STATISTICAL TOOLS FOR ENGINEERS –
George Noyes, Sr. Mfg. Engr.

Background

A large aircraft contains over 6 million parts, with an average of twenty-five dimensional characteristics per part, this results in over 150 million characteristics that must be designed, fabricated, assembled, inspected and tested before you have a finished product. Engineers who design and build today's complex weapon systems face many thorny technical decisions. Traditionally, engineers base their decisions on many years of experience, which they capture in design guides and rules. But, their experience is often not supported by scientific data. Quality guru, Dr. Deming, would advise us to "use profound knowledge" to support our decisions. World-class companies are finding profound knowledge through the use of statistical tools.

The Systems Engineering Process

Concurrent Engineering (CE) has emerged as a way to apply the systems engineering process and reduce risks on complex systems. Within the CE process is a family of tools that enable the engineering team to use structured methodologies to accomplish specific tasks to include:

- Quality Function Deployment (QFD)
- Design of Experiments (DOE)
- Statistical Process Control (SPC)

Quality Function Deployment (QFD)

Systems engineering begins with the identification of a need and then translates that need into a technical solution. Many programs have serious problems in this area, as evidenced by the high rate of Engineering Change Proposal (ECP) activity all the way through production.

How is the requirements process done today? First, someone from a requirements group (e.g. TRADOC) identifies a need and generates a requirements document. The program office translates that requirement into an RFP that a contractor responds to. The real user is not directly involved in the process and does not talk with the contractor creating many opportunities for errors.

World-Class companies use QFD in the front end of the design process to capture the requirements. QFD use many proven tools to capture what is called the "voice of the customer." These tools help to ensure that the requirements are not missed, misinterpreted, or not prioritized. The requirements then get put into a matrix called a House of Quality.

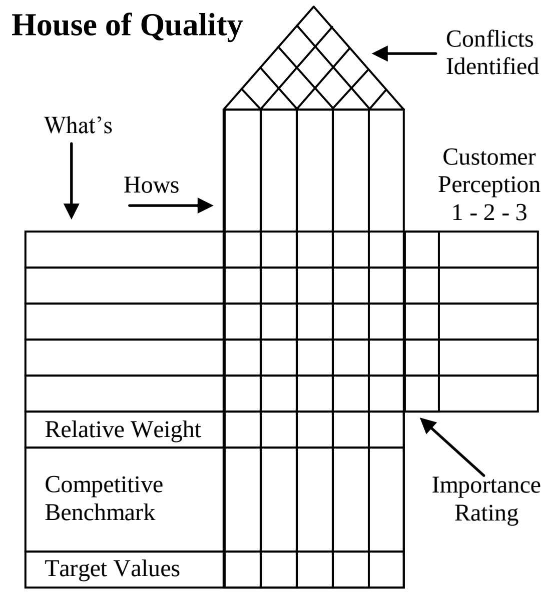

Figure 1

The matrix gives the engineers a structure for examining all of the requirements to ensure they develop solutions to meet the needs. The matrix also ensures that everyone on the team has the same definition for the terms and requirements. It forces the team to prioritize the requirements.

The roof of the House identifies any conflicting technical solutions. For example, you may want an aircraft to fly fast and get good fuel consumption. This could result in a conflict in the technical solution. Engineers need to know if there are technical conflicts early in the design phase so that they can resolve the conflict. QFD has been credited with reducing design times by as much as 40 percent while optimizing the design, providing better operational performance, and smoother production startup.

Design of Experiments (DOE)

As the aircraft design evolves from the system, to the subsystem, and down to the piece part decisions are continuously being made on the 150 million characteristics. Which material will provide the best performance at the lowest costs? Which characteristics are important and must be controlled? Which processes should be used to fabricate parts? What factors need attention to control the process? The engineers 1st work to get a design to yield the right performance parameters, this includes attention to product characteristics, tolerance and process parameter design. But, often the factory floor cannot fabricate parts without high defect rates and low yields. What the engineers need is a way to make the design robust, that is, a design that takes into considerations the inherent variations of the factory floor in a way that does not impact product performance.

