The Evolution Of Reliability

H. Paul Barringer, P.E.
Barringer & Associates, Inc.
P.O. Box 3985
Humble, Texas 77347-3985, USA
Phone: 1-281-852-6810
FAX: 281-852-3749
hpaul@barringer1.com
http://www.barringer1.com

International Maintenance Conference December 7-10, 2003
Sheraton Sand Key Resort, Clearwater Beach, Florida

Sponsored by
ReliabilityWeb.Com
Providing resources and solutions for maintenance & reliability professionals
http://www.reliabilityweb.com

The Evolution of Reliability

H. Paul Barringer, P.E.
Barringer & Associates, Inc.,

SUMMARY: Key issues describe how to put reliability into equipment and processes based on personal experiences. The steps along the way include both hardware and people so that we simply operate for reliability. A path for progress outlines how to ensure reliability considerations along with alternatives for the cost of unreliability driven by the concept for a reliability policy.

Keywords: cost of unreliability, reliability, reliability alternatives, reliability policy

1. WHAT IS RELIABILITY?

Long life without failure is the simple definition of reliability. Reliability always terminates in a failure. Of course, you must observe practical limitations to obtain long life without failure. It is easy to kill people, equipment and processes. It is difficult to make things survive for a long time. Most people, equipment, and processes have distinct periods of life, for example, people rarely live longer than 115 years when a birth certificate and death certificate exist. Most things have a distinct range of life for survival. For a reliability definition, you need to define failures—a simple definition of failure is loss of function when you needed it.

Formal reliability definitions may include **"Reliability is the probability that a device, a system, or process will perform its prescribed duty without failure for a given time when operated correctly in a specified environment."** This complicated reliability definition involves:

- probability (chances) for survival [absence of absolute statements about survival]
- components, systems, and processes [the issue is complex--not simple]
- functioning without failure [reliability (survival) terminates in a failure (death)]
- function for a given time period [state the elapsed time expected--nothing survives forever]
- duty cycles under the concept of prescribed duty [design for the cycle peaks—not the "average"]
- correct operation is a key element for survival [you must know right from wrong]
- design for use in the correct environment [successes in one environment is failure for another]

Designing reliability into the component, system, or process is the best practice. Designing for reliability means you must be able to specify the details. If you do not know what you want, how will you ever know if you get it? If you cannot specify what you want, you will be stuck in a take what you get environment and that usually involves high cost and much suffering.

If you have inherited equipment with low reliability, many failures, you may need improvements to gain competitive advantage. Improvements will cost money. Failures cost money. Expenditures for improvements are trade-offs against the cost of unreliability (COUR). COUR is a pool of money for funding improvements but you must do the calculations. You must have a path forward to a successfully achieve reliability?

2. A PATH FORWARD FOR RELIABILITY

To be rich and handsome/beautiful is easier to accomplish if you are born to rich, attractive parents. If you did not choose your parents wisely, you know your life is going to be more difficult!

I was very fortunate in my choice of "parents" for reliability. We did not speak the word reliability very often but we lived the reliability culture at every turn with "always safe practices for long life".

In 1960, I worked at Union Carbide's 5,000 acre Oak Ridge Gaseous Diffusion Plant also known by its grid locations known as K-25. This was the world's largest physio-chemical process.

- This single purpose plant separated the U_{235} isotope from the naturally occurring mixture.
- The plant was huge--the original WWII building was 1KM per side.
- The plant contained vast quantities of a very aggressive corrosive/toxic fluorine as the carrier gas.
- The feed stream gas carried a heavy metal, uranium that is harmful to living things.
- The product isotope has a 0.5% concentration in yellow cake feed stock and must be concentrated to ~3.5% for nuclear reactors or ~95%+ for weapons so this introduces radiological problems as the expensive product is concentrated.
- The process equipment involves huge centrifugal and axial flow compressors placing enormous electrical demands on 5 or 6 TVA power plants making the process unbelievably expensive.
- The diffusion process used a probabilistic method involving porous nickel barrier with repetitive passes through a cascade--it played the odds for separating U_{235} from the mixture of U_{235}+U_{238}.

