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SET-BASED DESIGN IN SHIP ACQUISITION FOR THE KOREAN NAVY

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THESIS

SET-BASED DESIGN IN SHIP ACQUISITION FOR THE KOREAN NAVY

by

Jeongha Kim

March 2019

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13. ABSTRACT (maximum 200 words)

How can the Republic of Korea (ROK) Navy minimize repetitive requirement changes while maintaining a low cost in its battleship design? This question pivots around the complexity of the ship design process. Although a naval vessel is a single unit, it incorporates a large collection of various systems that range from weapons and navigation systems to habitability and support elements. Interoperability concerns persist within the design phase, which reflects the reality that a naval vessel is part of a larger system, the country's naval force. Complexity and interoperability add to other challenges in the ship design process including high costs and lengthy schedules. Depending on the type of design procedure implemented, requirement changes increase, thereby extending the schedule and delaying operationalization. The need to establish and practice effective design methodologies has become imperative for achieving efficient naval ship acquisition with reduced costs and condensed timelines. Using the set-based design method—first implemented in U.S. Naval Ship Designs—this thesis explores the prospects of reducing repetitive requirement changes in the ROK Navy's ship acquisition process.

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SET-BASED DESIGN IN SHIP ACQUISITION FOR THE KOREAN NAVY

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ABSTRACT

How can the Republic of Korea (ROK) Navy minimize repetitive requirement changes while maintaining a low cost in its battleship design? This question pivots around the complexity of the ship design process. Although a naval vessel is a single unit, it incorporates a large collection of various systems that range from weapons and navigation systems to habitability and support elements. Interoperability concerns persist within the design phase, which reflects the reality that a naval vessel is part of a larger system, the country's naval force. Complexity and interoperability add to other challenges in the ship design process including high costs and lengthy schedules. Depending on the type of design procedure implemented, requirement changes increase, thereby extending the schedule and delaying operationalization. The need to establish and practice effective design methodologies has become imperative for achieving efficient naval ship acquisition with reduced costs and condensed timelines. Using the set-based design method—first implemented in U.S. Naval Ship Designs—this thesis explores the prospects of reducing repetitive requirement changes in the ROK Navy's ship acquisition process.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACV	amphibious combat vehicle
ASSET	Advanced Ship and Submarine Evaluation Tool
DAPA	Defense Acquisition Program Administration
DES	design and engineering system
EVF	Expeditionary Fighting Vehicle
FACT	Framework for Assessment Cost and Technology
HWS	high water speed
LEAPS	Leading Edge Advanced Prototyping for Systems
MND	Ministry of National Defense
NLL	Northern Limit Line
ORR	operational requirement review
PKG	Patrol Killer Guided Missile
PKM	Patrol-Boat Killer Medium
PKMR	Patrol-Boat Killer Medium Rocket
R&D	research and design
ROC	required operational capability
ROK	Republic of Korea
SBCE	set-based concurrent engineering
SBD	set-based design
SSC	Ship-to-Shore Connector
TISNE	Technical Information System for Naval Engineering
TLR	top-level requirement

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EXECUTIVE SUMMARY

Korea's ship acquisition system has been changing, and during that process, the ROK Navy wants a way to design ships with less money and time due to budgetary and scheduling problems. The cost and schedule risk factors in the acquisition system are a concern not only for Korea but also for many other countries. The set-based design (SBD) method recently introduced by the U.S. Navy, which has similar problems, has been proposed as one solution. Therefore, this thesis proposes guidelines for applying the SBD method to the Korean acquisition system by examining how the method is applied in the United States by understanding its advantages.

According to Singer, Doerry, and Buckley (2009, 35), SBD "define[s] a feasible design space, then constrain[s] it by regions where solutions are proven to be inferior." This method, which was developed by the automotive industry, has the advantage of obtaining an optimal alternative with a smaller budget in a shorter time than required for the conventional point-based design method. Also, the SBD method makes it possible to adapt flexibly to changes in requirements that occur during a program's execution. The U.S. Navy has applied the SBD method to the Ship-to-Shore Connector and Amphibious Combat Vehicle projects. Through the application of this method, the U.S. Navy quickly derived a solution under scheduling constraints and finally succeeded in those programs.

Korea's acquisition system is being developed based on systems engineering. Its acquisition process follows the procedure of planning and feasibility studies, preliminary study (including concept design), exploratory development (including preliminary design and contract design), full-scale development (including detailed design and construction), and the subsequent (follow-up) shipbuilding process (Defense Acquisition Program Administration 2016). Program managers determine alternatives to the system design through outputs and reviews at each acquisition stage. An analysis of this process revealed that the preliminary study stage could be designed by applying the SBD method for the initial conceptual design. In order to investigate the effectiveness of applying SBD, this thesis presents a case study on the ROK Navy's patrol boat. Based on this ship's mission, the initial required operational capability was created. At first, the design space was broadly

defined, the infeasible alternative was excluded according to the restriction condition, and the feasible alternative's range was narrowed.

This thesis concludes that the SBD method can be applied to Korea's ship acquisition system using a case study tailored to the process. The case study was a simplified simulation rather than the actual ship design, but the result was more reasonable than the current design of the operating patrol boat. In conclusion, the author suggests that the SBD method be applied effectively in Korea's ship acquisition system and that a guideline be established so that the method is applied systematically.

Recommendations for future research include two approaches. First, research into building a database that collects ship design data is needed for the future ship design. Second, developing a computer-based design synthesis and cost estimation tool is required for the validation of the designed model and cost analysis. These two studies would promote an understanding of the alternatives and measure the effectiveness of the model designed using SBD.

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I. INTRODUCTION

A. BACKGROUND

Disputes, escalations, and conflicts have taken place in many countries of the world since the beginning of civilization, and Korea is not an exception. At present, the Republic of Korea (ROK) is formally in a state of truce with North Korea. However, small but potentially dangerous disputes continue. Under these circumstances, Korea cannot neglect its efforts for national defense and must maintain a strong deterrent force. The role of the ROK Navy is particularly significant in such efforts.

Of particular interest to this study are disputes occurring at sea. Notable incidents include the 2002 Yeonpyeong sea battle (Republic of ROK Navy n.d.-b) and the 2010 sinking of the *Cheonan* (PCC-772) (Republic of ROK Navy n.d.-a). Partially as a result of such incidents and disputes, Korea's defense acquisitions have recently undergone many workforce changes. Such changes include shifting both the responsibilities and the overall acquisition system. Since the opening of the Defense Acquisition Program Administration (DAPA) in 2006, the authority of acquiring weapons systems transferred from each service to DAPA. A number of policies and systems have been studied to efficiently develop several ship types and their associated weapon systems. Although Korea's acquisition process has been tailored to the country's individual circumstances, it is based on the U.S. acquisition system as it existed before 2003.

A naval ship is a complex weapon system that must interoperate with hundreds of different types of equipment. At the same time, it must be consistent with efforts in platform development and integrate everything seamlessly to meet the performance requirements and specifications of the military. Due to the nature of this process, the development period takes a long time, and the acquisition cost can be high.

In recent years, the United States has been working on new ways to reduce unnecessary repetitive processes and to manage time and effort more efficiently as well as reduce the defense budget. One approach is to apply a new method called set-based design

(SBD) to ship acquisition projects (Singer, Doerry, and Buckley 2009). The fundamental benefit of such a method is the ability to study vast regions of the design space with significantly less effort than is required for aggregate collection-of-point designs. Despite the differences between U.S. and Korean specifications, missions, and acquisition processes, similar problems persist in meeting necessary schedules and budgets for acquisition. Therefore, we recognize that there is a need to understand what SBD is and to establish whether such a method could be adopted and applied effectively within the Korean ship acquisition environment.

B. PURPOSE OF THE STUDY

Naval ships are some of the major weapon systems employed by ROK's Navy. This is not surprising given the nature of the navy, which lacks a significant aviation capability and emphasizes the power of ship systems at sea. Because of the complexity of these naval ships, ROK's Navy must consider many different parameters including various weapon systems, navigation systems, communications and sensors, and living quarters for crewmembers during construction or refitting. As new science and technology systems mature, various sensor and weapon systems are developed to detect threats faster and strike them more accurately from a greater distance. Consequently, the platform itself must change and adjust its geometric characteristics and topside layout to minimize its detectability by adversaries. As a result, the cost of acquiring a total ship system has skyrocketed.

A ship acquisition program typically lasts for several years. It spans the time from the initial development of need, through requirements generation, analysis of alternatives, and down-selection to the final design, detailed construction calculations and drawings, and finally the shipbuilding—not to mention the integration of all subsystems and equipment into one platform (Lee, Kim, and Jung 2014). Even if the project progresses as planned, it takes too much time and costs too much money. In addition, in the real world, many unexpected events might occur that could not have been anticipated ahead of time. For example, users and operators often need to change the requirements, which entail program managers repeating the process again. In order to reduce this repetition, we must study a new method for the design and acquisition of naval ships that conforms to a broad set of requirements from the stakeholders.

The purpose of this study is to introduce the fundamentals of SBD, as has been proposed and applied as a potential solution to similar problems raised in the U.S. Navy, and to advise on the applicability of this method to Korea's ship acquisition design process.

C. BENEFITS OF THE STUDY

This study assesses whether SBD can be used within the framework of the Korean ship acquisition system and evaluates its potential benefits in terms of performance, scheduling, and cost. This study can provide a feasibility guide for further studies of the applicability of SBD in Korea's naval ship acquisition process.

D. SCOPE

This study focuses on the early stage of Korea's naval ship design process. When we studied different SBD application cases and related papers for ship acquisition projects in the United States, we noticed that the scope of the method was different depending on the characteristics of each project (Chan et al. 2016). However, one characteristic was evident; namely, most of the projects applied SBD during the early design phases such as during the materiel development decision (Chan et al. 2016). As the design process proceeded, the trade space was narrowed so that it became progressively more difficult to apply the SBD method. In this study, therefore, we intended to limit the scope of the study to the preliminary and early stages of design. We concentrated on the ROK Navy's early stage ship design and acquisition process and attempted to ascertain whether the overall ship acquisition program could benefit from the SBD method.

E. METHODOLOGY

This study focuses on problems in the initial design phase of acquisitions of ROK Navy ships and examines the SBD method with which the United States has tried to solve similar problems. A specific case study with the existing Gumdoksuri-class Patrol-Boat

Killer Medium Rocket program, which has already been developed in Korea, is provided to demonstrate this new ship design process (Defense Acquisition Program Administration 2017).

II. SET-BASED DESIGN

In a 2006 study from the United States, the researchers suggested a need for an environment in which people could develop joint products to address the Navy's tight budgetary and future design issues (Singer, Doerry, and Buckley 2009). This need derived from the challenges associated with the lack of experience among young engineers who were responsible for ship design. The application of SBD under these challenges presented an opportunity for improvement in design (Singer, Doerry, and Buckley 2009). This chapter first provides the history of the design process and the evolution of this process over the years, culminating in Toyota's set-based concurrent engineering process and the concept of set-based design. Next, it examines the theory behind the SBD method. Finally, it presents two case studies that demonstrate the applicability of SBD based on theory.

A. HISTORY

The traditional design process was a point-based serial engineering process beginning with a design plan, followed by a basic design, and ending with an execution design (Sobek, Ward, and Liker 1999). This method caused frequent redesigns during the design process due to the lack of expertise and information transfer at each stage. Also, design errors occurred early in the process due to the serial operation of separate organizations, which led to a delay in the process. In addition, excessive correction work might have been required because of the lack of design information, and it was difficult to consider information related to production at the design stage.

