TANGRAM PRO™ COST BENEFIT ANALYSIS

Original Issue - 4 December 2020

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EXECUTIVE SUMMARY

The benefits of **Component Based Engineering (CBE)** are well understood and documented. CBE breaks complex systems down into logically sized components, defines each component's behavior, and identifies its interfaces so that it may be reused or replaced more efficiently. Many of today's critical systems are monoliths, containing a mix of traditional hardware of the 20th century and, increasingly, sophisticated and complex software components that introduce a growing number of capabilities as well as new obstacles to safety, security, and competition at the speed of relevance. The proliferation of software in systems crosses industry boundaries, demanding a shift to CBE in private industry and Government-owned programs alike.

Challenges in system development persist even with the growing adoption of CBE methodologies, particularly in the DoD. Stated best in the Defense Innovation Board's 2019 report[1], *"The current approach to software development is broken and is a leading source of risk to DoD; it takes too long, is too expensive, and exposes warfighters to unacceptable risk by delaying their access to tools they need to ensure mission success."* This report and many like it go on to detail the crux of the challenge: **although we are improving at understanding what components exist within our systems, we are facing hurdles in communication, failures between requirements and development, loss of provenance technology handoffs, and failures in software delivery within system development lifecycles.**

Tangram Flex calls this problem the **treacherous gap.** Our product, Tangram Pro™, bridges lifecycle gaps between systems engineering and software development. Tangram Pro™ is a **Component Software Integration Platform (CSIP)** used by designers, developers, and maintainers of mission critical systems to simplify software integration for mission-critical defense systems, delivering four key benefits to customers:

1. Lower overall cost of component based program execution
2. Efficiency in testing, verification, and certification
3. Faster software delivery and release cadence
4. Eased transition to agile software development and DevSecOps adoption

REPORT OVERVIEW & MODEL

This report analyzes the economic benefit of incorporating the Tangram Pro™ CSIP into the software development lifecycle for a representative mission system. It assumes that our customer's team has already adopted CBE and uses a mission system interface and communication standard, criteria which prepare a customer for adopting a CSIP without shifting engineering strategy.

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[1] *Software Is Never Done*. Defense Innovation Board, 3 May 2019, media.defense.gov/2019/Apr/30/2002124828/-1/-1/0/SOFTWAREISNEVERDONE_REFACTORINGTHEACQUISITIONCODEFORCOMPETITIVEADVANTAGE_FINAL.SWAP.REPORT.PDF.

Our cost benefit analysis is carried out using a notional model program as our customer. We selected criteria for our model program following our experience with DoD customers who are looking to adopt a CSIP or similar technology. Our model program is a Major Defense Acquisition Program (MDAP) in the Command, Control, Communications, Computers, and Intelligence (C4I) or Science and Technology (S&T) category. Full program overview and methods and calculations for constructing the program's baseline budget are detailed in *Appendix B* and *Appendix C*.

KEY FINDINGS

This report considers quantifiable benefits in its financial calculations as well as improvements for which data was not easily available, which are described in detail in the following sections. In our analysis we identified 15 individual benefits from the adoption of the Tangram Pro™ CSIP. These benefits provide a quantifiable value in three categories:

KEY BENEFIT	ANNUAL VALUE
Lower Overall Cost of Component Oriented Program Execution	$6.9 million
Testing, Verification, and Certification Efficiencies	$1.07 million
Faster Software Delivery and Release Cadence	$5.63 million
TOTAL BENEFIT	**$13.6 million**

A fourth category is also considered in this analysis as a secondary benefit: programs which adopt the Tangram Pro™ CSIP have an improved ability to transition to agile software development and adopt DevSecOps processes. This benefit will require further data collection and analysis before it can be quantified and will be studied in future reports.

The benefit of Tangram Pro™ CSIP adoption was analyzed over a period of five years, with the initial years significantly discounted from what the annual value analysis shows. Our cost benefit analysis shows that **over 5 years, the Tangram Pro™ CSIP provides a $27.9 million benefit to the customers[2].**

The following sections detail our model, costs, and benefits in detail, with full calculations and methodology are provided in *Appendices C and D*.

[2] See Financial Analysis section for methodology

TANGRAM PRO™ CSIP CUSTOMER OVERVIEW

This analysis uses a model organization engaged in a notional program as our customer. Our model organization represents a business unit[3] of a mid-sized prime contractor to the DoD that develops and integrates components in connected defense systems and follows an industry-standard development lifecycle[4].

The notional program used in this analysis is defined with the following assumptions:

- The model program is a **Major Defense Acquisition Program (MDAP)** in the Command, Control, Communications, Computer, and Intelligence (C4I) or Science and Technology (S&T) category
- The model program is **already leveraging Component Based Engineering (CBE) and works within a common component interface and communication standard.**
    - CBE has already been accepted and implemented in the program, so analysis compares the program's execution without adopting Tangram Pro™ CSIP with its execution after leveraging Tangram Pro™ CSIP.
- The model program **maintains a mission system of 12 components using a common bus for communication.** The representative mission system is fully maintained and updated within the model program. It contains Commercial off the Shelf (COTS), proprietary, and custom components **which each require updates 3 times per year.**
- The model program **employs 20 team members, all government contractors in Research, Development, Test, and Evaluation (RDT&E) roles with an average labor rate of $135.74/hour**[5]
- The model program has an **annual budget of $23 million for mission system engineering**[6]

As the customer has already accepted and implemented CBE in its program, our analysis compares the program's execution without adopting any CSIP to its execution when levering the Tangram Pro™ CSIP. We are specifically interested in the portion of the program devoted to mission system engineering and focus our efforts on benefits to that portion of the notional program's budget.

[3] See Org Chart in Appendix B1

[4] See Development Lifecycle in Appendix B2

[5] See Labor Rate Calculation in Appendix B3

[6] See budget calculation in Appendix C

KEY CUSTOMER BENEFITS

The Tangram Pro™ CSIP allows customers to fully realize the benefits of CBE in their program by tightly linking systems engineering with software development with system modeling and visualization tools, automatic code generation and variation management features, and techniques that shift testing “to the left**”. Adoption of Tangram Pro™ provides benefits to serve three key customer needs:**

- **Customer Need:** Achieve efficiencies in CBE activities
- **Key Benefit:** Lower overall cost of CBE program execution by adopting CSIP with:
    - Reduced Engineering Effort
    - Integrated Assurance
    - Component Reuse

- **Customer Need:** Integrated and comprehensive testing, verification, and certification
- **Key Benefit:** Testing, Verification, and Certification Efficiencies with CSIP with:
    - Early Defect Detection
    - Improved Cyber Security

- **Customer Need:** Deliver software updates to the field at the speed of relevancy
- **Key Benefit:** Faster software delivery and release cadence with CSIP with:
    - Faster Production Time
    - Model Based System Engineering

ADDITIONAL CUSTOMER BENEFITS

The Tangram Pro™ CSIP provides improvements to system development and maintenance for which data is not readily available or which will vary by organization and are therefore difficult to quantify in our model. The overall cost benefit analysis calculations do not include these benefits, but they are relevant to organizations considering the adoption of Tangram Pro™.

