A SURVIVAL GUIDE FOR SYSTEMS ENGINEERING IN SHIP DESIGN PROJECTS

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SUMMARY

The many conflicting demands on defence projects suggest that the value of systems engineering should be ever clearer. This paper suggests that Ship Designers can help steer the systems engineering effort within their project to gain maximum value from the time, information and people available.

Although experience of systems engineering techniques has grown fast in recent years, and the tools and techniques are becoming more embedded in routine project business, there remain practical challenges that prevent the discipline reaching its full potential. Useful principles behind typical systems engineering strategies are discussed and practical ways to engage the full project team are reviewed against the lessons of experience. The paper draws attention to some of the realities the systems engineer has to face when a change of culture is just as important as the expanding range of analytical techniques.

Finally this paper addresses the challenges of effective quality management in situations where deliverables come from architectural models that are too large or complex for those outside the immediate modelling team to deal with.

NOMENCLATURE

CAE Computer Assisted Engineering
DOORS Dynamic Object-Oriented Requirements System
GNS General Naval Specification
JSP Joint Service Publication
MODAF Ministry Of Defence Architectural Framework
MoP Measure of Performance
SME Subject Matter Experts
SOMI Statement Of Modelling Intent
TM Trade Mark
TOGAF The Open Group Architectural Framework
UUV Unmanned Underwater Vehicle

1. INTRODUCTION

This paper hopes to help the Ship Designer, who has to lead a multi-disciplinary team, understand the contribution that a systems engineering approach can have within their project and how this approach can contribute to the three fundamental goals of simplicity, understanding and communication.

This is as much about winning hearts and minds as about the application of modelling techniques or the adoption of Zachmann, MODAF or any other framework. Projects have always been partitioned in different ways, whether by Gantt charts, work breakdown structures or other management structures, and Ship Designers are familiar with a wide range of Computer Assisted Engineering (CAE) techniques. If systems engineering is to make a difference, it has to be recognised as a cross-cutting discipline, attempting to rationalise levels of complexity that are more than any individual can hold within their own head. In projects without this inherent complexity, systems engineering can more readily be reduced to Requirements Management, which is viewed here as only one of a set of analytical techniques which Ship Designers should request from their systems engineering team. In return, Systems Engineers need to be able to communicate the complexity of the analysis they are attempting to conduct, and be able to easily and simply contribute to, and draw from, the analysis being conducted by the wider project team and to inspire commitment to a comprehensive adoption of systems engineering principles. There has to be a cultural shift and engagement across a team so that the wider context and the full landscape of relevant interactions can be brought to bear on the design process.

Working methods have to be continually refined and filtered so that project teams are not being asked to adopt practices they simply do not relate to or believe in. Equally, the landscape of potentially useful architectural disciplines needs to be explored and tested as experience grows and working methodologies become more comprehensive and more credible.
2. SYSTEMS ENGINEERING IN PRACTICE

It is people that matter in the end. A systems engineering strategy should be recognised as a practical and efficient way of applying useful thinking, not an unwelcome imposition of diagrammatic techniques. Unfortunately, experience suggests that valuable time can be wasted at the start of a project while people are trained, processes are discussed and the focus is on the method, not the outcome. This is exactly when the opportunities are greatest and the most benefit can be gained from clear, well structured analysis and strong teamwork.

The discussion below seeks wider recognition for some of the system engineering foundations and offers ways of expanding the range of techniques that are useful in practice. Where the scale and sophistication of the processes involved raise doubts about the ability to achieve suitable levels of quality assurance, there are ways of ensuring that the level of assurance applied is practical and a net benefit to the overall process, as discussed at Section 5.

2.1 INNOVATION

The programme, budget and resource pressures on a typical project make it difficult to find time for real innovation. It is worth stressing that innovation becomes immeasurably more difficult as the project gets underway and team members lock themselves into their established processes. Given the ability of systems engineering to shape and prioritise the whole course of the project, largely by tailoring the structure, or ‘architecture’, of the project to the opportunity at hand, it is well worth any imposition of diagrammatic techniques. Unfortunately, this often leads to less than the best possible set of techniques applied, as the team and the project are not trained, so an unwelcome decision needs to be made.