I started working in the K-25 plant Mechanical Development Department on an ultracentrifuge developed by Dr. Zippe, a German retained in Russia and repatriated ~1955. The Zippe centrifuge had a design speed of 90,000 rpm (1500 revolution/second). Our task was to start with the 90,000 RPM centrifuge and then build faster/better centrifuges. The centrifuge pilot plant had a development objective to put a less expensive isotope separation plant into operation to beat the cost of the expensive gaseous diffusion process. Putting ultra high-speed equipment into the isotope separation equation was not simple. High speed rotating equipment requires that everything must be done just so to achieve long life and few failures (i.e., reliability) when working with uranium hexafluoride!

My coach and mentor at K-25 was Edwin Babely. Ed Babely was a thoughtful, clever, wise, savvy, and patient engineer. He carefully taught me right from wrong about process gasses, ultra high vacuum systems, "always safe processes", and a "million" details in his daily drills. Babely excelled in a plant full of super techies and was named Union Carbide's Engineer of the Year for his excellence in mentoring and technical capabilities.

Babely's mentoring was in the form of daily coaching, asking questions that I had to research, requiring me to make detailed calculations to explain our mutual hypothesis, introducing me to the super technologist who were experts in chemistry, physics, metallurgy, mathematicians, main frame computer specialists, and top management (yes, he made sure I had exposure to the top brass). His demands were:

- **Read** (Study magazines and technical books including the Manhattan Project book on the separative efficiency of gaseous diffusion cascades written by 1934 Nobel Laureate Harold Urey.)

- **Ask the experts** (Work their numbers to understand how and why they got from A to B. Talk to them, you'll learn something every time.)

- **Study** (Learning is a full time, never ending exercise. If you're not learning, you're regressing.)

- **Talk** (Discuss problems, solutions, and examine all the corners and back alleys of issues.)

- **Hurry** (Tempus fugits! You don't have time for perfect solutions—hurry, move on!)

- **Gain experience--experiment** (Start with a good hypothesis, test it, revise it, and solve problems to gain experience very quickly. The more you learn the more you grow if you benefit from your mistakes, which forms your lessons learned library. Let experiments improve your calculations. Use your hypothesis and be competitive—someone else always has a competitive hypothesis so you need to learn fast to keep from eating dust.)

- **Money** (Good engineering without funding and without adding value is a waster of time/effort.)

- **Keep management informed** (You do not live in a vacuum. Update management frequently—but you had better have something useful to report, which means you need physical progress.)

With this agenda, we moved forward developing reliable rotating equipment for isotope separation that would run unattended for long periods without attention or intervention.

The gas centrifuge effort branched to solve a biological centrifuge reliability problem. Dr. Norman G. Anderson, of the Oak Ridge National Laboratory Biology Division, had biological centrifuges from a vendor that could not reliably operate at their design speed of 40,000 RPM. Dr. Anderson needed the centrifuges for continuous flow separation of viruses on a large scale.

From lessons learned with gaseous centrifuges, we quickly had biological centrifuges operating at rated speeds for long run, large batch size separation of viruses in zonal ultra centrifuges. Under National Institutes of Health funding, we installed other zonal ultracentrifuges into production lines at Eli Lilly and Pfizer to separate influenza (flu) vaccines. Zonal ultracentrifuges have a density gradient across the radius of the centrifuge. Viruses, under a centrifugal field move radially outward until they match their density to the fluid density. Virus concentration occurs in thin annular zones within the centrifuge.

Today, every time you get a flu shot, you can say thanks to Dr. Anderson for his separation technology and to the mechanical team of Barringer and Babely for solving the reliability problems, which made the biological technology possible. We solved mechanical problems that made zonal ultracentrifuges run reliably at 40,000 RPM (it was a rotor dynamics/damping problem) for producing flu vaccines that do not hurt your arm and give a very sore goose egg sized bump after the inoculation [for those of you receiving flue injections after 1970—you have no clue about the previous problems].

Seldom do biologists have engineers on their development teams. When they do, the merging of two different technology streams resulted in synergy for unique hardware (141,000 RPM centrifuges) along with new biological techniques for large scale separations. In the biological/medical/isotope fields, you must do things correctly every time. Otherwise, you may not personally get a second chance if you lack reliability!—and reliability must be demonstrated for long periods with biological centrifuges filled with virus that cause/prevent diseases.

