Belcan

— Engineering Better Outcomes

Managing Product Complexity with Systems Engineering

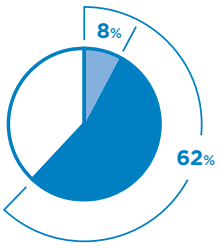
Today's products are no longer simple devices. They are complex, interconnected systems that are often part of a larger system. Traditional product development methods are ill-suited to bringing these products to market successfully. Systems engineering (SE) is a discipline that takes a holistic, interdisciplinary approach to managing the complexity inherent in these difficult development environments. It is also a crucial foundation for the adoption and success of Digital Innovation, which accelerates and improves an organization's product development and delivery. This paper outlines some common product development pain points and how SE helps alleviate them. It breaks down the fundamentals of SE and the steps you need to follow to integrate it into your organization.

Accelerating Product Development

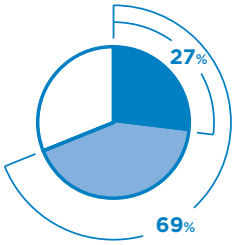
Aircraft, vehicles, consumer electronics, homes and buildings, medical devices – it's hard to find a product today that isn't a system. Our highly interconnected world brings new levels of complexity and difficulty to product development initiatives, especially in highly regulated industries such as aerospace, transportation, and medical devices. Traditional siloed development approaches are insufficient to bring today's innovative products to market quickly and with quality.

In fact, the majority of product development initiatives fail. Systems engineering (SE) is a discipline that significantly increases the odds of success. Projects where SE best practices are not followed have a slim 8% likelihood of success, compared with 62% for projects where they are, according to research from the International Council on Systems Engineering (INCOSE) Systems Engineering Effectiveness Working Group in collaboration with IEEE AESS and other groups. Teams that don't adopt SE best practices have a 69% chance of failure compared to 27% for adopters. SE is directly related to reduced development time and project costs.

Implementing SE is a crucial part of adopting Digital Innovation (DI), which is the tools, techniques, processes, and cultural changes that are used to accelerate and improve an organization's product development and delivery. Cultural changes are oneof the most important – and difficult – aspects of the new ways of working required for DI to take hold. A DI culture is one of continuous learning, trying new things, failing fast but recovering fast, and encouraging participation from everyone. Spanning numerous development areas from agile software development and security to machine learning, successful DI initiatives rely heavily on SE best practices.



The likelihood of success for companies who engage INCOSE best practices for product development increases from **8%** to **62%**.



The inverse is also significant. The likelihood of failure decreases from **69%** to **27%**.

What is Systems Engineering?

INCOSE defines systems engineering as an interdisciplinary approach and means to enable the realization of successful systems. SE takes into consideration all aspects of the product lifecycle from initial concept to product retirement, and brings together all facets of the business involved throughout the lifecycle. Adopting SE best practices helps ensure that 1) the right product is built by examining the entire product lifecycle; and 2) that it is built as efficiently as possible by applying best practices to the product development effort.

The Right Product ...

By taking into account the needs of all stakeholders – customers, marketers, designers, developers, testers, manufacturers, users, maintainers, and regulators, among others – SE helps ensure the right product is built the first time. This holistic approach ensures that the product is successful throughout its lifecycle, from entry to service through retirement.

... Built as Efficiently as Possible

To build anything efficiently, you need to know what to do and how to do it, have the proper tools, and understand how to use those tools correctly. SE provides this for product development projects: it is a set of processes, activities, tools, and techniques that have been proven to lower development costs, improve efficiency and quality, and shorten time to market.

> Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.
>
> -INCOSE

Processes provide the roadmap for the development effort, ensuring that the team knows what needs to be done to be successful and has the proper level of diligence and discipline along the way. INCOSE breaks processes into:

- Technical processes related to requirements, design, implementation, verification, etc.
- Technical management processes such as project planning and risk management
- Agreement processes related to acquisition and supply chain
- Organizational project-enabling processes including quality management and lifecycle model

Process is the "what".

Activities are the specific tasks or actions that can be completed to support each process and generate the required outputs. Activities are the "how" to the processes "what".

Tools are aids that help complete activities efficiently. A vast array of tools is available to help with things like defining product features, managing requirements, developing architectures, defining use cases, creating models and simulations, managing the configuration, analyzing failure modes and effects, assessing risk, and many others.

