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Towards A Generic Product-Oriented Work Breakdown Structure For Shipbuilding

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ABSTRACT

U.S. Navy ship acquisitions are currently managed using the Ship Work Breakdown Structure, or SWBS, which decomposes ships by separating out their operational systems. This was effective in an era when the entire ship procurement program was physically accomplished using a ship system orientation. However, this is no longer the case and the right type of design and management information is not being collected and analyzed under SWBS.

This paper reports the results of a cooperative effort on the part of shipyards, academia, and the Navy to develop a generic product-oriented work breakdown structure. This new work breakdown structure is a cross-shipyard hierarchical representation of work associated with the design and production of a ship using today's industry practice. It is designed to (a) support design for production trade-offs and investigation of alternative design and production scenarios at the early stages of ship acquisition, (b) supply a framework for improved cost and schedule modeling, (c) translate into and out of existing shipbuilding work breakdown structures, (d) incorporate system specifiers within its overall product-oriented environment, (e) improve data transfer among design, production planning, cost estimating, procurement, and production personnel using a common framework and description of both the material and labor content of a ship project, and (f) provide a structure for 3-D product modeling data organization.

NOMENCLATURE

BOM	Bill of Materials
BUCCS	Boeing Uniform Classification and Coding System
ERAM	Engine Room Arrangement Modeling
GBS	Generic Build Strategy
GPWBS	Generic Product-Oriented Work Breakdown Structure
IPC	Interim Product Catalog
IHI	Ishikawajima-Harima Heavy Industries
NSRP	National Shipbuilding Research Program
PODAC	Production-Oriented Design and Construction
PWBS	Product Work Breakdown Structure
SWBS	Ship Work Breakdown Structure
UMTRI	University of Michigan Transportation Research Institute
WBS	Work Breakdown Structure

BACKGROUND AND PROBLEM STATEMENT

During the past three decades, the shipbuilding industry has changed its production focus from shipboard systems to products and processes. The systems used to collect and manage product and process information in the U.S.-based shipyards have not evolved at the same pace, consequently American shipbuilders have not realized the potential of product orientation to the degree that their Asian and European colleagues have. As technology advanced, the tendency has been to layer new processes on top of the old instead of rebuilding the basic infrastructure. This is suggested by Table I.

The result is that multiple work breakdown structures (WBSs) are used in current U.S. shipbuilding projects. These include shipyard WBSs, supplier WBSs, and the Navy Ship Work Breakdown Structure (SWBS).

Business function	Mid-1960s	Mid-1990s
Ship specification	System	System
Ship design	System	Varies with zone, system, other
Cost estimation	System	Varies
Budgeting	System	Product and process
Planning	System	Product and process
Operations	System / trade	Varies with trade, area, skill

Table I. Evolving design/build orientation.

Problems With SWBS

SWBS is based on shipboard functional systems. "All classification groups in SWBS have been defined by basic function. The functional segments of a ship, as represented by a ship's structure, systems, machinery, armament, outfitting, etc., are classified using a system of numeric groupings consisting of three numeric digits" [1]. Later, the number of digits was increased to five in an "expanded" form of SWBS [2]. SWBS was intended to be "... a single indenturing language which can be used throughout the entire ship life cycle, from early design cost studies and weight analyses, through production and logistic support development, to operational phases, including maintenance, alteration and modernization" [2]. To a large extent, this goal has been realized.

Today, use of this functional systems architecture from initial concept studies to scrapping causes problems because an information disconnect happens during production. SWBS, being a system-based structure, fails to reflect today's shipbuilding practice. Modern shipbuilding is based on group technology and process analysis, which depend on identification of part and interim product attributes. Interim product information, however, is not available when data is classified exclusively by functional system.

At the early design stages, certain types of major cost drivers such as labor are not easily estimated when SWBS is used because SWBS data does not show the product and process attributes upon which labor expenditure depends. As shipyard technology evolves, capital improvements are made, and processes are improved, SWBS allows no adjustment to reflect increases in efficiency.

LITERATURE REVIEW

Design of Work Breakdown Structures

Product-oriented work breakdown structures are not a shipbuilding industry innovation. Slemaker [3], for example, describes general concepts of work breakdown structure development in civil and defense industries and observes that:

"In all but the simplest, most repetitive cases there is a need to define in detail the work that individual organizations are expected to perform. This work breakdown structure (WBS) should be a product-oriented (as opposed to functional) breakdown of the item being developed or produced or the service provided."

According to reference [4], "A work breakdown structure (WBS) is a product-oriented family tree composed of hardware, software, services, data and facilities which results from systems engineering efforts during the acquisition of a defense materiel item. A work breakdown structure displays and defines the product(s) to be developed and-or produced and relates the elements of work to be accomplished to each other and to the end product(s). "

During the 1980's the National Shipbuilding Research Program (NSRP) published classic reports [5], [6], [7] which documented the progress in product work breakdown structure (PWBS) development and implementation that had been made by Ishikawajima-Harima Heavy Industries (IHI) in Japan in the 1970's. Also published by the NSRP was a report [8] which presented the results of a PWBS development project and contained a re-publication of a Boeing Commercial Airplane Company internal report [9] describing a 1970's-era conception of a complete PWBS/group technology implementation. This system was called the Boeing Uniform Classification and Coding System, or BUCCS.

Boeing's product classification efforts in the 1970's had two stated goals: minimization of parts re-design via family-oriented design retrieval, and grouped production based on family identification [9]. The design retrieval goal was attacked first, then production considerations were built in. Boeing's approach was to classify products, means of production, and controls over production.

The late 1970's IHI approach to developing a product-oriented work breakdown structure as documented by Okayama and Chirillo [5], [6] shares with the Boeing BUCCS system a strong orientation towards part and sub-assembly description, but in addition it explicitly relates those processes to ship final assembly. A three-dimensional PWBS is laid out, with three axes of information:

1st axis: Type of work (fabrication or assembly; hull, outfit, or paint.)

2nd axis: Product resources (material, manpower, facilities, expenses)

3rd axis: Product aspects. (system, zone, problem area, stage.)

The third dimension in this method is closely linked to the product-oriented ship design cycle of basic design (total system), functional design (system), transition design (system, zone) and detail design/working drawings (zone, problem area, stage). The zone consideration adds a specific ship geography parameter.

Use of Work Breakdown Structures

Standard textbooks on production and operations management describe the use of work breakdown structures. Chase and Aquilano [10], for example, introduce WBSs as a tool to organize projects or programs through the decomposition of the statement of work into tasks, sub-tasks, work packages and activities. They observe that:

"The work breakdown structure is the heart of project management. This subdivision of the objective into smaller and smaller pieces clearly defines the system and contributes to its understanding and success. Conventional use shows the work breakdown structure decreasing in size from the top to bottom and shows this level by indentation to the right:

Level	
1	Program
2	Project
3	Task
4	Sub-task
5	Work Package."

Chase and Aquilano [10] go on to explain that this WBS indenture is imposed upon and controlled through the bill of materials (BOM) file:

"The BOM file is often called the *product structure file* or *product tree* because it shows how a product is put together. It contains the information to identify each item and the quantity used per unit of the item of which it is a part."

PROJECT FORMULATION

The goal of the project was to develop a generic product-oriented work breakdown structure (GPWBS) applicable to a merchant-type ship project for which the building yard had not yet been selected. The "generic" aspect is in the applicability of the structure to various shipyards. Specific goals for the GPWBS were that it:

- Support design for production trade-offs and investigation of alternative design and production scenarios at the early stages of ship design.
- Supply a framework for improved Navy cost modeling based on the way that ships are built.
- Translate into and out of other, existing shipyard work breakdown structures.
- Incorporate system specifiers within its overall product-oriented environment.
- Improve data transfer among design, cost estimating, procurement, and production personnel using a common framework and description of both the material and labor content of a ship project.
- Provide a structure for 3-D product modeling data organization.

