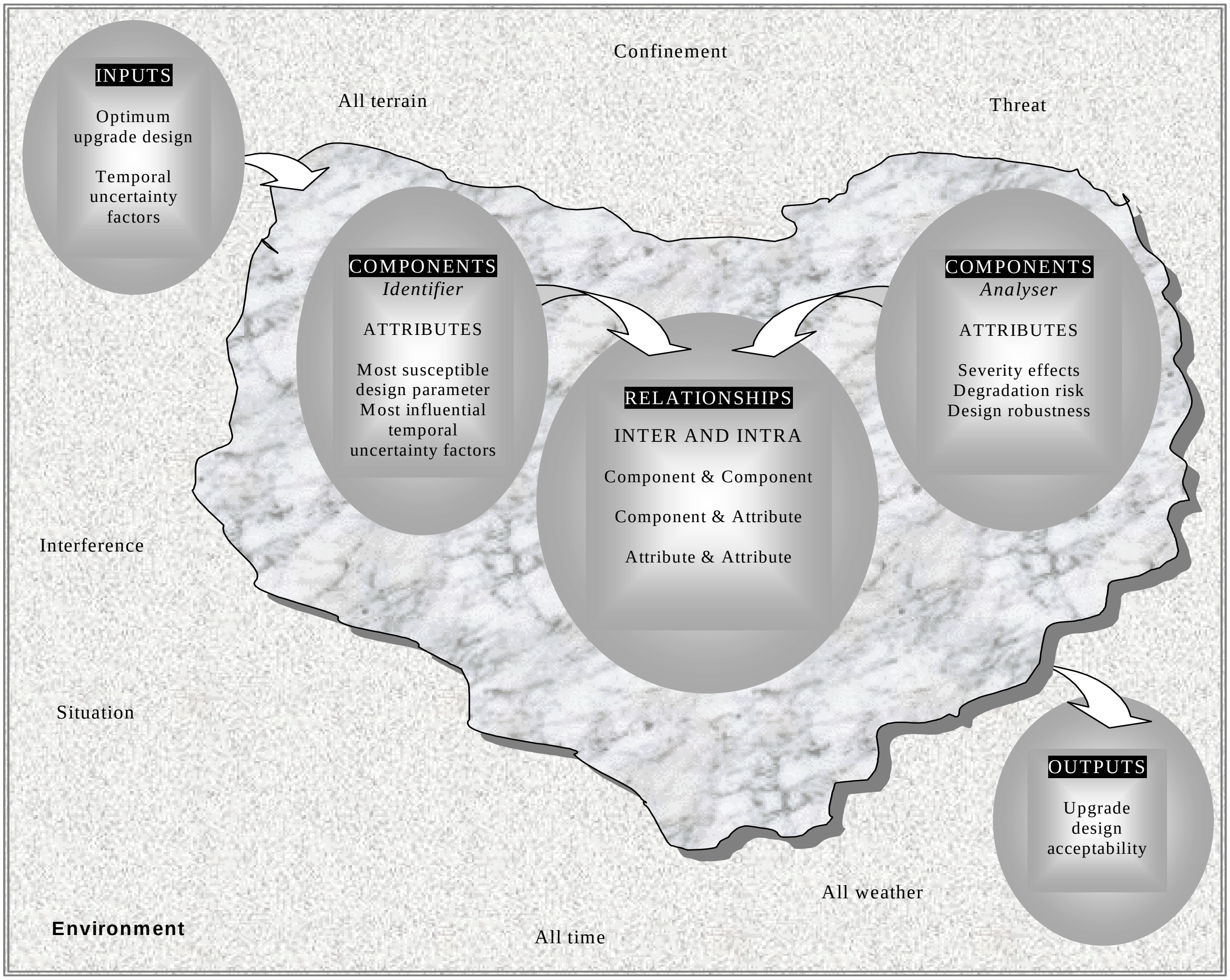

Figure 6. System Structure of DRA Sub-Model

The system structure of the DRA sub-model is developed based on the system elements and their functional characteristics (Figure 6). The structure provides the avenue to formulate the system framework of the DRA sub-model, to develop algorithms for automation of the design robustness analysis. The DRA system framework comprises of four components to study the effects of TUFs on upgarde design. The DRA components and their functions are as follows:

- **Cause and effect analysis:** To identify temporal uncertainy factors, and their potential effects on aircraft upgrade design;
- **Severity effect analysis:** To evaluate the
- **Acceptability analysis:** To evaluate the acceptability level of the upgrad design, considering the potential degradation.

