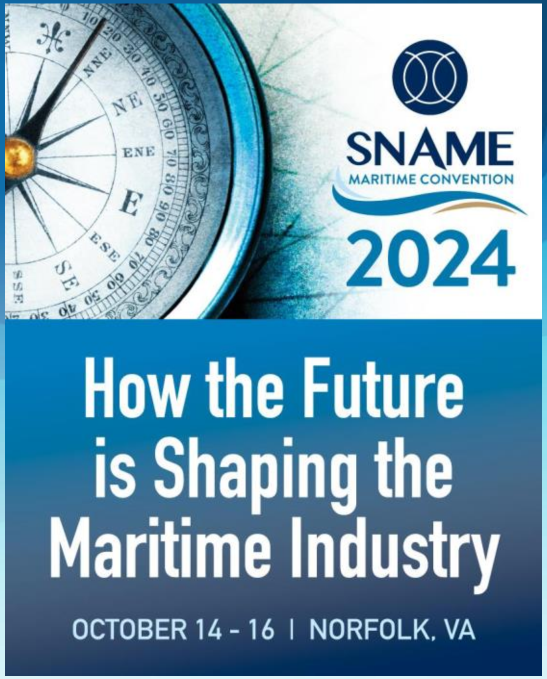


Estimating the Cost of Ships

Presented by: (Charles Greenwell, President SPAR Associates, Inc.)

Estimating the Cost of Ships
Outfit Density and Work Space Optimization

Outfit density is an indication of how much of a ship's design volume is consumed by machinery, equipment components and the many different outfit systems.

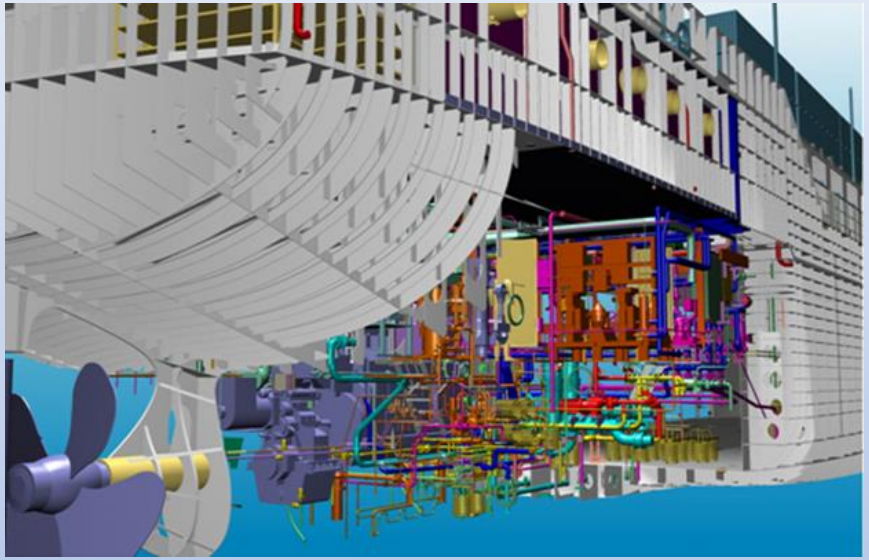
Highly dense spaces are often too difficult to gain easy access for equipment/system installations, operation, maintenance and potential upgrades.

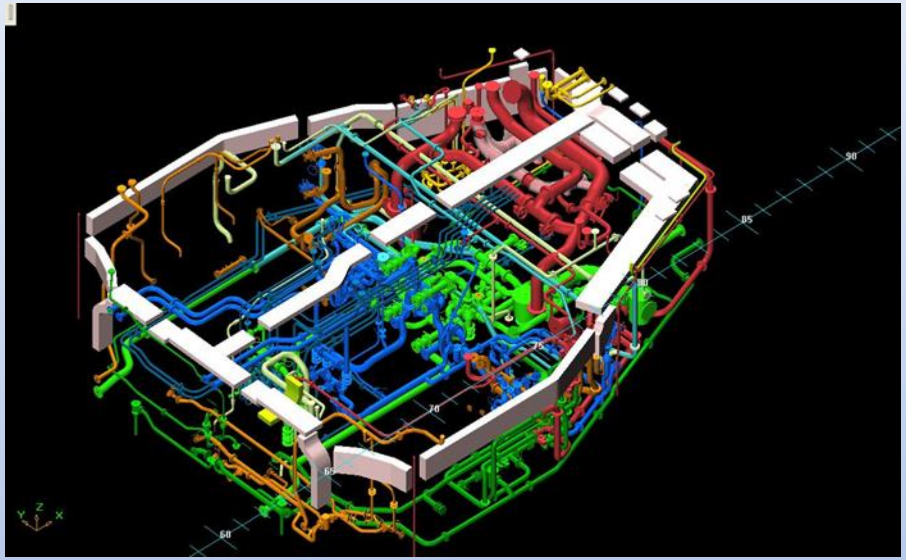
Highly dense spaces often require tortured and expensive routings of distributed systems to avoid interferences between competing systems.