The concurrent engineering process was proposed as a supplement to this point-based serial engineering process. Figure 1 shows the differences between serial engineering and concurrent engineering. Concurrent engineering was an attempt to perform the parallel processing of activities. However, this also required quick design decisions to proceed to the next phase, which led to repeated phases, yet delay issues were left unsolved.

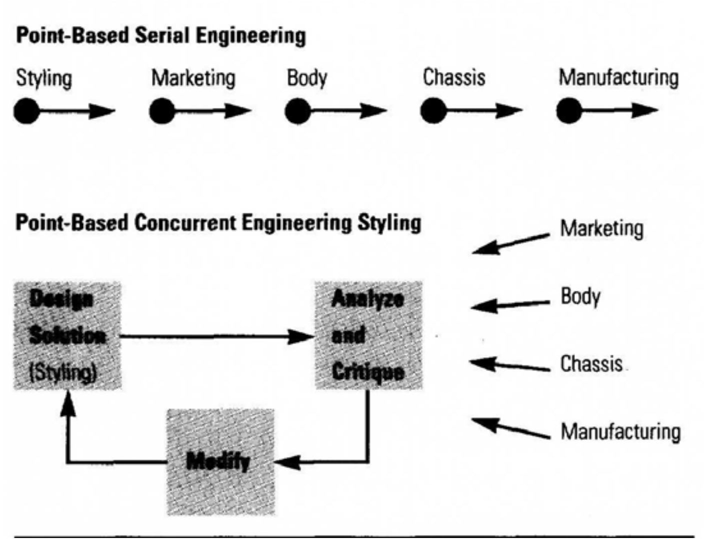

Figure 1. Traditional Point-Based Approaches to Product Development. Source: Sobek, Ward, and Liker (1999).

In the past, the Navy used the spiral design process—which goes through contract design, preliminary design, and concept design—when designing naval ships. Figure 2 shows this spiral design method in detail.

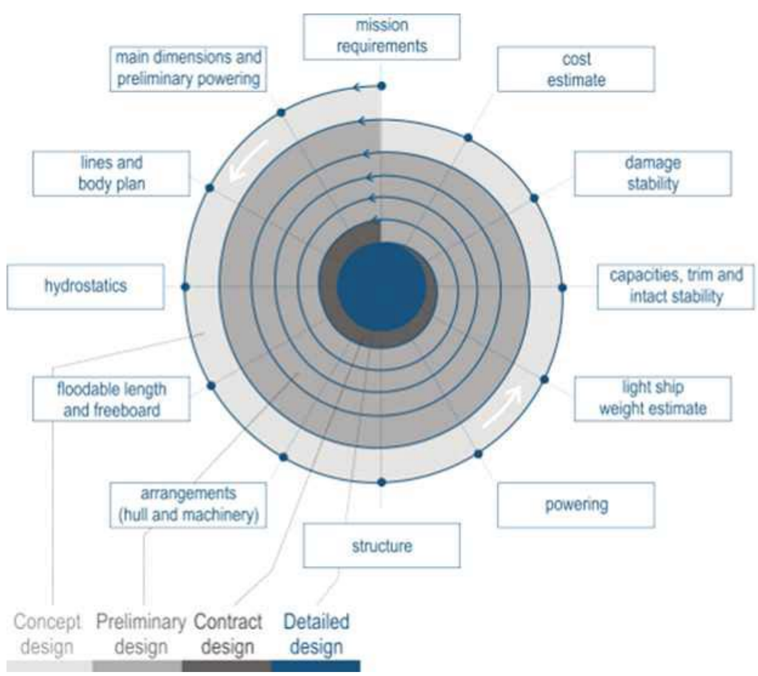

Figure 2. The Spiral Design Process. Source: Kwak (2016).

However, since the naval ship system is a System of Systems, the sum of various complex systems, new needs for a concurrent design method have arisen because they reduce the time and effort of repeated designs. Figure 3 shows the concurrent design method in detail.

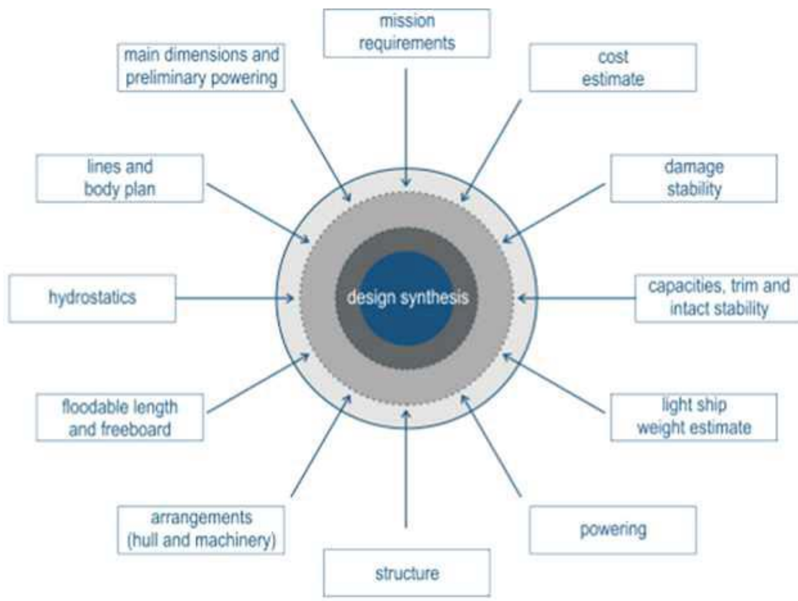

Figure 3. The Concurrent Engineering Process. Source: Kwak (2016).

To respond to these needs, Toyota introduced a new method called set-based concurrent engineering (SBCE). In 1995, Toyota was able to develop cars with better performance than its rivals using SBCE, eventually making the company a major player in the market (Singer, Doerry, and Buckley 2009).

As Singer, Doerry, and Buckley (2009) explain, the main features of this design process include

1. Broad sets of design parameters are defined to allow concurrent design to begin,
2. These sets are kept open longer than typical to more fully define tradeoff information,
3. The sets are gradually narrowed until a more globally optimum solution is revealed and refined.
4. As the sets narrow, the level of detail (or design fidelity) increases (34).

Figure 4 illustrates these characteristics. All activities among the various fields (e.g., marketing concept, styling, product design) are conducted simultaneously, and the number and range of the activities gradually narrow as the process progresses.

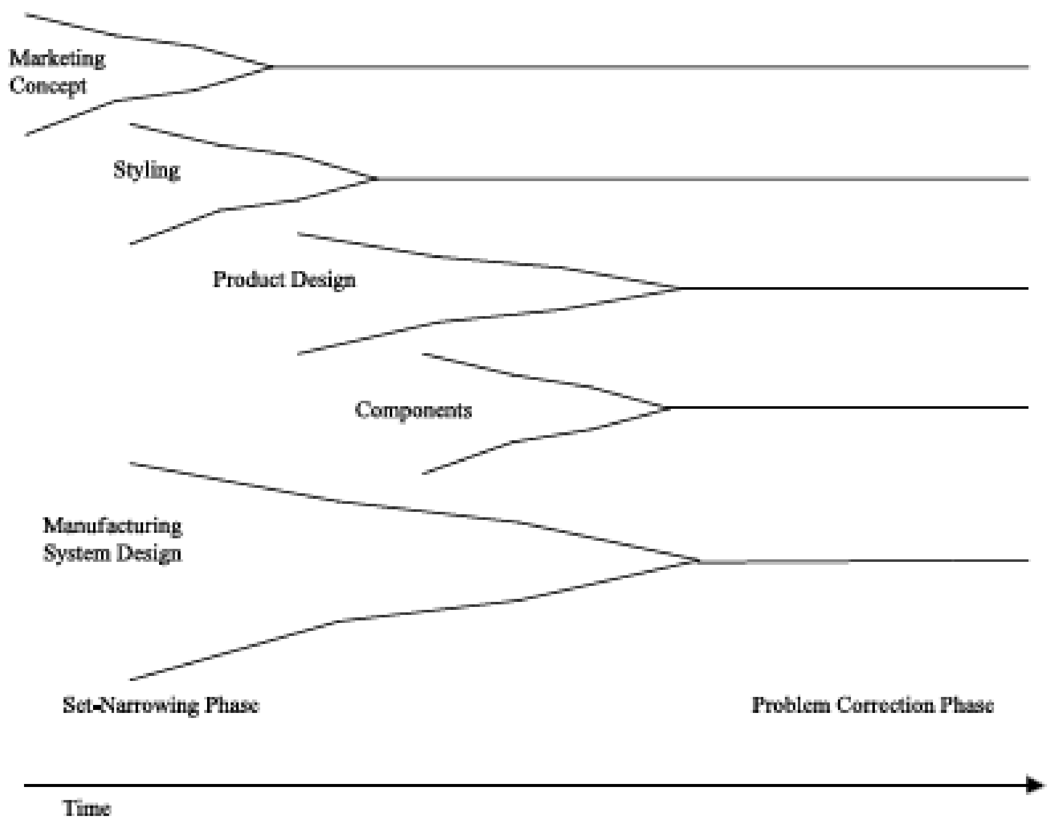

Figure 4. The Parallel Set Narrowing Process Illustrated by a Toyota Design Manager. Source: Ward et al. (1995).

Watching the remarkable growth of Toyota, many people thought that applying SBCE would result in obvious benefits. In particular, the U.S. Department of Defense conducted research on how to implement this method into naval ship design as part of a defense reform project. This research resulted in the introduction of the SBD process, which is currently a method for various naval ship designs.

B. SBD THEORY AND APPLICATION

In order to apply SBD, Sobek, Ward, and Liker (1999) recommend the following basic principles:

1. Map the Design Space
2. Define Feasible Regions
3. Explore Trade-Off by Designing Multiple Alternatives
4. Communicate Sets of Possibilities
5. Integrate by Intersection
6. Look for the Intersection of Feasible Sets
7. Impose Minimum Constraint
8. Seek Conceptual Robustness
9. Establish Feasibility before Commitment
10. Narrow Sets Gradually while Increasing Detail
11. Stay within Sets Once Committed
12. Control by Managing Uncertainty at Process Gates. (73)

1. Map the Design Space

When applying the SBD process, the most fundamental aspect is to understand the concept of “design space,” a collection of design sets that applies to the final product. That is, the collection of variables such as ship speed, ship size, and propulsion system could be included in the design space of a ship’s design. Professionals from each field would then set a possible “region” that includes such variables. Then, each alternative goes through analysis, and the possibilities for each set are reviewed (Sobek, Ward, and Liker 1999).

2. Integrate by Intersection

As different functional groups begin to understand the design from their points of view, the design team must integrate the design by gathering the overlapping parts (features) of each set to find a feasible solution (Sobek, Ward, and Liker 1999). Therefore, the alternative set for each group must place a minimum and maximum range to examine the intersections between other groups. To further develop the design integration, any given group has a limited time to confirm each set and submit modifications (Sobek, Ward, and Liker 1999). Moreover, as the range of possible sets narrows over time, the designer uses more detailed or advanced models to propose better ideas or designs (Sobek, Ward, and Liker 1999).

