PROJECT ARCHITECTURES FOR SHIP DESIGN

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SUMMARY

Modern warship projects invariably have a wide range of technical and acquisition options to consider during the Concept Phase, as typified by the MoD’s Mine counter-measures, Hydrography and Patrol Capability (MHPC) project. To address the associated business, technical and acquisition issues that arise, it is recommended that a project architecture be set up at the start of such projects. Within this process, a priority is to ensure that different concept solutions can be investigated and de-risked, an approach that relies primarily on functional analysis.

Each concept has to represent a coherent strategy within which the types of systems deployed are consistent with each other and that allows the various safety, interoperability, support and other viewpoints to be considered. These early concepts are built in a way that allows ‘design intent’ to be defined and sustained through life.

By learning from the experience of recent projects and looking ahead to the design, integration, operation and support environments, the early concept work can help by anticipating project interfaces that minimise commercial risk and that allow repeated upgrades through life to be incorporated without re-designing the associated services.

NOMENCLATURE

ALARP As Low As Reasonably Practicable
ATP Allied Technical Publication
CAD Computer Aided Design
CADMID Concept, Assessment, Demonstration, Manufacture, In Service and Disposal
CBS Configuration Breakdown Schedule
DLOD Defence Line Of Development
FLC Future Landing Craft
FMECA Failure Modes Effects and Criticality Analysis
FSM Future Submarine
MHPC Mine countermeasures, Hydrography and Patrol Capability
MoD Ministry of Defence
PBS Product Breakdown Schedule
PDM Product Data Management
PLM Product Lifecycle Management
QEC Queen Elizabeth Class

1. INTRODUCTION

The Concept Phase of a warship project has to respond to user requirements and develop suitable ship concepts that represent viable ways of delivering the required capability. In developing these concepts, it must also look ahead to the needs of through life management and the associated processes that are increasingly dependent on a sophisticated and fast growing suite of 3D CAD, Product Data Management (PDM) and most recently Product Lifecycle Management (PLM) systems to support the design and integration processes. Although these tools do not reach their full potential until the detailed design stages, they develop information flows between owners, designers, shipbuilders and suppliers, and influence the structure of the entire project from the earliest stages.

This paper considers how systems engineering disciplines and the associated development of a project architecture should develop this structure and ensure that the original design intent can be maintained through life.

Attention is drawn to some of the main collaborations that need to be addressed in preparation for a configuration managed design process. The structures involved support the wider integration process and help ensure that the main risks are addressed at the correct stage in the project.

2. CHALLENGE

This paper draws on experience being gained in the Concept Phase of the MoD’s Mine countermeasures, Hydrography and Patrol Capability (MHPC) project. The project has a number of distinguishing features that typify the challenges and opportunities which systems engineering is called upon to address in the early stages of a project.

The project addresses a military capability that will rely potentially on the ongoing development of technologies in fields such as unmanned vehicles and underwater communications, perhaps in collaboration with air or land based assets. Many strategies are under active investigation and portable assets may have a significant part to play, as considered within concepts such as the VENATOR, Figure 1.
There are a wider range of acquisition options than for the traditional warship project, yet the current financial climate and progress towards a strategic defence and security review make it all the more important that the proposed way ahead is supported by a convincing and comprehensive business case within which it is demonstrated that the required military capability can be delivered and managed through life.

By comparison with earlier projects, two challenges stand out and are the main focus of this paper:

a. From the unusually large number of possible concepts, how can the viability of the leading contenders be demonstrated in time to generate a clear acquisition and risk management strategy, and a convincing business case for onward investment?

b. How can the concept phase be structured to address life-cycle issues and help gain maximum benefit from Product Lifecycle Management (PLM) techniques?

3. STRATEGY

A systems engineering strategy should be instantly recognisable at the start of any project. There is an early drive, not only to set clear objectives for the project but to identify the working relationships, dominant issues and key parameters within a single overall structure, the ‘architecture’. When identified, these core elements need to be expressed in a way that allows stakeholders to see how the many activities within the project combine to deliver the intended outcome and should allow everyone to make the contributions for which they are best qualified.
traceability’ from user requirements to the eventual design solution.

