ISAHP 2007, Viña Del Mar, Chile, August 8-3, 2006

CONFIGURING A MAJOR AMPHIBIOUS VESSEL: A MULTI-CRITERON DECISION MAKING MODEL USING THE ANALYTIC HIEARCHY PROCESS

M. Murat Albayrakoglu
Coordinator, Business Informatics Program
Istanbul Bilgi University
Kurtulus Deresi Cd. 47 Dolapdere
34440 Istanbul Turkey
albayrak@bilgi.edu.tr

Keywords: amphibious vessel, configuration, modularity, multi-criterion decision making (MCDM), analytic hierarchy process (AHP).

Summary: *Recently, naval vessels have been designed increasingly modularly. Amphibious vessels also follow this trend. A major amphibious ship consists of one or more of the following resources to perform its assigned tasks: flight deck, ski jump, well deck, vehicle or cargo deck, hangar deck, hospital, command and control facilities, and, supply and support facilities. Each of these resources can be thought as a module. The relative importance of each of these modules can be used to determine the architectural configuration, and, therefore, the type of the ship The relative importance of each module, on the other hand, depends on the assets required for a set of tasks carried out under a set of scenarios ranging from disaster relief during peace time to participation in full-scale amphibious warfare. In this paper, a multi-criterion decision-making (MCDM) model using the analytic hierarchy process (AHP) is proposed to help determine the configuration of a major amphibious vessel under a set of scenarios, associated tasks and asset requirements. An application of the model is presented. Finally, advantages, limitations and extensions of the model are discussed.*

1. Introduction

Several developments in the last two decades had a profound impact on the force structures and composition of the World's navies: September 11 attack on New York in 2001; interventions under the United Nations (UN) mandate to Rwanda, Somalia, Haiti, former Yugoslavia, East Tumor and Afghanistan; and the natural disasters that took place in Japan, Bangladesh, Turkey, Indonesia, Pakistan and the United States (US). As a reaction to these developments, major navies and marine forces started emphasizing greater sealift capabilities for amphibious warfare (Annati, 2005; Braybrook 2005; Hoffman, 2006; Hooton, 2005a & 2005b; Kemp, 2006) as well as for humanitarian missions (Annati, 2007; Cavas, 2007;); smaller and more agile marine formations (Hoffman, 2006); and pooling naval and marine assets in multilateral rapid-reaction units under such organizations as the North Atlantic Treaty Organization (NATO) (Wörner, 1991) and the European Union (EU) (The Council of the EU, 2001).

After the disintegration of the Soviet Union, the World's navies were in a state of recession. Although there were numerous projects involving modern designs, the navies became smaller with less and less number of ships. During this period, the emphasis for new ships turned onto patrol ships and major amphibious vessels. (Baker III, 2001, 2002, 2003, 2004). Another development has been the construction of modular naval vessels (See for example General Dynamics; Lockheed Martin; Naval Team Denmark). The most recent amphibious vessel designs from Fincantieri in Italy and Schelde Shipbuilding from the Netherlands also follow this trend (Cavas, 2007; Schelde Shipbuilding).

Throughout the Cold War, only three major Western navies—the U.S. Navy, Royal Navy and French Navy with the exception of Greece and Spain—other than the Soviet Union used to own and operate major amphibious vessels larger than the landing ship tank (LST). Later on, Royal Dutch Navy, and Italian Navy acquired landing platform docks (LPDs). More recently, Indian Navy, Indonesian Navy, Japanese Maritime Self Defense Force South Korean Navy, and Spanish Navy included LPDs in their fleets. Recently, New Zealand Navy acquired a multi-role vessel (MRV) without a dock. Canadian Navy is working on a joint support ship (JSS) with amphibious capabilities in addition to fleet support duties. Argentinean, Brazilian, and Taiwanese Navies operate second-hand landing ship docks (LSDs). (Saunders, 2004; Wertheim, 2005, 2006, 2007). At present, countries such as Australia, Belgium, China, Germany, Norway, Portugal and Turkey are in various phases of acquiring similar naval vessels.

In order to procure a major amphibious vessel, navies should evaluate several alternative configurations, or types. The Appendix at the end of this paper lists the current amphibious vessel types and provides examples from the United States Navy (USN) and several European navies. The appendix also shows key physical and performance characteristics of each class of ships.

The decision for which type to procure should be made at an early stage of the ship design process. It is a complex problem that involves a set of qualitative factors at the highest level. In addition, various military and civilian stakeholders participate in the decision process to select a particular configuration.

Such a decision requires using a multi-criterion decision-making (MCDM) approach and the analytic hierarchy process (AHP), developed by Thomas L. Saaty at Wharton School of Business, is a suitable method to handle the problem. Figure 1 shows the ship design process as a set of iterations (Watson, 1998; Whitcomb & Szatkowski, 2000) and at which point during the design an AHP model should be used to configure the ship.

