Parametric Cost Assessment of Concept Stage Designs

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Abstract

Deriving the cost of a vessel in the early design stages can be difficult. The design itself may only be represented in a conceptual form providing little concrete data against which a cost can be generated. Aspects of the design may yet to be determined leading to a great deal of uncertainty. Consequently, there is little incentive to look into the costs of a design in anything more than an indicative manner. Early evaluation of costing can be based on weight or space depending on the type of vessel as the quantity of materials or level of outfitting can be determined with a greater level of certainty.

Paramarine's early stage design environment is based on the Building Blocks methodology developed by UCL. Combined with a parametrically defined structural definition, the complete design can be deconstructed into materials, equipment and construction activities allowing the producability to be evaluated before reaching the initial design stage. In both areas of the software, searchable design data is associated with semantic information (space, weight, type etc) which can be audited to identify items for cost evaluation. Time to perform a cost evaluation is reduced as is the potential for mistakes. However, the designer is left with just having to assign a cost values, a potentially laborious process.

This paper discusses the challenge of automating the process of cost assignment by using the semantic information associated with each item to determine how it is produced. By defining "production processes", cost can be assigned by evaluating how much material and resource each item requires. A (microscopic) cost evaluation can now be performed as early as concept design more easily than many existing subjective rule based approaches. Furthermore, the costing model is based on concrete data which may be determined directly from production activities.

1. Introduction

The cost of a new vessel is often pushed to the fringes of development by those designing the technical and engineering aspects of the product. However, it should not be forgotten that as well as producing a design which is balanced in terms its engineering characteristics, the primary objective is to make money for the (shipyard or design consultant) business and deliver a product that if possible represents value for money to the owner, leaving the door open for repeat orders in the future.

2. Background

Capturing construction cost during the design of a new vessel is one of the most difficult parts of the design process. The factors that cost depends on are always changing and only once the production design is finalised is it possible to make a direct evaluation. However, the pressure to deliver a new vessel on time and on budget means that construction must begin before detailed aspects of the design are finalised.

Construction cost must be tracked during the design process to ensure that the project remains viable to both yard and customer particularly as late changes introduced into the design can have considerable cost impacts. It is easy to imagine cost being established by accumulating the value of parts and labour required to construct the vessel. However, in the earlier stages of design there is rarely enough resolution in the physical components of the vessel product model to establish cost to a satisfactory level of certainty. Consequently, alternative approaches are used to establish cost by comparing critical factors in a new design with the delivery of previous vessels.

The role of the cost engineer in the design process is to provide models which are capable of establishing a cost value from data available at the different design stages. Cost estimation is often regarded as a mysterious art as it is somewhat more of a statistical discipline compared with the other engineering activities. Establishing a cost estimate at any stage of the design requires a high degree of appreciation of the processes which occur in both design and construction process. Detailed costing may require knowledge of how long it takes certain construction processes to be conducted, for example, joining a stiffener to plate taking into account size, material and welding technique, while costing for a concept design will require, for example, knowledge of how the utilisation of different spaces of the vessel impacts on cost. The cost engineer requires both a good database of historic information on previous ships and good contacts with industrial partners to forecast how technical and financial changes may impact on construction costs. Once this information is established, the cost engineer uses expertise to identify the cost estimation models which correlate well with both the type of vessel and capabilities of the shipyard and experience to enhance confidence in the result predicted by the model. The importance of good cost estimation cannot be undervalued as it will be one of the main factors upon which a customer will base the decision to move forward from design to construction. Consequently, it may be seen that the competitiveness of a shipyard may be encapsulated in the cost engineer's database making it a good reason to limit the number of people who have access to the data and this factor may contribute to the cost engineer's illusiveness.

This situation makes it difficult for the naval architects and design engineers to have a full appreciation of the effect of their decisions. The relationship between design and costing engineers is not always close because solutions with technical merit are not always the most cost effective. However, it is not necessary for the design engineers to have a complete knowledge of costing techniques. A basic appreciation of the factors involved and advice from the costing engineers should be enough to guide any decision process in the early stages of the design.

As ship design tools become more comprehensive, the possibility of supporting different engineering disciplines becomes ever more possible. In the case of cost estimation, often cost engineers are provided with hard copy information from data that must be manually extracted to populate the costing model. This means that for every design update, this process must be undertaken to establish the current construction costs. However, by integrating cost modelling techniques into ship design tools it is no longer necessary to manually translate data and the process of cost estimation can become more automated.

The integrated ship design tool Paramarine, produced by Graphics Research Corporation Ltd (GRC), is one of the few to provide an advanced ship and submarine early stage (concept) design module in addition to the common range of design and analysis features associated with most ship design tools. As part of the development of the early stage design module, many existing users of the Paramarine system were interested in being able to produce an estimate of cost from the design data entered into the tool. In 2004, GRC embarked on a research project, ITMC41, funded by the Ship Builders and Ship Repairers Association (SS&A), to develop a construction evaluation module in partnership with the Tribon system. The Design for Production (DfP) module remained an internal development until 2005 when funding assistance was obtained from the Price Forecasting Group (PFG) to complete the module. As part of this development, two cost estimation techniques were developed to address different resolutions in the level of detail in the vessel product model.

