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How Model-Based SE Makes Product/System Lifecycle Management Framework More Effective

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Abstract. Product Lifecycle Management business approach goals have always been key to foster product innovation and companies' competitive advantage through effective Intellectual Property creation, evolution and reuse management to successfully transition into successful product manufacturing and operations, taking into account the whole product lifecycle and its evolution through changes or derived products creations. Over the past few decades we went through several shifts in forces driving product development, from product digitization, to globalization, to regulation, to personalization, to servitization, to software intensive products, to connectivity increasing the complexity of the products, the processes required to develop, manufacture, operate, maintain and retire them, the amount of information and relationships between information to manage. Moreover a product can now be described as a complex system itself, or part of a bigger system or even part of a System of Systems, leading to an even grater complexity to manage in order to be sure that the initial requirements or needs are met by the product or system when it starts operating. This paper aims at showing how a Systems Engineering and Model Based Systems Engineering approach can complement and add value to a Product/System Life Cycle Management solution framework in order to improve the capability of an organization to meet initial requirements/needs on time and within budget.

Introduction

Intellectual Property is the asset allowing a company to be more competitive and successful in today's increasingly knowledge-based economy. It is all about value generated by a Company, in fact IP normally cannot be showed on the corporate balance sheet as an intangible asset, but its value determines the success or a failure of a business, being Managers' ability to exploit these effectively and turn them to a profit, so IP can affect the price of the stock.

IP can include many items, such as Patents, Proprietary Technologies, etc. but, overall, include the skills, the knowledge and all relevant data that a company has developed about how to build its products/product lines or services; the contributions come from individual employees or groups.

Maintaining, increasing and extracting value from intellectual property and preventing others from deriving value from it is an essential responsibility for any company.

Initially, IP was managed mainly through paper based documents and processes, such as requirements, specifications, drawings, etc. verified and approved through hand written signatures, then in the mid '80s a first wave of transformation in the manufacturing industry led to the product DIGITIZATION, the IP was transformed from paper and physical assets to digital assets, replacing analog product and service information with a fully accurate virtual representation that can be easily leveraged across the value chain (engineering, factory floor, service) and starting an evolution which went though several other transformations up to the present days.

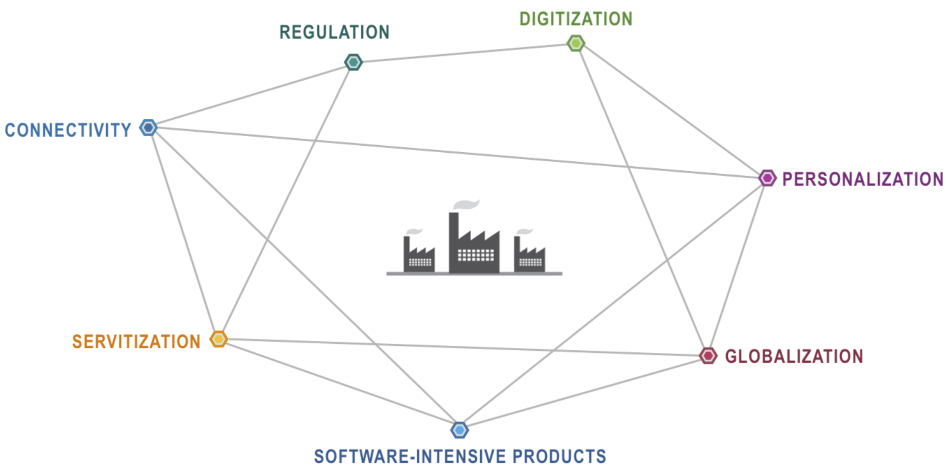

Figure 1. Waves of manufacturing transformations

Following the digitization transformation we went through 6 additional waves of evolution:

1. GLOBALIZATION

The general shrinking of the world driven by technology that eliminates economic and geographical divisions and opens new markets.

2. REGULATION

Enforcement of governmental rules, non-governmental organization policies and industry standards related to environment, health, safety and trade.

3. PERSONALIZATION

Efficiently tailoring products and services to accommodate regional and personal preferences.

4. SOFTWARE-INTENSIVE PRODUCTS

Integrated systems of hardware and software capable of sophisticated human-to-machine interaction, diagnostics and service data capture, with additional value delivered through enhancements.

5. SERVITIZATION

Fundamental business model shift in which products evolve to integrated "bundles" of services capable of delivering new value continuously throughout the customer experience lifecycle.