The Outfit Density of a ship is nonhomogeneous in that there are spaces that have no outfit installed.

Increasing the available Work Space will reduce the Outfit Density and thus the cost. One method to accomplish may be by designing smaller more compact equipment modules. Think of them as Line Replaceable Units (LRUs) found in the aircraft industry.

Estimating the Cost of Ships
Outfit Density and Work Space Optimization





Since outfit density varies by area of the ship, a cost model that allows for estimating cost by ship zones and blocks (Product Oriented) would provide a better capability for analysis of its affects.

Using the Ship Type design data we can estimate the Outfit Density for specific interim products. We can then use this number to develop a cost factor adjustment for that space

Estimating the Cost of Ships
Ship Costing Tools

- The Product Orientated Design and Cost Model (PODAC)
  - Early Stage Design Estimating
  - Estimates the way ships are built - by Product and Stage of Construction using Production Norms (Benchmarks)
  - Ship Type Specific
  - Weight is only used for estimating structure. Outfit is estimated based on the Scope of Work such as Volume, Area, Length, or Pieces.
  - Lean Design and Producibility – Better Outfit Density & Work Space Optimization visibility for cost
  - Better method for Trade-off Analysis

Estimating the Cost of Ships
The PODAC Cost Model

Basic HM&E Systems Costs
(Standard Shipbuilding CERs)

+ CER Adjustments for Military Requirements
- Mil-Spec Material
- NVR Requirements
- Redundancies
- CBRN Requirements
- Arctic Service Requirements

+ Add Military Systems
- Weapons Systems
- C4ISR
- Special Coatings

X Adjustments for Productivity
- Engineering Quality
- Commonality
- Applied Production Methods & Constr. Stage
- Prior Learning
- **Outfit Density**

= "Should Cost"

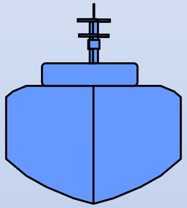
"Should Cost"

+ Cost Risk
- Engineering Performance
- Production Performance
- Management Performance
- Potential Impact of Schedule

= "More Likely Cost"

Estimating the Cost of Ships
What Makes it Different?

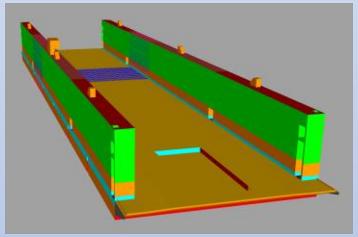
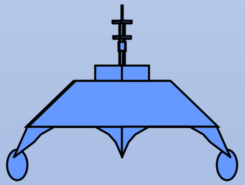
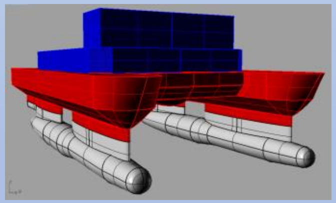
Ship Type
Cost Models

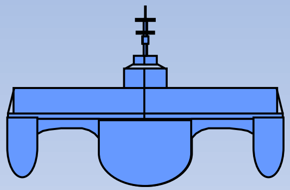








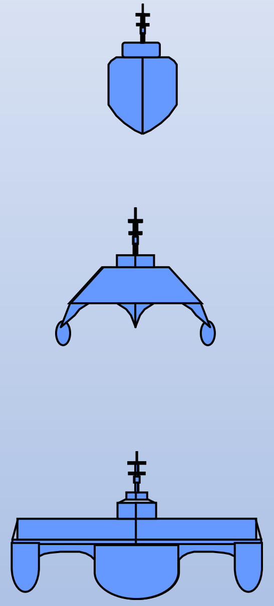


Each class of ship types has its own set of analogous ships.

