

Aging Infrastructures

As electric system equipment like utility poles, power transformers, and circuit breakers gets older, it deteriorates due to the wear and tear of continued service and the natural effects of time. Eventually, it just “wears out.” Many utility systems in the United States, Canada, and the rest of the world were originally built many decades ago. In some of these systems, a large portion of the equipment now in service was installed 50, 60, 70, or even more than 80 years ago. It has still provided satisfactory service, but this equipment is old, and bound to fail or raise problems in the near future. Thus, utilities have aging infrastructures – entire areas where everything is considerably old and deteriorating. This is a source of concern and study from a number of perspectives.

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High-Level Summary of Aging Infrastructures

Note: The following summary discussion is taken from [Aging Power Delivery Infrastructures – Second Edition](#), by H. L. Willis and R. R. Schrieber, to be published in mid 2012 by CRC Press, and used by permission of the lead author.

America’s electric utility systems are growing older. In many systems, significant portions of the equipment and facilities in place date from the economic boom following WWII, or during the heady growth periods of the 1950s and 1960s that many American cities and towns experienced. Equipment that is 50, 60, even approaching 70 years of continuous operation is still in service in many areas.

As any equipment gets older, it deteriorates from the wear and tear of service. At some point, it becomes worn out: either it fails outright, or weakens in condition such that it succumbs to forces, be it the high winds of a storm or the electrical pressure of high voltage, that it was designed to withstand but no longer can. Such failures cause interruptions in service to the utility's customers, and require expensive emergency repairs and system restoration work to be done. And monies will have to be found to pay for that work and the cost of new replacement equipment. Older equipment eventually gets to an age where deterioration and increase in failure rate is significant. This is the first fundamental truth of aging power infrastructures. Electric utility equipment is incredibly robust, but eventually time wins: *sooner but usually later, everything fails.*

The second fundamental truth for most utilities is that with regard to the infrastructure they owns and operate, it is later, not sooner. Some of the original equipment they first installed decades ago has failed in the decades since. Storms, floods, or other natural disasters have taken their toll. Accidents, such as a power pole alongside a street being hit by a car, or an underground cable being dug up by a construction crew, happen. Sometimes equipment just fails, and no obvious reason can be attributed. Regardless, all that failed equipment was replaced at the time of failure. As a result, even in the oldest areas of any utility system, there is a mix of equipment age, some quite old, and some much newer.

But the old predominates. Even in areas built immediately after WWII, rarely has more than 15% of the equipment has been replaced in the intervening decades. Well over 80%, and often more than 90%, of the equipment is original in spite of being five or more decades old. And that is a practical operating problem for the utility. Some of that equipment is in very good condition in spite of its age. Another portion, although showing some signs of wear and tear from decades of service, can be expected to provide satisfactory service for years to come. But a small portion of that equipment is badly deteriorated, perhaps not to the extent that it shows visible signs of imminent failure, but to the extent that it cannot do its original job *dependably*.

Simplistically, one might decide that the problem is easy to solve: just have the utility find and replace all the equipment that is going to fail in the next year or two. Do that on a routine basis every year and the problem is gone. Realistically, that is not easy to accomplish. To begin, the level of failures considered "bad" is remarkably low. Under normal circumstances, less than two tenths of one percent of equipment in good condition fails in a year. A utility might have 8000 steel lattice transmission towers in service, but it is a very bad year indeed if more than five experienced serious problems.

Power systems depend on long chains of transmission lines, substations with transformers and breakers and myriad other equipment, feeder circuits, reclosers, sectionalizers, fuses, cutouts, service transformers and service drops. All must function well if the utility is to deliver power to its customers. If anything fails, someone goes without power until service can be restored. A failure rate of half a percent per year is disastrous. It means service interruption rates that are completely unacceptable to customers, regulators, and stockholders alike, and emergency field work rates that exceed the utility's ability to dispatch crews to do the work. Thus, finding the future "bad actors" in a power system is a challenge – the proverbial needle in the haystack.

Finding that equipment is not easy. In many cases, badly deteriorated equipment does not give obvious signs of its undependability. Tests can be done to improve the knowledge that the utility has of equipment condition. But those require skilled personnel, always in short supply, specialized equipment, often quite expensive. And most tests are intrusive: utility technicians have to go into backyards and

factory equipment areas to set up and run their tests. In downtown areas they must cordon off several lanes of major streets while they work in equipment vaults under the pavement.

And these tests are not entirely dependable. A test that is 90% accurate might seem good, but it creates problems of its own. A utility might test 10,000 old wooden distribution poles in order to find the 500 poles it expects will fail in the next decade (half a percent times ten years is 500 poles). The test will find 450 of those, leaving 10% of the problem in the field. But a good testing procedure might have a false positive rate of 5%: it identifies as bad only one in twenty good poles it tests. That means the test will identify 475 of the 9,500 good poles as bad. Following the test results, the utility will replace more good poles than bad, and not entirely solve the problem, since 10% of the bad poles are still in the field. This may be the best that can be done, but it is not a clean elegant solution that inspires complete confidence among all stakeholders.

That replacement will be costly, too. There is a significant cost involved in installing a new distribution pole or a new underground distribution cable in a “greenfield” site (a new neighborhood being built). Money is required to buy the pole or the cable, the labor involved in every aspect from design to construction. Specialized equipment is required to do the work well and efficiently. But replacing an existing pole after many years of service is much more expensive. The old pole or cable has to be removed. The new has to be put back in its place and reconnected to the rest of the system. Ideally this work should be done while the rest of that equipment is in operation – i.e., energized – so that service to customers is not interrupted. But that means the utility’s personnel must working on live electric equipment: work will proceed much slower and cost a lot more. As a rule of thumb, replacement work is three times as expensive as the original installation.

So cumulatively, the cost of replacing even a small portion of aging equipment is a problem for a utility. Going back to the 10,000 wood poles discussed above, the utility will replace 925 of them in order to obtain a failure rate over the next decade only slightly above that for all new equipment. So far, that sounds like a good bargain. But those replacements will each cost about three times as much as new poles cost when originally installed. And the tests themselves will have a noticeable cost, as does the effort to correlate test results and manage the pro-active replacement in and around all the other activity the utility has keeping the lights on 8760 hours a year. Altogether the utility will spend about 5% of the cost of the original construction for these poles (adjusted for inflation, etc.) in order to keep failures and their consequences under control for another decade: about half a percent per year.

A typical utility might add about 1% new equipment each year for system expansion. Traditionally, the rates that it charges its customers, the budgets it puts together and manages to each year, the number and types of field crews and materials and equipment supply infrastructure it has, and its management bandwidth, are all geared to that level of capital spending and construction. This half a percent cost to handle aging equipment is a *50% increase* above that traditional rate of spending and activity. To a company that may have only a single-digit profit margin, that finds it difficult to hire skilled field personnel and managers, this can appear to be an untenable challenge.

Finally, in any practical sense, aging infrastructures are a new issue and “technology” for the industry to manage. Twenty years ago – half a career ago for the senior managers and most experienced engineers and operators at a utility – this problem simply did not exist. Equipment that is now sixty years old and beginning to give problems was only forty years old then: still reasonably robust in most cases and quite dependable. Over the years, utilities have institutionalized incredibly efficient methods, processes and

habits that result in very high levels of reliability (nationwide, about 99.98% reliability of service) at costs that regulators accept and approve as being as low as practically possible. Simply put, the problem of aging infrastructures did not exist in the past, so it is not part of the habits and institutionalized processes that utilities developed, that they are set up to manage, or prepared to pay for, or have the technology and skills to understand, or the executive priority and focus needed to address them. Neither, for that matter, have they been a priority for equipment manufacturers and service providers that support them: they go where the utilities go. It will take time for the industry to adapt the issue and develop the capabilities needed to handle them.