The development of the GPWBS was carried out by a team of naval architects, engineers, estimators, and planners from several major U.S. shipyards, the Shipbuilding Technologies Department at David Taylor Model Basin, the University of Michigan Transportation Research Institute, and Designers and Planners, Inc. Information and feedback was provided by a large European shipyard.

GPWBS ATTRIBUTES AND STRUCTURE

In order to meet the project goals, the following structural attributes were required of the GPWBS:

- Three basic types of information content -- product structure, stage or process, and work type.
- A clean product structure, devoid of process or organization information.
- Expression of the stages used in the full build cycle and the shipbuilding processes defined within each stage.
- Work type identification, with the work types characterizing product aspects in terms of organization, skill, and scope of work for interim products.
- Data from all participating shipyards must fit into the GPWBS.

The resultant is a hierarchical representation of work associated with the design and building of a ship based on product structure, classification and coding. The product structure is represented by connecting interim products, the classification is the organization of work type and stage (process) and the coding provides the name and address associated with the interim product.

Product structure

The GPWBS product structure has eight levels and is arranged to connect the interim products. The product structure is a hierarchical framework that identifies interim products and their related components and parts. Figure 1 represents the product classification by level within the product structure.

Of particular importance to this product structure is that it is product oriented only, with no organizational or process content.

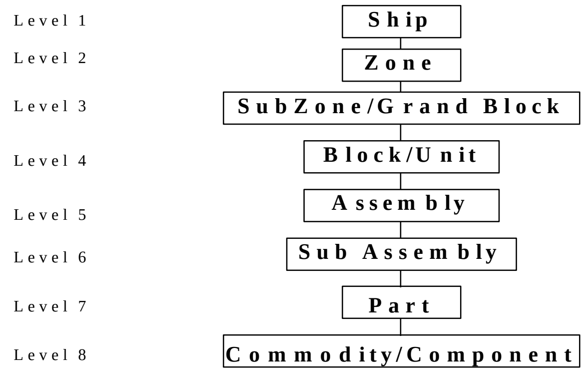


Figure 1. Product Structure.

Stages

Stages are the sequential divisions of the shipbuilding process. The GPWBS has adopted a broad view of shipbuilding stages by including the complete cycle from ship design to post delivery. They are sorted into construction and non-construction stages. Table II shows typical shipbuilding stages.

Non-construction	Construction
Design	Fabrication
Planning	Sub-assembling
Procurement	Assembling
Material management	On-unit installation
Launching	On-block installation
Testing	On-grand block installation
Delivery	Erection
Post-delivery	On-board installation

Table II. Shipbuilding stages.

Non-construction stages cover portions of the shipbuilding cycle that involve the design, planning, material definition, programmatic aspects, support, and other services of a ship project. Construction stages refer to the physical realization of a ship. In both the non-construction and construction stages, process is the key element. Stages can be divided into lower levels of processes depending upon the level of process management the shipyard uses to control its operations.

In the non-construction stages, design is defined as the preparation of engineering, material definition and documentation for construction and testing. The work description, sequencing, scheduling and resource allocation to build a product is the planning stage. The procurement stage is the requisitioning, ordering and expediting of materials. Material management is the receiving, warehousing and distribution of material. Other non-construction stages that are closely aligned to the construction stages are launching, testing, delivery, and post-delivery activities.

The construction stages address the sequence and specific processes to manufacture the ship. These stages are fabrication, sub-assembly, assembly, on-unit installation, on-block installation, grand-block installation, erection, and on-board installation.

Work Types

The third element of the GPWBS is the work type. Work type classifies the work by skill, facility and tooling requirements, special conditions and/or organizational entities. The work type is used to attach a scope or pallet of work to an interim product at a specified stage of shipbuilding. As an example, for a block interim product at the design stage with the work type "engineering," the scope of work is to produce the drawing of the block. Table III shows work types.

Non-construction	Construction
Administration	Electrical
Engineering	Hull outfit
Material handling	HVAC
Materials	Joiner
Operations Control	Machinery
Production Service	Paint
Quality assurance	Pipe
Testing/Trials	Structure
	Unit construction

Table III. Work types.

Application of work type to the GPWBS permits identification of all work whether the work is considered a direct or an indirect charge to a project. For each interim product, each work type has specific work type(s) attached to it at each stage.

Application of the Structure

The three elements (product structure, stage and work type) form the GPWBS as shown in Figure 2. These GPWBS dimensions represent different kinds of data -- the product structure is a hierarchy, stages are sequential and work types represent categories. A Cartesian space is not implied. However, a graphic representation using three axes has been found to be a useful device for introducing the GPWBS system at shipyards and in a university classroom.

As an example of a GPWBS system application, Figure 3 shows a “block” interim product at the “on block outfit” stage for the “pipe” work type. The intersection of the three coordinates can be pictured as the scope of work in piping.

An interim product over multiple stages for a single work type can also be identified. In Figure 4, the work type “pipe” through stages of “fabrication,” “sub-assembly” and “on block outfitting” is shown for a “block” interim product.

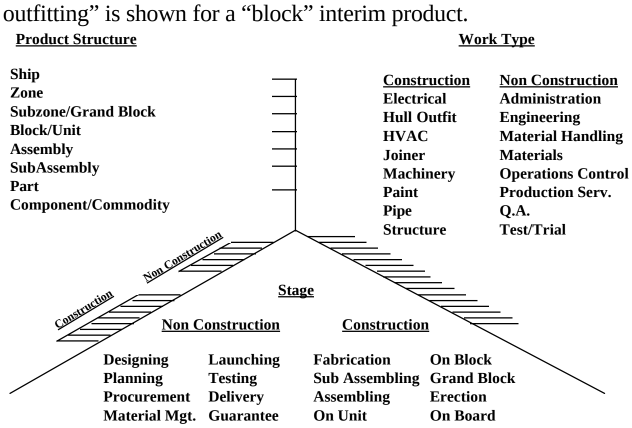


Figure 2. GPWBS system.

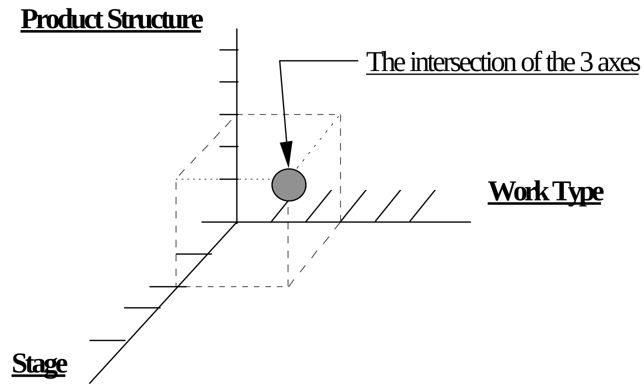


Figure 3. GPWBS interim product example.

A “unit” interim product at the “on unit outfit” stage, collecting multiple work types (“pipe,” “electrical,” and “machinery”) is shown in Figure 5. Figure 6 demonstrates that the interim product over multiple stages and multiple work types can be identified. Figure 7 indicates how multiple interim products are represented by defining the scope of work for multiple work types over multiple stages.