3. Establish Feasibility before Commitment

The last principle is establishing the feasibility before commitment. It refers to a flexible approach in which all participants in the design process fully understand the design and its possibilities before making a final decision (Sobek, Ward, and Liker 1999). First, an intersection between each design alternative must be found, and then the possibilities must be reviewed. Finally, the engineers gradually narrow down the range and materialize the design. In order to finish the design, certain decisions must be made on time (Sobek, Ward, and Liker 1999). Therefore, the engineering team must always consider the given resources—including time—for the project instead of focusing entirely on the design itself. Maintaining balance is essential for the whole process.

During the process, solutions for each design should be considered within the categories discussed in previous stages of the project. Therefore, at least one viable solution must be maintained to have a strong set of alternatives (Sobek, Ward, and Liker 1999). For example, Toyota sets “gates” to perform the design process successfully. Through these gates, they minimize uncertainty, increase the depth of design, and form a clear understanding of the whole process. Sobek, Ward, and Liker (1999) state that this kind of approach is better than the typical American approach since it gives the participants of the project a better sense of control over the whole process. Figure 5 shows the details of the SBD process.

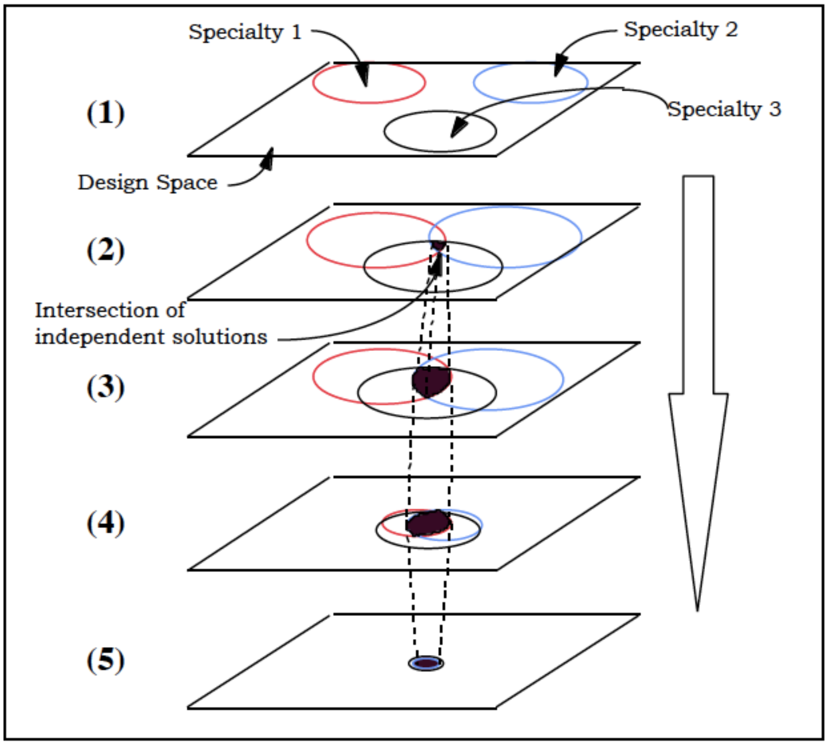

Figure 5. The Set-Based Design Process. Source: Bernstein (1998).

C. SBD CASE STUDIES IN THE U.S. NAVY

Examining past cases allows for a framework to explore how SBD methods are applied to the design of a naval vessel. Since the introduction of SBD into the U.S. Navy, several pilot applications have allowed the Navy to assess the applicability of this method. The Ship-to-Shore Connector (SSC) and the Amphibious Combat Vehicle (ACV) highlight some of these assessments. By examining these two programs, we can explore how the U.S. Navy has applied SBD in its systems.

1. The Ship-to-Shore Connector

The SSC program was the first application of SBD in the U.S. Navy (Mebane et al. 2011). For this program, it was determined that Naval Sea Systems Command would directly perform the preliminary design and contract design and apply the new SBD method without performing the point-based design due to the tight schedule.

Figure 6 shows the schedule of the SSC program. SBD had progressed beyond the preliminary design phase for this program (Mebane et al. 2011). According to Mebane et al. (2011), the SSC design team conducted SBD processes in three stages: trade space setup, element trade space analysis and reduction, and integration and scoring.

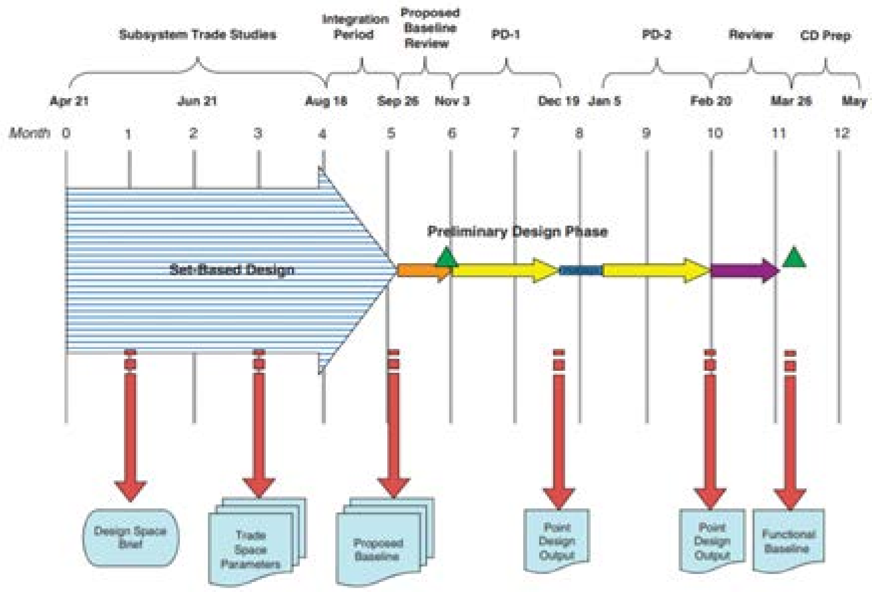

Figure 6. The Ship-to-Shore Connector’s Preliminary Design Schedule. Source: Mebane et al. (2011).

The first trade space setup phase led to the documentation of trade space summaries. This included potential key operational requirements, the review of the Systems Engineering Managers, and element-specific requirements. These were followed by the element trade space analysis and reduction phase, preliminary trade space refinements and analyses, requirements/subsystems variables and option reductions, the elimination of infeasible combinations, and the summation of feasible system design combinations. In the last stage of integration and scoring, the combination of feasible system options was put in a balancing loop to calculate the total weight and cost, and a score was given by comparing each option. Finally, the design team could diminish the trade space. Figure 7 shows the reduction.

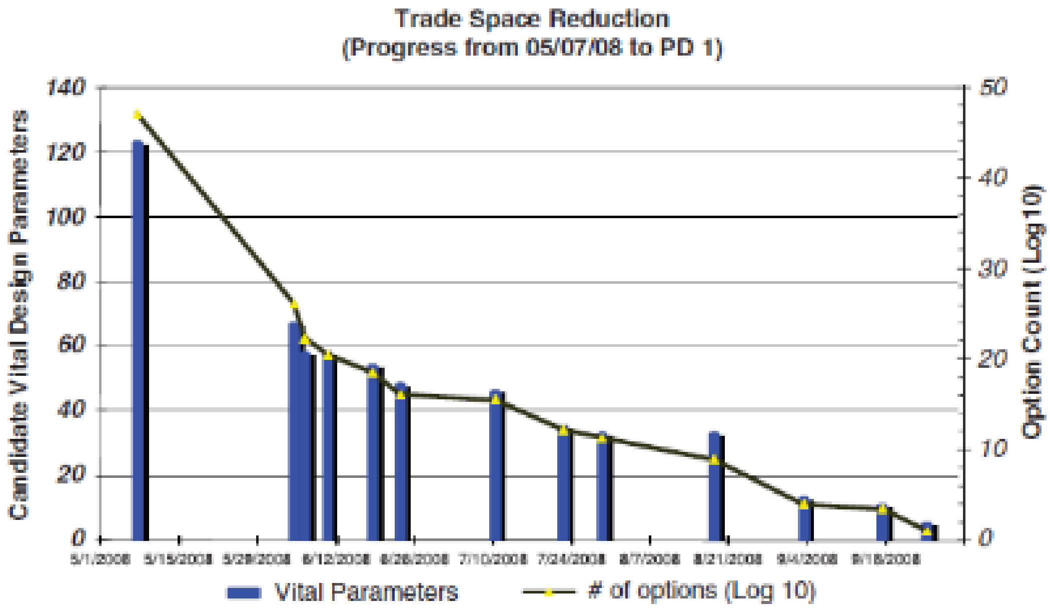

Figure 7. Trade Space Reduction over Time. Source: Mebane et al. (2011).

The application of SBD in this program enabled the SSC design team to quickly define and evolve the initial ambiguous requirements into detailed requirements and lead them to potential requirements until the capability development document was determined. In addition, the application of SBD allowed the SSC design team to explore and evaluate the entire trade space and to select the best solution (Mebane et al. 2011).

2. The Amphibious Combat Vehicle

The ACV of the U.S. Marine Corps is another program developed through the application of the SBD method. The U.S. Marine Corps had been operating the Assault Amphibious Vehicle for over 40 years and had explored replacement options for the Expeditionary Fighting Vehicle (EVF) program. However, the EVF program was canceled because of its high price and unfeasible operability. As the EVF's replacement, the ACV was a more affordable and sustainable platform, which featured high water speed (HWS) performance. The SBD method was applied to lower costs and improve performance (Burrow et al. 2014).

The ACV design team developed alternatives with considerations based on design information, complemented with the shortcoming of the canceled EVF program. The feasibility and price of applying HWS had not been examined during the first Analysis of Alternative of the ACV program. The ACV program bridged that deficiency through reorganization. An analysis plan was established, and the design study concentrated on four parts. Concurrent design led to the development of a series of ACV design studies, which allowed core field teams to share design knowledge (Burrow et al. 2014). Figure 8 illustrates the analysis plan:

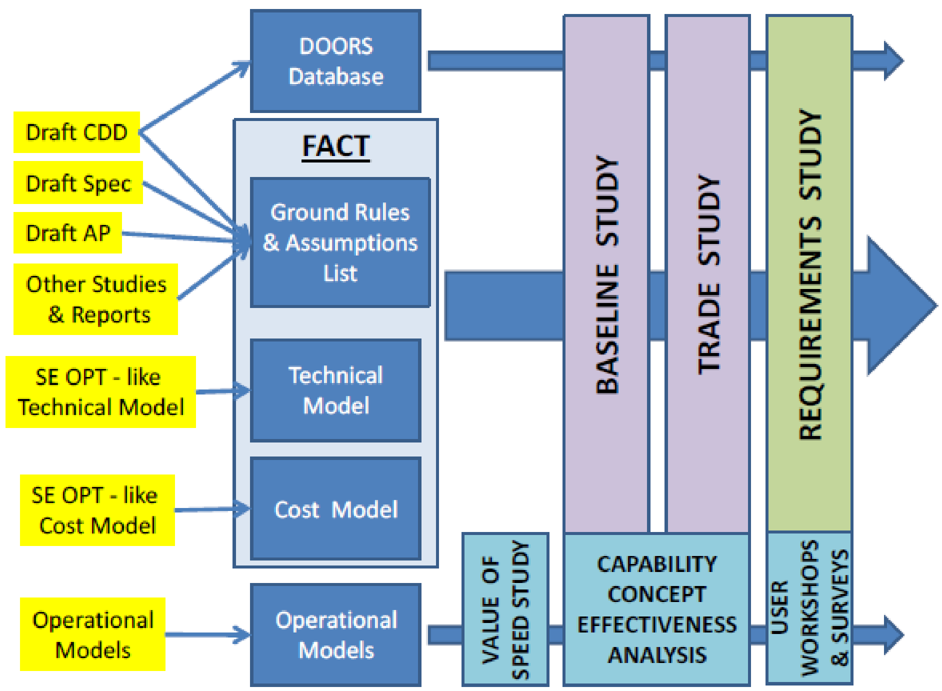

Figure 8. The Analysis Plan. Source: Burrow et al. (2014).