This is never easy, but it is possible to encourage a culture within which every team member expects to discuss the possibilities at the start of a project, contribute their ideas and, as the project progresses, receive credit as their own original thinking is put into practice.

Formalised methods need not be imposed. It is difficult to over-emphasise the value of getting people around the whiteboard and arguing through how the project’s main themes are to be addressed. The systems engineering strategy can and should be flexible and team members must be free to focus on the issues that matter most to them, whilst following a process that becomes a core part of their daily business. There is no harm done if team members choose to spend significant time working in a particular type of diagram, remaining blissfully unconcerned about the evolution of wider system engineering activities, provided they understand the purpose and relevance of their own contribution.

Teamwork is everything. Systems engineers do not try to do other people’s jobs for them but they do lead and energise invaluable analysis that has to be communicated as an integral part of the project. It is not a background service, nor can it be taken for granted. There’s a lot of facilitation to be done, but the effort is worthwhile.

2.2 GETTING MODELS TO WORK

It could be argued that models are the lifeblood of Systems Engineers. By abstracting the fundamental components of the project across domain boundaries, they allow the Systems Engineer to gain a unique insight into the interactions and issues within a project. By resolving context, key elements and relationships, expressed across a range of suitable views, the entire project life-cycle can be de-risked. Unfortunately, these views are often treated as little more than a collection of diagrams and even within the systems engineering community, the less experienced can be trapped into treating the various views as self-fulfilling activities.

It is possible to make a distinction between ‘modelling’ and ‘analysis’. The modelling techniques are tools to be used as a means to an end. The analysis works towards the end and provides useful support to the project and its decision making. The first step is therefore to check that all the Systems Engineers, especially those who are used to working within the reassuring structures of large projects, are aware of what their modelling effort is meant to achieve across the team and can communicate this to those around them. The analysis can then be built on solid teamwork and a shared understanding of the contributions everyone is making. Thereafter, designated members of the systems engineering team can carry the lion’s share of developing the model structure, ensuring diagram consistency and achieving coherency across all the modelling effort.

The fundamental challenge for both the Ship Design Lead and the systems engineering modeller is to collate views on the system which provide a positive return for the effort invested. The time spent deconstructing the system into these views must pay a dividend by solving the known problems and revealing hidden ones. To do this, there needs to be a conscious decision to include or omit specific aspects of a model, and to limit the scope of the effort applied so that each of the agreed deliverables can be adequately resourced and controlled. The delivery of modelling intent is discussed further below.

At the start of the project, discussions need to be held to decide which components of the project ought to be captured by the modelling team, and how and when the modelling team will contribute to decision making within the project timeline. To achieve this, the overall project team must understand the objectives of the project, the analysis that will be undertaken, and the answers that are sought. Only then can a suitable systems engineering approach at project level, and as a subset of this, a
modelling strategy, be developed in response and communicated across the project.

This is when considerations such as whether the project is taking a ‘Risk Based Approach’ (developing the systems engineering model to chase down and mitigate project risk), a wider ‘Enterprise Requirement Approach’ (developing a model to contribute to a wider modellng effort within the business), or a ‘Complexity Management Approach’ (developing views specifically to facilitate team understanding and concept assessment) need to be raised, as this will dictate the central drive within the project. In projects where the fundamental decisions are to be made by selecting from a range of concepts, each offering different logical approaches and system architectures, the modelling effort may be a dominant focus for the entire project team.

The project has a right to claim what systems engineering is always quick to offer, the ability to deal with complexity. The challenge is to do this in a way that is seen as lifting a burden off people’s shoulders and that does not impose additional unwanted complexities of its own.

To do this, the project lead and ship designer need to understand how to focus the systems engineering effort to achieve project goals. One approach is to focus on the analysis required to understand the interfaces between systems and eventually specify them. An alternative focus is the analysis required to manage and challenge the assumptions underpinning the project’s reason for being undertaken at all. Often an attempt to undertake both, without clear agreements on the issues to be addressed, leads to models being used with simultaneous all encompassing and ‘deep stove-pipe’ perspectives, leading to frustration and models which serve neither purpose adequately.