The system framework of DRA sub-model is presented in Figure 7.

Results and Discussion

A comprehensive framework has been formulated for the development of DRA sub-model. The function of the DRA sub-model for robustness analysis are the following: (a) Cause and effect; (b) Severity effect; (c) Risk; and (d) Acceptability. The DRA sub-model framework is on a generic format, hence, the

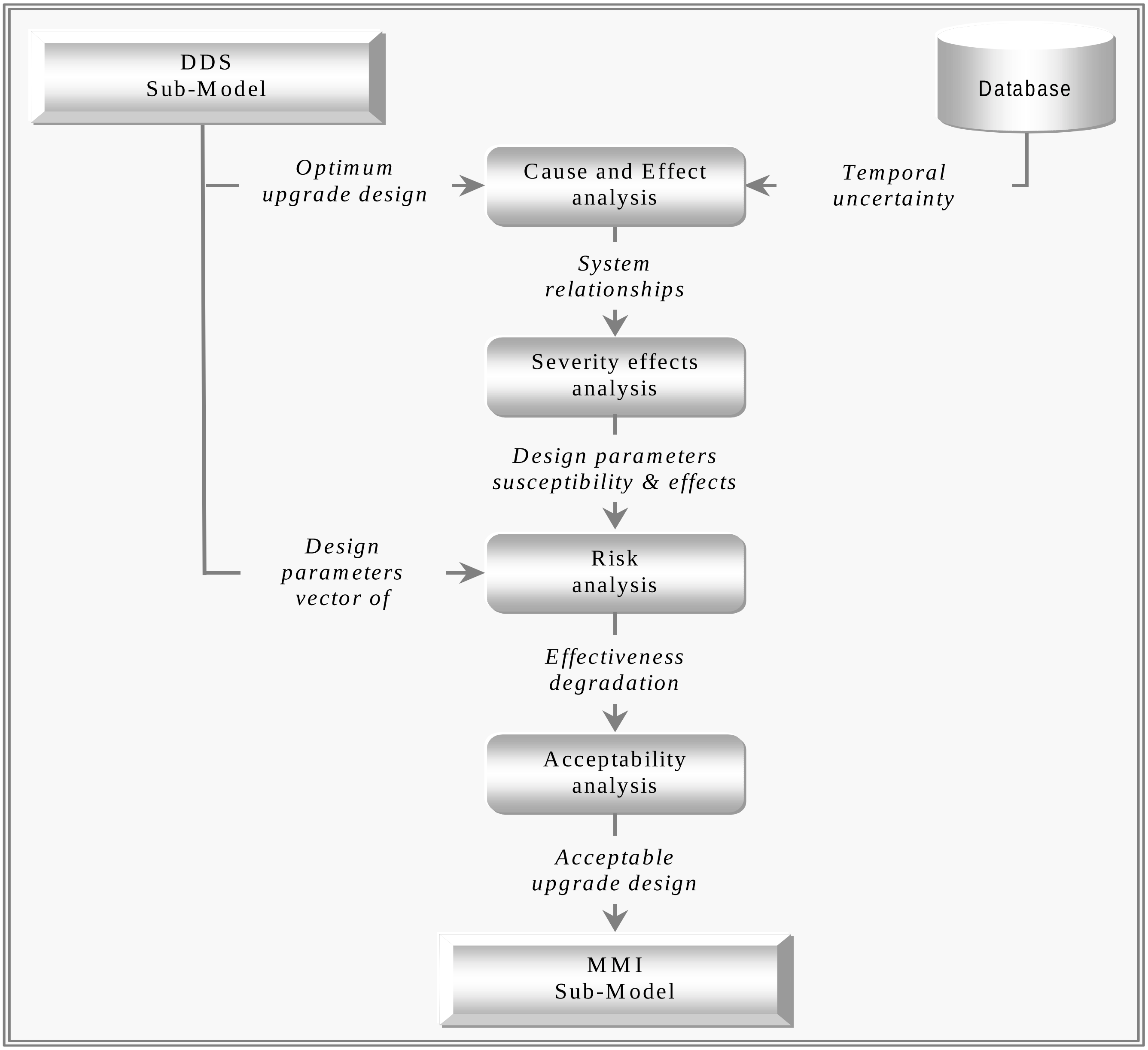

Figure 7. Functional Flow Block Diagram of DRA Sub-Model

application can be customised. The components of DRA sub-model framework need to be further developed for automation and synergistic integration, to provide the avenue for a user-friendly IDSS.