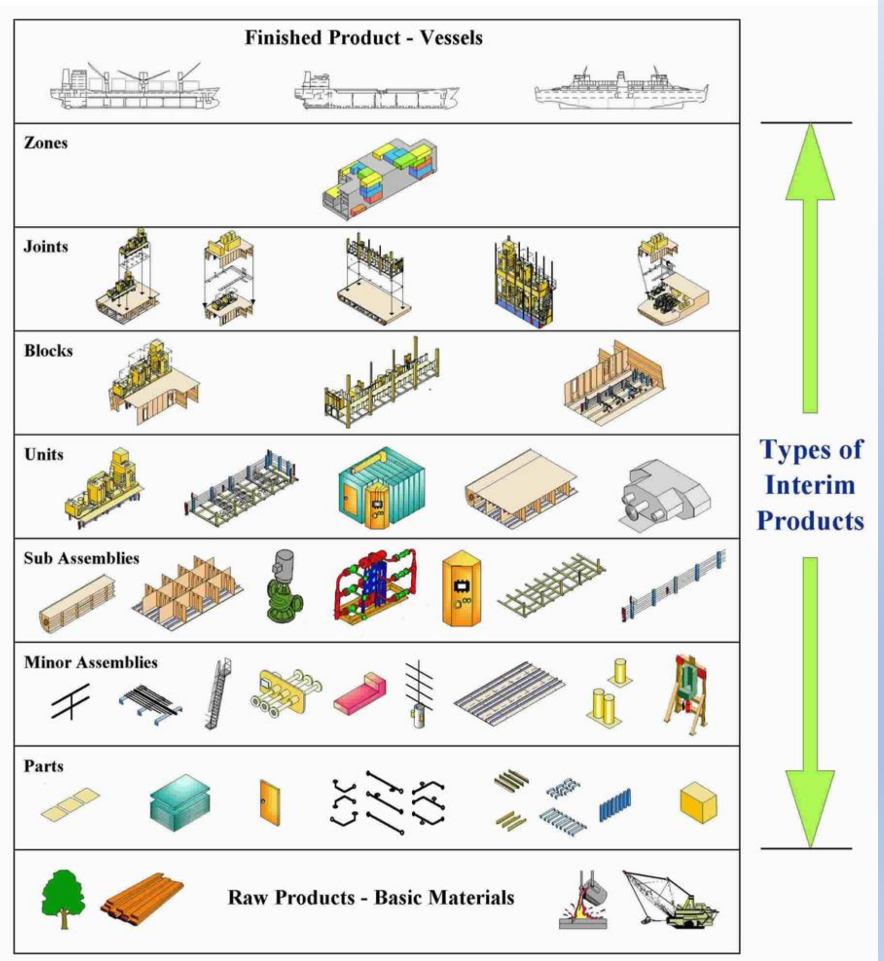
These are examples of the range of possibilities.

Estimating the Cost of Ships
What Makes it Different?

Cost Model



The Product Work Breakdown Structure (PWBS)



The interim product mix will define the process lanes and Production Work Centers that blocks will flow thru.

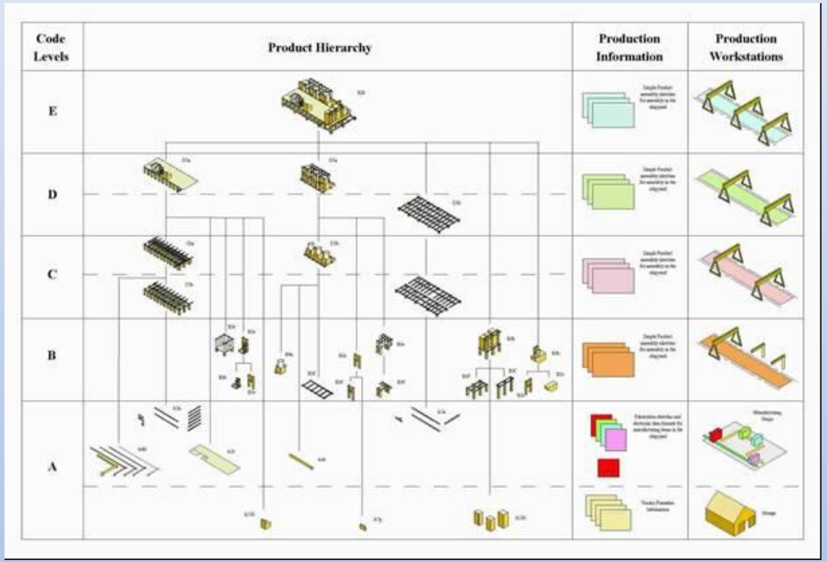
Structural Interim Products

Zone/Block Types	Description
Bow	Bow Zone
Bottom-dbl-3d-curve	
Deck-2d-flat	
Bulkhead	
Machinery	Machinery Zone
Bottom-dbl-2d-curve	
Side-dbl	
Deck-2d-flat	
Bulkhead	
Cargo	Mid Body Zone
Bottom-dbl-2d-curve	
Side-dbl	
Deck-2d-flat	
Bulkhead	
Deck House	Deck House Zone
Side-dbl	
Side-sgl	
Bulkhead	
Deck-2d-flat	
Stern	Stern Zone
Bottom-dbl-3d-curve	
Block-else	
Deck-2d-flat	