A Mainstream Future That Includes Aging Infrastructure Management

In most cases it makes no sense to replace a system that was originally installed seventy years ago in a wholesale fashion. Even among the oldest equipment, a majority might still be in serviceable condition and can provide years of good service. The utility's best course is to do what it can to find the bad actors and the questionable equipment and replace only those pieces of the system, continuing into the future each year with a system that is old but in a managed condition.

Thus, aging infrastructures are here to stay: over time the system has become old. It will continue to be old in the future, for the only affordable, and by far the most cost effective program to address the problem will be something that treats it in this controlled manner. Therefore, programs to manage aging equipment will not be special one-time efforts, which will be executed before the utility goes back to its old processes and procedures. They will be needed on a continuing basis.

Thus, some combination of *on-going* testing, tracking, mitigation of continued deterioration and the effects of failures, and pro-active replacement and refurbishment of deteriorated equipment, will be needed in the long run. Such programs will not make the problem go away, they will just control it to an "optimum" level, a stable, *sustainable point* at which equipment in service continues to age and the utility continues to test, maintain, and service replace equipment sparingly but in a targeted manner, with overall cost is kept at a minimum. Utilities that today have no processes and budgets in place to do this will have to develop these, and they will be a part of on-going operations forever.

What Is the Infrastructure Involved?

Even a small utility power system, one serving only a few thousand customers, is made up of tens of thousands of individual components – poles, ducts, underground vaults, substations, transformers, circuit breakers, voltage regulators, monitoring and control systems, service transformers, meters, transmission towers, and electrical conductor (wires). Together, all that equipment operates as a system and has to be maintained as a system.

To many people, that all-inclusive set of equipment is the infrastructure. But there is a lot more. The method of operation of the system is a big part of how it performs. Equipment specifications – the amount of electrical or mechanical load permitted on a unit – affects its expected failure rate and future condition: the expected remaining lifetime of a transformer can be increased by reducing the amount of load it will carry and the lifetime of an old cable can in some cases be marginally increased by reducing operating voltage a few percent. Determining whether that is a good idea or not requires a complicated evaluation. Every utility has equipment specifications and methods it is using to operate and manage its system. In many cases those specifications and the institutionalized habits built around them are as old as

the system itself. Revision of specifications to account for aging and its effects, and modification of the processes for using the specifications, should be updated periodically so that it fits into the utility's sustainable aging equipment management plan.

Similarly, the procedures for operating the system have a lot to do with how failures affect cost, customer service, public safety, and the utility's business performance. There are ways to prepare for contingencies, anticipate the needs one will have, and minimize customer inconvenience and utility cost, even if failures cannot be avoided. In a system that is seeing gradually escalating base failure rates due to aging, such methods take on more importance than in the past.

And given that a utility will have to perform testing of equipment and track condition of old equipment and perform pro-active refurbishment and replacement in an on-going basis, those activities should be merged with traditional maintenance and operating activities and managed in the most efficient manner possible.

Finally, the design and technology of the equipment and the utility's control systems is part of the infrastructure. Its system was originally laid out in a certain configuration of circuit routes, equipment connections, and control schemes. Different circuit configurations and control schemes can mitigate some of the reliability and cost effects of failures due to aging. New technologies can be retrofitted to detect insipient failure, to automatically respond to failure, or to further reduce reliability and cost impacts.

In many cases, changes to specifications, to operating guidelines and procedures, or to system configuration and design are more cost effective at reducing reliability problems and utility costs than efforts aimed squarely at equipment condition and replacement. In many more cases – a majority perhaps – they can affect the efficiency and quality of results from equipment testing, lifetime extension, and replacement programs. They are therefore a vital part of the “infrastructure” that should be managed.

Condition, Criticality and Consequences define Priority

Condition is a classification, scoring, or categorization of equipment that identifies which equipment is most in need of attention based on its characteristics and features. It is determined for all information known about an item, including negative information (explicit recognition of what one does not know).

To be most useful, a condition score or categorization must be *single-valued*. For example, a condition evaluation system that lists a transformer as [A, D, C] on an A-F scale, where A, D, and C respectively indicate the shell and outside systems are in first class condition, the bushings test very weak, and the core is in average shape for cores of this type, will still have to be boiled down to single valued score that can help answer a fundamental question: “Do we do something about its condition or leave it in service as is?” Besides, the utility has all the base data and information that led to each of those three categorizations. It can use them to come up with one score (D: the bushings are bad so go out and replace them and check everything else while there.).

A high level of quantization is not necessarily an advantage in a condition score or classification and may be a hindrance. A score that ranges from 0 to 100 in units of 1 gives the impression of great accuracy, but in practice leads to no better results than a 1-10 scale or an A-B-C-D-F scale. The utility's goal is to find equipment that is in bad condition. Frankly, a digital scale of [bad, not bad] can get a big portion of the job done.

Conditions Have Consequences

Conditions have consequences – they mean something with respect to the utility’s goals. The goal is not to develop a scoring system that puts equipment into “bins” on the basis of available data. The purpose is to find equipment that helps ferret out equipment that is counterproductive to corporate goals.

As an example, a condition scoring system based on DGA (dissolved gas analysis) data could be devised that would group the 900 power transformers a utility had into five bins of 180 each. The 15 transformers (1.7% of the total) in most need of attention are in bin F – but so are 165 other units. A three-tiered condition method that would perhaps put 850 units in class A (good to go as is, no special attention needed), 35 of them in class D (inspect very frequently so that developing problems can probably be caught in time) and 15 in class F (has a high probability of failure or breakdown or other problems).

Criticality

Condition measures should be based on the status and characteristics of the equipment itself: its DGA readings, its impulse test results, the evaluation of inspectors training in visual classification of defects, and its age, model type, and installation details. A separate measure is *criticality*, which recognizes that a utility might care about one potential failure or problem due to deterioration more than another of equal condition and likelihood, because it was more critical to achieving the utility’s goals.

For example, among a utility’s wooden distribution poles might be one that would cause 200,000 customer minutes of service interruption if it failed: among all 718,000 poles in the system it is the most critical to service, in the sense that it would create the most customer disruption and SAIDI increase if it failed. At the other end of the criticality scale are thousands of poles supporting single-phase laterals and service lines that lead to only one or a few customers and thus will have far less impact on customer service and reliability, creating perhaps fewer than 500 customer minutes of outage if they fail. Clearly, the utility wants to put more focus on tracking and controlling the condition of the most critical poles and prioritize these poles of lesser potential impact on operations to a lower level of attention.

Condition versus Criticality

Generally, a first step in the study on any particular class of equipment (e.g., medium voltage breakers) in an aging infrastructure is to classify them in two dimensions by condition and criticality. Equipment in the top ranking (that of most concern) in both will get the most attention. Figure 1 shows such a matrix for the 894 medium voltage breakers in a particular power system.

Fuzzy Evaluations and Staged Prioritization

A reality of aging infrastructure management is that nearly everything that must be analyzed and evaluated in development of a condition estimate is “fuzzy.” Data and models might provide good results and significant statistical fits when applied to an entire class of equipment (e.g., 900 breakers over twenty years of operation, all 723,000 poles in the system). But the data and evaluations for any one breaker’s condition or one pole’s level of deterioration and losses of strength are subject to a good deal of uncertainty. Experience has led the authors to strongly favor aging-asset management approaches that acknowledge the uncertainty and that it cannot be practically reduced beyond a certain amount. Such

approaches are therefore designed to deal with it efficiently.

From a practical standpoint the uncertainty or fuzziness means that the units assigned to each box in Figure 1 have some likelihood of belonging in a nearby box instead, particularly as regards the vertical (condition evaluation) ranking. There is little doubt that the three units in the upper right most box are in need of very focused attention: anything scoring that high in the initial screening will definitely “make the playoffs.” But the twelve units in the box right below are an example of the conundrum the utility faces due to uncertainty. A few of these units probably belong be in the box above and should receive attention now. Several probably should be in the box below and are not really a priority this year. For this reason, condition versus criticality matrices only a first step in staged or hierarchical process as depicted in Figure 2. As shown, the sixteen breakers in the two categories closest to the upper right are scheduled for immediately inspection and evaluation. Based on those results several may be moved into the upper category and would be assigned for refurbishment or replacement. In this way, every one of the 894 medium voltage breakers in the system is assigned to an appropriate category of work to support the aging asset management program.