The requirements for the ACV materialized into the DOORS database and the Framework for Assessment Cost and Technology (FACT) using, for example, the draft capability development document or the draft specifications. The component size, weight, and cost information became the basic data for the Market Research Database. The performance of the ACV was evaluated using FACT (Burrow et al. 2014).

The U.S. Marine Corps and the Navy used the SBD method in this program. The following four areas were analyzed by each design team: requirements analysis, effectiveness analysis, trade space analysis, and affordability analysis. Figure 9 depicts the traditional design approach in which the design is developed step-by-step with various concepts. However, using the traditional approach is disadvantageous since it takes a long time and the final alternative comes later. On the other hand, when the SBD method is used, the four parts operate independently and concurrently. By combining the respective measures, the intersection becomes a space for alternatives. As a result of the ACV team's independent and simultaneous design review of each area, the team was able to save time and evaluate more feasible alternatives.

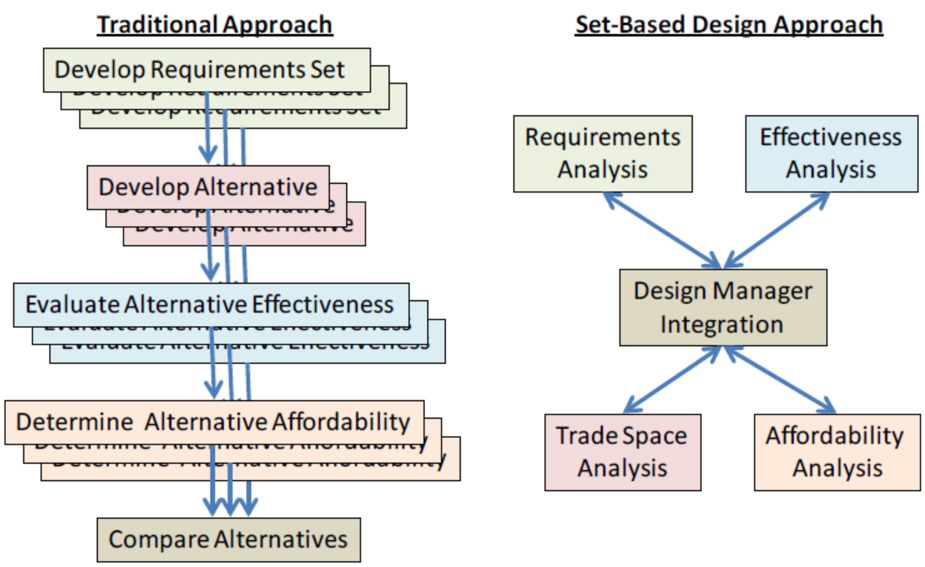

Figure 9. Traditional vs. Set-Based Design Approaches.
Source: Burrow et al. (2014).

One significant point in this study is that five items—coined "big rocks"—were prioritized in the effectiveness analysis. The five characteristics are high vs. low water speed, the number of embarked troops, the weapon system, the level of under-blast protection, and the level of direct fire protection (Burrow et al. 2014). In trade space analysis, the application of HWS and the balance of the other four characteristics were examined. The parts of the requirements exclusive of these five were also examined in the requirements analysis. Affordability analysis investigated the impact of investment on the ACV vis-à-vis the U.S. Marines' total budget. Figure 10 illustrates these concepts.

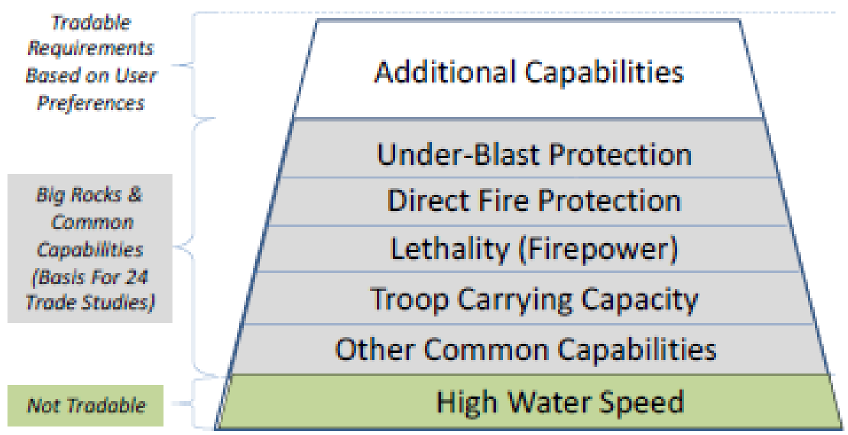

Figure 10. Partitioning of ACV Capabilities. Source: Burrow et al. (2014).

The alternatives considered in these studies include a combination of 80,000 syntheses. These alternatives were narrowed down to 24 possible alternatives through a trade study. This was done by reviewing the trade-space of the aforementioned big rocks and the nearly 40 additional requirements, costs, and weights. As a result, through the outlined process, the ACV team was confident that HWS-capable ACVs were highly effective and would be rated positively in both technical and risk assessments (Burrow et al. 2014). Burrow et al. summarize the important results as follows:

- A diverse team consisting of technical, operational and program management experts from across the naval acquisition, operational and technical communities, as well as industry and academia.
- The ability to address leadership questions with technical and analytical rigor that traditional approaches have not yet demonstrated an ability to do.

- The ability to develop in depth knowledge of the technical problem and potential solution set, a risk-based understanding of what was feasible and infeasible, and high confidence cost estimates based on technical feasibility and diversity of solutions. In turn, the team provided leadership (15).

In summary, the achievements of the design team provided a solid analytical base that not only helped decision makers reach an informed decision but also provided them with confidence in the decision (Burrow et al. 2014).

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III. THE BASIC ACQUISITION PROCESS OF ROK NAVAL SHIPS AND THE EARLY PHASE OF SHIP DESIGN

The task of acquiring weapons systems was carried out separately according to the specifications of each service. However, since the creation of DAPA in 2006, all acquisition projects have been integrated and conducted by DAPA. Since then, the ROK Navy's ships were obtained in accordance with the "shipbuilding" procedure specified in Defense Acquisition Law (Defense Acquisition Program Administration [DAPA] 2016). In 2012, the shipbuilding procedure, which had until that point been a separate endeavor, was integrated into the research and design (R&D) work process of the general weapon systems (DAPA 2016). For efficient R&D of weapon systems during the acquisition process, the ROK Navy has institutionalized systems engineering into the life cycle, and since 2010, it has been prescribed as mandatory (DAPA 2016). This chapter examines the basic acquisition procedures for Navy ships in Korea and discusses the initial stages of ship design for SBD application in more detail.

A. KOREA'S DEFENSE ACQUISITION SYSTEM

The acquisition process of Korean naval ships reflects the establishment of DAPA in 2006, changes in the planning system for military acquisition, and the mandatory application of systems engineering in 2010 (DAPA 2016). Notably, the primary planning system for obtaining national defense weapons has changed from a performance-oriented acquisition system to a capability-oriented one. Such a change has been made to adapt to current—and future—threats and operating environments.

As featured in Figure 11, the Korean government has proclaimed the following instructions about naval ship acquisition and the design process through the Department of Defense. There was a procedural change in the naval acquisition process within DAPA in June 2012. The term and procedures of naval ship acquisition programs have changed due to the integration into the general weapon system's R&D process (DAPA 2016). As a result, the R&D process for naval ships follows the same process as that of general weaponry. The process still accounts for the inherent traits of naval ship acquisitions and follows the procedure of planning and feasibility studies, a preliminary study (including concept design), exploratory development (including preliminary design and contract design), full-scale development (including detail design and construction), and the subsequent (follow-up) shipbuilding process (DAPA 2016).

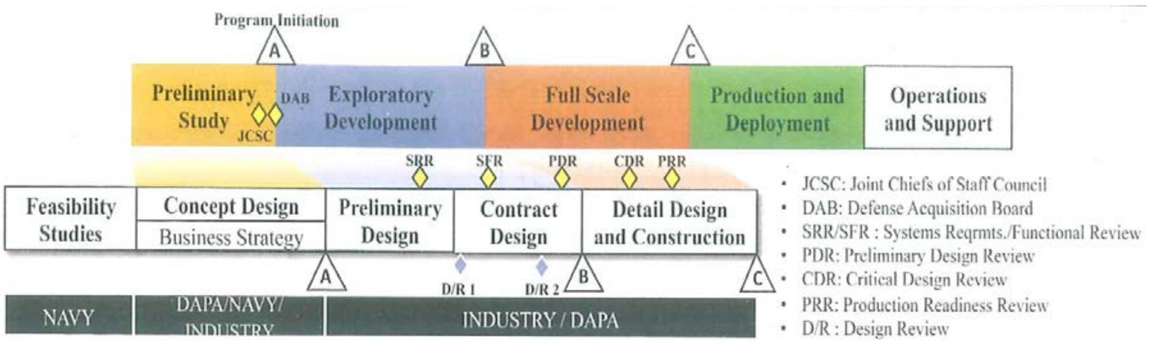

Figure 11. Korea’s Defense Acquisition System and Navy Ship Design Process. Source: Park et al. (2016).

The first stage is planning, which includes the feasibility and concept formation study for the Navy. In the feasibility study, the initial required operational capability (ROC) is set, including all equipment on the ship and the drivable type of the ship. The ROK Navy considers the possibility of building a ship for the operation, and the Agency of Defense Development conducts a concept formation study according to the Navy’s request (Lee, Kim, and Jung 2014).

The preliminary study stage carries out the conceptual design for the confirmation of the ROC based on the initial ROC and the documentation of the top-level requirement (TLR) draft. Unlike the general weapon systems, the preliminary study on the ships includes a conceptual design. Also, policy research is performed based on the initial ROC. Such research may include the concept development of operations, acquisition or alternative analyses, or a parallel technical review, which includes a rough draft of the ship platform, major equipment acquisition planning, system integration, and the special performance of the ship (DAPA 2016). The main difference between the acquisition procedure of the ship and the general weapon system is the time for determining the ROC.

The general weapon system determines the ROC after the completion of exploration development while the ROC of a ship system is determined after the completion of the preliminary study (Lee, Kim, and Jung 2014).

In the exploratory development (preliminary design and contract design) phase, the specification of the ships and performance, the arrangement of the weapon system and equipment, the specification of the equipment, and the interoperability between the systems are determined by the required performance specified in the TLR. In the step, the design team also calculates the cost for shipbuilding with contract design (Lee, Kim, and Jung 2014).

The full-scale development (detail design and construction) of the system is based on the results of exploration development, and it is the step of creating the detailed drawings for the construction and technical documents for the operation of the ship. In this stage, the Navy builds the ship if the ship is the first of the batch (Lee, Kim, and Jung 2014). Table 1 summarizes the subjects and duration of work by acquisition step.

Table 1. The Main Tasks and Duration According to the Ship Acquisition Steps. Adapted from Lee, Kim, and Jung (2014).