The remainder of Section 2 outlines some of the fundamental systems engineering components and their potential contribution to the project.

2.3 REQUIREMENTS MODELLING

For defence projects, requirements engineering is firmly embedded, with Requirements Managers providing professional and well structured sets of requirements, usually in the DOORS tool. The emphasis on requirements as an expression of the client’s need is entirely appropriate and well established. However, there are conflicting pressures at work and the desire to avoid pre-empting later design solutions also discourages a vital interest in understanding the implications of adopting those requirements.

Figure 1 illustrates that the project architecture provides the basic building blocks by which requirements are defined. The concept, as discussed further below, will then become the means by which requirements can be put into context and de-risked via the various viewpoints within the architecture. To develop the theme that was argued so forcibly at Reference 2, it is essential to emphasise that ‘concepts are not solutions’. They may be seen as potential solutions, perhaps, but this misses the point that they explore the implications of satisfying requirements in a particular way and therefore provide a perspective that informs the client’s decision making. They are not intended as design solutions which, in general, will be the supplier’s concern. In any case, it is extremely unlikely that a concept will be turned directly into a design because the concept’s main emphasis is on the performance, cost and other trade-offs that need to guide the strategy on which a specification will be built, not the refinements that guide detailed design and manufacture.

Concepts may be matured, of course, and modelled in some depth, but they are more likely to grow by combining useful elements from the range of concepts being considered than from the pursuit of detail. Concept development is about building confidence that the client’s needs can be met cost-effectively and is best thought of as ‘requirements modelling’ that leaves much of the feasibility work until after the Concept Phase.

2.4 FUNCTIONS

The humble function still needs its activists. Functions appear abstract and are a source of scepticism for those with more traditional design processes to follow but it is difficult to over-emphasise the significance of the role functions have to play in a modern project.

It is the function that holds together the analysis in the early stages and it is best seen in the context of the relationship between requirement, function and system. Since many requirements are functional by nature, there is a close link between a requirement, the function that implements it, and the notional system that will deliver that function. These elements then diverge for their own
purposes, the requirement to express the client’s needs, the function to convey how the system performs and the system to become the procurable item of equipment. The UK’s General Naval Specification is an excellent example of a functional structure which can be readily applied both to ship designs and, with suitable interpretation, to a wide range of other craft with related capabilities.

Since requirements take time to evolve and system options should be kept open for as long as possible, at least within the range of concepts being explored, it is the function that becomes the most influential player in the early stages. In almost every situation, the parties involved will have a well informed understanding of what the system has to do and are therefore well placed to capture its functions. It should be noted however, that the function carries the measure of performance and since performance tends to be constrained by the system architecture, the measure of performance will take longer to tie down than the parent function.

Functional structures are needed to embody the safety case. To meet the full intent of the UK’s JSP 430, a proactive and integral safety case should be built from the earliest stages of the project. This can only be done by identifying those functions that are safety related and then ensuring that the eventual system architecture protects those functions at acceptable levels of cost and risk.

As system configurations start to develop, it follows that the reliability engineering, often closely related to the safety analysis, has the functional definitions it needs to underpin the early Failure Modes and Effects Analysis (FMEA).

2.5 SYSTEMS

As distinct from a function, a system is a procurable unit with a physical existence, whether existing or planned. It becomes impossible to retain a purely functional perspective because a function is abstract and cannot be built or bought in its own right. A system has to be procured to perform that function. The project boundary provides the scope within which the system and sub-systems of interest are defined and for which the procurement process should be de-risked.

Many of the most spectacular risks will be associated with interfaces and the downstream system integration process. It is difficult to address all the key risks if the project takes a purely functional stance and relies entirely on the contractor to offer suitable system solutions. Valuable time and money may be wasted, either inside or outside contract, as the two parties resolve the range of solutions that are acceptable.