Med Voltage Breakers		Criticality				Row Total
		1	2	3	4	
Condition	D	0	6	4	3	13
	C	7	10	11	12	40
	B	65	150	134	37	386
	A	24	51	145	235	455
	Col Total	96	217	294	287	894

Figure 1 Condition versus Criticality Matrix for 894 medium voltage (feeder) breakers at a medium size utility in the central US identifies three transformers as having both a poor condition and high criticality of failure/breakdown consequences, and 16 others of high concern.

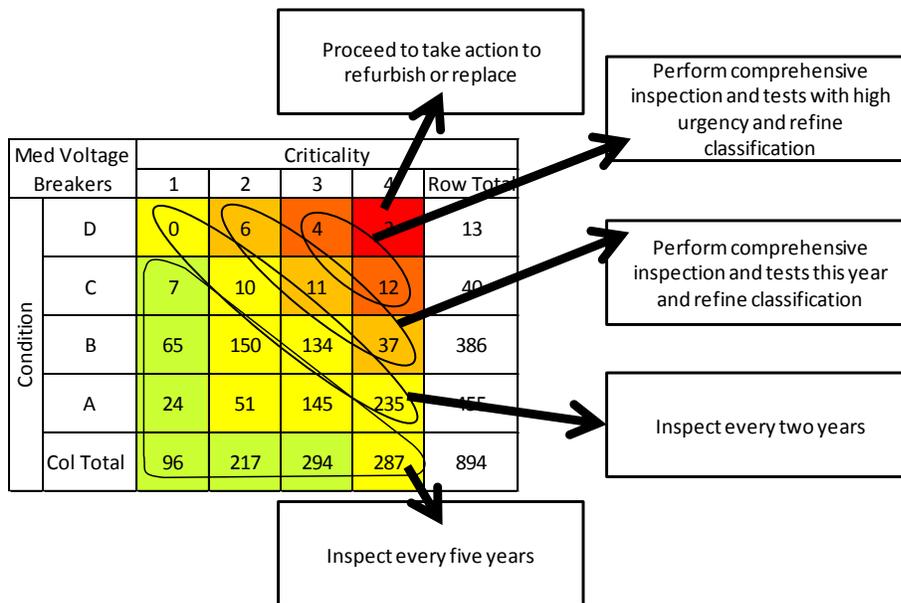


Figure 2 Condition and Criticality leads to actions that recognize the underlying uncertainty in condition evaluation and seek to clarify condition in all but the most urgent situations before prescribing further action.

Perspective on Ownership and Management

Aging power delivery infrastructures include utility system equipment and facilities that are old and of concern due to deterioration of condition, which leads to high failure rates, repair and replacement costs, and customer service interruptions (Table 1). The infrastructure also includes the operating and management processes and methods that the utility uses to determine and control its use of that system and its equipment. In many cases these processes and methods are as old as that system's equipment and in need of revision and augmentation just as the system is. Regardless, making changes and additions to its operating processes and methods and perhaps the power delivery system, too, a utility can control condition deterioration and impacts on customer and system performance so that it can get the business results possible.

Table 1 Characteristics of the Typical Aging Infrastructure Area

1. The system layout and design was first put in place more than forty years ago.
 2. The majority of equipment in the area is more than forty years old.
 3. The system is well engineered and fully meets minimum engineering criteria.
 4. The area is seeing steady, if perhaps low, load growth in load.
 5. The area is plagued by above average equipment failure rates. Labor overtime may be quite high due to large amounts of unscheduled repair and restoration.
 6. SAIFI began rising some years ago; SAIDI is beginning to rise now.
 7. Major interruption events always occur due to a bizarre series of outages.
 8. Things go bad a lot.
 9. No comprehensive plan exists to control the situation
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Manage Both Effects and Causes

Managing an aging infrastructure is about *both* reducing the effects of aging equipment as much as possible (if you can't control the disease, control the symptoms) and controlling the deterioration of the system as much as possible (but keep the disease under control as much as you can). Some combination of effort and budget split between these two will be optimum. That is the primary focal point for executive management. For example, a distributed secondary network design renders a power system almost completely immune to a high incidence of small random failures through the system. Compared to the traditional radial central trunk feeder system, they are an order of magnitude more tolerant of failures. Should a utility with aging equipment shift to such a design so the system and the customer base "just doesn't care" about increasing failure rates? Of course not. Making that move would be very expensive, and distribution networks carry their own operating characteristics that would be difficult to live with en masse over an entire system.

But a move in that direction might be a good idea. There is a huge range of distribution configurations between the distributed secondary network approach and the traditional central trunk radial feeder approach, such as multi-branch feeder/highly sectionalizable feeder layouts, open and closed loop systems of various types. Particularly in combination with "smart" equipment and control systems, these can provide a certain amount of immunity from increasing rates of equipment failure. The failures still occur, but they lead to far lower SAIDI and SAIFI increases.

But ultimately, the utility has to address, or at least control, the root cause, which is deterioration of equipment due to the wear and tear of service. This correlates with age more than anything else, but age is not the direct cause. There is also a noticeable element of random luck involved: a brand new transformer can be struck by lightning and greatly weakened, too. As much as justifiable based on cost and results, the utility needs to find a way to address this.

Condition Data, Modeling, and Tracking is the Key to Success

Regardless of the concepts and approach taken in managing an aging infrastructure, condition estimation is the foundation of any aging infrastructure management program. The extent to which the utility can, in an affordable and practicable manner, separate the bad equipment (poor condition) from the good (otherwise) determines the potential it has to manage its infrastructure and achieve economical success. Ultimately, any path to success requires the utility to separate the equipment that is in a condition to give satisfactory service, regardless of age, from equipment, old or new, that is deteriorated or flawed to the point that it will not provide satisfactory service.

The Future System Will Not Necessarily Be Good, Just “Good Enough”

Power system engineers and operators dream of a system in which all of the equipment is in first class shape: in top operating condition, clean, nicely painted, shiny, and new. That is only a dream. It is not the practical future of any power system (even one that is brand new today). Any well-managed aging power delivery infrastructure will have high portions of old equipment in it. Quality and condition will not be uniformly first-class throughout, but only “barely good enough” in places.

The service transformers shown in Figure 3 are old, have a patina of rust and mildew, and do not live up to that dream. They are a bit noisy, too, indicating their cores are a tad loose. If tested, it is likely they would return mediocre results – within specifications, but not near the “new” end of the test range. Yet for all that, this these transformers is in place and doing their job, and their condition and criticality does justify attention. Replacing them makes little sense, particularly when money is needed to replace and repair equipment that is in much more need of attention.

An Optimum Path Toward an Optimum Sustainable Point

Earlier the the term *sustainable point* was introduced to mean an operating status at which the infrastructure no longer deteriorates and performance no longer worsens each year. This concept is explored and discussed later in this web page in further detail.

Ideally, a utility would find an affordable and effective way to manage aging equipment to achieve a good sustainable point. It would put the resources, tools and management processes needed in place to affect that program. The system and its performance would then be controlled. The system would be an infrastructure with *controlled aging*, managed to a set of cost and results goals.



Figure 3 A bank of service transformers does not look new, because they aren't, but they are good to go in a system that is trying to get the most from its past investments in equipment. The utility's challenge is to separate these units, which can be expected to give satisfactory service for many years to come, from other units that won't.

