Using Analytic Hierarchy Process with Operations Analysis in Project Evaluation

ABSTRACT

The Analytic Hierarchy Process (AHP) is a structured decision making support tool that has been used by the Ministry of Defence and DSTA for evaluating weapon systems and platforms. Since 2005, AHP has also been adopted in the evaluation of several large-scale non-defence government tenders.

As the Singapore Armed Forces transforms into a Third Generation fighting force, new technologies and concepts of operations have evolved, resulting in military systems becoming highly interconnected and interdependent. Multiple and complex interactions among systems that are part of a larger system are expected during missions. Systems evaluation which requires assessing the military worth of a system in an operational scenario has thus become more challenging. Methodologies such as operations analysis and simulation techniques have been adopted to complement AHP in the evaluation process.

This article describes the successful adoption of AHP for the evaluation of several large-scale government tenders as well as the enhanced AHP methodology developed within the defence community for evaluating complex systems.

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INTRODUCTION

"Singapore's evaluation was widely praised as being thorough, in-depth and comprehensive, and the competition was hard fought."

'Unique F-15SG is Perfect for Singapore's Fighter Project'
Flight Daily, 21 Feb 2006

As the defence procurement agency for the Ministry of Defence (MINDEF) and the Singapore Armed Forces (SAF), DSTA employs an objective and transparent procurement process where acquisition decisions are the result of comprehensive and rigorous technical evaluations (Soh, 2008).

The defence procurement system has enabled DSTA to secure the best available defence systems at the most competitive prices. The procurement system uses a structured technique known as Analytic Hierarchy Process (AHP) to support acquisition decisions on major weapon systems and platforms. AHP provides a rational framework for decision making by breaking down the process into components with respect to an overall goal. Alternative solutions are then evaluated using a method called "pairwise comparisons".

Up till 2005, MINDEF and DSTA were the only organisations in Singapore with extensive experience in AHP. In December 2005, the Minister for Trade and Industry Lim Hng Kiang announced that AHP would be used to evaluate the Marina Bay Integrated Resort project. DSTA was engaged as a consultant to the Singapore Tourism Board (STB) to provide advice on using AHP for the project evaluation.

Following the successful application of AHP to the Marina Bay Integrated Resort project, other government agencies in Singapore have also consulted DSTA on the use of AHP. DSTA was engaged for several national projects including the Singapore Sports Hub and the Changi Motorsports Hub projects by the Singapore Sports Council (SSC), the National Broadband Network project by the Infocomm Development Authority of Singapore, as well as the upgrading of the Changi Airport Terminal 1 by the Civil Aviation Authority of Singapore. The AHP technique proved to be versatile and flexible with successful applications to projects which differed significantly in scope and objectives.

FEATURES OF THE ANALYTIC HIERARCHY PROCESS

AHP is a decision making support tool developed in the 1970s by Thomas Saaty, a mathematics lecturer from the University of Pittsburgh, US. The process requires the establishment of a hierarchy of criteria which is important to achieve the goal of the decision problem. A simple AHP hierarchy used to evaluate the acquisition of a fixed-wing aircraft is illustrated in Figure 1.

