SYM-AM-24-065

Excerpt from the Proceedings of the Twenty-First Annual Acquisition Research Symposium

Acquisition Research: Creating Synergy for Informed Change

May 8–9, 2024

Published: April 30, 2024

Prepared for the Naval Postgraduate School, Monterey, CA 93943.

The research presented in this report was supported by the Acquisition Research Program at the Naval Postgraduate School.

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System Product Line Cost and Investment Modeling Applied to UUVs

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Abstract

Integrated cost and product modeling applied to the acquisition of unmanned underwater vehicles (UUVs) demonstrated the economic benefits of a product line strategy. The modeling framework includes system modeling language (SysML) for product modeling and a constructive cost model set. The constructive product line investment model (COPLIMO) framework was used for return on investment (ROI) analysis with the constructive systems engineering cost model (COSYSMO) for single system investment and reuse costs. Cost model inputs were extracted directly from the SysML requirements and executable activity models for the UUVs. Model integration reduces effort since only product modeling is performed without the need for independent cost modeling expertise.

The case study research investigated the reduction of acquisition costs applying the integrated product line acquisition model for UUV missions with overlapping requirements. The key research question focused on the ROI of a product line approach for UUV systems developing a baseline architecture for reuse. Supporting questions addressed the reuse savings for individual UUV systems, the size and complexity of the resulting system, and their estimated effort. Results indicate a strong ROI when using a product line approach for UUV systems.

Keywords: product lines, economics, COPLIMO, COSYSMO, cost modeling, ROI, UUV, systems engineering

Introduction

The product line engineering concept (PLE) integrates well with the adaptive acquisition framework introduced in the fall of 2020. Because the PLE is based on the concept of a common platform that can be used to develop a family of products It offers the capability to reduce acquisition cost and “time to market.” PLE is based on a two–life cycle model That integrates the domain of interest with relevant applications. This facilitates the development of systems through the identification of commonalities and system variabilities. This premise is the basis for the application of the constructive product line investment model (COPLIMO) framework to case studies with the intent of developing a viable cost modeling methodology that would support the adaptive acquisition framework.

Active student research (group capstones and individual theses) on combat system product line architectures and costs using model-based systems engineering (MBSE) methods with COPLIMO variants have been applied and extended across Naval domains at NPS (Table 1).

Table 1. Naval Case Studies

System Case Study	Sizing Unit(s)	Equivalent Size Adjustments	Reuse and Investment Model	MBSE Models	Empirical Data Used	Baseline System Size for Analysis
Cruise Missile Tiers	system component	reuse category	Basic COPLIMO	OVM, data flows	subsystem costs	20 subsystems
Aegis Ship Software	lines of code	reuse category	Basic COPLIMO		variant lines of code variant cost savings	2.35 MSLOC

ASW Combat System Cross-domain	system component lines of code	reuse category	Basic COPLIMO	Requirements models, OVM	system costs system lines of code	18 system components 2.1 MSLOC
DoN UUV Missions	system requirements system interfaces	reuse category complexity level	COSYSMO 2.0	Requirements models activity models		57 system requirements 14 system interfaces
Mine Counter Measure UUVs	system requirements system interfaces	reuse category complexity level	COSYSMO 2.0	OVM		16 system components

Known cost models were adapted for different system types, processes, and estimation relationships at the systems and software levels. The basic reuse and investment model was supplanted with alternate cost models relevant to the system types under consideration. This was supported by the development of an integrated method for representing architectural variants using orthogonal variability modeling (OVM) to enumerate parametric inputs for COPLIMO.

The rest of this paper will present an overview of the cost modeling followed by a more detailed explanation of the case studies presented in Table 1.

Cost Modeling

The two basic cost models used are the COSYSMO model and the COPLIMO model. The COSYSMO model inputs for system size include requirements and interfaces classified by reuse category and complexity. It uses size weights to account for the relative effort for the reuse categories: New, Designed for Reuse, Modified, Deleted, Adopted, and Managed. The complexity levels also have equivalent size weights for Easy, Nominal, and Difficult ratings.

COPLIMO provides a trade space for determining initial investment and future return on investment (ROI) for product line systems versus non-product line systems. Product line investment models must address two sources of cost investment or savings which were afforded by COSYSMO in this approach. The relative cost of developing product lines is the added effort of developing flexible product line architectures to be most cost-effectively reused across a product line family of applications, relative to the cost of developing a single system. In COSYSMO, this investment cost is captured in the Designed for Reuse category.

The relative cost of reuse is the cost of reusing system architecture in a new product line family application relative to developing new systems. COSYSMO has the categories for Reuse, Modified, Deleted, Adopted, and Managed to quantify the relative costs compared to the New category.

The model size inputs were extracted from the product models for each mission type. Each requirement and interface in the models were further tagged for reuse category and complexity level. The COSYSMO size weights are then applied in the estimation tools.

Model outputs provide decision makers with essential information on product line savings, investment, ROI, cost per mission type, and savings per mission type. It supports the initial investment decision as well as a starting point for planning the individual system developments. The cost and schedule of each system is already estimated and can be planned over time per the mission needs.

Table 18. ROI Analysis for RCDR 1.5 through Six Architecture Alternatives

	Eq. Size - Reuse Model	Non-Reuse Size	PL Effort Savings	Cumulative Savings	ROI	Cumulative ROI
Alternative 1 (Baseline)	23.50	16	-7.50	-7.50	-1.00	-1.00
Alternative 2	3.20	17	13.80	6.30	1.84	0.84
Alternative 3	4.20	18	13.80	20.10	1.84	2.68
Alternative 4	3.80	17	13.20	33.30	1.76	4.44
Alternative 5	4.20	18	13.80	47.10	1.84	6.28
Alternative 6	5.20	19	13.80	60.90	1.84	8.12
PL Reuse Investment	7.5					

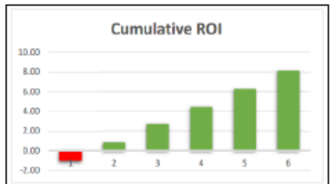


Figure 51. Cumulative ROI for RCDR 1.5

Table 19. ROI Analysis for RCDR 1.6 through Six Architecture Alternatives

	Eq. Size - Reuse Model	Non-Reuse Size	PL Effort Savings	Cumulative Savings	ROI	Cumulative ROI
Alternative 1 (Baseline)	25.00	16	-9.00	-9.00	-1.00	-1.00
Alternative 2	3.20	17	13.80	4.80	1.53	0.53
Alternative 3	4.20	18	13.80	18.60	1.53	2.07
Alternative 4	3.80	17	13.20	31.80	1.47	3.53
Alternative 5	4.20	18	13.80	45.60	1.53	5.07
Alternative 6	5.20	19	13.80	59.40	1.53	6.60
PL Reuse Investment	9.0					