Key points with respect to management of an aging infrastructure and finding a sustainable operating point for it are:

A sustainable point exists from every power delivery infrastructure. The sustainable point for a particular infrastructure is a function of the power system's layout and design, the equipment it is composed of and the ages and conditions of that equipment, and the ownership strategy, operating rules and guidelines and standards being used to care for and operate the system made up of that equipment.

A different sustainable point can exist, if changes are mad. Change anything within this infrastructure – change the system layout and the way circuits are configured, or the equipment or its condition, or how it is loaded or how it is inspected and maintained, or the ownership strategy and operating rules for refurbishment and replacement, etc., and the sustainable point will change.

A power delivery infrastructure trends toward its sustainable point – slowly. As a mental exercise, suppose one installs 100,000 wooden distribution poles, all new, and puts all of them into service on January 1 of particular a year. Ignore infant mortality failure rates in this example and operate them as most utilities do (basically, do nothing until they fall over or a period of five to ten years, when they are inspected treated with an anti-fungal spray).

Very few will be replaced in the following 365 days of operation because they are all new and in good condition and few will fail. As a result, nearly all the poles will make it into year two. The “system” will age almost exactly 1.0 year in its first year of operation, and enter the following year with average age just slightly less than one year.¹ In that following, second year of operation, the poles will again exhibit a good failure rate, etc.

Over time the average age continues to climb at about one year per year, but as they age increases, the average failure rate begins to increase – very slowly at first because deterioration rates are very gradual initially. More and more failures will occur each year, meaning that more and more new poles are installed each year, until at some point the new poles counteract the continued aging, at least on average. To make the sustainable point and this trend understandable for the moment, suppose that this balance occurs when average age reaches 50 years, at which failure rate is 2%. This means in this¹ year, 2% of poles will be replaced with new (because they fail) and 98% will not fail and will be a year older going into the next year. Average age will then be 98% x 51 years + 2% x 0 years = very nearly exactly 50 years again. The system will not have aged: it is at its sustainable point.

The reader should note that this is a *very* simplified example, far too simple for useful application or generalization. It is used here only to quickly communicate the concept that *eventually* a balance point – the sustainable point – is reached. The fact that this point exists for any and all power infrastructures can be proven mathematically and demonstrated by example based on just about any power system. But in the real world, the sustainable point is more complicated than this example makes out. In particular, in the real world failure rate and age are never reciprocal (in this example, the age, is equal to the inverse of the failure rate of 2%, i.e., $50 = 1/.02$).

¹ Perhaps failure rate for new poles is .25%, meaning that 250 poles failed. Treated the new poles as age = 0 and the originals as age =1, at the beginning of the next year average age is .9975 years.

Furthermore, due to non-linearities in just about every relationship and factor involved, and non-uniformities in nearly all the statistical distributions involved, it is much more common for a sustainable point for a set of wooden utility poles to be something like 64 years at .61%. In addition, the sustainable point is reached when not just average, but distributions about the mean are stable. This is often quite important to a utility. All this will be discussed as needed in later chapters, It is covered in detail in Appendix B's tutorials.

Practical Implications: the Good and the Bad

From a practical standpoint, what is important to electric utilities and the people who manager and operate them about the sustainable point is:

Good: Most power systems are not at their sustainable point – yet. With no significant exceptions, all utility systems in the US are not yet at their sustainable point. Despite age and aging, including perhaps pockets of seriously old equipment and facilities (80+ years old) even the oldest systems in the US are still getting older ever year.

Bad: The sustainable point is much worse than now. In almost every power system throughout North America, the sustainable point for the power delivery infrastructure (power system in combination with current operating and management rules) would be completely unacceptable to customers, utility, and regulators alike. It represents a combination of failure rate, reliability, and cost that is far worse than present.

Good: The system will take time to get there: one can count on the slow, steady trend. Power systems do not fall “off the edge” with regard to aging and its effects, nor does aging typically lead to catastrophic “system meltdowns” when failure rates and costs skyrocket over a short period of several years. Aging power delivery infrastructures instead are very similar to quicksand: the situation slowly but inexorably worsens, perhaps until it is very bad. This is a particular apt analogy in other ways, too. First, often measures taken to get out of the mess are counter-productive, and only worsen the situation in the long run. Second, only a sustained steady pull will extract one from the situation.

Bad: all this means its going to get worse every year. Things move slowly, and storms and year-to-year randomness mean volatility will be seen in annual results, but the long term trend is inevitable: things will gradually get a lot worse.

Good: the sustainable point can be moved. The utility can change its strategy, its ownership and operating policies, its maintenance and service guidelines, etc., and move the sustainable point to something more to its liking.

Bad: it takes a good deal of time for systemic changes to have a significant impact. The “sluggish” response of the system to aging and its effects works the other way, too. Perhaps a utility is at uncomfortable point with regard to particular equipment (i.e., failure rates are 3X that of new equipment due to significant deterioration of condition) in a system on its way to a sustainable point that is much worse (10X). A change in inspection, maintenance, repair and refurbishment policies that results in a sustainable point that has a failure rate “as good as new” will not make a huge impact overnight. Even targeted as effectively as possible, these changes might take five years or more to drive failure rates back down to only 2X.

Effective programs cost a lot of money. As discussed in Section 1.1, it costs more money. The industry will ultimately have no choice but to either accept worsening reliability or somewhat higher costs.

Good: changes in design and configuration along with the addition of “smart equipment” reduce the system’s vulnerability and sensitivity to aging and deterioration-related effects. Basically they mitigate the consequences of failure. Old, deteriorated equipment still fails as frequently as before, it just does not matter as much or have as much effect.

More good: these measures lower the cost all around. Actually, these changes move the sustainable point themselves, but the way many people chose to look at them is that they make changes to operating guidelines, maintenance and inspection programs, etc., more cost effective (less is needed).

The Optimum Plan Does Not *Quickly* Reach Its Sustainable Point

The sustainable point is a useful concept because it makes the basic behaviors and trends of an aging power delivery infrastructure (see above) more understandable and intuitive. It also can help in some statistical analytics applications and numerical modeling steps (knowledge of the characteristics of an answer can help solve for it with minimal error). However, most often the optimum business strategy is not to quickly jump to the sustainable point. Generally, given the “sluggish” response of aging systems and the effectiveness of methods like circuit configuration revision and the addition of smart equipment in reducing system sensitivity to equipment failures, the optimum business strategy is to start now, on a path that optimizes results but might take as long as twenty years to reach a sustainable point: as the system continues to age and deterioration continues to take its toll each year, the utility makes staged changes that keep the effects of aging just barely at bay: the program just barely erases the increases in reliability problems and operating costs that would have occurred.

Thus, every year, as the system’s failure rates increase just a small amount, the utility spends a little more on smart equipment and targeted circuit configuration changes to make the system a little less susceptible to failures than it was the year before. It begins to remove the most worrisome equipment and replace it with new or refurbished equipment. It applies life extension in areas and to equipment where it makes economic sense. It starts to apply inspection and maintenance programs that will have an effect over the long run. All of this is done in a coordinated manner, with the most effective measures being “used up” first, and generally only to an extent needed each year.

Thus, when all is said and done, a lot is changing each year, but what is not changing are the key performance indicators. SAIFI, SAIDI, safety, system performance, utility profit margin, and business results basically stay where they have been and were traditionally. The utility is on a long-term, *gradual* path that will take years but gradually change sustainable point to an acceptable status. Perhaps the original sustainable point represented reliability and cost problems that are three times what last year’s were. And perhaps it would take twenty years for the quick-sand like pace of deterioration to take its toll, (these values are representative of many real systems). Then the roll out of the program can be viewed as taking about that long. The utility gradually moves the sustainable point to that operating point it wants.

