AN INTRODUCTION TO SYSTEMS ENGINEERING
Center for Innovation in Engineering and Science Education Stevens Institute of Technology

Systems engineering activities present an opportunity for students to do engineering the way engineers do it. Students can work together to identify problems or opportunities, explore alternatives, create models and test them. The Internet and computer-aided design software make it feasible for students in multiple locations to work together to develop solutions to complex engineering challenges.

What is a System?

We are surrounded by systems. Some of them are natural and others are engineered. The solar system and a beehive are examples of natural systems. Engineered systems are designed and built to satisfy human needs and wants. Wireless telephone networks, power generation plants and our highways are examples of engineered systems.

A **system** is collection of different elements that interact to produce results that are not obtainable by the elements alone. An automobile is made up of thousands of parts and each part must work with the others if the vehicle is to function as desired. From a functional viewpoint systems have **inputs, processes and outputs**. Inputs are the resources put into a system. Processes combine the resources to produce the output which can be a product, service or enterprise. From a physical viewpoint, the system consists of mechanical, electrical and software components (and even humans) that interact to realize these functions. Many engineered systems, particularly those that incorporate electronics, are built in a way to determine if the system is working properly. To do this the goal of the system and the output are compared. This is called **feedback**. Systems also have **boundaries**. Everything outside the boundary of a system is part of another system.

Systems Engineering

Engineers have been building systems from the time of the pyramids. It is no longer possible for a single engineer to plan and execute a complex project. Generally engineers work in teams. Most engineers are experts in one engineering discipline such as mechanical or electrical engineering. Systems engineering is interdisciplinary in that it seeks to improve the way engineers from different disciplines work together. In the past **systems engineers** were usually selected from among experienced engineers who demonstrated good communication and leadership skills. Today institutions such as Stevens Institute of Technology have designed courses and programs to formalize the preparation of systems engineers. Systems engineers are trained to look at the "big picture" as they coordinate communication among others and the development of products such as airliners and enterprises such as mass transit and homeland security systems.

Systems engineers work on complex projects. Not all engineering projects are complex. Although engineers design appliances such as washing machines these are not complex products. Systems engineering is widely used in the aviation and defense industries for activities such as designing and building airliners and submarines. Today's submarines resemble the fuselage of an airliner, have a nuclear power plant, serve as the hotel for 100 people, carry advanced weapon and communication systems and must operate silently underwater. They are truly complex. Designing airliners requires the expertise of structural engineers, materials engineers, mechanical engineers, electrical engineers, human factors engineers and others. Companies designing these and other complex products use systems engineers to provide leadership and coordinate the work of the many professionals that contribute to the project.

Industries outside the aerospace and defense domain, such as the automotive industry, telcom, and IT are also increasingly showing an interest in systems engineering. One explanation for this is the increased level of electronics and software in products that only a decade ago hardly had anything. Another factor is the increased interconnectedness between products that used to live isolation (e.g. on some cars your power steering now talks directly to your ABS brakes to help you swerve around obstacles more safely).

Core Principles of Systems Engineering

Engineers create systems for customers but others are also affected by the systems they design. All those affected are referred to as stakeholders. Systems engineering activities continue throughout the entire **lifecycle** of the system. During the early stages of design it's important to understand the needs of the various stakeholders and translate this into specific **requirements** for the system. Requirements detail what the system must do. After the requirements are established the focus is on using the engineering design process to develop, construct/build, test, use, maintain and retire the system. An important task for systems engineers throughout these phases is to be the "advocate" for the whole system. This means to ensure that all components of the system make their assigned contribution to the system, as well as make sure that the components interact in the way they are supposed to. Assessment should be ongoing and include a continuous feedback loop to insure that the system is working properly and provide an opportunity for continuous improvement.

Dr. Rashmi Jain, an Associate Professor of Systems Engineering at Stevens Institute of Technology, has identified five core concepts of systems engineering: value, context, trade-offs, abstraction and interdisciplinarity. Systems provide **value** when they meet the needs of stakeholders. The **context** of a system is important. Engineers need to consider where the products and processes they design will be used. For example, the engineers who recently designed double-decker passenger train coaches for New Jersey Transit had to make sure that the new cars worked with existing systems including the power lines, platforms, signals and locomotives. **Interdisciplinarity** supports the systems approach which is based on the idea that systems design must consider the needs of all relevant stakeholders and that design teams are made up of members from many disciplines. This means that a systems engineer needs to obtain a good understanding of the environment (often referred to as the *problem domain*) where the system is used. Although not an expert, he/she will need a good working knowledge of the different engineering disciplines that are involved in creating the system.

Potential design concepts should be evaluated based on **tradeoffs** such as cost, time and performance. The goal is to select the optimal solution and recognize that there is no perfect solution for all stakeholders. A tank-like automobile designed to prevent injury during every crash would be inefficient to drive and probably too expensive to build. Instead engineers have focused on seat belts, air bags and designing the structure surrounding the driver and passengers to reduce the forces transferred to them during a crash.

Abstraction is another element of the systems engineering process. Engineers need the ability to abstract a design concept independent of the solution. It's important to consider a wide range of alternative and not select a specific solution too soon. For example, early in the space program NASA wanted astronauts to be able to take notes in a zero gravity environment. They spent millions to develop a ball point pen that would work. Russia solved the problem by having their astronauts use pencils.

Systems engineers are also concerned with **risk management**. Risk management involves identifying what may go wrong in a system and then planning to prevent it or solve the problem should it occur. For example, many companies manufacture components for their products in multiple locations so that a tornado or other natural disaster will not totally disrupt production of the final product.

Systems and Global Engineering
Our global economy creates opportunities and challenges. The US economy is growing very slowly compared to that of many other countries. This creates an opportunity to sell consumer products in countries that have rapidly growing economies. It has become increasingly common for a product to be designed in one location, tested at another site and manufactured at a plant thousands of miles away. Since labor costs make it expensive to manufacture in the United States many companies have their products manufactured in China, India and other developing countries. Advanced communication systems including the Internet, and Computer-Aided Design software have helped to make this a common practice. In addition, a combination of global and systems engineering makes it possible to take advantage of the expertise of engineers and companies located throughout the world. A good systems design will facilitate this type of collaboration, by creating modular subsystems that reduce the amount of micro-management needed to coordinate the development effort. The new Boeing 787 Dreamliner, which will have a fuselage built of 50 percent carbon fiber, is being assembled from components produced by 43 companies at 135 sites around the world. This approach has presented challenges. Manufacturing problems are causing costly delays. Boeing hopes that its systems engineers will be able get the project back on track shortly.