- Vendor Flexibility
- Improved Interoperability
- Increased Confidence and Traceability
- Automated Change Management
- Improved Access to Analysis Tools
- Certification Support
- Shortened Threat Mitigation Windows
- Support for Transition to Agile Development and DevSecOps
    - Cross-Team Flexibility
    - Third Party Integrations

BENEFIT ANALYSIS

This section describes each benefit realized by our customer with adoption of the Tangram Pro™ CSIP. Each category is described and broken down into its quantifiable benefits and their annual value, followed by additional benefits for which data is not available. The methodology and data used for calculating each quantified benefit is presented in *Appendix D*.

KEY BENEFIT A: LOWER OVERALL COST OF CBE PROGRAM EXECUTION

The Tangram Pro™ CSIP provides a range of tools to bridge lifecycle gaps and support efficiencies in CBE. With component modeling tools tied to software development code and interface generation, Tangram Pro™ can reduce communication and tool gaps between software development and systems engineering. Integrated assurance methodologies tie certifications to requirements, design, and models, reducing the gap between software development and test, and its component library and automated code generation allows engineers with varying degrees of expertise to participate in CBE with less training time. We summarize the benefits in this domain in the sections below.

QUANTIFIED BENEFITS

BENEFIT DESCRIPTION	ANNUAL VALUE
Reduced Engineering Effort[7]	$1.6 million
Integrated Assurance[8]	$2.3 million
Component Reuse[9]	$2.29 million
TOTAL ANNUAL BENEFIT	**$6.9 million**

- **Reduced Engineering Effort:** The Tangram Pro™ CSIP automatically generates interface code, supporting component integration without the effort of writing interface code by hand and reducing the development cost for system updates.
- **Integrated Assurance:** Automatic assurance tools shift testing to the left, reducing the number of errors delivered to the testing phase and decreasing overall testing expenses.
- **Component Reuse:** Operating and maintaining a library of components and their configurations is essential to CBE programs but has a high overhead cost. The Tangram Pro™ CSIP simplifies the process of component reuse through its component library interface and with tools for rapid creation and updating of existing components, reducing effort and cost in component reuse.

7 See Appendix D1.1 for methodology

8 See Appendix D1.2 for methodology

9 See Appendix D1.3 for methodology

ADDITIONAL BENEFITS

BENEFIT DESCRIPTION	PREDICTED VALUE
Vendor Flexibility	Reduced reliance on proprietary component integration and maintenance
Improved Interoperability	Faster and safer integration of components using different standards and languages
Increased Confidence and Traceability	Reduction of time and expense needed for change and version management

- **Vendor Flexibility:** Tangram Pro™ enables the reuse and implementation of COTS, custom, and proprietary components without vendor support.
- **Improved Interoperability:** Adapting a single component to meet a range of standards is key to joint force operations. Tangram Pro™ can be configured to generate interfaces with transforms and translation code between varying message sets and standards.
- **Increased Confidence and Traceability:** Automatic documentation and provenance generated by Tangram Pro™ can improve traceability throughout the software development lifecycle, providing greater trustworthiness in the system and improving version control.

KEY BENEFIT B: TESTING, VERIFICATION, AND CERTIFICATION EFFICIENCIES

Up to 80% of mission systems software program budgets are devoted to testing, verification, and certification of software[10]. CBE greatly improves the quality of systems through these efficiencies, however, there is an industry-wide need to lower costs in this area. The Tangram Pro™ CSIP provides key analysis tools and provides evidence of compliance and correctness that benefit programs both in schedule and cost.

QUANTIFIED BENEFITS

BENEFIT DESCRIPTION	ANNUAL VALUE
Early Defect Detection[11]	$485,045
Improved Cybersecurity[12]	$583,647
TOTAL BENEFIT	**$1.07 million**

10 Petrucci, Lt Col David. "Squeezing More Value From Test." *DAU News - Squeezing More Value From Test*, 1 Jan 2020, www.dau.edu/library/defense-atl/blog/Squeezing-More-Value-From-Test.

11 See Appendix D2.1 for methodology

12 See Appendix D2.2 for methodology

- **Early Defect Detection:** The Tangram Pro™ CSIP's integrated assurance tools identify defects and errors earlier in the development cycle, improving the quality of code and testing and reducing the number of defects that escape to production. This results in better overall delivery and reduces the cost incurred by reactive work.
- **Improved Cybersecurity:** Nearly two thirds of software security vulnerabilities are caused by coding errors[13] and often remain undetected until after implementation. The Tangram Pro™ CSIP provides a variety of integrated static analysis tools that can identify source-level security vulnerabilities and errors that are difficult to detect with standard quality practices before code is deployed.

ADDITIONAL BENEFITS

BENEFIT DESCRIPTION	PREDICTED VALUE
Automated Change Management	Reduction in the time needed to communicate changes between teams, update test plans, and debug errors.
Improved Access to Analysis Tools	Increased access to advance assurance tools without the need for a specialist to operate.
Rapid Certification Support	Automated documentation provides evidence that can be used to prove compliance with security requirements and standards.

- **Automated Change Management:** Tangram Pro™ includes workflow plugins that generate documentation and artifacts to provide highly accurate information to distributed teams about their components and component changes.
- **Improved Access to Analysis Tools:** The sophistication of assurance tools on the market is a barrier to adoption in many programs. With a CSIP, these tools can be used without the cost of specialized training or hiring an expert.
- **Rapid Certification Support:** The Tangram Pro™ CSIP provides artifacts and generates documentation that can be used to support team members responsible for ATO and related government certification processes.

13 Kuhn, Rick, et al. *What Proportion of Vulnerabilities Can Be Attributed to Ordinary Coding Errors?* National Institute of Standards and Technology, tsapps.nist.gov/publication/get_pdf.cfm?pub_id=925468.

KEY BENEFIT C: FASTER SOFTWARE DELIVERY & RELEASE CADENCE

The DoD struggles to deliver new components to the warfighter at a relevant pace: *"We can build the best airplanes and satellites, but we will lose if we can't update the software at the speed of relevance in this century."*[14] Customers seek to adopt tools that shorten the time to deliver new and updated capabilities to the field. The Tangram Pro™ CSIP enables customers to benefit from digital twin enabling technologies and model-based systems engineering (MBSE) tools to improve their release cadences.

