LifeCycle Analysis

Developing Economic Lives When Multiple Forces of Depreciation & Obsolescence are Present.

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Modeling the LifeCycle of Multiple Forces of Depreciation

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Abstract

The depreciation of machinery and equipment (M&E) is often determined using an average life and an actuarial survivor curve, such as Iowa Curves. Survivor curves are the result mortality (actuarial) studies of observed life indications. Unfortunately, however, such studies, while reliable for predicting physical depreciation and ordinary obsolescence, are often insufficient for property that is subject to technological and other forms of abnormal (excessive) obsolescence.

There are two principle reasons for this: First, abnormal obsolescence, by definition, is depreciation that will have a more profound impact on the future levels of depreciation than it had in the past. Second, traditional survivor curves are not well suited to model the depreciation impacts of abnormal obsolescence. A mortality survivor curve is not mathematically capable of modeling the dynamic impacts of most forms of abnormal obsolescence; additionally, a single survivor curve cannot model both physical depreciation and abnormal obsolescence simultaneously. Several writings, published in the 1980's and 1990's, speak of the need to compliment tradition survivor curves with additional models specifically addressing the dynamic implications of abnormal obsolescence.

> *W.C. Fitch and F.K. Wolf in their paper, titled Conceptual Framework for Forecasting the Useful Life of Industrial Property, Iowa State Regulatory Conference, 1984, recognized the need to enhance the Prescribed Projection Life process and conceptualized on how forward-looking impacts such as technological obsolescence could be modeled to give better life estimates.*
>
> *K. A. Kateregga, Department of Industrial Engineering, Iowa State University, concluded in his paper Technological Forecasting Models and Their Applications in Capital Recovery, that "there is a justifiable need to incorporate technological forecasting in the overall life analysis framework especially in those industries experiencing fast technological changes."*
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> *S. L. Barreca, Technological Obsolescence – Assessing the Loss in Value of Utility Property, published in the Journal of the Society of Depreciation Professionals, Volumn-8, 1998, presents a methodology for modeling abnormal technological obsolescence. This methodology has come to be called LifeCycle Analysis. LifeCycle Analysis allows the analyst to separately model any number of individual classes or causes of depreciation using modeling techniques specific to each class and/or*

> *cause of depreciation. LifeCycle analysis provides a framework for combining the individual LifeCycles for multiple forces of depreciation into one composite LifeCycle that reflects the total depreciation and obsolescence impacting the subject property.*

These articles directly or indirectly document the shortcomings of the use of survivor curves when abnormal/excessive obsolescence is anticipated. In more recent years, we have seen presentations and writings critical of the use of survivor curves in the valuation of machinery and equipment. While survivor curves have their limitations, they are still the most reliable technique to capture the depreciation impacts of physical depreciation and ordinary obsolescence.

Contrary to popular belief, economic lives and the resulting depreciation factors are not directly computed from survivor curves. There is an additional, but subtle, step in the process which is often overlooked. Economic lives and depreciation factors are developed from LifeCycle curves. The numerical process used to compute the life directly from a survivor curve is essentially equivalent to first converting the survivor curve to a LifeCycle curve and then computing the life. While survivor curves have limitations, LifeCycle curves have none. Any (and every) force of depreciation that one can theorize can be modeled with LifeCycle curves; and any number of LifeCycle curves can be combined to yield a composite LifeCycle curve from which the net economic life can be determined.

In other words:

1. *Any force of depreciation that can be quantified can be modeled in the form of a LifeCycle curve.*
2. *Any number of LifeCycle curves can be statistically combined into a single composite LifeCycle curve.*
3. *Economic lives and depreciation factors are readily calculated from the composite LifeCycle curve.*

Thus, any and all forces of depreciation can be equated into a single LifeCycle curve and reflected in the economic lives and resulting depreciation factors.

LifeCycle Analysis allows the analyst to not only take advantage of the proven reliability of survivor curves in modeling physical depreciation and ordinary obsolescence, but to also incorporate any additional depreciation or obsolescence that exists or is anticipated. This paper presents LifeCycle Analysis to the valuation and depreciation professions. It also provides an overview of the development and proper use of mortality survivor curves, with emphasis on its strengths and limitations. Additionally, this paper provides an overview of the extension of Technology Substitution Analysis which has proven to be a reliable method of modeling abnormal obsolescence resulting from technology substitutions as well as other forms of abnormal obsolescence.

Introduction

This paper presents a methodology called LifeCycle Analysis that can be used to assess the depreciation impacts of any number of forces of depreciation. This methodology allows the analysis to separately model individual classes of depreciation using modeling techniques appropriate for each class. It proposes that the analyst use traditional mortality analysis techniques (i.e., actuarial analysis) to assess the influences of physical depreciation and ordinary obsolescence; and use other modeling techniques to assess the depreciation resulting from abnormal functional or external obsolescence; and finally, utilize LifeCycle techniques to represent and combine all forces of depreciation and obsolescence into a composite LifeCycle from which the net depreciation and economic lives can be determined.

The life analysis techniques presented in this paper, which have become to be known as LifeCycle analysis, were developed in the 1980s and 1990s. They are consistent with modern Actuarial theory which dates back nearly 200 years. This author is one of the primary researchers of modern LifeCycle analysis and formally published his research in the Journal of the Society of Depreciation Professionals in 1998.

Background

Depreciation manuals define depreciation as the loss in service value incurred in connection with the consumption or prospective retirement of a property[1]. Valuation manuals define depreciation as the difference between the initial value of a property and its current value. While similar in meaning, it should be noted that for purposes of valuation, depreciation may include economic influences that are independent of the fixed-assets, such as an economic loss in the going-concern of the business that is not the result of a deficiency in the physical property. Whereas for book depreciation purposes, the analyst is often primarily concerned with losses in value directly attributable to the fixed-assets. Whether a depreciation analyst or an appraiser, our goal is to quantify depreciation commensurate with the intended purpose of the assignment.

For most of the last century, all causes of depreciation were typically assessed collectively using actuarial studies, whereby the observed mortality patterns of a group of similar property are determined and represented in the form of a survivor curve and average life. Before 1970, actuarial studies generally provided a reasonable estimate of the service lives and loss in value of most property. The reason such studies were successful, was that the overwhelming drivers of depreciation were traditional forces of mortality forces, namely: physical depreciation and ordinary (normal) obsolescence. Depreciation attributable to traditional forces of mortality is a constant function of the age of the property, which is well suited for actuarial techniques and models. Many forms of abnormal obsolescence, however, are not constant functions of age and therefore not well suited to actuarial models.

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[1] *Public Utility Depreciation Practices*, National Association of Regulatory utility Commissioners (NARUC), 1996, page 318.

Prior to 1970, the pace of technological change was slow by today's standards, and its impact on the depreciation of machinery and equipment, while noticeable, was gradual and readily captured using actuarial analysis and other age-based models. With the introduction of integrated electronics and the computerization of M&E, the pace of technological change accelerated. Early attempts to capture the influence of technological change centered on actuarial models. These attempts proved inadequate.

About the same time that depreciation analyst began to recognize the shortcomings of actuarial techniques, two engineers at General Electric, Messrs. Fisher and Pry, introduced a mathematical model in 1971 that eventually proved highly successful in quantifying and predicting the pace of new technology adoption. This model is now called the Fisher-Pry Technology Substitution model. In the mid 1980's, the Bell Operating Companies began applying the Fisher-Pry model to estimate the technological remaining life of equipment that was being substituted by a newer technology.

While the use of technology forecasting techniques were an improvement over actuarial models when major technological substitutions were imminent, early techniques only considered the impact of the technology substitution and did allow for other forces of depreciation simultaneously impacting the property. What was needed was a modeling technique that allowed any number of forces of depreciation to be combined. This would allow individual or homogeneous groups of depreciation influences to be independently analyzed using modeling techniques appropriate for each influence. The depreciation results from each influence could then be combined and the resulting net impacts to the lives, depreciation and value determined.

Throughout the late 1980's and early 1990's a few depreciation analysts, including this author, investigated this problem. By circa 1990 a defacto model was in common use, primarily by telecommunication carriers in the U.S. and Canada. Initially, this modeling process was somewhat crude in that it simply utilized the greater of the annual depreciation rates from either the physical survivor curve or the technology substitution curve. While an improvement over the legacy practice of relying on either a survivor or a substitution curve, this process still had many shortcomings, including but not limited to:

1. Limited to a single survivor curve and a single substitution curve,
2. Did not account for the influences of growth on technology substitution curves,
3. Did not allow for multiple simultaneous influences.

In the early to mid-1990s, building on the work of W.C. Fitch and F.W. Wolf, cited earlier, and others, I developed a general theory for modeling the combined impacts of multiple forces of depreciation. As noted earlier, this generalized model was formally documented in 1998 in the Journal of the Society of Depreciation Professionals and has come to be called LifeCycle Analysis[2]. LifeCycle Analysis allows any number or causes of depreciation

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[2] It should be noted the LifeCycle Analysis represents an extension of the traditional LifeCycle techniques which were applied to a single survivor curve.

to be combined; and is consistent with accepted actuarial, depreciation, and valuation theory and practice. LifeCycle analysis is now commonly accepted practice. It is included in the Society of Depreciation Professional (SDP) training curricula and included in the SDP's professional certification examination.