![Diagram](image.png)

**Figure 4:** Contributions to Satisfaction Arguments

3.2 SYSTEM BOUNDARY

With so many potential ways of satisfying the military capability across maritime, land and air domains, the Project must define its own boundaries with care. Work is in hand to define the ‘capability boundary’, a process that helps to build valuable lines of communication with key stakeholders and ensure that the Project’s planning and resources are in tune with its, as yet unconfirmed, long term acquisition responsibilities. As the capability boundary is refined and concept solutions are developed, the full ‘system boundary’ takes shape and allows interface agreements to be set up with other projects.

3.3 FUNCTIONS

As discussed further below, functional analysis dominates the early search for conceptual design solutions. Functions carry measures of performance and are implemented by whichever technologies and systems are brought together to collaborate within a particular concept. User requirements, OA analysis and technology reviews are useful indicators of the higher level functions.

3.4 SYSTEMS

At the start of the Concept Phase, it is too early to know which equipment will need to be procured but a top-down hierarchy of potential systems, grouped in functional terms, is enough to start exploring outline system configurations. For example, there will clearly be a need for a command system and the allocation of suitable functions to this notion system can be explored for each concept, but the scope and configuration of the eventual hardware and software will not be decided until the design process itself.

3.5 CONCEPTS

Concepts can be considered as ‘configurations of systems’ that explore how the ship and its mission packages could be procured to achieve a suitable balance between capability and affordability.

The systems integrated within each concept must collaborate in a way that implements the necessary functions and delivers the overall performance on which the capability will depend.

3.6 PROJECT ARCHITECTURE

The technical dimension of the project architecture unites the operational analysis, requirements management, functional modelling and the various viewpoints that apply to the Defence Lines Of Development (DLODs), all uniting to generate concepts and investigate how they can be implemented and supported.

There is also a business dimension that justifies and de-risks the potential investment. Investment appraisals have to be supported directly and it has to be shown that the original design intent can be sustained through life. In practice, this means that a design solution must not only meet requirements but must be understood in terms of the functional services it delivers and the business goals that are being supported. This allows maintenance, support and obsolescence management strategies to focus resources where they will best sustain the capability and its availability to UK forces.

The procurement dimension considers the interests of the wider stakeholder community and investigates how every element of the desired capability is to be procured, whether from within the Project or, in some cases, by relying on services and equipment from other projects. Internal business agreements have to be negotiated to avoid the risk of gaps in the procurement chain.

4. FUNCTIONAL MODELLING

Although the ‘system’ is the physical and procurable element that lies at the heart of the design and manufacturing processes, the main currency in the Concept Phase and the key link between requirement and eventual solutions, is the ‘function’. Many requirements are functional by nature and, even when the requirements themselves are immature, it is invariably possible to resolve many of the functions that will inevitably be needed as the project progresses.

A functional breakdown provides a baseline structure against which different system configurations can be assessed. The construct that maps functions to systems allows any number of system configurations to be considered as the basis for possible concepts.
Generators are involved directly to their addressed. For example, early discussions may focus on developing a platform-wide functional model, both to suggest there is a case to return to the practice of managing ‘design intent’ through the life of the vessel and this is often best expressed by a function and its intended performance. The associated hardware may have a much shorter lifecycle.

The principles of functional modelling are well known but there is scope to encourage a wider understanding of how functional analysis can support a project’s Concept Phase and prepare for an efficient transition into Assessment and Stage 1 design. Recent experience suggests there is a case to return to the practice of developing a platform-wide functional model, both to support the design process and to underpin the maintenance of design intent through life.

The technique involves building functional breakdowns, Figure 6, that are disciplined, top down and entirely logical. In the Concept Phase, they should be taken only to a level of detail that is appropriate to the issues being addressed. For example, early discussions may focus on whether an unmanned vehicle is subject to manual or automatic control and which underwater search patterns need be hosted in the vehicle itself. The detailed search and control functions may not need to be resolved until later.

Performance parameters are linked directly to their parent functions but the overall performance of the integrated system relies on the integration of its subsystems to deliver the capability required. A ‘system hierarchy’, Figure 7, is developed in parallel with the functional hierarchy, providing a menu of potential subsystems that can be tried in different configurations to deliver the performance and point to the wider implications, such as interoperability and training, that a particular configuration may involve. In the early stages, the systems hierarchy need be taken only to the level of detail necessary for the functions being investigated and their definition is therefore functional by nature. Physical system and procurement boundaries may be clear in some cases but do not dominate the analysis.