QUANTIFIED BENEFITS

BENEFIT DESCRIPTION	ANNUAL VALUE
Faster Production Time[15]	$1.41 million
Model Based System Engineering[16]	$4.22 million
TOTAL BENEFIT	**$5.63 million**

- **Faster Production Time:** The Tangram Pro™ CSIP enables teams to create and maintain digital twins of complex software-driven systems, allowing for faster and more efficient delivery, maintenance, and sustainment of component-based systems and systems-of-systems. Customers realize efficiencies in system development life cycle time with the ability to visualize cyber-physical systems at the component-level, build connections between components and systems, maintain high-quality traceability artifacts, and generate evidence that describes the behavior of a system or system-of-systems to improve lifecycle efficiency and reduce the time needed to deliver software to fielded systems.
- **Model Based Systems Engineering (MBSE):** The Tangram Pro™ CSIP includes tools that allow customers to shift from traditional document-based systems engineering to MBSE. MBSE is a natural complement to CBE. It uses system models to understand the system's requirements, design, and architecture by describing its components, their interfaces, and their behavior, enabling faster and less costly delivery of systems and components. Tangram Pro™ customers can connect their models to code and dramatically reduce delivery time for system updates.

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14 Christopherson, Amy. "Faster, Smarter: Speed Is Key in Acquisition Reform." U.S. Air Force, 28 Feb. 2019, www.af.mil/News/Article-Display/Article/1771387/faster-smarter-speed-is-key-in-acquisition-reform/.

15 See Appendix D3.1 for methodology

16 See Appendix D3.2 for methodology

ADDITIONAL BENEFITS

BENEFIT DESCRIPTION	PREDICTED VALUE
Shortened Threat Mitigation Windows	Reduction in the time needed to identify, repair, and deploy fixes to the field.

- **Shortened Threat Mitigation Windows:** Typically, when an error is found or there is some kind of outdated software that needs to be updated, the time to report the error, debug it, repair it, and redeploy it presents a threat to the active users of the system. The efficiencies provided by a CSIP can greatly reduce this timeline.

SECONDARY BENEFIT: TRANSITION TO AGILE DEVELOPMENT & DEVSECOPS

Agile development and DevSecOps are natural partners. Agile methodologies are focused on continuous delivery and are made possible by a solid DevSecOps toolchain. Standard DevSecOps tools allow for continuous integration and continuous deployment (CI/CD) with features like faster testing, verification, and deployment. These methodologies and practices are beneficial to system development and maintenance in general, but overall perform best when applied to a set of small components rather than large and complex ones.

Component Based Engineering makes the transition to agile development methodologies and DevSecOps easier by nature- systems that are composed of small pieces are easier to update, automate and maintain, however, the treacherous gaps between systems engineering and software development in CBE can be roadblocks to transitioning to agile development. On its own, even MBSE lends itself more to waterfall approaches to integration with software development due to manual handoffs and communication gaps between phases of development (for example, requirements are defined and manually transitioned to software development).

The benefits of adopting the Tangram Pro™ CSIP detailed earlier in this report bridge many of the gaps in CBE that create barriers to transitioning more modern and efficient development methodologies and paradigms. Along with those above, Tangram Pro™ provides flexibility and pipeline integration that can help teams more fully realize the value of CBE.

DESCRIPTION	BENEFIT
Cross-Team Flexibility	Tangram Pro™ can be used in programs in which each team has its own process and resources without loss of fidelity
Third-Party Integrations	Integration with code repositories and engineering pipelines improves the effectiveness of models and software delivery

- **Cross-Team Flexibility:** The Tangram Pro™ CSIP allows all members of a program to use a shared model as the single source of truth and to access well defined components, creating confidence and transparency in system design and software development even in diverse and distant teams.
- **Third-Party Integrations:** Tangram Pro™ integrates with code repositories and DevSecOps pipelines, allowing customers to build more effective models, trigger automatic interface generations, and deliver new component implementations with minimal manual work. This supports the CI/CD critical to agile development.

FINANCIAL ANALYSIS

Tangram Pro™ is a licensed, web-based software product that can be deployed on secure GovCloud environments or on-premise as required. The annual cost of the Tangram Pro™ CSIP is the license price and estimated support costs that come with the maintenance and support of any software product a company may adopt.

COST DESCRIPTION	VALUE
Cost to purchase Tangram Pro™ Licenses	$1 million annually[17]
Miscellaneous support costs	$500,000 annually
TOTAL ANNUAL COST	**$1.5 million**

The benefits of the Tangram Pro™ CSIP are realized over a five year period. Given the quantified annual benefits and costs of adopting Tangram Pro™ and adjusting for the percent realized each year, our analysis finds a negative net benefit in the first year of use, followed by positive net benefits in each following year. The overall net present value of adopting Tangram Pro™ is **$27.9 million over 5 years.**

	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL (PV)	NPV
Lower Overall Cost of Component Oriented Program Execution	$6.9m	$6.9m	$6.9m	$6.9m	$6.9m		
Testing, Verification, and Certification Efficiencies	$1.07m	$1.07m	$1.07m	$1.07m	$1.07m		
Faster Software Delivery and Release Cadence	$5.63m	$5.63m	$5.63m	$5.63m	$5.63m		
Subtotal	*$13.6m*	*$13.6m*	*$13.6m*	*$13.6m*	*$13.6m*		
Percent Realized	10%	25%	50%	75%	100%		
Benefit	$1.36m	$3.4m	$6.8m	$10.2m	$13.6m	$35.36m	
Cost	$1.5m	$1.5m	$1.5m	$1.5m	$1.5m	$7.5 m	
Net Annual Benefit	($140k)	$1.9m	$5.3m	$8.7m	$12.1m		**$27.9m**

17 Based on standard Tangram Pro™ license cost of $50,000/user per year and program RDT&E staff size of 20. Licensing costs vary by installation and user type.

CONCLUDING REMARKS

The cost benefit analysis carried out by Tangram Flex found a positive impact to a program from adopting its CSIP, Tangram Pro™. In analyzing the economic value of incorporating the use of Tangram Pro™ into a representative mission system development life cycle for a program already using Component Based Engineering, a net benefit of **$27.9 million over 5 years** was calculated for the customer.