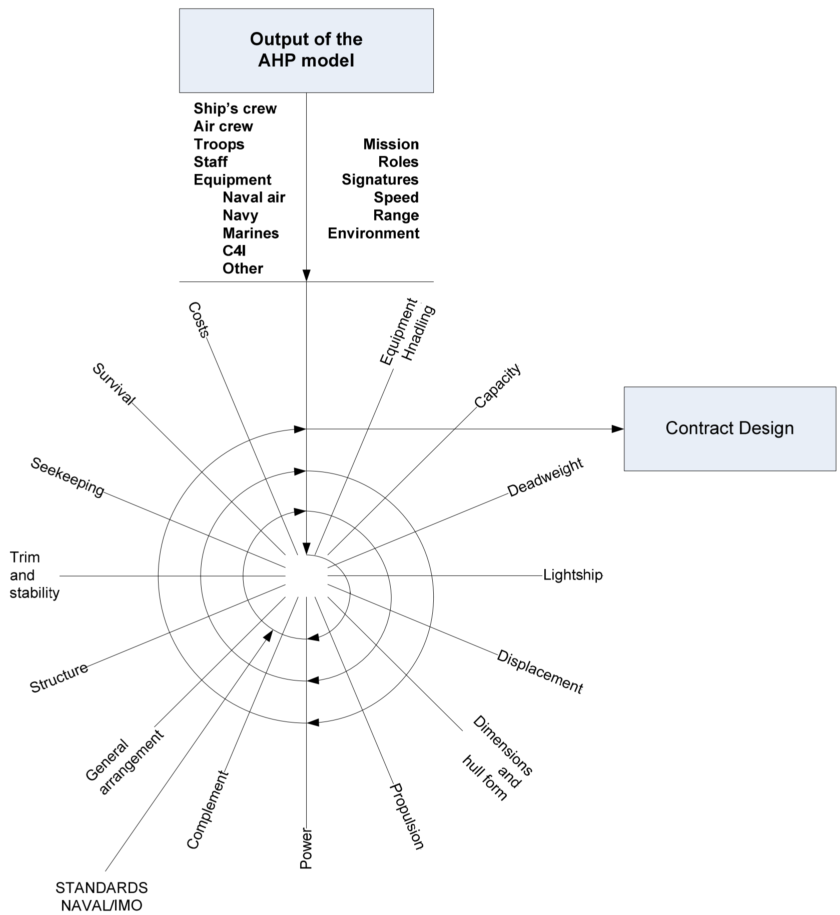


Figure 1. The Ship Design Spiral

In the rest of this paper, the AHP method will be briefly described. An AHP model that can help configure an amphibious vessel will be developed and implemented. The findings and implications of the implementation will be discussed. How the results of the model can be interpreted to decide the type and characteristics of the vessel is demonstrated. Finally, advantages, limitations and extensions of the model are presented and its potential uses and users will be listed.

2. The Analytic Hierarchy Process

The AHP, developed by Thomas L. Saaty throughout 1970s, is a method used to make multi-criterion decisions when it is possible to represent the decision elements hierarchically in the form of a tree (Saaty, 2000, 2001). At the top of the hierarchy, there is a goal to be reached by a decision maker or a group of decision makers. Under the goal, there is a set of primary criteria that would be evaluated in pairs for their importance with respect to the goal. Subcriteria, such as secondary or tertiary criteria and so on, follow the primary criteria. At the bottom of the hierarchy, there exists a set of decision alternatives. Each level consists of clusters made up of similar elements in order to ensure homogeneity.

The AHP is based on four axioms: (1) *reciprocality* that allows the decision maker conduct paired reciprocal comparisons for each element within the clusters; (2) *homogeneity* that requires the decision maker to compare similar elements with respect to a common property; (3) *dependence* that implies elements at a particular level to depend on one element at a higher level, and be independent of each other; and (4) *expectations* that require the decision maker to include all relevant criteria and all relevant alternatives in the hierarchy in order to reach to a meaningful decision (Saaty, 1986; Forman & Gass, 2001).

In order to derive local priority of each element, the AHP uses a 1-9 ratio scale. Pairwise comparisons are made according the scale shown in Table 1. On the scale verbal definitions are assigned to discrete values that change from 1-9. In addition to importance, the verbal definitions can be based on the likelihood or preferability of each element within a cluster with respect to each other element in the same cluster. During comparisons, the decision maker should pay attention the consistency of his or her judgments.

Intensity of Importance	**Definition**
1	Equally important
2	Between equally and moderately important
3	Moderately important
4	Between moderately and strongly important
5	Strongly important
6	Between strongly and very strongly important
7	Very strongly important
8	Between very strongly and extremely important
9	Extremely important

Table 1. The Fundamental Scale of the AHP

The AHP tolerates some inconsistency in pairwise comparisons for each cluster with respect to its parent element. Existence of inconsistency in most cases is a direct result of using a limited scale and redundant comparisons necessary to determine local priorities (Saaty, 1994). In order to be consistent, comparisons must satisfy two conditions: (1) transitivity, and (2) proportionality. However, along with Gödel's second incompleteness theorem, when a restricted scale is used, most of the time, it is impossible to satisfy the proportionality requirement. Therefore, the AHP allows for inconsistency up to 10% of randomly made comparisons. However, in order to keep inconsistency under control, Saaty (2001) recommends at least satisfying the transitivity requirement.

