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Hi-Tech Equipment Reliability
A Practical Guide for Engineers and the Engineering Manager

By Dr. Vallabh H. Dhudshia

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High-Tech Equipment Reliability Series

WWK recently received permission to reprint sections from Dr. Vallabh H. Dhudshia's book, *Hi-Tech Equipment Reliability: A Practical Guide for Engineers and Managers*. This book, first published in 1995, is now *back in print:*

http://www.iuniverse.com/bookstore/book_detail.asp?isbn=0-595-69727-5

Dr. Dhudshia has been an equipment reliability specialist with Texas Instruments and with Xerox Corporation. He served as a Texas Instruments assignee at SEMATECH for three years. Dr. Dhudshia received a Ph.D. in IE/OR from New York University. He is an ASQ fellow and a senior member of ASME. He has developed and taught courses in equipment reliability overview and design practices. He is an affiliate of WWK, specializing in reliability consulting.

In this issue of Applied Cost Modeling we are reprinting Chapter 4. We hope that you find the information in this series useful.

[Continued on Page 3]

[1] ©1995, 2007 Dr. Vallabh H. Dhudshia

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Calendar of Events

March 2008

2-4 **Industry Strategy Symposium (ISS) Europe**
The Westin Dragonara Resort, Malta

11-13 **FPD China**
Shanghai International Exhibition Center
Shanghai, China

18-20 **SEMICON China**
Shanghai International Exhibition Center
Shanghai, China

April 2008

6-10 **SEMI Spring Standards Meetings**
Adam's Mark Hotel, Dallas, TX

28-30 **Strategic Business Conference**
The Meritage Resort, Napa Valley, CA

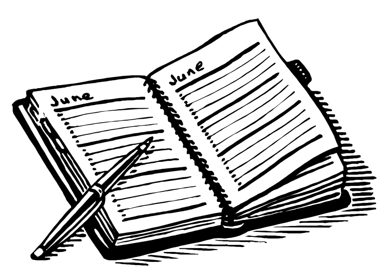
May 2008

5-7 **SEMICON Singapore**
Suntec Convention Center, Singapore

June 2008

2-4 **SEMICON Russia**
World Trade Center, Moscow, Russia

5-7 **Global STC Conference**
Hilton Hotel, San Diego Mission Valley, CA



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Reliability of Systems

In this chapter, we will present the analytical/theoretical relationship between the reliability level of components and systems. A system's reliability level depends upon the reliability of its components and how they are functionally related to the system.

First, we will look at the following three basic systems:

1. Series system
2. Parallel system
3. Standby system

In the final section of this chapter, we will expand on the repairable system (defined in chapter 2) and determine the distribution of time between two successive failures.

4.1 Series System

The series system is probably the most common configuration for modeling equipment. It is also the simplest to analyze. In a series system, all components must perform their intended function successfully if the system is to perform its intended function (i.e., if any component fails, the entire system fails).

The block diagram of a series system is given in figure 4.1. Mathematically, the reliability level of a series system is given by (equation 4.1):

$$R_s = R_1 \times R_2 \times R_3 \times \ldots \times R_n$$

WHERE:
R_s = System-level reliability
R_n = Reliability level of n^{th} component

For the exponential distribution, system MTBF is given by (equation 4.2):