In 1998 the Telecommunications Technology Forecasting Group[3] (TTFG) commissioned a study to test the reliability and accuracy of LifeCycle Analysis in quantifying the remaining economic lives when rapid technological obsolescence is present or pending. Several case studies using actual observations were used in the study; and in all cases, LifeCycle Analysis proved highly accurate and reliable[4].

Depreciation Fundamentals

Before we get into LifeCycle Analysis, we need to have a common understanding of the various depreciation terms and a basic understanding of life concepts.

Sources of Depreciation

There are many causes of depreciation; however, they are typically classified into three broad categories: *Physical Depreciation, Functional Obsolescence and External Obsolescence*. For reasons we will discuss later in this paper, Function and External Obsolescence are further subdivided in two types: *ordinary and abnormal.*

Physical Depreciation is the loss in value of an asset due to exposure to the elements and usage. The causes of Physical Depreciation include wear and tear with usage, deterioration with age, and accidental or chance destruction. Physical depreciation is best modeled using traditional mortality techniques and survivor curves. These techniques are rooted in actuarial theory and were established by Messrs. Gompertz and Makeham in the 19th century.

Functional Obsolescence is the loss in value resulting from a flaw or deficiency in the property that inhibits its ability to function for its intended purpose relative to current market expectations. Functional requirements of equipment are subject to change over time, often due to changing consumer expectations. For example, increasing consumer expectations may promote new functionality that older equipment cannot accommodate. To the extent that changing expectations reduce the utilization or utility of the subject property, the depreciation of the property increases. Similarly, technological enhancements in newer models may offer increased economic efficiency, thereby decreasing the efficiency of the older model relative to that of the newer one.

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[3] The TTFG consisted of representatives from each of the then Regional Bell Operating Companies (RBOCs), Bell Canada, and several of the larger independent operating companies.

[4] The TTFG commissioned Technology Futures Inc. (TFI) to perform the case studies. The results of the case studies are contained in the report "*Comparison of Economic Life Techniques*", which can be purchased from TFI.

The relative loss in functionally, to the extent that it reduces the service life or utility of the subject property, increases the depreciation of the subject property.

External Obsolescence, also referred to as Economic Obsolescence, is the loss in value resulting from causes external to the property. The obsolescence is not intrinsic to the subject property, but rather is the result of external forces, such as a downturn in the market. External obsolescence is generally outside the control of the property owner.

An example of external obsolescence is excess capacity in fiber optic cables. For various reasons, fiber cables in some routes is sufficiently oversized such that fiber strands within the cable have no reasonable expectation of being used within the remaining life of the cable. This excess capacity, formally called *super adequacy or Inutility,* is not intrinsic to the cable and is outside the control of the property owner; thus, it is a form of external obsolescence.

As you may have surmised, the various causes of depreciation may overlap. Accidental destruction, for example, is generally considered physical depreciation, yet it meets the definition of external obsolescence.

> **In modeling depreciation and estimating value, it is not critical how the analyst classifies each cause of depreciation. What is important is that the analyst accounts for all forms of depreciation impacting the subject property and does so only once.**

This is a very important point. For example: if an analyst uses depreciation factors based on economic lives that were significantly reduced below the *Normal Useful Life* due to anticipated technology change within the industry and then applies an additional obsolescence adjustment based on the owner's modernization plans; it is highly likely that the analyst accounted for the same obsolescence twice.

Ordinary versus Abnormal Obsolescence

Because some sources of obsolescence exhibits depreciation patterns different from other sources of obsolescence, for modeling purposes it is helpful to draw a distinction between *Abnormal* and *Ordinary* obsolescence.

Ordinary Obsolescence is obsolescence that has achieved a state of equilibrium such that anticipated future patterns of depreciation are generally consistent with recently observed experience. In other words, past depreciation patterns are a reliable indicator of future depreciation patterns. The depreciation impacts resulting from ordinary obsolescence are readily captured in traditional mortality/actuarial models and survivor curves along with physical depreciation.

Abnormal Obsolescence is obsolescence that is expected to result in significantly different levels of depreciation over recently observed experience. Abnormal obsolescence, therefore, cannot be reliably predicted from traditional mortality models.

When abnormal obsolescence is present, the analyst may have to separately model and quantify the resulting impacts to depreciation.

Abnormal functional obsolescence is often associated with the substitution of one technology for another, such as fiber cable substituting for metallic cable in communication networks. During the first roughly 50 to 70 percent of a technology substitution, the rate of substitution steadily increases. While traditional mortality models may capture recently experienced obsolescence, they may not adequately reflect the future levels depreciation[5]. Technology substitution models have proven to reliably predict future levels of depreciation resulting from various sources of abnormal obsolescence.

> *The history of metallic cable provides a good illustration of the difference between ordinary and abnormal functional obsolescence. Throughout the 1960s and 1970s substantially improved new generations of buried metallic cable technology were introduced.*
>
> *During this period, five major generations of metallic cable were introduced.[6] While the impact to depreciation was material, it did not cause the wholesale displacement of prior generations of metallic cable. Rather, the remaining life of older cables fell gradually and slightly as the economics of replacing older cables incrementally improved. The increased depreciation resulting from this technological obsolescence was readily captured in traditional mortality studies and models. Hence, the introduction of successive generations of metallic cable technology resulted in* ***ordinary*** *obsolescence.*
>
> *In stark contrast, the introduction of fiber optic cables in the late 1970's resulted in abnormal functional obsolescence of metallic cable. Unlike successive generations of metallic cable, the availability of fiber cable resulted in the wholesale substitution of metallic cable; and significantly increased the depreciation of metallic cable. The adoption of fiber cable, therefore, resulted in* ***abnormal*** *obsolescence of metallic cable.*

Depreciation's Impact on Value

To effectively model the causes of depreciation, we first need to understand how depreciation reduces the value of property. There are three ways that depreciation can

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[5] Often when a new technology will soon be available, engineers are reluctant to replace older technology until the new technology is available. This phenomenon can cause observed life indications to temporarily lengthen; giving the observer a false indication of the property's service life.

[6] Air-core, paper insulated, lead-sheath cable gave way to air-core, plastic-insulated, plastic-sheath cables. Early plastic technology eventually gave way to air-core polypropylene insulated conductors and sheath (PIC) cables; followed by dual-expanded PIC cables (DPIC). Air-core DPIC cables quickly gave way to petroleum-jelly-filled DPIC cables; the standard for today's buried metallic cable applications.

influence the value of personal property. Depreciation, regardless of the type, can reduce the value of the property by:

1. Reducing the service life of the property,
2. Reducing the utilization or utility of the property, and/or
3. Reducing the net income or profitability of the property.

Reduction in Service Life

The service life of a property or more importantly, the remaining service life of a property, directly influences the value of the property. Consider two similar existing properties, each identical in functionality, cost, and age, but having different expected remaining service lives. The property with the longer remaining life is obviously worth more to the owner – as it will generate the same level of net income but do so for a longer period of time. The property with the shorter remaining life has experienced more depreciation than the other similar property.

All causes of depreciation can influence the service life. Physical depreciation, by definition, results from deterioration due to exposure to the elements and wear and tear through usage. The property's accumulated deterioration and wear and tear directly influences the property's remaining service life. Physical depreciation always, and directly, influences the service life of the property. Similarly, functional obsolescence will always impact the useful service life of a property. External (or economic) obsolescence, however, may or may not influence the remaining service life of a property.

Reduction in Utilization/Utility

A reduction in the utilization or utility of a property may influence its life and value. Consider a printing company that has just one printer that operates at its rated capacity. Due to growing demand, the company invests in a second more modern printer. Because of its higher efficiency, the company runs the newer printer at rated capacity and the older printer at only 50% of rated capacity. While the physical remaining life of the older printer may not have changed, technological advances have reduced the future utilization of the older printer by 50% and hence reduced its value to the business. This form of depreciation is classified as a form of obsolescence, specifically: abnormal obsolescence.

To account for the abnormal obsolescence in our printer example, an appraiser could simply make an Inutility adjustment to the replacement cost new of the underused printer. When the obsolescence impacts all similar property within an industry, however, it is more desirable and appropriate to adjust the economic lives for the class of property. For instance, in the case of fiber cable substituting for metallic buried cable, discussed earlier, LifeCycle techniques were used to adjust the economic lives and resulting depreciation factors to account for the ongoing decline in the utility of metallic buried cables.

Reduction in Profitability

Obviously, any factor that reduces a property's contribution to the net income (profitability) of the business directly influences the value of the property to the owner.

The useful service life of the property may or may not be affected by changes in the profitability of a business. Generally, depreciation that impacts the profitability of a company through means other than a reduction in the utilization or useful service life of a property are classified as economic obsolescence. It should be noted that economic loss due solely to a reduction in net profitability may not be applicable for some assignments involving the valuation of machinery and equipment.

Double Counting Obsolescence

The above impacts of depreciation are not mutually exclusive. The same obsolescence may manifest itself in different ways. In quantifying the impact of abnormal obsolescence, the analyst must take precautions not to count the same obsolescence more than once.

Consider the following example:

> A property was damaged in a hurricane. As a result, the property is only able to operate at 60% of its typical operating capacity. The source of the obsolescence is *hurricane damage*. The property now operates at 40% less than its typical operating level. Thus, abnormal obsolescence in the form of a *reduction in utilization* exists and is due to *hurricane damage*. Additionally, because of the reduced operating level, the net income potential of the property is likewise reduced. Hence, the hurricane damage also results in a *reduction to the net income potential* of the property.