Once all local priorities are derived, they are multiplied with the priority of their parent to derive global priorities of the decision alternatives throughout the hierarchy to reach an overall judgment, or a synthesis, about each decision alternative with respect to the goal. After the synthesis, each cluster is studied to determine how sensitive the local priorities with respect to their parent are. The sensitivity analysis helps the decision maker to assess robustness of his or her model.

3. An AHP Model to Configure the Amphibious Vessel

In addition to all elements that make a vessel become a ship, a major amphibious vessel is configured around a combination of specific modules: (1) the living quarters for crew, troops, and staff; (2) cargo-vehicle deck; (3) the flight deck; (4) the hangar deck; (5) the well deck; and (6) the command, control, communications, computers and intelligence (C4I) facilities. Each module provides a distinct capability to the ship. The living quarters and cargo-vehicle deck enables the ship to transport people, equipment, supplies and vehicles for long distances. The vehicle deck also provides roll-on/roll-off (RO-RO) capability: vehicles, trailers, and other wheeled cargo can be driven on and off through a ramp. The flight deck is used to transport and operate helicopters, aircraft or unmanned aerial vehicles (UAVs). The hangar deck is used to store, transport, and maintain helicopters, aircraft or UAVs. The well deck is needed to store, transport, maintain, or operate amphibious craft and amphibious assault vehicles (AAVs). The C4I facility is required to conduct the ship's own operations at a minimum and, to the highest extent, to conduct the operations of an entire amphibious group that consists of other vessels, including amphibious ships, surface combatants, mine counter-measure ships, submarines, and support ships.

The first step to procure a new amphibious ship is to decide about the type. Once the type has been determined, an existing design, or an existing class can be selected, or, a new ship is designed based on the type decision. The type decision should be made either by qualitatively evaluating concept designs or by using a more structured approach using an MCDM model. Figure 2 shows the general structure of an AHP model that can be used to determine the type. In the figure, the scenarios include three levels.

At the top of the seven-level hierarchy, there is the goal of determining the importance of the decision alternatives, or modules which make up an amphibious ship. The modules at the bottom constitute the solution space that will be interpreted to determine the type of the ship.

The primary criteria are comprised of three of the four states of conflict that range from peace to general war. The second-level criteria consider whether the operations are carried out unilaterally or multilaterally. The unilateral or multilateral operations performed by the ship constitute the third level. These three levels of criteria are regarded as *scenarios*—a hierarchical construct made up of the states of conflict, the number of participating countries, and the operations carried out. The fourth-level criteria include clusters of tasks, each carried out under a particular scenario.

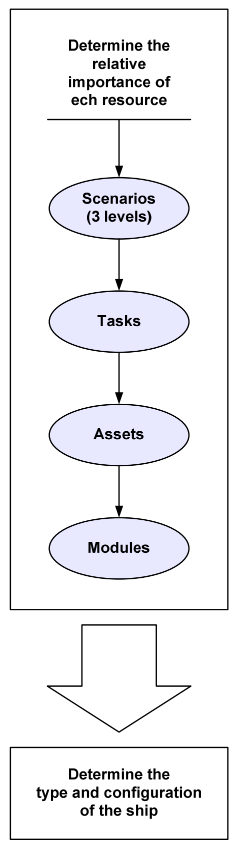


Figure 2. The General Structure of the AHP Model

The assets required to carry out each task constitute the fifth-level criteria. In order perform each task, assets utilize different modules. Some modules are dedicated only to a single asset: for example the living quarters are used by the personnel, or the hospital is dedicated to sick and wounded. Some other modules can be used to support or operate two or more assets, and, thus, give Type III flexibility (MacKenzie & Tuteja, 2006) to the ship: for example, both flight deck and well deck can be used to transport cargo or vehicles as well as the cargo-vehicle deck.

Like any armed force, a major amphibious vessel operates in a set of different environments: peace; low-intensity conflict; high-intensity conflict; and general war. These four environments constitute the *spectrum of conflict* (RAN Sea Power Centre). Under peace [PEACE], bilateral or unilateral problems among the nations are solved through negotiation. Military intervention takes place only to stop violent internal political conflict, or to establish international order through peace-keeping operations usually under the mandate of a supranational organization such as the U.N. or NA.T.O. Another requirement during peacetime is deterrent that implies the ownership of the military assets and demonstration of capability to use these assets through exercises, port visits and show of flag. Humanitarian operations during major natural disasters—earthquakes, floods, volcano eruptions etc.—are also considered peacetime activities.

Low-intensity conflict [L_I_CONFLICT] is a violent conflict that is not a full-scale war: it sporadically takes place between the armed forces and irregular armed militias, such as terror organizations, guerrillas, rioters etc. Operations under low-intensity conflict conditions are seldom carried out unilaterally; a mandate of a supranational organization is usually required.

