Revisiting DDGX/DDG-51 Concept Exploration

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Abstract

This study revisits concept exploration for DDG-51 using reconstructed 1978–1979 DDX and 1979–1980 DDGX requirements and options, and 2005 tools. The goal of this study is to assess and highlight the benefits of current tools and processes for concept exploration by comparison with a well-known design that did not use these tools. This case study was completed in a summer and fall ship design project at Virginia Tech. In 1979, the acquisition and design process did not begin with a Mission Need Statement, Analysis of Alternatives or Integrated Capabilities Document as is required today. It began with studies, Tentative Operational Requirements, and Draft Top Level Requirements. In this study, we revisit the 1978–1980 DDG-51 (DDX/DDGX) concept exploration based on the guidance, goals, and constraints of the DDX and DDGX studies, using a notional mission statement, concept of operations, and list of required capabilities. The design space is defined to include many of the same design alternatives that were considered in the DDX and DDGX studies. A multiple-objective genetic optimization (MOGO) based on military effectiveness, cost, and risk is used to search the design space and perform trade-offs. A simple ship synthesis model is used to balance the designs, assess feasibility, and calculate cost, risk, and effectiveness. Alternative designs are ranked by cost, risk, and effectiveness, and presented in a series of non-dominated frontiers. Concepts for further study and development are chosen from this frontier and a comparison with DDG-51 is made based on these results.

Motivation and Introduction

The traditional approach to ship design is largely an "ad hoc" process. Experience, design lanes, rules of thumb, preference, and imagination guide the selection of design concepts for assessment. Often, objective attributes are not adequately synthesized or presented to support efficient and effective decisions. This case study uses a total system approach for the design process, including a structured search of the design space based on the multi-objective consideration of effectiveness, cost, and risk (Brown and Thomas 1998; Brown and Salcedo 2003).

The scope of this study includes only the first phase in the ship design process, concept, and requirements exploration. The concept exploration process followed in this study is shown in **Figure 1**. The first step in this process is to develop a clear and precise mission definition and list of required operational and functional capabilities starting with a Mission Need Statement and Acquisition Decision Memorandum, or an Integrated Capabilities Document. This process should not begin by jumping into specific requirements or design characteristics. These should be products of concept exploration, not initiating constraints. Requirements and design characteristics cannot be rationally specified without a thorough understanding of their impact on total ship cost, risk, and effectiveness. Refinement of the mission definition typically

Nomenclature:

AAW: Anti-air warfare
AHP: Analytical hierarchy process
AOA: Analysis of alternatives
ASN(S&L): Assistant Secretary of the Navy for Systems and Logistics
ASROC: Anti-submarine rocket
ASUW: Anti-surface warfare
ASW: Anti-submarine warfare
BHP: Brake horsepower
CAS: Combined antenna system
CBG: Carrier battle group
CCC: Command, control, communication
CIWS: Close-in weapon system
CODAG: Combined diesel and gas turbine
COGAG: Combined gas turbine and gas turbine (Cruise/Boost)
COGAS: Combined gas turbine and steam
CONOP: Concept of operations
CPP: Controllable pitch propeller
CPS: Collective protection system
DNSARC: Department of the Navy Systems Acquisition Review Council
DV: Design variable
DOE: Design of experiments
ECM: Electronic countermeasures
FCS: Fire control system
FPP: Fixed pitch propeller
GFCS: Gun fire control system