Techniques and best practices are specific ways of using tools and completing activities that ensure high quality. For example, certain techniques for speaking with customers and users make it easier to extract key capabilities and characteristics needed for the product. Good techniques for defining requirements will ensure the work statement is clear and design is not unnecessarily constrained. And using the appropriate techniques for creating architectures makes it easier for problems to be discovered early, when they are less costly to fix.

The Origins of Systems Engineering

Bell Labs first used the term systems engineering in the 1940s during the development of the Nike surface-to-air missile system. Products and systems had become so complex that existing development approaches were no longer working. New methods were devised to manage these difficult, innovative projects. One of the first conscious applications of modern SE was NASA's Apollo program in the 1960s – a highly complex system of systems. To this day, few problems have been as challenging as those solved during this program. The processes developed along the way have stood the test of time and have since evolved to address the challenges of modern developments.

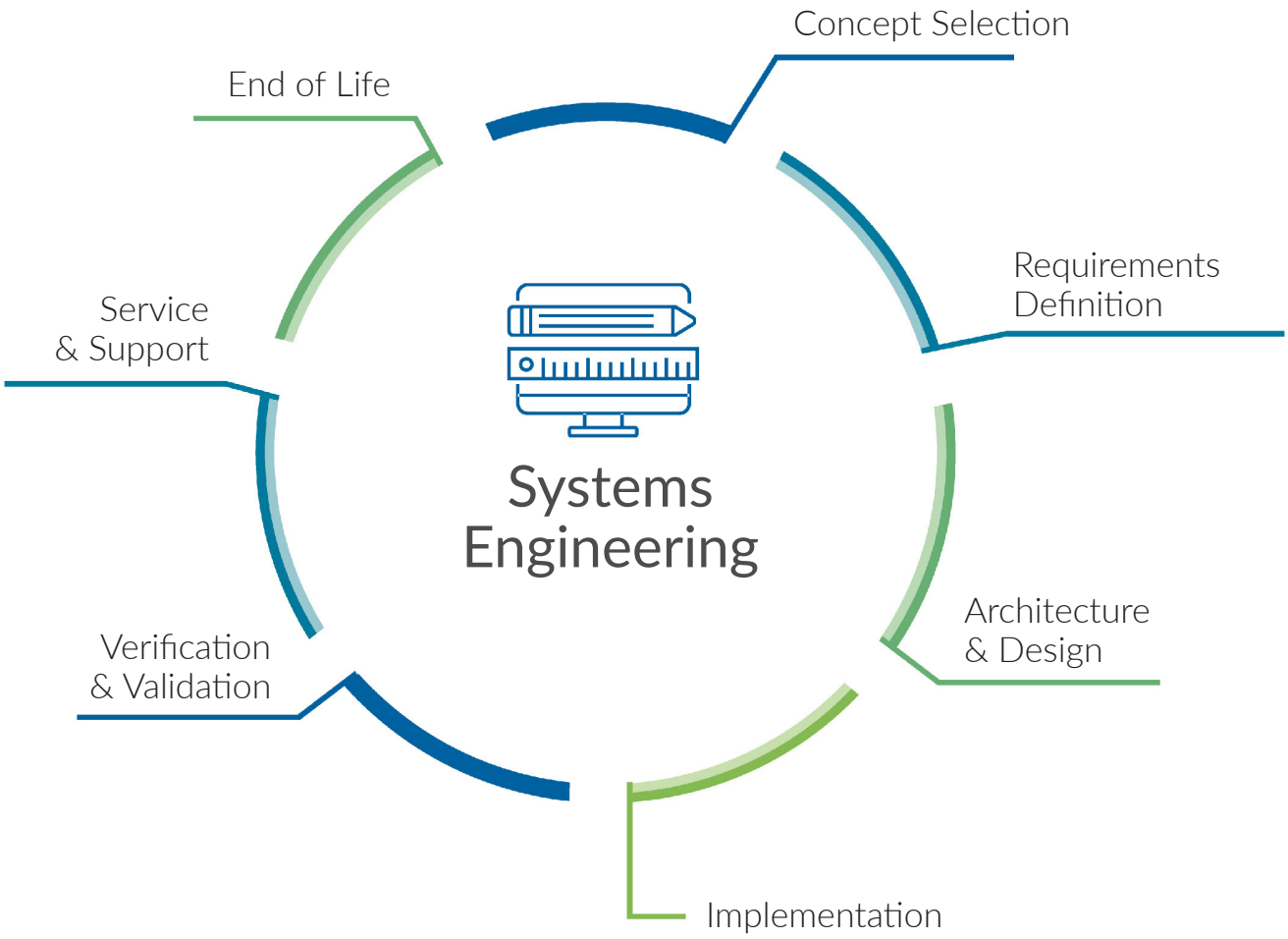
Systems Engineering in Practice

There are numerous product development methodologies to choose from – Agile, Waterfall, Spiral, Rapid Application Development (RAD), and Rational Unified Process (RUP) to name a few. Regardless of which methodology is chosen, there are certain elements that are key to any successful product development project:

- **Concept Selection** – Understand market, customer, business, regulatory, and technical needs and select the right design concept to meet it.
- **Requirements Definition** – Define and analyze requirements, risks, and alternatives and capture what needs to be done without unnecessarily constraining the design; develop a product roadmap.
- **Architecture and Design** – Develop the right architecture to fulfill the requirements.
- **Implementation** – Build the product efficiently; ensure the pieces work together as they should, and integrate it with larger or ancillary systems.
- **Verification and Validation (V&V)** – Ensure the productmeets requirements (verification)and that the requirements meet market and business needs (validation).

An upfront investment in SE also takes into account the requirements for product support and retirement as part of the entire product lifecycle beyond the development phase:

- **Service and Support** – Upon entry into service, make sure the product can be maintained and supported efficiently.
- **End of Life** – Ensure the product can be sunsetted, retired, or replaced with a newer model.



How Can SE Help My Development Process?

By applying SE to the entire product development lifecycle, teams can see cost and schedule improvements in every phase of the project, maintain higher product quality, and ensure products meet business and customer needs. A typical example of an organization in need of SE is one where multiple teams are working independently on different parts of the product or system. They may not be aware of each other's activities, understand the full scope of requirements, or know how their decisions impact other teams. This disjointed approach is likely to lead to costly, time-consuming development problems, rework, and an end product that doesn't meet customer or business needs.