In terms of military operations and their outcomes, high-intensity conflict [H_I_CONFLICT] and general war are not very different. In fact, both are similar from a tactical point of view. Both are more intense than the low-intensity conflict, and require the use of assets in a coordinated fashion. However, the latter consumes much greater amount of resources throughout a much longer period than the former does. Consequently, [PEACE], [L_I_CONFLICT], and [H_I_CONFLICT] are the primary criteria in the hierarchy.

In any of the states of the spectrum of conflict, the amphibious ships conduct operations either on a unilateral basis [UNI_LATERAL] solely for the national interests; or, on a multilateral basis [MULTI_LATERAL] for interests shared by two or more nations. The difference between unilateral and multilateral operations is the lack or the availability of other resources that can supplement the capabilities of the amphibious ship during peacetime, low-intensity conflict, or high-intensity conflict.

During peacetime, whether on a unilateral or multilateral basis, there are three major operations to be conducted: disaster relief [DISASTR_REL], peace keeping [PEACE_KEEP], or command and control [COMND_CON] operations. During low-intensity conflict, low-scale air-mobile [L_SCL_AIR_M], low-scale sea-mobile [L_SCL_SEA_M], and command and control [COMND_CON] operations are carried out. Finally, during high-intensity conflict, high-scale air-mobile [H_SCL_AIR_M], high-scale sea-mobile [H_SCL_SEA_M], and command and control [COMND_CON] operations are conducted.

During each of these operations, one or more tasks are performed. Ship-to-shore or shore-to-ship transfer of people, vehicles or cargo by sea [AMP_TRANS] and by air [AIR_TRANS] is a task of general nature. When it is necessary to put the assets in harms way during a conflict, air assault [AIR_ASSAULT] and amphibious assault [AMPH_ASSAULT] are carried out. In contrast to transfer tasks, assault tasks may require fire support from the air and from the sea. Consequently, the compositions of the assets for transfer and assault tasks are somewhat different although the assets for the former are also required for the latter. In certain cases, an amphibious ship, such as an LHD or LHA, can act as a small aircraft carrier as part of a naval task group for sea control [SEA_CONTROL] duties.

In order to implement the assigned tasks, the ship carries and operates a subset of the following assets: marines [MARINES]; cargo [CARGO]; fixed-wing aircraft or UAVs [AIRCRAFT]; rotary-wing aircraft or UAVs [HELICOPTERS]; amphibious craft [AMPH_ CRAFT] such as landing craft utility (LCUs) or landing craft air cushion (LCACs); vehicles [VEHICLES]; and C4I equipment [C4I_EQPMNT]. Each subset of these resources makes up a cluster corresponding to a particular task.

In order to transport and facilitate the operations of onboard assets and others, the amphibious ship requires the following facilities or modules: the flight deck [FLIGHT_DECK]; the well deck [WELL_DECK]; cargo-vehicle deck [VHL_CRG_DCK]; the hangar deck [HANGR_DECK]; the C4I facility [C4I_FACILITY]; and the living quarters [ACOMMODATN]. Under each asset, a subset of these modules needs to be grouped in a cluster. For example, the living quarters are used by all the personnel who maintain and operate all the assets including the crew handling the ship itself. The fixed-wing and rotary-wing aircraft require a hangar in most cases, but the vehicle or cargo deck, or the well deck can be used to store and transport aircraft as well.

The complete AHP model is shown in Figure 3. In the model the goal to determine the importance of each module is seen on the left and the decision alternatives are located at the right. Between the goal and the decision alternatives lie the criteria beginning with the primary criteria to the right of the goal to the fifth-level criteria just before the decision alternatives on the right. The figure also shows how lower level criteria are related to their parents to compose the clusters.