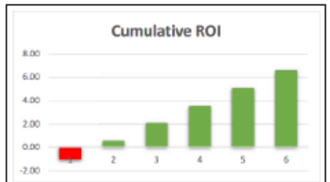


Figure 52. Cumulative ROI for RCDR 1.6

Table 20. ROI Analysis for RCDR 1.8 through Six Architecture Alternatives

	Eq. Size - Reuse Model	Non-Reuse Size	PL Effort Savings	Cumulative Savings	ROI	Cumulative ROI
Alternative 1 (Baseline)	28.00	16	-12.00	-12.00	-1.00	-1.00
Alternative 2	3.20	17	13.80	1.80	1.15	0.15
Alternative 3	4.20	18	13.80	15.60	1.15	1.30
Alternative 4	3.80	17	13.20	28.80	1.10	2.40
Alternative 5	4.20	18	13.80	42.60	1.15	3.55
Alternative 6	5.20	19	13.80	56.40	1.15	4.70
PL Reuse Investment	12.0					

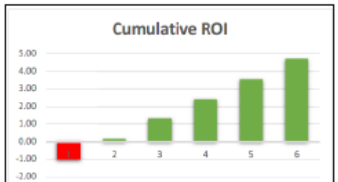


Figure 53. Cumulative ROI for RCDR 1.8

Basic COPLIMO

The basic version of COPLIMO supports software product line cost estimation and ROI analysis within the scope of the product line life cycle. Basic COPLIMO shown in Figure 1 consists of two components:

- Product line development cost model
- Annualized post-development life cycle extension

The model is based on the COCOMO II software cost model and has been statistically calibrated to 161 projects, representing 18 diverse organizations.

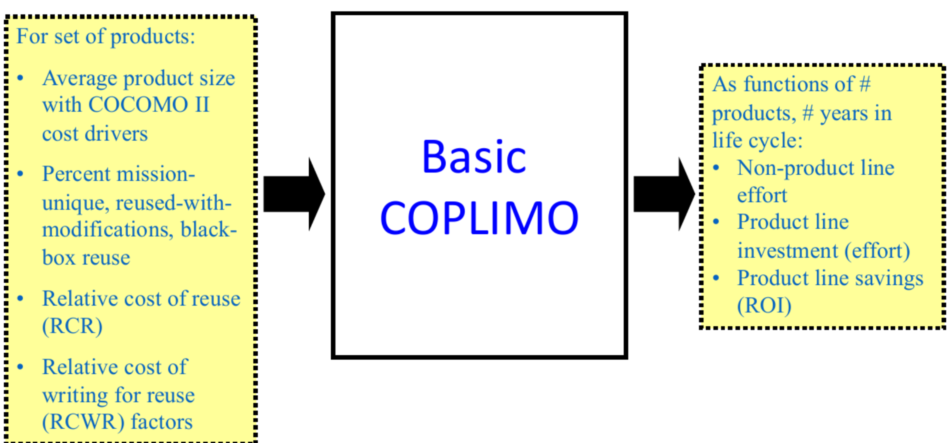


Figure 1. Basic COPLIMO

Table 2 is a list of extensions that have been made to basic COPLIMO.

Table 2. Basic COPLIMO Extensions

- Separate factors for calculating software RCR
  - Design, code, test fractions modified
  - Software understanding, assessment factors
- Separate factors for calculating software RCWR
  - Reusability, reliability, documentation
- Full set of COCOMO II cost drivers
- Maintenance and life cycle cost estimation
- Components with different sizes, RCR, RCWR factors
- Present-value discounting of future savings
- Monte Carlo probability distributions

System Product Line Investment Model

Figure 2 presents the system product line investment model. It differs from the Basic COPLIMO model in that the results are based on the product line total ownership costs and the product line flexibility investment. The model uses generic system components for software and hardware, size-based modeling or direct cost, annual change cost, and full life cycle total ownership cost.

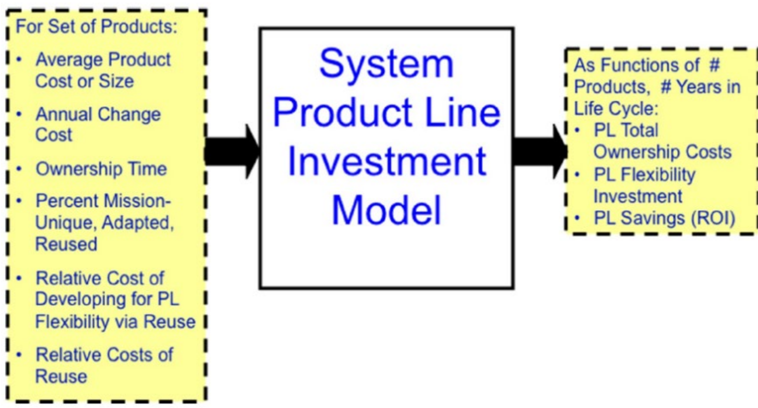


Figure 2. The System Product Line Investment Model

Selected Cost/ROI Modeling Tools

Figure 3 presents selected cost and return on investment modeling tools.