This works: performance stays where it was. It is often optimum or close to it from just about any and all standpoints. But it is necessary for one practical reason. Any solution to the management of an aging

power delivery infrastructure will involve increasing spending. This can be done optimally but it will still represent a significant increase – the discussion in section 1.1 mentioned a 50% increase and that is representative of what most utilities will face. Rolling that out gradually, a few percent a year, is really the only option that will be viable to the utility, to regulators, and to the utilities’ customers. That said, there are two final points executive management will need to consider:

1. *The best sustainable point may not have today’s performance results.* When all is considered, a gradual change to less reliability, or different reliability (higher SAIFI, lower SAIDI, or vice versa) may be best. Given historical trends, the authors expect our society will expect better reliability, particular with respect to storm damage. Regardless, executives and planners should not assume that the only answer lies with keeping results where they are now.
2. *It is never too early to start.* The sustainable point might be 20 years in the future. The point where the continuing gradual trend becomes untenably unreliable and costly serious might be eight to ten years in the future. Regardless, the time to begin putting a solution in place is now: a 50% increase in spending spread over 20 years is much more palatable and manageable than a similar increase spread over only 15 years.

What Can and Should Be Done

The most easily identifiable characteristic of an aging delivery infrastructure is that a lot the equipment is old. However, “old” alone is not enough to cause concern and age is not the real issue. A good deal of that old equipment is very likely in satisfactory condition – good enough to remain in service for at least a few and perhaps many more years. The problem in an aging infrastructure system or area is that an unacceptably high portion of the old equipment is not dependable enough for continued service. It is deteriorated to the point that failure rate or capability is seriously degraded, and from a practical and economic standpoint, it is incapable of providing satisfactory service in a dependable manner in the future.

Major Challenges Need to Be Overcome

The first major challenge to a utility is *finding* that equipment with poor condition amidst the greater mass of merely old equipment, determining what it faces overall (when it looks at all old equipment, its entire system, and its options) and then doing something *affordable* and *effective* about the situation.

The second major challenge a utility faces is to determine what its viable alternatives are and which to pick. This usually involves folding aging infrastructure management into its long-term business strategy and mainstream processes.

A final challenge is in finding the money to implement its plan. At its best, any successful program will cost more, period. A big part of the effort will be communicating this to other stakeholders and arranging cost escalation to be slow enough that it is palatable to others.

Several paragraphs below, this discussion gives ten key recommendations for how to proceed. These recommendations and the approach they support work best in conjunction with a condition-based sustainable-point focused, multi-attribute asset management framework. This complicated-sounding approach is straight-forward in concept even if rather intricate to apply well in some of its technical steps:

- Condition based. It is condition, not age, that should be the major focus. Old equipment is actually preferable: it means the utility is getting its value from what it spent long ago.
- Sustainable point means that the utility does focus on the long-term aging trends and where they are going, and in determining how to manage them best in the long run.
- Multi-attribute means the utility is considering all its important goals and targets, such as customer reliability, system efficiency and cost, safety, public image, capital spending limits, and overall business risk.
- Asset management is a method of performing such work in a way that prioritizes work and planning alternatives so that spending is as cost effective as possible (Willis and Brown).

Ten Recommendations for Managing and Aging Infrastructure

1. *Use a results-focused approach.* The two results desired are customer service quality and lowest possible cost. Thus, the guiding principle above all others is to maximize them. A focus on them rather than old equipment and deteriorating condition is not sweeping the problem under the rug. It is a management and planning method that leads to optimum results.
2. *Build the strategy, policies and technology plans first.* This is a long-term problem that affects nearly every aspect of utility operations and business results. Create a sound long-term solution that matches it in scale.
3. *Zero-based all decisions and budgets.* *Nothing* is sacred, and no level of expense or traditional function should be considered untouchable as the company considers revising and changing its processes and approaches. Planning should consider going both ways: increasing as well as decreasing everything.
4. *Marginal benefit/cost ratio* should be used as the basis for all evaluation of “bang for the buck.” This provides far superior results to prioritization done on the basis of benefit/cost ratio or other means. This concept is discussed and developed in detail in Chapters 5 (section 5.3), 11, and 14.
5. *Macro-comparison of intra-project alternatives* using that marginal benefit/cost ratio should be used across departmental and functional boundaries to prioritize spending decisions among candidate projects and budgets. This rather lengthy, “technical title” actually describes a rather simple but critical procedure, in which the keys to making results-centered management work, is covered elsewhere (Willis and Brown)
6. *Reliability-based planning*, engineering, operating and maintenance methods should be employed throughout the organization and a customer reliability-focused approach should guide all decisions on IT.
7. *Planning for failure.* The best results come by recognizing that equipment failures cannot be avoided but can be managed. Failures are a natural consequence of equipment use, and they will happen. However, their likelihood and consequences can be engineered and managed to the best business case.
8. *Make inspection and tracking a large part of any aging power delivery system infrastructure*

management effort. As stated earlier, significant amounts of old equipment will be a reality for the foreseeable future. Old equipment that is still in satisfactory shape can go from “good enough” to “bad” in a relatively short period of time. The only protection is to inspect and track condition well, and frequently.

9. *Gather all the data practically possible.* Historical ownership and operating records are often useful in ways not immediately obvious.. When data sources or old records are found, they should at least be preserved so that planners have the option to use them in the future.
10. *Be patient but skeptical.* Aging infrastructures are a problem that won't go away. But neither will it defy solution. That said, all aspects are fuzzy. Data is never perfect or sufficient. Models are approximate. Staff are skilled but probably not as confident as they would like. Expect reversal of aging trends to take time and to initially move slowly, but look for signs it is not working according to plan and be prepared to take appropriate measures.

-----[Summary excerpted from Lee Willis's book ends here]-----

Aging Infrastructure Math: Why Systems Grow Older Each Year

A utility might enter a new year with 718,000 wooden distribution poles installed on its system that have been in service on average 42.6 years. During the next 365 days, perhaps 600 fail due to storms, automobiles hitting them, or unknown causes. They are replaced with new poles. The utility might remove and relocate another 200 as streets are widened, etc.: the old poles are not relocated but replaced with new ones when moved. And the utility will add perhaps as many as 1,000 new poles as it expands its system into new subdivisions, etc., to keep up with population growth. At the end of the year there will 719,800 poles, of which 1,800 are less than a year old. But 717,200 of the original poles are still in place. Even with the new poles included, the average age of the entire set of poles has increased to 43.5 years. The system ages .9 years in spite of the year, in spite of replacements and additions.

For almost all electrical equipment, as it stays in service and ages, its potential failure rate increases, slowly year by year, at least for many, many decades. The increase in failure rate from an average of 42.6 to an average of 43.5 years will be smaller. Perhaps in the following year, 612 poles would be expected to fail. But each year the increase would itself increase: 625 a year later, then 640, 657, and so forth. The problem would not get better by itself, at least for a long time: long after failures reach an “epidemic” level that would be unacceptable to the utility, its customers, and regulators.

The Aging Infrastructure Panic of the 1990s

In the late 1990s, a number of people in the power industry woke up to the fact that this situation was not sustainable in perpetuity. Inevitably all equipment wears out, so eventually that population of poles would reach an age where deterioration due to rot and weakness due to years of service would lead to very high failure rates. Poles would start collapsing at alarming rates. Storms that are ranked as merely bad now would decimate the system. And of course, it was not just poles: power transformers, circuit breakers, steel lattice towers, underground cable and everything else in the utility system was also aging in a qualitatively similar manner. Those equipments, too, would eventually reach their respective service

life limits and begin to fail. When this happened, service reliability would plummet, replacement costs would skyrocket, and the utility's business performance would nose-dive.

Something akin to panic arose at some large entities when they realized that significant portions of their systems were comprised of equipment already approaching 50 years of utility. In one large metropolitan system, the average medium voltage circuit breaker age was 47 years. In another, fully half of all power transformers had been in service over 40 years. What if all this equipment started failing at age 50? Failure rates and reliability problem rates would become catastrophic. Operating costs would outstrip revenue. Was a crisis in the horizon? Would the system "fall off a cliff" in a few years, as failure rates skyrocketed and reliability and profits plunged?