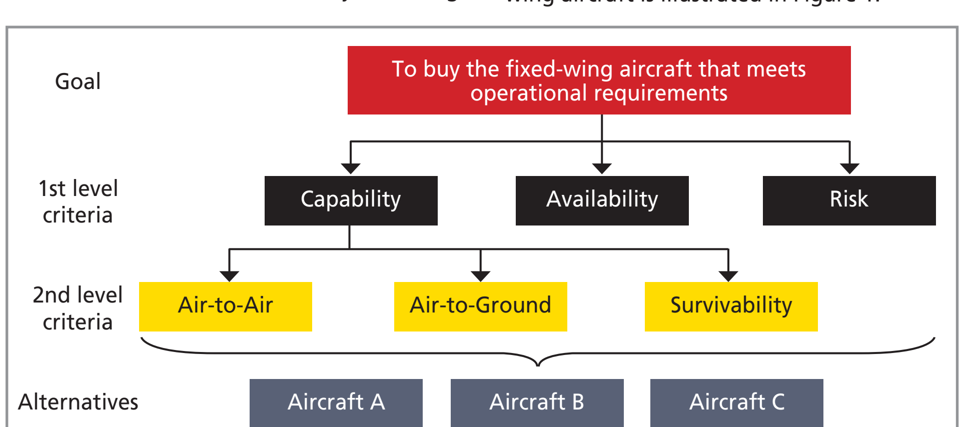

Figure 1. An AHP hierarchy

Weights denoting the relative level of importance are assigned to each criterion using pairwise comparison – a method which compares two criteria that are on the same level to determine their relative importance. The comparison is done based on a simple ratio scale of one to nine as defined in Table 1. For example, when Capability is compared with Availability, and Capability is assessed to be moderately more important than Availability, a weight of '3' will be assigned to the former.

The comparison process is used to assess all levels of criteria and the outputs are synthesised using eigenvectors to determine their respective weights in the hierarchy. For each criterion, the alternatives or choices available are compared with one another to determine the overall score of each alternative. The alternative with the highest score is the preferred solution.

APPLICATION OF ANALYTIC HIERARCHY PROCESS IN DSTA'S PROCUREMENT SYSTEM

During the tender and evaluation process, Project Management Teams (PMT) employ a two-envelope system (see Figure 2) in conjunction with AHP. This two-step process consists of a technical evaluation of the relative performance of the alternatives, independent of price information, followed by a cost-benefit evaluation when the price proposals are released. Evaluating the benefits of an alternative without price information ensures a more objective and fair evaluation.

Definition	Intensity
Equal importance / quality	1
Moderately more important / better	3
Strongly more important / better	5
Very strongly more important / better	7
Extremely more important / better	9
Intermediate values	2, 4, 6, 8

Table 1. Saaty's scale for pairwise comparison

DSTA'S INVOLVEMENT IN GOVERNMENT PROJECTS

Understanding the Project

Prior to providing AHP consultancy services to other government agencies, DSTA's competency in AHP lies mainly in the evaluation of defence systems. The first-level criteria and some lower-

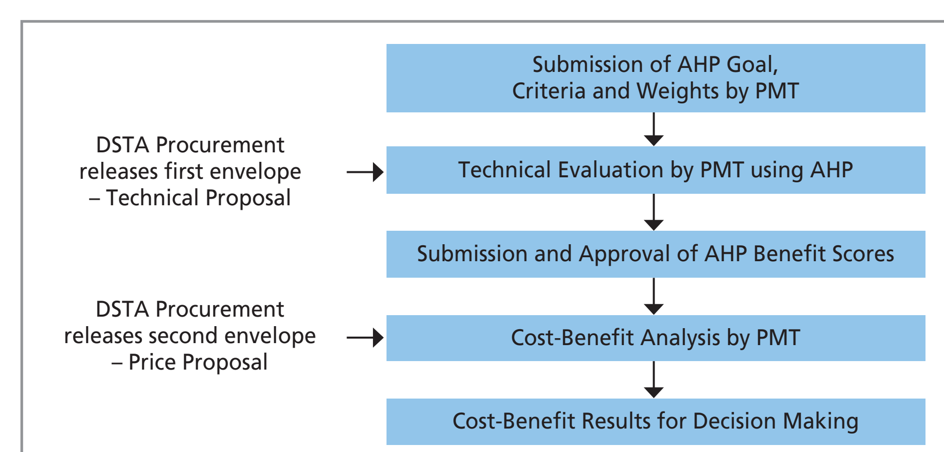

Figure 2. DSTA's two-envelope tender evaluation system

level criteria used in these evaluations have been well established and refined over the years through applications in multiple projects. Hence, the approach is relatively straightforward for DSTA PMTs. To tackle non-defence government projects, the DSTA consultancy team had to understand the technical and business aspects of the projects before working with the various project teams to determine the project objectives and criteria hierarchies.