	Planning/ Feasibility Studies	Preliminary Study	Exploratory Development	Full-Scale Development
Main Tasks	• Shipbuilding feasibility study • Concept development • Initial ROC development	• Concept design (including equipment and the special performance) • Cost estimation • Decision on acquisition method • operational requirement document development • Development of basic program strategy • Development of TLR • Development of exploratory development plan	• Development of the management plan for exploratory development • Determination of the shape of the ship (using Modeling & Simulation) • Development of ship work breakdown structure • Review of allocation and performance of equipment • Setting and design the standard for special performances • Classification of government supply/contract supply • Determination of the target system • Development of full-scale development plan	• Agreement of full-scale development • Development of management plan • Development of detailed ship work breakdown structure • Development of test and evaluation management plan • Shipbuilding (all parts) • Installation and linkage of equipment • Technical review (critical design review, design decision review, production readiness review) • Development of supporting element of force integration
Subject	ROK Navy	DAPA	DAPA	DAPA
Duration	6–12 months	10–12 months	3–3.5 years	4–5 years

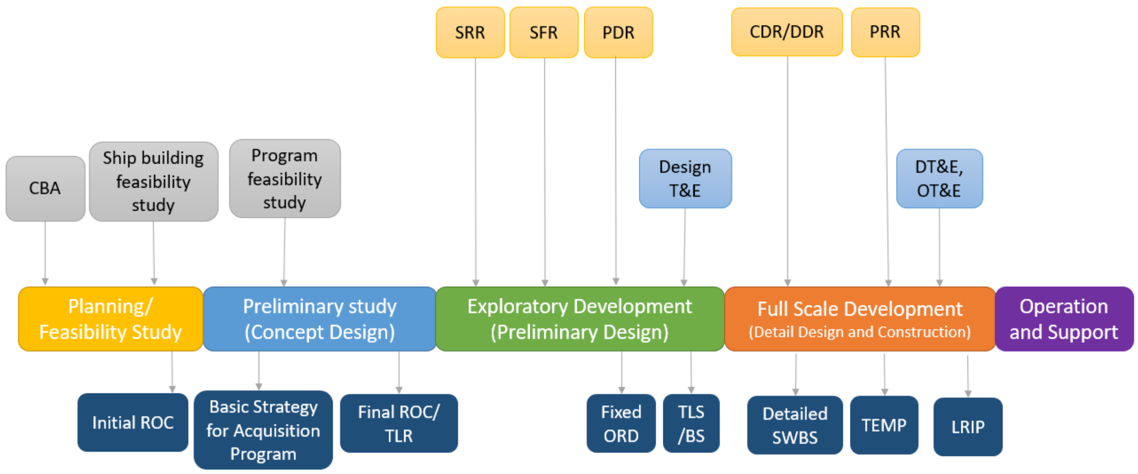

Figure 12. The Ship Acquisition Process

B. KOREA'S EARLY-PHASE SHIP DESIGN PROCESS

Prior to 2010, Korea's ship design followed a sequential process as did the U.S. Navy's in the past, as discussed in Chapter II. Korea's system gradually changed as the application of systems engineering (SE) to the acquisition system was emphasized and made mandatory. According to Choi (2009), the ROK Navy, which was at the crossroads of change in 2008, built the Technical Information System for Naval Engineering (TISNE). TISNE integrates the design and engineering system (DES), the project management system, and the knowledge management system under one portal. This platform controls all of the data and the sub-systems (Choi 2009). Through TISNE, the ROK Navy was able to carry out all concept design processes. Figure 13 shows how the concept design phase progressed using TISNE.

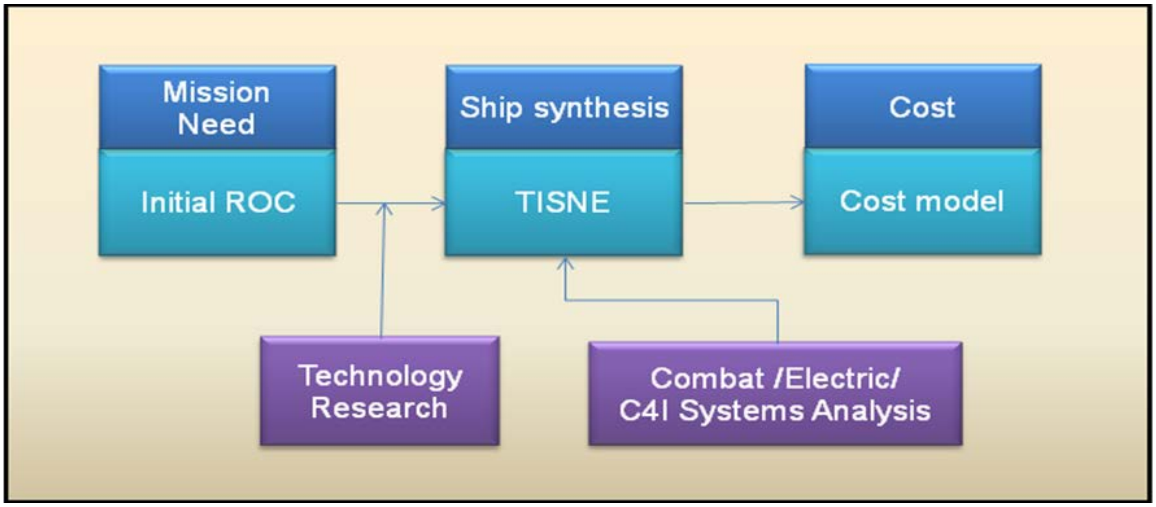

Figure 13. The ROK Navy's Concept Design Process Using TISNE. Source: Choi (2009).

More specifically, TISNE identifies the basic characteristics of the target system based on the ROC and then designs specific subsystems sequentially. Then, cost estimation is performed using the final design obtained during this process. Figure 14 shows this ship synthesis process.

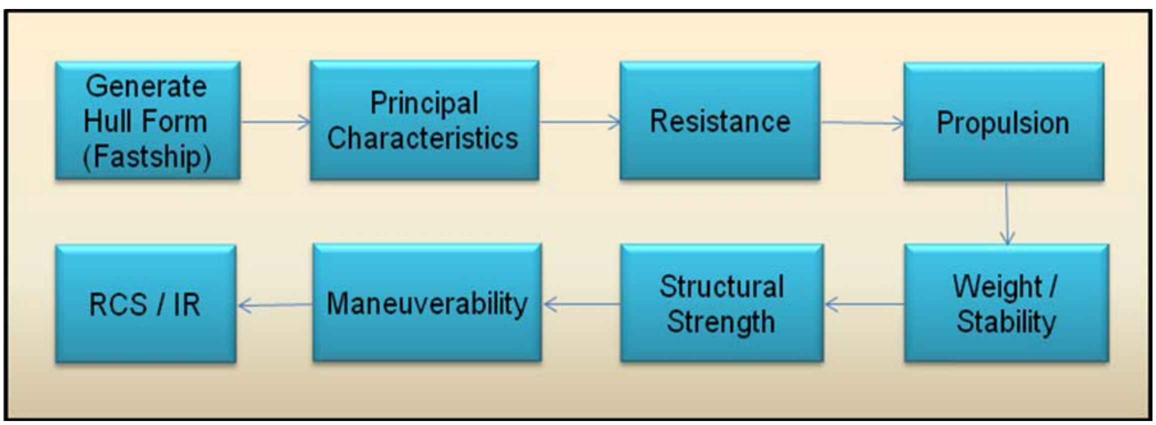

Figure 14. The Ship Synthesis Process under DES. Source: Choi (2009).

Korea's design process has changed to an SE perspective. Prior to entering the preliminary study phase, the Navy reviews the feasibility of the request. To examine the possibility of shipbuilding, the Navy adheres to the following sequence: requirement analysis, functional analysis and allocation, and design combination (see Figure 15).

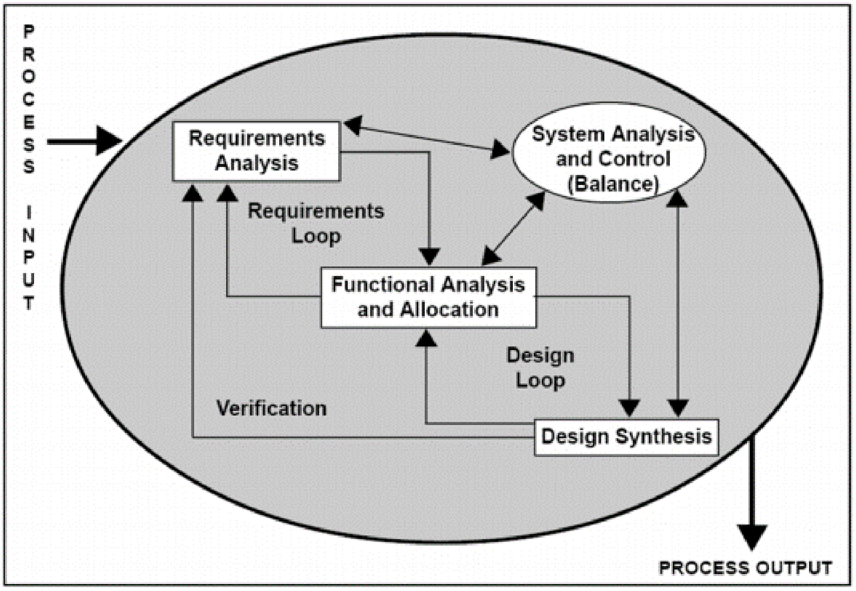

Figure 15. Systems Engineering Process Model (MIL-STD-499B). Source: Department of Defense (1993).

During requirements analysis, after receiving the feasibility review request, the integrated concept team establishes a review plan. At this stage, the team redefines the concept of operations in peace- or war-time and defines the operating environment and threats. It also visits bases to identify operator requirements. Through this process, the design plan is established. Similar types of ships are investigated, and the ship development trends of other countries are analyzed. The trade space is derived from these investigations, and the initial ROC is derived from the trade space.

In the functional analysis and allocation phase, the concept of operation and the functional hierarchy are created according to the ROC from the previous step. It can allocate requirements and functions to a requirement-function-physical matrix through functional and physical architecture configurations.

Finally, design synthesis is used to review the alternatives in different sectors, to compile and optimize the requirements, and to draft the feasibility review report. The final output of the whole feasibility study is the final feasibility review report, the integrated requirement analysis table, and the initial ROC.

When the Joint Chiefs of Staff raise the demand of the system, the next conceptual design begins. It is the step of investigating and analyzing the possibility of R&D for the determined weapon system, the schedule and quantity of the weapon, the level of defense science and technology, and cost-effectiveness (DAPA 2016). The integrated program team establishes a preliminary study plan for the identified program. For this plan, the team confirms the operational environment, procedures, and the cooperativeness and interoperability with other weapon systems in the battlefield as well as establishes a plan by synthesizing them.

The conceptual design should include the hull, the propulsion plant, the electric plant, the command and communication system, the auxiliary system, outfit and furnishings, and the combat system or armament, among other things—all of which should be included in the operational requirement document. Also, the conceptual design should suggest the cost based on the document. When the conceptual design is completed, the ROC is finalized, and then the TLR is created. The TLR is a document that provides basic guidelines for the design and construction of ships, defining the missions, operational requirements, performance requirements of major weapons systems and equipment, and concepts of maintenance and logistics support based on the conceptual design result and the ROC. Finally, the requirements are finalized, and the project is approved through the Defense Acquisition Board under the minister of the Ministry of National Defense (MND) (Park et al. 2016).