In this example, the same obsolescence manifest itself in two different ways: reduced utilization and reduced net income. If the analyst reduced the value or life based on reduced utilization and further reduced the value or life based on reduced net income, they would be double counting the same obsolescence. While it is obvious in this example, double counting the same obsolescence is often not so obvious in the real world.

Verifying the Existence & Applicability of Abnormal Obsolescence

The nature and purpose of the assignment, and where applicable the *premise of value*, dictates whether a particular cause of obsolescence is applicable to the subject property. For example, a loss to the business value of a company due to a reduction in the value of the company’s goodwill would not normally be applicable to the value or life of the tangible personal property.

There is a simple four-part test for the presence and applicability of abnormal obsolescence that an analyst should consider before making an adjustment to the life or value of personal property:

1. The root cause of the obsolescence is identifiable.
2. The magnitude of the obsolescence can be reliably quantified.
3. It can be credibly demonstrated that the subject property has suffered an actual loss in value due to the identified obsolescence; and

4. The obsolescence is consistent with the purpose of the assignment and its premise of value.

Unless all criteria are satisfied, the abnormal obsolescence is not applicable to the subject property.

These same criteria should be followed in any LifeCycle analysis. For example, if the objective is to develop economic lives and depreciation factors for a class of property across an entire industry then Inutility specific to a given property or owner should not be included in the economic life or resulting depreciation factors. On the other hand, Inutility resulting from technological obsolescence is generally applicable to the entire class of property and should be reflected in the economic lives and resulting depreciation factors.

Plant Lives

The ***physical life*** is the estimated period of time that a property would be in service if only physical depreciation is present, i.e., absent the influence of functional and external obsolescence. Because retirement patterns reflect all depreciation impacting the retirements, it is not generally possible to identify physical depreciation separate from ordinary obsolescence. To some extent ordinary obsolescence is always present; therefore, a pure physical life is not generally observable in practice.

The ***normal useful life***, also commonly referred to as the ***useful (or average) service life***, is the service life that would be realized if only physical depreciation and ordinary obsolescence were present, i.e. absent the influence of abnormal obsolescence. Unlike the physical life, the normal service life is directly observable from historical retirement patterns. When abnormal obsolescence is present the normal useful life can often be observed from mortality data that predates significant influence from the abnormal obsolescence. The normal useful life is generally less than the physical life. Note: it is common practice to (incorrectly) use the terms normal useful life and physical life interchangeably.

The ***productive service life*** or productive life is the actual period of time that a property is expected to provide productive service to the owner. It includes the influences of all depreciation and obsolescence directly impacting period of time the property is physically in service providing a benefit to the owner. The productive life is always less than or equal to the normal useful life.

The ***economic life*** is the period of time that the property is expected to provide productive service to the owner adjusted to reflect any reductions in utilization or utility. It includes the influences of all depreciation and obsolescence impacting the utilization, utility, or remaining productive life of the subject property. The economic life is always less than or equal to the productive life.

In general, obsolescence unique to a given property or owner would not be included in the economic lives and depreciation factors. If applicable, such obsolescence should be separately accounted for. For industries with high levels of technological obsolescence, the normal useful life is often reduced to reflect the displacement in utility resulting from the technology obsolescence or other forms of abnormal obsolescence. In such cases, the economic lives and depreciation factors include the impacts of technological obsolescence and no additional adjustments are required.

Average Life Development

This section gives the reader a basic understanding of what constitute the life of property, plant, and equipment; and how plant lives are developed. We will walk through the development of the average life expectancy for a homogeneous group of property that is experiencing only physical depreciation; thus a single survivor curve is needed to capture all depreciation.

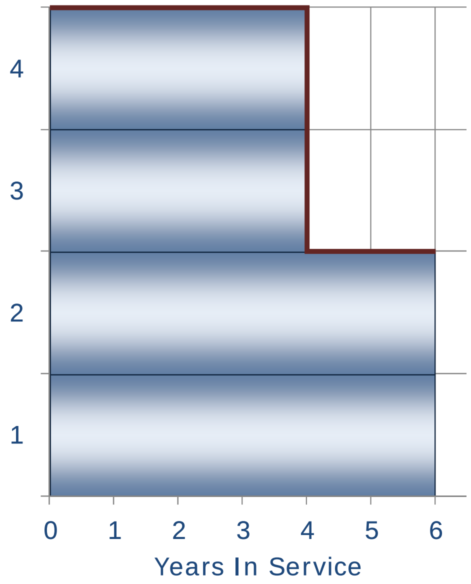
The concept of plant lives is rooted in actuarial theory. The service life of a single asset is the period of time it is in service. For a group of assets, individual items will likely have different lives; therefore, the service life is defined by the average life of the group and the dispersion of the individual lives about the average. The survivor curve documents the dispersion or variance in the life about the average.

First, consider a very simple example: Our *mortality record of experience* (MORE) shows that four widgets were place in service on the same day. Two widgets lived six years and two widgets lived 4 years. See Figure 1. Obviously, the average observed life is 5 years.

The formal solution is to sum the *life-weights* and divide by the total number of widgets. In this case:

- 2 widgets lived 6 years,
    - 2 * 6 = 12
- 2 widgets lived 4 years,
    - 2 * 4 = 8
- Total Life-weight = (12+8) = 20
- Average Life = 20 / 4 = 5

Figure 1 – Record of Experience: 4 Widgets

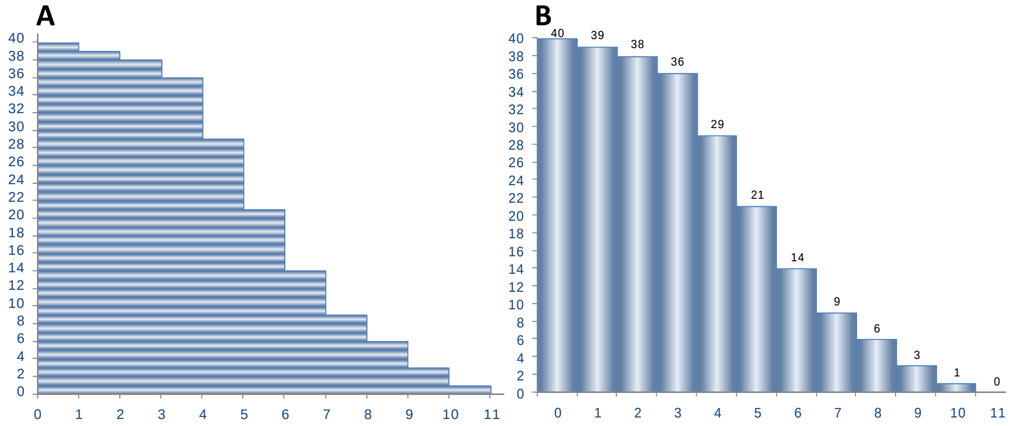


Note that the total life-weight is simply the sum of the area of each rectangle in the figure; or the sum of the rectangles encompassing each of the two equal life groups. The solid line along the top edge of the widgets represents the ***observed survivor curve*** for our sample. Note, that the average life can now be stated as:

$$Average\ Life = \frac{Area\ Under\ the\ Survivor\ Curve}{Total\ Number\ of\ Widgets}$$

Expanding our example to now include 40 widgets having various lives. See Figure 2A. However, knowing that the average life equals the area divided by the starting point; In Figure 2B, I choose to draw the rectangles vertically for each time interval instead of horizontally for each widget.

Figure 2 – Record of Experience: 40 Widgets



Finally, knowing that the average life is the area divided by the total number of widgets, I get the same answer if I divide each vertical rectangle by the total number of widgets. In other words, I am dividing the number of widgets surviving at the start of the age interval by the total number of widgets. In terms of a percentage, this represents the observed percentage of the total widgets still surviving at the start of each age interval – a.k.a. the ***observed survivor curve***. See Figure 3.

Figure 3 – Development of the Observed Survivor Curve from the Mortality Record of Experience.

From Figure 3 we see that the observed average life (Area/Starting Point) is simply the area under the observed survivor curve divided by 100%; and readily calculated as the sum of the percent survivors for each time/age interval. In this example, the observed life indication is 5.9 years.

Selecting the Survivor Curve

The actuarial life analysis process described above would typically involve hundreds or even thousands of items of property placed at different points in time. Once the observed survivor curve is determined, the final step is to fit a generalized survivor curve, such as an Iowa Curve, to the observed curve. See Figure 4. This final step is necessary to smooth out any discontinuities, mitigate extremes, and complete the curve when the observed data does not reach zero.

Figure 4 – Generalized Survivor Curve (Iowa L2) Fit to the Observed Data

The Average Remaining Life

Mortality survivor curves, like the Iowa curve plotted in Figure 4, are functions of the age of the property. As noted earlier, survivor curves define the dispersion pattern of the observed life about the average life. Generalized, or standard, survivor curves, such as Iowa Curves, can be scaled to any life.