Figure 5: Concepts assembled from functions and systems

In functional analysis, it is established practice to describe functions as verb phrases such as ‘Sense depth of water’ and, since measures of performance are associated directly with functions rather than with the physical systems that may implement them, a failure mode is considered as a situation where one or more functions are compromised. More generally, it is important to realise that Design Authorities have to manage ‘design intent’ through the life of the vessel and this is often best expressed by a function and its intended performance. The associated hardware may have a much shorter lifecycle.

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Figure 6: Possible high level functions within a Functional Hierarchy

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Figure 7: Possible high level systems within a Systems Hierarchy

The distinction between function and system will remain through life and, as the Configuration Management Def Stan 05-57 makes clear, functional and physical aspects have to be documented for all Configuration Items (CIs).

4.1 SAFETY

The MHPC Project seeks to minimise the risks to personnel by using unmanned off-board systems and, for example, allowing the host vessel to stay out of the minefield. At the same time, the increasingly sophisticated mine threat and the technical challenges of using remotely operated equipment serve only to emphasise how difficult it may be to reduce the level of risk to an acceptable level. Ultimately, the safety of people and shipping is directly linked to the availability and performance of the mine counter-measures themselves.

The safety analysis should start early in the project and does not need to wait for the physical system architecture to be resolved. Safety cases should be proactive by using early hazard identification to resolve those functions that are safety related, allowing the design process to find the most cost-effective way of implementing them. In a similar vein, any environmentally sensitive functions should be identified as early as possible for pre-emptive design action to be taken.

An underlying principle is that by understanding the functions that are needed and the risks involved if they are compromised, a design process can focus resources on measures that represent best value for money. This is consistent with the aim of reducing risks to As Low As Reasonably Practicable (ALARP). It avoids the
inefficiencies of design processes that are dominated by design standards and for which safety and environmental issues may not be discovered in time to avoid expensive corrective action.

5. SYSTEM HIERARCHY

The system hierarchy provides the building blocks from which concepts are defined and becomes the early Product Breakdown Structure (PBS), effectively the ‘point of truth’ for the start of the design process. As concepts are down-selected and analysed in more detail, the system hierarchy helps define the technologies and supply chain options that may apply for each procurable system.

The Work Breakdown Structure (WBS) is developed at the same time. Working boundaries are the basis of responsibility matrices, a suitable way of mapping resources onto work packages as the procurement strategy takes shape.

If a system hierarchy is to provide maximum benefit, it must form the basis of a robust PBS and WBS and underpin the project’s documentation structure. It must also be compatible with future requirements for configuration accounting. It is anticipated that the PBS of the future will designate design objects down to a greater level of detail than is currently done and form a single product structure to become a ‘Configuration Breakdown Structure’ (CBS) such as that outlined at Figure 8. Once fully developed, such a structure would uniquely identify objects for reference, not only during the entire design process but for parts codification, maintenance planning, failure mode analysis, and, in situations where ship systems can be delivered and set to work in stages, for the tracking of sub-systems and components at different points in their lifecycle. For the construction of major warships, it may often occur that different sub-systems within a single plant are delivered, set to work and brought into maintenance at different times.

![Figure 8: Outline Configuration Breakdown Structure (CBS)](image)

6. CONCEPT EVALUATION

For the MHPC project, a warship platform is the baseline solution but the project team has to find a way of considering the wide range of alternatives and filtering out unsuitable concepts without wasting valuable time and effort. This is both a management and a technical challenge and is being addressed in two stages.

The first stage collates any ideas, however unusual, as ‘seed concepts’ that are treated as little more than strategies with which certain technologies and types of equipment may be associated. There is no limit to the number of seed concepts that can be raised and, having tried to identify all conceivable ideas, this initial collation provides the basis for the most unrealistic ones to be eliminated without wasting significant time and effort. The current collation holds 150 seed concepts of varying types.

The second stage is to start defining viable concepts as integrated packages. To be useful for analytical purposes a concept must be:

- **Conceptual.** The aim is to explore how different ideas, technologies or principles can be applied and resist the temptation to eliminate novel approaches over a perceived lack of feasibility.