3. Cost Estimation Techniques

The characteristics of cost are very similar to weight. Early in the design process there is a very low degree of confidence in the values of both cost and weight as the resolution of the design is too coarse. As weight embodies the amount of physical material in a vessel it is often correlated with costing information to produce an estimate. Other factors such as main particulars and space utilisation can also be used as drivers of costing models. As mentioned in 2, the role of the cost engineer is to identify parameters that drive the costing of different aspects of a vessel and use previous experience to construct a costing model. Consequently, any design parameters or ship characteristics which correlate well with cost may be used to drive a cost estimation model.

Cost estimation models for naval vessels are often more comprehensive than those used for commercial ships in general, *Ennis, (1998)*. As well as business, there are also political and social-economic factors behind the production of these types of vessels. Furthermore, complexity of systems means that naval vessels may be three to five times more expensive than commercial vessels of a similar size. Consequently, cost estimation models for naval vessels are developed to capture many different factors and be flexible to different approaches and data resolution with the overall aim of having greater confidence in the results for the information available.

Ross, (2004), discusses several approaches which may be used to estimate the construction costs of a vessel. The techniques may be classified into two groups which naval cost estimation techniques often describe as Ship Work Breakdown Structure (SWBS) and Product-Orientated Work Breakdown Structure (PWBS).

3.1 Ship Work Breakdown Structure (SWBS)

Ship Work Breakdown Structure can be considered the more traditional approach to cost estimation. It relies heavily on historical data and the experience of the costing engineer. This approach often breaks the design down into different grouping based on structure, equipment and systems very similar if not the same as weight groupings. Weight is often used as the primary driving factor for cost estimation as it encapsulates the amount of material and to some extent work associated with an item. Weight is an important characteristic to establish early in the design of any vessel and there are several parametric rules such as *Schneekluth, (1998)*, which can be used to estimate weight based on such minimal information as the main dimensions and hull form coefficients. Space based approaches can also be used on vessels, such as passenger ships, where cost may be driven by the degree of outfitting rather than weight.

While these parametric costing techniques can be applied to a new design fairly easily they often do not possess ability to capture factors such as the introduction of new production techniques and process. Consequently, it is very difficult to identify how any optimisation of production processes may impact on cost. This approach will prove very successful if applied to vessels which the yard has previous experience. However, if construction requires the introduction of production process of which the yard has no previous experience, these techniques can only provide a much reduced degree of confidence in the cost estimation.

3.2 Product Orientated Work Breakdown Structure (PWBS)

The product orientated work breakdown structure aims to capture costs resulting from production effort in as much detail as those due to material quantity. The relationship between the design model and cost is much more attributable to measurable data compared with the primarily statistical based relationships used in the SWBS approach. Consequently, this approach will capture enough detail to allow the effectiveness of production processes to be evaluated and potentially optimised. In the past, extracting the information from the design to perform this kind of analysis would have been very laborious because the cost engineer would have to measure production details directly from plans. However, with modern ship product modelling software, the identification of parts and junctions can be automated providing the cost engineer with a full breakdown.

One of the prerequisites of this approach is that the product model needs to be detailed enough to allow materials and production labour to be established. This means that the structural definition, systems and equipment need to be defined and may rule out this approach being used in the earliest stages of design. However, as ship design tools improve, it is becoming easier to add preliminary production details at the start of design so that production considerations can be incorporated in the design process. Consequently, this technique may be employed shortly after the initiation of a design project.

One drawback of this approach is that while it is capable of accurately extracting the measurable amounts of work and materials defined within the ship product model, it can provide a lot of individual items that require cost information to be associated with them. While most of this information is real cost or measurable resource based data which may be obtained from catalogues, suppliers or from the production floor, a large database of this information may be required. It is obviously a large task to collate this information but as it relates directly to a shipyards performance it is useful information which may enable to the design of the vessel to be adapted to best meet the yards production capabilities.

4. Paramarine Concept Design Environment

Paramarine is an integrated ship and submarine design environment developed by embracing the full capabilities of modern object-orientated software development. The tool itself features an object-orientated design framework which allows the parametric connection of all aspects of both the product model and analysis elements together. The system supports analysis disciplines in common with most ship design tools such as stability, powering and structural analysis, which when combined with parametric connectivity, allow designers to build up complex designs using all of the features of the solid modelling kernel provided by the industry standard Parasolid tool set. In addition, Paramarine features several unique modules specifically orientated towards the development of concept designs where the role of the vessel may require the designer to explore innovative solutions.

As mentioned in 2, users had requested that Paramarine should be able to address costing aspects of concept design. The tool already provides the user with the ability to define their own functions and calculations so techniques based on simple parametric expression can be included without any additional development. Even so, Paramarine Early Stage Ship Design module already models many design characteristics of a vessels such as weight, buoyancy for example and cost could be incorporated in a similar fashion. However, it was also felt that the tool could support a much more advanced approach to cost estimation taking into account materials, equipment, systems and production effort. As a result, the Design for Production module was developed as a way of analysing production with respect to construction cost.

4.1 The Early Stage Design Module

The Early Stage Design module is a unique solution which provided the designer with an alternative method of exploring ideas without being forced to follow the traditional approach of defining hull form, subdivision etc. Based on the University College London (UCL) Functional Building Block methodology, *Andrews, (2002)*, the framework consists of a hierarchy of objects called building blocks which are used to represent the different functional aspects of the design. The module provides the designer with a “free space” to construct solutions to requirements and determine the overall form of the vessel. While the methodology can be considered abstract when compared with the traditional approach, the process is much more rigorous as it forces the designer to define exactly how the solution will function. Consequently, decisions are addressed earlier reducing the amount of time it takes to deliver a design.