C. PROBLEMS WITH KOREA'S DESIGN PROCESS

Chapter II described Korea's overall ship acquisition system and the design process in the early stage. Korea has been developing its system by proceeding with ship design and acquisition through an SE approach. However, there are many problems in the initial stage of ship acquisition.

First, the feasibility study and conceptual design period are short, and the budget is insufficient considering the scope of those stages. In terms of the research period, preliminary research on the ship has been carried out for more than one year in advanced countries, including the United States, because the conceptual design must include the concrete design of the weapon system and equipment, the allocation of subsystems, and the primary performance and characteristics of the ship. In Korea, it is necessary to carry out 50 research activities—including concept design and the operational requirement document—in the scope of the preliminary study and submit the contract purpose document, but the research period is less than one year (Lee, Kim, and Jung 2014).

Second, the Navy could not establish the operational concept sufficiently in the planning stage, so its requirements are frequently modified in the exploratory development (basic design) and full-scale development (detailed design and construction) phase. It is necessary to clarify the operational concepts: "How is the ship operated?" and "What tasks will be performed?" However, DAPA established the operational concept using a government-funded R&D center due to limitations in manpower and the budget (Lee, Kim, and Jung 2014).

Lastly, there has been no in-depth review of the appropriate requirements due to the inadequate progress in research focusing on the expertise of the research institute or the choice of acquisition method. In fact, in many cases, the technology readiness level and total program cost are derived by analyzing similar equipment domestically and abroad and relying on qualitative methods, such as interviews of companies and experts, without specific planning or research of the conceptual design. Therefore, considering the need to provide more precise, accurate, and feasible design specifications despite time and budgetary constraints, the application of SBD to the early phase of the ship design process is a solution for these problems.

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IV. METHODOLOGY

Chapter III examined the process of Korean ship acquisition and its early design process. It also raised two primary problems that could arise during the process: limited analysis due to the lack of research time and effort and frequent ROC change requests. Moreover, in Korea, the Joint Chiefs of Staff and Navy are required to take up the planning stage, and then during the preliminary study, DAPA conducts and manages the study and conceptual design through contact with an external organization. However, since there is no standardized guidance in this process, the method and the level of research continues to change whenever the performer and the programs change. Considering the case studies of U.S. ship acquisition, as described in Chapter II, the application of the SBD method has provided successful results in broad conceptual studies within tight schedules. Therefore, this chapter presents a process that could standardize guidance for Korea's current system and solve the problems through the application of SBD much like in the U.S. pilot projects.

A. PLANNING STAGE

During the planning stage, determining whether the desired ship can be constructed with existing and developable technologies and resources is important. It is during this stage that the Navy, as the primary user, presents its initial requirements. An accurate diagnosis of present capabilities forms the foundation for initial needs, and the diagnosis can provide the need and purpose of introducing a new system. An investigation into current and future threats and the battlefield environment of Korea, on the one hand, and the analysis of the operational response and the difference between the threat and our capability, on the other, constitute necessary steps. These steps are capability-based planning. By identifying capability gaps through such analysis and planning, operational analysts consider initial conceptual alternatives that meet their operational concepts.

The deliverable of the initial concept study should not be a specific design outcome or performance metric but a reference to the fighting, maneuvering, and other major capabilities of the target vessel. Also, it should be a qualitative expression based on a feasible capability. If the ROC is presented in an excessively detailed manner according to the existing method, it could be disadvantageous for applying the SBD method because the design domain has already been narrowed in the subsequent preliminary study stage. Therefore, the Navy should draw up the initial ROC based on the operational concept and the required capability according to the scenario, thus ending the planning stage and beginning the preliminary study phase. Figure 16 shows the process of drawing the initial ROC.

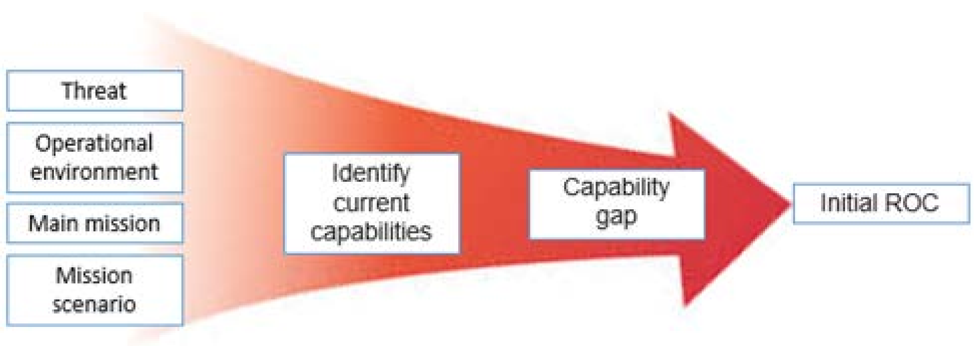

Figure 16. The Process of Drawing the Initial ROC

B. PRELIMINARY STUDY

Upon receipt of the initial ROC from the Navy, DAPA develops a plan for the preliminary study. The main content of this study is a conceptual design for the ship. In the conceptual design, designers form teams according to their respective fields and start to explore the design domain. Each design team derives all possible design options to meet the target capability need. For example, meeting the need could involve investigating combinations of propulsion systems for the maximum and cruising speeds of the target ships or finding a weapon system and sensor suites for achieving the target attack ability.

First, the designers consider present technologies that could be applied to each area. Then, they evaluate future technology that could be developed. For these analyses, researchers investigate the equipment or systems applied in other countries. Next, if some of the alternatives are determined impossible to build from an engineering perspective, they are excluded. Another important consideration in design alternatives is key performance variables. These variables define the performance parameters for satisfying the design goals. The designers set an objective and threshold goal. As in the U.S. ACV program, these capabilities are the big rocks to adjust in the design space.

An operational requirement review (ORR) is conducted within three months of the preliminary study. The ORR re-examines the operational requirements and suggests design options for the design areas based on the ROC. The ORR proposes specific design alternatives based on the traditional method. The results of the ORR through the SBD method is a procedure that identifies and investigates the possibility of design alternatives in each field and reaffirms the needs and preferences of stakeholders. Based on the concept base identified in the ORR, the design alternatives for each field are reviewed at a wider range without any early confirmation.

Once designers narrow the alternatives for each area, they review the combinations for the entire system. It is possible to determine the weight, size of the whole vessel, and the acquisition cost with the combinations of alternatives in each field. Options are filtered if there are restricted solutions in the overall view. Table 2 summarizes this process.

Table 2. The Summary of the SBD-Applied Process for the Initial ROC

1. Map the Design Space	a. Define feasible regions: Identify all applicable concepts based on the ability analysis capability of the operator. b. Explore alternate alternatives: Define essential mandatory skills or thresholds for each area, identify other overall skill requirements, and identify alternatives for each area. c. Communicate sets of possibilities: Derive forecasts for alternative area settings that meet requirements. The ORR examines stakeholders and their possibilities.
2. Integrate by Intersection	a. Look for the intersection of feasible sets: Identify the possible sets in which they can be harmonized with one another. b. Impose minimum constraints: Do not try to narrow down alternatives too much or set constraints on the basis of whether they meet the power of the higher concept. c. Seek conceptual robustness: Ensure that the sets of identified design combinations meet the capability gap initially granted.
3. Establish Feasibility before Commitment	a. Narrow sets gradually while increasing detail: Identify Key Performance Parameters by identifying limits such as full tonnage and factors affecting them. In addition, the region further reduces the area based on the additional desired elements within the available area. b. Stay within sets once committed: Consider specific design alternatives within a narrow set of capabilities. c. Control by managing uncertainty at process gates: Proceed to the next step through ROC confirmation.

In order to find an optimal system alternative, it is necessary to analyze the effectiveness of each synthetic alternative that has been filtered and narrowed. The effectiveness of the overall system is determined by compiling measures of effectiveness in each area, which are scored against respective measures of performance. Depending on the importance of each field, the weights are set differently (weight selection); weights reflect stakeholders' opinions obtained through the ORR. Several selected alternatives are narrowed further through trade-off analysis in terms of the total cost (displacement) versus the total effect by the participation of stakeholders such as operators, design experts, and program managers. One or two final alternatives become the "performance baseline."

Based on the performance baseline, the engineering design is executed according to the functional aspect. Functional baselines provide details on performance, interoperability, and requirements for interfaces and their verification. Ship designers design physical subsystems to achieve the desired effect with an appropriate combination. The combination of required subsystems, their comparison, and their acquisition is discussed based on the performance baseline.

At this stage, the initial TLR is created based on the ROC. The TLR is a document that defines the technical and operational requirements that further refine the requirements for existing capability gaps and describes key performance and equipment to be loaded on each component operation. Once the initial TLR is created, it becomes the input for the next step: the exploratory development phase. The SBD method can be applied once again in this step. Table 3 summarizes the process.

Table 3. Summary of the SBD-Applied Process for the Initial TLR

1. Map the Design Space	a. Define feasible regions: Determine feasible system configurations that can satisfy a defined ROC and then be a combination of the various subsystems of each system. b. Explore trade-offs by designing multiple alternatives: Consider a variety of ways to implement the functionality through the subset of each system. c. Communicate sets of possibilities: Get feedback from stakeholders and document in the draft TLR.
2. Integrate by Intersection	a. Look for the intersection of feasible sets: Mature the draft TLR and determine the intersection of each set to remove unrealizable sets. b. Impose minimum constraints: Concentrate on checking key performance parameter ranges of subsystems that can trade off. c. Seek conceptual robustness: Among the set of alternatives identified as a solution, find the conceptually less robust alternatives and eliminate them.
3. Establish Feasibility before Commitment	a. Narrow sets gradually while increasing detail: Refine each set of alternatives further. b. Stay within sets once committed: Ensure that the performance ranges of the systems and subsystems derived from the ROC and the SDR are consistent with their requirements and parameters, maintain traceability, and do not set new boundary ranges c. Control by managing uncertainty at process gates: This TLR will be the basic data of the TLS in the next step, and TLS will be confirmed at the exploratory development phase.

C. CASE STUDY

Based on the theoretical application of the SBD process, this section presents a conceptual design of a virtual ship. The ship is a newly constructed patrol boat that is operated by the ROK Navy. The reason this ship was chosen is that it is the Navy's smallest battleship for anti-surface warfare. Since this boat is small and has simple subsystems, it was easy to analyze and design conceptually. The capability gap was determined by modeling the operational mission of the Patrol-Boat Killer Medium Rocket (PKMR) and its operational environment. The concept base and the performance baseline were created using the SBD method, which also allowed for the exploration of alternatives.

1. What Is a PKMR?

Figure 17. The ROK Navy's Gumdoksuri-Class Patrol Boat (PKMR–211). Source: Yonhap News Agency (2017).

The PKMR is a ship that will replace the Chamsuri-class Patrol-Boat Killer Medium (PKM), which has been in operation for about 30 years in the ROK Navy.

Construction began in 2014, and the first ship was delivered in 2017 (DAPA 2018). Figure 17 shows the first PKMR. Coastal disputes between the ROK and North Korea, along with the latter's frequent crossing of the Northern Limit Line (NLL), led to the development of the PKMR. Coastal rejection and close combat with an enemy Navy comprise the primary mission of this platform (DAPA 2018).