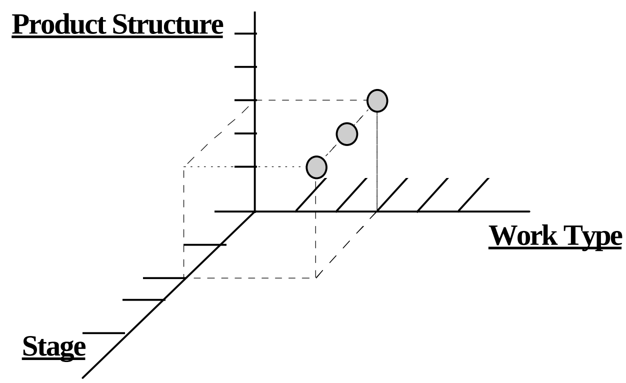


Figure 4. Interim product for multiple stages and a single work type.

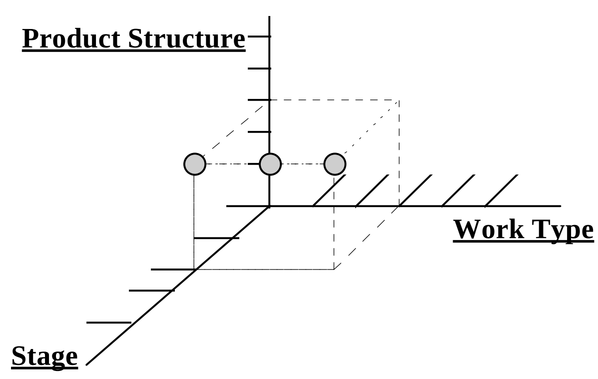


Figure 5. Interim product for a single stage and multiple work types.

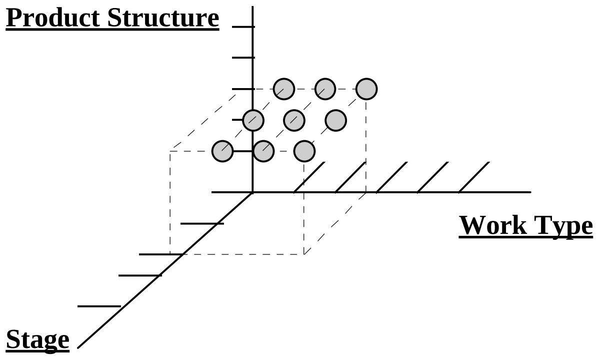


Figure 6. Interim product for multiple stages
and multiple work types.

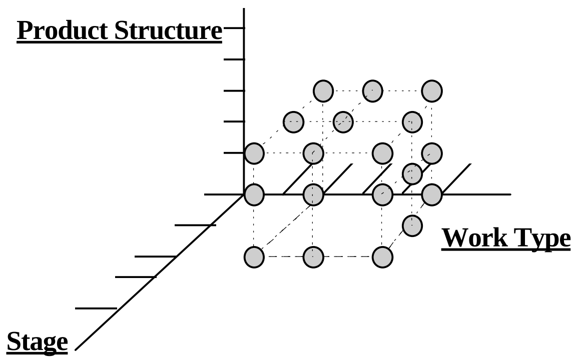


Figure 7. Multiple interim products with
multiple stages and work types.

Two significant uses of data and cost measurement are actively used by shipyards. While the three elements of the GPWBS organize the bill of material (BOM) data such that the intersection describes work associated with an interim product, the shipyards further divide cost measurement into product and process controls.

Figure 8 introduces an aspect of control that focuses on process measurement without reference to the product cost. The process measurement is more focused on the lower tiers of the product structure, while product measurement is used in the higher tiers of the product structure. The point of demarcation varies between shipyards, generally a result of the level of automation applied in their build plans. The more automated or volume driven the shipyards' factories are run the higher the level of process measurement usually applied.

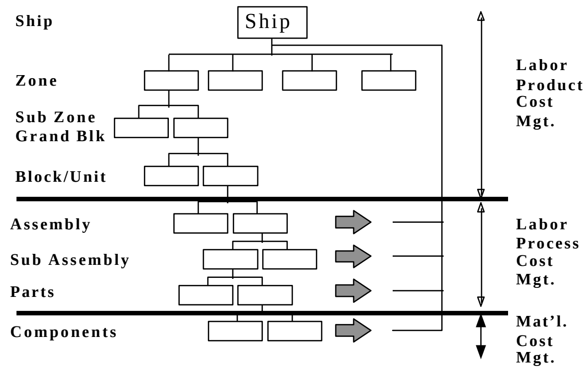


Figure 8. Product and process logic.

CODING

A useful coding system for the GPWBS must be capable of handling the three axes of the GPWBS structure. In addition, it must include coding fields for interim products and incorporate the following data elements:

- Sub-stages
- Ship type
- Drawings
- Process
- Schedule
- Unit of measure
- Quantity
- Labor hours
- Material catalog
- System
- Find number (number on drawing for each interim product.)
- Location.

Available Methods

Classification and coding systems generally fall into one of three categories.

- Monocode is hierarchical and is based on a tree structure where the digits at one level determine the subsequent digits at lower levels in the tree.
- Polycode (or chain code) is a non-hierarchical code which has a chain relationship seen through a matrix formation.
- Hybrid code (or mixed code) combines elements of the mono and poly coding structures.

Each type can use numerical, alpha or alpha/numerical characters in information fields. In the past, computer capacity limited both the available field lengths and the use of alpha or alpha-numeric codes. This is no longer a practical constraint. However, for this project, existing shipyard limits or practices must be accommodated.

The monocode tree structure is organized such that the fields of information are strung together to provide very specific addresses for each coded element within the PWBS. Therefore, the lowest level element, "part," is uniquely coded to the highest level element in the tree, "zone." Figures 9 and 10 demonstrate the monocode applications using both numerical and alpha/numeric fields.

When a polycode system is used a chain of digits is defined in the fields of information. One reason to use polycodes is that it reduces the number of digits to name the fields of information. However, reference tables are required as the code does not provide a transparent, "Dewey decimal"-style address to each element within the structure as monocodes do. Table IV is an example of a polycode system. Without a reference table the user is unable to associate a lower level interim product with the higher level interim product to which it belongs.

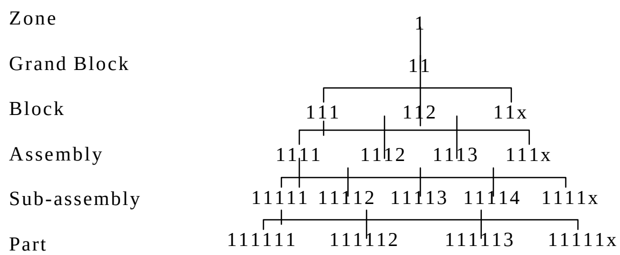


Figure 9. Numerical monocode.

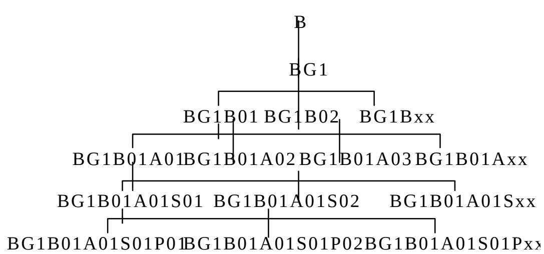


Figure 10. Alpha-numeric monocode.

Interim Product	Code
Zone	B
Grand Block	G011
Block	B023
Assembly	A041
Subassembly	S023
Part	P079

Table IV. Polycode application.

Hybrid coding is used when a mixture of associative and non-associative information is acceptable. For example, the higher levels of a product structure may require hierarchical associativity while the lower interim products may only require sequentially coded fields to attach to the higher interim products or parent relationship.

CODING APPROACH

The following approach has been adopted in the GPWBS coding system.

- Separate fields are used to identify product structure, stage and work type.
- A monocode (hierarchical) system is used in the product structure field, with polycodes in the other two fields.
- Alpha-numeric code is used in the product structure field while Roman letters are used in the stage and work type fields.