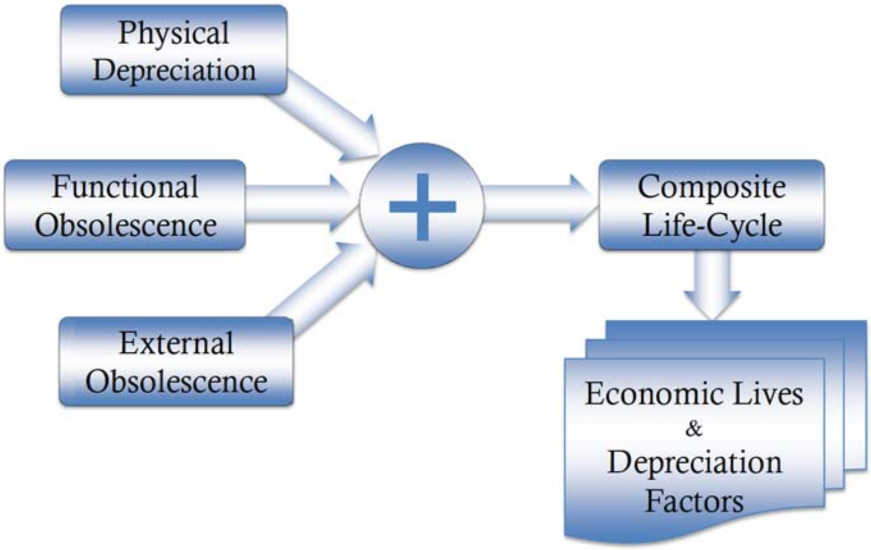
Once the survivor curve and average life are determined, the survivor curve can be applied to any age of property and the corresponding LifeCycle curve as of the assignment date can be determined. For example, if we have a widget that is 4.5 years old on the effective date of an appraisal, the expected remaining life of the widget can be determined from the survivor curve as the area under the curve starting at age 4.5 through the end of the curve, divided by the initial percent surviving, i.e., the percent surviving at age 4.5.

The LifeCycle Process

LifeCycle Analysis is the process of analyzing each forces of depreciation impacting the life and value of the property and quantifying the nature and pattern of the ongoing economic consumption of the assets.

The fundamental process of modeling depreciation involves analyzing the individual impacts of all material causes of depreciation, and then combining the impacts to yield the net or composite depreciation of the subject property. The causes of depreciation are: Physical Depreciation, Functional Obsolescence, and External Obsolescence. Because of the differences in the nature of the three classes of depreciation, each class, or in some cases, each cause of depreciation must be separately modeled using techniques appropriate for the class or cause. This LifeCycle process, depicted in Figure 5, involves developing a unique LifeCycle for each class or cause of depreciation and combining the individual LifeCycles into a single composite LifeCycle from which the composite economic lives and depreciation factors can be determined.

Figure 5 – The LifeCycle Process



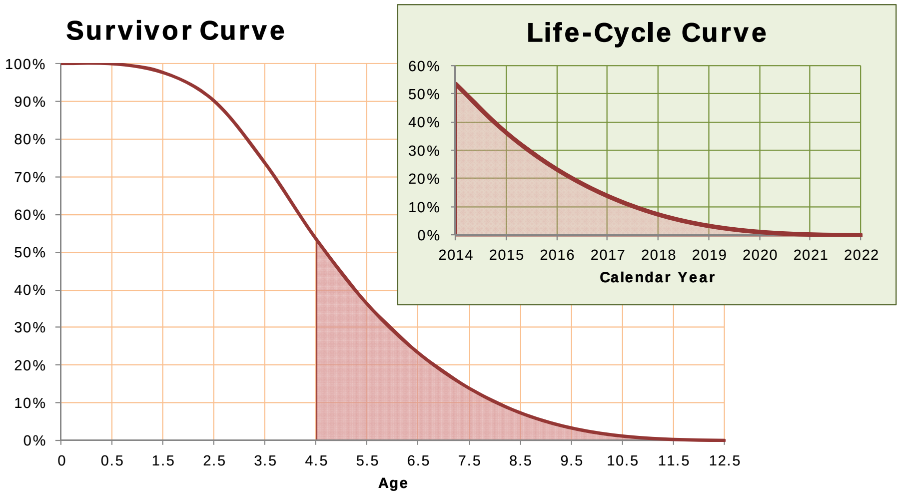
The LifeCycle Curve

LifeCycle curves, unlike survivor curves, are functions of time. The LifeCycle curve is defined as the plot of the anticipated percent surviving starting on the effective date of the assignment going forward.

The LifeCycle curve for the 4.5 year old widget from the previous example is that portion of the survivor curve from age 4.5 to the end. Figure 6 illustrates both the survivor curve for all ages of plant and the resulting LifeCycle curve for property that is 4.5 years old on the effective date of the assignment, in this example 1//1/2014. The area under the

LifeCycle curve divided by the starting point, ≈53%, gives us the estimated remaining life of the 4.5 year old property as of the effective date.

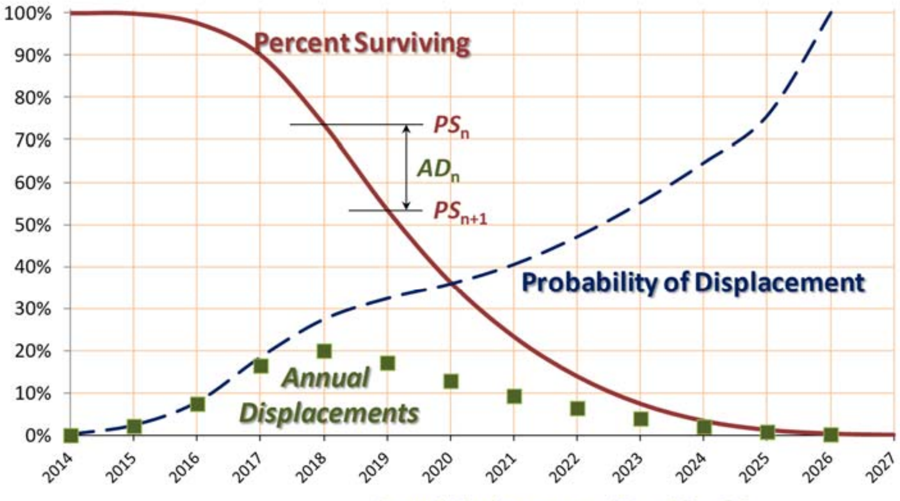
Figure 6 – Survivor Curve versus LifeCycle Curve



LifeCycle Parameters

A LifeCycle curve tells us much about the survivability of the subject property. There are several key parameters we should be familiar with in both developing and interpreting the LifeCycle curve. Figure 7 plots the typical LifeCycle curve and identifies the key LifeCycle parameters, which are discussed further in the ensuing text.

Figure 7 – The LifeCycle Curve



Annual Displacements: $AD_n = PS_n - PS_{n+1}$

Probability of Displacement: $DR_n = AD_n / PS_n$

Probability of Survival: $SR_n = PS_{n+1} / PS_n = 1 - DR_n$

Percent Surviving (PS)

The percent surviving represents the decline in relative utility or service value of the property as we move forward in time from the effective date. It can be calculated from a verity of metrics, depending on the nature of the depreciation or obsolescence being analyzed. When derived from mortality data, the percent surviving reflects the most probable percentage of plant surviving. In obsolescence studies, the percent surviving may reflect the anticipated utilization of the property, or in the case of technology substitutions, the percent surviving is derived from the decline in relative market share of the property. All of these attributes are surrogates for the forward-looking decline in the utility (i.e., obsolescence) of the subject property. While it is not necessary, by convention, the LifeCycle curve is scaled such that the percent surviving is 100% on the effective date of the analysis.

Annual Displacements (AD)

From the percent surviving we can directly determine the annual displacements of the subject property. The annual displacement for any year is computed by substracting the percent surviving at the end of the year from that at the start of the year.

$$AD_t = PS_t - PS_{t+1}$$

In physical depreciation studies, the annual displacements represent the most probable retirements relative to the survivors at the start of the year. In obsolescence studies, the annual displacements often represent the relative decline in utilization or utility.

Probability of Displacement (DR)

The probability of displacement is simply the statistically most likely displacement rate in any given year or period. The probability of displacement may also be referred to as the probability of depreciation or loss and is often simply referred to as the depreciation rate. The propability of displacement is the ratio of the displacements during the period to the percent surviving at the start of the period (i.e., the plant exposed to displacement during the year).

$$DR_t = \frac{AD_t}{PS_t} = \frac{PS_t - PS_{t+1}}{PS_t}$$

Probability of Survival (SR)

The probability of survival is simply the statistically most likely survival rate in any given year or period. The probability of survival is the ratio of percent surviving at the end of the period divided by the percent surviving at the start of the period; and is also equal to one minus the probability of displacement.

$$SR_t = \frac{PS_{n+1}}{PS_n}$$

$$SR_t = 1 - DR_t$$

Similarly: $DR_t = 1 - SR_t$

It is important to note that given any one of the above LifeCycle parameters, the other parameters can be readily calculated. Of specific interest is computing the percent survivors, from which the life and resulting depreciation factors are determined.

$$PS_0 \equiv 100\%$$

$$PS_{t+1} = PS_t \cdot SR_t$$

$$PS_{t+1} = PS_t \cdot (1 - DR_t)$$

$$PS_{t+1} = PS_t - AD_t$$

Combining Multiple Forces of Depreciation

Combining multiple forces of depreciation is often a tedious process. The approach one takes is dependent on whether the forces of depreciation is impacting all or a portion of the subject property.