6. CONNECTIVITY

Pervasive networks of "things" – often mobile – embedded with sensors and individually addressable to enable sophisticated monitoring, control, and communication.

Alongside the evolution waves a disciplined approach and supporting tools emerged to manage the lifecycle of products and the information created and consumed along the lifecycle, this approach and tools are recognized with the name of PLM or Product Lifecycle Management.

The components of an effective PLM framework, able to effectively support manufacturers across the transformations, have extended the original classical PLM and CAD (Computer Aided Design) domains to SCM (Supply Chain Management), ALM (Application Lifecycle Management), SLM (Service Lifecycle Management) and IoT (Internet of Things) domains, as show in Figure 2.

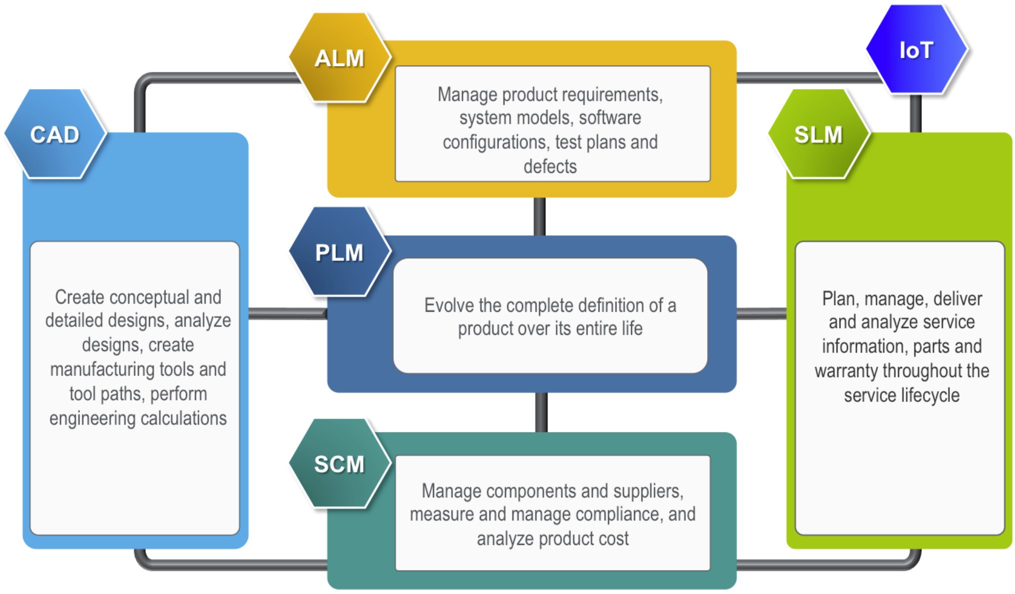

Figure 2. Extended PLM framework

Each step in this evolution also brought with it an increased complexity in products and systems definition as well as related IP management, leading to increasing difficulties in getting the right products to the market, on time, within budget and at the right price point.

How can organizations cope with this increasing complexity of today systems, in a scenario where the market asks not just for products but also for configurable products and services? The solution is augmenting the Extended Product Lifecycle Management framework, to transform it into a collaborative, multi-disciplinary Systems Engineering practice through the adoption of a fully embedded Model-Based Systems Engineering methodology.

Of course, this makes sense especially for complex products, and allows formally describing and designing a system since the start of requirements analysis phase.

For the scope and objectives of this paper, we will analyze the components involved in the management of the system definition process and information, describing the positive impacts of adopting a MBSE/PLE approach to System Development.

Content

We will introduce the objectives of Manufactures in current market context and will explain how the new Model Based approach extends the traditional PLM and Systems Engineering vision.

Then we will talk about our guiding principles and the 4 Systems Engineering vision cornerstones and will highlight that technical approaches on this extended Systems Engineering vision need to be driven by industry, mainly the mission and safety critical, embedded system industry.

Manufacturers' Objectives and Engineering Challenges

Today, as organizations struggle to produce more innovative products in the context of the transformations the market went through, undoubtedly, they will continue to increase the amount of software within those products, which will further drive complexity at levels much higher than before, especially taking into accounts the tight requirements about safety imposed by national and international regulations.