Building blocks in the design are associated with attributes which encapsulates the geometric, functional and topological characteristics to clearly define the role of a block. Characteristics (Weight, Space, Buoyancy, Consumable, Manning etc) can be used to define both requirements and solutions in the style of supply or demand. In many cases a block providing a solution to a particular problem may introduce further requirements which must be subsequently addressed. By working through this design process all of the requirements associated with a design can be captured and solutions to requirements defined. The Early Stage Design module collates information from within the building blocks hierarchy and compares related characteristics together, a simple example being a comparison between the buoyancy and weight characteristics to see if the design will float.

Ultimately, the designer aims to develop a balanced design by making decisions based on information extracted from the building blocks hierarchy.

The early stage design module is capable of performing a cost assessment of the design using a SWBS based approach. The technique is implemented in an equivalent form to the product based approach described in this paper. The production cost estimate allows elements of an estimate performed in the Early Stage Design module to be reused to account for limited detail in the outfitting of spaces.

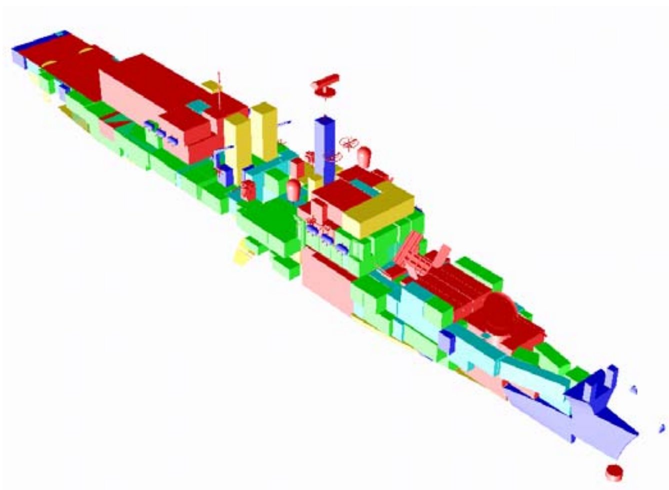


Fig. 1: Detailed Building Block Model of a Frigate (Geometry)

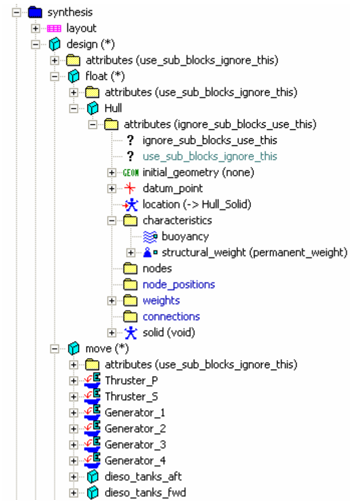


Fig. 2: Building Block details of the hull and propulsion.

4.2 The Design for Production Module

The design for Production module is used to analyse the design definition and produce a breakdown of parts for construction based on a build strategy and various production parameters. The module collates information from other design modules of the software combining information that can be used to develop a production definition of the ship. Primarily this is information from the structural definition module as well as block, equipment and system information from the Early Stage Design Module. Once the design definition has been analysed, the production data is formatted in a hierarchy of production blocks, sub assemblies and individual parts. Associated with each stage is construction information on junctions representing joins, welds or cut outs. This information can be audited to identify a range of information such as the weight and size of all parts in the production hierarchy as well as the amount of cost and resources.

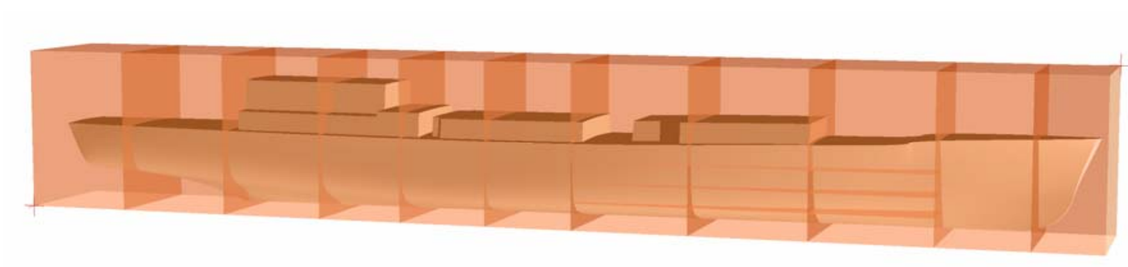


Fig. 3: The Production Build Strategy Definition

The analysis process is mostly automated and the user only has to provide definition for the build strategy, Fig. 3, and resolve the intersection between plate subassemblies (i.e. which structure in an intersection between a bulkhead and deck should be continuous), Fig. 4.

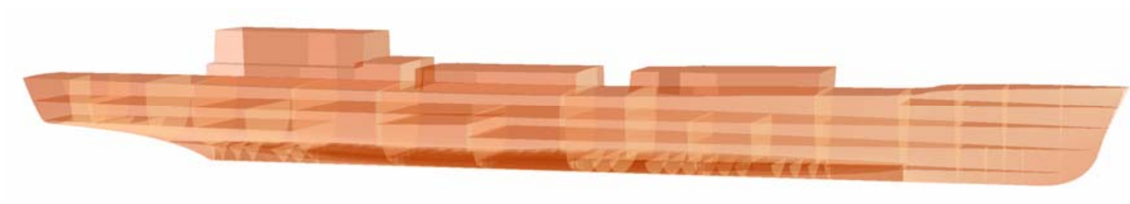


Fig. 4: Plate Sub-Assemblies

Production parameters, Fig 5, are then defined to specify how "continuous" materials such as plating, stiffeners and service lines (pipe and cabling) may be supplied to the construction site. Coating such as paint, insulation etc, can be assigned to parts of the design and included in the production calculations. For equipment and service line design definition, the analysis references the design information from the early stage design module.