Early involvement in these projects was critical as it allowed the DSTA consultancy team to understand the project, and map out a comprehensive evaluation approach that identifies key requirements to be included in the tender documents.

Managing Diverse Stakeholders

MINDEF is typically the main stakeholder of defence projects. For projects involving users from different Services, there is often a consensus on the key project criteria and their relative weights since the overall objective is to achieve robust systems effectiveness at an affordable cost.

However, for commercial projects which involve several stakeholders, deciding on the weights for the criteria is challenging due to different interests of the stakeholders. For example, the key stakeholders in the Marina Bay Integrated Resort project are STB, the Ministry of Finance (MOF) and the Urban Redevelopment Authority (URA) – whose areas of interests are tourism appeal, development investment and architectural excellence respectively.

Given the different motivations of the stakeholders, a strong facilitator was required to manage the evaluation process in order to arrive at a set of criteria and weights acceptable to all parties. The then STB Chief Executive Lim Neo Chian, facilitated by the DSTA consultancy team, led the evaluation process and played a pivotal role through his firm and objective approach in managing the diverse views of the stakeholders. Through his persuasion and reasoning, the stakeholders were able to arrive at an outcome acceptable to all parties.

Criteria Used

Project evaluation criteria differed significantly among non-defence governemnt projects due to their varied nature, which can be illustrated using two examples.

Figure 3 shows the first-level criteria of the Marina Bay Integrated Resort project and key stakeholders for each criterion. The goal of the project was kept generic as "Selecting the proposal that maximises economic benefits for Singapore" (STB, 2006). This goal was supported by the first-level criteria of tourism appeal, architectural excellence, development investment and strength of consortium. While architectural excellence does not contribute directly to economic gains and therefore should not have a higher weight than development investment, it can be argued that an iconic monument could lead to higher tourism appeal and investment. Thus, a significant weight of 30%

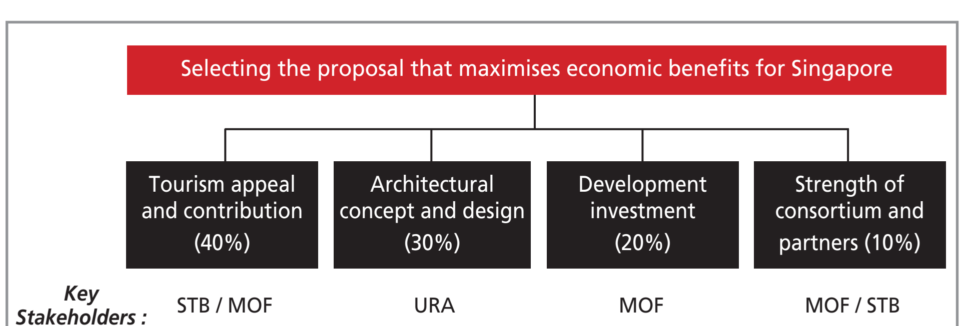

Figure 3. Goal and first-level criteria for the Marina Bay Integrated Resort project (Source: STB)