Organizations have driven significant improvements in the way they engineer and deliver those products in order to address these trends. A key area for improvement is fostering a transformation from isolated systems, hardware, and software engineering disciplines to a collaborative, multi-disciplinary engineering practice, that begins with product requirements and continues throughout the lifecycle, conveying the following set of engineering challenges:

- Ensuring customer needs are met
- Reducing and mitigating program/product risks
- Increasing reuse while supporting system/product variants
- Understanding trade-offs between and across needs, requirements and system performances

The most suitable way to confront those challenges for complex, safety critical products and systems is a disciplined approach such as Systems Engineering.

However, traditional Systems Engineering frameworks, as the one described by the popular V-Model portrayed in Figure 3, are incomplete, missing important elements, which require system design activities in order to "enable the realization of successful systems" and to support all waves of manufacturing transformations. We defined and propose a reference framework aiming at supporting the Total System Lifecycle Management, enabling true whole life support.

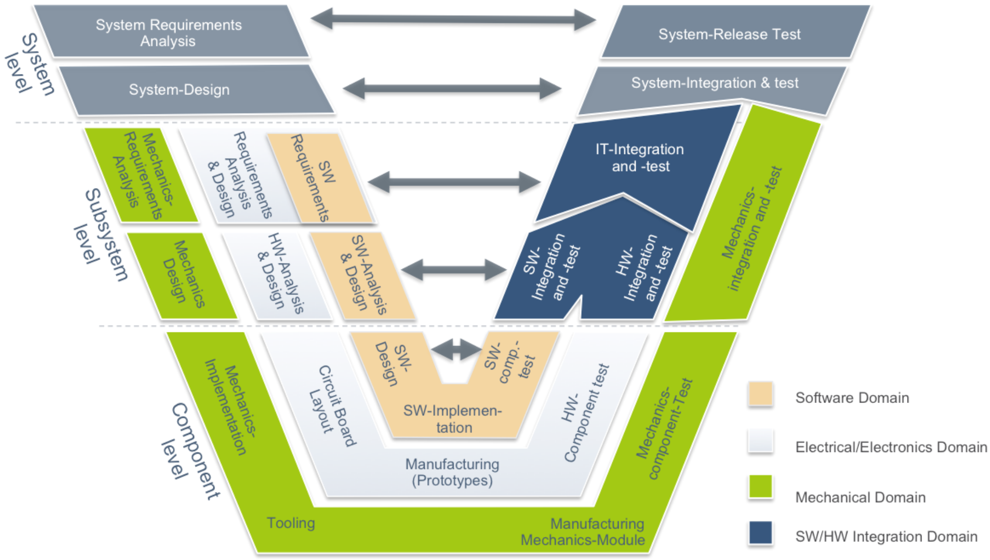

Figure 3. Traditional Systems Engineering framework

System Lifecycle Management

Figure 4 illustrates our proposal for the Extend Systems Engineering and Lifecycle Management framework, where the traditional Software, Mechanical and Electrical/Electronic disciplines are complemented by the Manufacturing and Service planning streams, which become part of the concurrent engineering process under the control of the Systems Engineering methodology.

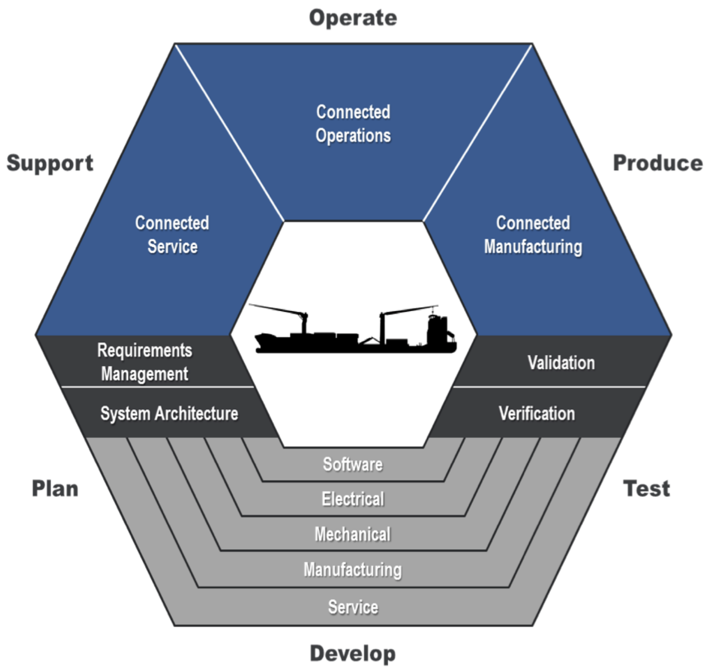

Figure 4. Extended Systems Engineering and Lifecycle Management framework

The framework extends its coverage to the manufacturing, operations and in-service phases of the lifecycle (up to the retirement, if needed) taking advantage of the possibility to connect smart, software enriched products through sensors gathering product and surrounding environment parameters or through actuators, enabling the possibility to monitor, operate and service smart products remotely, and, in some cases, enabling products to self-heal or self-adapt to operating conditions.

