Acquisition Research Program:
Creating Synergy for Informed Change

Benchmarking Naval Shipbuilding with 3D Laser Scanning, Additive Manufacturing, and Collaborative Product Lifecycle Management

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The DON Shipbuilding Challenge

- **Target**: Grow from 289 to 306 battle force fleet in 30 years
- **Required shipbuilding:** 264+ ships, including replacements
- **Average shipbuilding cost:** $16.7b / year (2014$)
- **Shrinking budgets**
- **Evolving threats**
- **Advancing technologies**

A Technology Adoption Challenge

- Cost constrained DoD environment requires cost reduction
- Threats require US military to retain technological superiority
- Complex technology acquisition process
- **Improved shipbuilding through technology adoption and implementation has the potential to successfully addressing these needs.**

Research Context

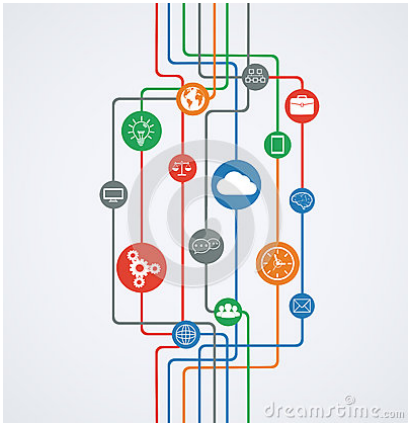
Problem: Scale of potential savings in shipbuilding is needed for technology adoption decision-making and planning.

This research estimates the potential savings of adopting and implementing three advanced technologies for naval shipbuilding.

- Product Lifecycle Management
- 3D laser scanning
- Additive Manufacturing (3D printing)

Advanced Technology:

Product Lifecycle Management (PLM)



- An integrated, information-driven approach of people, processes/practices & technology from design through manufacture, deployment & maintenance, removal, and final disposal (based on Greives, 2006)
- Electronically integrates design documents, data bases, 3D LST, etc., for participant collaboration across physical distances and time
- Common, shared sets of documents improves access, collaboration, coordination, communication
- Common platform for program change management
- **Example application industries:**
  - Consumer goods - Machinery - Automotive
  - High tech - Aero & defense

Advanced Technology:

3D Terrestrial Laser Scanning

- Laser scans space from highly articulated mount, often combined with 360^{o} camera
- Software processes points into 3D image of the space. Processed into CADD format
- Currently used in automotive, offshore construction and repair, civil and transportation, building construction, fossil fuel and nuclear power plants
- **Example naval uses:**
  - Shipcheck scans ship as-built interior ship spaces for retrofit & upgrades. Est. 37% cost & 39%time savings
  - Naval Undersea Warfare Center reverse engineers complex parts for competitive bidding when OEM designs are unavailable

Potential Technology:

Additive Manufacturing ("3D Printing")

- 3D design/image of final part.
- Geometric slicing of image into horizontal layers for manufacturing
- Incrementally add small amounts of material in very thin layers of material to build-up part
- Variety of possible materials (plastic, titanium) & methods (e.g. for material bonding)
- No dominant method, materials, suppliers
- **Example Armed Forces uses:**
  - US Army AM lab deployment to Afghanistan (2012)
  - 70 Naval research projects (up to 65% cost savings)

Research Approach

1. Collect data on use of advanced technologies.
2. Build simulation model of naval shipbuilding
3. Describe potential applications of technologies to naval shipbuilding
4. Simulate steady-state shipbuilding without and with technology adoption and use
5. Build Knowledge-Value-Added models of shipbuilding, using simulated completion rates to simulate Returns-on-Investment (ROI)
6. Use Returns-on-Investment to estimate costs and thereby cost savings of technology adoption and use