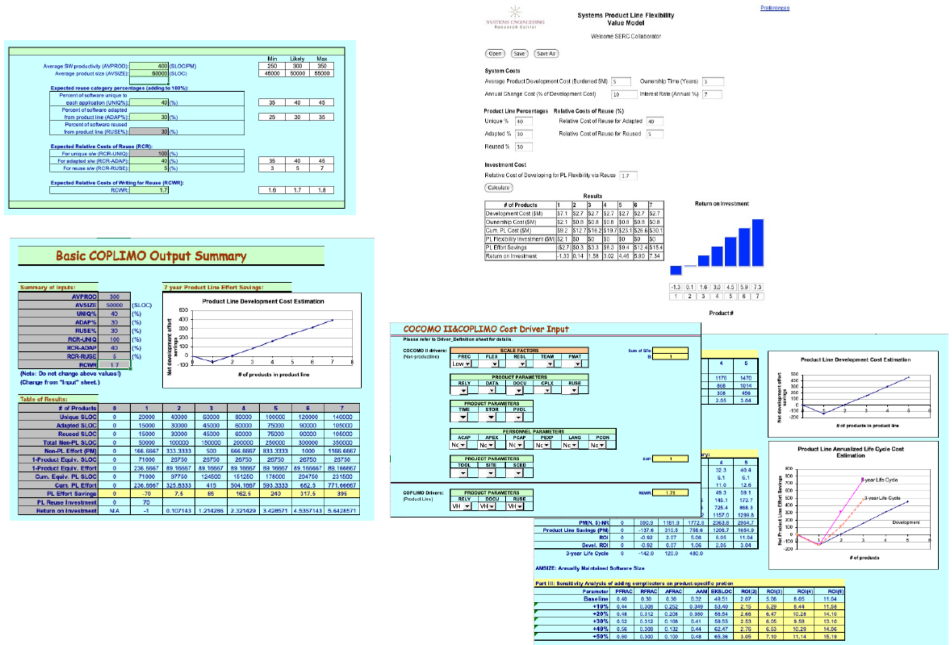


Figure 3. Selected Cost and Return on Investment Modeling Tools

Of interest is the tool in the upper right corner of Figure 3. Known as the Systems Product Line Flexibility Value Model, one can adjust system costs, product line percentages, and the relative cost of reuse to see how they impact ROI. A larger version of Figure 3 is shown in Figure 4.

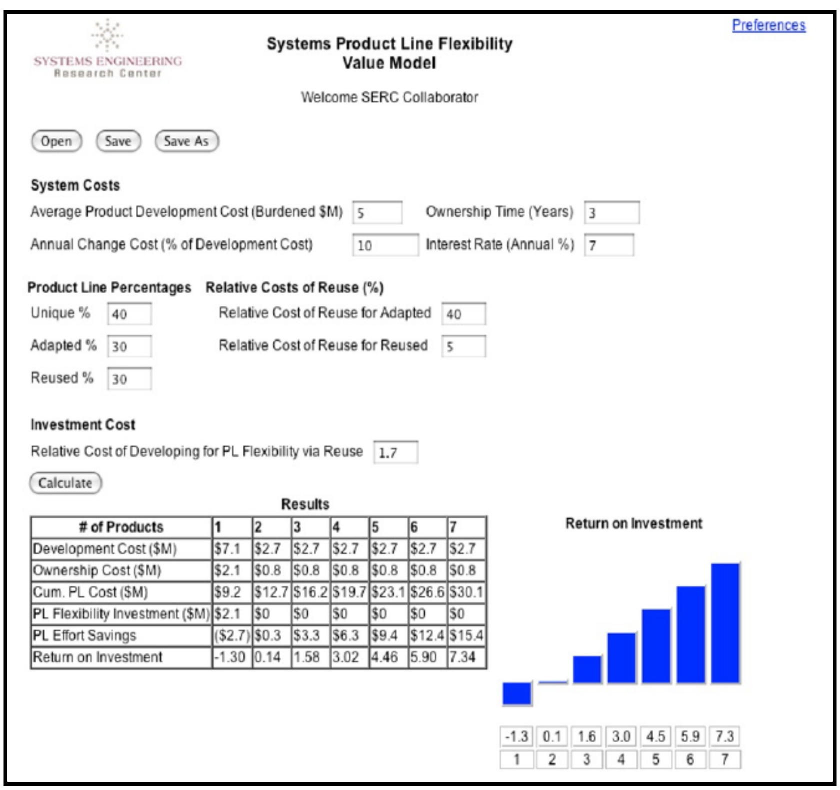


Figure 4. Systems Product Line Flexibility Value Model
(http://coplimo.org/tools/flexibility)

Case Studies

The following section provides an overview of the case studies shown in Table 1. Each of the case studies is readily available through the NPS institutional archive: Calhoun (https://library.nps.edu/nps-archive).

Combat Systems Product Lines

The approach to the initial case study used a domain-specific model-based system engineering (MBSE) framework focused on a reference architecture of a general combat system product line. The MBSE approach was integrated with COPLIMO for size inputs derived from the MBSE models including OVM.

Specifically, the reference architecture was based on an underlying detect-control-engage architecture. This top-level functional architecture was then allocated to mission-specific system components which were assessed for reuse. The OVM model was used to quantify change percentages for new, modified, and deleted components. The method used is described below.

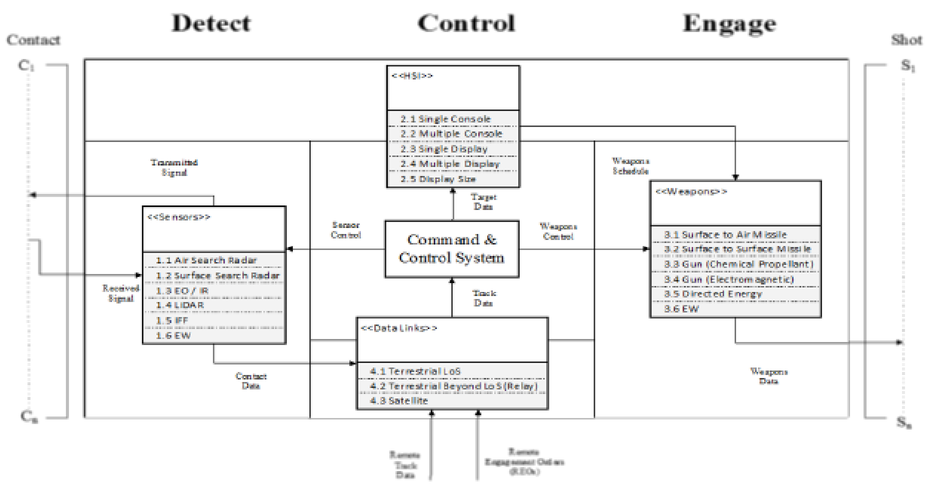


Figure 5. Generic Combat System Reference Architecture

Method Overview

Step 1: Describe a general domain model of the given system with common elements. For a combat system, the architecture includes sensors, weapons, and hardware/software which are formally modeled to identify common functions and variations for different case studies.

Step 2: Develop a reference product architecture with variation points. Variation points are identified for sensors, consoles, weapons, and data links with alternative choices to serve as cost model inputs.