In the Extended Systems Engineering framework we move the manufacturing planning and service planning processes upstream, so that organizations are in a better position to deliver on-time and on budget, considering as early as possible the impacts of design decisions on downstream processes.

For many organizations, Manufacturing and/or Service activities are outsourced or carried on by separate legal entities; nevertheless, they must be considered highly integrated processes to allow for optimal system performances design across the lifecycle. Like for traditional concurrent engineering activities involving software, mechanical and electrical/electronic components of the product organizations must empower and support collaboration across geographical dispersed teams for manufacturing and service planning and execution teams, also.

Like the traditional V-Model SE framework, the Extended Framework supports a process involving decomposing the systems into subsystems and components and guides through the flow of requirements analysis, system/subsystem/component design, development, integration and test.

Within this framework Model Based Systems Engineering is of uttermost importance during the requirements management and system architecture definition phases, also enabling very early stage system simulation activities, allowing to analyze and take best possible decisions about functional, RAMS (A. Garro, A. Tundis, 2012) and performance requirements trade-offs.

Moreover, the use of a MBSE approach enables practices such as Set Based Design, being adopted, for example, by the U.S. Navy for complex systems acquisition programs such as the Ship-to-Shore Connection (SSC), to increase the chances to define an optimal system solution for the required capabilities (D. J. Singer, N. Doerry, M. E. Buckley, 2009).

Benefits and contribution of MBSE extends to the verification and operation phases of the System Lifecycle, allowing to define Verification and Validation procedures as well as formally describing operating procedures and supporting training activities (Friedenthal, Sanford et al. 2007)

MBSE-Enabled Extended Framework

To successfully enhance the Extended Systems Engineering and Lifecycle Management framework with MBSE methodology and overcome Manufactures' engineering challenges 4 elements are the cornerstone of an effective solution and must work together seamlessly, integrating the processes, the people – with related organizations – and the technologies enabling the automation of process and facilitating the activities of systems engineers and other participant roles in creating and managing the product information and their relationships throughout the System Lifecycle. These cornerstones are shown in Figure 5 and detailed in Figure 6.

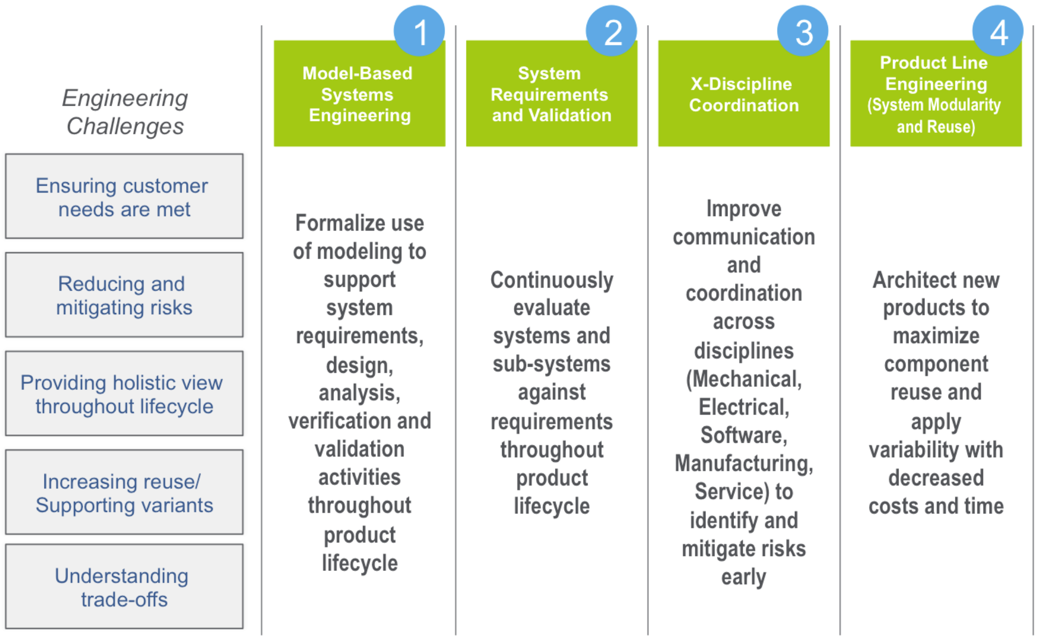

Figure 5. The 4 cornerstones for an MBS-enabled PLM framework overcoming Manufacturers' engineering challenges