The answer is no; it's not like that. The situation can and will continue forever. Yes, equipment deteriorates as it ages, and eventually every component in the power system will fail. But the proper perspective begins by realizing that qualitatively, the situation will never change, just gradually deteriorate for many years to come. There is no sudden crisis looming in the future, no decade when failure rates blow up and system and business performance plummets. Aging infrastructures do not create catastrophes. Instead, they are like quicksand: the problem slowly grows worse, and as it does, makes getting out all the more difficult. The proper perspective begins by realizing several truths about all equipment which makes up the system's infrastructure:

It's not really age that matters. It's condition.

Condition is the real issue. Some units of equipment might deteriorate so that condition is poor after only 40 years. Another unit, aged 70 years, might be in that same condition. The utility should be equally concerned about each. Still, age is in many ways the best overall proxy one has for the long-term effects of condition and deterioration because as equipment ages, its condition worsens.

Equipment starts failing from the moment it is installed.

Put up 100,000 new wooden distribution poles and several hundred will fail the following year. Some will tangle with wind gusts or ice loadings or lightning strikes which no pole could withstand. A few will be hit by cars, trucks, or buses. A very small percent will fail because they were flawed from the factory or will not be installed well enough, and fail for that reason.

Failure rate increases very gradually as a function of age.

As the reminder, as those 100,000 poles enter their second year of service, failures for all sorts of reasons will continue. Rot and other forms of deterioration will begin and continue throughout these equipments' lives. Statistically, failure rate will increase every year. But it will increase *very* gradually. At 50 years, failure rates may be only two times that of new poles.

Not all equipment fails at the same age.

There is a huge variation in when poles of apparently equal quality and strength will fail. If a utility owns 100,000 poles that have an expected average failure age of 50 years, some will fail at age zero (in their first year) and some not until after 90 years of service - the standard deviation.

An aged infrastructure is made up of survivors.

A set of 100,000 poles that are 50 years old, and have a statistical expected average failure age of only 50 years, will not fail in the next year. Roughly half of the original set installed 50 years ago

already has failed. The units making up that set still in service are survivors and can be expected to last a good deal longer. For example, in one system in the North East, the average pole lifetime is 56 years, but the average pole in service after 52 years has an expected remaining lifetime of 19 more years. That means that half will fail in the next 19 years and will have to be replaced. It also means that half will not fail: 19 years from now, they will be 75 year old survivors with an expected 11 years of further service life left.

Ages in any infrastructure, particularly an old one, are well mixed.

Fifty years after those 100,000 poles were first installed, there will be a wide variation in ages of poles now in service. A few failed in that first year and are currently 49 years old. Others failed the next year and are 48, etc. There are poles of every age, even if about half of the original remain so that 50-year old poles make up half the pole population. And of course, the utility is actually adding poles all the time as it expands its system. So any utility asset base is a mixture of old survivors, new poles, and everything in between.

The Sustainable Point

Importantly, as any group of equipment remains in service, it ages only up to a sustainable point, at which average age, failure rate, and reliability and cost impacts do not increase in subsequent years. At the sustainable point, failure rate has reached a point where so many replacements are made each year that they statistically counteract the aging of what remains. This isn't necessarily all good news: the failure rate and its consequences might be unacceptable to the utility.

A simple mental exercise can help one understand the sustainable point and several important ramifications for utilities. Imagine a set of equipment for which failure rate increases gradually until it is 2% when it the equipment averages 50 years of age, and suppose that it is in its 50th year of service now. In the next year, 2% of the units will fail and be replaced by new equipment. The following year, the 98% of units that were not replaced will be 51 years of age, and 2% of the units that are replacements will be new. Average age will still be 50 years and average failure rate still 2%. It will remain so every year.

That example is quite simplistic, but explains the basic concept – at the sustainable point, failures and aging balance one another. In the real world, due to non-linearities and non-uniformities of age distributions, failure rates are never the reciprocal of age (i.e., in this example $1/50 = 2\%$), usually failure rate $< \text{sustainable age}^{-1}$. For example, for that system with 718,000 poles mentioned earlier, statistical analysis based on its last 30 years of operation indicates that it will eventually reach a sustainable point where average age is 61.1 years and failure rate is just under 1%. It will never get any worse than that. Of course, that is over 7,000 poles failing each year, compared to about 600 now. The reliability degradation that causes the replacement costs that failures create and the anticipated level of customer complaints which will result will be ten times what they are today. That situation will be untenable. In fact, the situation will be intolerable long before that point is reached.

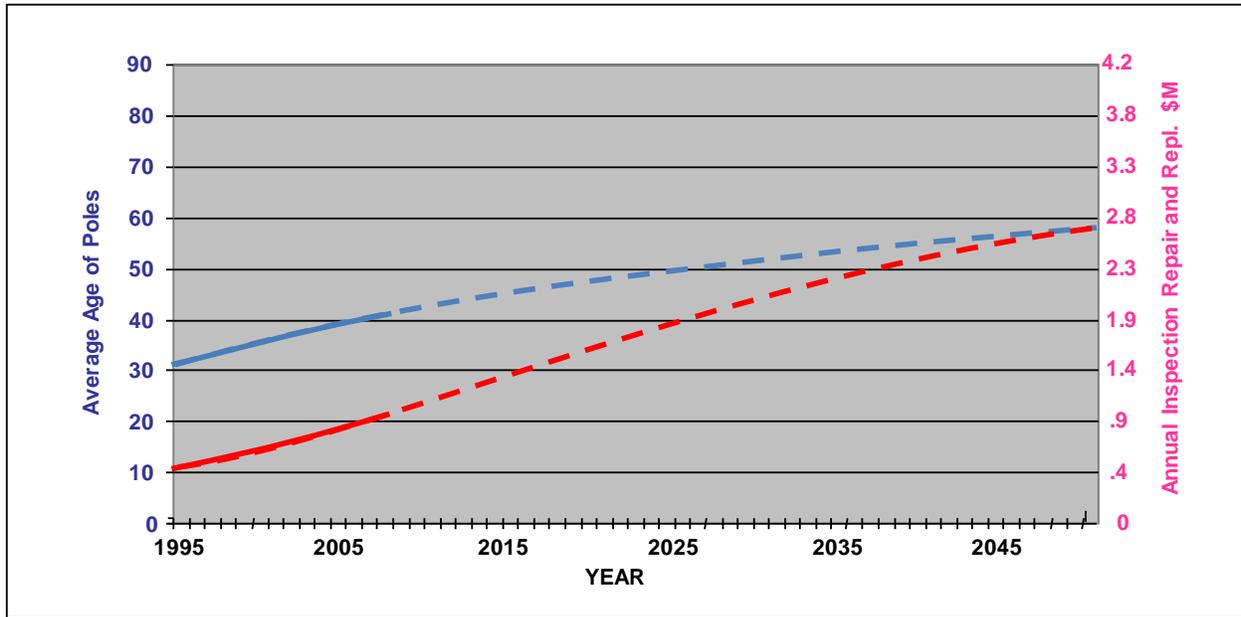


Figure 4: The set of 718,000 poles with an average age of 42.4 years in 2010 is expected to age to a sustainable age of just over 61 years eventually (off the scale to the right). The issue of concern to the utility is not that far-off future point, but the next 15 years, during which operating costs (red line) and reliability problems (not shown) will double.

The challenge is to move *the sustainable point* by changing operating policy programs. A program that includes inspection tailored to the utility's needs, pro-active services including refurbishment in places and at times, and replacement when necessary, and cuts to costs and the escalation rate of costs (Figure 4, base case) significantly, resulting in the trends shown in Figure 5.