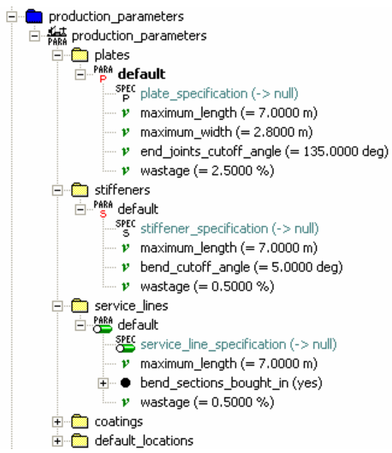


Fig. 5: Production parameters defining the size of actual plate, stiffeners and service line parts.

Fig. 6: Hierarchy of an individual production block.

Once the user has set up all the basic production information, a single calculation module is used to analyse the entire definition. This is a very large calculation and can take around an hour to perform the analysis for a very detailed definition. The analysis module takes the vessel definition through a very similar process to ship construction. For each sub assembly, it combines plating and stiffener definition together and then subdivides them on the basis of the production parameters details. Then the junctions between individual plate and stiffeners are identified, defining all the locations where there is a need for welding or cut outs. Service lines are analysed in a similar manner taking into account whether sections such as bends will be constructed in the yard or brought in as piece parts. The results of the analysis are presenting in a hierarchy based on the build strategy, Fig 6. At the lowest level, the sub assembly brings together individual plate, stiffeners and junctions of a panel that will go to make up a production block. A production block captures all the sub assemblies, service lines and equipment associated with that part of the build strategy. It also captures all of the junction information required to join all of the sub assembly parts together. Subsequent production blocks higher up in the hierarchy capture the junctions between the block beneath. The benefits of this approach is that it is possible to capture differences in the manufacturing process, and hence cost, which may depend on where the block is located both within the build strategy, geographical within a shipyard or across multiple yards.

The number of parts generated by this analysis may be very large, Fig. 7. However, as this information is generated parametrically, mostly from the structural definition and audited automatically there is no particular overhead on the user. In fact, it is not usually necessary to review the data in detail because the parts produced by the calculation are of no interest on an individual basis at the concept stage of design.

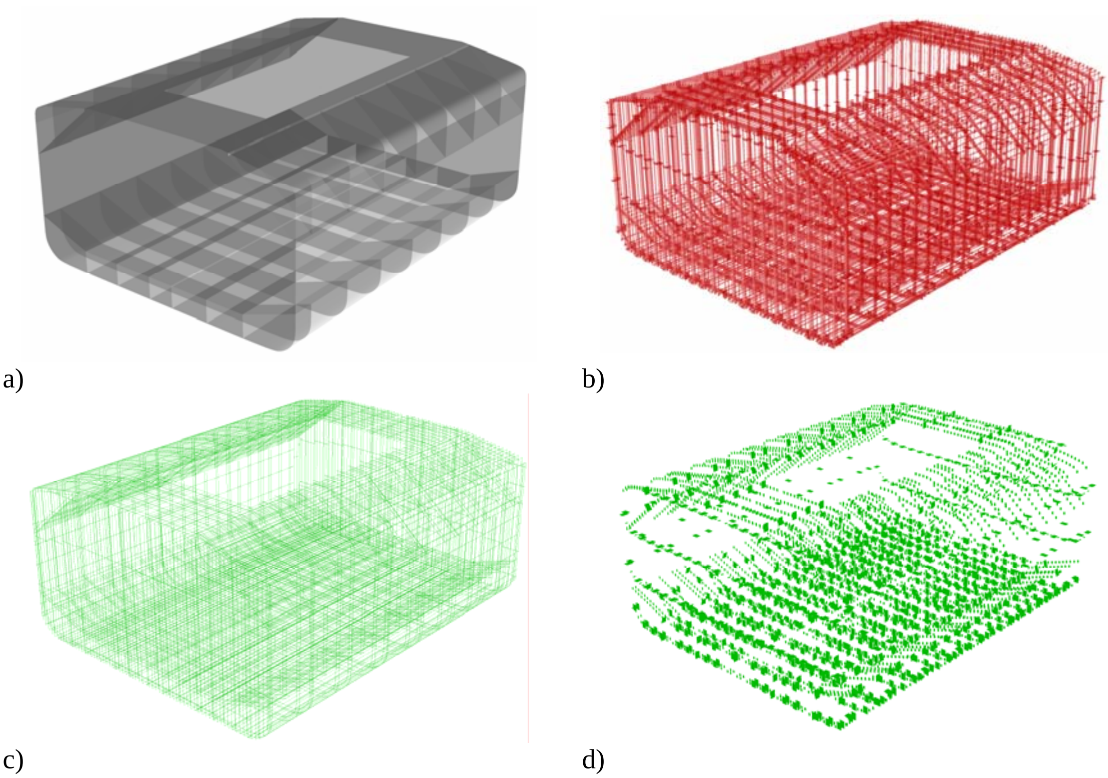


Fig. 7: Production information for a hold of a bulk carrier for the structural definition alone a) plating, b) stiffener lengths (square define end of the stiffener run), c) continuous junctions (welds between plate and stiffeners) d) discrete junctions (welds between stiffeners and intercostals).