$$MTBF_S = \frac{1}{(1/MTBF_1)+(1/MTBF_2)+(1/MTBF_3)+\ldots+(1/MTBF_n)}$$

WHERE:
$MTBF_s$ = System-level MTBF
$MTBF_n$ = MTBF of n^{th} component

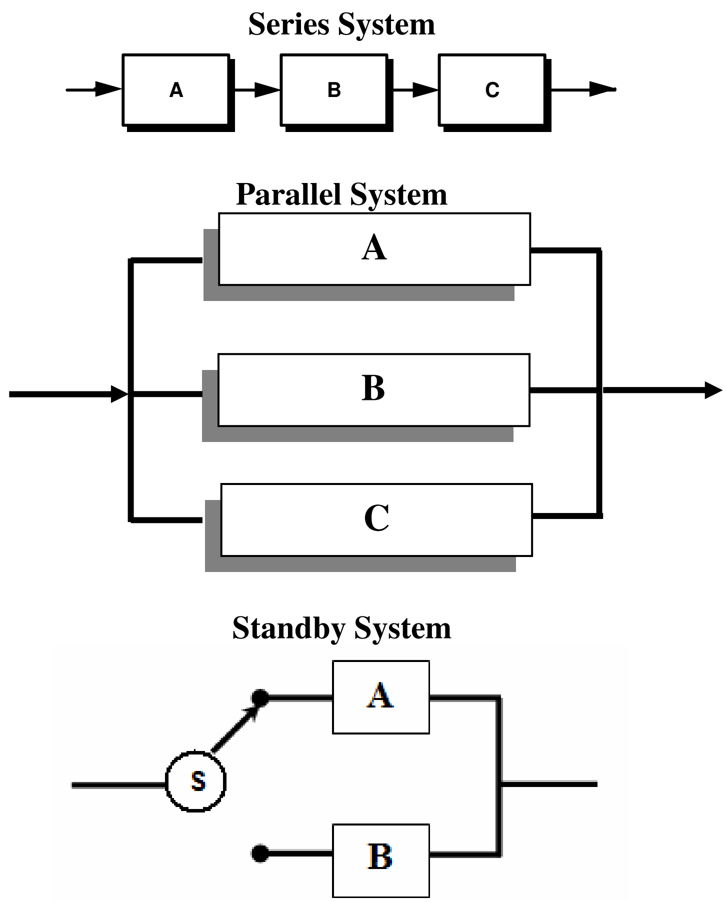

Figure 4.1 Series, Parallel, and Standby Systems

For example, for a three component series system, if $MTBF_1$ = 5,000 hours, $MTBF_2$ = 4,000 hours, and $MTBF_3$ = 2,000 hours, then $MTBF_s$ = 1,052 hours.

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Note that the system-level MTBF is shorter than that of the component with the shortest MTBF.

4.2 Parallel System

A parallel system is one that fails only when all the components in parallel fail. A parallel arrangement of components is usually used to improve system reliability.

The block diagram of a parallel system is given in figure 4.1. Mathematically, the reliability level of a parallel system is given by (equation 4.3):

$$R_S = 1 - \{(1 - R_1)x(1 - R_2)x(1 - R_3)x.....(1 - R_n)\}$$

WHERE:
R_s = System-level reliability
R_n = Reliability level of n^{th} component

For a system with two parallel components, with the exponential PDF, the system MTBF is given by equation 4.4:

$$MTBF_S = \frac{1}{\lambda_1} + \frac{1}{\lambda_2} - \frac{1}{\lambda_1 + \lambda_2}$$

WHERE:
λ_1 and λ_2 = Failure rate of components 1 and 2, respectively

For example, if component one's $MTBF$ = 1,000 hours, and component two's $MTBF$ = 1,000, hours (λ_1 and λ_2 = 0.001), then

$$MTBF_s = 1{,}500 \text{ hours}$$

Note that system-level MTBF of a parallel system is larger than that of any individual component.

As shown in reference 1, equation 4.4 becomes very lengthy as the number of components increases.

4.3 Standby System

The parallel system introduced in the previous section is a "pure" parallel system. In real life, variations of the parallel system are more typical. One of the most common variations is the standby system, which uses an active component, idle components that only operate(s) when necessary, a sensing device, and a switching device. When the sensing device detects failure of the active component, the switching device switches a load to an idle component.

In contrast, the pure parallel system operates all of its components simultaneously.

Figure 4.1 shows a typical two-component standby system. The system-level reliability depends upon the sensing and switching mechanisms and the component repair policy. The following examples illustrate the relationship between component and system-level reliability for standby systems. Both examples assume that the sensing mechanism is capable of sensing a failure instantaneously and that the switching mechanism switches the load to the idle component instantaneously.

- If repair policy calls for instantaneous repair of the failed component, then the standby system will never fail.
- Repair policy is to repair only after both components fail. Then the standby system MTBF is given by (equation 4.5):

$$MTBF_S = MTBF_1 + MTBF_2$$

Note that two components with MTBF = 1,000 hours in a standby system yields a system-level MTBF = 2,000 hours.

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4.4 Repairable System

As defined in chapter 2, a system that, after failing to perform at least one of its intended functions, can be restored to perform all of its intended functions by any method other than replacing the entire system is called a *repairable system*. Replacing, repairing, adjusting, cleaning the appropriate components, rebooting, or re-installing software can restore a repairable system. Most large systems such as semiconductor manufacturing equipment are repairable systems.