- **Consistent.** All elements of a concept must be compatible with each other, meet a common set of assumptions, be capable of integration and represent as realistic an approach as the underlying strategy allows.

- **Coherent.** The elements of a concept must not only show consistency but also deliver coherency, allowing the entire system to be understood within a single viable strategy that can be implemented, operated and tested. A practical implication is the need to define suitable operating, complementing, training and logistic support strategies.

- **Complete.** Even high level concepts should include all the main elements and identify the main interactions across interface boundaries. An incomplete concept, which addresses off-board systems alone, for example,
soon becomes difficult to analyse because there is no basis on which it can be compared to baseline solutions and there is no structure to which new elements can be joined as the model expands. It is better to make a balanced judgement, select one complete configuration for analysis, assess the outcome, and then iterate as necessary.

A 3 stage down selection process might start with up to 30 concepts in the first batch. After about 6 or 9 months, there should be no more than 12 as these need to be developed in sufficient detail to win endorsement across the project as the leading contenders. The third and final set would usually include up to 4. These have to be defined to a level that supports the business case for Initial Gate, whilst recognising that further iterations and design assessments will inevitably continue into the Assessment Phase.

7. INTEGRATION ASPECTS

There are many activities initiated during the Concept Phase that look ahead to the needs of the integration process, whereby the various sub-systems are made to work together and, in due course, are accepted as delivering the total system performance required. The organisation that will later fulfil the integrator role will provide the vital link between owner and suppliers and will have to take particular care over the management of working and design interfaces.

The role of the integrator can vary widely in scope, depending on the complexity and novelty of the design, but the integration process will in any case pay early attention to the interpretation of requirements, impose effective interface management processes, address safety issues and actively manage risk throughout. Work during the Concept Phase can help by the following:

- Developing concepts that offer a cost-effective means of achieving the desired capability, minimising the risk that major changes will be necessary during detailed design;

- Identifying as clearly as possible the design trade-offs that will need to be resolved at the end of the Concept Phase, since projects such as MHPC are unlikely to have eliminated all the design and technology options at this point. The overall system performance may be difficult to achieve when multiple systems interact and networked communications support services are shared with third parties;

- Setting up a disciplined framework for interface management that includes the allocation of risk between the parties involved;

- Assessing likely organisational, procurement and commercial boundaries within the architecture, with particular attention to the system hierarchy and its influence on the PBS and WBS. Responsibility matrices help to define the boundaries between potential work packages. Such analysis is crucial if collaborative programmes are being considered because work-shares may be impossible to agree if IPR or security issues are not anticipated and resolved at the earliest opportunity;

- Establishing the preliminary documentation structure which, for complex software projects will need to anticipate the need for a full range of specification, design description and interface requirements documents. All projects will need an Architectural Design Document (ADD). The concepts being actively considered by the end of the Concept Phase will have outline physical and information architectures that will reflect the evolving functional and system hierarchies and will later be developed further within the ADD as part of the integration process;

- Approaching the definition of functional needs as loosely coupled ‘services’ that are independent of the underlying data structures and defined by business processes rather than by specific functions. This service oriented perspective will significantly reduce the risk that expensive system modifications will be needed through life whenever operational or other procedures are changed. Similarly, it will help obsolescence management by allowing IT infrastructure to be upgraded without compromising the operational service and, ideally, without the operators needing to be aware of the changes. Although the principle tends to be associated with software functions, it applies also to equipment in general, particularly in the MHPC project where there is scope to rely on portable equipment as well as dedicated platforms;

- Paying attention to the core processes downstream that will be subject to lifecycle management processes, such as configuration control, object maturity management, codification and RCM, as discussed below.
8. LIFECYCLE MANAGEMENT

Current warship projects continue to make substantial progress in the application of lifecycle management techniques and are taking advantage of the valuable experience gained in the Type 45, FSM and QEC projects. The following themes are inter-related and all support the case for a strong architectural structure originating in the Concept Phase.

The design intent has to be maintained through life if the many potential changes and upgrades through design, build and operational service are to be undertaken efficiently under Design Authority management. Throughout the design process, every element must retain its links to relevant design intent and the capability it represents.