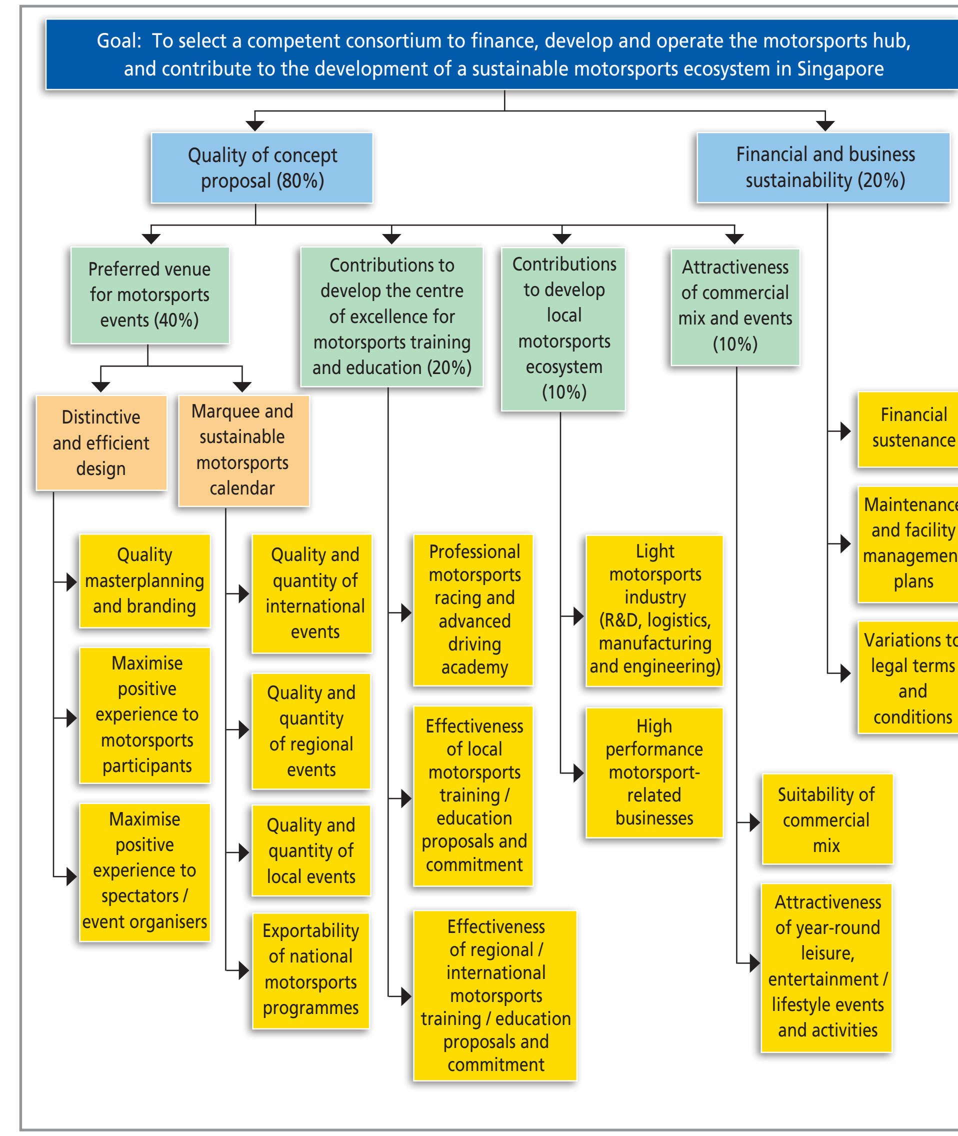

Figure 4. AHP Tree for the Changi Motorsports Hub project

was allocated to architectural concept and design, which was only 10% lower than the 40% weight allocated to tourism appeal.

For the Changi Motorsports Hub project, SSC's goal extended beyond building a world-class race track. It had a more encompassing objective to promote and develop Singapore's motorsports ecosystem, which includes motorsports training, the motorsports industry as well as commercial set-ups and events to augment the appeal of racing activities. These objectives were then grouped under the first-level criteria – quality of concept proposal – which was given 80% of the weight. The other 20% went to financial and business sustainability to ensure that the winning bid has sufficient finances for the project's design, development and operations in the long term. Figure 4 illustrates the goal of the Changi Motorsports Hub project, the first three levels of criteria and some of the weights (SSC, 2010).

The derivation of the criteria for each project was not a straightforward matter as these projects were diverse in nature. Each project team had to agree on the overall goal of the project before the first-level criteria could be established. This process to arrive at the final hierarchy could take several weeks of intense deliberation.