2. Assumption

This case study makes two assumptions. First, it applies a capability-based analysis to the ROK Navy rather than to the current mission of the ship. Second, it assumes that the analysis and preferences of stakeholders were randomly selected due to the confidentiality of the ROC.

3. Design Reference Mission

1. Potential tasks
    a. Peacetime: Coastal patrol/Defend NLL against the enemy patrol boat
    b. Wartime: Defeat the enemy patrol boat and high-speed amphibious craft
2. Potential threats
    a. Enemy: Ship, missiles, aircraft
    b. Natural: Sea state, wind, water plants
    c. Obstacles: Fishing nets
3. Stakeholders
    a. ROK Navy
    b. DAPA
    c. Warfighters
    d. MND
4. Mission statement
    a. It is a ship to replace the existing 150-ton class PKM, and this ship has a mission to defeat enemy patrol boats and high-speed amphibious crafts at the maritime border and NLL of Korea.

4. Capability Gap

The existing PKM is a 150-ton boat with a maximum speed of 37 knots, 30mm or 40mm main gun, 20mm guns on the stern, and a small anti-aircraft or anti-ship missile. When engaging an enemy ship, it is difficult to penetrate the thick deck of an enemy boat with a 40mm gun. In addition, fishing nets, which often interfere with operations, cause the screw to malfunction in coastal areas. The 500-ton Yoonyongha-class Patrol Killer Guided Missile (PKG) has been supplemented with the development of sea power instead of the PKM, but a number of small boats are needed for normal operations and access to the island bases. It is also necessary to minimize the number of crew by supplementing the automation system of the ship by reducing the number of naval personnel.

5. Initial ROC

- The maximum speed of the ship: Over 40 knots
- Limit maximum full displacement: Less than 300 tons
- The number of crew members: Fewer than 30 persons
- Propulsion system: Needs propulsion power for maximum speed/ propulsion type not to be disturbed in shallow and fishing nets area
- Weapon systems: Needs guns for close combat and for loading guided weapons for high-speed amphibious boats

6. SBD Application

Based on the design reference mission and the initial ROC, I researched the ships of other countries with a similar purpose and size to explore the design domain. Data from Jane's by IHS Markit showcased the comparison between inshore patrol boats and missile boats, which have similar full displacement. In total, I summarized the maximum speed, length, beam, draft, full displacement, and propulsion systems of approximately 40 vessels.

Then, creating two teams, one for the ship's platform and one for the weapon system, we started an investigation. First, the platform team considered the length and beam, which indicate the size of the ship in the platform field. The team also considered a more detailed plan by dividing the size of the ship and the propulsion system. Next, we checked the length and beam of ships whose full displacement is 100 to 300 tons based on the data. Within the range of 30–50m in length and 6–8m in width, the scope of the alternative was narrowed. For the propulsion system, the required engine power—which can achieve performance above the target speed—is important in considering the displacement of the ship. In addition, the number of crew members for the operation of the ship was also considered in the platform area.

A statistical model was established to verify the validity of each combination. The dependent variable *y*, which is the objective function of the target vessel, and the parameter related to the ship performance is defined as the independent variable *x*. In a battleship acquisition program, *y* might be cost and displacement, and *x* might be the speed, the propulsion system's type and power, or the cruise range. Regression analysis was used to develop a statistical model for *y* and to predict the extent of the rough design for each concept alternative.

One requirement of the ROK Navy is to limit full displacement to avoid duplication with the PKG. Therefore, a statistical model for optimization was constructed by changing the full displacement from 100 tons to less than 300 tons and the dependent variable *y* of the target function to the full displacement. The maximum speed, type of propeller, required horsepower, number of crew members, length, width, and draft of the ship, which appeared in the surveyed database, were defined as independent variables.

Correlation analysis was applied to find the linear relationship between dependent and independent variables. The correlation between continuous variables, expressed by the correlation coefficient (r), appear at the top of each graph in Figure 18.

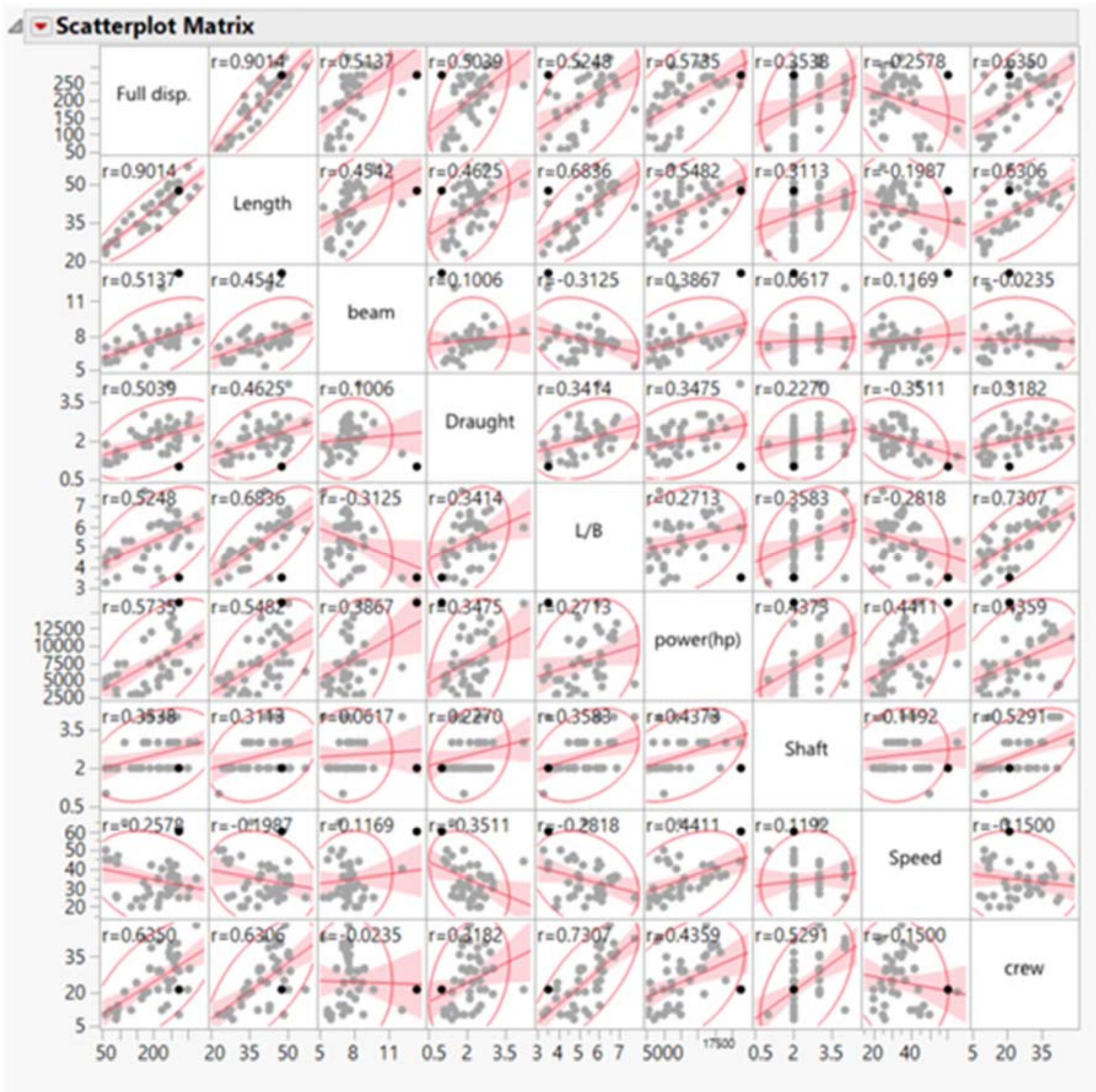

Figure 18. Multivariate Correlation Analysis Chart

There is a strong correlation when the correlation coefficient is greater or equal to 0.7. Conversely, a correlation coefficient of 0.5 to 0.7 indicates a weak correlation. When a straight line is tilted to the left side, the correlation is positive—and to the right, negative. The correlation analysis implies a linear correlation between the continuous variables and a direct causal relationship. In other words, statistical rhetoric may be a causal relationship between correlated variables. The results of the analysis were used in alternative analyses of the development concept and engineering design process (Park and Park 2015).

Through the JMP program, we could see which of the independent variables has the greatest effect on the dependent variable and the full displacement of the ship. The result is shown in Figure 19.

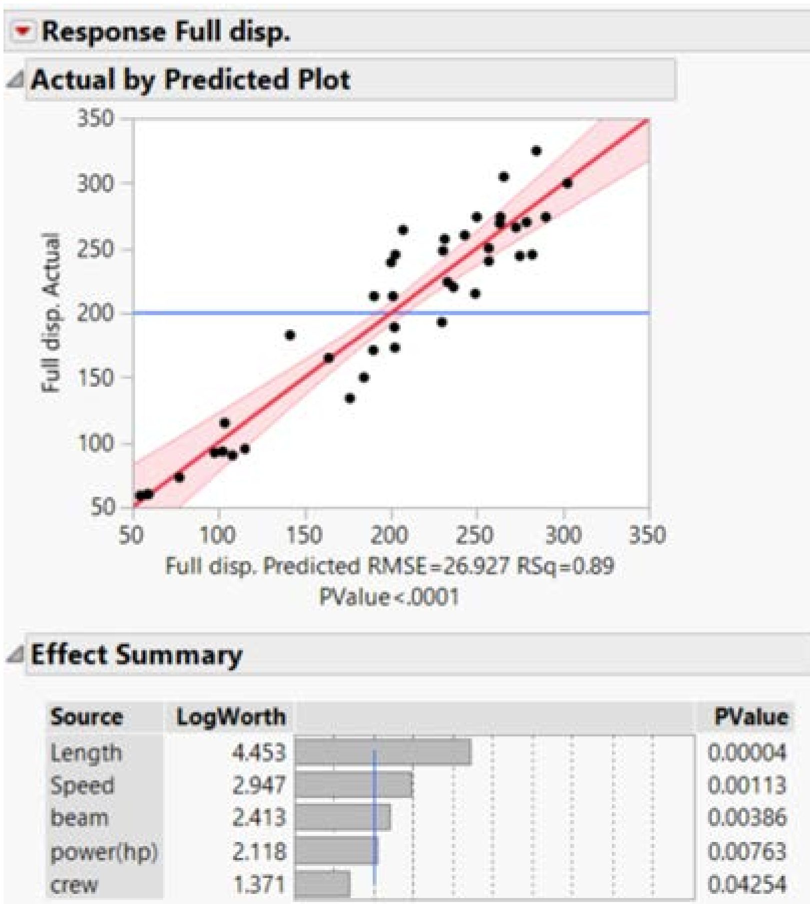

Figure 19. Predicted Plot and Effect Summary of the Regression Model

Length, speed, beam, power (hp), and crew were the most influential factors. These key variables appear in the expression for full-load tonnage.

$$\text{Full Disp.} = -56.436 + 4.241 * \text{Length} + 11.283 * \text{Beam} + 0.005 * \text{power(hp)} - 2.006 * \text{Speed} + 1.195 * \text{Crew}$$

Using the five key variables, we set the scope—as shown in Table 4—and created 720 alternatives in the design of the experiment.