Table V lays out the fields of information to be coded. In this figure, the third row identifies the product structure titles, the fourth row identifies the product structure levels, and the fifth row corresponds to the descriptions in the work section.

Code

The code for the GPWBS is as follows, working through Table V from column 1 to column 15:

<u>Product Structure:</u>

1. *Ship* code is a numeric code in sequence with the shipyards' numbering scheme.

2. *Zone* is the second level of the product structure. The zones are:

Bow	B
Stern	S
Machinery	M
Cargo	C
Deckhouse	D
Ship-wide	W

3. *S/O ind.* is the structure vs. outfit indicator coded as:

Structure	S
Outfit	Z

This indicator, as mentioned before, is required to avoid any duplication in the coding between the structural interim products and outfit interim products.

4. *I/P ind.* is the interim product indicator. The code is:

Sub-zone	Z
Grand block	G
Block	B
Unit	U
Assembly	A
Sub-assembly	S
Part	P
Commodity/Component	C

5. *Location* is the identifier for position on the ship. Longitudinal beginning with 01 denotes the number within each zone from forward to aft, Vertical beginning with 01 denotes the number within each zone from bottom to top, and Transverse locations within each zone are numbered with centerlines as zero, starboard odd and port even.

6. *Assy.* is the assembly interim product. Assemblies are numbered sequentially within each block, unit or sub-zone.

7. *S/A* is the sub-assembly interim product. Sub-assemblies are numbered sequentially within each assembly. A sub-assembly can go directly to a block, unit or sub-zone.

8. *Part* is the lowest manufactured level of the structure. Parts are numbered sequentially within a sub-assembly or other interim product.

9. *Mat. id.* is the material identifier for commodity and component. This column is also used to indicate system when system is the identifier. The code is:

- Commodity MYYXX
- Component CYYXX
- System SAAAB

Most shipyards have existing commodity (raw material) codes and may even have a standard part numbering system for components (purchased equipment). It should be possible for them to use their existing codes here.

10. Column 10 classifies the interim product types by *ship types*. For example, geared bulk carrier or post-Panamax containership might be specified.

11. *Interim Product Type* identified in column 11 is the classification of interim products within the

Prod Struc	Product Structure																Stage	Work Type
					Location							Ship type	I/ P Type	Attr 1	Attr 2		
	Ship	Zone	S,/O ind.	I/P ind.	long.	vert.	trans	Assy	S/A	Part	Mat. id.						
	L-1	L-2	L-3 & L-4					L-5	L-6	L-7	L-8						
	1	2	3	4	5			6	7	8	9	10	11	12	13	14	15

Table V. Fields of data by product structure, stage and work type.

Prod Struc	Product Structure																Stage	Work Type
					Location							Ship type	I/ P Type	Attr 1	Attr 2		
	Ship	Zone	S,/O ind.	I/P ind.	long.	vert.	trans	Assy	S/A	Part	Mat. id.						
	L-1	L-2	L-3 & L-4					L-5	L-6	L-7	L-8						
	1	2	3	4	5			6	7	8	9	10	11	12	13	14	15
	7408	B	S	P	01	01	0	02	13	13	S11	HBC	1	1	0	FB	ST
	7408	B	Z	S	01	05	1	03	21	00	S24	HBC	3	1	0	SA	PI

Table VI. Coding examples.

Prod Struc	Product Structure																Stage	Work Type
					Location							Ship type	I/ P Type	Attr 1	Attr 2		
	Ship	Zone	S,/O ind.	I/P ind.	long.	vert.	trans	Assy	S/A	Part	Mat. id.						
	L-1	L-2	L-3 & L-4					L-5	L-6	L-7	L-8	L-1	L-3 - L-7				
Grand Block	7408	**B**	**S**	**G**	**01**	**01**	**0**	**00**	**00**	**00**	**S 1000**	**HBC**	**1**	**1**	**4**	**GB**	**ST**
Block	7408	**B**	**S**	**B**	**01**	**01**	**0**	**00**	**00**	**00**	**S 1000**	**HBC**	**1**	**2**	**2**	**AS**	**ST**
Assy	7408	**B**	**S**	**A**	**01**	**01**	**0**	**12**	**00**	**00**	**S 1000**	**HBC**	**1**	**1**	**2**	**AS**	**ST**
S/A	7408	**B**	**S**	**S**	**01**	**01**	**0**	**12**	**09**	**00**	**S 1000**	**HBC**	**1**	**2**	**0**	**SA**	**ST**
Part	7408	**B**	**S**	**P**	**01**	**01**	**0**	**12**	**09**	**71**	**S 1000**	**HBC**	**1**	**7**	**1**	**FB**	**ST**
Comm	7408	**B**	**S**	**C**	**01**	**01**	**0**	**00**	**00**	**00**	**MHP13**	**HBC**					
S/Z	7408	**B**	**Z**	**Z**	**01**	**05**	**1**	**00**	**00**	**00**	**0000**	**HBC**	**4**	**0**	**0**	**OO**	**HV**
Unit	7408	**B**	**Z**	**U**	**01**	**05**	**1**	**00**	**00**	**00**	**S 5140**	**HBC**	**7**	**5**	**0**	**OU**	**UC**
Assy	7408	**B**	**Z**	**A**	**01**	**05**	**1**	**17**	**00**	**00**	**S 5140**	**HBC**	**4**	**7**	**3**	**AS**	**HV**
S/A	7408	**B**	**Z**	**S**	**01**	**05**	**1**	**17**	**21**	**00**	**S 5140**	**HBC**	**4**	**1**	**1**	**SA**	**HV**
Part	7408	**B**	**Z**	**P**	**01**	**05**	**1**	**17**	**21**	**11**	**S 5140**	**HBC**	**4**	**1**	**4**	**FB**	**HV**
Comp	7408	**B**	**Z**	**C**	**01**	**05**	**1**	**17**	**21**	**11**	**MH0 12**	**HBC**					

Table VII. Examples of code for all levels of the product structure interim products.

Z	Sub-Zone	2	Machinery

CODE	**PROPULSION MACHINERY**	**SHAFTING**	**PROPULSOR (S)**	**AUXILIARY MACHINERY**	**MACHINERY CONTROLS**
0	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED
1	SLOW SPEED DIESEL	SOLID SHAFT	SINGLE PROPELLER	DIESEL GENERATORS	PNEUMATIC
2	GEARED MEDIUM SPEED DIESEL	SOLID MUFF COUPLED SHAFT	TWIN PROPELLER	STEAM GENERATORS	HYDRAULIC
3	GEARED HIGH SPEED DIESEL	HOLLOW FLANGED SHAFT	SINGLE WATERJET	EXHAUST GAS BOILER	ELECTRIC/ ELECTRONIC
4	DIESEL ELECTRIC	HOLLOW MUFF COUPLED SHAFT	TWIN WATERJET	OIL FIRED BOILER	
5	STEAM TURBINE			DISTILLER	

Table VIII. Machinery interim product attribute #1.

product structure levels. The interim product type subdivides the product structure by group technology and other major categories.

12 and 13. The last two columns of the product structure field are used to set up interim product attributes.