This study was conducted using a model customer whose budget was calculated using publicly available federal budget data, cited and described in Appendix C. Figures, statistics, and further data used to calculate the annual value of each benefit was provided by a variety of published sources, all cited in footnotes in Appendix D. Assumptions made in our model were conservative so as to avoid inflation of value.

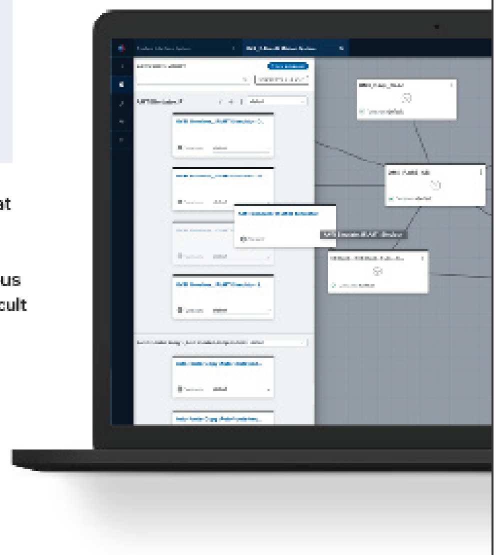
This report was last updated in December 2020 and will be revisited quarterly as more information is available. Please contact Mark Stadtmueller for additional information about this report (mark.stadtmueller@tangramflex.com).

APPENDIX A: TANGRAM PRO™ DATA SHEET

Visit https://tangramflex.com/insights to download the latest.

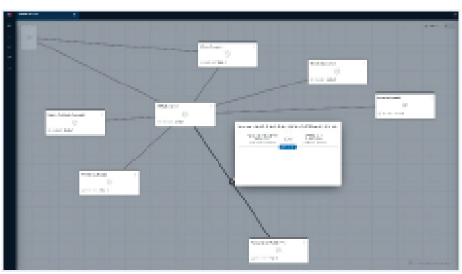
TANGRAMPRO™

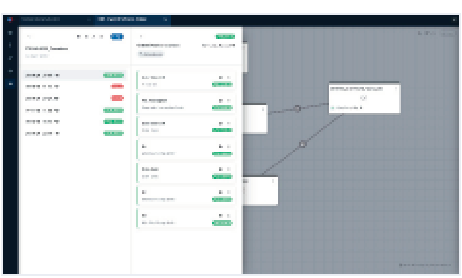
The Leading Component Software Integration Platform (CSIP) for Mission Critical Systems



Today's mission-critical systems rely on complex software components that are slow and risky to update. Component-based design has the potential to improve the way we build systems with simpler component reuse and replacement, but missing links in engineering lifecycles and the treacherous gap between system engineering and software development make it difficult to deliver at the speed of relevance.

We have taken learnings and experience from our research, prototyping, and services work to build our CSIP, Tangram Pro™. Tangram Pro™ bridges the treacherous gap between system engineering and software development with a practical engineering workspace for assured component deployment.





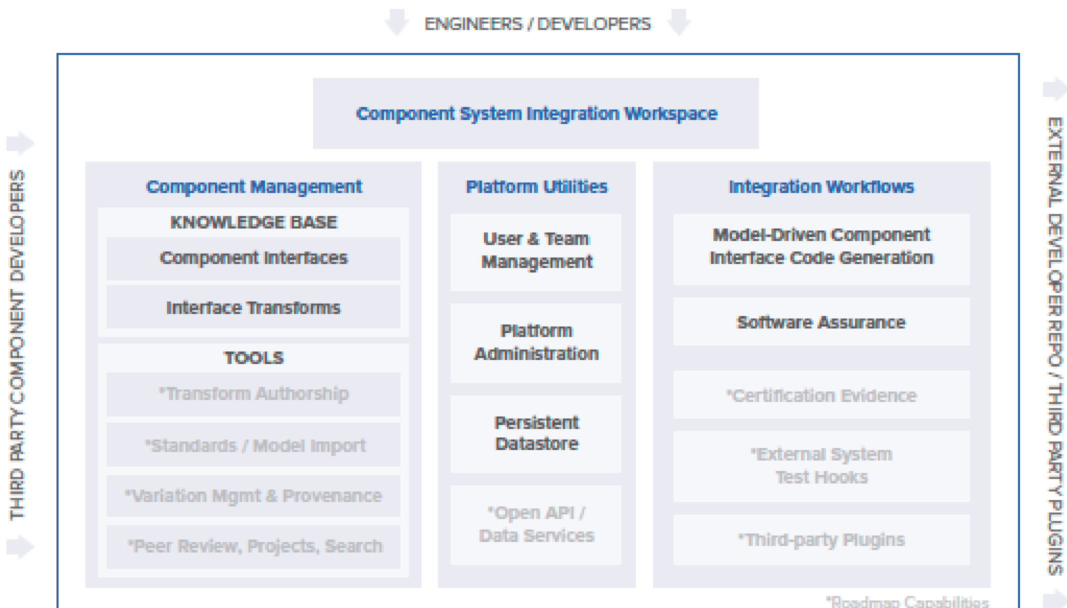
Tangram Pro™ CSIP Capabilities

Tangram Pro™ provides tools to bridge engineering lifecycle gaps so new technology can be delivered rapidly with confidence.

- Linking System Engineering and Software Development: MBSE models are linked to automatic code generation for tight coupling of system requirements and software code
- Code Generation per Message Standards: Automatic generation of Component Software Interfaces for a growing list of standards enabling fast, secure component updates
- Streamlined Transformation Capability: The Tangram Pro™ CSIP uses the Flex Translation Language to map native component communication capabilities to mission requirements and messaging standards
- Built-in Assurance: Analysis and workflow plug-ins shift V&V left to rapidly incorporate new capabilities with confidence
- Variation Management and DevSecOps Features: Integration with common CI/CD toolsets for improved release cadence

TANGRAMFLEX

RAPID INTEGRATION WITH CONFIDENCE
tangramflex.com



TANGRAMPRO™ Architecture

Tangram Pro™ supports PaaS, Cloud, or VM deployment based on customers' unique environments. The CSIP tools in Tangram Pro™ are provided in four modules:

- An easy-to-use workspace for systems engineers and software developers to create individual software components and connect them to design complex systems
- A Component Management toolkit powered by a knowledge base of components, standards, transforms, and tools to manage the lifecycle of components
- An Integration Workflows module enabling model-driven automatic code generation, assurance checks, and hooks to external code repositories, CI/CD, and DevSecOps pipelines
- A Platform Utilities Module providing team and user management and administrative controls as well as a persistent datastore

Currently Supported Standards
- OMS
- LMCP
- STANAG-4586

Supported Transformations
- Any mapping between standards or proprietary protocols on a 1:1 message translation
- Mapping created in Flex Translation Language and imported into the platform