We had high-speed centrifuge bearings that were OK, but you always need better bearings. We made our trip to visit with the German expatriate missile teams at the Redstone Arsenal to learn about their high-speed gyro bearing systems and to get a quick spin-up in reliability issues.

However, we missed a singularly important issue in our discussions with the German technologists: We did not make the new vocabulary speak to us in clear, definitive, and action oriented terms attached to the math. We talked about reliability but we did not understand how to make the reliability technology work for us. We heard the words but we did not see the quantification path for success—we were probably too busy to see the trees for the forest and the trees were our obstacle.

We were reliability dwarfs. We did not leverage the German reliability technology in a cumulative manner. We could have seen and achieved more by standing on the shoulders of the German technology giants with whom we were speaking. We failed to comprehend the language of the missile experts. We failed to convert their information into language of mathematics. We heard them but we did not fully understand. We missed a big opportunity! You must understand technology by <u>both</u> words and numbers or you will never grow beyond the dwarf stage.

Isaac Newton (b. Christmas 1642, d. March 19, 1727) clearly illustrates the language and math problem he faced explaining motion (Gleick 2003, p 43, 45, 58, 96, 188)—"He was hampered by the chaos of language—words still vaguely defined and words not quite existing". The culture of Newton's late 1600s lacked technology for time, speed, acceleration, mass, and gravity.

Newton had to invent words to communicate his math with words such as velocity, a mid 16th century word, (at that time the idea of speed was a sailors term based on throwing a log overboard and watching how fast the knots in the line passed). Issues such as rate of change required velocity and position, then came the problem of acceleration—how can you explain the rate of change based on another rate of change? How can you explain mass where the root of Newton's word meant "barley cake"? How can you explain gravity, which stems from a 15th century word for heaviness? How can you measure force, a 13th century word meaning strong and what units will you use for measuring force? How do you define the word centrifugal and centripetal, an early 18th century word describing, "seeking the center"? How do you connect the centrifugal/centripetal concept to the motion of planets and comets when no one can physically see a physical connection that explains their motion across a 13th century word called space? How can you explain the concept of something so small that it's slightly larger than zero by use of the mid to late 17th century word infinitesimal to describe Newton's concept of calculus?

To understand motion, Newton had to first invent the math. Then Newton had to invent the words to express the math. Many of Newton's contemporaries had three strong views of his work on motion:

1. It's too hard to understand! All that math! All those new words! "…lack of a vocabulary hindered the effort" and Newton "…needed a foundation of words that did not exist in any language",

2. Newton's work has no practical purposes—it's the stuff of clever dreams, and

3. The rat! He stole the idea from me.

"What Newton learned entered the marrow of what we know without knowing how we know it."

So what is the point of this Newton language discussion? You must understand the language, which requires you study the subject. Convert language into mathematical expressions so it becomes a working concept. If you do not understand both the language and the math, you will fail to comprehend the issues. Comprehension failures mean missed opportunities.

Ben Koff, a leading designer of gas turbines for General Electric and Pratt & Whitney describes missed opportunities for a great aircraft propulsion technology advance in this way (Koff 2003):

> "The Americans got a late start in the development of the gas turbine engine because responsible leaders didn't believe the gas generator cycle consisting of a compressor, combustor and turbine was practical. The reasoning was that after the power was extracted from the turbine to drive the compressor, there wouldn't be enough residual energy in the exhaust gas for useful work".

Key experiments and calculations [we simply did not understand and we did not get our numbers together] were missing from American decisions about jet engines. This persisted after the English inventor of a gas turbine engine, Whittle, came to the States to teach Americans' how to build the engine and two engines manufactured by General Electric powered the Bell XP-59A in jet flight in 1942. The USA had no combat jet fighters in WWII. We learned important lessons about gas turbine engines the hard way in mortal combat against superior weapons in WWII. Abernethy (Abernethy 2003a) reports early German jet engines had obvious reliability problems:

> "… the original German Jumo gas turbine engines for the Messerschmitt Me 262 jet fighter had a mean time of 25 hours/failure for in-flight shutdowns. This short life was acceptable as the Me 262 had an average combat life of 7 hours and 10 minutes (Abernethy 2003b). Contrast early German gas turbine engines 25 hour/failure to today's average of 25,000 hours/failure (in-flight shutdowns) for reliable modern jet engines on commercial aircraft."