Estimating the Cost of Ships
By Product and Stage

Typical Shipyard Manufacturing Process Lanes – Stages of Construction

A	B	C	D	E	
Warehouse	**Fabrication**	**Sub-Assembly**	**Panel Assembly**	**Unit Assembly**	**Unit Erection**
Plate	PL – 3 Axis CNC	M/T Fabrication	Light Panel Assy Line	MR Lower	MR Lower
Profile	PL – 2 Axis CNC	Beam/Girder SA	Heavy Panel Assy Line	MR Upper	MR Upper
Pillars/Beams	PL – Flame Planner	Curved Web SA	Block Assy Line	Hull Lower	Hull Lower
	Profile – Robotic	Bhd./Flat SA	Shell Panel Assy	Hull Upper	Hull Upper
	Profile – Manual	Lg. Bhd./Flat SA	Custom Assy	Superstructure	Superstructure
		Custom SA		Double Hull	Double Hull
				Cargo	Cargo
				Bow/Stern	Bow/Stern
Graphic Courtesy of Peter Jaquith					



Labor Content for a Typical Curved Inner Bottom by Process Lane

Block Type	SOC	Description	UoM	WBS Group	WBS Acct	Zone	Work Center	Labor rate
bottom-dbl-2d-curve	1	Fabrication	KG	1	110		ST-FB	0.03
bottom-dbl-2d-curve	2	Assembly	KG	1	110		ST-AS	0.0177
bottom-dbl-2d-curve	3	Sub Assembly	KG	1	110		ST-SA	0.0058
bottom-dbl-2d-curve	4	Block Assembly	KG	1	110		ST-WD	0.0088
bottom-dbl-2d-curve	5	Erection	KG	1	110		ST-ER	0.0183
bottom-dbl-2d-curve	6	Production Services	KG	9	900		PS	0.0248

While we show weight as the UoM, it could be any UoM. We often see meters of weld as an alternate metric.

Estimating the Cost of Ships
Outfit Density

Ship Type: Monohull		
Offshore Patrol Vessel		
Ship Characteristics	**Metric Units**	
LOA, Length Overall	109.73	M
LWL, Length Waterline	103.73	M
Beam, Molded	16.38	M
Depth, Molded	8.08	M
Draft, Design Full Load, Molded	5.03	M
Cubic Number (LWL x Beam x Depth)	13,727	CUNO(M)
SVI, Ship Volume Indicator (LWL x Beam x Draft)	8,547	CUM
Cb, Block Coefficient	0.4362	COEF
SDI, Ship Displacement Indicator (Cb x SVI)	3,728	CUM
Estimated Wetted Surface Area	2,049	M2
Length of Machinery Space	30.17	M
Height of Machinery Space	6.07	M
Volume of Machinery Space	2,941	CUM
Superstructure Deck Area	1,167	SQM
Volume of Superstructure	3,798	CUM
No. Decks of Superstructure (Incl roof over upper bridge deck)	3	
Number Decks Below Weather Deck	2.00	
Number of Transverse Bulkheads	16.00	
Number of Longitudinal Bulkheads	-	
Total Areas of Below Decks OMS	3,399	SQM
Volume Below Decks OMS	10,197	CUM
Average Deck Heights	3.00	M

SWBS		Volume (M3)	Weight (MT)	Displacement (M3)	OD	Productivity Factor
2	Propulsion (less Stern outfit weight)	2,941	258	252	0.0857	1.0872
3	Electrical (only machinery weight)	2,941	157	153	0.0519	1.0519
4	Electronics	3,798	65	64	0.0167	1.0165
5	Auxiliary Systems (only machinery weight)	2,941	174	170	0.0577	1.0579
6	Outfit (less Exterior Paint weight)	3,798	244	238	0.0628	1.0632

If we assume a majority of the outfit for SWBS groups 2,3, and 5 will be in the machinery zone, less some outfit located I other areas, then we can calculate the OD for those SWBS groups. Using a similar assumption for SWBS 4 and 6 being contained in the Deckhouse we can do the same.