14. *Stages* are the sequential shipbuilding processes coded as two alphabetic digits as follows:

<u>Non-Construction Stages</u>

Design	DS
Planning	PL
Purchasing	PR
Material management	MM
Launch	LA
Testing	TE
Delivery	DL
Post-delivery	PD

<u>Construction Stages</u>

Fabrication	FB
Sub-assembly	SA
Assembly	AS
On-unit installation	OU
On-block installation	OB
On-grand block installation	GB
Erection	ER
On-board installation	OO

15. *Work Types* are classed by skill, facility and tooling, special conditions and organizational entities. The code for the work type is alphabetic as follows:

<u>Non-Construction Work Type</u>

Administration	AD
Engineering	EG
Material handling	MH
Materials	MA
Operations control	OC
Production services	PS
Quality assurance	QA
Test & trials	TT

<u>Construction Work Type</u>

Electrical	EL
Hull outfit	HO
HVAC	HV
Joiner	JN
Machinery	MC
Paint	PA
Pipe	PI
Structure	ST
Unit construction	UC

Table VI gives two examples of how the system is applied. The first example belongs to a ship 7408, bow zone, structural part, located in the forward most part of the bow lowest level and on centerline. The stage is fabrication and the work type is structure.

The second example is a pipe piece. It belongs to ship 7408, bow zone, outfit, sub-assembly interim product, located in the forward most part of the bow at the fifth level up from the bottom and on the starboard side. The stage is sub-assembling and the work type is pipe.

These two examples indicate how to build a coded number for an interim product at a certain stage and designated to a specific work type assignment. Other attributes can be added as required or customized to suit individual practice. As an example the unit of measure and labor hours would be covered in an interim product catalog (IPC).. This effort is under way as described in the Conclusions and Recommendations sections below.

Table VII shows the application of the coding system to all levels of the product structure. Columns 10 through 13 in Tables V through VII are further detailed in Tables VIII through XIII, which show some of the other attributes that can be applied to an interim product.

CODE	DESCRIPTION
0	NOT USED
MTVL	Merchant - Tanker, VLCC
MLNG	Merchant - Liquified natural gas carrier
MBGL	Merchant - Bulk carrier, geared, large
MOBO	Merchant - Oil/bulk/ore carrier
MCPM	Merchant - Containership, Panamax
MROR	Merchant - Ro-ro
NLSD	Naval - Landing ship dock
NDDG	Naval - Guided missile destroyer
TAKR	Sealift - Vehicle cargo ship
	. . . etc . . .

Table IX. Sample ship type codes.

CODE	DESCRIPTION
0	NOT USED
1	STRUCTURE
2	MACHINERY
3	PIPING
4	HVAC
5	ELECTRICAL
7	UNIT
8	

Table X. Interim product type code.

Z	Sub-Zone	3	Piping
CODE		TYPE	
0		NOT USED	NOT USED
1		STRAIGHT PIPE	
2		BENT PIPE	
3		PIPE FITTING	
4		VALVES	
5		PUMPS	
6			

Table XI. Pipe interim product attributes #1 & 2.

Z	Sub-Zone	4	HVAC
CODE		TYPE	GEOMETRY
0		NOT USED	NOT USED
1		STRAIGHT DUCT	CONSTANT SECTION
2		DUCT SINGLE 90 RADIUS	REDUCING SECTION
3		DUCT SINGLE <90 RADIUS	
4		DUCT FLANGES	

5	DUCT HANGERS	
6	DUCT INSULATION	
7	FANS	
8	INLETS	
9	TERMINALS	

Table XII. HVAC interim product attributes #1 & 2.

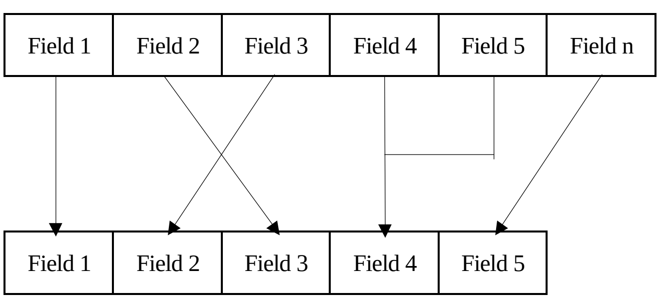
B	Block	1	Structure
CODE	TYPE		GEOMETRY
0	NOT USED		NOT USED
1	SINGLE BOTTOM		3D PLANE
2	DOUBLE BOTTOM		3D CURVED
3	SINGLE SIDE		2D PLANE
4	DOUBLE SIDE		2D CURVED
5	DECK		
6	TRANSVERSE BULKHEAD		
7	LONGITUDINAL BULKHEAD		
8	FLAT		
9	MAJOR FOUNDATION		

Table XIII. Structure interim product attributes #1&2.

MAPPING TEST

Mapping is the process of converting data from one work breakdown structure to another. There are two steps in the mapping process. The first is to establish a relationship between the fields of the two WBSs so that data records in the first format can be converted to the second. This is shown in Figure 12. Having aligned the fields, the transfer of cost data or other information (for example, bill of materials data) can then be accomplished. The complete procedure is laid out in a series of examples below.

Shipyard PWBS Data Record *



Generic PWBS Data Record

* Data records include information from Work Orders (labor data) and from Purchase Orders (material data).

Figure 12. WBS mapping: alignment of fields.

Mapping "Shipyard A" Work Breakdown Structure To The GPWBS

To demonstrate the process, a shipyard-specific map similar to the general one shown in Figure 12 was constructed for aligning the product-oriented WBS of an actual shipyard, "Shipyard A," with the GPWBS.

The product-oriented work breakdown structure for Shipyard A is used in their work order records (used to track labor data) and purchase orders (used to track material data). Because the nature of the information in work orders is different from that in purchase orders, the data fields in these two records are different. Table XIV shows the format of Shipyard A's work order and purchase order records, which were derived from the shipyard's product-oriented WBS. The remainder of this section of the paper will focus on mapping shipyard A's product-oriented WBS to the GPWBS.

Table XV shows the GPWBS record structure, to which the fields in Shipyard A's product-oriented WBS from the previous page must be mapped. This record structure is fully described in the Coding section and is not repeated here except in summary form, and as it relates to each specific example. The fields in these records are shown and explained in successive steps to show the overall map in its entirety.

Table XVI shows how shipyard A's job number, the first field in their work order and in their purchase order, implicitly includes shipyard A's hull number.

Shipyard "A" Work Order Record	
Job Number	
Group Number	
Sub-group Number	
Item Number	
Block/Unit Number	
Zone Number	
Weight	
Description	
Quantity	
Unit of Measure	
Estimated Hours	
Planned Start Date	
Actual Hours	
Actual Start Date	
Actual Completion Date	
Product Type (Work Type)	

Shipyard "A" Purchase Order Record	
Job Number	
Group Number	
Sub-group Number	
Item Number	
Weight	
Description	
SWBS Reference	
Quantity	
Unit of Measure	
Total Cost	
Date Ordered	
Expected Receipt Date	
Actual Receipt Date	

Table XIV. Work order and purchase order format, shipyard A.

Shipyard A does not explicitly assign a ship type. Since the generic product-oriented WBS explicitly includes ship type, the table shows how the shipyard's job number and hull number would be used to assign the ship type in the generic product-oriented WBS.

Table XVII shows how shipyard A's zone designators relate to the generic product-oriented WBS zone designators. The descriptions in these zone designator tables relate specifically to commercial vessels. Other ship types will likely have different zone descriptions.

Table XVIII shows typical relationships between shipyard "A" block number/locating scheme and the generic PWBS. As explained in the previous section, blocks represent structural elements only. Non-structural elements are discussed later.

Note that all blocks in these examples are in the shipyard's zone 4. Therefore, the corresponding generic product-oriented WBS zone designator is D, as shown in Table XVII. All shipyard block numbers for zone 4 are three digit numbers beginning with 4.

The shipyard’s transverse location and deck level fields correspond directly to the generic product-oriented WBS transverse and vertical location fields.