- Map existing systems to the reference architecture
- Collect empirical costs and map them to system elements from above

Empirical cost data from DoD programs is allocated to the system functions in the architecture models to calibrate and populate the cost model for specific system configurations. Collect empirical costs and map them to system elements from above.

Figure 6 is an example OVM from Alves' thesis (Alves, 2022). The actual OVM presents more detail.

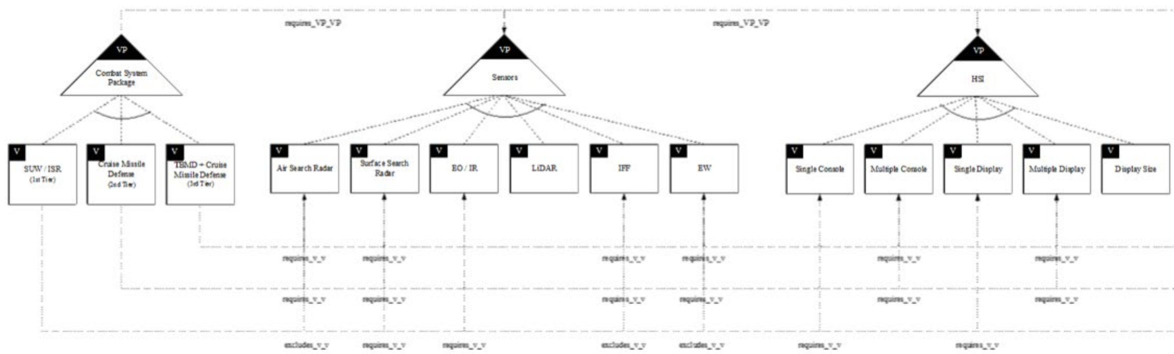


Figure 6. Example Orthogonal Variability Model (Alves, 2022)

Figure 7 is a table of the OVM symbology. Hause describes how the OVM can be used in the block definition diagram (BDD) "to define relationships between and properties of the elements which are represented on those diagrams" (Hause, 2014).

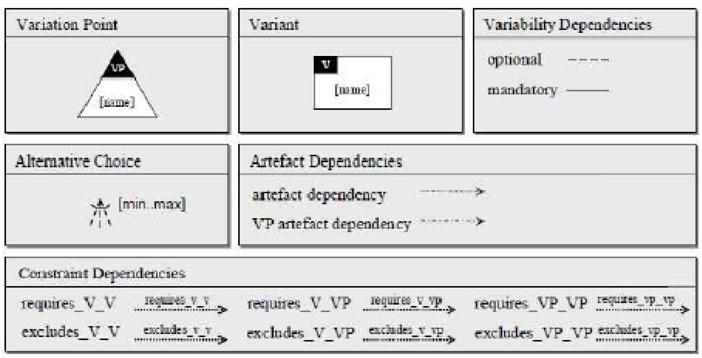


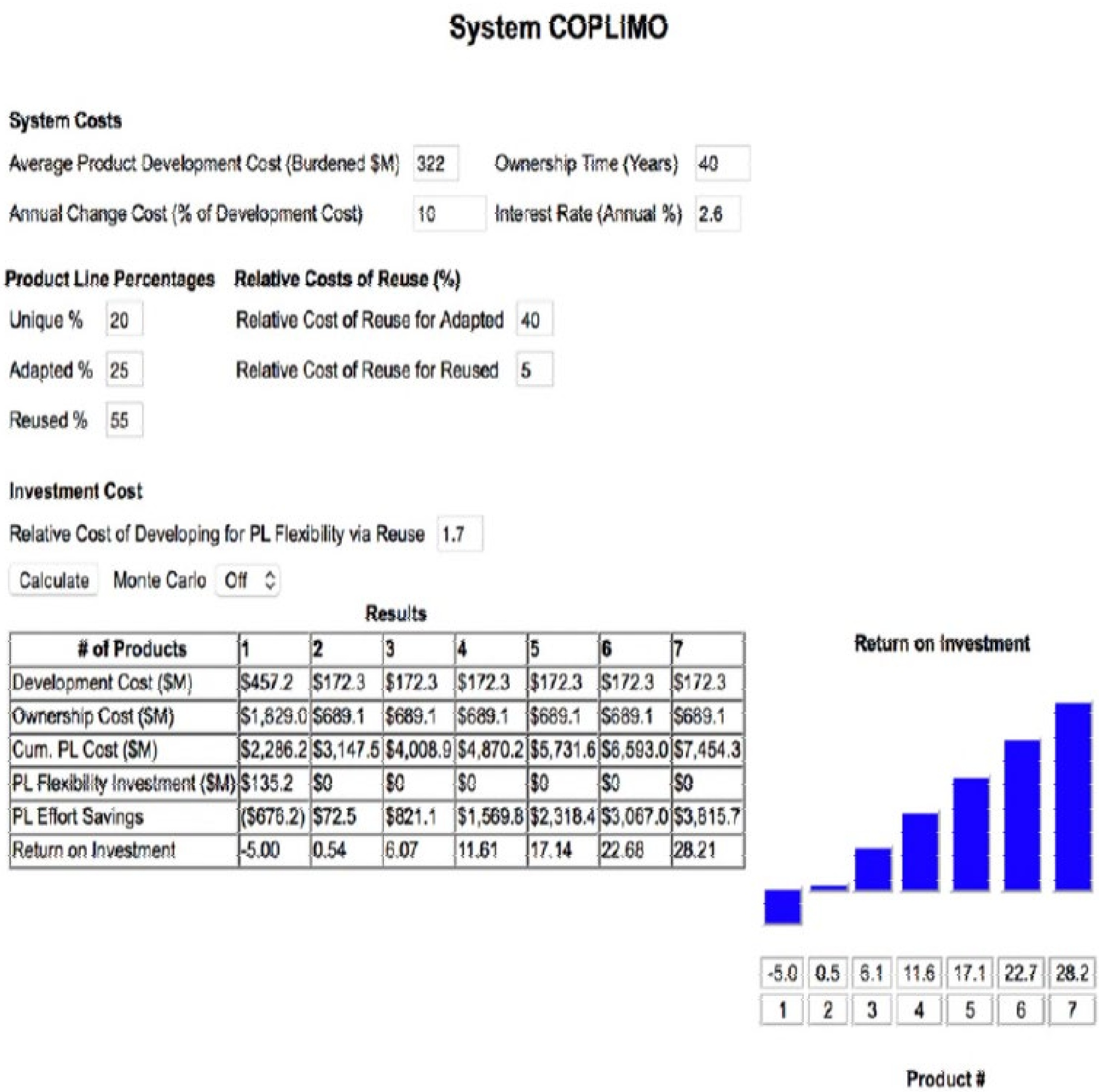
Figure 7. OVM Notation (Pohl et al., 2005)

Table 3 presents example product line components used in the case study.