When Depreciation Forces Are Impacting the Same Property

Multiple forces of depreciation acting on the same property are said to be mutually exclusive. That is, while all the forces are present simultaneously, only one of them can actually cause the displacement of the property. For example, each time you leave your house there exist a small probability that you will be killed by lightning and a small probability that you will be run down by a car. While both probabilities of loss are present, you can be killed by only one of them. Such forces are said to be mutually exclusive. The combined probability of displacement or loss, DR_T, resulting from two mutually exclusive probabilities, DR_1 and DR_2, is given by the following equation:

Net Probability of Loss: $DR_T = DR_1 + \big((1 - DR_1) \cdot DR_2\big)$

Thus, if you had a 10% chance of being killed by lightning and a 15% chance of being killed by a car, the combined chance of being killed by either one is 23.5%, not 25%.[7]

$$0.15 + \big((1 - 0.15) \cdot 0.10\big) = 0.235 \; or \; 23.5\%$$

In terms of the probability of survival, the combined probability is simply the multiplication of the mutually exclusive probabilities of survival.

Net Probability of Survival: $SR_T = SR_1 \cdot SR_2$

When Depreciation Forces Are Impacting Different Property

Often the depreciation analyst must combine the depreciation impacts for different groups of assets, such as different technologies within a broader class of property. In this case, the analyst has several options for computing the composite LifeCycle. The most common method is to sum the annual depreciation amounts for each LifeCycle. Alternately, the depreciation analysis can develop a weighted average of either the percent survivors or the annual probabilities of loss.

Developing the Remaining Life (RL)

As we discussed earlier, the remaining life of the subject property can be directly computed from the percent survivors of the LifeCycle curve. The remaining life, RL, at any

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[7] If these probabilities are applicable to you…Stay Inside!

point in time, is the area under the remaining portion of the percent survivor LifeCycle plot divided by the percent survivors at that point in time. The mathematical equation for the remaining life is:

$$RL(t_0) = \frac{\int_{t=t_0}^{\infty} PS(t)}{PS(t_0)}$$

Which we know is the area under the percent survivor curve divided by the starting point. In our widget example earlier, we saw that the sum of the percent survivors gave us the area under the observed survivor curve. In real life, summing the percent survivors will slightly overstate the area. This error can be minimized by subtracting half the time interval.[8] If "I" is the time interval, then the numerical formula for the remaining life is:

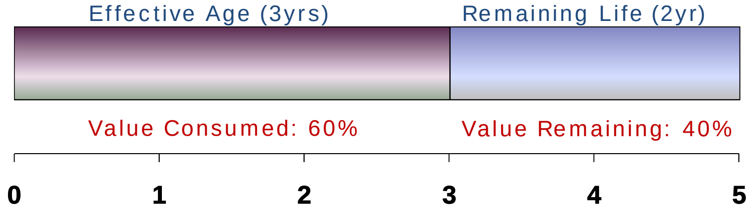
$$RL_{t_0} = \frac{\sum_{n=t_0}^{\infty} PS_n}{PS_{t_0}} - \frac{I}{2}$$

Depreciation Factors/Tables

For valuation purposes, depreciation is commonly presented in the form of remaining value factors or percents. When applied to the cost basis of the property, the depreciation factors yield an estimate of the remaining value of the property. These factors are commonly called *percent good factors* or simply the *depreciation factors.* For example, a depreciation factor of 0.40 or 40% would indicate that forty percent of the property's value is still remaining as of the lien date.

Depreciation factors are determined as the percentage of the economic life of the property remaining. The economic life typically represents the period of time that the property contributes to the ongoing concern of the business. Consider an asset that has been in service for 3 years and is expected to remain in productive service for another 2 years (Figure 8). The asset has an estimated total service life of 5-years (3+2). It has consumed 60% of its useful life, 3 of its 5-year useful life; and has 40% of its useful life remaining, 2 of the 5-year life remaining.

Figure 8 - Depreciation Factors Defined



As the above example demonstrates, the remaining value of the subject property is dependent on the age and remaining economic life of the property. Mathematically, the

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[8] This numerical technique for estimating the area under a smooth curve that approaches zero is called the *Trapezoidal Numerical Integration* technique; and can be found in most Calculus textbooks.

depreciation factors are computed using the classic *age-life* ratio. The age-life ratio is the commonly accepted premise for representing the accumulated depreciation of an asset. One less the age-life ratio yields the remaining non-depreciated value of the asset. The age-life formula for the depreciation (percent good) factor is provided below.

$$Depreciation\_Factor = \frac{Remaining\_Life}{(Age + Remaining\_Life)}$$

It is important to note that in the above formula for the depreciation factor, the *Age* (i.e., effective age) is generally known, leaving the *Remaining Life* as the primary unknown. Thus, to estimate the remaining value, an appraiser must estimate the remaining life of the property. In a fee-appraisal, the appraiser will often estimate the remaining life of each individual property and then determine the resulting depreciation factors. In a mass appraisal cost approach, the appraiser typically looks to published economic lives and depreciation tables.

Summary of the LifeCycle Process

1. Develop a LifeCycle model for each force of depreciation/obsolescence impacting the subject property.
    a. Model each force of depreciation impacting the subject property using a model appropriate for the nature of the force.
    b. Equate each force of depreciation in terms of one or more of the LifeCycle parameters.
2. Develop a composite LifeCycle.
    a. Combine the individual forces of depreciation using the formulas identified in this section.
    b. Compute the percent surviving for each year from our lien date forward.
3. Compute the remaining economic life from the percents surviving.
4. Compute the depreciation factors from the remaining economic lives.

Modeling Physical Depreciation & Ordinary Obsolescence

Traditional forces of mortality, physical depreciation and ordinary obsolescence, are commonly modeled using actuarial techniques, which were mathematically quantified in the mid-19th century. This type of analysis is commonly referred to as historical mortality analysis. Mortality analysis typically involves the statistical analysis of observed mortality data, primarily observed retirements or survivors. The result of this analysis yields a survivor curve and average service life. Together these results reflect the ongoing depreciation of the subject property resulting from physical depreciation and ordinary obsolescence.

In the context of this paper, traditional forces of mortality refer to those forces of mortality that can be reasonably modeled as a function of the age of the asset. Traditional mortality generally results from usage and exposure to the elements; and, in some cases, incremental improvements in a technology.

Accumulated usage of an asset, barring unusual usage patterns, is effectively a function of age. Wear and tear of an asset resulting from accumulated usage is, therefore, also a function of age. Similarly, some forms of deterioration are a direct function of age, while others are a function of accumulated exposure to the elements, which in turn is a function of age. Accidental or chance destruction is more a function of the environment surrounding the asset and generally constant for all age groups.

There are two commonly accepted traditional mortality analysis techniques: ***Actuarial Analysis*** and ***Simulated Plant-Record*** (SPR) Analysis. Actuarial analysis involves developing the mean probability of loss (retirement rate) for each age of plant; whereas, SPR analysis statistically compares either observed total survivors or retirements to simulated survivors or retirements. In both techniques, the best-fit average life and survivor curve is statistically determined from the observed mortality record of experience.[9]

The physical depreciation LifeCycle for any age of plant is that portion of the survivor curve to the right of the age. Because physical depreciation is different for each age of plant, each vintage/age of property will have a unique physical depreciation LifeCycle and unique remaining physical life expectancy. This was illustrated earlier in Figure 6, which plotted the survivor curve and the LifeCycle curve corresponding to 4.5-year old property.

Modeling Abnormal Obsolescence

To the extent that future abnormal obsolescence is expected to be significant, it should be separately quantified and added to the physical depreciation and ordinary obsolescence reflected in the mortality survivor curve.

Abnormal Obsolescence

Abnormal obsolescence may take a variety of forms. The form and nature of the loss dictates the approach one must take to assess its contribution to depreciation. Regardless of the modeling technique the analyst uses, the key is to format the results into at least one of the four LifeCycle parameters, effectively establishing the LifeCycle for the obsolescence being analyzed. In this form, it can be readily combined with other causes of depreciation and obsolescence. While the possibilities are endless, some of the common forms that abnormal obsolescence can take are presented below along with a discussion of the development the resulting LifeCycles.

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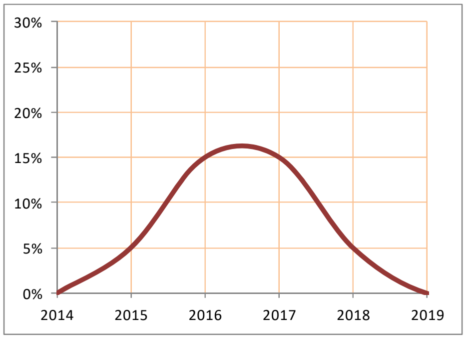
[9] A full discussion of Actuarial Analysis and Simulated Plant-Record Analysis can be found in "*Public Utility Depreciation Practices*", National Association of Regulatory Utility Commissioners (NARUC), 1996.

Known Replacements

Supposed the owner's engineering staff embarks on a maintenance initiative to replace a certain model of equipment. From your analysis, you determine the initiative will result in additional replacements of 5% of the property by 2015, 15% by 2016 & 2017, and dropping to 5% by 2018. The LifeCycle of the maintenance initiative is readily defined in terms of the annual displacement rates, which is shown in Figure 9.