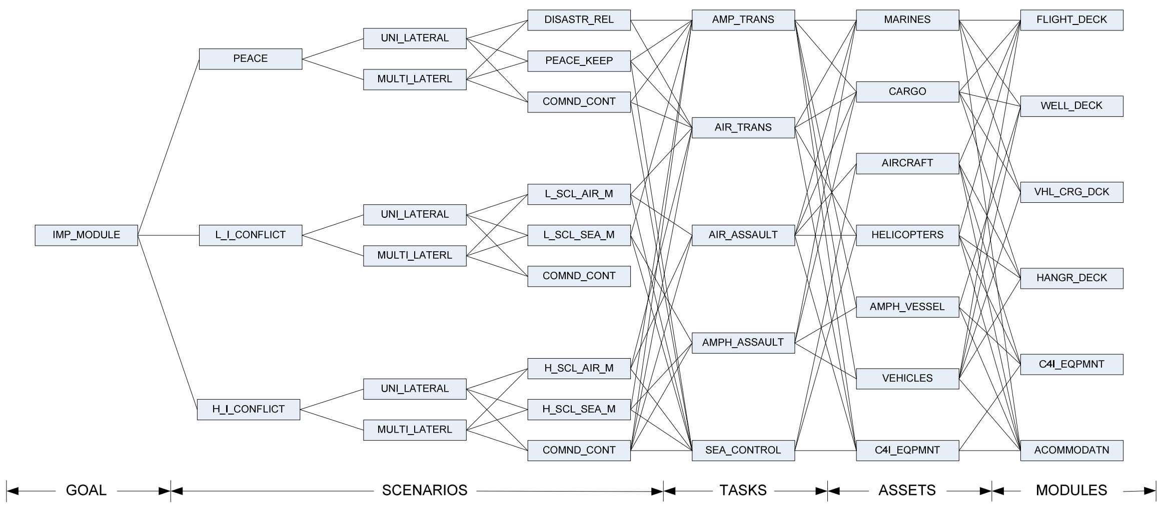


Figure 3. The Hierarchy to Determine the Importance of Each Module.

4. An Implementation of the Model

An spplication of the AHP model is implemented on WebHIPRE (HIerarchical PREference analysis on the World Wide Web), a decision making tool based on the Java® technology and used for general-purpose decision analysis. In addition to the AHP, WebHIPRE supports other weighting methods and allows for developing hybrid models (Mustajoki & Hämäläinen, 2000). One difference between the implementations of the original AHP and WebHIPRE is the different measures used for inconsistency: instead of the consistency ratio (*CR*) of the original method, the consistency measure (*CM*) is used in WebHIPRE.

Figure 4 shows the WebHIPRE model. In the figure, all the elements are the same as those of Figure 3 with the exception of the goal that is stated explicitly. Since this is a very high-level model without any hard data, the verbal importance scale of Table 1 is used to derive the local priorities. The derivation of the local priorities with respect to the goal is shown in Figure 5. Although there is no specific recommendation by Mustajoki & Hämäläinen (2000) for how *CM* should be used, *CM* is treated as *CR* and is not allowed to go beyond 10% in the application. Figure 6 gives the global importance of the importance of each module with respect to the goal. In the figure, the well deck, living quarters and the flight deck are the three most important modules.