Generic Product-Oriented WBS Data Record	
Ship Type	
Hull Number	
Product Structure:	
Zone	
Structure/Outfit/Material Indicator	
Interim Product Indicator	
Longitudinal Location	
Vertical Location	
Transverse Location	
Assembly	
Sub-Assembly	
Part	
Commodity/Component	
Interim Product Type	
Interim Product Attribute 1	
Interim Product Attribute 2	

Interim Product Attribute n	
Stage of Shipbuilding:	
Non-construction Stage	
Construction Stage	
Work Type:	

Table XV. GPWBS data record format.

While this shipyard uses P for port, S for starboard, and C for centerline, the generic product oriented WBS uses the standard Navy system of “even

Shipyard Job Number	Shipyard Hull Number	**Generic** Product-Oriented **WBS Ship Type Code**
C8-275G	2367	TAO
C8-230C	2371	LSD
C3-300	2379	LSD
C3-075B	002	MHC
C3-075C	003	MHC
C3-075D	004	MHC
C3-0140	2372	WAGB
C3-222A	2373	TAKR
C3-222B	2374	TAKR
C3-222C	2375	TAKR
C3-222D	2376	TAKR

Table XVI. Sample lookup table showing shipyard A job number & hull number relation to GPWBS ship type.

number to port, odd to starboard” with “0” denoting a centerline location. Associating the shipyard’s frame number directly to the generic product-oriented WBS longitudinal locator is not quite as straightforward.

Shipyard A Zone Designator	Shipyard A Zone Description	**Generic** Product-Oriented **WBS Zone Designator**
1	Stern	S
2	Cargo (Ballast, Fuel)	C
3	Cargo (Ballast, Fuel)	C
4	Deckhouse	D
5	Cargo	C
6	Cargo	C
7	Bow	B
8	Cargo	C
9	Machinery	M
		W*

* W = ship-wide zone, used only in Generic PWBS

Table XVII. Zone designator relationships, shipyard A to generic product-oriented WBS.

The generic product-oriented WBS longitudinal locator, as explained in the previous section, shows the forward-most block(s) in each zone at a given vertical to be 01, and the block(s) immediately aft of these to be 02. The longitudinal locator continues to increment proceeding aft until reaching the zone’s aft boundary. It is reset to 01 for each vertical level addressed, and for each zone.

The generic product-oriented WBS side of the table can be seen to include two fields not explicitly addressed by this particular shipyard, namely the Structure/Outfit/Material Indicator and Interim Product Indicator. These are fully explained in the previous section. For the cited examples, the shipyard’s block number represents only the structural elements within the region containing that block, while the outfit elements are shown by this shipyard in terms of sub-zones. Examples of sub-zones are presented later. In the simplest case, a block contains all the structural elements in a given region, and a sub-zone contains all other elements in that same region. However, block and sub-zone boundaries need not be identical.

Since Table XVIII shows only blocks (i.e., structure), note that the corresponding S/O/M Indicators in the generic product-oriented WBS are all shown as “S” entries. Similarly, all Interim Product Indicators in the generic PWBS are all shown a “B” entries, for Block. Table XIX shows similar typical relationships between the shipyard sub-zone numbering/locating scheme and the generic product-oriented WBS. As explained in the previous section, sub-zones represent outfit elements only.

Shipyard A Structural Blocks					**Generic PWBS Structural Blocks**					
Zone	Block No.	Transv. Loc.	Fr.	Dk.	Zone	S/O/M Indicator	I/P Ind.	Longl. Loc.	Vert. Loc.	Transv. Loc.
4	420	P	85	02	D	S	B	01	02	2
4	421	S	85	02	D	S	B	01	02	1
4	422	P	90	02	D	S	B	02	02	2
4	423	S	90	02	D	S	B	02	02	1
4	424	P	95	02	D	S	B	03	02	2
4	425	S	95	02	D	S	B	03	02	1
4	426	C	100	02	D	S	B	04	02	0
4	427	C	100	02	D	S	B	04	02	0

Table XVIII. Shipyard A structural block relation to GPWBS.

All sub-zones in these examples are in the shipyard’s zone 4. Therefore, the corresponding generic product-oriented WBS

Zone Designator is D, as shown in Table XVII. All shipyard sub-zone numbers are defined by the sub-zones' vertical, longitudinal, and transverse locations. Associating the shipyard's location scheme for outfit sub-zones with that for generic product-oriented WBS is the same as for the structural blocks discussed above.

Again, the generic product-oriented WBS side of the table shows the Structural/Outfit/Material Indicator and the Interim Product Indicator. For the cited examples, the shipyard's sub-zone number represents only the outfit elements within the region containing that sub-zone. Since Table XIX shows only sub-zones (i.e., outfit), note that the corresponding S/O/M Indicators in the generic product-oriented WBS are all shown as "Z" entries, with Z representing outfit. Similarly, all Interim Product Indicators in the generic product-oriented WBS are all shown as "Z" entries.

Table XX shows how Shipyard A's group numbers relate to the work types defined in the GPWBS. The codes shown for the GPWBS work types were explained in the previous section so they are not repeated here. Table XXI shows the shipyard's material cost group codes and descriptions, and their associated Ship Work Breakdown Structure (SWBS) numbers. This information supports purchase order record mapping examples which follow.

Shipyard A Outfit Sub-Zones				Generic Product-Oriented WBS Outfit Sub-Zones					
Zone	Sub-zone Number	Fr.	Dk.	Zone	S/O/M Ind.	I/P Ind.	Longl Loc.	Vert. Loc.	Transv Loc.
4	01-083-1P	83	01	D	Z	Z	01	01	2
4	01-083-1S	83	01	D	Z	Z	01	01	1
4	01-091-1P	91	01	D	Z	Z	02	01	2
4	01-091-1C	91	01	D	Z	Z	02	01	0
4	01-091-1S	91	01	D	Z	Z	02	01	1

Table XIX. Shipyard A outfit sub-zone relation to generic product-oriented WBS.

Shipyard A Group Number	**Shipyard A Group Description**	**Generic** Product-Oriented **WBS Work Type**
01	Engineering	EG
02	Hull Steel	ST
03	Superstructure	ST
04	Joiner	JN
06	Piping	PI
07	Machinery	MC
08	Electrical	EL
09	Sheet metal	HO
10	Carpentry	HO
11	Insulation	HO
12	Clean and Paint	PA
13	Construction Services	PS
16	Fittings	HO
17	Outfitting	HO
18	Deck Covering	HO
19	Jigs and Dies	HO
20	Foundations	HO
23	Tests and Trials	TT
25	Mold Loft	PS
26	Launching	PS
27	Production Department	PS
28	Quality Control	QA
31	Warehousing	PS
33	Dry-docking/Shifting	PS
34	Insurance	AD
43	Weld Rods, Steel Freight	MA
45	Spares	MA
46	Machinery Package Units	UC
81	Program Management	AD
82	Estimating	AD
97	Miscellaneous Materials	MA

Table XX. Shipyard A product types versus generic work types.

Shipyard A Material Cost Group Number	**Shipyard A Material Cost Group Description**	**SWBS**
02-00	Steel Group	100
02-02	Hull Steel	110
02-06	Structural Hull Piping	
03-00	Superstructure Steel	150
06-00	Piping	505
06-01	Bilge and Ballast System	529
06-02	Cargo System	
06-03	Firemain System	521
06-04	Salt Water Cooling System	524
06-05	Flushing System	521
06-06	Fresh Water Cooling System	532
06-07	Potable Water System	533
06-08	Wash Water System	
06-09	Fuel Oil System	261
06-10	Lube Oil System	262
06-11	Compressed Air System	551
06-12	Steam Systems	517
06-13	Heating System	511
06-14	Fire Extinguishing System	555
06-15	Mud System	
06-16	Refrigeration System	516
06-17	Hydraulic System	556
06-18	Plumbing and Drains	
06-19	Sounding Tubes, Vents	506
06-23	Distilled Water System	531
07-01	Main Propulsion	200
07-02	Generators	310

Table XXI. Shipyard A material cost groups vs. SWBS.