R. A. Fisher, an English scientist and statistician, used statistical experimentation (DOE) to identify key characteristics (factors or causes) that contribute the most to agricultural output. A **characteristic is key** if variation causes problems with fit, function, or service life. Fisher found that certain factors within their control had more influence on crop output than other factors. This Dr. Deming would say was "profound knowledge" that farmers could use to increase crop yields. The same statistical techniques can be used to improve manufacturing yields.

Dr. Genichi Taguchi is credited with simplifying DOE. His approach required only a few experimental runs to capture most of the knowledge about a process and its factors. His experiments build on a concept of an orthogonal (balanced) array as illustrated in Figure 2.

Most experimentation today is in response to problem solving. That is, you have a process that is not providing the necessary yields, so you run an experiment to find out what the causes are. While this type of experimentation has its place, the real value is up front, making the product and processes robust. That way you identify and control the key/critical factors all the way from design to the factory floor and fielding.

FACTOR LAYOUT ON L_8 ORTHOGONAL ARRAY

		FACTORS OF THE EXPERIMENT							
FACTOR	A B C D E F G	PREHEAT	TIME	TEMP.	SPEED	PRESSURE	SOLDER	FLUX	NUMBER DEFECTS PER 1000 UNITS
COL. / NO.	1 2 3 4 5 6 7	1	2	3	4	5	6	7	
1	1 1 1 1 1 1 1	HIGH	HIGH	LOW	10 RPM	HIGH	LOW	LOW	21
2	1 1 1 2 2 2 2	HIGH	HIGH	LOW	8 RPM	LOW	HIGH	HIGH	17
3	1 2 2 1 1 2 2	HIGH	LOW	HIGH	10 RPM	HIGH	HIGH	HIGH	12
4	1 2 2 2 2 1 1	HIGH	LOW	HIGH	8 RPM	LOW	LOW	LOW	47
5	2 1 2 1 2 1 2	LOW	HIGH	HIGH	10 RPM	HIGH	LOW	HIGH	5
6	2 1 2 2 1 2 1	LOW	HIGH	HIGH	8 RPM	LOW	HIGH	LOW	46
7	2 2 1 1 2 2 1	LOW	LOW	LOW	10 RPM	HIGH	HIGH	LOW	23
8	2 2 1 2 1 1 2	LOW	LOW	LOW	8 RPM	LOW	LOW	HIGH	4

Figure 2

Statistical Process Control (SPC)

SPC came into existence in the early 1900's, as a result of the work done by Walter Shewhart, a physicist at Bell Labs. Shewhart's studies of manufacturing variation led him to develop the control chart and thus provided his engineers with a tool for reducing manufacturing variation and for the establishment of process control.

Key characteristics flow from key customer requirements, down to assembly characteristics,

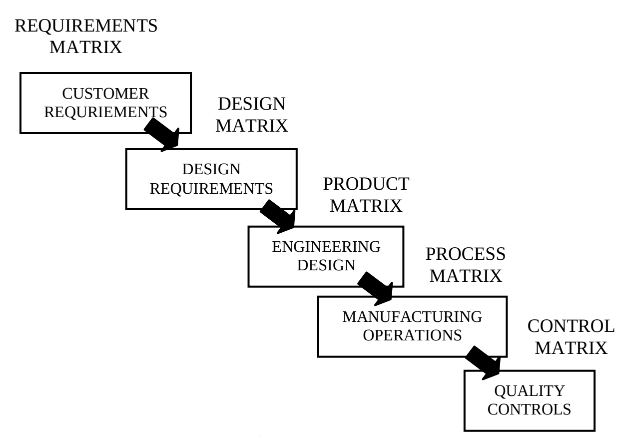

Figure 3

which generate key product characteristics, which generate key process characteristics, which become key test or inspection characteristics. You want to put your key characteristics under SPC.