Language problems existed for early gas turbines. Language problems still exist today in other industrial areas. For example, some people think availability and reliability are the same word. Failure to understand the difference that availability ≠ reliability sends organizations to work on the wrong problems.

- **Availability** tells how you are using time. In simple form, Availability = (uptime)/(uptime + down time). We have 8760 hours in a typical year--we know the denominator. If the uptime is 7884 hrs/year, then availability = 7884/8760 = 90%. This says 90% of the time we are alive and ready to do the assigned task. Management is often happy about the percent availability and do not work on the number of failures causing down time (failures drive waste and loss of productive effort).

- **Reliability** tells the probability for a failure free interval. In simple form, Reliability = e^{-N} where N = number of failures expected during the mission period. Suppose we set a mission time of one year expecting one failure, the probability for running one year without a failure is 36.8%. However, if we have (allow or accept) 12 failures during the year, then we have a 0.0006% chance of running one year without a failure. Of course, high reliability requires few failures during the mission. Failures destroy reliability. Reliability highlights failures and consequently drives the cost of unreliability. You can have high availability and low reliability by fast repairs. High reliability requires few failures over many mission intervals.

I could have done a better job in centrifuge design if I had better understood the difference between the language and the mathematics of reliability. Modern examples are available for putting reliability into design (SAE 1999). If you cannot understand the specifications, you cannot translate the specs into hardware. Likewise, many reliability specification details are available on the World Wide Web (Barringer 2003). The reliability specifications and standards describe how the puzzle fits together into design, testing, and equipment utilization.

My next job was with Union Carbide Stellite Division as Plant Engineer. Here I learned about time and money in spades! Capital projects are justified by business units with too little budget for both time and money. The businesses expect that "engineering will find a way…" Engineers do wonders. Engineers do not perform miracles! Projects are justified on a weak foundation and implemented poorly for lack of funding--the homework is usually deficient. The SAE document, listed above, advocates more preliminary design effort to avoid poor implementation of plans that result in unreliable systems. Better homework results in projects that cannot survive the return on investment criteria. We learn about these failures when implementation of poor projects fails under the business gun. Better, the poorly funded projects should die an early death in the proposal phase as unworthy of capital expenditures without the waste of time, money, and careers. This period reinforced my mentor's principle of money.

Manufacturing came into my engineering world when I became manufacturing manager in rolling mill operations down stream of the forge shop for nickel and cobalt based wrought alloys. Reliability issues were everywhere in mill applications for superalloys! Once you are a technologist, you continue to see ways for reliability issues to solve mundane operating problems to improve the success/attempts ratio. We had a poor man's cold strip mill for high alloys, which produced a coil from welding together plates. The welding process required improvement with key-hole plasma welding to improve yield and reliability of weld integrity to prevent coil breakage so that the manufacturing process could function without failure. Likewise, we improved surface integrity of cold rolled stock by reduce surface defects by grit blasting to prevent surface defects and improve the reliability of on time delivery of products without defects.

An important learning from manufacturing was to make the production process reliable to meet delivery schedules, which preserves integrity of the monthly paycheck for the company. In most cases if your personal paycheck had the variability of the paycheck for most companies, you would receive more "free" advice from the home front than you could tolerate!

Reliability issues prevailed in manufacturing components for nuclear subs, gas turbine engines, steam turbines, earth-moving equipment, and a host of other products made from cobalt and nickel based alloys. In the manufacturing world, the most important tool for reliability is the Pareto distribution based on money (not based on things). Manufacturing quickly teaches that money, time, and successes are key performance indicators. You can not make on time and on quality deliveries from a low reliability system.

Books and magazine articles tell you careers go from A→B→C. Figure 1 shows what really happens.