In a repairable system, the distribution of failure times between two successive failures is of prime interest. If we assume that:

- Each component failure is an independent renewal process, i.e., when a component fails, it is replaced by a new component and this does not affect any other components
- When a component fails, it has no effect on failure rate of any other components
- The system is a series system with many (more than thirty) independent components

Then, under very generic conditions, the system-level failure is a superimposed renewal process as shown in figure 4.2. The time between two successive failures approximately follows an exponential distribution (see references 2 and 3 for more details). This approximation makes reliability analysis of a repairable system very easy. We need to know only one MTBF parameter of the distribution to be

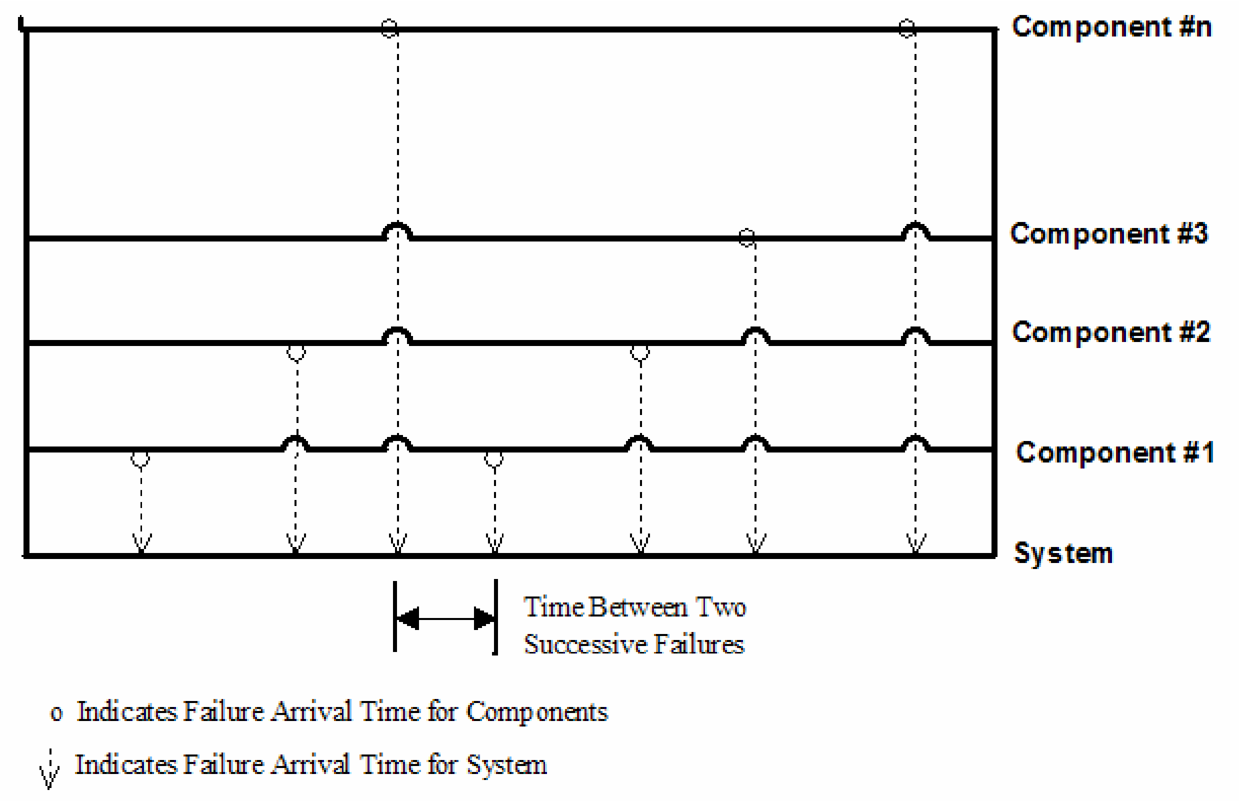

Figure 4.2 Repairable System as a Superimposed Renewal Process

able to perform system-level reliability analyses.

REFERENCES

1. Dimitri Kececioglu, Reliability Engineering Handbook, Volume 2 (Englewood Cliffs, NJ: PTR Prentice Hall, 1991).
2. Paul A. Tobias and David C. Trindale, Applied Reliability (New York, NY: Van Nostrand Reinhold, 1994).
3. Harold Ascher and Harry Feingold, Repairable Systems Reliability (New York, NY: Marcel Dekker, Inc., 1984).