5. The Costing Problem

Both the Early Stage Design and Design for Production provide logical methods that design and cost engineers can understand and work together to populate calculations. Audit functions are used to accumulate the characteristics for all items in the respective hierarchies and compared with costing information. Items that do not have an associated cost definition are flagged up as an infringement and listed, Fig. 8. This mechanism ensures that all items are incorporated in the costing calculation unless explicitly excluded.

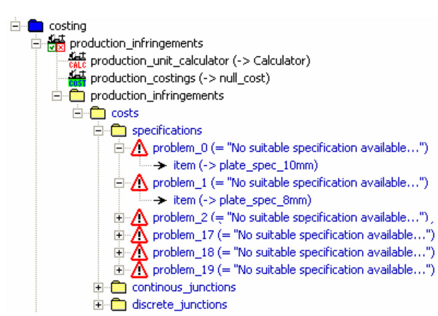
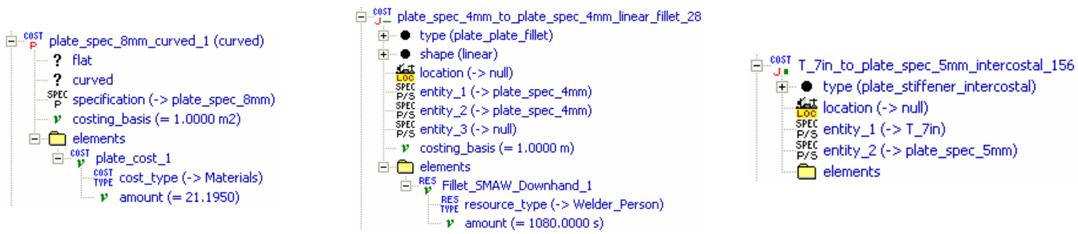


Fig. 8: Items without cost information associated with them are flagged up by the production infringements object.

However, the analysis produced by the Design for Production calculation my identify tens of thousands of parts which, although it is not necessary to cost individual parts, the number of cost cases may number in the thousands. For example, the frigate illustrated in Figs. 3 and 4 has a basic structural definition with realistic scantlings, no equipment or systems and produces 1664 individual cost case scenarios. Populating a cost database with this quality of information would take an incredible amount of time. Each scenario, Fig. 9, defines the complete cost information for all the processes an individual part may go through in the construction process and it remains the job of the user to collate the composition of this costing information. Consequently, the management of this information is incredibly difficult as a single process in construction may affect several cost scenarios.



a) b) c)

Fig. 9: Example cost scenarios for (a) plate (8mm), (b) continuous junctions (4mm Flat Plate to 4mm Flat Plate), (c) Discrete Junctions (7in 'T' profile stiffener through 5mm plate).

6. Process based Parametric Cost Generation

In the early stages of design, the SWBS is a very effective approach as it uses a few characteristic design parameters to determine the cost of the vessel, but as previously mentioned it cannot capture factors resulting from the introduction of new technology or when a shipyard has no previous experience with a vessel of a particular type. The PWBS approach can capture this information but it would usually be inefficient to perform this type of cost assessment in the early design stages as there is not enough detail in the design and too much effort would be required to identify all the costs. The Design for Production module is capable of performing such a cost assessment on an early stage design because it can use a parametrically defined structural definition and automatically identifies all the items requiring costing from both the structural definition and outfitting. However, the detailed aspects can only be hidden up to the point where it is necessary to assign cost details to each costing scenario.

Both Early Stage Design and Design for Production modules aim to assist the designer as much as possible by performing calculation and definition automatically as part of the design process. The requirement on the designer to assign a significant number of cost details even if from a standard database goes against the approach generally followed by Paramarine. Consequently, an improved means of populating all these cost details had to be identified to allow the Design for Production module to be used effectively in the concept design of ships and submarines.

A review of the cost scenarios identified by the module highlights that the majority of them are very similar, particular items relating to structure, with only material details being different. Costs for each scenario could be generated on the basis of the processes each goes through in the construction process. Consequently, the procurement, forming and joining process could each be defined separately for a range of material sizes. The number of discrete processes is fairly low compared with the number of cost scenarios and the metrics relating to the amount of time and resources each process requires should be known to the yard. By chaining processes together, the details of each cost scenario can be determined by accumulating the amount of cost and resource required by process for the size of material or task involved. A database of yard process could be developed and updated as new technology is introduced. As each process represents something realistic, it is not necessary for the user to determine the breakdown of costs for each cost scenario. This is something that is now performed automatically by the software.

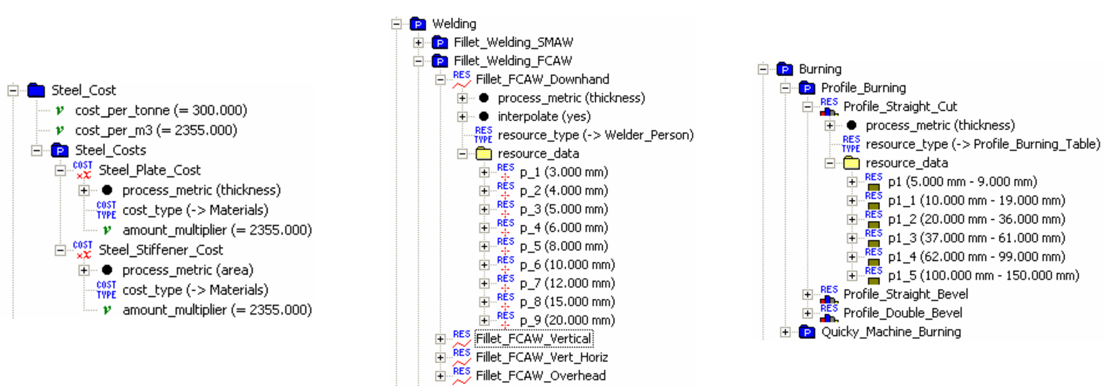
To implement process based costing, two key object definitions are required. One to define the details of the process and a production schema used to combine processes together and select what cost items the processes will be applied to.

