## 2.1 ORIGIN AND EVOLUTION OF SYSTEMS ENGINEERING

Prior to World War (WW) II, architects and civil engineers were, in effect, the Systems Engineers of their time, on large, primarily civil engineering projects such as: the Egyptian pyramids, Roman aqueducts, Hoover Dam, the Golden Gate Bridge, and the Empire State Building. Other architects covered trains and large ships. Nevertheless, these early Systems Engineers operated without any theory or science of Systems Engineering or any defined and consistently-applied processes or practices.

During WW II a project manager and chief engineer could oversee the development of an aircraft program if assisted by leaders for key subsystems, such as propulsion, controls, structure, support systems, etc. Some additional elements of Systems Engineering, such as operations research and decision analysis, gained prominence during and after WW II. Today, with more complex requirements and systems, the chief engineer uses a Systems Engineering team to help him with requirements development and to work with all the project teams.

Systems Engineering began to evolve as a branch of engineering during the late 1950's. During this time, when both the race to space and the race to develop missiles with nuclear warheads were considered absolutely essential for national survival, extreme pressures were placed on the military services and their civilian contractor teams to develop, test, and place in operation nuclear tipped missiles and orbiting satellites. There were intense inter-service rivalries between the U. S. Army, Navy, and Air Force to develop reliable systems and gain government approval for a leading role in managing the deployment and operation of these powerful new weapons and surveillance satellites.

In this competitive climate, the services and their prime contractors (such as Boeing, Lockheed, and Rockwell) sought tools and techniques that would help them excel at system performance (mission success), and project management (technical performance, delivery schedule, and cost control).

One such tool to emerge from this environment was PERT, the Program Evaluation & Review Technique. PERT is a quasi-statistical scheduling technique that is useful in making better estimates of the completion time of a project that has numerous sequential, parallel, and interdependent tasks. It provides visibility into the potential impact on the completion date of delays or speedups in any specific task. The U.S. Navy used PERT to advantage during the Polaris A1 development program to enable the first test launch within 18 months of program start.

Systems Engineering was also evolving in parallel in the commercial sector. Arthur Hall, with an AT&T communications background, published an early book on Systems Engineering in 1962.

Engineering management evolved and standardized the use of specifications, interface control documents, design reviews, and formal change control. The advent of hybrid and digital computers permitted extensive simulation and evaluation of systems, subsystems, and components; thus accurate synthesis of system elements and design trade-offs became possible.

During this time period many lessons were learned from difficulties and failures. These lessons led to innovations in practices in all phases of high technology product development, including all phases of engineering, procurement, manufacturing, testing, and quality control. A driving force for these innovations was attainment of high system reliability. Some examples of changes introduced during the period are:

1. Parts traceability. Identical parts were acquired from two or more suppliers. However, one might prove faulty, the other good. Sometimes one supplier's process would vary unacceptably from batch to batch. Processes were developed to identify all parts by their supplier and batch number and to track them to all installation locations, so they could be replaced if bad parts were found.

2. Materials & process control. The finish on a circuit board and the adhesive or bonding technique to attach devices to the board might be subject to failure after many orbit cycles, due to temperature variations in vacuum at zero-g conditions. These materials and processes and their use by all suppliers had to be carefully determined, specified, tested, and verified.

3. Change control. Designs, manufacturing and testing processes were sometimes informally changed to "improve" the product, without updating drawings or process descriptions or fully disclosing the changes. When failures occurred, it was difficult to trace the causes. This led to more careful procedures, by all affected groups, to document, review, and approve changes in advance. In most organizations, formal change control boards were established.

4. Improved product accountability. Mass production techniques, with each worker focusing on only a few items, left no one responsible and accountable for individual, high value-added products. Although the proper reports may have been issued, action may not have been taken. Often critical parts, software, or tests were not available on schedule, and costly delays resulted. This led to the establishment of product managers and "bird watchers" on one missile program, to ensure that all parts were available when needed and that all tests were conducted properly.

5. Formal interface control. Without early definition and strict control of interfaces between components, subsystems, and system elements, the individual elements were delivered which, while performing their task, would not operate in the overall system. While some programs recognized this from the outset, others did not. This resulted in chaos during integration tests, as teams worked round-the-clock to fix the incompatibilities. At times, it was too late, resulting in major program delays or outright cancellations.

The Systems Engineering processes, which have evolved over the past thirty-five years, encompass techniques to address potential problems represented by the five above examples plus many hundreds of others.

In its present (and still evolving) form, Systems Engineering combines elements of many disciplines such as operations research, system modeling and simulation, decision analysis, project management and control, requirements development, software engineering, specialty engineering, industrial engineering, specification writing, risk management, interpersonal relations, liaison engineering, operations analysis, and cost estimation. Any one Systems Engineer is not expected to be expert in all of the above disciplines. However, over the years, a typical Systems Engineer gains experience in most of them.

Systems engineering is an overarching discipline, providing the tradeoffs and integration between system elements to achieve the best overall product and/or service. Although there are some important aspects of project management in the Systems Engineering process, it is still much more of an engineering discipline than a management discipline. It is a very quantitative discipline, involving tradeoff, optimization, selection, and integration of the products of many engineering disciplines.