WWK offers "Equipment Reliability Overview" training based on this book's content. This training can be customized for your organization. For more information, please contact WWK at info@wwk.com.

Look for installment 6 (chapter 5) in the spring edition of Applied Cost Modeling or get a head start by ordering the entire book at: http://www.iuniverse.com/bookstore/book_detail.asp?isbn=0-595-69727-5

COO Class at SEMICON West
16th Annual Workshop by WWK

WWK will be holding it annual public COO training class again this year at SEMICON West. The workshop will be held on July 17, 2008 at the San Francisco Marriott. Sign ups can be done directly with SEMI (semi.org) or by calling WWK. Any client ordering TWO COOL® between now and June 15, 2008 will receive two free seats in this workshop.

Wright Williams & Kelly, Inc.
Featured on Sky Radio
Industry Innovators to be Aired on Northwest and Aloha Airlines

February 13, 2008 (Pleasanton, CA) – Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today that it will be featured on Sky Radio's Industry Innovators broadcast to be aired in March and April on Northwest and Aloha Airlines flights. The interview between Sky Radio's business reporter Dennis Michael and WWK's president David Jimenez discusses the value derived from implementing WWK's products and services.

The interview will be heard on 2,900 Northwest flights reaching 700,000 passengers in March 2008 and over 300,000 passengers on Aloha Airlines in March and April. The three-minute interview can also be heard on WWK's web site at http://www.wwk.com.

Sky Radio Network provides business, technology, health and entertainment programming to some of the largest airlines in the world, including United, American, Delta, Northwest, US Airways and America West. The mission of the Sky Radio Network is to produce high-quality business and technology programming which educates, informs and entertains airline passengers. Sky Radio is proud to deliver unparalleled programming, which addresses the needs and interests of the Executive Business Traveler and contributes to making each passenger's flight an enriching experience.

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Hi-Tech Equipment Reliability Now Back in Print

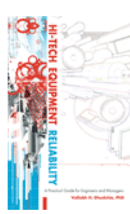
WWK is pleased to announce the long awaited update to "Hi-Tech Equipment Reliability: A Practical Guide for Engineers and Managers" by WWK consulting affiliate Dr. Vallabh Dhudshia. The book can be purchased directly from the publisher and through links at http://www.wwk.com/resources.html. Click on the link "Recommended Books on Cost and Productivity" and you will find Dr. Dhudshia's work at the top of the page.

Hi-Tech Equipment Reliability is based on Dr. Dhudshia's experience at Texas Instruments, Inc., International SEMATECH, and Xerox Corp. Hi-Tech Equipment Reliability is an excellent guide for improving equipment and product reliability by equipment manufacturers and end users.

In Hi-Tech Equipment Reliability, Dr. Dhudshia describes, in a factual and thorough manner, reliability basics and measurement techniques, as well as reliability improvement processes and testing methods. In addition, he clearly defines the phases of the equipment life cycle and associated reliability improvement activities and the three primary growth mechanisms for each stage of the equipment's maturation. Dr. Dhudshia makes a compelling case for pursuing a corporate-wide program of reliability improvement, education, and implementation. He not only proposes the basic structure of such reliability programs but also delivers recommendations for structuring reliability teams as part of an overall quality program as well as discusses ways to assess and improve reliability improvement programs.

In addition to engineers and engineering managers, Hi-Tech Equipment Reliability provides a foundation of understanding for any non-reliability professionals including part and equipment buyers concerned with equipment or product reliability. He shows how to buy reliable parts and equipment.

Vallabh H. Dhudshia holds a Ph.D. in Industrial Engineering and Operations Research from New York University and MS ME from the Illinois Institute of Technology. He is a Fellow of American Society for Quality. He spent his entire career in the quality and reliability fields at Xerox, SEMATECH, and Texas Instruments. He is a contributing author for The Handbook of Semiconductor Manufacturing Technology, authoring the equipment reliability section. He pioneered quality and reliability improvement activities in the equipment and parts buying process. He served, in various capacities, for development and refinement of SEMI E10 and SEMI E79 Specifications and SSQA process. He is a worldwide recognized equipment reliability expert, author, and trainer in the semiconductor manufacturing equipment industry. He has conducted many equipment reliability training sessions and improvement process assessment all over the world. He served on the Board of Examiners for 2007 Malcolm Baldrige National Quality Award.