6.1 Process Definition

Processes are generally fairly simple definitions as they only have to capture the relationship between the nominal size of a material item to be processed and the related amount of time or money it takes to process it. There are three key parameters to each process:

metric:	Metric defines what aspect of the material the process works on and is used to select the right cost or effort values from the process data. The options are thickness, length or area. For example, the amount of time it takes to weld or cut a unit length of plate is dependant on the thickness.
resource or cost type:	Processes can be cost or resource based. Resource based processes need to be associated with a resource type and are used to define the cost of utilisation. For example, a flame cutting process should be associated with a flame cutter resource, a worker requiring wages, tools and administration. Both resource and cost type are used to provide additional breakdown information in the production audit.
data:	The data associated with each process defines how long it takes or how much it costs for the process to function on a unit of material characterised by the chosen metric. The data can be entered in the form of a single scalar value, Fig. 10a, or a single value, Fig. 10b, or range based lookup tables, Fig. 10c.

The process definition database only needs to be populated once and updated when new techniques are introduced, costing is updated or process duration reassessed. The database can be used as a resource within the design office and imported into a design when costs needs assessed. Processes are defined as generically as possible so that any type of cost or resource based operation may be accommodated.



a) b) c)

Fig. 10: Process based on (a) scalar multiplier, (b) single value lookup table, (c) range based lookup table.

6.2 Production Schemas

Production schemas are used to combine processes together and define which cost scenarios each should be applied to. The number and variety of schemas is dependant on the range of scenarios identified by the analysis and subdivided into meaningful process groupings. The main schemas are as follows:

Type	Schema Name	Coverage
Material Processing	Plate	Procurement and forming of plate material
	Stiffener	Procurement and forming of stiffener sections
	Service Line	Procurement and forming of cable lengths or pipe elements
	Coating	Application of surface treatment (paint, insulation etc)
Continuous Junctions	Continuous Junctions	Joining Plate to Plate, Stiffener to Plate or Stiffener Web to Flange
Discrete Junctions	Stiffener Junctions	Joining ends of Stiffeners to Plate or other Stiffeners
	Intercostal Junctions	Cut outs and Junctions where stiffeners or service lines penetrate plate
	Service Line Junctions	Joining ends of cable or piping runs

In order to assign process based costing information to cost scenarios, four types of definition information are required:

selection criteria: The selection criteria are used to define the cost scenarios which should be addressed by the schema. Criteria select scenarios on the basis of the configuration i.e. the type of joint (fillet, butt) or material shape (curved, flat) and material specification.

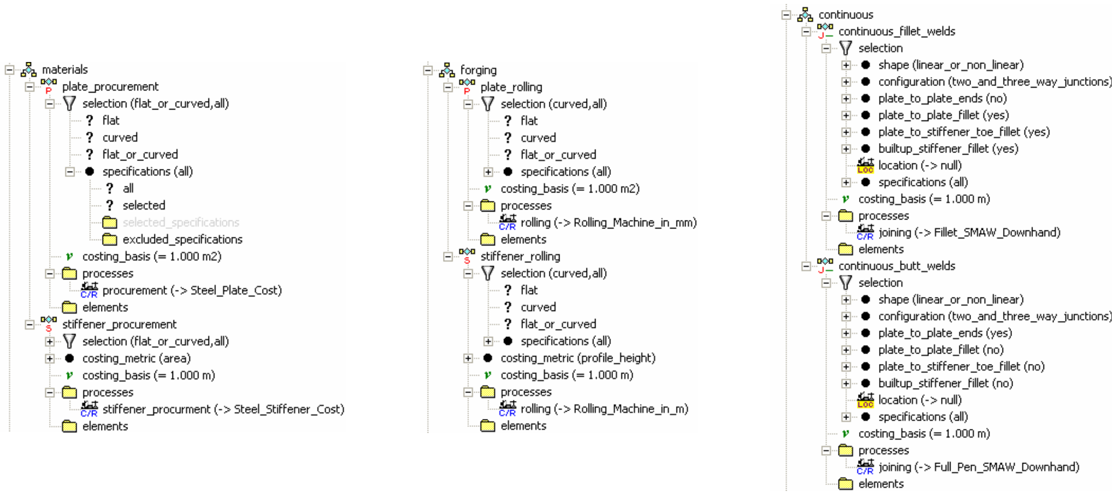
costing metric: The costing metric of the production schema and process metric need to be compatible and an error is raised if an incompatible process is attached to a schema. For most schemas the costing metric is implicit, plate is measured in area, stiffeners are measured in length etc. However, for discrete junctions the metric is sometimes dependant on the junction configuration. The costing metric is used in cases where this information needs to be explicitly defined allowing the right processes to be attached.

processes: References the processes which should be applied to the cost scenarios fulfilling the selection criteria.

elements: Used to define fixed costs for each scenario

Production schemas for material and continuous junctions are fairly straight forward to construct as all of the details required to make the process work are contained within the cost scenario. However, discrete junctions are just points in space, associated with the junction configuration and details of the materials that intersect. The dilemma of identifying the right level of detail for concept design is again faced as there is not nearly enough information in the cost scenario to identify what construction processes should be applied. Furthermore, a single object is used to assign cost details for all discrete junctions, Fig9c. However, a single generic production schema for all discrete junctions is potentially too generic making it very difficult for the user to intuitively work out how to generate cost information based on the objects structure.

