Another characteristic of construction projects is increased complexity and number of stakeholders. Unlike other types of projects, large construction projects are often at least partially funded by government agencies. In many cases, there are multiple funding agencies at different levels of government (city, county, state, and federal). Add to this the many groups affected by the project, from local communities to utilities and transit systems that must be crossed or relocated, along with potential land use restrictions and environmental impacts, and the requirements list grows exponentially.

The codes and standards that form part of the requirements add another layer of complexity to construction projects. Unlike aerospace or other types of projects, construction projects can cross into different jurisdictions, leading to varying and sometimes conflicting requirements for the different physical locations of packages of work.

**Systems Engineering for Design-Build Projects**

Design-Build projects have some unique characteristics of their own that have the potential to increase project risk. On design-build projects, there is a shift in responsibility for the quality of the work, including the development of final requirements and specifications, away from the agency and towards the contractor. The design is initiated by one firm, but completed by another: this handoff increases the potential for misinterpreted requirements or incomplete incorporation of requirements. Internal integration is much more complex, as the work is broken down into much smaller packages to enable a more continuous construction effort.

**Status of Systems Engineering in Construction**

Systems engineering can help address all of the issues previously described. However, the application of systems engineering in construction lags behind that of some other sectors, such as aerospace. Progress has been made on applying systems engineering to construction projects in the EU and Australia. While there has been no clear mandate for SE historically, the US High Speed Rail projects create an opportunity for future large-scale infrastructure projects to follow the same path.

The California High Speed Rail Project is an example of a large construction project requiring its contractors to use an SE approach. This project is perfect situation for an early application of systems engineering in the USA.
What is Different About Systems Engineering?

Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and conducting design synthesis and system validation. S.E. considers both the business and technical needs of customers with the goal of providing a quality product that meets user needs (http://www.incose.org/AboutSE/WhatIsSE).

Systems engineering involves multidisciplinary teams working together to define project requirements, identify alternative designs, select the optimal solution, build the product, conduct testing to ensure the product meets stakeholder needs and requirements, and operate and maintain the product through its lifecycle.

Many of these steps are undertaken on traditional design projects. The systems engineering approach differs in a few fundamental aspects:

- Requirements are thoroughly defined, refined and allocated to lower-level system elements, assigned to suppliers and subcontractors, and tracked, through the testing and verification phase of the work.
- The product is viewed from a system perspective: links between requirements are identified so that changes to any one area can be analyzed for impacts to the requirements for the system as a whole.
- The entire product lifecycle is considered from the start of the project, including disposal of the final product.

Design Engineering as a Process

This figure provides a simple context diagram showing design engineering as a process.

**Inputs**
- Specifications
- Requirements
- Functional Interfaces

**Design Functions**
- Define
- Analyze and Evaluate
- Integrate
- Document and Control Change
- Provide Oversight

**Outputs**
- Integrated Design
- Interface Requirements
- Design Elements

The design engineering process gathers inputs from the specifications and system requirements, identifies and specifies all systems, structures and major components to be designed and produces an integrated design with interface requirements and descriptions of the system elements.

**Systems Engineering in Design**

From a systems engineering perspective, effective design management requires the following activities to be well executed:

**Define**

Describe a high-level system consistent with stakeholder requirements and specifications. Refine and allocate the system requirements to lower-level system elements as appropriate. Identify interfaces between system elements, and between the system and other external systems.

**Analyze and Evaluate**

Analyze the system as a whole to determine how best to achieve user and client requirements. Establish criteria for selecting from among the design alternatives. Evaluate design alternatives and decide on the best option.

**Integrate**

Define and manage interfaces with external systems. Define the strategy for integrating system elements. Ensure the design elements are integrated throughout the effort, from preliminary engineering through final design. Resolve interface issues.

**Document and Control Change**

Document the preliminary engineering phases and the baseline design. Establish traceability between requirements and system elements.

Analyze design changes for their full impact on the integrated design and the requirements. Approve changes through a prescribed process and appropriate levels of authority. Understand the impact on the rest of the system before committing to the change. Ensure approved changes are propagated to all affected items.

**Provide Oversight**

Manage the resulting information and the processes being implemented. Develop metrics useful to show the quality of the design management activities.

**Benefits of Systems Engineering**

As infrastructure projects become more complex with regard to the size of the systems, the number of requirements and stakeholders involved, and the sophistication of the associated technology, the risks of project failure increase. The application of systems engineering can help ensure these projects are delivered on time and budget, and that they meet requirements.

**Systems Engineering in Construction**

There are several unique aspects of systems engineering on large infrastructure construction projects. One difference is that the system elements are often completed by different firms under separate contracts, and often at different times. This makes it more difficult to integrate the work (as it’s done across projects), and to successfully complete the verification and validation that all of the requirements have been met (as each contract is only a part of a larger system).

**Improving system quality**

Systems engineering involves an increased focus on thorough planning at the start of the project, including identifying stakeholder needs, documenting how the desired system will operate, and establishing system requirements, including tracing all requirements to their source documents. It also provides a detailed approach for ensuring those requirements are tracked through the testing stage and verified in a disciplined manner, through the use of a requirements verification traceability matrix (RVTM).

**Gaining increased stakeholder participation**

Systems engineering requires the involvement of all stakeholders throughout the project to ensure the project continues to meet stakeholder needs. This continuous involvement helps the project team identify and document any changes to the requirements as early in the project as possible. The use of a standard systems engineering project process helps stakeholders actively participate in the development of the system, and facilitates the involvement of new stakeholders by reducing the learning curve.

**Ensuring design integration**

The thorough and detailed documentation of requirements in a requirements matrix provides a good foundation for design integration. The matrix documents the connections from the source files, such as contract documents, down to very detailed requirements for smaller system elements. It also documents interfaces and traceability between requirements, both internal and external. It also helps document changes in requirements, and enables the team to identify impacts of the changes on the requirements for other parts of the system.

**Reducing cost and schedule overruns**

Combined with the disciplined project controls that form part of the systems engineering approach, the rigorous tracking of requirements helps reduce the risk of schedule delays and cost overruns.

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