Figure 2: The Concept Analysis Layer

As shown at Figure 2, it is the concept, as a configuration of systems, that explores how to exploit technology and achieve desired levels of performance across the range of operational scenarios. Where interoperability has to be achieved in circumstances that are outside the management or operational control of the project organisation, the emergent problems have to be anticipated within a ‘system of systems’ strategy and considered further within the risk management process.

2.6 CONCEPTS

The generation of concepts is considered one of the most fundamental and useful strategies within the systems engineering process and deserves its place, as its name suggests, within any Concept Phase. The concept provides a means to explore and filter all the new ideas that should be encouraged at the start of the project and links all the discussions above to create a set of high level but coherent models. As these models mature, they provide a basis for increasingly powerful trade studies that allow suitable performance, risk and cost comparisons to inform decision making and business case development.

For the Ship Designer, the concepts themselves tend inevitably to relate to ship designs and yet the platform may be only one element of a wider system. Concepts of interest may include, for example, autonomous underwater, surface and airborne vehicles that are to operate together and perhaps be interoperable with international partners. It is the concept that allows the many interfaces and interactions of the static system architecture to be modelled in a consistent way, providing a basis against which the dynamics and cost benefits can also be resolved.
In the context of the Concept Phase, it is re-emphasised that concepts support, above all, the interpretation and testing of requirements. Although they form part of a seamless life-cycle management process and may contribute directly to an eventual design, this is a benefit in the early stages, not a core objective. By exploring the implications of implementing requirements in a particular way, they help mature those requirements and remove major elements of risk for both the client and supplier by allowing realistic acceptance processes to be planned from the start.

2.7 PEOPLE

Stakeholders are anyone or anything with a direct interest in the outcome of the project. Neither people nor system stakeholders should be omitted as they all lead to important sets of related requirements within the system boundary. In a military system, the enemy is a stakeholder whose interests will not be entirely benign, but the corresponding requirements are inside the system boundary and are developed entirely to meet the interests of the system, in this case to frustrate the enemy’s ambitions.

Of paramount importance are the requirements that reflect the needs of the operators themselves. Much could be discussed under the heading of ‘human factors integration’, but for the purposes of this paper, it is enough to point out that the simplest and oldest techniques work best when exploring operator needs.

Activity or ‘swimlane’ diagrams, whether drawn in a spreadsheet, with the UML or SysML notation, or as the MODAF SV10c, provide a working template for stakeholders of any background to discuss or investigate how a particular mission is conducted. By following the various activities through a simple time-based process, the mission or task can be understood in simple terms and it is easy to link each activity to the functions, systems and human resources needed to implement them. Operators instinctively understand such diagrams, which quickly expose the implications of operating, for example, with high or low levels of automation.

It is good practice to engage with operators early and start with the more generic mission view of a MODAF OV-O5 or equivalent. This considers the interactions between generic mission activities without the constraints of time-based analysis and is typically expressed in the IDEF format. Thereafter, with suitable working assumptions, it is well worth setting up activity diagrams to hold together the ongoing dialogue.

3. OPPORTUNITIES

The discussion above concentrates on some of the systems engineering basics that, even if often misunderstood, deserve to be applied effectively in any project. They are sufficiently well known and understood to deliver early results. This section considers where there is scope to broaden the range of techniques that project teams may relate to if they are introduced with care.

3.1 REQUIREMENTS AGAIN

The management of requirements, as discussed above, is familiar territory but may still seem daunting for those that cannot rely on Requirements Managers to see the process through for large projects. The Context
Diagram, based on the Use Case, is an established if under-used method of deciding where requirements are needed and linking them to both their stakeholders and eventual acceptance.

The use case diagram, when drawn with a boundary across which there are associations between the stakeholder and the use cases themselves, as at Figure 4 above and Figure 6, is acting as a Context Diagram. Each elliptical use case represents a group of requirements that consider the interests of its stakeholders.

Deceptively simple, these diagrams challenge a project team to identify influential stakeholders and may be drawn at three levels: business, project and system. The business and project levels tend to inspire user requirements. The system level points to engineering constraints that become system requirements.