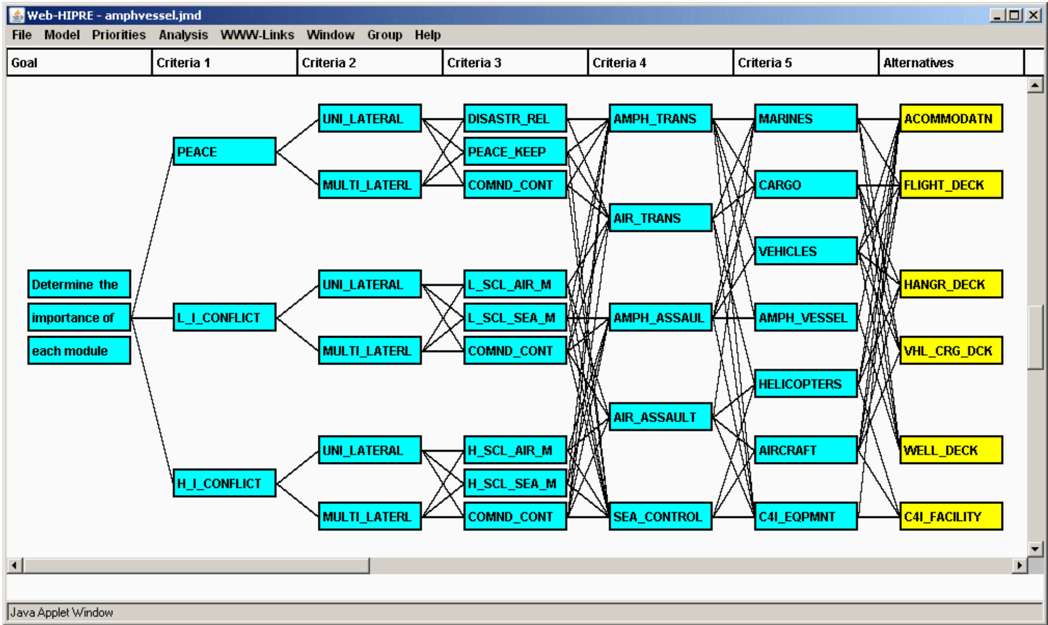


Figure 4. The WebHIPRE Model for Configuring an Amphibious Vessel

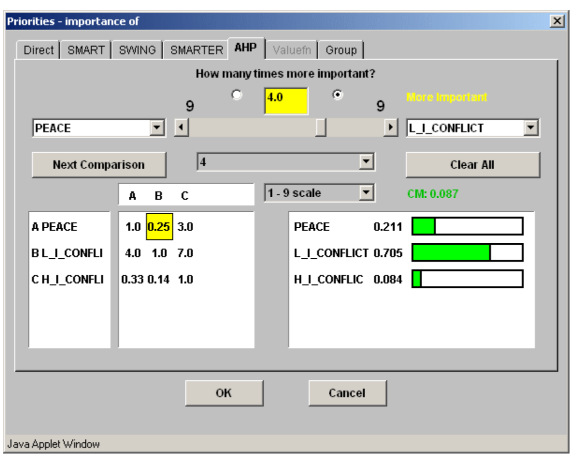


Figure 5. derivation of the Local Priorities with Respect to the Goal

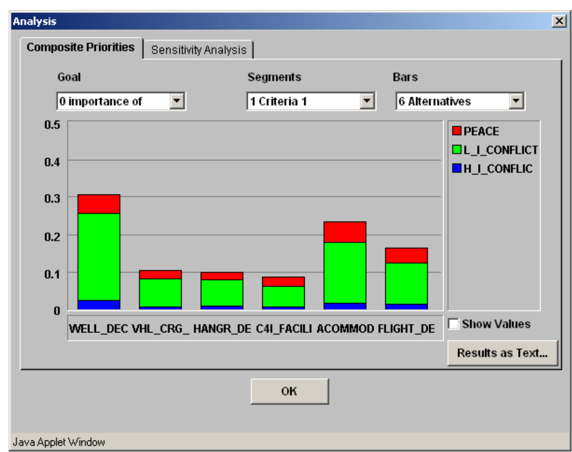


Figure 6. The Results of the Model

Figure 7 and Table 2 show the solution space for typical examples of amphibious ships-versus-the AHP solution. In addition to the amphibious ship types, a RO-RO vessel is added to the typical examples for reference purposes. The priorities for each typical ship in the table are derived by considering the operational requirements. The ordinal importance of each module is converted into cardinals by assuming that the least important module has a unit magnitude of importance and the rest is proportional to the ordinal importance.

A differential analysis shown in Table 2 is conducted between the AHP solution and the typical examples: the minimum difference is found between a typical LPD and the AHP solution. As a result, this particular implementation suggests an LPD with a large well deck, a half-deck helicopter pad with about two landing spots, a small hangar for one medium helicopter and a C4I facility mainly to support the ship's own operations. As exemplified in Figures 8(a) through 8(c), the model is significantly robust.

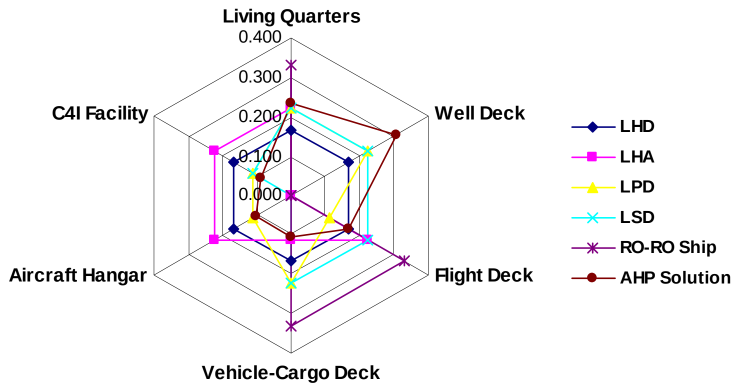
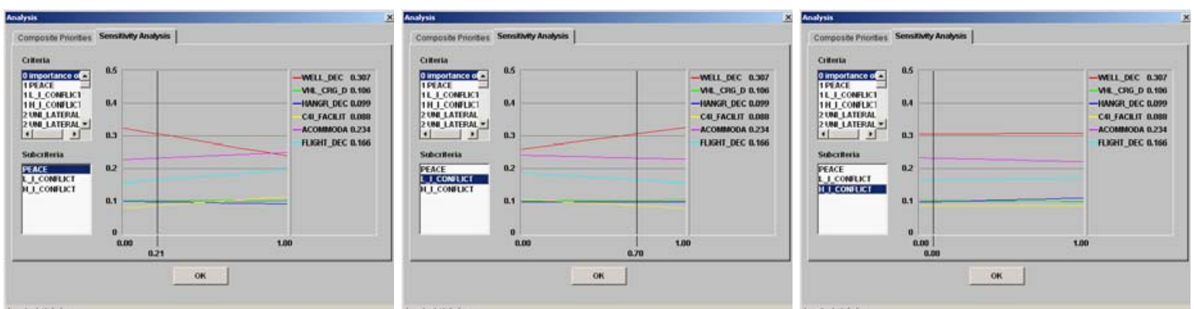


Figure 7. The Solution Space, Typical Examples and the AHP Solution

	SOLUTION SPACE AND MODEL RESULTS							DIFFERENTIAL ANALYSIS						
Type	Living Quarters	Well Deck	Flight Deck	Vehicle-Cargo Deck	Aircraft Hangar	C4I Facility	Sum	Living Quarters	Well Deck	Flight Deck	Vehicle-Cargo Deck	Aircraft Hangar	C4I Facility	Sum
LHD	0.166	0.166	0.166	0.166	0.166	0.166	1.00	0.068	0.141	0.000	0.060	0.067	0.078	0.41
LHA	0.222	0.000	0.222	0.111	0.222	0.222	1.00	0.012	0.307	0.056	0.005	0.123	0.134	0.64
LPD	0.222	0.222	0.111	0.222	0.111	0.111	1.00	0.012	0.085	0.055	0.116	0.012	0.023	0.30
LSD	0.222	0.222	0.222	0.222	0.000	0.111	1.00	0.012	0.085	0.056	0.116	0.099	0.023	0.39
RO-RO	0.333	0.000	0.333	0.333	0.000	0.000	1.00	0.099	0.307	0.167	0.227	0.099	0.088	0.99
AHP Solution	0.234	0.307	0.166	0.106	0.099	0.088	1.00	0.000	0.000	0.000	0.000	0.000	0.000	0.00