Mapping Labor Data to the GPWBS

Shipyard A labor data is tracked via work orders. Figure 13 shows the yard's work order for installing miscellaneous outfit items in the deckhouse of an LSD (Landing Ship Dock). In this figure, Yard A's Group Number maps to the GPWBS Work Type, Sub-Group Number maps to Stage, and Zone Number is broken into the GPWBS Product fields. Having established the GPWBS code for this work order, the schedule and labor data is then assigned to the GPWBS code and in this way the GPWBS data set is built for this ship.

Figure 14 shows a second outfit item installation work order very similar to the first. Comparing the two records, one can see that the labor man-hours associated with each of these work orders cannot be viewed below the HO (hull outfit) work type at product structure level 3, deckhouse sub-zone.

Figure 15 shows a pipe welding work order for a system that will eventually be in the machinery zone. The work for this particular activity is performed On-unit and its Work Type is mapped to GPWBS Unit Construction, as shown in Table 20. This work can be viewed at GPWBS product structure level 4, machinery unit, as shown in Figure 1.

Mapping Material Data to Generic PWBS

Figure 16 shows a representative shipyard purchase order. Working through the mapping process will show how it works. The shipyard A group 6 entry corresponds to GPWBS Work Type Piping (PI) as shown in Table XX. The purchase order includes a description of the functional system, Bilge and Ballast System, and its associated Ship Work Breakdown Structure (SWBS) number. This particular purchase order represents a "roll-up" or summation of all purchased elements of the Bilge and Ballast System, the elements including pumps, piping, valves, etc. The GPWBS Zone for this system is shown to be ship-wide (W). All purchase orders would inherently carry an S/O/M Indicator of M for material. This system's Interim Product (I/P) Indicator is shown as "F" for Functional as can be seen in the list of Interim Product Categories in the Coding section (which does not yet include any `F` entries). There are no locators shown (i.e., longitudinal, vertical, and transverse) since the piping run extends throughout the entire length of the ship. Because the system is ship-wide, it is not associated with a GPWBS Assembly, Sub-Assembly, or Part, so each of these fields has a `0` entry. Since this record actually represents a roll-up of purchase orders executed for the entire system, it has a `0` shown in the Component/Commodity field. Material purchases would be considered in the Purchasing (PR) stage and of the Material (MA) Work Type. The SWBS number entry is a direct transfer from the purchase order to the GPWBS. The GPWBS product level chart (Figure 1) indicates that the cost data can be viewed at two levels (at level 8 for the piping when it is bought; level 3 and above for the functional system after it is installed in the ship.

Figure 17 is a purchase order for flanges of a specified piping system. On a GPWBS level chart, there would be two separate views of the flange cost -- as flanges (level 8, commodity) and as part of a piping system (level 3, functional system).

Figures 18 and 19 show other ship-wide roll-up purchase orders similar to the first example, but for other systems (Fire Extinguishing System/SWBS 555 and Sounding Tubes, Vents & Overflows/SWBS 506).

APPLICATION OF GPWBS TO OTHER CURRENT R&D EFFORTS

The GPWBS is the integrator that provides the linkage between the various projects currently underway under the Mid-Term Sealift Ship Technology Development Program. An overview of this program may be found in reference [11]. The Generic Build Strategy, Production-Oriented Design and Construction (PODAC) Cost Model, and Engine Room Arrangement Modeling (ERAM) tasks will use the GPWBS to enhance inter-project communication and data transfer, and as a test case for the interdisciplinary use of a single, unifying work breakdown structure.

In addition to this inter-project integration role, the GPWBS is a fundamental element of the PODAC Cost Model, having been designed from the outset to be used as its information structure. This on-going GPWBS implementation in ship cost estimating is further discussed in the Conclusions section below.

TRANSFERRING TO INDUSTRY AND GOVERNMENT USERS

The completed GPWBS was presented by project team members to their respective organizations, but it was not within the project scope for the team to directly present it to other organizations. Instead it was planned to provide an instruction manual.

This task was carried out by the University of Michigan Transportation Research Institute (UMTRI), who discussed training needs with the training staff of team member shipyards. It was decided that a self-learning manual, with a computer aided interactive version, would be the best way to accomplish transfer of the GPWBS to the user community.

The self-learning manual was completed and distributed to the industry and the Navy. The computer version was not completed due to time constraints, but will be completed under new funding, which will also enlarge the guide to include examples of the use of the interim product tables.

In addition, the use of the GPWBS is currently being taught in two professional short courses offered by UMTRI under the sponsorship of the National Shipbuilding Research Program. Future shipbuilders are learning the use of the GPWBS in the Marine Systems Manufacturing course in the Department of Naval Architecture and Marine Engineering, University of Michigan.

Work Order Record	Work Order Data
Job Number	CX-333
Group Number	17
Sub-Group Number	F3
Item Number	01
Block Number	
Zone Number	02-083-1S
Weight	
Description	Install Misc. Outfit
Quantity	
UoM	
Estimated Man-hours	
Planned Start Date	
Planned Complete Date	
Actual Hours	
Actual Start Date	
Actual Complete Date	

Generic PWBS Data Record

	Product								
Ship Type	Hull No.	Zone	S/O Ind.	I/P Ind.	Long	Vert.	Tran.	Stage	Work Type
LSD	2379	D	Z	Z	01	01	2	OB	HO
			(1)	(2)	(3)	(4)	(5)		

(1) Structure / Outfit Indicator

(2) Interim Product Indicator

(3) Longitudinal Location

(4) Vertical Location

(5) Transverse Location

Figure 13. Sample work order record mapped to GPWBS, miscellaneous outfit.

Work Order Record	Work Order Data
Job Number	CX-333
Group Number	17
Sub-Group Number	F3
Item Number	01
Block Number	
Zone Number	03-099-1C
Weight	
Description	Install Misc. Fittings
Quantity	
UoM	
Estimated Man-hours	
Planned Start Date	
Planned Complete Date	
Actual Hours	
Actual Start Date	
Actual Complete Date	

Generic PWBS Data Record

	Product								
Ship Type	Hull No.	Zone	S/O Ind.	I/P Ind.	Long	Vert.	Tran.	Stage	Work Type
LSD	2379	D	Z	Z	02	03	0	OB	HO
			(1)	(2)	(3)	(4)	(5)		

(1) Structure / Outfit Indicator

(2) Interim Product Indicator

(3) Longitudinal Location

(4) Vertical Location

(5) Transverse Location

Figure 14. Sample work order record mapped to GPWBS, miscellaneous fittings

.

Work Order Record	Work Order Data
Job Number	CX-333
Group Number	46
Sub-Group Number	01
Item Number	02
Block Number	501
Zone Number	
Weight	
Description	Weld Pipe in LO unit
Quantity	
UoM	
Estimated Man-hours	
Planned Start Date	
Planned Complete Date	
Actual Hours	
Actual Start Date	
Actual Complete Date	

Generic PWBS Data Record

	Product								
Ship Type	Hull No.	Zone	S/O Ind.	I/P Ind.	Long	Vert.	Tran.	Stage	Work Type
LSD	2379	M	Z	U	00	00	0	OU	UC
			(1)	(2)	(3)	(4)	(5)		

(1) Structure / Outfit Indicator

(2) Interim Product Indicator

(3) Longitudinal Location

(4) Vertical Location

(5) Transverse Location

Figure 15. Sample work order record mapped to GPWBS, lube oil pipe welding.