3.2 OPERATIONAL ANALYSIS AND CONTEXT MANAGEMENT

Operational analysis has a strong pedigree in defence business, where government experts have access to policy generation and can provide valuable guidance and Measures of Performance (MoPs) with the full backing of policy. Outside defence, such in depth guidance is seldom available, making it all the more valuable if a project can understand the operational context within which it will be used.

Understanding the requirements for a system requires a great understanding of the context within which this performance needs to be delivered, which in many projects is almost impossible to tie down. Typically users rely on current practice and current solutions to provide a context for the performance of a new system being developed. It is here that the Systems Engineers should attempt to bridge the gap between the ambitions of the customer organisation and the project team’s engineering judgement. The stronger the link between this vision and the performance requirements for a new system, the less the project will be confronted with operator and user feedback which challenges the direction taken or the outcome achieved. The context has to reflect the real world conditions within which the system will be operated.

It is with this contextual understanding that solutions should be judged and project trade studies should be undertaken. For the physical environment within which the system may be deployed, for example, should the project be designing the system to achieve 100% of its performance requirements in every environmental situation? Should the system perform in Arctic environments as much as it does off the shores of its home ports? What proportion of the system’s life will be spent operating in challenging sea state conditions, and how much of the overall system performance needs to be guaranteed in these conditions?

If it can be understood that an element of system performance will only be relevant for a low percentage of the system’s life then engineering effort may be redirected to answer problems with a much greater potential impact. User requirements are seldom sacrosanct, and in the early stages of a project, special effort to develop a clearer understanding of the performance and operational context can avoid unnecessarily compromising value for money.

It is the experience of the authors that the value of maturing and, critically, maintaining this view on the ‘real’ balance of requirements is rarely understood to a sufficient level of maturity, particularly for mobile, deployable systems.

The mechanisms to do this are varied, and include familiar elements such as the definition of the Concept of Employment (CONEMP), the Concept of Operations (CONOPS) and a core process of assumptions management. There are SE tools which can add significant clarity to these efforts by expressing the scenarios and assumptions in an unambiguous way through simple descriptions, or descriptive diagrams such as those in Figure 7, which can be shared among the design team.

This approach may add to the configuration control burden of the project if a large number of diagrams and documents all have to be updated together to ensure consistency. In practice, however, many such diagrams are exploratory during the early investigations and a relatively small number will need to be taken forward in support of the leading concepts and under stricter configuration control. Here, as always, a balance of investment is required.

The case remains to conduct scenario modelling where the risks associated with environmental conditions, operating modes and emerging ‘system of system’ issues can be better understood.
3.3 PERFORMANCE MODELLING

Even within the requirements analysis alone, setting measures of performance is much more difficult than drafting the requirement itself, and yet the sooner performance targets can be set, the sooner acceptance strategies can be developed and suitable constraints can be placed on potential system solutions.

Performance analysis is a high level activity that takes place in the early stages of a project and reduces the extent of simulation needed downstream, without necessarily involving mathematical computation. The analysis does, however, investigate the constraints that apply to the various mission based activities and seek out performance and cost drivers associated with meeting important requirements. Development, production and acceptance costs can be reduced where solutions would not otherwise be aligned to those requirements.

Much of the system performance data can be stored in the functional model, which can be revisited in due course as the high level design process moves ahead. The ideal is to develop the functional model to a point where all the performance related functional requirements are accounted for, although it is more likely to be used for individual investigations of special interest. It should be noted that this type of analysis is primarily functional. It is also difficult, but a valuable asset within the skill range of an experienced systems engineering team.

Linking the characteristics of systems to performance is even more difficult, especially when there are so many possible design solutions to be considered. However, the logical conclusion to performance modelling, if followed through, leads to the linkage of these characteristics to equations and hence specific measures of performance.