Table 2. Solution Space, Typical Examples and the Differential Analysis



(a) Sensitivity of Peacetime Configuration **(b) Sensitivity of Low-Intensity Conflict Configuration** **(c) Sensitivity of High-intensity Conflict Configuration**

Figure 7. Sensitivity of Primary Criteria

7. Conclusion

The high-level model discussed in this paper is a useful tool for an earlier clarification of the requirements before procuring an amphibious vessel. It is based on the qualitative evaluation of the factors that constitute the procurement problem before the design process. The solution space can be expanded to cover all possibilities ranging from RO-RO carriers to command ships similar to the USN's Blue Ridge class. The model helps stakeholders and decision makers to identify, understand and communicate the factors that make up the procurement problem and helps facilitate consensus among the stakeholders by linking the architectural elements that make up the ship to assets required to fulfill tasks under the light of tactical and strategic priorities of a naval force or the marines. The decision situation is very suitable for the application of the AHP.

The model presented here is a generic one. However, it can be customized or extended for a particular navy by adding new elements or removing some of the existing elements. For example, instead of treating all multilateral states of conflict, a navy can easily incorporate operations conducted under particular supranational organizations such as the UN, NATO, EU etc. Among the potential users of the model are the ministries of defense and naval staff, naval consultants and shipyards. Whereas ministries and naval staff can use the model for procurement decisions on a particular type, naval consultants and shipyards can use the model as a tool for making product portfolio decisions and consulting purposes.

References

Annati, M. (2005). Strategic Force Projection and Sealift Ships. *Military Technology*, *29*(8), 83-91.

Annati, M. (2007). Naval Assets for Long-Term Deployment. *Military Technology*, *31*(4), 84-90.

Baker III, A. D. (1999). World Navies in Review. *U.S. Naval Institute Proceedings*, *12*5(3), 76-82.

Baker III, A. D. (2000). World Navies in Review. *U.S. Naval Institute Proceedings*, *126*(3), 30-40.

Baker III, A. D. (2001). World Navies in Review. U.S. *Naval Institute Proceedings*, *127*(3), 32-43.

Baker III, A. D. (2002). World Navies in Review. *U.S. Naval Institute Proceedings*, *128*(3), 32-42.

Baker III, A. D. (2003). World Navies in Review. *U.S. Naval Institute Proceedings*, *129*(3), 44-57.

Baker III, A. D. (2004). World Navies in Review: World's Navies Are in Decline. *U.S. Naval Institute Proceedings*, 130(3), 32-49.

Braybrook, R. (2005). From A to B, ASAP! *Armada International*, *29*(5), 1-24.

Cavas, C. P. (2007). Amphib Makers Pursue Growing World Market. *DefenseNews.com*. November 6, 2007. Retrieved May 21, 2007, from http://defensenews.com/story.php?F=2329772&C=navwar.

The Council of the E.U. (2001). Council Regulation (EC) No 381/2001 of 26 February 2001: Creating a Rapid-Reaction Mechanism. *Official Journal of the European Communities*. *44*(L57), 5-9.

Forman, E. H. & Gass, S. I. (2001). The Analytic Hierarchy Process: An Exposition. *Operations Research*, *49*(4), 469-486.

General Dynamics. (n.d.). *Operational Capabilities: Maximum Warfighting-Minimum Expense*. Retrieved May 21, 2007, from http://www.gdlcs.com/gd_opsCapability.html.

Hoffman, F. (2006, March). How Marines are Preparing for Hybrid Wars. *Armed Forces Journal*. Retrieved May 22, 2007, from http://www.armedforcesjournal.com/2006/03/1813952/.

Hooton, E. R. (2005a). Send an Amphib, the Future Cry. *Armada International*, *29*(1), 10-13.

Hooton, E. R. (2005b). Shipping New Challenges. *Armada International*, *29*(5), 19-23.

Kemp, I. (2006). Assault from the Sea. *Armada International*, *30*(4), 35-40.

Lockheed Martin. (n.d.). *A Flexible Innovative Ship*. Retrieved May 21, 2007, from http://www.lmlcsteam.com/solution.html.

MacKenzie, S. C. & Tuteja, R. (2006) Modular Capabilities for the Canadian Navy's Single Class Surface Combatant: A Perspective on Flexibility. *Defence R&D Canada Contract Report*. Retrieved June 2, 2007 from http://pubs.drdc.gc.ca/inbasket/dguertin.061103_1515.p526474.pdf.