Conclusion

System approach provides the avenue for the development of DRA sub-model. The DRA sub-model facilitates the automation to analyse the robustness of upgrade design for decision support. The robustness analysis is holistic and covers the effects of all TUFs on the design. The results of the analysis provides the base to determine the acceptability of upgrade design. The automation framework of DRA sub-model is generic and can be customised for application.

References

1. Bostock, I. (2001) “Australia Plans Mid-Life Upgrade for Seahawk Fleet,” Jane’s Defence Weekly, Volume 35, Issue 6, pp 14.
2. Hobson, S. (2001a) “Canadian CF_18s Begin Upgrade,” Jane’s Defence Weekly, Volume 35, Issue 17, pp 6.
3. Hobson, S. (2001b) “Canada Defines Contractor’s Helicopter Role,” Jane’s Defence Weekly, Volume 35, Issue 23, pp 5.
4. Mulholland, D. (2000) “USAF puts upgrades

before platforms," Jane's Defence Weekly, Volume 33, Issue 26, pp 8.

5. Sinha, A.K., Kam, B.H., Wood, L.A. & Caterson, J. (1996a) 'Toward a Compromise Solution for Helicopter Multi-Mission Modification Decisions," 52nd Annual Forum and Technology Display of American Helicopter Society, 4-6 June, Washington, D.C., U.S.A.
6. Sinha, A.K., Kam, B.H., Wood, L.A., Caterson, J. & Flood, R.L. (1996b) "A System prespective of Multi-Mission Helicopter Design," 2nd Australian Systems Conference, 29 September-02 October, Melbourne, Victoria.
7. Sinha, A.K., Bil, C. & Scott, M.L. (2000a) "Design of Payloads for Mid-life Upgrade of Maritime Helicopters: Stage I, II, III and IV," 3rd Australian Pacific Vertiflite Conference on Helicopter Technology, 12-14 July, Canberra, A.C.T.
8. Sinha, A.K., Bil, C. & Scott, M.L. (2000b) "Design of Payloads for Mid-life Upgrade of Maritime Helicopters: Stage V and VI," International Conference on Systems Thinking in Management, 8-10 November, Melbourne, Victoria.
9. Flood, R. L. & Jackson, M. C. (1991) "Creative Problem Solving - Total Systems Intervention", John Wiley & Sons, England, U.K.
10. Kusumo, R., Sinha, A.K. & Scott, M.L. (2001a) "Framework for the Development of an Integrated Decision Support Systems for Mid-Life Upgrade of Helicopters," 9th Australian International Aerospace Congress, 5-8 March, Canberra, A.C.T.
11. Kusumo, R., Sinha, A.K., Scott, M.L. & Schrage, D.P. (2001b) "Mission Systems Identification Sub-Model of an Integrated Decision Support Systems for Mid-Life Upgrade of Helicopters", AHS International 57th Annual Forum and Technology Display, 9-11 May, Washington, D.C.
12. Kusumo, R., Sinha, A.K. & Scott, M.L. (2001c) "A System Approach to the Conceptual Design of an Upgrade Mission Payload for Maritime Helicopters", 11th Annual International Symposium of The International Council on Systems Engineering, 1-5 July, Melbourne, Victoria.
13. Kusumo, R., Sinha, A.K. & Scott, M.L. (2001d) "A System Approach to Automate Decision Support in Aircraft Upgrade for System Effectiveness", Systems in Management 7th Annual ANZSYS Conference, 27-28 November, Perth, W.A.
14. Kusumo, R., Sinha, A.K., Scott, M.L. & Irani, Z. (2002a) "A System Approach to Identify Optimum Payload for Aircraft Upgrade", 2nd International Conference on System Thinking and Management, 03-05 April, Salford, U.K.
15. Kusumo, R., Sinha, A.K., Bourmistrova, A., Bil, C. & Schrage, D.P. (2002b) "Multi-Parameter Based Automated Analysis for Mid-Life Upgrade of Helicopters", AHS International 58th Annual Forum and Technology Display, 11-13 June, Montreal, Canada.
16. Kusumo, R. & Sinha, A.K. (2002c), 'Common Development Tools for an Integrated Decision Support System for Mid-Life Upgrade Analysis,' *23rd International Congress of the Aeronautical Sciences,* 8-13 September, Toronto, Canada.