Automatic Code Generation Outputs
- C++
- Java

Code Generation Supported Message Buses
- Kafka
- RabbitMQ
- ZeroMQ
- ActiveMQ

Deployment
- User/Team Management
- Platform Administration
- PaaS or VM Deployment
- GitLab, GitHub, Bitbucket Integration
- Integrated Software Assurance Checks
- Persistent Datastore (Included MongoDB)

TANGRAMFLEX

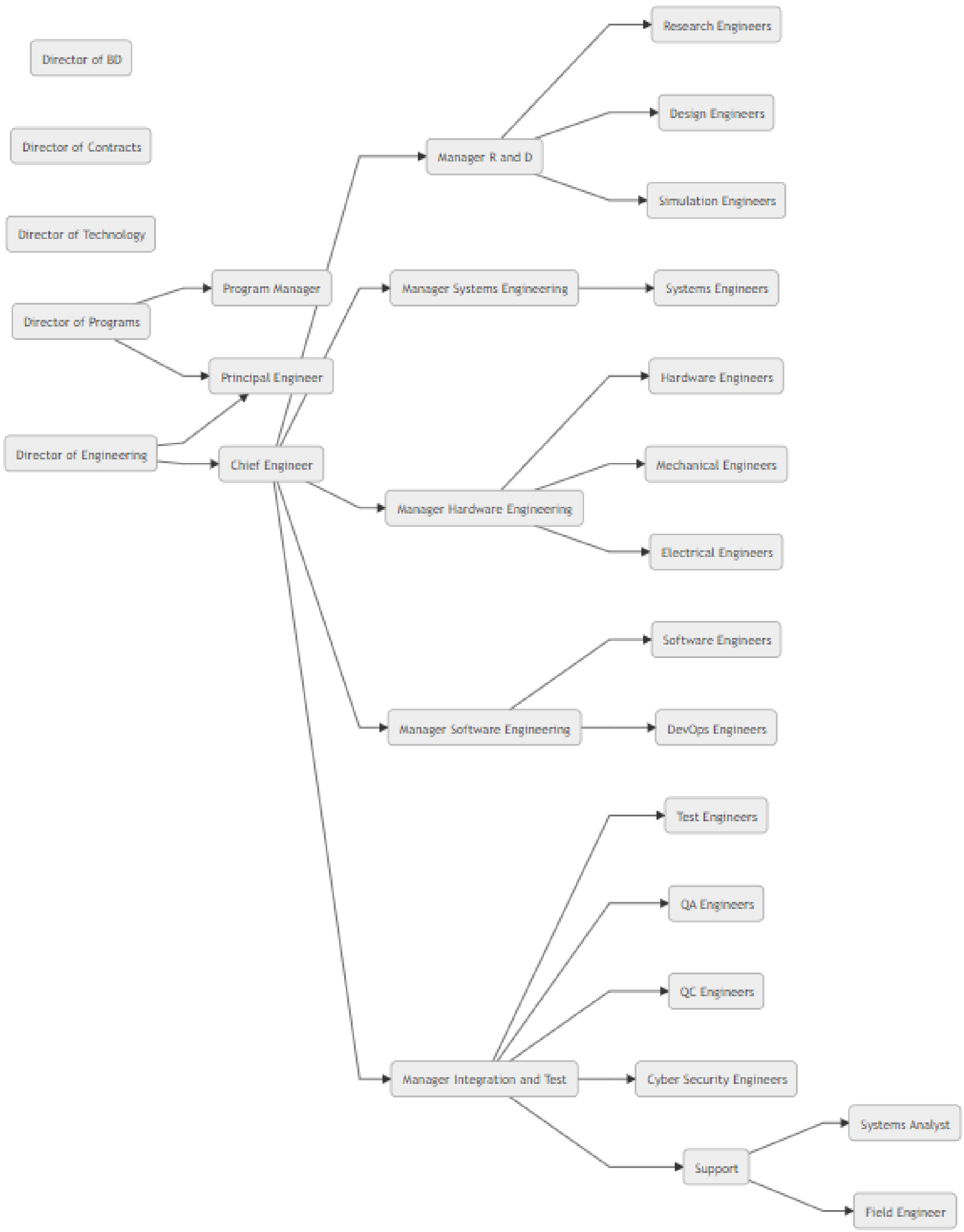
RAPID INTEGRATION WITH CONFIDENCE

tangramflex.com

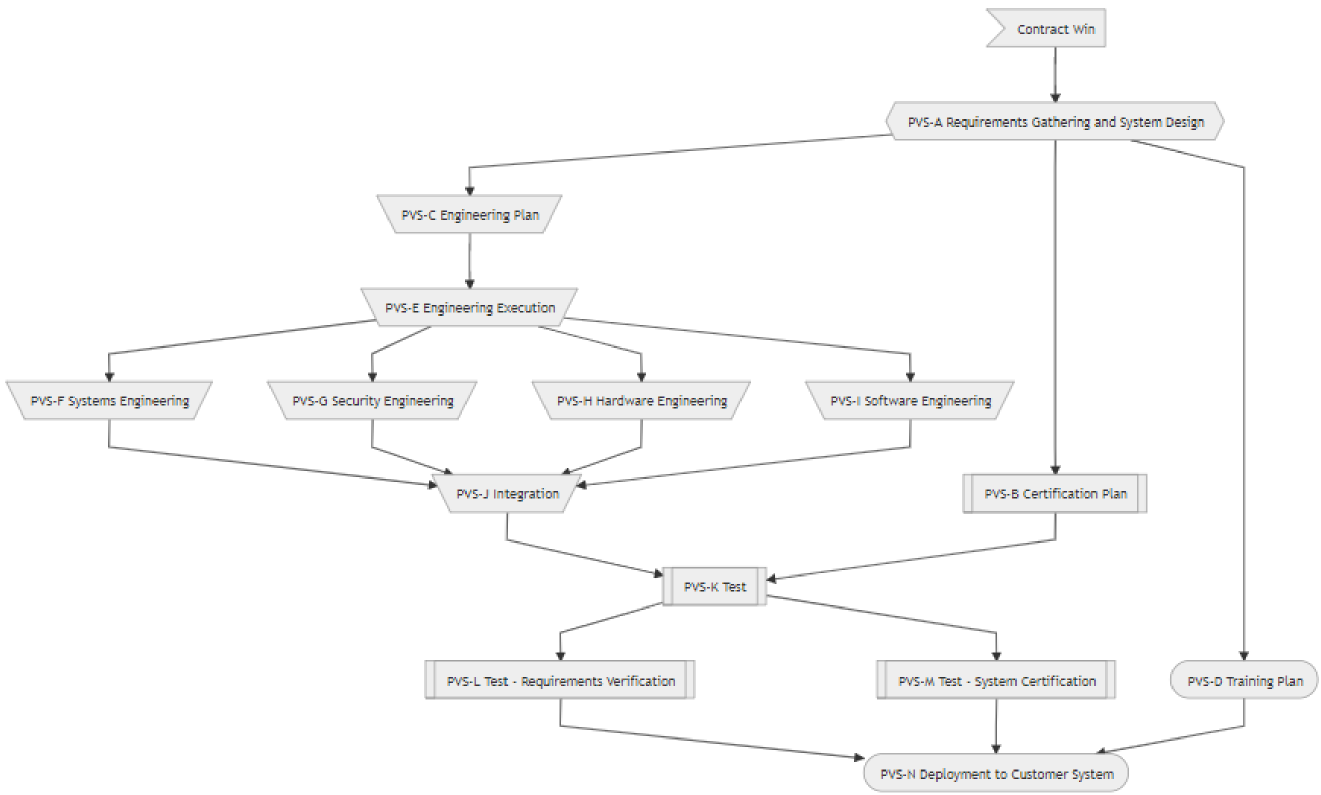
Headquartered in Dayton, Ohio, Tangram Flex, Inc. is a venture-backed startup supporting organizations building mission critical software systems. We believe every mission deserves access to innovation so we deliver capabilities to allow rapid integration with confidence.