Table 3. Example Product Line Components

Product Line Classification	Variant	Justification
Variation Point: Sensors		
Adapted	Air Search Radar	Power, beam forming, and search / track functions different for 2nd and 3rd tier packaged variants.
Adapted	EW	Power and physical size requirements may be different for 2nd and 3rd tier packaged variants.
Reused	Surface Search Radar	Physical size and capabilities of sensor can be used for 1st, 2nd, and 3rd tier packaged variants.
Reused	EO / IR Sensor	See Surface Search Radar justification.
Reused	LiDAR	See Surface Search Radar justification.
Reused	IFF	Hardware and interfaces are the same for 2nd and 3rd tier packaged variants.
Variation Point: HSI		
Product Line Classification	**Variant**	**Justification**
Reused	Single Console	Consoles common across 1st, 2nd, and 3rd tier packaged variants.
Reused	Multiple Console	See Single Console justification.
Reused	Single Display	Displays common across 1st, 2nd, and 3rd tier packaged variants.
Reused	Multiple Display	See Single Display justification.
Adapted	Display Size	Displays are common but size can be specified by customer.
Variation Point: Data Links		
Product Line Classification	**Variant**	**Justification**
Reused	Terrestrial LoS	Data links standardized across US and NATO platforms, therefore they will also be common across 1st, 2nd, and 3rd tier packaged variants.
Reused	Terrestrial Beyond LoS	See Terrestrial LoS justification.
Reused	Satellite	See Terrestrial LoS justification.
Variation Point: Weapons		
Product Line Classification	**Variant**	**Justification**
Mission Unique	Surface to Air Missile	Ranges and kill mechanisms are different for 2nd and 3rd tiers.
Mission Unique	Surface to Surface Missile	Ranges and size of missile different for 1st, 2nd and 3rd tiers based on mission and ship size.
Mission Unique	Gun Electro-Magnetic	Power and size constraints dependent on ship size and cost for 2nd and 3rd tiers.

Figure 8 presents example cost and ROI results for the cruise missile product line included in the case study.



# of Products	1	2	3	4	5	6	7
Development Cost ($M)	$457.2	$172.3	$172.3	$172.3	$172.3	$172.3	$172.3
Ownership Cost ($M)	$1,829.0	$689.1	$689.1	$689.1	$689.1	$689.1	$689.1
Cum. PL Cost ($M)	$2,286.2	$3,147.5	$4,008.9	$4,870.2	$5,731.6	$6,593.0	$7,454.3
PL Flexibility Investment ($M)	$135.2	$0	$0	$0	$0	$0	$0
PL Effort Savings	($676.2)	$72.5	$821.1	$1,569.8	$2,318.4	$3,067.0	$3,815.7
Return on Investment	-5.00	0.54	6.07	11.61	17.14	22.68	28.21

Figure 8. Results for Cruise Missile Product Line (Chance, 2019)

Table 4 presents the detailed COPLIMO model for the Aegis combat system as analyzed. Actual values were used in the analysis. However, the values in Table 4 are representative sizes per agreement with Lockheed Martin.

Table 4. AEGIS Combat System Detailed COPLIMO*

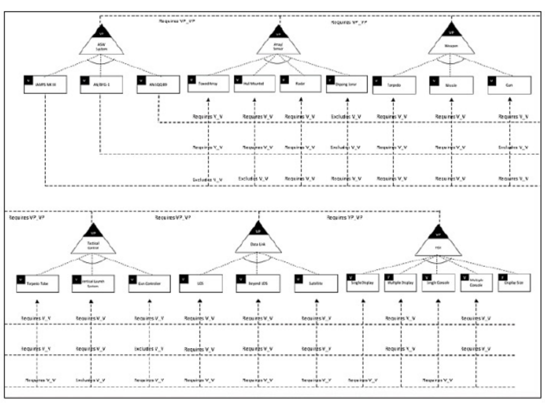
# of Products	0	1	2	3	4	5	6
Aegis Baseline		A	B	C	D	E	F*
Unique SLOC	0	100000	200000	400000	200000	400000	200000
Adapted SLOC	0	540000	570000	630000	750000	810000	930000
Reused SLOC	0	1260000	1330000	1470000	1750000	1890000	2170000
Total Non-PL SLOC	0	1900000	4000000	6500000	9200000	12300000	15600000
Total Non-PL Effort (PM)	0	11656	24540	39877	56442	75460	95706
1-Product ESLOC	0	3304000	379000	379000	379000	379000	379000
1-Product Equiv. Effort (PM)	0	20270	2325	2325	2325	2325	2325
Cum. ESLOC	0	3304000	3683000	4062000	4441000	4820000	5199000
Cum. PL Effort (PM)	0	20270	22595	24920	27245	29571	31896
PL Effort Savings (PM)	0	-8613	1945	14957	29196	45890	63810
PL Reuse Investment	0	8613	0	0	0	0	0
Per Product Non PL Effort (PM)	0	11656	12883	15337	16564	19018	20245
Per Product PL Effort (PM)	0	2325	3034	4451	3604	5021	4175
Per Product Cost Savings (PM)	0	-8613	9850	10887	12960	13997	16071
Per Product Cost Avoidance	0	-173.89%	23.55%	29.02%	21.76%	26.40%	20.62%
Cum. ROI	0	-2.00	-0.86	0.41	1.91	3.54	5.40

*Actuals were used but these are representative sizes

Cross-Domain Antisubmarine Warfare Combat Systems

This case study investigated the application of a product line model to both surface ship and submarine combat systems. Most of the software performs the same function regardless of whether the antisubmarine warfare (ASW) combat system is aboard a surface ship or a submarine. The variability is in the sensors and weapons. Current acquisition practice is to procure the ASW combat system separately from different sources thus there is little reuse, if any.