A manufacturing is not, by nature, in a state of statistical control. Control can only be achieved through dedicated effort. One of the 1st requirements of manufacturing is to study a process and see what that process yields. By collecting data and arranging that data into a histogram, the engineer is able to get a picture of the process. A process has three features: how much variation (spread), where (centering), and shape (normal, skewed, bimodal, etc.). If the process is stable, then these features will remain constant and predictable over time. If the process is unstable, then these features will change, and the output will become unpredictable. If the goal of manufacturing is to achieve uniform, defect-free products, then it becomes the job of the engineering team to reduce or eliminate the sources of variation.

A Stable Process

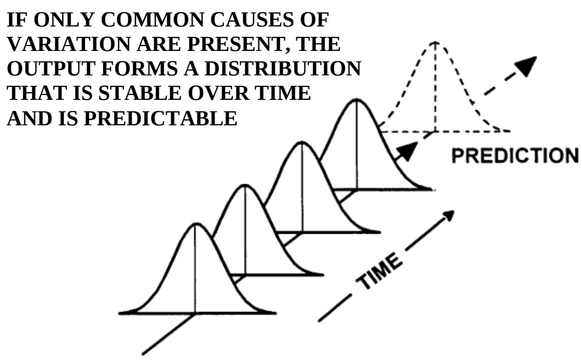

Figure 4

A process is considered stable (Figure 4) when all special causes of variation have been eliminated, and only common (random) variation is present. Common causes are due solely to chance and represent the best that the people operating the factory can attain. Management must take action on the system in order to improve output. Note that just because a process is stable does not mean you are producing good product, it only means your output is predictable.

A process is unstable (Figure 5) when special causes of variation are present. Special causes come from outside the system and must be removed or prevented from occurring in order to achieve stability.

An Unstable Process

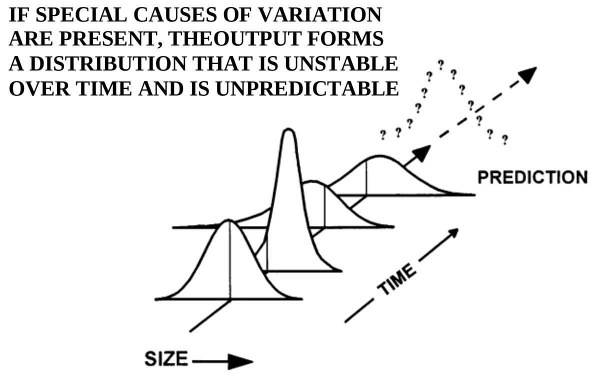

Figure 5

The ideal state for a process is to be both stable and capable (Figure 6) producing 100 percent conforming product. The control chart can be used to ensure that the process stays in control and to give warning if anything in the process is changing that will cause the process to go out of control.

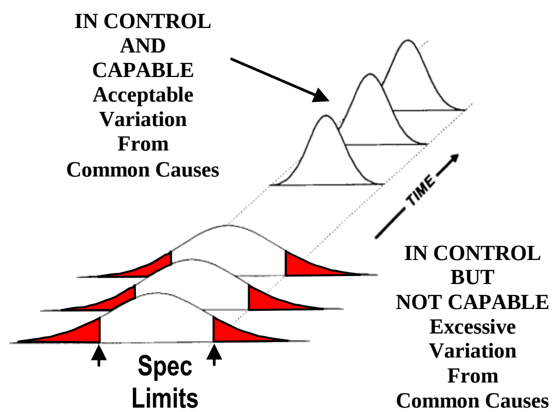

Figure 6

A second state for a process is when the process is stable and in control but is producing some nonconforming product. You could inspect the product and sort the good from the bad, but that is expensive and not 100 percent effective. You could tighten the spec limits, which would give you better product in the field, but would raise your scrap rates. Or you could manage the process using control charts and make process improvements based on profound knowledge.