DOI: 10.1111/j.1559-3584.2007.00069.x

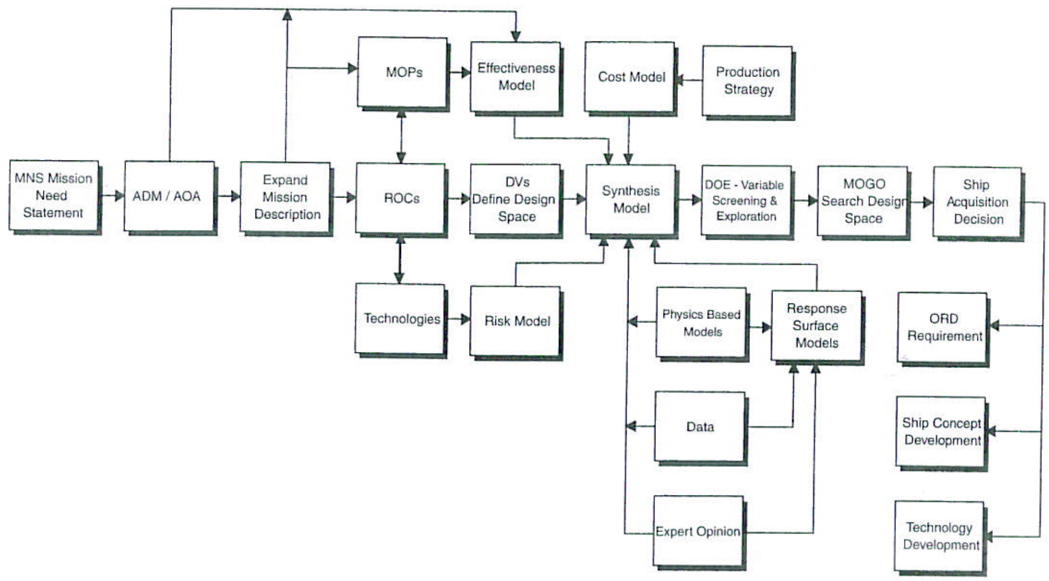

Figure 1: *Concept Exploration Process (Brown 2005)*

GM: Metacentric height above center of gravity

IED: Integrated electric drive

IR: Infrared

KG: Height of center of gravity

LAMPS: Light airborne multi-purpose system

MAVT: Multi-attribute value theory

MD: Mechanical drive

MFCS: Missile fire control system

MOGO: Multi-objective genetic optimization

MOP: Measure of performance

NBC: Nuclear, biological, chemical

NCO: Non-combatant operations

NDF: Non-dominated frontier

NSFS: Naval surface fire support

OMOE: Overall measure of effectiveness

OMOR: Overall measure of risk

ORD: Operational requirements document

includes a concept of operations (CONOPs), projected operational environment and threat, specific missions and mission scenarios, and required operational capabilities (ROCs).

Next, the design space is defined using available or developing technology necessary to provide required capabilities. In this case study, this includes most of the design alternatives that were considered in the DDX and DDGX studies. Concept exploration needs to consider only those requirements and design parameters that have a significant impact on ship balance, military effectiveness, cost, and risk. Cost, risk, and effectiveness models must be developed consistent with mission requirements and the alternative technologies. A simple ship synthesis model is used to balance the designs, assess feasibility, and calculate cost, risk, and effectiveness.

Finally, a multiple-objective genetic optimization (MOGO) is used to search the design space for non-dominated feasible designs using the synthesis and objective attribute models (Shahak 1998; Salcedo 1999). Feasible designs are ranked by cost, risk, and effectiveness, and presented as a series of non-dominated frontiers (NDFs). An NDF represents ship designs in the design space that have the highest effectiveness for a given cost and risk. Concepts for further study and development are chosen from this frontier and a comparison with DDG-51 is made based on these results.

This optimization requires mathematically defined objective functions for effectiveness, cost, and risk. Mission effectiveness, cost, and risk have different metrics and cannot logically be combined into a single objective attribute. Multiple objectives associated with a range of designs must be presented separately, but simultaneously, in a manageable format for trade-off and decision making. There is no reason to pay or risk more for the same effectiveness or accept less effectiveness for the same cost or risk. Various combinations of ship features and dimensions yield designs of different effectiveness, cost, and risk. Preferred designs must always be on the NDF. The selection of a particular non-dominated design depends on the decision-maker's preference for cost, effectiveness, and risk. This preference may be affected by the shape of the frontier and cannot be rationally determined a priori. Overall measure of effectiveness (OMOE; Demko 2005; Brown and Demko 2006) and overall measure of risk (OMOR; Mierzwicki 2003; Mierzwicki and Brown 2004) objective functions are developed using the analytical hierarchy process (AHP),