Figure 9 – Maintenance Initiative

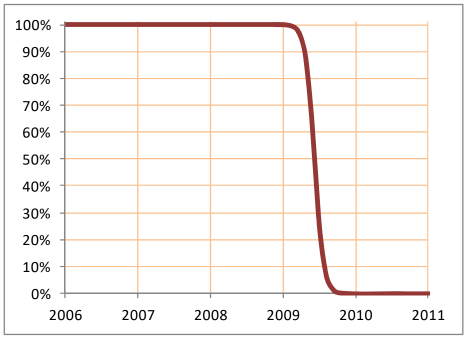


Decline in the Remaining Life

Generally, we compute the remaining life from other depreciation impacts; however, in some cases the remaining life is given. For example, the Federal Communications Commission (FCC) mandated that all TV broadcasting equipment must be digital (DTV) by July of 2009. Thus, all analog (NTSC) equipment not compatible with the DTV standard would have to be replaced by July 2009.

Assuming the broadcasting industry would put off replacing their NTSC equipment until near the due date; a somewhat square LifeCycle curve could be expected. If the lien date were 1/1/2006, then a reasonable LifeCycle for the obsolescence associated with the FCC mandate is provided in Figure 10.

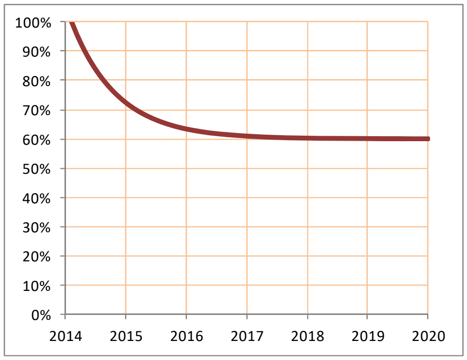
Figure 10 – LifeCycle: FCC Mandate



Long-Term Impairment to Net Income

For an income producing property, circumstances outside the control of the property owner will result in a decline in net income from the subject property. Your analysis concludes that the decline will begin gradually starting on the lien date and continue for three years where the loss will stabilize near 60% of the historical net income. The LifeCycle for this decline in net income is reasonably depicted in Figure 11.

Figure 11 – LifeCycle: Net Income Loss



Technology Substitution Analysis

In many industries abnormal obsolescence is often the result of a new technology causing the displacement of the embedded technology sooner than would otherwise occur. Technology displacements can be a decline in utilization, physical retirements, or both. Fiber cable substituting for metallic cable and packet switches substituting for circuit switches are two technology substitutions that are resulting in significant levels of abnormal obsolescence.

The replacement of older technology by newer technology is called *technology substitution*. When the pace of the technology substitution results in premature retirement or a decline in utilization of the older technology, increased depreciation is realized. This form of depreciation is abnormal obsolescence. As noted earlier, incremental improvements in an existing technology do not generally result in abnormal obsolescence.

The common method for assessing the adoption of new technology is *substitution analysis.* Substitution analysis is a technique that has proven effective in projecting the adoption of new technology. Substitution refers to the displacement of an established technology by a newer technology because the new technology provides improved capabilities, performance, or other efficiencies. Many forms of abnormal obsolescence, especially technological obsolescence, can be modeled using an extension of technology substitution analysis.

The process of technology substitution occurs over time and follows predictable patterns. Substitution patterns are remarkably consistent from one technology substitution to another. It is characterized by an S-shaped curve when the market share of the new technology is plotted over time. Because virtually all technology substitutions follow the classic S-curve pattern, they can be reliably forecasted from minimal observed experience. Figure 12 shows the S-shaped curve for the Fisher-Pry model. Of several substitution models available the Fisher-Pry model, and its extensions, notably, multiple substitution models[10], are the most useful in assessing the rate of substitution of industrial property.

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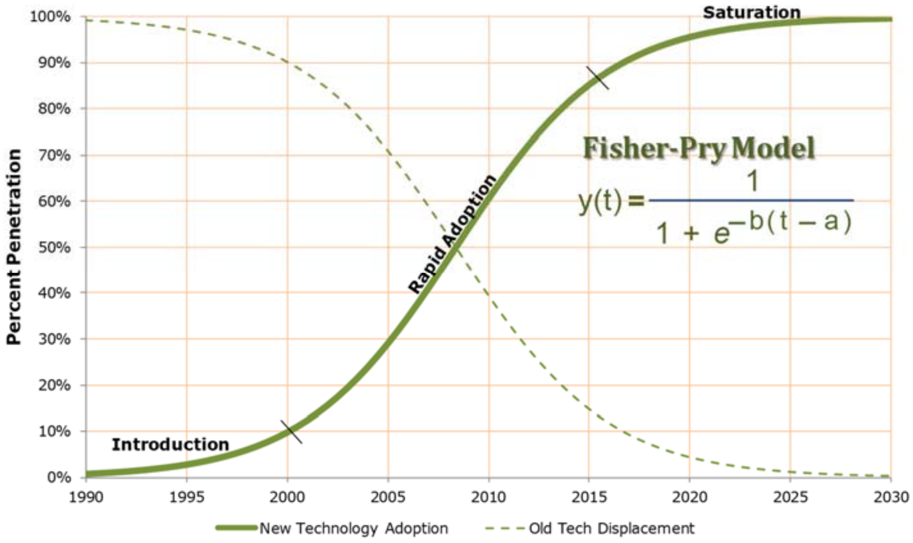
[10] Multiple substitutions occur when the substitution of one technology for another is in progress and a third technology enters the market. For example, digital switching was introduced before analog electronic switches had completely replaced electromechanical switches, so both analog and digital switches were substituting for electromechanical switches simultaneously.

Figure 12 – The Fisher-Pry Model



In the Fisher-Pry equation, shown above, *y(t)* is the percent penetration and 'a' and 'b' are parameters which define the curve. The parameter 'a' is the point in time when the percent penetration equals 50% and 'b' is a measure of the pace of adoption. For similar technologies within an industry, values of b tend to be similar.

The adoption of a new technology is generally considered to have three phases: The Introduction phase, the Rapid-Adoption phase, and the Saturation phase. Each phase constitutes about a third of the total adoption period. The three adoption phases are highlighted in Figure 12.

The Introduction Phase

The adoption of a new technology starts slowly. There are several reasons for this. When a new technology is first introduced, it is generally inferior to the old technology in many ways. The new technology is usually more expensive and imperfect. The new technology has not achieved economies of scale; and more often than not, many manufacturing and design defects only become apparent through usage.

The newer technology is usually unfamiliar to field personal and less understood by management. History has shown that lack of understanding by upper management is often a major impediment to deployment. Often, senior management has achieved their position of influence based on their understanding of the embedded technology. Thus, some in management may perceive the new technology as a threat.

As a result of these and other factors, initial deployment of a new technology is generally confined to niche applications where the advantages of the new technology can be exploited. Typically, the bulk of deployment in the early years is for new growth and replacement applications where the property was likely to be replaced anyway.

Rapid Adoption Period

As deployment continues, many of the impediments to adoption diminish. Defects are corrected, economies of scale are increasing, field forces become familiar with the new technology, prices are dropping, and management comes to understand and recognize the superiority of the new technology. All these factors, and others, combine to make the new technology increasingly more economical, which leads to accelerating deployment, which leads to even more improvements,… At this point, technology reaches the rapid adoption phase. Here, in roughly a third of the adoption period, the new technology will capture about 70% of the total applicable market.

Market Saturation

As the new technology deployment continues to gain market share, it eventually saturates the market. The pace of adoption begins to slow as the last strongholds of the old technology are penetrated. Often the few remaining old technology applications represent niches where the attributes of the old technology are essential, and circumstances render replacement not worth the effort. For these and other reasons, the pace of new technology deployment slows as we near the end of the adoption period.

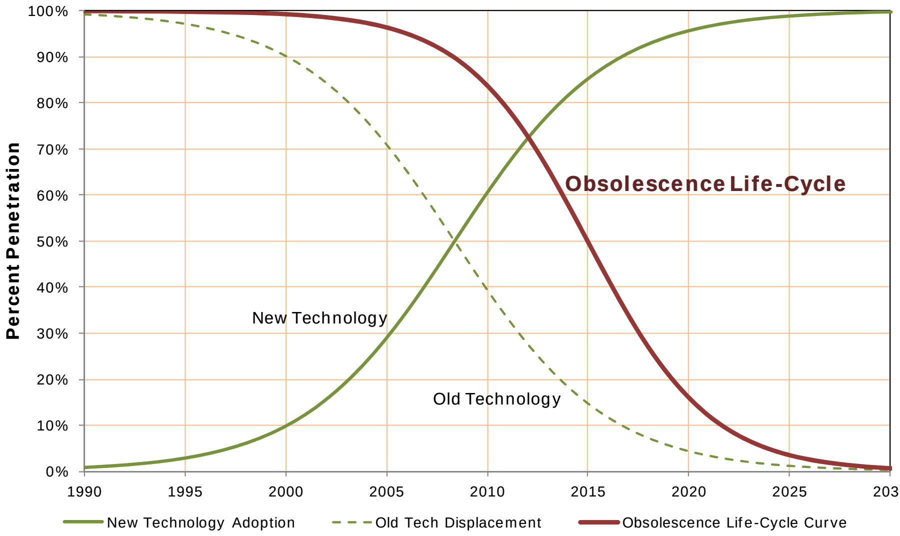
Technological Obsolescence

The obsolescence of the embedded technology occurs roughly proportional to its decline in market share. During the introduction phase, new technology is deployed primarily for new growth applications and as a replacement vehicle for equipment being replaced due to traditional mortality forces. Thus, technological displacement and the corresponding obsolescence of the old technology are minimal.