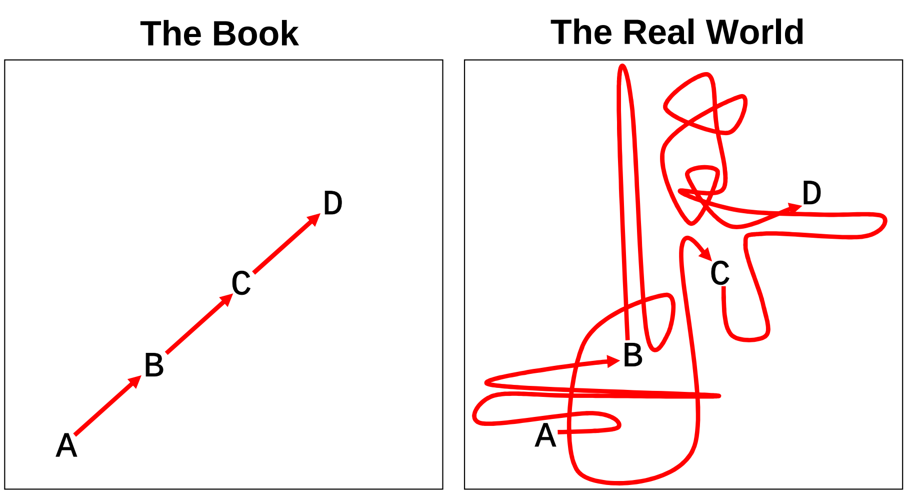

Figure 1: Perceptions Of Progress

My career proceeded from manufacturing manager to plant manager to director of manufacturing with multiple plants. Statistical process control made plants more predictable and factory output more reliable.

Operation by the numbers created a culture of manufacturing consistency during the oil boom of the mid 1970s to early 1990s where we manufactured products for use in the world's deepest and highest-pressure wells for oil and gas. Progress was similar to the real world conditions in Figure 1 with new techniques, new machine tools, and expanding work forces around the world.

Organizational redeployment resulted in a return to the world of engineering as director of engineering. This was an opportunity to put numbers to the reliability of highly reliable products with home study such as the updated reading list (Barringer 2003b). I learned about quantification of reliability from a Weibull analysis seminar conducted by Dr. Bob Abernethy using **The New Weibull Handbook** (Abernethy 2003). Weibull analysis pulled the puzzle together for both manufacturing issues and engineering issues. The lights turned on! The keystone Weibull tool made sense out of the variability in test data and production data! Wes Fulton's Weibull analysis software (Fulton 2003) took away the drudgery of processing data for Weibull analysis and the reliability results became understandable.

Weibull analysis and lognormal analysis of shear ram blow out preventer test data on one side of paper summarized a series of test data for a highly reliable product. Blow out preventers keep oil and gas wells from looking like they do in the movies when control is lost during a drilling or completion activity—you really do not want oil and gas coming out of a gas well in an uncontrolled condition! A shear ram is the last line of defense for pressure control. Shear rams perform two tasks as two rams move radially inward on the pipe in the middle of the blowout preventer: 1) shear (cut) whatever is in the well bore and drop the materials into the bottom of the hole, and 2) seal the high wellbore pressures to prevent leaks at usually 5,000 to 20,000 psi.

After nearly 20 years in the oil patch tool industry, the opportunity arose for reliability consulting. Consulting focused all reliability aspects into training courses as industry around the world discovered reliability. The favorite motto of scouting is "Be prepared" and that is clearly the case for consulting engineers. Consulting engineers must have a product(s)! My products are training classes (Barringer 2003c). In my gray haired years, I transfer information learned the hard way for:

1. Reliability Engineering Principles (how to make the numbers describe reliability in both technical and business results),

2. Life Cycle Cost (how to convert birth/death of components into net present values for communication with the financial community), and

3. Process Reliability (how to find the hidden factory and take specific corrective actions to reduce production losses to make the money machine more reliable).

Training courses also lead to other traditional consulting efforts. Most reliability professionals have never run a business. They lack hands-on operating skills and hands-on business basics centered on money by performance driven values. These two hands-on features make the training effort useful for the business community as these courses are not about statistics and finance—they are about business results using proven tools to get to the money.