APPENDIX B: MODEL ORGANIZATION OVERVIEW

B1. ORGANIZATION CHART



B2. DEVELOPMENT LIFECYCLE



B3. LABOR RATES

RDT&E WAGES

ROLE	BLS OCCUPATION CODE	MEAN HOURLY WAGE[18]
Research Engineer	15-1221	$61.28
Design Engineer	15-1221	$61.28
Simulation Engineer	15-1221	$61.28
Systems Engineer	15-1221	$61.28
Hardware Engineer	17-2061	$59.15

18 “May 2019 National Occupational Employment and Wage Estimates.” *U.S. Bureau of Labor Statistics*, U.S. Bureau of Labor Statistics, 31 Mar. 2020, www.bls.gov/oes/current/oes_nat.htm.

Mechanical Engineer	17-2141	$44.97
Electrical Engineer	17-2071	$49.75
Software Engineer	15-1256	$53.66
DevOps Engineer	15-1256	$53.66
Test Engineer	15-1256	$53.66
QA Engineer	15-1256	$53.66
QC Engineer	15-1256	$53.66
Cyber Security Engineer	15-1212	$51.68
Systems Analyst	15-1211	$46.23
Field Engineer	17-3020	$29.87
Engineering Manager	11-9041	$73.52
AVERAGE HOURLY WAGE		$54.29

METHODOLOGY

In our labor calculations we assume that the program employs 20 staff members who contribute to mission systems software development. We calculated the hourly RDT&E labor rate by averaging the mean hourly wage for each of the program's RDT&E roles and multiplying by a standard wrap rate of 2.5.

$54.29 average hourly wage * 2.5 wrap rate = **$135.73 average hourly labor rate**

APPENDIX C: BASELINE BUDGET

Our model program budget is based on data provided in the *Program Acquisition Cost By Weapon System Report*[A] delivered by the Under Secretary of Defense (Comptroller)/Chief Financial Officer in March 2019 in preparation for the FY 2020 Budget.

CORE ASSUMPTIONS

- Our model program is a Major Defense Acquisition Program (MDAP) in the Command, Control, Communications, Computer and Intelligence (C4I) or Science and Technology (S&T) category
- The Research, Development, Test, and Evaluation (RDT&E) expenditures for MDAPs are proportional to those of the entire Major Weapons Systems
- All programs receive an equal portion of the FY 2020 Budget
- 80% of our model program's RDT&E activities are related to software development
- 25% of our model program's RDT&E software development activities are related to mission system development
- The calculated figures represent annual expenditures

METHODOLOGY

CSIP tools are specifically intended for use in the engineering lifecycle for mission systems, encompassing the requirements gathering, system design, engineering execution, integration, test, certification, and verification, and deployment phases. As such, our specific interest is in the portion of the FY 2020 Budget dedicated to Research, Development, Test, and Evaluation (RDT&E) funding.

FY 2020 Total Investment = **$247.3 billion**
FY 2020 Major Weapons Systems RDT&E Budget= **$104.2 billion**

Thus, the proportion of FY 2020 acquisition budget devoted to RDT&E is:
(104.2/247.3)*100% = **42.1%**

We are primarily concerned with RDT&E expenditures in the Command, Control, Communications, and Intelligence (C4I) and Science and Technology (S&T) categories. At the time of publication, our data source reports a budget of **$10.2 billion** and $**14.1 billion** for these categories, respectively. Given this data and assuming **42.1%** of budget is dedicated to RDT&E, we calculate the relevant RDT&E Budget for our category as such:

($10.2 billion + $14.1 billion) * .421 = **$10.23 billion total RDT&E budget for C4I and S&T**

At the time of the budget report, 89 programs were categorized as MDAP. For simplification we assume that each MDAP has an equal budget. The information available does not break MDAPs down by category, so we used the full number of programs in our calculation. This is an assumption made for purposes of our own model program and we recognize that it may differ from the allocation of budgets in practice.

$10.23 billion/89 MDAP programs = **$114.95 million RDT&E budget per MDAP**

We further assume that 80% of our model program's RDT&E activities are devoted to software, leading us to the following budget calculation.

$114.95 million * .80 = **$91.96 million software RDT&E budget**

Our final assumption is that 25% of our model program's RDT&E software activities are related to mission system development, providing us with the baseline budget for our model program's mission system activities that can benefit from the adoption of a CSIP.

$91.96 million * .25 = **$23 million mission systems software RDT&E budget**

APPENDIX D: BENEFITS METHODOLOGY

D1. LOWER OVERALL COST OF CBE PROGRAM EXECUTION

D1.1 REDUCED ENGINEERING EFFORT: $1.6 MILLION ANNUAL BENEFIT

An estimated 30% of RDT&E time is spent on coding[19], and in an ideal software development team, 80% of time is to "productive work", or the creation of new code.[20] Given our program's annual RDT&E budget of $23 million for mission systems,

$23 million * .3 * .8 =
$5.52 million cost for writing new code per year without CSIP

Assuming 30% of new code written is updated integration code used for interfaces between components in the mission system,

$5.52 million * .30 =
$1.6 million cost for writing interface code per year without CSIP

ANNUAL BENEFIT

The Tangram Pro™ CSIP automatically generates interfaces for connecting components together, thus eliminating the engineering effort for manually written integration code and providing an **annual cost savings of $1.6 million.**

D1.2 INTEGRATED ASSURANCE: $2.3 MILLION ANNUAL BENEFIT

Software test and assurance accounts for 50-80% of program costs[21]. We assume that 50% of our model program's missions systems software RDT&E budget is spent here.