Mustajoki, J. & Hämäläinen, R. (2000). Web-Hipre: Global Decision Support by Value Tree and AHP Analysis. *INFOR*, 38(3), 208-220.

Naval Team Denmark. (n.d.). *Standard Flex Concept*. Retrieved May 21, 2007, from http://www.navalteam.dk/ships/std_flex_concept.aspx.

RAN Sea Power Centre. (n.d.). *Australian Maritime Doctrine: RAN Doctrine 1 - 2000*. Retrieved May, 25, 2007 from http://www.navy.gov.au/spc/amd/amdintro.html.

Saaty, T. L. (1986). Axiomatic Foundation of the Analytic Hierarchy Process. *Management Science*, 32, 841-855.

Saaty, T. L. (1994). How to Make a Decision: The Analytic Hierarchy Process. *Interfaces*, *24*(6), 19-43.

Saaty, T. L. (2000). *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process*. Pittsburgh, PA: RWS Publications.

Saaty, T. L. (2001). *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*. Pittsburgh, PA: RWS Publications.

Saunders, S. (Ed.). (2004). *Jane's Fighting Ships: 2004-2005*. Surrey, UK: Jane's Information Group.

Schelde Shipbuilding. (n.d.). *Schelde Enforcer Series*. Retrieved May 21, 2007, from http://www.scheldeshipbuilding.com/enforcer/.

Watson, D. G. M. (1998). *Practical Ship Design*. Oxford, UK: Elsevier.

Wertheim, E. (2005). World Navies in Review: A Year of Compromise. *U.S. Naval Institute Proceedings*, 131(3), 32-40.

Wertheim, E. (2006). World Navies in Review: Finding the Right Mix. *U.S. Naval Institute Proceedings*, 132(3), 46-64.

Wertheim, E. (2007). World Navies in Review. *U.S. Naval Institute Proceedings*, 133(3), 44-53.

Whitcomb, C. A. & Szatkowski J. J. (2000 June). Concept Level naval Surface Combatant Design in the Axiomatic Approach to Design Framework. *First International Conference on Axiomatic Design (ICAD2000)* (pp. 300-308). Cambridge, MA: ICAD2000.

Wörner, M. (1991). Nato Transformed: The Significance of the Rome Summit. *NATO Review*, 39(6), 3-8.
Whitcomb, C. A. & Szatkowski J. J. (2000 June). Concept Level naval Surface Combatant Design in the Axiomatic Approach to Design Framework. *First International Conference on Axiomatic Design (ICAD2000)* (pp. 300-308). Cambridge, MA: ICAD2000.

Appendix. Current Amphibious Vehicle Types and Examples (Saunders, 2004)

	Type	**Landing Ship Dock**	**Landing Platform and Dock**	**Landing Helicopter Assault**	**Landing Helicopter and Dock**
	Abbreviation	*LSD*	*LPD*	*LHA*	*LHD*
U.S.N. Examples	**Class**	*Whidbey Island*	*San Antonio*	*LHA(R)*	*Wasp*
	Dimensions (m)	185.8 × 25.6 × 6.3	208.4 × 31.9 × 7	280.7 × 34.8 × N/A	257.3 × 32.3 × 8.1
	Displacement (t)	15,950 full load	25,300 full load	50,905 full load	40,650 full load
	Speed (knots)	22	22	20+	22
	Range (miles)	8,000	N/A	N/A	9,500
	Cargo Deck	Yes	Yes	Yes	Yes
	Flight Deck	Yes (half deck)	Yes (half deck)	Yes	Yes
	Hangar Deck	No	Yes (half deck)	Yes	Yes
	Well Deck	Yes	Yes	No	Yes
	Complement	413	363	1,100	1,108
	Air Crew	N/A	N/A	N/A	N/A
	Troop Lift	402	699	1,800	2,000
	Aircraft	Platform only	3-6 helicopters	38 helicopters and STOVL aircraft	36 helicopters and STOVL aircraft
E.U. Examples	**Class**	*Bay Class*	*Rotterdam*	*Ocean*	*BPE*
	Dimensions (m)	176.6 × 26.4 × 5.1	166 × 25 × 5.9	203.4 × 34.4 × 6.6	230.8 × 32 × 7
	Displacement (t)	16,190 full load	12,750 full load	21,758 full load	27,082 full load
	Speed (knots)	18	19	19	21
	Range (miles)	8,000	6,000	8,000	9,000
	Cargo Deck	Yes	Yes	Yes	Yes
	Flight Deck	Yes (half deck)	Yes (half deck)	Yes	Yes
	Hangar Deck	No	Yes (half deck)	Yes	Yes
	Well Deck	Yes	Yes	No	Yes
	Complement	59	113	285	243
	Air Crew	N/A	N/A	206	220
	Troop Lift	356	611	830	900
	Aircraft	Platform only	4-6 helicopters	18 helicopters	30 helicopters and STOVL aircraft