There are common pain points that organizations experience during different phases of development projects. The focus of SE is to address pain points as efficiently as possible.

Concept Development Phase

No amount of technical design rigor can make up for a poorly selected concept. In order to select the right concept, there must be a clear understanding of the problem being solved. Vague market, customer, and business requirements make this difficult. Also, a limited understanding of technology options and how they align with business objectives can send teams off on tangents. Teams may struggle to effectively compare alternative options and reach consensus on a path forward.

SE focuses on clearly defining the problem, the requirements for a solution, and then selecting the right concept to meet them. This process includes obtaining buy-in from all impacted stakeholders; considering risks, issues, and opportunities; and accounting for both the things the product must do (features and capabilities) and how it must do them (cost, security, usability, and scalability, for example).

Modernizing Electronic Software Distribution

Objective

An aerospace manufacturer wanted to execute a company-wide, seamless switchover from loading aircraft software using floppy disks to a secure, online electronic vault. They also needed to manage the risks associated with this major transition, while ensuring compliance with FAA regulations.

Challenges

Two major constraints existed: there could be no disruption to manufacturing and there could be little to no disruption to customers. For five years, the manufacturer had been attempting to accomplish this transition internally but had been unsuccessful due to the massive extent of organizations impacted. There was a lack of understanding around the value of the project, who owned it, and why it was urgent.

Solution

Experienced SE consultants drew on their big-picture thinking and consensus-building expertise to determine the project's impacts across the organization and establish the true story. Initial project requirements were whittled down to only what was necessary for success. The project was broken down into phases to contain the scope, manage risk, ensure compliance, and be more successful.

Outcome

Eighteen months after executing a multi-phased migration across nearly 80% of the company's entire manufacturing and distribution process, the switchover was a success – and a perfect example of Digital Innovation. Where software was previously managed using floppy disks, it is now stored in a secure, online electronic vault. It is accessed via a laptop, which can connect to an aircraft, or to a piece of equipment in a factory anywhere in the world.

Architecture and Requirements Phase

There are many myths and misconceptions that perpetuate the belief that investing time in requirements and architecture isn't necessary:

"We understand all the requirements."

"We can always make changes later if this doesn't work."

"Hardware will be more capable by the time we need it."

"We can sort that out in the implementation." "We'll just handle that with software."

"We've always done it this way."