As the new technology matures and its deployment gradually increases, it begins to trigger the displacement of older technology that otherwise would have remained in service. These premature displacements are the direct result of the adoption of the new technology and represent technological obsolescence. As the new technology reaches the rapid adoption stage and deployment accelerates, technological obsolescence also accelerates. Finally, as the new technology saturates the market and its deployment decreases, the rate of obsolescence stabilizes.

Figure 13 shows the relationship between new technology adoption and old technology obsolescence. It depicts the gain in relative market share of the new technology over time and the loss in market share of the embedded technology. The corresponding obsolescence of the embedded technology is also depicted. As seen in the figure, the old technology realizes very little obsolescence initially. During this period, traditional mortality forces drive the depreciation of the property. Technological obsolescence doesn’t become noticeable until circa 1998, as we approach the rapid deployment phase. Going forward, the obsolescence pattern follows that of old technology displacement. Both curves eventually converge to zero as the old technology is completely displaced by the new technology.

Figure 13 – Technology Obsolescence



While the old technology and new technology adoption curves represent their respective market share; the obsolescence curve can be thought of as representing the relative decline in the utility of the old technology. In other words, it represents the LifeCycle curve directly as a result of the deployment of the new technology.

Near the very end of a substitution a departure from the classic S-curve substitution may occur. For some technologies, adoption of the new technology may accelerate rapidly at the very end; or conversely, the substitution my come to a near standstill. A rapid increase at the end of a substitution may result from the industry deciding to quickly remove the remaining old technology due to the increased operational savings associated with the complete removal of the older technology. A virtual standstill may also be experienced due to little or no economic motivation to remove the remaining old technology holdouts.

Technology substitution analysis is predicated on pitting one technology against another. Multiple substitutions exist when more than two technologies are simultaneously competing for market share. Multiple substitution analysis is beyond the scope of this paper; however, the technique involves subdividing the applicable market to achieve a 1:1 technology substitution in each submarket. Note, often technologies older than one generation removed from the new technology can be combined and treated as a single technology. Additionally, it should be noted that, when properly constructed, technology obsolescence, unlike physical depreciation, will generally impact all ages of property equally.

The method of determining the impact of technological obsolescence is straightforward. First determine the pace of adoption of the new technology. This is accomplished by fitting a substitution curve to observed (or forecasted) deployment of the new technology. Care should be taken to ensure that the measure of market share (i.e. units of substitution) is indicative of the overall utility of the technology. Experience has shown that using investment dollars will generally distort the substitution and yield erroneous results. Selecting appropriate units of substitution comes with experience. Generally, measures that capture the utilization or utility of the competing technologies work best.

Next, the analyst must determine the start of obsolescence. While each situation is different, as a general rule technological obsolescence becomes noticeable as the new technology approaches 10% market penetration. By convention, the start of obsolescence is defined as a 1% drop in market share. Thus, the fist data point for the obsolescence curve is 99% at the point in time when the new technology adoption approaches 10% penetration.

We know that when the new technology reaches 100% penetration, the old technology has been totally displaced so the obsolescence must also be complete. In other words, the substitution curve, and the obsolescence curve, end at the same point in time. Substitution curves are asymptotic, that is while they approach 100%, they never actually get there. This presents problems when using PCs to determine the obsolescence curve. Experience has shown we can get around this problem by setting the obsolescence percent survivors to 3% when the new technology has reached 97%.

The analyst now has two data points which can be used to directly determine the obsolescence curve. The obsolescence curve is inversely proportional to the substitution curve; therefore, the ‘b’ value in the Fisher-Pry equation will be negative. Taking the portion of the obsolescence curve starting with the effective date of the assignment and normalizing it to 100%, we have the resulting LifeCycle curve. In this form, the depreciation impacts of technology obsolescence can be readily combined with other forms of depreciation that may be impacting the subject property.

LifeCycle Example

The following example walks through the process of computing the combined depreciation rates for a group of properties subject to both traditional forces of depreciation and abnormal obsolescence, specifically technological obsolescence plus a planned maintenance initiative to replace certain models of equipment over the next several years. In this example, we will compute the composite LifeCycle, the remaining economic life, and the depreciation percent good factor for the newest property on the effective date of 1/1/2014.

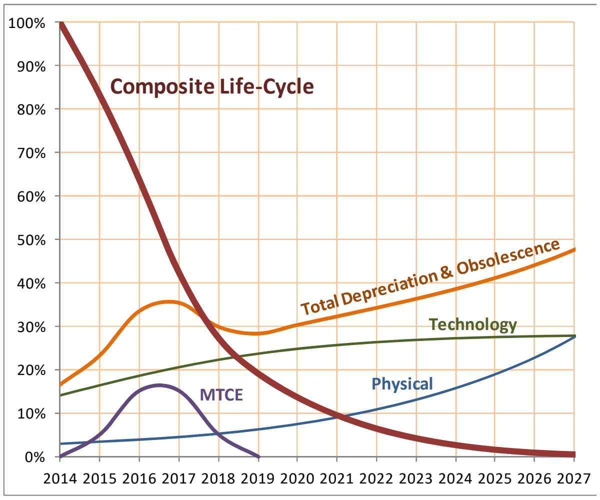
From our investigation and discussions with the owner, we determine that the average life expectancy is 10 years, absent the influence of abnormal obsolescence. Additionally, studies indicate that the property reasonably follows an Iowa R1 survival pattern. We obtain the Iowa R1\10 survivor curve from published sources and compute the annual displacement rates for newly placed property, age=0.5 on the effective date, using the formula given earlier:

$$DR_t = \frac{PS_t - PS_{t+1}}{PS_t}$$

The resulting physical depreciation displacement rates are listed in column A of Figure 14 and plotted in the accompanying graphic.

Figure 14 – Example Results

Year	Depreciation & Obsolescence				Life Cycle (Pct.Surv.)
	Phys.	Tech.	Mtce.	Total	
	A	B	C	D	E
2014	2.97%	14.05%	0%	16.60%	100.0%
2015	3.43%	16.35%	5%	23.26%	83.4%
2016	3.92%	18.53%	15%	33.47%	64.0%
2017	4.51%	20.49%	15%	35.46%	42.6%
2018	5.26%	22.18%	5%	29.96%	27.5%
2019	6.24%	23.58%	0%	28.35%	19.2%
2020	7.48%	24.70%		30.33%	13.8%
2021	9.02%	25.57%		32.28%	9.6%
2022	10.87%	26.24%		34.25%	6.5%
2023	13.08%	26.74%		36.32%	4.3%
2024	15.72%	27.11%		38.57%	2.7%
2025	18.89%	27.38%		41.10%	1.7%
2026	22.73%	27.58%		44.05%	1.0%
2027	27.47%	27.73%		47.58%	0.6%
2028	33.43%	27.83%		51.96%	0.3%
2029	41.08%	27.91%		57.52%	0.1%
2030	51.10%	27.97%		64.78%	0.06%
				Remaining Economic Life:	**3.27**



The subject property is also subject to substitution by a newer technology. Industry studies document the ongoing substitution, which is provided in Figure 13. Using the obsolescence curve, we can determine the technology LifeCycle and compute the corresponding displacement rates. The resulting technology obsolescence rates are provided in column B of Figure 14 and plotted in the accompanying graphic.

In addition to the above technological obsolescence, the company plans to replace all of a particular model over the next several years. Working with the company's engineers we estimate the additional displacements of the subject property. The resulting obsolescence displacement rates are provided column C of Figure 14 and plotted in the accompanying graphic.

Using the survival rate formula for combining multiple forces of depreciation, we compute the net annual probabilities of displacement. The formula used in terms of the column labels is provided below and the resulting total probability of displacement is given in column D of Figure 14 and plotted in the accompanying graphic.

$$Total\ Depr\ Rate = 1 - \big((1 - \mathrm{A}) \cdot (1 - \mathrm{B}) \cdot (1 - \mathrm{C})\big)$$

From the total annual depreciation rates, it's a simple matter to compute the composite LifeCycle, which is listed in column E of Figure 14 and plotted in the accompanying graphic. Summing the percent surviving in column E and subtracting ½ year yields the remaining economic life for newly placed property as of the effective date: 3.27 years. The resulting depreciation factor is readily computed as the remaining life divided by the age plus the remaining life. The resulting percent good factor for property 0.5 years old on the effective date is 86.7%.

Case Study

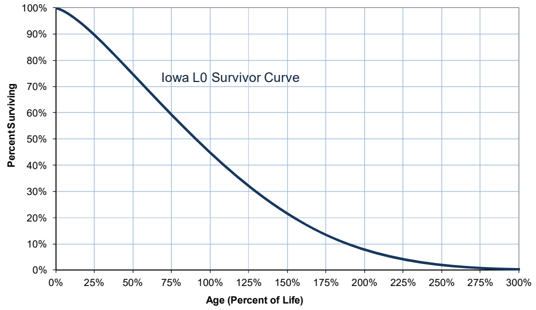
Circa 1997, the telecommunications industry undertook several case studies to demonstrate the reliability of LifeCycle analysis techniques when significant technological obsolescence is present. To accomplish this several plant accounts were selected for analysis. A study date was selected for each account which predated the rapid deployment stage of the new technology. Independent LifeCycles were developed for both physical depreciation and technological obsolescence; and combined. The resulting composite economic life was estimated and compared to the subsequently observed economic life. In all cases, the estimated economic life was reasonably close to the subsequently observed economic life. One of the case studies undertaken is presented, in part, below.