During my career, I have implemented safety policies for an accident free work environment when just 40 years ago people thought this was impossible. I have conceived and implemented quality policies to ship defect free products when just 20 years ago people though this was impossible. I have monitored the implementation of environmental policy, which says we will have no environmental spills or releases, and just 2 years ago people thought this was a pipe dream. Today I'm helping implement formal reliability policies which say we will build an economical and failure free production process which will operate for 5 years between planned outages, and most people think this is nuts to reduce the high cost of unreliability---just as they have over the earlier policies.

Reliability policies are important. (Barringer 2003d) and set the organization to work for reducing failures, improving profits, and making production more predictable and more reliable.

The next evolutionary step for reliability is to make reliability a cornerstone of business—not a happenstance. Consider the evolution of the gas turbine as an example of reliability by working the numbers. For business, working the numbers requires control of the cost of unreliability (Barringer 2003e). Quantifying and controlling the cost of unreliability is a portion of forward looking business practices to help guide decisions.

So, what is the cost of your unreliability for your plant? What are you going to do to make your process more reliable, by using the numbers rather than emotion, to fix your problems? Show me the results--don't tell me.

3. SUMMARY

Understanding reliability requires both words and numbers to support each other. Traditionally they grow from a technical background into a business background to control costs and performance. Reliability for any organization is not a destination—it is a journey. The reliability journey has many twists and turns but today, the drive for reliability is money and performance. Reliability has grown from the realm of techies to the tool of business enterprises. For competitive reasons you must understand the technology to get to the money.

4. REFERENCES

Abernethy, Dr. Robert B., **The New Weibull Handbook**, 4th edition, ISBN 0-9653062-1-6, 536 Oyster Road, North Palm Beach, FL 33408-4328, phone 516-842-4082, 2003—page 8-5 for von Ohain's quotation, page 8-11 for modern in-flight shutdowns of gas turbine engines.

Abernethy, Dr. Robert B., Personal communication of a meeting with Hans von Ohain, designer of the Me 262 Jumo jet engine, reported in August 2003

Barringer, H. Paul, **Reliability Standards**, http://www.barringer1.com/rs.htm, 2003

Barringer, H. Paul, **Reading List**, http://www.barringer1.com/read.htm, 2003

Barringer, H. Paul, **Training Classes**, http://www.barringer1.com, 2003

Barringer, H. Paul, **Reliability Policy**, http://www.barringer1.com/reliability-policy.htm, 2003

Barringer, H. Paul, **Cost Of Unreliability**, http://www.barringer1.com/cour.htm, 2003

Fulton, Wes, **WinSMITH Weibull Software**, Fulton Findings, 1251 W. Sepulveda Blvd, PMB 800, Torrance, CA 90502, Phone: 310-548-6358, 2003.

Gleick, James, **Isaac Newton**, Pantheon Books, New York, 2003.

Koff, Bernard L., **Gas Turbine Technology Evolution-A Designer's Perspective**, AIAA Paper 2722, AIAA International Air and Space Symposium, 14-17 July 2003, Dayton, OH, 2003.

Reliability and Maintainability Guideline for Manufacturing Machinery and Equipment, Second Edition, M-110.2, Society of Automotive Engniers, Inc., Warrendale, PA, 1999

BIOGRAPHIC INFORMATION-

H. Paul Barringer, P.E.
Reliability, engineering, and manufacturing consultant. Author of the basic reliability training course **Reliability Engineering Principles,** a practical financial evaluation course **Life Cycle Costs**, and **Process Reliability** which is a high level method of assessing and understanding process reliability. More than forty years of engineering and manufacturing experience in design, production, quality, maintenance, and reliability of technical products. He is a contributor to **The New Weibull Handbook**, a reliability engineering text published by Dr. Robert B. Abernethy. Barringer is named as inventor in six U.S.A. Patents and numerous foreign patents. Registered Professional Engineer in Texas. Education includes a MS and BS in Mechanical Engineering from North Carolina State University, and participated in Harvard University's three week Manufacturing Strategy conference. Other details and technical papers on a variety of reliability issues are available at **http://www.barringer1.com** for other background details or send e-mail to **hpaul@barringer1.com**.

August 23, 2003