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Ramblings on Manufacturing Benchmark Metrics

At WWK we have done a number of manufacturing benchmark studies for clients and we have learned the following about metrics -- the most important metrics are the ones you can get and the most useful metrics are the ones you can't get.

Many manufacturing metrics are based on the Japanese TPM (Total Productive Maintenance) philosophy. In semiconductor manufacturing it is referred to as OEE -- Overall Equipment Effectiveness (or Efficiency). There are numerous books about TPM that go on *ad infinitum*. But I simplify it to three areas:

1. Manufacturing availability
2. Manufacturing capability
3. Manufacturing quality

Rather than a rigid assembly line – high tech manufacturing is much more like a job shop that "places a premium on the ability to change configurations or short manufacturing cycle times." Following are a few thoughts on each of the three areas from a flexible manufacturing perspective:

Manufacturing availability -- Availability is more useful than utilization. Flexibility and short cycle time needs the resources to be available when they are needed so that WIP spends less time waiting for resources to become available. High utilization comes at the cost of availability -- the higher the resource utilization, the more likely that product must wait for that resource to become available.

One important metric is Manufacturing Cycle Time. This is an important part of an availability measure. The other part is Average Manufacturing Time per Product. This is the time that someone or something is actually working on the product. The rest of the time is waiting (queue) time. The ratio of these two metrics is called X or how many times [X] of Average Manufacturing Time is Average Manufacturing Cycle Time. The closer that X is to 1 -- the less time WIP is waiting for resources and the higher the availability is.

The "Lean Manufacturing" movement is one method of improving availability.

Manufacturing capability -- Much industrial engineering research has been focused on measures of manufacturing capability. For example, standard assembly times for repetitive tasks are a method of improving manufacturing capability. A more useful metric is average Technician Hours per Product. The more capable the manufacturing, the lower this number should be. Having well trained techs is one way of improving manufacturing capability. Design for manufacturing also helps improve this number. For example, a snap-in/plug-in power supply replacing one that must be fastened with screws and then have wires soldered to the chassis is a way to improve manufacturing capability. Revenue/Manufacturing Employee is another measure of manufacturing capability -- but that metric is harder to relate back to ways of improving manufacturing.

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Manufacturing quality -- Quality is the third leg of this stool. Out-of-the-box quality is an excellent metric to follow. A related metric is warranty service call rates or internal rework rates. High out-of-the-box quality is meaningless as a measure of manufacturing if internal rework rates are high.

Overall Manufacturing Effectiveness (OME) is the product of the three areas mentioned above. It can be estimated using the following equation:

OME = (1/X)(Tech Hrs per Product/Mfg Time per Product)(Out-of-the-box Quality)

These three areas are interrelated -- improvements in one area will often result in improvements in the other two areas.

WWK has significant experience in improving both manufacturing efficiency and manufacturing cost effectiveness.

- Implementation of manufacturing metrics
- Review of existing operations with suggestions for improvement
- Employee training on the application and importance of these metrics
- Manufacturing improvement cost/benefit analysis

Wright Williams & Kelly, Inc. Examines 450-mm Wafer Fab Economics

Unbiased report compares 300-mm and projected 450-mm cost structures

February 20, 2008 (Pleasanton, CA) – Wright Williams & Kelly, Inc. (WWK), a cost & productivity management software and consulting services company, announced today the availability of an unbiased report examining the cost structures of 300-mm and 450-mm wafer fabs. The report can be ordered directly from WWK at http://www.wwk.com/450order.pdf.

In April 2007, WWK conducted the first survey of semiconductor industry professionals asking, among other things, about the expected arrival date of 450-mm wafers. The most common answer was 2013 or later, which was the last date specific choice. However, WWK was surprised to find that nearly 40% answered that 450-mm wafers would never happen. Subsequently, WWK decided to look closer at 450-mm wafers and their impact on semiconductor manufacturing economics. The findings of that study are presented in the report entitled, “An Economic Comparison of 450-mm and 300-mm Fabs.”