STRENGTHS AND LIMITATIONS

A key strength of AHP is the ability to incorporate a variety of tangible and intangible criteria into the same hierarchy to allow comparison using the same ratio scale. AHP facilitates group dynamics and organises feelings, intuition and logic from different stakeholders using a structured approach to enable objective decision making. Having a structured approach also minimises the unintended exclusion of any criterion that could be important to the evaluation outcome.

AHP is also simple to use as government agencies with no prior knowledge of AHP were able to apply it to their projects after going through some basic training. The criteria used for these projects are generally not mission-oriented and are relatively independent of one another, making AHP an ideal tool. The swiftness with which AHP has been learnt and applied in diverse projects, as well as the project teams' satisfaction with the outcomes, testify to the efficacy of AHP. As a result, MOF has decided to mandate the use of AHP for the evaluation of all government projects costing more than S$50 million. This policy was included in MOF's revised Instruction Manual on Procurement issued in June 2009.

In defence applications, evaluation using AHP has become increasingly challenging for complex acquisitions as AHP cannot model the dynamic scenarios that are prevalent in the SAF's network-centric operations. This is because the factors defined in the traditional AHP approach are treated independently, and their interdependence and interactions in a network-centric operation cannot be adequately accounted for. The consequences of such interactions in operational scenarios over time and space are often too complex to be deduced intuitively by human perception or a panel of experts.

In addition, different stakeholders also have different ideas of utilising the systems capabilities to conduct a mission. While AHP has been employed in many acquisition projects, MINDEF is continually seeking to enhance AHP evaluation approach so as to better determine the military worth of increasingly complex and interdependent weapon systems and platforms operating as a System of Systems (SoS). The complex interactions among these systems and the multiple roles they play in numerous mission scenarios require more comprehensive evaluation tools. Hence, there is a need to develop new methodologies to complement the traditional evaluation approach. This has led DSTA to leverage Operations Analysis (OA) to offer a more encompassing approach as part of an enhanced AHP framework to support tender evaluation.

ENHANCED METHODOLOGY USING OPERATIONS ANALYSIS TOOLS

OA, also known as Operations Research, has been associated with systems analysis, systems engineering, management science and cost-effectiveness analysis (The RAND Corporation, 1968). Its origins can be traced to World War Two when UK and US scientists applied OA techniques to search and destroy enemy submarines, protect merchant ships and minimise the loss of aircraft from bombing missions. Today, OA is applied in many areas beyond military applications e.g. industrial engineering, supply chain management, as well as business and financial management.

OA focuses on the operational nature of the issues that are being studied. In this respect, the definition by Morse and Kimball (2003) is adopted i.e. "Operations Research is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control". In other words, OA is a systematic and iterative approach that uses analytical techniques to provide a measurable result on an operational issue. Its purpose is to facilitate decision making among operational commanders, key stakeholders and decision makers. These analytical techniques include statistics, probability theory, queueing theory, game theory, optimisation and simulation.

As OA is mathematical and computational in nature, it relies heavily on computer science technologies to develop tools and models for analysis. With the advancement of computing technologies, Modelling and Simulation has evolved into a mature discipline with wide-ranging applications, and it has also become an essential technology and tool used in OA.

For evaluations that require the use of OA to complement AHP, the benefits assessment provides inputs to the main branches of the AHP tree as shown in Figure 5. For the Capability branch, traditional factors such as air-to-air capability, air-to-ground capability and survivability have been replaced with tactical and mission analysis. For example, tactical analysis can help to assess the effectiveness of a fixed-wing aircraft against another fixed-wing aircraft in a single engagement scenario. Mission analysis helps to assess the effectiveness of combat air patrols to defend against incoming airborne threats.

The key benefit of OA is its ability to consider both engineering and operational factors in a dynamic scenario to determine the military worth of the various alternatives. It can also incorporate different concepts of operations from various operational users and stakeholders. As a result, the force multiplier effects of a candidate system that can be integrated with a suite of networked sensors and weapon systems were observed when compared with stand-alone systems and platforms that offer limited or no integration with the SAF networked SoS. More importantly, the military utility of a candidate system applied to different concepts of operations could be quantified, providing greater clarity for different stakeholders.