1. Model-Based Systems Engineering. This is obviously one of the components and it is meant to manage the System Architecture and the UML/SysML/UPDM Model methodology in a collaborative way, supporting a multi-user, multi-location model authoring and sharing, even among geographically dispersed design teams. Thanks to the common repository a full consistency is ensured, providing enterprise visibility to functions, interfaces and all model elements with their relationships. A real-time full traceability is a key element for an error-free model design.

2. System Requirements and Validation. Customer needs are elicited early in the development cycle and come from different sources, like external requirement management tools, general-purpose tools like MS Word or MS Excel, etc. Through this framework component, it is possible to import external requirements from the most common formats (ReqIF, MS Word, Excel, etc.), and then analyze, decompose, detail, trace them through system development. It is also key to enable the continuous validation of lifecycle assets from requirements to test as they are created and changed and verify as-designed and as-built product against requirements and validate it actually meets initial needs throughout operations.

The adoption of a MBSE approach improves this component allowing the creation of a link between unstructured, informal requirements and a formal, suitable for simulation, definition of the same requirements.

Moreover MBS enable system engineers to formally define system requirements and performance targets from high level needs, creating a early formal view of the solution domain, directly linked to the problem domain which may be described informally.

Another added value of MBSE for the Systems Engineering and Validation component is the capability to design and document early test cases and allow to define and simulate system components' behavior to start verification activities very early in the development cycle, thus allowing for maximum efficiency in analyzing performances and requirements trade-offs easily enabling early analysis of multiple solutions at once.