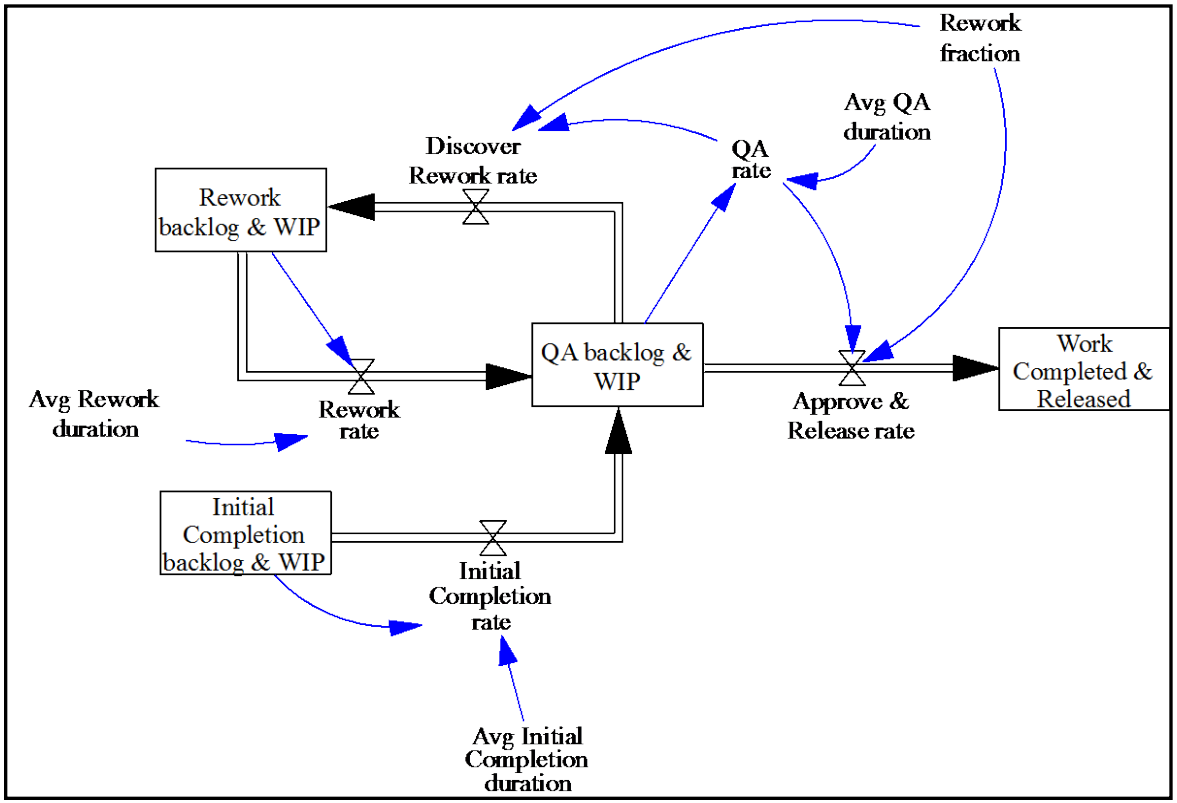
A Simulation Model of Naval Shipbuilding

Shipbuilding Phases (Based on GAO-14-122, 2013)

- Concept design
- Detailed engineering design
- Pre-construction planning
- Block fabrication
- Assembly and outfitting of blocks
- Keel laying and block erection
- Pre-delivery final outfitting
- System testing and commissioning
- Sea trials
- Post-delivery final outfitting
- Post-delivery tests and trials
- Post shakedown availability

A Simulation Model of Naval Shipbuilding

Work moving through a Single Phase



Simulating Shipbuilding: Drivers and Constraints on Shipbuilding Operations in a Single Phase

Potential Applications of Advanced Technologies to Naval Shipbuilding

- Integrated Ship Development
- Design & construction document management
- Prototype generation
- Final parts manufacturing
- Manufacturing inspection
- Radio Frequency Identification (RFID)
- Animated Instructions
- Construction inspection

Examples…

Potential Applications of Advanced Technologies to Naval Shipbuilding: Examples

- **Manufacturing inspection**
  - 3D images of parts are electronically compared to CADD designs to confirm compliance of manufacturing with designs or identify anomalies
  - Reduces inspection times and labor costs
  - Primarily uses 3D LST
  - Benefits are leveraged by the application of Product Lifecycle Management
- **Animated Instructions:**
- CADD drawings used to create animated and annotated “movies” of construction or testing operations
- Viewed (e.g. on a tablet) and used in the field by the construction workforce
- Provides rich information (designer intent, access routes, potential pitfalls and solutions) – reduces required skills & labor costs & operation durations
- Reduces rework
- Primarily uses PLM with the design documents and construction plans