OA also offers insights into potential weak links in systems design, rules of engagement

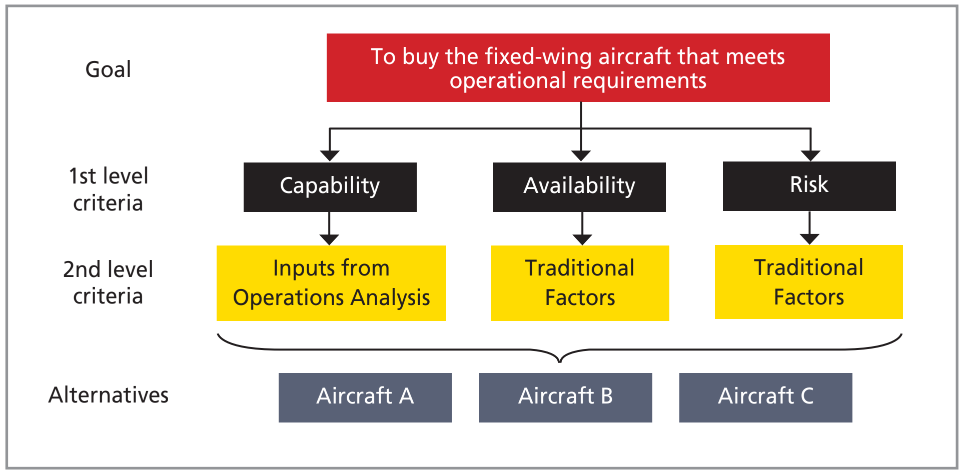

Figure 5. Enhanced AHP hierarchy

and supportability issues. For example, an OA analysis in systems design can reveal that leveraging a platform with high endurance may result in more on-board systems failures and poorer mission effectiveness.

DSTA has been using the enhanced AHP methodology to evaluate weapon systems and platforms such as the F-15SG Fighter Aircraft, Apache Longbow Attack Helicopter and the Formidable-class Stealth Frigate, hence validating the effectiveness of the enhanced AHP framework. Stakeholders and decision makers were able to obtain a better understanding of the effects of an acquired system in an operational context.

CONCLUSION

The use of AHP for evaluation has proved to be successful despite the varied nature of government projects. The criteria used for these projects are generally not mission-oriented and are relatively independent of one another, making AHP an ideal tool. For systems which have criteria that are more dynamic and interdependent, the use of OA to complement AHP produces a more representative and accurate assessment of the systems being evaluated.

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BIOGRAPHY

Kwok Yoong Fui is a Principal Engineer and Resident Lecturer (DSTA College). He oversees the DSTA Basic Systems Engineering and Management Course and conducts lectures in Systems Engineering, Life Cycle Management, Project Risk Management and Analytic Hierarchy Process (AHP). He plays a key role in advancing AHP and provides advice on the use of AHP for tender evaluations, as well as issues related to life cycle management and project risk management. Yoong Fui was instrumental in the development of the Project Risk Management methodology. He obtained a Bachelor of Engineering (Electrical Engineering) degree with Honours from the National University of Singapore (NUS) in 1988.

Lim Hang Sheng is a Lead Analyst (DSTA Masterplanning and Systems Architecting). He has worked on integrating systems on fighter platforms and is currently conducting systems effectiveness studies. He has also served as Senior Manager (Organisational Change and Learning) in Corporate Planning and Development. Hang Sheng is a member of the project team which attained the Defence Technology Prize Team (Engineering) Award in 2001. He obtained a Master of Science (Electrical Engineering) degree from NUS in 1999 and a Master of Business Administration (Management of Technology) degree from Nanyang Technological University in 2002. Under the DSTA Postgraduate Scholarship, he graduated in 2007 with a Master of Science (Defence Technology and Systems) degree from NUS and a Master of Science (Operations Research) degree from the Naval Postgraduate School, US.