Purchase Order Record	Work Order Record
Job Number	CX-333
Group Number	06
Sub-Group	01
Item Number	00
Weight	
Description	Bilge and Ballast Sys
SWBS Ref	
Quantity	
UoM	
Total Cost	

Generic PWBS Data Record

	Product												Stage	Work Type	SWBS
Ship Type	Hull No	Zone	S/O Ind	I/P Ind	L	V	T	Assy	S-A	Part	C C				
LSD	2379	W	O	F	0	0	0	0	0	0	0		OU	UC	529
		Notes:	1	2	3	4	5	6	7	8	9				

(1) Structure/Outfit Indicator
(2) Interim Product Indicator
(3) Longitudinal Location
(4) Vertical Location
(5) Transverse Location
(6) Assembly
(7) Sub-Assembly
(8) Part
(9) Commodity/Component

Figure 16. Sample purchase order record mapped to GPWBS, rolled up to Bilge and Ballast System level.

Purchase Order Record	Work Order Record
Job Number	CX-333
Group Number	06
Sub-Group	23
Item Number	03
Weight	
Description	Flanges (in Distilled*
SWBS Ref	
Quantity	
UoM	
Total Cost	

Generic PWBS Data Record

	Product													
Ship Type	**Hull No**	**Zone**	**S/O Ind**	**I/P Ind**	**L**	**V**	**T**	**Assy**	**S-A**	**Part**	**C C**	**Stage**	**Work Type**	**SWBS**
LSD	2379	W	M	F	0	0	0	0	0	0	0	OU	UC	531
		Notes:	1	2	3	4	5	6	7	8	9			

* in distilled water system

(1) Structure/Outfit Indicator
(2) Interim Product Indicator
(3) Longitudinal Location
(4) Vertical Location
(5) Transverse Location
(6) Assembly
(7) Sub-Assembly
(8) Part
(9) Commodity/Component

Figure 17. Sample purchase order record mapped to GPWBS, commodity level.

Purchase Order Record	Work Order Record
Job Number	CX-333
Group Number	06
Sub-Group	14
Item Number	00
Weight	
Description	Fire Ext Sys
SWBS Ref	
Quantity	
UoM	
Total Cost	

Generic PWBS Data Record

	Product													
Ship Type	**Hull No**	**Zone**	**S/O Ind**	**I/P Ind**	**L**	**V**	**T**	**Assy**	**S-A**	**Part**	**C C**	**Stage**	**Work Type**	**SWBS**
LSD	2379	W	Z	F	0	0	0	0	0	0	0	PR	MA	555
		Notes:	1	2	3	4	5	6	7	8	9			

(1) Structure/Outfit Indicator
(2) Interim Product Indicator
(3) Longitudinal Location
(4) Vertical Location
(5) Transverse Location
(6) Assembly
(7) Sub-Assembly
(8) Part
(9) Commodity/Component

Figure 18. Sample purchase order record mapped to GPWBS, rolled up to Fire Extinguishing System level.

Purchase Order Record	Work Order Record
Job Number	CX-333
Group Number	06
Sub-Group	14
Item Number	00
Weight	
Description	Tank Vents
SWBS Ref	
Quantity	
UoM	
Total Cost	

Generic PWBS Data Record

	Product													
Ship Type	Hull No	Zone	S/O Ind	I/P Ind	L	V	T	Assy	S-A	Part	C C	Stage	Work Type	SWBS
LSD	2379	W	M	F	0	0	0	0	0	0	0	PR	MA	506
		Notes:	1	2	3	4	5	6	7	8	9			

(1) Structure/Outfit Indicator
(2) Interim Product Indicator
(3) Longitudinal Location
(4) Vertical Location
(5) Transverse Location
(6) Assembly
(7) Sub-Assembly
(8) Part
(9) Commodity/Component

Figure 19. Sample purchase order record mapped to GPWBS, rolled up to Tank Vents System level.

CONCLUSIONS

The GPWBS system was developed by a joint industry/government/academia team. The team synthesized practical shipbuilding know-how with concepts resident in the technical and academic literature to develop a new system.

The system was validated by testing it on actual shipyard work orders and purchase orders which were furnished to the team by a large U.S. shipyard. It was found that the GPWBS can provide good production information visibility for a variety of technical and management purposes. In addition, managers at a large overseas shipyard reported that the GPWBS fit their practice and data quite well.

The progress made towards a generic product-oriented work breakdown structure for shipbuilding has significant potential for build strategy development, cost estimating, design for production, and integration of current Mid-Term Sealift R&D projects.

Build Strategy Development

This GPWBS formalizes the logic and structure of the methods applied under current shipbuilding practice worldwide. It is generic in the sense that it has not copied any one shipyard structure. However, the outcome is such that any shipyard can identify the components of their WBS within it. Build strategies can be facilitated by the GPWBS structure because it systematizes the main components that must be addressed in the strategy. The three axes in the GPWBS bring attention to the individual aspects that drive the build strategy without loosing sight of the integrated structure.

Cost Estimating and Design for Production

Cost model development is the GPWBS application that is being pursued most intently right now. The GPWBS is already being implemented by at least one large shipyard for the development of new tools for ship cost estimation under the PODAC Cost Model project. Use of the GPWBS offers several significant advantages in this area:

- The system provides a conversion tool which enables information on past newbuildings to be converted into a common format for ready use on future projects.
- It enables the development of new estimating processes which will produce ship estimates based on how production builds the ship.
- Under GPWBS, return costs can now be used to validate the cost estimating relationships that produced the estimate.
- Finally, with the above processes in place, it becomes possible to correctly identify cost drivers and their impacts so that designers can design more producible, lower cost ships.

The PODAC Cost Model is using the GPWBS as its data structure and has validated it using shipyard-supplied data. Seven complete ship-sets of estimated cost and return cost data, including contract changes, have been mapped from the shipbuilder's WBS into the GPWBS. No need for modification of the GPWBS has arisen. Further development of the GPWBS for the purposes of cost model development are currently under way and consist of taking the Interim Product Catalog to a greater level of detail.

Integration of Mid-Term Sealift R&D projects

The GPWBS project team included members of the PODAC Cost Estimating Model. The PODAC Cost Model used the GPWBS as its foundation.

The Engine Room Arrangement Model (ERAM) project is developing three merchant vessel engine room designs. The project team must use trade-off analysis and comparative cost estimating in the evaluation of these designs. The ERAM team plans to use the GPWBS for their interim product classification and coding, and for their production-oriented design decisions.

RECOMMENDATIONS

More detailed development of the GPWBS structure's

Interim Product Catalog is needed to fully realize the concept for use in early stage design, contract design, zone layout, production engineering, cost estimation, and "design for ownership." This work is currently taking place in support of the PODAC Cost Model and the Generic Build Strategy projects.

Programs such as ATC, AOE(X) and SC21 could be excellent opportunities for early-stage naval applications of the GPWBS. In addition, the Navy should consider using the GPWBS to model the work breakdown structures of the builders of the LPD-17 class.

A particularly valuable GPWBS application for both shipyard managers and Navy ship acquisition managers would be ship procurements in which vessels of one class are constructed at more than one shipyard. Multi-yard procurements have often been done for naval surface combatants and certain other kinds of warships. One class, multi-yard procurements are also sometimes done in the international merchant shipping industry and the GPWBS could be a good tool for inter-yard cooperation in these cases.

The Navy's functional systems-oriented work breakdown structure evolved over many years. This new generic product-oriented work breakdown structure should be implemented and evolved in a similar manner. The author's hope that the GPWBS will prove a valuable enabler, opening the door to significant process development in our shipbuilding community.

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