“Given the historical framework of the aborted introduction of 300-mm wafers and the dire impact that had on the supply base, it is easy to see why equipment companies are taking a hard line on who will pay for the next wafer size jump,” states Daren Dance, Vice President of Technology at WWK. “We have endeavored to look at the issue of transitioning from 300-mm to 450-mm wafers from an unbiased perspective that is neither funded nor supported by suppliers, IDMs, or foundries. We believe this report is the first honest examination of the economic and other driving factors that will support or refute the move to 450-mm wafers.”

Despatch Industries Drives Photovoltaic Cost Reductions

Partners with Wright Williams & Kelly, Inc. to Drive Continuous Cost of Ownership Improvements

Minneapolis, Minn., U.S.A. – January 15, 2008 - Despatch Industries, a world-leading provider of innovative photovoltaic manufacturing equipment, announces a strategic partnership with Wright Williams & Kelly, Inc. (WWK), a cost and productivity management software and consulting services company. Despatch is utilizing WWK's software system and consulting expertise to reduce the cost of ownership of its key photovoltaic (PV) product lines.

"Despatch is the most aggressive PV equipment supplier we have worked with in the area of cost of ownership and overall equipment improvement," states Daren Dance, Vice President of Technology at WWK. "When compared to traditional batch furnace operations, we have seen a considerable cost reduction."

"Our goal is to significantly reduce the overall costs of producing high quality solar cells through innovative tool designs and process integration," says Brian Bunkenburg, Director of Custom Products and New Product Development. "WWK's analysis of our Inline Diffusion Systems demonstrates a significant improvement for the industry as compared to the traditional batch methods available."

In PV manufacturing, materials and consumables account for the largest costs per cell produced. It is critical for equipment to be reliable and efficient to minimize the amount of materials and consumables wasted in production. Backed by 105 years of experience in heat technology, Despatch has created PV manufacturing equipment that features innovations, which provide the highest levels of reliability and decrease the cost of ownership to manufacturers. Despatch's patented drop-down chamber design offers convenient access for routine cleaning and provides superior across-the-belt uniformity. These features increase equipment uptime and reduce energy consumption. Overall, Despatch's equipment requires less power and labor, reduces breakage and minimizes waste.

Despatch has achieved several milestones in the PV market. The company has shipped over 4GW of production capacity in metallization firing furnaces and these firing furnaces currently hold the number one market share in China. Despatch has also expanded their integrated, in-line diffusion line to include five different models, including pilot scale and R&D models.

About Despatch:
Since its inception in 1902, Despatch Industries has worked at the forefront of thermal processing technology. Building on the company's foundation of expertise in engineering and manufacturing, Despatch has grown to become a global supplier of innovative equipment in some of the world's most sophisticated industries, including: photovoltaic energy, carbon fiber materials, medical devices and electronic components.
www.despatch.com

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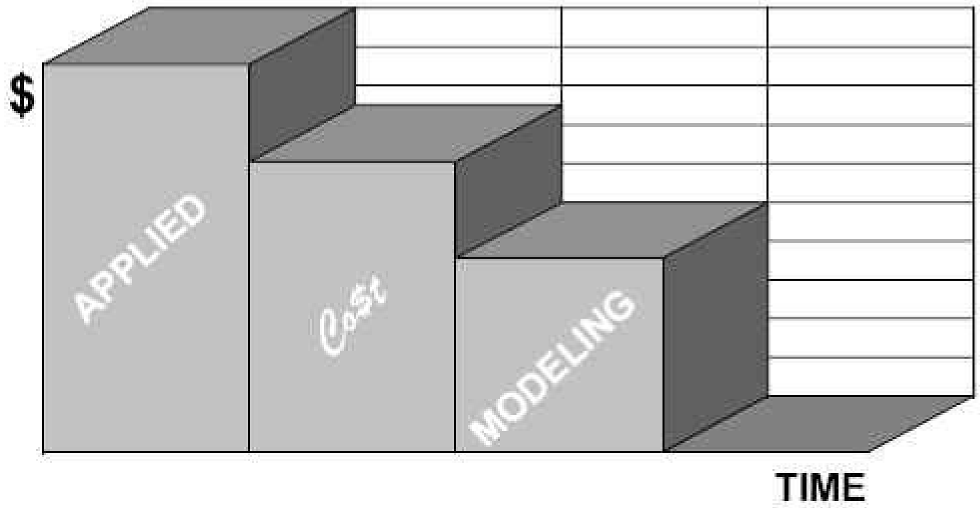

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