Table 4. Key Performance Parameters and Alternatives

KPP	Alternatives
Length (m)	30, 35, 40, 45, 50
Beam (m)	6, 7, 8, 9
Max Speed (kts)	40, 45
Crew (no.)	25, 30, 35
Power (hp)	3000, 6000, 9000, 12000, 15000, 18000

Considering the embedded future weapons and other equipment, I set the upper limit to 250t, and a total of 305 alternatives were excluded. Given the ratio of the engine power to full tonnage, the present technology, and existing ship data, the value had to be greater than 30 to reach a speed greater than 40 knots. As a result, there were 221 alternatives left, with the exception of alternatives that would be less than 30. Next, assuming that the additional requirements of the Navy were to require fewer than 30 personnel deployed to reduce military personnel and automation systems in the ship; alternatives were eventually reduced to 130.

On the other hand, the field of weapons systems was divided into main guns, secondary guns, and a guided weapon. Table 5 depicts examples of the alternatives for each part.

Table 5. Examples of Alternatives for a Weapon System

Weapon system	Alternatives
Main gun	127mm, 76mm, 40mm, 30mm, 12.7mm
Secondary gun	76mm, 40mm, 30mm, 12.7mm, None
Guided weapon	harpoon, mistral, 130mm rocket, None

Considering these alternatives in each part yielded more than 100 alternatives. The number of combinations was even larger given the placement and installation number of each armament. Analyzing enemy threats—accounting for the enemy's armor status, dominance, and speed—the number of possible weapons systems syntheses were reduced.

The next step was to assume that each platform design team and weapon system design team would talk about each other's alternatives and discuss the feasibility of the combination. When considering the weapon system, it was necessary to install guns of 76mm or larger to inflict damage on the external structure of the enemy ship. The ship platform team considered the engineering design limit of the ship size for the larger gunnery installation; the alternatives were reduced to 15. Figure 20 and Table 6 present brief conceptual design results for the PKMR.

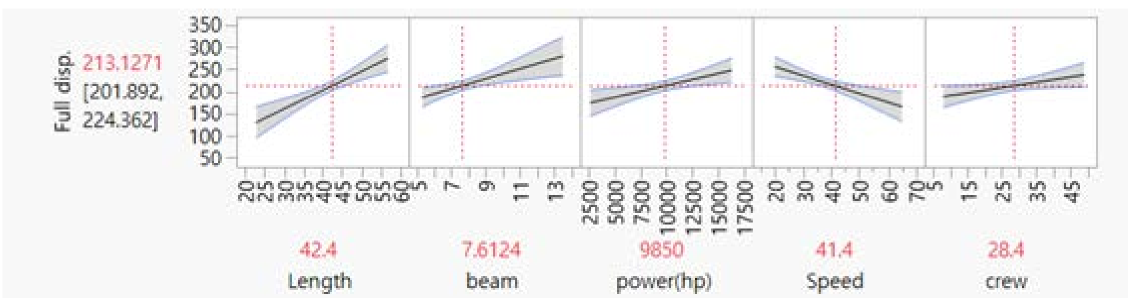

Figure 20. The Prediction Profiles of Each Factor

Table 6. The Result of the PKMR Conceptual Design

Length	Beam	Speed	Crew	Power	Full Disp.	Weapon System
40-45m	6-8m	40-45kts	25-30	9000-10000hp	220-250 ton	Guided Rocket, 76mm gunnery

Through the simplified conceptual design example, we tried directly to optimize the ship design through SBD, and it was a simplified method. However, when compared with the current PKMR, the ship was in this range in each part. Therefore, it could be effective for the conceptual design of the Navy's ship.

7. Limitation

Despite the empirical requirements of the ship-designing process, the scope of the concept design was limited. Additional limitations of the research include the conspicuous absence of an accurate displacement or cost consideration. This was due to constraints in design synthesis programs in Korea. Foreseeably, the design and development aspect of this research could facilitate a useful framework for any ship design.

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V. CONCLUSION AND RECOMMENDATIONS

A. CONCLUSION

This thesis explored the prospects of applying the SBD method to the ROK Navy's ship designs. It described the SBD method and then presented pilot programs in the U.S. Navy that demonstrate how SBD can determine the feasibility of an application. Relevant to the discussion of applying SBD to the ROK Navy's ship designs, the author has explored the U.S. Navy's application of SBD method to present a framework for properly applying SBD in the early stage of the ROK Navy's ship acquisition system.

Currently, both Korea and the United States have a common problem in that they want to acquire weapon systems with the highest performance and cost-effectiveness, but there are constraints such as defense budget cuts and tight schedules. Ship acquisition requires more time, more manpower, and a higher budget than other weapon systems because a ship is a complicated system. In this regard, the application of the SBD method in the U.S. ship acquisition process suggests this method can be a solution to these challenges. Therefore, the application of SBD—borrowing similar concepts that have shown some success in the U.S. Navy's examples—is potentially a more practical approach to South Korea's ship designs.

In this thesis, a guideline was suggested for applying the SBD method in the Korean ship design process, and a conceptual design of the ROK Navy's PKMR was presented. As a result of the case study, the dimension and features of the PKMR were in the range designed through the SBD method. It is therefore suggested that the SBD method can be applied to Korean ship designs with potential benefits of cost and schedule savings.

In conclusion, applying the SBD method to Korean ship designs may be effective at reducing the time and cost for the acquisition, and this method may become the best alternative from a naval architectural perspective. This thesis suggests the design process improvement because Korea does not have definitive guidelines for the ship design process. If Set Based Design methods are used for the development within the Korean acquisition system, it could help ship designers and decision makers achieve a satisfactory result in the ship design, given all other programmatic constraints.

B. RECOMMENDATIONS FOR FUTURE RESEARCH

There were two major difficulties in conducting my case study for this thesis: one was the challenges in data collection, and the other was the limitation in the computer-based modeling for effectiveness and cost estimation. Therefore, the following paragraphs present two recommendations for future studies.

First, the study of a developing database for ship designs is needed. Past ship design data could be an important basis for future model development. Particularly, if the database had the necessary data for ship design according to the type of ship and the full displacement, it would provide valuable data for design analysis. Therefore, proceeding with a study to develop a ship design database is necessary for the ROK Navy, and the ship designers should add new data after they build a new ship. When Korea has created this database system, engineers may explore the design area more accurately and easily based on the SBD method.

Second, the ROK Navy needs to establish a computer-based design synthesis and cost estimation tool. It would have been helpful to design more precisely if the case study in this thesis had used Korea's design synthesis program. However, computer-based synthesis tools, such as the Advanced Ship and Submarine Evaluation Tool (ASSET) and Leading Edge Advanced Prototyping for Systems (LEAPS) of the U.S. Navy, are not currently being developed in Korea (Park et al. 2016). Therefore, I recommend the development of design synthesis and cost estimation tools, such as ASSET or LEAPS, as demonstrated in the United States. Using these tools would make it possible to analyze the exact effect and cost of alternatives using SBD, which would be very helpful for choosing the best option.

APPENDIX. PATROL BOAT DATA

No.	Class	Full disp.	Length	Beam	Draught	Propulsion source	Power(hp)	Propulsion type	Shaft	Speed	Crew	Weapon	Missile
1	Aadesh	270	50	7.6	1.7	D/E	11,238	Waterjet	3	33	36	M	None
2	Admidale	300	56.8	9.7	2.7	D/E	6,225	PP	2	25	21	S	None
3	Asheville	245	50.1	7.3	2.9	CODOG	13,300	PP	2	36	37	L	None
4	Azteca	150	34.4	8.7	2.2	D/E	3,000	PP	2	24	24	M	None
5	Bangaram	260	46	7.5	2.5	D/E	7,492	PP	2	30	33	M	None
6	bay	134	38.2	7.2	2.4	D/E	2,816	PP	2	20	12	S	None
7	Car Nicobar	325	48.9	7.5	2.1	D/E	11,238	Waterjet	3	35	49	M	None
8	Centauro	90	28.4	5.95	1.4	D/E	3,600	PP	2	26	8	S	SSM
9	Clurit	248	44	7.4	2.4	D/E	5,400	PP	3	27	35	M	SSM
10	Corrubia	93	26.8	7.6	1.2	D/E	5,800	PP	2	43	12	M	None
11	Fremantle	245	41.8	7.1	1.8	D/E	6,140	PP	2	30	24	M	SSM
12	Grajaú	220	46.5	7.5	2.3	D/E	5,480	PP	2	26.5	29	M	SSM
13	Hamina	274	50.8	8.3	2	D/E	7,510	Waterjet	2	32	29	L	SSM
14	Hayabusa	244	50.1	8.4	4.2	G/T	16,200	Waterjet	3	44	21	L	None
15	Helsinki	305	45	8.9	3	D/E	10,230	PP	3	30	30	L	None
16	Houbei (Type 22)	224	42.6	12.2	1.5	D/E	6,865	Waterjet	4	40	12	M	None
17	KAAN29	95	31.7	6.7	1.4	D/E	7,300	Waterjet	2	47	14	S	None
18	KAAN33	115	35.6	6.7	1.4	CODOG	7,396	Waterjet	3	65	20	S	None
19	Kartal	193	42.5	7	2.4	D/E	12,000	PP	4	42	39	M	None
20	Kiisla	274	48.3	8.8	2.2	D/E	7,510	Waterjet	2	25	10	S	None
21	Kuang Hua VI	171	34.2	7.6	3	D/E	10,944	PP	3	33	19	S	SSM

No.	Class	Full disp.	Length	Beam	Draught	Propulsion source	Power(hp)	Propulsion type	Shaft	Speed	Crew	Weapon	Missile
22	La Combattante IIa	269	47	7	2.7	D/E	12,000	PP	4	36	41	L	None
23	Matka	264	39.6	7.6	2.1	D/E	10,800	PP	3	42	30	L	SSM
24	Orca	213	33	8.4	2.5	D/E	5,000	PP	2	20	21	S	None
25	Osa	213	38.6	7.64	2.7	D/E	8,025	PP	3	35	29	M	SSM
26	Pacific	165	31.5	8.1	2.1	D/E	2,820	PP	2	20	17	S	SSM
27	Priyadarshini	215	46	7.5	2.09	D/E	4,025	PP	2	23	42	M	None
28	Protector	183	33	6.7	2.1	D/E	3,483	PP	3	30	20	S	None
29	Marine protector	92	26.5	5.8	1.6	D/E	2,680	PP	2	25	10	S	SSM
30	Rauma	240	48.5	8	1.5	D/E	8,850	Waterjet	2	30	25	M	None
31	Sa’ar 3	250	45	7.62	1.8	D/E	12,800	PP	4	40	40	L	None
32	Sarojini Naidu	266	50.44	7.5	2.1	D/E	10,942	Waterjet	3	35	35	M	None
33	Shaldag	59	24.7	6	1.2	D/E	5,000	Waterjet	2	50	10	S	None
34	Shanghai III	173	41	5.3	1.8	D/E	4,400	PP	4	25	43	L	None
35	Skjold	274	47.5	13.5	1	G/T	16,320	Waterjet	2	60	21	L	None
36	Sparviero	60	22.95	7	1.87	CODOG	5,044	Waterjet	1	50	10	L	None
37	Stenka	257	39.4	7.9	2.5	D/E	14,100	PP	3	37	25	M	None
38	Super Dvora Mk II	60	25.4	5.67	1.1	D/E	4,175	Waterjet	2	45	10	M	SSM
39	Super Dvora Mk III	73	27.4	5.67	1.1	D/E	5,470	Waterjet	2	45	12	M	SSM
40	T.991	189	38.7	6.45	1.8	D/E	7,400	PP	2	27	30	M	None
41	Tenochtitlan	239	42.8	7.11	2.52	D/E	5,600	PP	2	26	14	S	None

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