$23 million * .5 =
$11.5 million test and assurance costs per year without CSIP

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19 *Software Development Cost Estimating Handbook*. Vol. 1, Developed by the Software Technology Support Center, www.dau.edu/cop/ce/dau%20sponsored%20documents/sw%20cost%20est%20manual%20vol%20i%20rev%2010.pdf.

20 "How Much Could Software Errors Be Costing Your Company?" *Raygun Blog*, Raygun Blog, 22 Mar. 2017, raygun.com/blog/cost-of-software-errors/.

21 Petrucci, Lt Col David. "Squeezing More Value From Test." *DAU News - Squeezing More Value From Test*, 1 Jan 2020, www.dau.edu/library/defense-atl/blog/Squeezing-More-Value-From-Test.

ANNUAL BENEFIT

Tangram Pro™ CSIP provides integrated assurance tools, including those for static analysis and requirement verification, which drastically reduce the amount of testing time required to identify errors introduced during the requirements, design, and coding phases of development. We assign a conservative estimate of **20% reduction in test costs** as a result of this functionality, leading to our net benefit calculation:

$11.5 million * .20 =
$2.3 million reduction in test costs per year with Tangram Pro™ CSIP

D1.3 COMPONENT REUSE $2.29 MILLION ANNUAL BENEFIT

The textbook *Software Reuse: Methods, Models, and Costs*[22] estimates that component reuse comprises 10-15% of programmatic costs in typical component-oriented engineering. Given this figure and our program budget of $23 million for mission systems software RDT&E, we calculate the total cost of component reuse without CSIP as follows.

$23 million * .10 = **$2.3 million per year without CSIP**

The Tangram Pro™ CSIP greatly simplifies the process of component reuse through its component library interface and tools for rapid creation and updating of existing components. The average time to create a new implementation of (or reuse) a component with the Tangram Pro™ CSIP is 2 hours.

Our model program maintains a system of 12 components, each of which is updated 3 times per year. Given this information, we calculate the cost of component reuse for our program with the assistance of the Tangram Pro™ CSIP as follows:

12 components * 3 reuses/year = 36 component reuses/year

36 component reuses * 2 hours/ component reuse = 72 hours/reuse/year

72 hours * $135.73 hourly labor rate = **$9772.56 per year with Tangram Pro™ CSIP**

ANNUAL BENEFIT

Component Reuse Without CSIP - Component Reuse with CSIP = Benefit

$2.3 million - $9772.56 = **$2.29 million annual savings with CSIP**

[22] *Software Reuse Methods, Models, and Costs,* by Ronald J. Leach, Verlag Nicht Ermittelbar, 2012, p. 182.

D2. TESTING, VERIFICATION, AND CERTIFICATION EFFICIENCIES

D2.1 EARLY DEFECT DETECTION: $485,045.53 ANNUAL BENEFIT

In an ideal software development team, 20% of each team member's time is devoted to "reactive work", or the debugging and fixing of errors introduced during productive work[23]. Given a standard 2080 hour work year, 20 RDT&E staff members, and our model program's average hourly labor rate of $135.73,

2080 hours * 20 staff members = **41,600 RDT&E labor hours/year**
41,600 labor hours * .20 = **8320 hours labor hours/year spent on reactive work**

8320 * $135.73 =
$1,129,273.46 reactive work cost per year without CSIP

The Defense Innovation Board's 2019 report *Software Is Never Done* reports approximately 75% of errors for COTS and custom software are resolved before deployment[24]. We interpret this to indicate that **25% of errors are not found until a component is in production.** Given that the cost of repairing an error or defect after release is 30 times greater than pre-release[25], 91% of reactive work cost is spent repairing issues found in production.[26]

$1,129,273.46 * (.91) **=**
$1,027,638.85 labor cost to resolve errors found in production per year without CSIP

Well-sourced studies report that 55[27]-85[28]% of errors in software development are introduced during the requirements and design phases, with a commonly accepted rate of 70%. As such, we determine that:

$1,129,273.46 * .70 =
$790,491.42 labor cost for resolving errors introduced in requirements and design per year without CSIP

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[23] "How Much Could Software Errors Be Costing Your Company?" *Raygun Blog*, Raygun Blog, 22 Mar. 2017, raygun.com/blog/cost-of-software-errors/.

[24] *Software Is Never Done.* Defense Innovation Board, 3 May 2019, media.defense.gov/2019/Apr/30/2002124828/-1/-1/0/SOFTWAREISNEVERDONE_REFACTORINGTHEACQUISITIONCODEFORCOMPETITIVEADVANTAGE_FINAL.SWAP.REPORT.PDF.

[25] "The Exponential Cost of Fixing Bugs." *DeepSource*, DeepSource, 29 Jan. 2019, deepsource.io/blog/exponential-cost-of-fixing-bugs/.

[26] If 100 errors are discovered in a year, 75 are found pre-release and 25 post-release.
Assuming a pre-release error costs $1 to fix and a post-release error costs $30 to fix, pre-release errors cost $75 total to repair and post-release $750. The total cost of error fix is $825, so: (750/825)*100%= 91% of cost incurred by 25% of error fixing.

[27] *Error Cost Escalation Through the Project Life Cycle*. NASA Johnson Space Center, ntrs.nasa.gov/api/citations/20100036670/downloads/20100036670.pdf.

[28] *How to Eliminate Over Half of All Design Errors Before They Occur*. QRA Corp, Oct. 2020, qracorp.com/wp-content/uploads/2020/10/Leveraging-NLP-in-Requirements-Analysis.pdf.

Given that 25% of errors are not identified until after release, we assume that **47.2% of errors found in production were introduced early in the software development lifecycle**.

$1,027,638.85 * .472 =
$485,045.53 labor cost for resolving errors found in production introduced in requirements and design per year without CSIP

ANNUAL BENEFIT

Assurance tools in the Tangram Pro™ CSIP are specifically designed to identify requirements and design errors before implementation, thus eliminating the cost to resolve them in production and resulting in a **benefit of $485,045.53 annually.**

D2.2 IMPROVED CYBERSECURITY: $583,647.38 ANNUAL BENEFIT

Research has shown that 26% of software defects are security vulnerabilities[29], and that components introduce an average of 24 security vulnerabilities[30] when reused in an application. Given this data, we assume that each component update introduces 92 total software defects.