- Product line orthogonal variability model



- Variant Classification

Variation Point: Array/Sensor		
Product Line Classification	Variant	Supporting Rationale
Adapted	Towed Array	Array only used for surface and subsurface platforms
Adapted	Hull Mounted Array	Array only used for surface and subsurface platforms
Reused	Radar	Standard across all systems
Unique	Dipping SONAR	SONAR only used for LAMPS MK III
Variation Point: Weapon		
Product Line Classification	Variant	Supporting Rationale
Unique	Torpedo	Weapon dependent on ship size and mission
Unique	Missile	Weapon dependent on ship size and mission
Adapted	Gun	Size of the gun varies between air and surface ship ASW systems
Variation Point: Tactical Control		
Product Line Classification	Variant	Supporting Rationale
Adapted	Torpedo Tube	Torpedo tube varies between systems
Adapted	Vertical Launch System	Vertical launch system varies between systems
Adapted	Gun Controller	Guns vary between systems
Variation Point: Data Link		
Product Line Classification	Variant	Supporting Rationale
Reuse	LOS	Standard across all systems
Reuse	Beyond LOS	Standard across all systems
Reuse	Satellite	Standard across all systems
Variation Point: HSI		
Product Line Classification	Variant	Supporting Rationale
Reuse	Single Display	Displays common across systems
Reuse	Multiple Display	Displays common across systems
Reuse	Single Controller	Controllers common across systems
Reuse	Multiple Controller	Controllers common across systems
Adapted	Display Size	Size specified by restrictions of the system

Figure 9. ASW Product Line Orthogonal Variability Model (Fraine et al., 2019)

Table 5 presents the results of a most likely scenario where the ASW combat system was built as a product line. The net development effort savings follows the typical path for product line development.

Table 5. Cross-Domain ASW Combat System Product Line Most Likely Scenario (Fraine et al., 2019)

Summary of Inputs				
	Baseline Product	Product 1 (LAMPS MK III)	Product 2 (AN/BYG-1)	Product 3 (SQQ-89)
Product Cost ($M)	$221.30	$221.30	$221.30	$221.30
Ownership Time (years)	40	25	40	40
Annual Change Cost (%)	10	10	10	10
Interest Rate (%)	3.63	3.63	3.63	3.36
Unique (%)	11.1	13.3	13.3	12
Developed for Product Line Reuse (%)	88.8	0	0	0
Adapted (%)	0	33.3	33.3	41
Reused (%)	0	53.3	53.3	47
RCR-Unique (%)	100	100	100	100
RCR-Adapted (%)	40	40	40	40
RCR-Reused (%)	5	5	5	5
RCWR	1.7	1.7	1.7	1.7
Non-Product Line Cost ($M)		189	212.5	262.4

Summary of results						
Product #	Development Cost ($M)	Ownership Cost ($M)	Investment	Savings ($M)	Cost Avoidance	Cum. ROI
0	$358.64	1434.56	$137.56	($687.80)		-6.00
1	$64.81	162.02	0	$546.95	85%	-2.02
2	$64.81	259.23	0	$781.35	83%	3.66
3	$97.74	390.98	0	$766.25	68%	9.23

Unmanned Underwater Vehicles Product Lines

The U.S. Navy has nine primary missions:

1. Intelligence, surveillance, and reconnaissance (ISR),
2. Mine countermeasures (MCM),
3. Antisubmarine warfare (ASW),
4. Inspection and identification (INID),
5. Oceanography (OO),
6. Communication or navigation network node (CN3),
7. Payload delivery (PD),
8. Information operations (IO), and
9. Time critical strike (TCS).

Detailed analyses for the UUV mission types were used to develop the SysML models that encapsulated system size and complexity measures. Analysis and comparison of the defined UUV missions identified ISR as having the most commonality across the set and was chosen as the reference architecture. Development of the ISR UUV constituted the investment costs.

Requirements models were generated and provided enumeration of system requirements by reuse type and complexity. Detailed executable activity models of mission operations were used to quantify interfaces with their complexities for inputs to the cost models.

Figure 10 illustrates the relationship between the mission sets and the COPLIMO model. The model is extended further by the use of the COSYMO 2.0 model

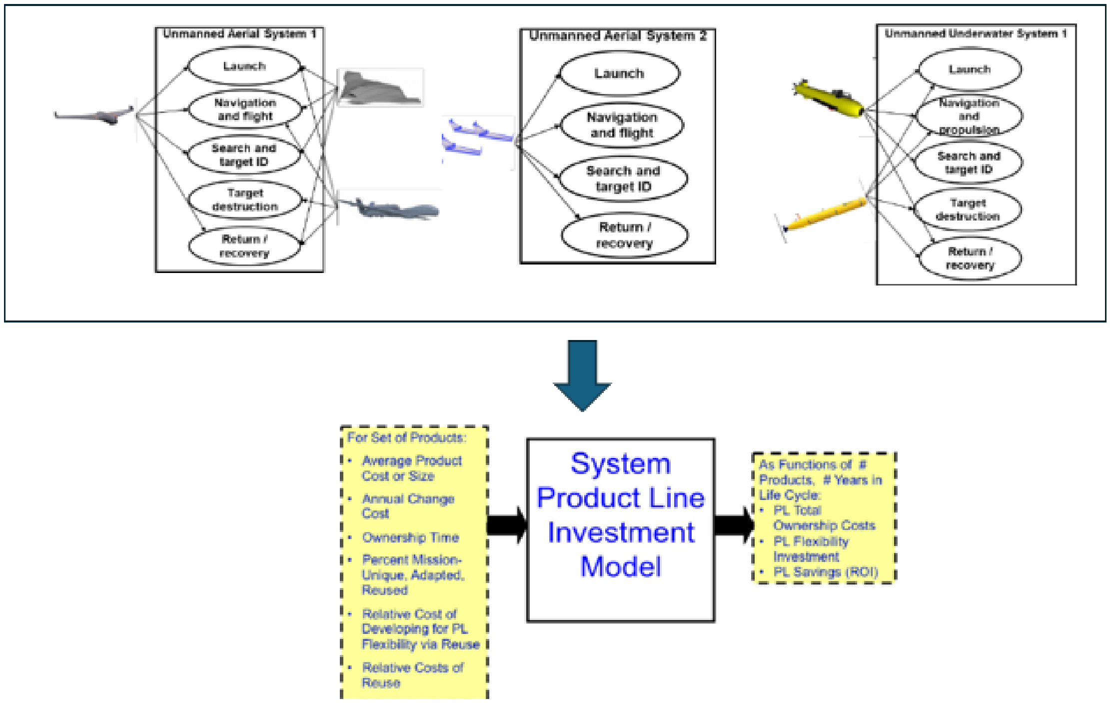
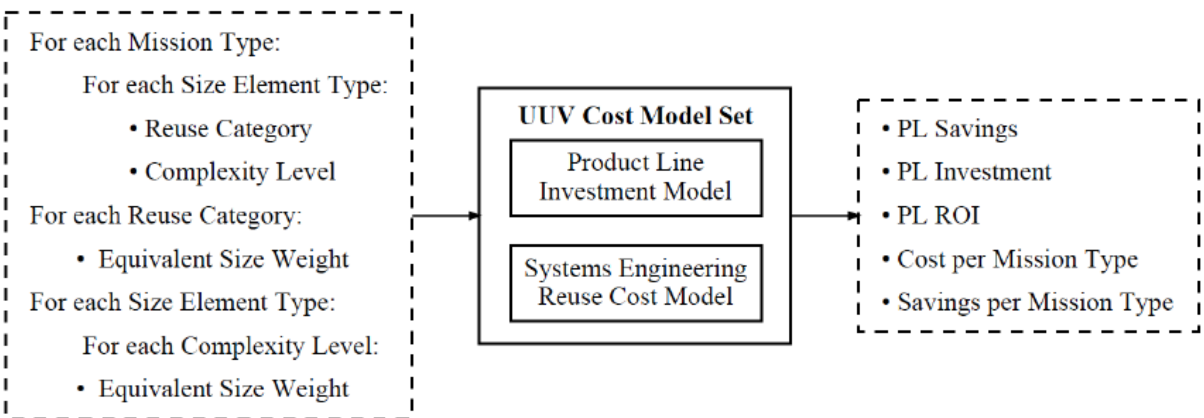