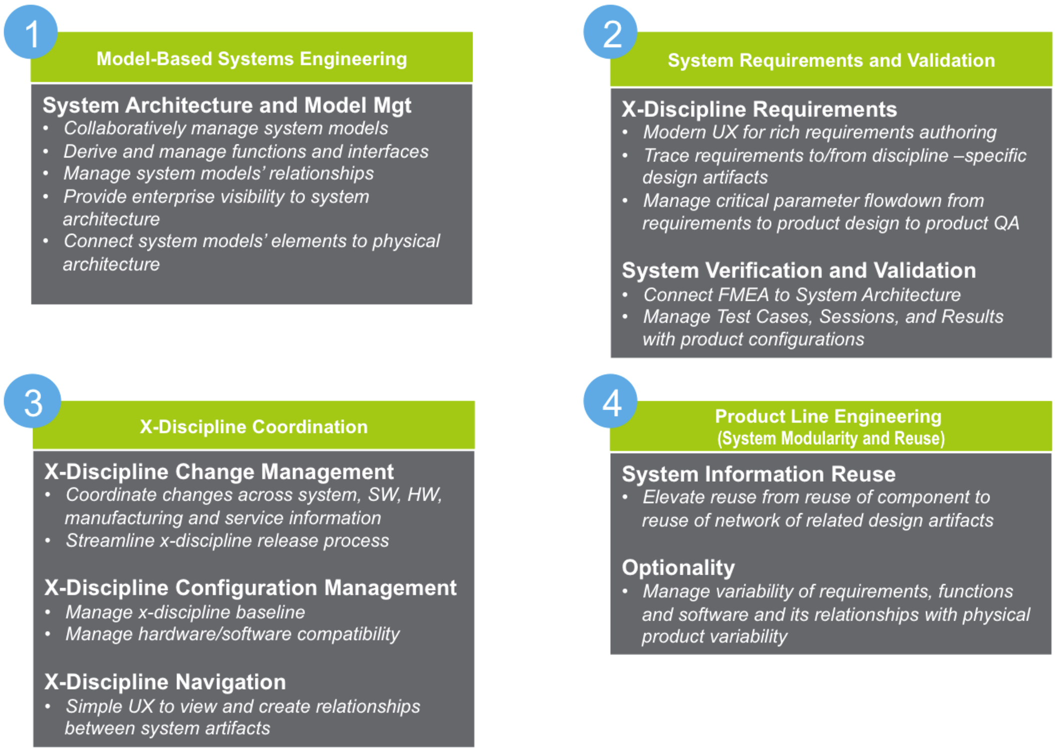

Figure 6. Content of the 4 cornerstones

3. X-Disciplines Coordination. A complex system is made up by the means on different disciplines: mechanics, electromechanical, electronics, software, etc. Being extremely successful and effective in one discipline and lousy in the others lead to less then optimal system performances and, possibly, to failure. It is key to take advantage of high value collaboration between mechanical, electrical & software as well as manufacturing and service engineering to be fully successful in designing complex systems across multiple disciplines and interchange all the data in an easy, error-free way.

Collaboration must be ensured also in order to control the system configuration as it evolves through changes requested by participants in the system development process, such as marketing, manufacturing, customer or design, tracing the change process and evaluate their impacts on system quality, services, functions and interfaces, as well as enable cost impacts estimation on system TCO (Total Cost of Ownership).

MBSE enhances this component improving the ability to easily correlate:

- the needs and requirements
- the functions and related behavior
- the interfaces
- the physical structure

creating a bridge between a usually highly unstructured and informal definition of the system (needs and requirements) and a very formal and structured description (the product structure an related information needed to describe it, build it, quality control it, etc.) and keeping those relationships up to date throughout system modifications, facilitating change impacts analysis and reducing errors discovered at late stages of development.

4. Product Line Engineering. Mass customization and best matching different solutions for the same class of problems require the capability to reuse as much as possible existing subsystems, components and engineering artifacts as well as manage product platforms and product lines, optimizing the costs in order to satisfy multiple needs with matching product and system variants.

The possibility to identify from the start the commonalities and develop at once multiple versions of the same system, defined by a set of options and rules based on option choices, for all disciplines is fundamental in order to govern the amount of information needed to define, design, manufacture, test, operate and service all the possible variants in an efficient way.

The use of formal, modeling, methods, such as OVM (Orthogonal Variant Modeling) from PALUNO – The Ruhr Institute of Software Technology, coupled with classical PLM product configurators enable the possibility to manage the design and definition of system variants across the whole lifecycle, allowing to define a set of choices identifying a specific system variant and filtering all the relevant information for that specific variant at once, including needs, requirements, functions, activities, tasks, interfaces, software, physical design, build instructions, service manuals, etc.

These components, which are not exhaustive of the whole framework but are the most impacted by the introduction of a MBSE approach, improve collaboration across disparate and geographically/functionally dispersed design teams, shorten development cycles, allow to achieve higher product quality, faster time to market, and, overall, increased design reuse.

Conclusions

Development and operation of complex systems requires a disciplined approach.

Extending a traditional PLM framework through adoption of Systems Engineering and Model-Based Systems Engineering methodologies multiplies its typical benefits of increasing product quality, reducing Time to Market and increase the number of successful product launches.

Analysts and researchers agree on Systems Engineering effectiveness and the value added of Model Based Systems Engineering.

Boeing found that the most rigorous systems engineering practices applied to the most complex system enables the completion of the project in ½ the time when compared with the least complex system manufactured with the least rigorous systems engineering practices. (E. C. Honour, 2004).

Aberdeen Group found (2012) that leading companies are 50% more likely than their peers to credit success to effective systems engineering. Gains recorded include:

- Met 88% of quality targets
- Met 86% of revenue targets
- Met 85% of product launch targets

- 12% decrease in development time over previous years
- 9% increase in profit margins on new products.

A model-based approach to product line engineering delivers 23% more projects on time, at 62% lower cost, than alternatives – based on a survey of 667 engineering respondents conducted by analyst firm Embedded Market Forecasters (J. Krasner, 2014).

Definitions

Term	Definition	Source
Intellectual Property	Something (such as an idea, invention, or process) that comes from a person's mind	Merriam-Webster dictionary
Model-Based Systems Engineering - MBSE	MBSE is the formalized application of modeling to support system requirements, design, analysis, verification and validation, beginning in the conceptual design phase and continuing throughout development and later life cycle phases	INCOSE MBSE Initiative
Product Lifecycle Management (PLM)	A strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life—integrating people, processes, business systems, and information	CIMdata – "PLM – Empowering the Future of Business" report
Systems Engineering	SE is an interdisciplinary approach and means to enable the realization of successful systems	INCOSE Systems Engineering Handbook v. 3.2.2, page 6

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