	M3	%	OD	Productivity Factor
Ship Volume (Molded)	8,547		0.1618	1.1710
Machinery Volume	2,941	34%	0.1574	1.1660
Deck House Volume	3,798	44%	0.0446	1.0445
Stern and Bow	1,808	21%	0.0255	1.0252

Looking at the Outfit Density (OD) for the ship based on the Light Ship Weight, we note a value of 0.16 M3 of Outfit per M3 of volume for the ship. If the OD for the whole ship is used we see that the machinery zone is more dense. We also note that if this value is used then we would over estimate the SWBS Groups.

Recent PODAC Cost Model Use
National Shipbuilding Research Program (NSRP)

- National Shipbuilding Research Program (NSRP)
  - NSRP Project RA2017-443, Ship Structural Design Optimization (SSDO) for Improved Producibility and Enhanced Life-Cycle Performance. This project has been completed and the results are available via NSRP.
  - NSRP Project RA 21-11 - Minimize Work Content in Production and Maintenance and Reduce TOC Using Early-stage Structural Design Optimization. This project is on going.

Recent PODAC Cost Model Use NSRP

- NSRP Project RA2017-443, Ship Structural Design Optimization (SSDO) for Improved Producibility and Enhanced Life-Cycle Performance.
  - Developed a Large Surface Combatant (LCS)Cost Model.
  - Using that CEM performed structural trade-off studies based on various Stages of Construction (SOCs) changes based on Lean Design Principles and Producibility.
  - Shows a Life Cycle Cost savings for Structure.

Recent PODAC Cost Model Use
NSRP

Groups C, D and E Savings/ROI	
Notional 14,000-ton Large Surface Combatant [DDG(X)]	
Category C. Material Savings	
- 5% savings in material costs resulting from reduced plate and profile variation and use of mill runs vs. warehouse suppliers.	
Total structural material costs (single ship)	$18,250,000.00
5% material cost savings (per ship)	$912,500.00
Category D. Construction Savings	
- 12% reduction in total steel fabrication and assembly cost based on reduced weld length, fewer interestions, use of automation, lean design priciples.	
Total structure fabrication cost (single ship)	$66,500,000.00
12% reduction in structure fabrication cost savings (per ship)	$7,980,000.00
Category C + Category D Per Ship Cost Savings	$8,892,500.00
EROM @ two ships per year for 5 year return period, total savings	$88,925,000.00
Navy/NSRP Investment in RA Project	$1,139,695.00
Cat. C + D: Navy ROI for NSRP Project (Savings - Navy Investment)/Navy Investment	**77**
Category E. Structural Repair Savings	
RAND Reported 2003-2015 SWBS 100 Repair/Maintenance Cost	$3,050,000,000
Per Year Average SWBS 100 Repair/Maintenance Cost	$254,166,667
Rounded Per Year Average SWBS 100 Repair/Maint. Cost	$250,000,000
Assume save 7% per year of 2003-2015 SWBS 100 Costs	$17,500,000
EROM @ 7% Savings over 5 Years	$87,500,000
Category E: ROI for 7% In-Service Savings Only	**76**

Cells C9 and C14 are updated with a simple average of the Material and Fabrication costs from SPAR in columns I-L.

Material Cost		**Reduced Shapes**	
w/Distributor	**Mill Cost (100%)**	**by 50% (Dist)**	**Mill Cost**
$ 19,741,356	**$ 16,758,091**	**$ 18,573,992**	**$ 15,785,287**
Savings	**-17.8%**		**-6.2%**
			$ 2,788,705
Buy all steel from Distributor	Buy all steel from mill.	Reduce the # of shapes by 50% and buy them from a distributor	Reduce the # of shapes by 50% and buy them from mill

Labor	**Mat**	**Total**	**Savings**
$ 48,758,808	$ 15,785,287	$ 64,544,095	**$ 7,745,291**
$ 48,758,808	$ 19,741,356	$ 68,500,165	**$ 8,220,020**
			As done today

Hull Maintence (Current Process)	
Every 15 Years	Life of Ship (30 Years)
$ 8,132,340	$ 243,970,187

By reducing the number of shapes and plate sizes along with design changes, the LSC CEM showed a significant Life Cycle Cost Savings/ Avoidance for structure.

A software interface was groomed and successfully tested from the MAESTRO structural model to SPAR's LSC cost model providing an important capability to leverage existing work content cost estimating relationships, and which can also be utilized in early-stage design to drive improved designs. Structural Affordability metrics were successfully demonstrated.

Thank you for your attention this concludes the presentation

Questions?