Given that our system includes 12 components that are each updated 3 times per year, and assuming a flat rate of defects,

12 components * 3 updates * 92 defects =
3312 total software defects introduced per year

3312 total software defects * .26% **=**
862 security vulnerabilities introduced per year

Assuming that all defects are identified and given equal effort, we find,

$11.5 million / 3312 defects =
$3472.22 average cost per defect without CSIP

$3472.22 * 862 =
$2,993,055.56 total annual cost of security vulnerabilities without CSIP

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29 *Software Fail Watch: 5th Edition*. Tricentis, 2018, www.tricentis.com/wp-content/uploads/2019/01/Software-Fails-Watch-5th-edition.pdf.

30 *How Do Vulnerabilities Get Into Software?* Veracode, www.veracode.com/sites/default/files/Resources/Whitepapers/how-vulnerabilities-get-into-software-veracode.pdf.

Static analysis tools capture 50%[31] of security vulnerabilities before software enters testing, where the cost per fault is 61%[32] of those found during the testing phase.

Given that 862 security vulnerabilities occur per year and that the average cost per defect is $3472.22 without CSIP,

862 vulnerabilities * 50% =
431 vulnerabilities captured with static analysis tools before testing phase

$3472.22 * 61% =
$2118.05 cost per defect found before testing phase with CSIP

431 * $2118.05 **=**
$912,881.36 cost to fix security vulnerabilities found before testing phase with CSIP

Assuming that the remaining 431 errors are not found until testing, we calculate:

$912,881.36 + (431 * $3472.22) =
$2,409,408.18 total annual cost of security vulnerabilities with CSIP

ANNUAL BENEFIT

Cost of Security Vulnerabilities without CSIP - Cost of Security Vulnerabilities with CSIP = Benefit

$2,993,055.56 - $2,409,408.18 = **$583,647.38 annual savings with CSIP**

D3. FASTER SOFTWARE DELIVERY & RELEASE CADENCE

D3.1 FASTER PRODUCTION TIME: $1.41 MILLION ANNUAL BENEFIT

The use of Digital Twins is reported to provide an overall **30% improvement in cycle time**[33] for delivery of system updates. Given that our model program delivers updated components 3 times per year, we assume that **each delivery cycle takes 4 months (or ⅓ year) without CSIP**. With a standard 2080 labor hour year and our team of 20,

(2080 hours * 20 team members) / 3 =
13,866.7 labor hours per system update without CSIP

31 Okun, Vadim, et al. *Effect of Static Analysis Tools on Software Security.* National Institute of Standards and Technology.

32 Aldrich, Jonathan. *Static Analysis for Software Quality*. Carnegie Mellon University, 7 July 2011, resources.sei.cmu.edu/asset_files/Presentation/2011_017_101_51582.pdf.

33 Marr, Bernard. "What Is Digital Twin Technology - And Why Is It So Important?" *Forbes*, Forbes Magazine, 6 Mar. 2017, www.forbes.com/sites/bernardmarr/2017/03/06/what-is-digital-twin-technology-and-why-is-it-so-important/?sh=5d8e6e5a2e2a.

Given our average hourly labor rate of $135.73,

13,866.7 * $135.73 =
$1,882,127.19 total labor cost per system update without CSIP

With a 30% improvement in cycle time from use of Digital Twin technologies, the time to deliver an update decreases from 4 months to 2.8 months. We round up to 3 months, or ¼ year, for simplicity. This gives us the following:

(2080 annual labor hours per team member * 20 team members) / 4 =
10,400 labor hours per system update with CSIP

10,400 * $135.73 =
$1,411,589.00 total labor cost per system update with CSIP

ANNUAL BENEFIT

In our analysis we quantify the benefit to the program by calculating the labor cost savings related to the production cycle time reduction enabled by the Tangram Pro™ CSIP's Digital Twin capabilities. For each system update:

$1,882,127.19 labor cost without CSIP - $1,411,589.00 labor cost with CSIP =
$470,538 reduction in labor cost per system update

Given that the system's components are updated 3 times per year, the annual cost savings is calculated as:

$470,538 * 3 = **$1,411,614.57 reduction in cycle costs per year with Tangram Pro™ CSIP**

D3.2 MODEL BASED SYSTEMS ENGINEERING: $4.2 MILLION ANNUAL BENEFIT

The Tangram Pro™ CSIP enables an easy transition from traditional document-based systems engineering to MBSE. Given that our model program delivers updated components 3 times per year, we assume that each delivery cycle takes 4 months (or ⅓ year) without CSIP. Thus, given our annual mission systems software budget of **$23 million for RDT&E,**

$23 million * ⅓ year =
$7.7 million per update without CSIP or transition to MBSE

Projects following an MBSE approach deliver software up to 3x earlier than those following traditional systems engineering approaches when 15-17% of effort is dedicated to systems engineering.[34] Given this data, using an MBSE approach can reduce delivery time for updates from 3 months to 1 month, or 1/12 year:

$23 million * 1/12 year =
$1.9 million per update after transition to MBSE with CSIP

Given our RDT&E staff of 20, a standard 2080 labor hour year, and average hourly labor rate of $135.73, we find that the investment needed to realize the value of MBSE through a CSIP is:

(20 team members * 2080 labor hours * $135.73) * 17% =
$5,646,368 annual System Engineering cost

ANNUAL BENEFIT

To determine the benefit of transitioning to MBSE, we calculate the following:

(Cost of Update without MBSE - Cost of Update with MBSE) - annual MBSE cost = Benefit

($7.7 million * 3 updates/year) - ($1.9 millon * 3 updates/year) - $5,646,368 =
$11,603,634 benefit of transitioning to MBSE with Tangram Pro™ CSIP

The benefits of adopting MBSE practices frequently include lower overall cost of CBE program execution and early defect detection. Due to this overlap with other benefits of adopting the Tangram Pro™ CSIP, we are discounting the MBSE benefit to avoid double counting:

$11,603,634 - $6.9 million - $485,045 =
$4,218,589 annual benefit of transitioning to MBSE with Tangram Pro™ CSIP

[34] Carroll, Edward R, and Robert J Malins. *Systematic Literature Review: How Is Model Based Systems Engineering Justified?* Sandia National Laboratories , Mar. 2016, www.incose.org/docs/default-source/enchantment/161109-carrolled-howismodel-basedsystemsengineeringjustified-researchreport.pdf.