Potential Applications of Advanced Technologies to Naval Shipbuilding

		Advanced Technology		
		3D Laser Scanning Technology	Additive Manufacturing	Product Lifecycle Management
Shipbuilding Phase	Concept design		Prototype generation	Integrated ship development Design & construction document management
	Detailed engineering design		Prototype generation	Integrated ship development Design & construction document management
	Pre-construction planning			Integrated ship development Design & construction document management
	Block fabrication	Manufacturing inspection Construction inspection	Final parts manufacturing	Integrated ship development Design & construction document management Final parts manufacturing RFID Animated instructions Construction inspection
	Assembly & outfitting of blocks	Manufacturing inspection Construction inspection	Final parts manufacturing	Integrated ship development Design & construction document management Final parts manufacturing RFID Animated instructions Construction inspection
	Keel laying & block erection:	Manufacturing inspection Construction inspection	Final parts manufacturing	Integrated ship development Design & construction document management Final parts manufacturing RFID Animated instructions Construction inspection
	Pre-delivery final outfitting	Manufacturing inspection Construction inspection		Integrated ship development Design & construction document management RFID Animated instructions Construction inspection
	System testing & commissioning	Animated shipbuilding instructions		Integrated ship development Design & construction document management Animated instructions
	Sea trials			Integrated ship development Design & construction document management
	Post-delivery final outfitting	Manufacturing inspection Construction inspection		Integrated ship development Design & construction document management RFID Animated instructions Construction inspection
	Post-delivery tests & trials			Integrated ship development Design & construction document management Animated instructions
	Post shakedown availability			Integrated ship development Design & construction document management

Mapped technology applications to shipbuilding phases

Estimated impacts of each application on shipbuilding operations.

Simulated shipbuilding completion rates.

Naval Shipbuilding Simulation Results

		AVERAGE COMPLETION RATE (work packages / day)	
		As-Is Scenario	To-Be Scenario
Shipbuilding Phase	Concept design	0.593	0.8958
	Detailed design	3.115	4.454
	Preconstruction planning	1.407	1.741
	Block fabrication	3.084	9.302
	Block assemby and outfitting	2.865	11.61
	Keel laying and block erection	3.439	13.53
	PreDelivery outfitting	3.439	13.53
	System testing	2.047	3.508
	Sea trials	6.34	6.896
	PostDelivery outfitting	3.273	13.27
	PostDelivery tests	1.827	1.963
	PostShakedown maintenance	1.827	1.963

Average Completion Rates of Shipbuilding Phases for As-Is and To-Be Scenarios

Used simulation output as input to Knowledge Value Added (KVA) models (As-Is and To-Be).

KVA models used to estimate returns on investment for shipbuilding without & with technologies.

Knowledge Value Added Models of Shipbuilding

Returns on Knowledge (ROK) and Returns on Investment (ROI)

AS IS			
		ROK	ROI
Shipbuilding Phase	Concept design	98%	-2%
	Detailed design	661%	561%
	Preconstruction planning	318%	218%
	Block fabrication	33%	-67%
	Block assemby and outfitting	83%	-17%
	Keel laying and block erection	37%	-63%
	PreDelivery outfitting	605%	505%
	System testing	380%	280%
	Sea trials	1118%	1018%
	PostDelivery outfitting	576%	476%
	PostDelivery tests	339%	239%
	PostShakedown maintenance	321%	221%
	TOTALS	**235%**	**135%**

KVA Model Results for As-Is Scenario

TO BE				
		ROK	ROI	Automation Tools
Shipbuilding Phase	Concept design	194%	94%	AM, PLM
	Detailed design	1926%	1826%	AM, PLM
	Preconstruction planning	344%	244%	PLM
	Block fabrication	69%	-31%	3DLS, AM, PLM
	Block assemby and outfitting	216%	116%	3DLS, AM, PLM
	Keel laying and block erection	101%	1%	3DLS, AM, PLM
	PreDelivery outfitting	1370%	1270%	3DLS, AM, PLM
	System testing	682%	582%	3DLS, PLM
	Sea trials	1061%	961%	PLM
	PostDelivery outfitting	1343%	1243%	3DLS, AM, PLM
	PostDelivery tests	382%	282%	PLM
	PostShakedown maintenance	301%	201%	PLM
	TOTALS	**564%**	**464%**	