Figure 10. Example Unmanned Systems Product Line Commonality

Figure 11 is Figure 10 extended for the UUV mission set. Table 6 lists the reuse categories that satisfy the UUV requirements.



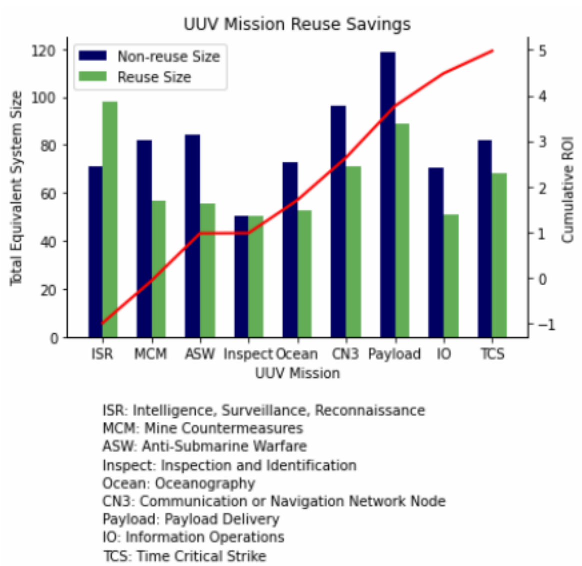
Where:
Size Element Types = (Requirements, Interface, Algorithms, Scenarios)
Reuse Categories = (New, Designed for Reuse, Modified, Deleted, Adopted, Managed)
Complexity Levels = (Easy, Nominal, Difficult)

Figure 11. COPLIMO Extended with COSYSMO 2.0 for UUV Missions

Table 6. COSYSMO 2.0 Reuse Categories Interpreted for UUV Requirements

Category	Definition for Requirements	Definition for Interfaces	Weight
New	Similar requirement does not exist in the baseline (completely new)	Similar interface does not exist in the baseline (completely new)	1.00
Designed for Reuse	New requirement and includes extra investment to enable potential reusability	New interface and includes extra investment to enable potential reusability	1.38
Modified	Change to the requirement's Measures of Effectiveness (MOEs)	Interface is tailored to the mission	0.65
Deleted	Similar requirement does not exist in new system	Similar interface does not exist in new system	0.51
Adopted	Change to the requirement's Measures of Performance (MOPs)	Interface is incorporated unmodified with testing	0.43
Managed	Requirement does not change from the baseline	Interface is incorporated unmodified with minimal testing	0.15

Figure 12 presents the UV mission reuse savings and ROI. The figure also list some of the important considerations involved in building the model.



- Requirements and interfaces from UUV MBSE models were enumerated and input into the COSYSMO cost model.
- This indicator displays the total equivalent system sizes and resultant ROI of a product line approach for UUV systems with overlapping mission capabilities.
- The savings for subsequent missions are the differences between a traditional non-reuse approach and the product line reuse approach.
- The cumulative ROI is the net savings over
- time divided by the investment cost based on the relative sizes.
- The size is used as input to systems engineering cost models to quantify estimated costs.
- The equivalent size difference represents a work savings, and added equivalent size represents the additional work investment to make the UUV baseline reusable.

Figure 12. UUV Mission Reuse Savings and ROI (Haller et al., 2022)

Mine Counter Measure UUV Product Line Modeling

The most mature case study to date is the Mine Counter Measure (MCM) UUV study completed by Alves (Alves, 2022). This study will provide a foundation for work going forward.