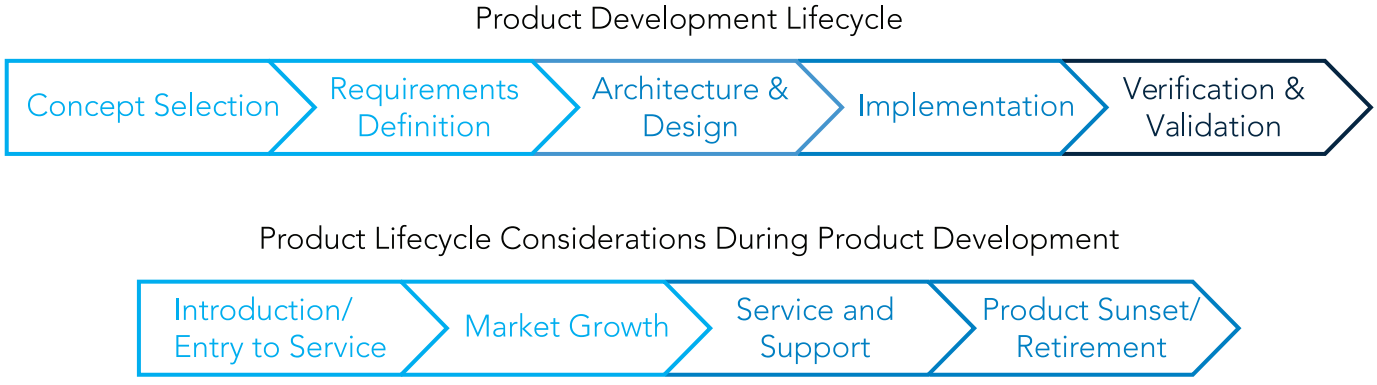
The result of these perceptions is that teams can move too quickly into detailed design and lack a true understanding of how each piece fits into the bigger picture. Customers speak the language of desires and pains. Engineers speak the language of requirements and features. Architecture is the Rosetta Stone that ensures the translation between the two is accurate. Without this clarity, teams tend to go off in different directions or misinterpret the real needs, which causes unnecessary pain and friction. Teams sometimes have a tendency to focus on what's "cool" instead of what stakeholders really need. Not taking a holistic approach makes it hard to quantify why one design decision is better than another or understand the broad impacts of changes and decisions. Finally, many teams lack an ability to determine up- and down-stream impacts of design decisions or to predict overall system behavior.

Through architecture and requirements, SE provides the insight needed to make better informed trade-offs, smarter technology choices, and more thoughtful design decisions. It helps teams translate the well- selected concept into a design that meets business and technical objectives, including regulatory compliance, and gives design teams the information they need to be successful and stay on the same page.

Implementation Phase

It is not unusual for the bulk of product development efforts to be focused on implementation without investing time and effort into the preceding phases. Siloed design teams may encounter integration problems once they try to get their separate pieces to work together. Requirements may change often with efforts heavily influenced by assumptions rather than facts. The tribal knowledge of a few key personnel may drive decision-making, hindering the team's ability to weigh different implementation choices or causing them to lose sight of the big picture.

SE helps teams efficiently build each piece of the product and integrate them together according to the design established in the architecture and requirements phase. Communication and feedback are essential to coordinate decisions, address integration issues, and manage design changes. Risk reduction activities and a focus on preparing for formal validation and verification remain constant throughout implementation.



Verification and Validation (V&V) Phase

Development without ongoing testing via prototyping, models, and simulation can result in some unpleasant surprises once a product or system is turned over for formal testing. Frequent test failures and erratic system behavior can cause expensive and time-consuming rework, with the end result falling short of customer expectations.

SE provides many benefits to V&V. It helps teams identify problems earlier on, before formal V&V, when they are cheaper to fix. It considers how the system must be tested during the design phases to ensure efficiency during V&V. And finally, it helps teams effectively plan for V&V and improves test efficiency. Through SE, there is clear evidence and documentation that the right product was built and is ready for customer acceptance. Defects can be traced through test, requirements, and objectives, and known issues are documented and dispositioned.

Getting Started with Systems Engineering

In order to capitalize on SE's return on investment (ROI) and accelerate the adoption of Digital Innovation, SE needs to be effectively integrated into your development processes. There are three key steps to achieving this:

1. Scale SE to your project, needs, and budget

While SE can have a positive impact on any project, no activities come without cost. The level of investment in activities should be sized appropriately. For example:

- Developing a new product line to break into a new market would likely require more SE investment than evolving an existing product for an established market – and the ROI would be higher with the former.