KVA Model Results for To-be Scenario

Impacts of Technologies on Shipbuilding Returns on Investment (ROI)

		As-is ROI	To-be ROI	Change in ROI	Automation Tools
Shipbuilding Phase	Concept design	-2%	94%	96%	AM, PLM
	Detailed design	561%	1826%	1265%	AM, PLM
	Preconstruction planning	218%	244%	25%	PLM
	Block fabrication	-67%	-31%	36%	3DLS, AM, PLM
	Block assemby and outfitting	-17%	116%	133%	3DLS, AM, PLM
	Keel laying and block erection	-63%	1%	64%	3DLS, AM, PLM
	PreDelivery outfitting	505%	1270%	764%	3DLS, AM, PLM
	System testing	280%	582%	301%	3DLS, PLM
	Sea trials	1018%	961%	-57%	PLM
	PostDelivery outfitting	476%	1243%	767%	3DLS, AM, PLM
	PostDelivery tests	239%	282%	42%	PLM
	PostShakedown maintenance	221%	201%	-20%	PLM
	TOTALS	135%	464%	329%	

Changes in Return on Investment due to Use of Three Technologies

Estimating Shipbuilding Costs and Cost Savings

ROI = (Benefits – Costs) / Costs

Cost (As-is) = Benefits (As-is) ÷ (ROI (As-is) + 1)
Cost (As-is) = 1,200 ÷ (1.3546 + 1)
Cost (As-is) = $509.64 Million
Cost (To-be) = Benefits (To-be) ÷ (ROI (To-be) + 1)
Cost (To-be) = 1,200 ÷ (4.6409 + 1)
Cost (To-be) = $212.73 Million

Estimated Savings:

$509.64m – $212.73m = **$296.91m saved per ship**

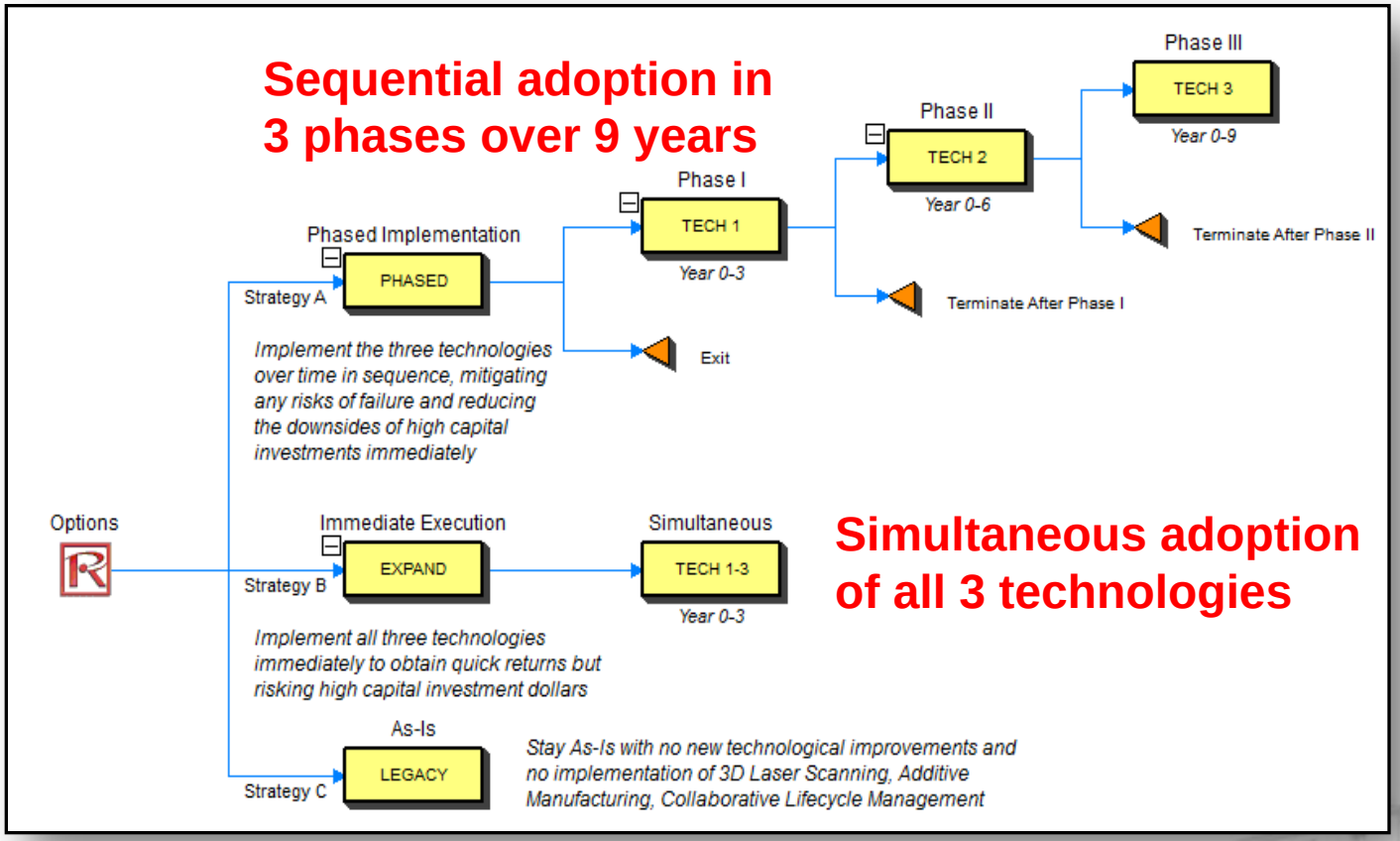
$296.91m / $1,200m = **24.74% savings to DON**

Estimating Shipbuilding Costs and Cost Savings

- Savings estimate is conservative compared to results of industry adopters (e.g. >30% cost savings for 3D LST alone and up to 80% for AM)

- **Estimated Annual Potential Savings:**
  $296.9m/ship × 264 Ships ÷ 29 Years = $2.70b/yr

Integrated Risk Management and Strategic Real Options Analysis



No technology adoption (As-Is)

Strategic Real Options

Integrated Risk Management and Strategic Real Options Analysis

From KVA results

As-Is Cost	$	509,642,661
To-Be Cost	$	212,733,874
To-Be Cost Savings	$	296,908,787
To-Be Immediate Strategic Value	$	337,632,796
To-Be Sequential Strategic Value	$	370,736,221
Number of Ships		264
Number of Years		29
To-Be Sequential (Strategy A) Strategic Value	$	3,374,978,008
To-Be Immediate (Strategy B) Strategic Value	$	3,073,622,690
To-Be Strategy (Base Case) Strategic Value	$	2,702,893,785

Opton Values (value of flexibility)
$672m/yr
$371m/yr
$0 (As-Is)

Summary of Strategic Values

Conclusions

- US Navy can save an average of over $2.70b/year over 29 years with full adoption and implementation of 3DLST, PLM, and AM, ***regardless of the implementation approach***
- **Strategy 1**: Sequential Adoption and Implementation
  - Increases savings by $672m/yr to $3.38b/year
  - Adds flexibility to abandon
  - Requires larger budget
  - Can absorb more uncertainties
- **Strategy 2:** Simultaneous Adoption and Implementation
  - Increases savings by $371m/yr to $3.07b/year
  - Accelerates capture of benefits

Implications

- Savings assessment will help decision-makers choose how much, when, and how to exploit the benefits and minimize costs of advanced technology adoption and implementation for shipbuilding.
- **Future research:**
  - Collect and apply more specific parameter values for improved model calibration
  - Specific decision-maker flexibility and inherent implementation options can be determined and modeled in more detail to provide specific implementation recommendations.

Questions
Comments
Discussion