Attempting to describe the performance of a ship through the use of equations is the focus of Naval Architects, the performance of the marine engineering systems onboard the focus of Marine Engineers, and the performance of the communications suite the subject of Communications Engineers. The translation of these individual levels of performance into total system performance and then to the achievement of the effects required by the customer is the focus of Systems Engineering. Therefore systems engineering models should aim to provide the Ship Designer with the means to combine the contribution of all disciplines within the design team.

This point of view creates a distinction between project systems engineering, with its main focus on the ship or equivalent force element, and the more localised analysis, such as that employed to develop the specification for automation systems or the workload of a command team within an Operations Room. It is this viewpoint which should be the greatest ally of the Ship Designer when attempting to resolve the more credible solutions with the customer.

4 NEW PERSPECTIVES

The discussions above have tried to recognise how far there is to go if systems engineering is to be truly embedded in project culture, thereby allowing its full potential to be realised. It is understandable that, like the complexity it claims to deal with, systems engineering itself is seen as complex. Nevertheless, if properly analysed, that complexity reflects nothing more than reality and the goal is to reduce the emphasis on modelling processes whilst providing easy access to the information needed.

Much of the progress made in recent years has continued to focus on the analysis within the architectural frameworks themselves. This would all be much more palatable if people felt at ease with the ways they could interact with the process on the ‘input’ side, using workshops for example, and with the way that deliverables are achieved on the output side, using automatic report generation and other ways to extract valuable information.

The latest tools on the market are starting to provide more powerful ways of helping project members interact with the information they need. The underlying problem is that most project modelling relies on large databases, not least the DOORS databases used typically for requirements management. By any standard, they are too indigestible to use in large doses, and yet the databases get bigger and systems engineering finds it harder to persuade everyone that the process is more efficient.

In a workshop environment, for example, tools such as TraceLineTM allow engineers to set up the linkages that are needed to support a review process. With suitable preparation, the engineers can link requirements to any suitable elements in the project architecture and then review them one at a time with only the information of interest on the screen. Attendees need not be subjected to interminable switching between different sections in each database or between documents of interest. Sufficient information on a particular requirement, its
satisfaction argument, related constraints and risks or anything else of interest can be set up on a single slide.

The point of principle is that neither reviewers nor anyone else can review more than one thing at a time. People deserve to be presented with each point of discussion in a sensible sequence and should not have to make decisions under the tyranny of seemingly endless database entries.

Figure 8: Reviews with a Single Point of Focus

This approach means that the structure of the project architecture, as represented by its schema or ‘meta-model’, can be represented directly by individual ‘strings’ of related information in which a reviewer or stakeholder is interested. Essentially, this approach allows reviewers to contribute to and work with the model without having to understand the processes that produced it.

In summary, the tools and experience already exist to not only analyse complex problems but extract and trace the issue, and turn judgements on it into useful knowledge. This encourages systems engineers to set up their architectures more carefully than ever and put further thought into the structure of the requirements themselves, confident that the content is accessible for re-use.

5 DELIVERING SE MODEL ‘QUALITY’

For systems engineering models, containing the elements described elsewhere in this paper, quality can be associated directly with the appropriateness of the model for its purpose. There is a large array of possible references against which systems engineering models can be constructed, including languages, frameworks and international standards so the only consistent definition of model quality is the realisation of intent.

Capturing and managing the intent of a model, prior to beginning the modelling exercise, is an essential discipline if Quality Assurance is to be achieved. Otherwise, if the many possible avenues of investigation that the Systems Engineer may use to understand and communicate the problem are combined with a dogged acceptance of unconstrained complexity and imprecise language, inconsistency and incoherence will breed, calling into question the validity of the entire modelling effort.

To address this, the ‘Software Management Plan’ in the IS domain, for example, and the ‘Architectural Vision’ recommended by the TOGAF process, set out logical structures that capture intent.