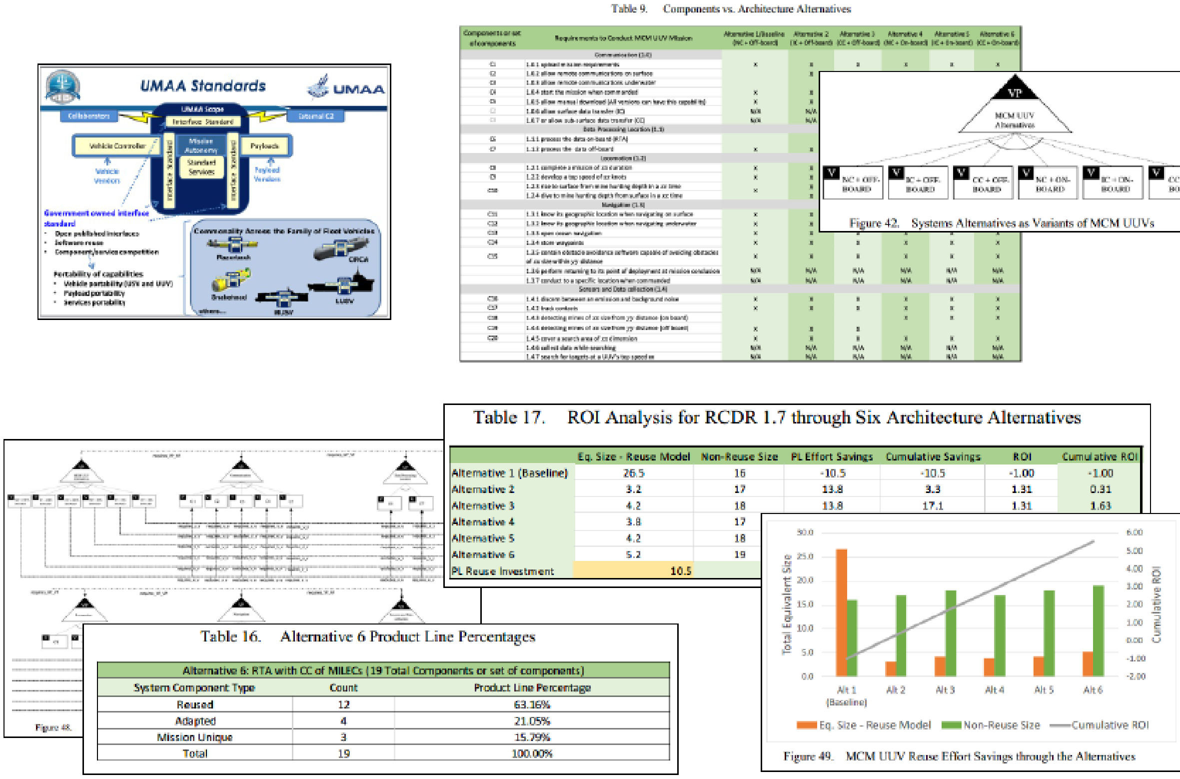


Figure 13. A Montage of the Analysis Steps Involved in the MCM UUV Product Line Modeling (Alves, 2022)

MCM UUV Economic Sensitivity Analysis

Table 18. ROI Analysis for RCDR 1.5 through Six Architecture Alternatives

	Eq. Size - Reuse Model	Non-Reuse Size	PL Effort Savings	Cumulative Savings	ROI	Cumulative ROI
Alternative 1 (Baseline)	23.50	16	-7.50	-7.50	-1.00	-1.00
Alternative 2	3.20	17	13.80	6.30	1.84	0.84
Alternative 3	4.20	18	13.80	20.10	1.84	2.68
Alternative 4	3.80	17	13.20	33.30	1.76	4.44
Alternative 5	4.20	18	13.80	47.10	1.84	6.28
Alternative 6	5.20	19	13.80	60.90	1.84	8.12
PL Reuse Investment	7.5					

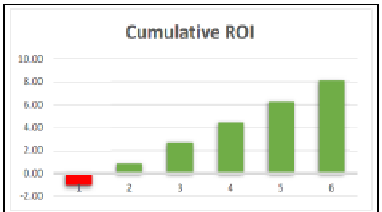


Figure 51. Cumulative ROI for RCDR 1.5

Table 19. ROI Analysis for RCDR 1.6 through Six Architecture Alternatives

	Eq. Size - Reuse Model	Non-Reuse Size	PL Effort Savings	Cumulative Savings	ROI	Cumulative ROI
Alternative 1 (Baseline)	25.00	16	-9.00	-9.00	-1.00	-1.00
Alternative 2	3.20	17	13.80	4.80	1.53	0.53
Alternative 3	4.20	18	13.80	18.60	1.53	2.07
Alternative 4	3.80	17	13.20	31.80	1.47	3.53
Alternative 5	4.20	18	13.80	45.60	1.53	5.07
Alternative 6	5.20	19	13.80	59.40	1.53	6.60
PL Reuse Investment	9.0					

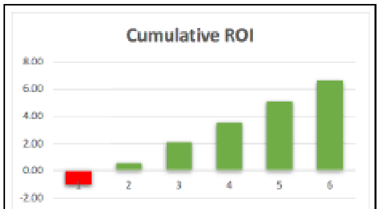


Figure 52. Cumulative ROI for RCDR 1.6

Table 20. ROI Analysis for RCDR 1.8 through Six Architecture Alternatives

	Eq. Size - Reuse Model	Non-Reuse Size	PL Effort Savings	Cumulative Savings	ROI	Cumulative ROI
Alternative 1 (Baseline)	28.00	16	-12.00	-12.00	-1.00	-1.00
Alternative 2	3.20	17	13.80	1.80	1.15	0.15
Alternative 3	4.20	18	13.80	15.60	1.15	1.30
Alternative 4	3.80	17	13.20	28.80	1.10	2.40
Alternative 5	4.20	18	13.80	42.60	1.15	3.55
Alternative 6	5.20	19	13.80	56.40	1.15	4.70
PL Reuse Investment	12.0					

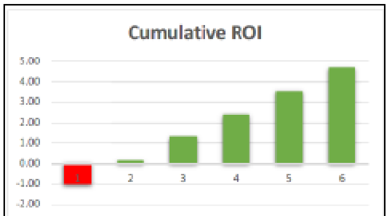


Figure 53. Cumulative ROI for RCDR 1.8

Figure 14. A Sensitivity Analysis of ROI for Architecture Alternatives (Alves, 2022)

The case study outcome was a substantial ROI of five for the product line approach over the single system approach for the nine UUV systems. This result corroborates previous product line economic analyses, demonstrating that many DoD systems and other types of system families would benefit from a product line strategy.

Conclusions and Future Work

COPLIMO provides a useful trade space for determining initial investment and future ROI with respect to product line systems versus non-product line systems.

- Virtually all case studies have demonstrated high ROI of product line practices on defined DoD missions.
- System architectures for chosen domains should focus on the product line, instead of mission specific systems. Plan for the reuse of system components over time.
- Applying the engineering product line methodology to system architecture design and development needs to happen at the earliest stage of design.
- System architectures for unmanned systems should focus on the product line, instead of mission specific systems. The product line modeling approach has a broader application for acquiring systems that are based on similar functions and will be applied to future case studies.

Future work includes additional case studies and combined modeling of systems effectiveness with the economics of product lines. The model integration is being further streamlined. We are developing improved tools for SysML 2 to automate the product and cost model integration. With this, we can also include a broader range of system size information from activity models, use case models and sequence models.

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