This case study LifeCycle techniques to estimate the economic life of interoffice (IOF) metallic underground cable[11] for a telecommunications Local Exchange Carrier (LEC), referred to as LEC-A. An effective date of 1/1/1986 was chosen because IOF fiber deployment at that time was just reaching the rapid deployment stage. Additionally, at that time many industry experts and regulators did not appreciate the full impact that fiber deployment would have on the economic life and depreciation of IOF metallic cable. For clarity and to save trees, in the illustrations below only the vintage of property that was 14.5 years old on the effective date is included. This age was chosen because it roughly equals the average age of the subject property.

Traditional Mortality

Telecommunications carriers began deploying fiber cable in the late 1970's. By 1980, fiber cable deployment in the IOF was still in the introductory stages and had not materially displaced metallic underground cable. To avoid double counting technological obsolescence mortality experience prior to significant impact of technological obsolescence was used to quantify the depreciation from traditional forces of mortality. To this end, mortality data was limited to that experienced between 1978 and 1980.

Figure 15 - Mortality Survivor Curve



The actuarial analysis was conducted by the LEC-A's depreciation staff. The results indicated that the Iowa L0 survivor curve provided a good fit to the observed mortality patterns. An average service life of approximately

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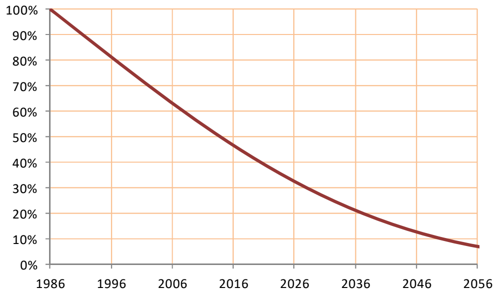
[11] The Interoffice or IOF network consists of the cabling and associated electronic that interconnect a telecommunications carrier's many Central Offices. In the IOF network, distances are long (30 to 100 miles or more) and concentrations of communication traffic are high. Underground cable is cable that is placed in conduit.

40 years was observed. A 40-year average life was also consistent with life indications from other communication carriers across the U.S. The resulting mortality survivor curve is shown in Figure 15. The corresponding LifeCycle plot for age 14.5 property is shown in Figure 16.

Figure 16 - LifeCycle: Traditional Mortality
(Iowa L0\40yr | Property Age 14.5)

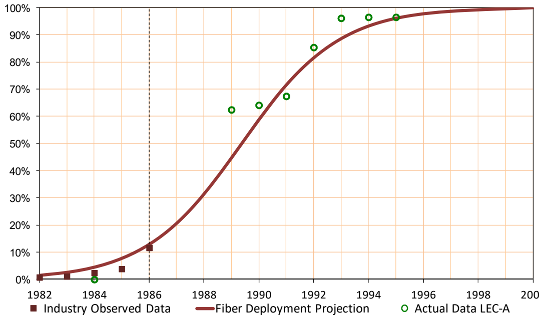


This figure illustrates what the LifeCycle of 14.5 year old IOF metallic cable would look like, in 1986, absent any influence from abnormal obsolescence. From the figure we see that it would take over 70 years for physical depreciation to displace 95% of 14.5 year old metallic cable. Today, we know that it actually took just over 11 years (1986 to 1997) to displace 95% of all IOF metallic cable. Clearly, forces other than the traditional mortality forces influenced the mortality of these assets. That missing force was technological obsolescence.

Technological Obsolescence

The case study used <u>industry</u> fiber deployment data known on the effective date. Prior to 1986, there was very little fiber deployed and many experts were skeptical about its long-term potential. While the empirical data was limited, there was sufficient industry data to make a reasonable projection of fiber adoption and the resulting substitution of IOF metallic underground cable.

Figure 17 - Projected Fiber Deployment



The pre-1986 industry data and the resulting technology substitution projection are shown in Figure 17. Also shown is LEC-A's actual IOF fiber deployment through 1995. From the graph, we see that the substitution projection, while not exact, does provide a rough approximation of LEC-A's subsequent IOF Fiber deployment.[12]

From the projected market share of fiber, the corresponding market share of IOF metallic cable was computed. New IOF fiber cables were generally deployed to accommodate anticipated growth and typically placed parallel to existing metallic cables. Over time, metallic cable circuits would migrate to the fiber cables as turnover in the network

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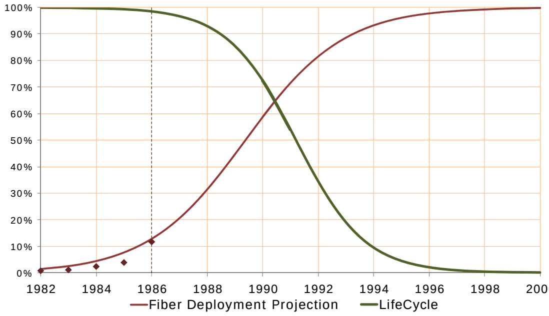
[12] One reason this particular LEC was selected for this study was precisely because the industry substitution trend only roughly approximated the LEC's subsequent fiber deployment. Generally, other LECs and jurisdictions more closely followed the projection. Thus, if the results of this case study produce reasonable life estimates, then it demonstrates the robustness of this approach and as well as its reliability and accuracy.

presented opportunity to do so. Accordingly, it was assumed that the obsolescence of metallic cable would be negligible until fiber approached 10% market penetration. Then, as deployment moved into the rapid deployment stage, metallic cable displacement would track inversely with fiber adoption. The resulting projection for the obsolescence IOF underground metallic cable is provided in Figure 18.

Figure 18 - Obsolescence of IOF Metallic Cable



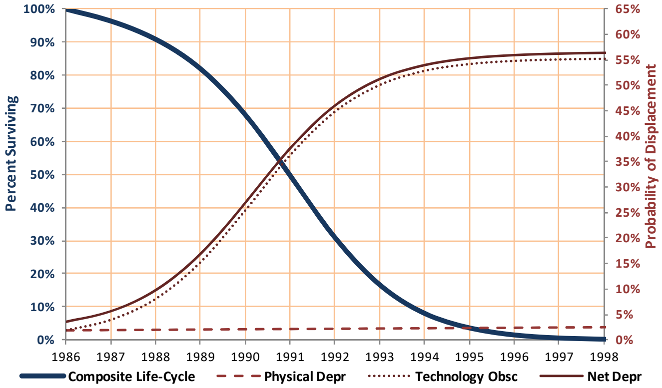
Resulting Economic Life

To determine the remaining economic life, we need to combine the LifeCycles for all depreciation impacting the subject property, which in this case is limited to traditional mortality and technological obsolescence. Since physical depreciation increases with age, each age of plant has a different traditional mortality LifeCycle; whereas for technological obsolescence, the LifeCycle provided in Figure 18 is applicable to all ages of property.

For our 14.5 year old property, we combined the LifeCycles developed earlier and shown in Figure 16 and Figure 18. For this task, I chose to use the probabilities of displacement to combine traditional mortality and technological obsolescence. The individual probabilities are listed in columns A and B of Figure 19. The combined probability of depreciation is computed in column C; and the resulting combined LifeCycle curve is provided in column D. All are plotted on the right side of the figure.

Figure 19 – Development of the Composite LifeCycle for Age 14.5

Activity Year	Physical Depr	Technology Obsc	Net Depr	Composit Life-Cycle
	A	B	C=A+((1-A)*B)	$D_t=D_{t-1}*(1-C_{t-1})$
1986	1.83%	1.81%	3.60%	100.0%
1987	1.88%	3.90%	5.70%	96.40%
1988	1.93%	8.03%	9.80%	90.90%
1989	1.98%	15.24%	16.92%	81.99%
1990	2.02%	25.45%	26.96%	68.12%
1991	2.07%	36.31%	37.62%	49.76%
1992	2.11%	44.85%	46.01%	31.04%
1993	2.15%	50.11%	51.19%	16.76%
1994	2.20%	52.88%	53.92%	8.18%
1995	2.24%	54.22%	55.25%	3.77%
1996	2.28%	54.84%	55.87%	1.69%
1997	2.33%	55.12%	56.17%	0.74%
1998	2.38%	55.25%	56.31%	0.33%
1999	2.42%	55.31%	56.39%	0.14%
2000	2.47%	55.33%	56.43%	0.06%



Summing the composite percent surviving, column D, dividing by the starting point, and subtracting ½ year, we get a remaining economic life of 5.0 years. The corresponding depreciation factor (percent good factor) is

$$DeprFactor_{age} = \frac{RL_{age}}{(Age + RL_{age})} = \frac{5.0}{(14.5 + 5.0)} = 25.6\%$$

Absent technological obsolescence, the normal useful life of 14.5 year old property would be 32 years (not shown). Technology obsolescence reduced the economic life from 32 to 5 years, a reduction of over 84%. The actual case sturdy yielded an economic life for new property of 6.8 years, an 83% reduction to the normal useful life. The subsequently realized economic life was 6.5 years – just three tenths of a year less then estimated via LifeCycle analysis. Circa 1986 the FCC's prescribed economic life for IOF metallic cable was on average 23.6 years.

The LifeCycle techniques presented in this paper provide the life analyst an objective, systematic, and robust foundation to evaluate the depreciation influences from any number of diverse sources. The techniques have been used by depreciation analysts, in whole or in part, for over 25 years. They have proven highly reliable in estimating the remaining economic lives of machinery and equipment, especially when subject to abnormal obsolescence.

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