After several different approaches the solution (which still remains to be implemented in the software at the time of writing, hence the lack of appropriate cost information for all discrete junctions in the example in the next section) is to specialise producing three separate production schema discrete junction scenarios covering stiffener end, intercostals and service lines. Specialising allows a specific range of process tools to be provided for each type of junction and make the assignment of processes more intuitive. The intercostal junctions are perhaps the most complicated because of the variety of processes that may need to be used each comparable to a different characteristic of the intersecting stiffener or service line. A cut out for example will be a process with length equivalent to the perimeter of the profile while the weld length may only be along one side of the flange or web. To allow this, separate costing metrics are required for each process.



a) b) c)

Fig. 11: Example production schema definitions (a) procurement (attached processes are illustrated in Fig. 10a), (b) forging (selection criteria chooses only curved plate or stiffeners), (c) continuous junctions (selection criteria distinguishes between fillet and butt junctions so that different weld process can be used).

6.3 Generating Costs for each Cost Scenario

Both the Early Stage Design and Design for Production modules rely on an audit process to extract data in a specific format from the design definition. The data collection itself follows the Visitor pattern, *Gamma*, *(1995)*, running through every piece of definition collecting characteristic information. In the case of the Design for Production module information covers:

- Surface Areas (identifying areas for coatings)
- Part Dimensions (for comparing against the size of production bays and locations)
- Part Weights (for comparing against crane and transportation capacity)
- Part Specifications (Plate, Stiffener definition with associated area and length respectively)
- Continuous Junctions (lengths of joints)
- Discrete Junctions (number of joints)

To generate cost and resource information, the production calculation is audited thereby producing a large list of all the production specifications and junctions. Each item is passed through to the costing database which performs a search to match the details of the specification or junction with a cost definition, Fig. 12. The details of the selected cost, parameterised by the relevant area or length of the specification or junction, are added to a second audit list.

The process of generating cost information using production processes needs to be transparent so that the origin of any costing data can be determined. To achieve this, the object which produces costing information creates its own cost definition database for every specification and junction on which a production process functions, Fig 13. It receives the audit list of production specifications and junctions and for each item meeting the criteria of a least one process produces a cost definition. The cost definition is then sent to each process which assigns a separate cost element to the definition. Each cost element is visible beneath a definition allowing the user to query the details of any cost item.

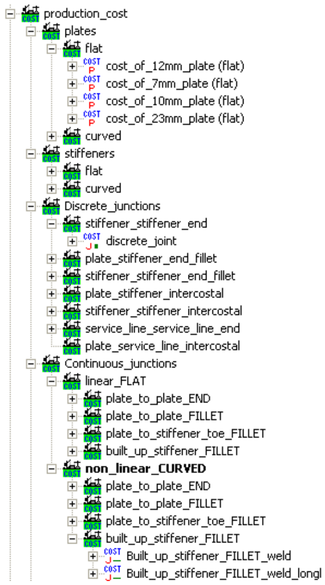


Fig. 12: a costing database produced manually.

Fig. 13: a costing database generated from processes. The elements of each map to the individual processes which produced the cost definition

7. Example Calculation

To demonstrate this process on a full ship definition, a cost will be generated for the frigate example shown in Fig. 4. The costing will only cover materials and continuous junctions as processes covering discrete junction are still under development. Furthermore, the example contains no systems definition (cabling or piping). The basic information used to generate costs is as follows:

- All Steel is costed at a £300 per tonne.
- All Labour is costed at a £20 per hour.
- A rolling process is applied to all curve specifications.
- All fillet junctions are welded using Shielded Metal Arc
- All butt (ends) junctions are welded using Full Pen Shielded Metal Arc

The data used for the welding processes is illustrated as follows:

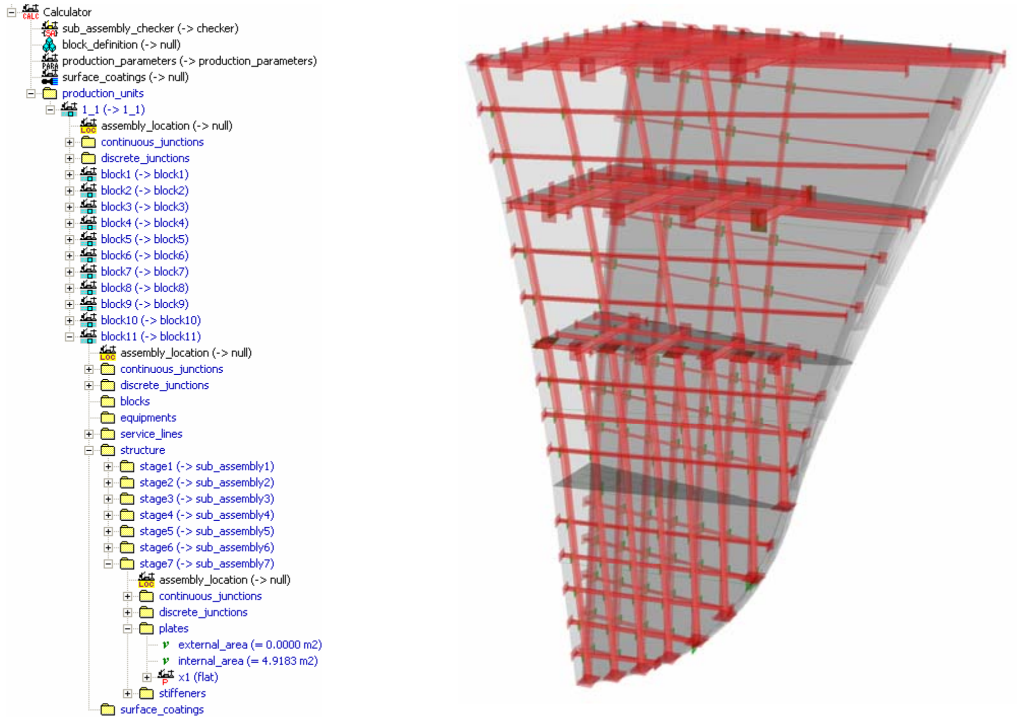
Plate Thickness(mm)	Weld Time per meter (s)
3	1030
4	1110
5	1200
6	1330
8	3400
10	4700
12	6000
15	8490
20	12350

Table 1: Fillet Weld Times for Shielded Metal Arc

Plate Thickness(mm)	Weld Time per meter (s)
5	4700
6	5400
8	8500
10	11100
12	13500
15	17800
20	23900
25	32400
30	47500
35	62900

Table 2: Fillet Weld Times for Full Pen Shielded Metal Arc

The analysis takes and hour or two to compute and typical results of the process are presented in Fig. 13. At the end of the process, 1664 separate cost scenarios are identified. Six production processes are defined to address covering materials, forming and continuous junctions. To allow the calculation to function discrete junctions are covered by a dummy process developing zero cost.



a) b)

Fig. 13: Results of the production analysis, (a), the tree view structure containing the production breakdown hierarchy of all the parts and junctions, (b) the graphical view of the plates, stiffeners and junctions of the entirety of block 11.

A cost evaluation of the production analysis is performed by associating an audit object with the production calculation and the cost database. For the example, the cost evaluation of this design in terms of material and labour due to continuous junctions is shown in Table 3. Note that the labour cost shown for the "production_envelope" includes not only the labour from each block, but also the work required to join the blocks together. The audit is capable of presenting detail results down to individual parts. This, however, does make for very large tables.

	Labour (£)	Materials (£)
Total	986602.07	337256.65
production_envelope	986602.07	337256.65
block1	38879.43	14889.31
block2	70950.63	27380.50
block3	115517.50	41326.57
block4	99502.99	34818.82
block5	115419.50	39022.22
block6	114188.60	39713.13
block7	143491.09	48806.75
block8	127031.16	43573.86
block9	78774.44	27968.88
block10	41184.40	15626.59
block11	10248.43	4130.02

Table 3: the cost breakdown of the frigate example.

The audit is also capable of presenting a breakdown of resources in terms of the utilisation of each resource at every stage in the construction. Table 4 shows a breakdown of work hours for the welder and rolling machine setup in this example.

	Welder_Person (hr)	Rolling_Machine (hr)
Total	48849.98	480.13
production_envelope	48849.98	480.13
block1	1919.62	24.36
block2	3506.56	40.97
block3	5713.91	61.97
block4	4922.81	52.34
block5	5720.63	50.35
block6	5656.70	52.73
block7	7118.85	55.71
block8	6287.91	63.65
block9	3895.93	42.79
block10	2033.33	25.89
block11	503.04	9.38

Table 4: a breakdown of the resources utilisation identified by the cost assessment.

8. Conclusion

Cost is often a secondary consideration for the engineers concentrating on delivering the technical aspects of a new design. Costing can only be addressed once the technical details have been resolved and it is possible to review the composition of the design. This two stage process results in a degree of separation between technical and costing departments working on the project and creates the situation where there may be a need for further design iterations. While these two engineering groups operate separately there may be little opportunity to go through an optimisation process to improve cost.

Cost is seldom an issue addressed by integrated ship design tools. The calculations are generally simple and often remain within the domain of the costing engineers. However, there is a considerable amount of data within a ship product model which could be used for generating costing information if analysed and presented in a manner which costing engineers can utilise. The Paramarine Design for Production module aims to bring both the technical and costing engineers closer together by providing a tool in which both groups can interface their skills and expertise. The module conducts a considerable amount of analysis on a simplified representation of the production information reducing the amount of manual effort required to identify all the cost elements of a design and it reduces the amount of cost information that must be provided by using implied production processes to generate cost details for both material and work elements of construction. When used in conjunction with the Early Stage Design module, users have the facilities to generate costing information directly from the contents of the module as demonstrated in the example or use a ship work based approach based on the types of weight or spaces in the design.

Although the Design for Production module will be part of the Paramarine release in the middle of 2006 it has already attracted a lot of interest. This would seem to reinforce the conclusion of limited support for detailed cost estimation in many of the integrated design tools used for both ship and submarine design. GRC hopes to work closely with users of this new module to understand how cost analysis can be integrated into the design process and allow the technical engineers to understand how they can produce a more cost effective design.

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