- Due greatly to complexity, designing an automated factory floor would require more SE investment than designing a new process or integrating a new machine into an existing factory.

Resolving CAPAs to Keep Devices Shipping

Objective

A medical device manufacturer of Class III life-saving devices had two Corrective and Preventative Actions (CAPAs) that had been outstanding for over a year and a half. The company needed to have the CAPAs resolved to ensure that product elements in question were compliant with all pertinent regulations and allowed to continue shipping.

Challenges

Internal teams in both cases believed they had electromagnetic compatibility issues and had spent 17 months working to identify the root cause without success. In one case, a power adapter redesign was already underway.

Solution

Experienced SE consultants thoroughly examined design history files, product requirements, and testing documentation against the IEC 60601 suite of standards. The detailed assessment revealed that both products actually met the required specifications and did not require any modifications. The consultants wrote root cause analyses for both CAPAs and secured cross-functional agreement on their assessments.

Outcome

Both CAPAs were closed about two months after retaining the SE consultants, allowing both products to continue to ship without any costly design changes.

- Identifying ways minimize a product's life cycle costs to the customer or reduce time to market for a new product might require more investment than finding ways to do the same on a smaller scale – like reducing selling price or improving the efficiency of an individual process.

The ROI for SE is higher with higher levels of technical complexity, product novelty, level of integration, and greater volatility.

2. Apply SE throughout the product development lifecycle

SE is intended to provide a solid foundation upon which both the product and the development processes are built. It is far less efficient to apply SE after cost overruns occur, defect rates increase, products fail to meet regulations, or customers become dissatisfied.

While SE principles can help you recover in these situations, the ROI really comes when it is applied early on and continued throughout. Considerations for the entire product lifecycle should be taken into account, starting when the product enters service, expected market growth, service and support, and through product sunset.

3. Ensure SE is present within key roles of your organization

The only way to inject SE into your business is to make sure that those skills are present in essential roles throughout your organization:

- Decisionmakers who are driving the direction of business and technology
- Those responsible defining the product and its roadmap
- Engineers designing or improving parts, processes, and tools
- Managers responsible for the overall success of the project or business impacts
- People acting as liaisons between relevant areas or domains
- Advisors who assist management with tasks, problem resolution, and communication with teams and customers

If the people in your organization are committed to applying SE in their daily routines, you will see positive impacts in your business.

What Do Systems Engineers Do?

Systems engineers bring the processes, activities, tools, and techniques that allow organizations to extract greater value from existing teams and core expertise. Their primary role is to lead and support a system's technical development through the lens of an entire system lifecycle. From the earliest phases of the project, systems engineers help define where to go and how to get there. Effective SEs diplomatically cross organizational boundaries, ensure communication between groups, and help integrate SE best practices into a company's processes.

Hiring SE Consultants

If your organization lacks the bandwidth or expertise to undertake the application of SE internally, partnering with SE consultants can jump-start the process and simultaneously promote the adoption of Digital Innovation. Experienced consultants work as embedded team members to inject the right talent exactly when and where it's needed, and coach team members to support their long-term success. They bring an impartial perspective that offers new ways of doing things and often makes it easier to reach across organizational boundaries and take the bold actions required for innovation and problem solving.

Successful consulting firms employ seasoned SEs that specialize in systems engineering, understand technical disciplines and project management, and bring broad technical domain knowledge and strong leadership skills. Their experts stay current with the latest industry trends and SE methodologies. They are also able to tap into the ideas, experiences, and expertise of the rest of their firm, greatly increasing the value they can provide.

SE: The Key to Unlocking Digital Innovation

Organizations that embrace SE and a culture of Digital Innovation can achieve significantly greater product development success than those who don't, especially as products become more interconnected and complex. SE's processes, activities, tools, and techniques ensure that the right products and systems get built the first time, with high levels of quality and compliance. They are also a vital foundation for adopting the process and cultural changes required for Digital Innovation, and the interdisciplinary approach improves team engagement and performance.

For organizations that don't have the bandwidth or expertise to adopt SE best practices themselves, partnering with experienced consultants can help guide the process and allow companies to focus on their core competencies of bringing innovative ideas and products to market for competitive advantage.

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