Configuration management strategies are still evolving and will probably do so for some time. The historical reliance on weight codes as the underlying structure of the PBS continues to be influential because it is such an integral part of the shipbuilding process but it is also limited by its inability to deal efficiently with software intensive systems and the lack to date of full rationalisation across shipbuilding organisations across the country. There is an inevitable trend towards a single data structure such as the configuration breakdown structure discussed above.

The data management backbone can be expected to evolve along the lines of the guidance in Def Stan 05-10. The various project applications can be given access to product data via a ‘data warehouse’, Figure 9, that extracts the appropriate data from the project’s PDM tool, an improvement over historical arrangements where proprietary PDM solutions made data exchanges difficult. Modern data structures should allow data mining that retains links with the design intent as the data is used within the maturing design, assisted partly by traceability back to ‘functional asset groups’ or their equivalent.

![Data Management Strategy](image)

Figure 9: Data Management Strategy

A data structure that links objects to their associated functions and performance provides the basis for RCM analysis, including the Failure Modes and Effects Criticality Analysis (FMECA), Figure 10. The associated reliability levels required of the various systems and sub-systems are fed back into the design process to try and maximise the availability that is eventually achieved in service. If this process is conducted efficiently against a common object structure, it is easier to manage the production and ongoing configuration of ship’s maintenance instructions.

![RCM Process](image)

Figure 10: RCM Process (Extract based on Def Stan 00-45)

The transition to codification and life cycle support inevitably builds on the data management structures and configuration management accounting discussed above, as developed within Def Stan 05-10, Figure 11.

![Life Cycle Support](image)

Figure 11: Life Cycle Support (Extract based on Def Stan 05-10 Issue 5)

Inter-connectors, such as pipes and cables, have often been treated in the past as abstract components that are bought in or built to link systems together. Through life management principles, however, demand that they be treated as an integral part of their associated systems with full configuration control of their identity, purpose and performance. Their contribution to the transmission of high pressure fluids, high voltages or...
mission critical data, for example, is no less important than the systems they connect. Work in the concept phase will seldom address inter-connectors directly but may have to allow for safety or reliability issues associated with solutions relying on particular types of connector.

In addition to the CBS or equivalent breakdown structures mentioned above, there are arguments to introduce a ‘Site Breakdown Structure’ within which the compartments, survey sites and other locations are identified and subject to appropriate configuration management. Such an approach helps resolve ambiguities that can arise when a particular location is not defined directly by the physical objects defined within the design process.

Product Lifecycle Management (PLM) tools are a feature of modern ship design and their increasing use in warship design demands these ongoing improvements in data management within the design process. It is recognised that neither the final configuration management regime nor the PLM tools are likely to be resolved fully until project definition at the start of the Assessment phase, prior to entry into Stage 1 of the ship design process but, at this point in the programme, it is difficult to place design activities on hold whilst tools and processes are selected and configured. There will be pressure to let designers do their job and it may well be too late to introduce changes that have a major impact on working practices across the many organisations involved, particularly if the ship is to be built from blocks assembled in different yards, as for the QEC.

The Concept Phase is the time to set the long term direction and develop a robust architecture that provides a suitable starting point for processes that will continue through life. The configuration management structures, in particular, must be sustainable because they provide the data framework on which so many applications and organisations depend.

9. CONCLUSIONS

The Concept Phase develops the requirements set and establishes ‘design intent’ that should be sustained throughout the life of the project.

Understanding the ‘function’ is the key to turning requirements into exploratory design concepts.

Concepts, at their simplest, are ‘configurations of systems’. They establish the interface structure and therefore the working relationships by which the project’s technical and commercial risks can be managed. The logical down-selection of suitable ship concepts during the Concept Phase builds an essential audit trail and helps set up the cost/capability trade-offs that underpin the investment appraisal process.

The project architecture is fundamental to any modern project where there are business goals to be achieved, complex working relationships across multiple organisations, a highly integrated design process and the need to exploit efficiently the power of PLM and other data management intensive tools.

10. ACKNOWLEDGEMENTS

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11. DISCLAIMER

This paper represents the views of the author and are not necessarily those of the MHPC Project or the MoD.

12. AUTHOR’S BIOGRAPHY

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