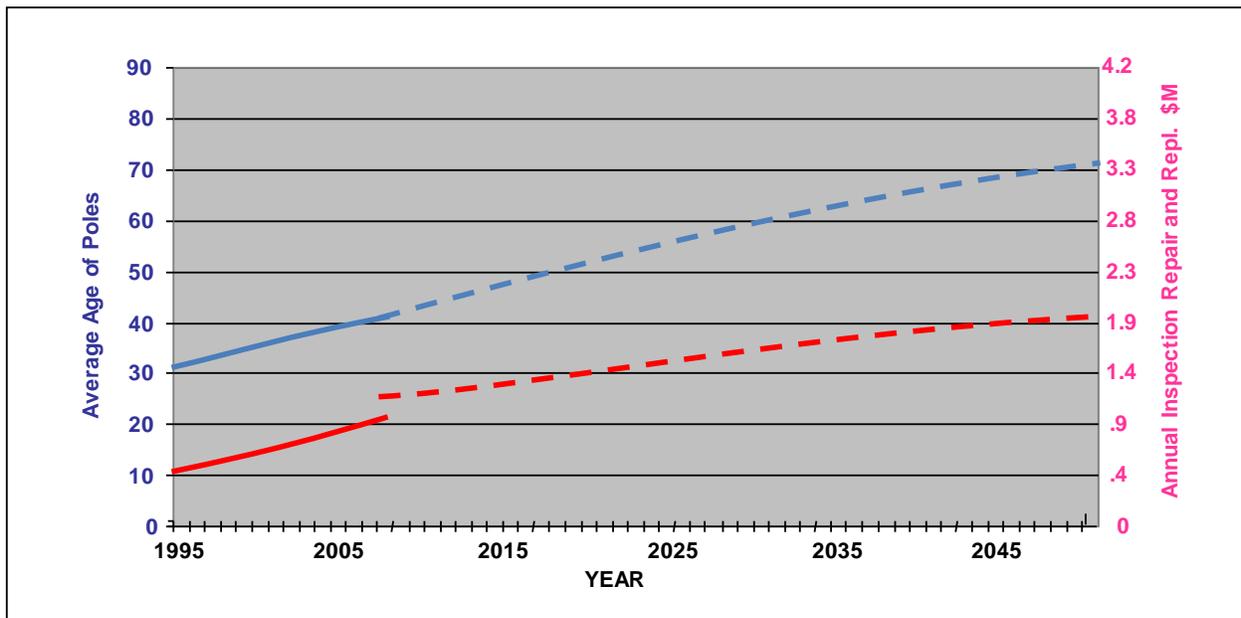


Figure 5: an effective combination of inspection, service, refurbishment and replacements cuts costs within a few years while raising the sustainable age and the average age at any point in the future.

Note that this program moves the sustainable point by increasing the sustainable age, in this case adding 14 years to the expected average life of a pole. Almost all effective programs do this. Age is not a negative factor. Deterioration due to age is. Cut that, and the average lifetime of equipment goes up, which is a very desirable outcome.

Back to that mental exercise for a moment. Imagine a program that doubles the average lifetime to 100 years. In order for failures and replacements to balance now, failure rate would have to be only 1%. *A good, near optimum aging equipment management program both extends the expected lifetime of equipment and cuts the failure rate at that higher lifetime.* Again, the example is simplistic and real systems behave in more complex manners, but this is still, qualitatively, nearly always true: lifetime of equipment is extended; failure rate, even though equipment is now older than ever, is less. Both are good outcomes all around.

Figure 6 shows another view of an aging infrastructure, in this case showing the past, present, and future cost for all major equipment categories in a utility system. All equipment categories will see gradually rising costs in the future as the system continues to age, but there is a good deal of variation among equipment categories. Some types of equipment have expected average lifetimes of 50 years, others 60 years or more, others even longer, and a few much shorter, perhaps only 30 years or less (e.g. certain types of cable, back batteries for substation control systems). Equipment may have been put in at different times, too, and have received different levels of service and maintenance.

Regardless, for every category there is a program something like that illustrated in Figure 2, a program that brings about an optimum or near-optimum sustainable point with regard to overall results and cost. In some cases it will be more important to the utility (there is more money to save) and in other cases less than for poles (there is little to save or little that can be done). But most important to the utility, it can control the destiny of its equipment and extract the maximum value (benefit for costs) for every system asset.

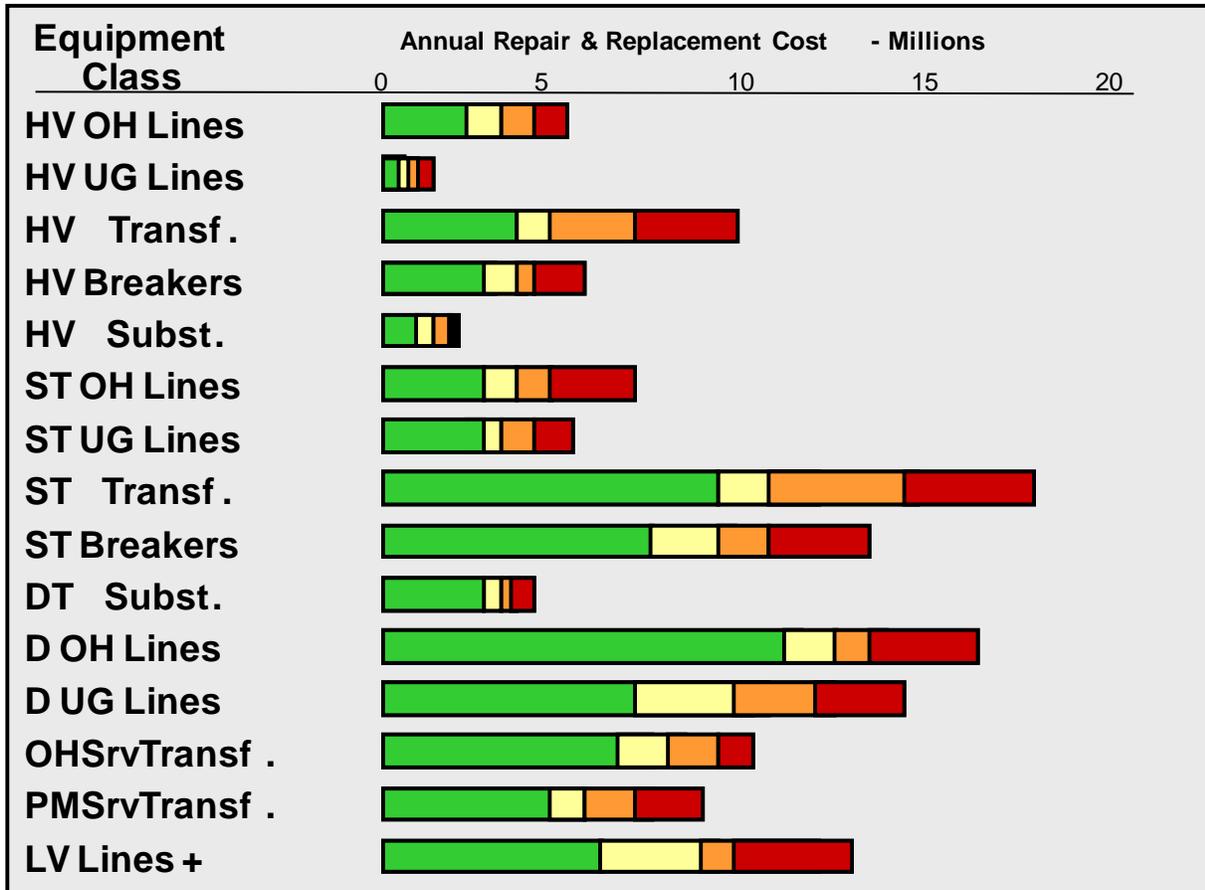


Figure 6: Analysis of equipment categories for a utility system shows the total cost of operation, repair, and replacement if all the equipment were new (green), and as it is now due to aging (yellow), and projected for ten years ahead (orange) and twenty years ahead (red).