5.1 STATEMENT OF MODELLING INTENT

Experience suggests that the following should be formally recorded:

1. The model purpose including:
   a. The origin and context;
   b. The anticipated benefits of the model;
   c. How the model is to be delivered and whether there are expectations for it to outlive its immediate purpose.
2. A definition of the project ‘meta-model’ (See below);
3. The timescales involved in the task;
4. The stakeholders involved, or a reference to the definition of project stakeholders;
5. The information sources to be used / found.
6. Guidance on how to measure the completeness / successfulness of the model;
7. Guidance on special conditions surrounding the model, such as a high security requirement or need for configuration control;
8. A description of any required interface to other models;
9. Identification of any applicable guides to ‘Best Practice’ to be adopted in the construct of the model;
10. An indication of any requirements for the model to be constructed in a particular tool or format.
11. Requirements for peer-review of the model, among the various available Subject Matter Experts (SMEs) within the area to be modelled, or the tool within which modelling will be conducted.

This Statement of Modelling Intent (SOMI) should provide enough context and guidance to allow the person designing the model to grasp the level of detail required, and enable the appropriate level of consistency and coherency checking for the model to ensure quality.

The SOMI should become the controlling document for the modelling effort. All extensions and adjustments to the aim, inputs or outputs should be captured, and their impact on the overall objectives understood, before they are formally used to drive the model.

The SOMI should not become a bottleneck that eliminates small supporting investigations where they are needed, provided that these are done outside of the core modelling effort and do not impact on the fundamental modelling objectives and the related views, elements and data.
5.2 META-MODELLING

The ‘Meta-model’ referred to above is not a new concept. Meta-models are simply models of models.

Depending on the techniques, tools and framework adopted, Meta-models may be recommended, enforced or simply referenced in the background. In any case, the following Meta-models are recommended for a typical project:

**Analysis and Views Meta-model** – This model shows how the elements of a project are clustered within the model, whether to support some specific analysis or to gather together related information in tailored diagrams. Such clustering may rely on a single representation (report chapter, presentation slide, or model HTML view) that is of specific interest to a stakeholder, thereby contributing to focused deliverables and the overall value of the model. This Meta-model allows the builder to check the model outputs and logical structures which contribute to them.

**Elements Meta-model** – Describes the types of relationship between the model elements. This model can be as simple or as complex as desired, but will have a major influence on the effort required to check that all of the elements within the model adhere to the rules set by this Meta-model. Such consistency checks are built into some tools, but not all.

**Data Meta-model** – This model represents the data to be managed and is in fact a further Meta-model on top of the ‘Elements’ Meta-model, relating each element type to the data elements associated with it. The allocation of data to elements cannot always be controlled within tools, so this level of planning feeds directly into the quality assurance process and is a crucial indicator of where project control may be needed.

The SOMI and Meta-models allow the systems engineering modeller to analyse the quality of a model without having been involved in its creation. They help project managers and lead designers concentrate on the inputs and outputs of their work without becoming unnecessarily embroiled in the complex analysis in between.

The Ship Designer, as a major stakeholder within the project, is entitled to a dedicated viewpoint within the Meta-models, identifying all the relevant information needed to understand the current state of the model and the implications for the ship design. The low demand for such viewpoints indicates how far there is to go before systems thinking becomes culturally embedded in ship design projects.

6. CONCLUSIONS

Systems Engineers need to win hearts and minds at the start of a project by strong teamwork, active innovation and a determination to provide a service that brings clarity and value to the project. The whole project team should be engaged in setting up the modelling effort.

The diverse services provided by systems engineering and its models need to be resolved with care as projects are set up. SE is able to provide a natural home for the logical structure of both project and system, and for the management of the project boundaries and resources. With clear objectives and strong teamwork, it is also possible to turn functions and performance into detailed specifications without compromising the wider benefits of good communication and the knowledge gained from comprehensive analysis.

Modelling intent should be clearly defined and linked to defined products within an overall plan. Review processes should be structured to focus on key information that is presented independently of the underlying analysis.

There are many ways in which systems engineering skills can be developed to provide direct support to a Ship Designer but the fundamentals remain. Communication and simplicity are the most valuable commodities of all.

7. DISCLAIMER

The opinions offered are those of the authors and do not necessarily represent those of their companies or host organisations.

8. REFERENCES


9. AUTHOR BIOGRAPHIES

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