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How the Design Life Affects the System Design

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When a system is being designed, one of the system requirements will specify the intended life of the system, which is called the design life, the system life or the service life. For example the design life for a new system might be set at 3, 9, or 100 years. This paper suggests how specifying this design life affects the design of the system.

If the customer requires a longer design life, then the system will cost more. Figure 1 shows the manufacturer's suggested list price (dollars) as a function of design life (number of pages) for 166 laser printers (Computer Select, 1994). The cost increases as the design life increases. The correlation for these data is a surprisingly high 0.84.

Figure 1

Design life might mean operational life or it might mean shelf life (or age). For some systems operational life is most important: for airplanes the number of hours that the engines have run is more important than the age of the engines. For other systems age is more important: for camera film, age is important; we do not care about exposure time. For other systems operational life and shelf life are both important: batteries are usually rated for both. We will sum the two until the need for more complication is demonstrated.

There is a category of systems called long-life systems. Such systems cannot be life-tested in their operational environments, and preventive maintenance and repairs are impossible or economically unfeasible. Some examples of such systems are planetary spacecraft, communications satellites, human organ implants, undersea telephone cables, nuclear power plants, and nuclear weapons (Miies, 1974). It is obvious that long-life systems cost more to design and build and have lower maintenance costs. Moreover, we think these attributes generalize to most systems that have long design lives.

Why should a long-life system cost more than an equally reliable short-life system? New technologies may have to be used which will substantially increase development costs. A long-life system requires more systems engineering and more design time. Redundant components will be used. The effects of aging and corrosion will be considered, and more expensive materials might be specified. The system might be designed to minimize the number and criticality of moving parts. A failure modes and effects analysis (FMEA) will have to be done to ameliorate the consequences of single-point failures. More simulation and testing will be required to identify design mistakes before manufacturing. Testing will be more complicated because accelerated-life tests will have to be developed and validated. Finally the systems engineering documentation will have to be more extensive, because the system will have to be better understood and understood by more people.

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The design life affects the training of personnel. When a new system is put into operation, the design engineers perform the startup. But if a system has a long life and is seldom restarted, then the startup expertise can be lost. Computers illustrate this quite well. For example, it is very difficult to restart a computer after a crash that destroys vital boot information, because the people who created those files are gone or have forgotten how to do it. This even holds for small personal computers. For example, few people can restore CMOS, partition disks and rewrite config.sys and autoexec.bat files. The apocryphal Maytag repairman on the TV commercials illustrates another aspect of this problem: if he never repairs a Maytag appliance, he will forget how to do it. If the designers are no longer around, then the documentation must be more extensive, and therefore more expensive. Also training courses must be created to maintain the skills of the operating personnel.

Sometimes the design life is set by the customer's needs. If we were to build a new house, we would specify its design life to be 100 years. It would be built with concrete block. All exterior wood would be covered with aluminum siding. We would use 10-year acrylic caulk. We would use a primer and 15-year paint. The exterior doors would be hung on steel frames with ball bearing hinges. If we were to build a playhouse for the kids in the backyard of that new house, we would specify its design life to be 3 years. The playhouse would be built with plywood. We would use 1-year acrylic caulk and patch it as necessary. Exterior wood would be painted annually with economy paint. The front door would be hung on the wood frame with gate hinges. The annual maintenance cost, as a percentage of the original construction cost, would be much more for the playhouse than for the family house.

Sometimes the design life is set by the technology of the system. The first systems to use a new technology should have short design lives and high maintenance costs: examples are the first computers to use transistors instead of vacuum tubes, the first computers to use integrated circuits instead of transistors, and the first airplanes to use jet engines instead of piston engines. These avant-garde systems have high development and manufacturing costs because the components are "handmade." Lack of knowledge about possible failure modes contributes to the high maintenance costs. Systems using mature technologies could be expected to have longer design lives. However it is often difficult to estimate the design life. In retrospective studies we can use the life of the manufacturing process or the operational lives of some individual systems. The DC3 (C-47) had a long manufacturing process life running from 1935 to 1947 and some of these airplanes are still flying commercially. The B-52 is another long-lived airplane. These airplanes were not on the forefront of technology. They were designed to be flexible, not optimal. The design type was planned evolution. In contrast, the B-1 bomber was on the forefront of technology and optimized performance. The B-1, however, was short-lived, and was abandoned with the next increment of technology. The F-117 stealth fighter is now on the forefront of technology and has high maintenance costs.

For two of the laser printers of Figure 1, we obtained additional information from the manufacturer, Advanced Technologies International. We chose two duplex laser printers with 8 Mbytes of memory and a 25 MHz speed. The Model 6820 has a print engine life of 2.1 million pages, costs \$16,000, and has a yearly maintenance contract costing 21% of the purchase price. The Model 6832 has a print engine life of 4.8 million pages, costs \$26,000 and has a yearly maintenance contract costing 14% of the purchase price.

These examples allow us to suggest that the annual maintenance cost, as a percentage of the original purchase price, is often a monotonic decreasing function of design life, as is shown in Figure 2.

Figure 2

Here is a simple hypothetical example of specifying design life. Should we buy a widget system that has a nine-year design life, or should we buy a widget system with a three-year design life and replace it every third year? Figure 3 shows estimated maintenance costs as a function of time for a nine-year widget and for three three-year widgets. Integration over the nine-year time interval shows that total maintenance costs are greater for the tandem of three-year widgets. One nine-year widget might cost more than three three-year widgets (considering the time value of money), as is shown in Figure 4. However the total maintenance costs over the nine years will be lower for the nine-year widget. When we sum the purchase prices and the maintenance costs over nine years, which will be cheaper? Probably something in the middle, as is suggested by Figure 4.

Figure 3

Figure 4

In conclusion, we suggest that the design life of a system is a system requirement that deserves serious thought. For most systems, there is an optimal design life that will minimize the total life cycle costs. This optimal design life is most assuredly not the longest conceivable design life.

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