Civil and Structural Facilities Are the Greatest Long-Term Concerns

Electrical equipment like transformers, circuit breakers, reclosers and cable is the focus of a good deal of attention by utilities: it is expensive and critical to good performance of their systems. But electrical equipment is only half of the challenge, and arguably the lesser half, at that. To begin, electrical equipment is relatively easy to diagnose. There are tests and analysis that can determine condition and prescribe measures to refurbish only those portions needed. Adding electrical equipment is straightforward and quick. Does detailed study show a particular 24 MVA power transformer is so worn that it really must be replaced? It's a relatively simple matter, even if a major expense. Buy a new unit, remove the old and install the replacement. It's done quickly and completely.

By contrast, the situation for structural and civil facilities such as transmission towers, distribution poles, transformer vaults under the street in downtown areas, and similar equipment is far messier and more complicated. These facilities' failure consequences are often extremely serious – not only do the lights going out when they fail, but when poles fall they damage property and hurt people, transformer vaults are under pavement and sidewalks of busy streets, etc.

Then, too, often the deterioration is very slow, taking years to make visible effects. And diagnostic equipment is not always 100% dependable. It is often difficult to determine just when action is needed, and often the result is that a utility waits a bit too long to act. For example, rusting steel lattice towers and decaying concrete foundations for them are not easy to diagnose as to condition remotely – they require inspection on-site by knowledgeable field technicians and that process takes time and skill. And they are not easy to replace, particularly if the transmission line is to be left in service while that work is being done. Wooden distribution poles are another example. Many are in easements close to the public. Diagnostic methods that are dependable are expensive and those that are economical are not as dependable. Concrete or older brick and mortar underground transformer vaults are particularly difficult to assess. Eventually these materials wear out, but often they do so from the outside of the vault, which cannot be inspected: when signs of deterioration first appear, it's almost too late.

Finally, replacement of civil facilities and equipment is expensive and messy. Underground transformer vaults in downtown areas are perhaps the worst. To begin, they cost a lot to replace; and they are under streets and sidewalks in densely populated, active business centers, where construction causes tremendous public inconvenience. Transmission towers may be out in the open, and outside of downtown areas in most situations, but they too are expensive to replace, particularly if the utility needs to keep the line in service while the new towers are erected and put into service.

Make Aging Infrastructure Programs Part of Long-Term, Mainstream Operations

Many utilities currently have special programs to focus on equipment or age-related problems that are causing concern now. Masses of equipment were installed in the post-WWII period or the economic booms of the 1960s, but that equipment is now nearing an age when failure rates are a concern. Some managers, engineers and operators view these programs one time efforts – they will focus on older equipment, make changes and repairs, and the problem will be fixed. Everyone will go back to ‘business as usual.’”

But that is not the case. Once aged and aging equipment becomes a perceivable problem for a utility, it will remain a problem, even if a controlled problem. In fact, if it is managed well, an aging equipment population will require more focus and more management over the long-term. As stated earlier, a good program will increase average age and expected average service lifetime of equipment, but reduce failure rates. Go back to business as usual, and the system will rebound to higher failure rates than ever. Good continuing results depend on continuing that inspection, that service, and that refurbishment. The reward will be the lowest possible costs.

Inspection programs are a critical piece of any continuing program because they provide the knowledge the utility needs to manage age, aging, and condition and its consequences. As equipment ages, its condition varies more widely. Neglecting the tiny portion of equipment that comes from the factory with flaws and causes what is called infant mortality reliability issues, a set of new equipment has no variation in condition at all. Ten years later it will show some slight differences. The worst units might look like the average unit that has been in service 15 years, and the best, hardly worn at all. After 30 years the differences will be even more dramatic. After 50 years there will be a wide variation, with some equipment in need of attention while other units are obviously good for more years of service, and many more are in one or those categories, in between, but it is not obvious from simple inspection.

Further, the potential rate of deterioration tends to increase with age. There is virtually no likelihood that new equipment can go from good to bad in ten years. A good portion of 50 year old equipment will. The only way for the utility to stay on top of these two characteristics of its asset base is to inspect and track regularly and well, so it knows where equipment of marginal condition is and so it can track deterioration rates.

The best policy is to build these aging infrastructure measures into normal operations so that the programs, technical analysis, and management needed to deal with aged equipment, and aging of equipment becomes an institutionalized habit of the utility.

Quanta Technology and her staff is the industry leader in guiding utilities through this process. Two founding partners, H. Lee Willis and Dr. Richard E. Brown have pioneered work on aging infrastructure management. Her staff has over 40 years of field experience in utility and systems management, regulatory leadership, and independent consulting. Quanta Technology is confident it has the knowledge, skills, experience and resources to take on any technical project involving management of an aging network. Quanta Technology can provide the following:

Network Assessment and Evaluation

Including condition assessment of equipment and facilities, identification of critical elements and prioritization of needs and work plans.

Lifetime Extension

There are several sound approaches to, and many “tricks” and innovative technologies for, extension of aged equipment’s life, and the slowing down of aging rates in any system. A widely known example is cable injection. Less well known examples include re-insulating “tape,” structural augmentation kits for vaults and ducts, antler switches, blast screens, and various specialized protective equipment. The QT network team is experienced with these as well as the engineering and economic methods to determine how to use and coordinate them well in a sound, business-based program down to the bottom line.

Maintenance and Service

Quanta Technology is familiar with methods, technologies, and best practices for inspection, condition tracking, maintenance and service for all types of power systems. We can help evaluate methods and sufficiency and fine-tune and prescribe improvements to bring about increased maintenance effectiveness, service, and refurbishment plans directed toward any set of corporate and operating goals.

Arc-Flash Standards and Hazard Mitigation.

High fault levels are a fact of life on the low-side buses of distribution secondary network systems. Arc-flash potential and the safety hazards this presents is a concern to all utilities. Quanta Technology has extensive experience, skill, and capability in analysis of fault and arc-flashes, fault-limitation and reduction means, arc-flash mitigation methods and overall programs to most cost-effectively deal with the program in a justifiable and defensible manner.

Planning for the Future

Should the utility keep its aged network or replace it with some other type of system? If replacement is the designated best plan, when, how, and why should replacement occur and what should replace the existing system? Network planning is different from other types of power systems. Networks have unexcelled capabilities that should not be thrown away lightly, but there are times when another system type makes sense. And there are times when the network should be retained, and expanded. Regardless, the unique qualities and characteristics of networks require specialized methods to fully exploit their potentials and accommodate their quirks. Quanta's team has extensive experience working on the planning, replacement, expansion of, and continuation of downtown underground systems around the world.

Engineering and Technical Support

Many times a utility simply wants access to experts and technical advice and support while it carries the majority of the burden of assessing, planning, and re-engineering its networks. Quanta Technology provides everything and anything from simple periodic long-distance advice and technical support as needed and requested, to every-day on-site technical assistance, all tailored to fit the utility's needs and desires.

Technology Upgrades and Integration

Networks were developed before the digital age and can achieve truly impressive levels of reliability and voltage stability without the aid of any modern or "smart" technology. But this does not mean that modern equipment, automation, and systems cannot provide high value when properly retrofitted to a network area. Quanta Technology can help identify what makes sense (and what doesn't), and why, and how if when it is cost justified. In particular, our team has experience and skill in the use of modern technology-based solutions as part of a life extension and to mitigate the effects of aging and arc-flash standards.

Training and Professional Development

All of Quanta Technology's knowledge and skill in Networks is available for transfer to utility staffs and personnel as needed. We offer a series of standard, one to five day seminars and workshops from introductory to advanced levels in all aspects of distribution underground networks (and all other areas of power engineering, for that matter).

Quanta Technology Experts in Distribution Planning

[Bill Snyder](#)

[Mike Marshall](#)

[Dr. Richard E. Brown](#)

[H. Lee Willis](#)

[Dr. John Spare PE](#)

References and Resources

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Note: Amazon and other sources list this book's publication date as January 2012. Actually it will be July 2012.

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