A Comparison of Asset Valuation Methods For Civil Infrastructure

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Abstract

Highway networks generally represent the largest asset of public infrastructure. Management of the performance of this asset through timely rehabilitation and/or maintenance is well understood, however, less is known about how to manage the value within the context of public-private partnerships or other delivery models. The recent trend to privatization coupled with a new requirement to report tangible capital assets on annual government statements has focused the need for an understanding of the impact of valuation method and performance prediction models on network asset valuation.

Asset valuation holds great promise as a readily understood (to the public and private sector) performance measure and, as an asset management integration mechanism for trade-off analysis between competing components (pavement, bridges etc.). However, uncertainty within the valuation method and a lack of understanding of the performance basis for valuation has created barriers to acceptance of performance based valuation by the financial community.

The paper describes the role of asset valuation within asset management, followed by a comparison of asset valuation methods and application. Using the City of Edmonton pavement database as a case, the network asset valuation is calculated for five valuation methods to gain an understanding of the variation between methods and as such the impact of selecting one approach over another. Uncertainty is investigated through the use of Monte Carlo simulation to calculate asset value using probability distributions for key variables in the calculations.

Introduction

In the 1997 Federal Election, the Canadian Alliance Party of Canada aired a television commercial that showed a relaxed Leader of the Opposition, Stockwell Day, holding his granddaughter and making the alarming statement that even at the young age of four, Janelle's share of the national debt was $26,000. As anyone who has ever had to request a mortgage or loan from a bank knows, debt is secured by collateral, so the question that begged to be asked and answered is, if Janelle owes $26,000, what does she own to secure that debt? The answer lies in the national public infrastructure: roads, bridges, rail, ports, airports, electrical systems, government buildings, and land. However, the ability to assign a value to those assets is much more difficult than adding up the value of debt held as bonds debentures and other fiduciary implements and the issues and difficulties associated with valuation of tangible capital assets held by public agencies, specifically, transportation agencies is the topic of this paper.

Many agencies are moving toward the implementation of asset management systems as a result of two driving changes in the delivery of transportation systems. Firstly, as a result of privatization within highway agencies, there is an increased need for management of not only the decision making process for rehabilitation programming, but also a requirement to safeguard the investment of the shareholders (taxpayers) through timely and appropriate levels of maintenance. A second reason for the move to asset management is the recent requirement by United States Government Accounting Standards Board (GASB) and the Canadian Public Sector Accounting and Auditing Board (PSAAB) for accounting of tangible capital assets within annual government statements. This requirement means that for the first time agencies must show the value of their infrastructure assets (Tangible Capital Assets) and demonstrate, through annual reporting, that the value of the asset is being maintained. This twofold change has resulted in an acceptance by road agencies that private sector principles may be applicable for management of public systems; however, the transfer of such principles and methods to the public sector is not straightforward. These agencies do not have profitability as an ultimate bottom line and they are expected to meet a plethora of objectives. Nevertheless, asset management does represent some new ways of thinking, how a public agency should conduct its business and how to deal with the range of practical problems.

Well-established component management systems for pavements, bridges, traffic congestion, safety, etc. precede asset management and most, if not all, of these systems are based upon the principles of life cycle management of the asset [Cowe Falls 2001]. These systems have been designed to answer three fundamental questions: "What assets do we have; where are they; and, what condition are they in?" The supplementary questions being asked are "How many dollars do we need to maintain or improve the current condition?" and "What will the condition be as a result of a given funding level?" Asset management requires accounting of the investment made in the asset and as such adds a fourth fundamental question – "What is the value of our asset?"

Using asset management systems as a mechanism to monitor performance, from an investment point of view, requires an understanding of the uncertainty created through both the asset valuation method and the performance models. In pavement or bridge management systems where the decision support system is centered on the optimization of cost-effectiveness (as defined by the area under a performance/depreciation curve), it is possible to provide answers to the question “what will the condition of my network be in year x as a result of expenditure y?”. Due to a lack of understanding of the uncertainty surrounding valuation method, performance modeling and the interaction of the two, it is not possible to answer the question ‘what expenditure do I need to have “x” probability of having value (or level of service) “y” in year(s) “z”?’ It is because of this that some of the agencies that are in the throes of implementing GASB34 have chosen not to use the modified approach and senior administrators are challenged to determine, with any confidence, the correct level of funding to maintain future network value.

Without the ability to answer the above posed question, managers are unable to adequately build an argument for increased funding of infrastructure (particularly when borrowing to finance improvements) and if a change in accounting methods is proposed as data becomes available, there is little understanding of the impact of such a change on the reporting of asset value.

Value Defined

Asset valuation is defined by Marston [1970] as,

> “the art of estimating the fair monetary measure of the desirability of ownership of specific properties for specific purpose…”

He furthers refines the definition in terms of engineering valuation as,

> “…engineering valuation is the art of estimating the value of specific properties where professional engineering knowledge and judgment are essential. … based fundamentally upon [the asset’s]ability to produce some kind of useful service during its expected future life in service....”

Within these definitions are several important points. First, the process of valuation is an estimation of monetary value using engineering judgment and knowledge. In engineering, estimation is a common practice that indicates computation of some quantity, whose magnitude cannot be exactly determined, usually because of a lack of real data and/or the reality that the data is better represented as a statistical range of values. The estimate, therefore, is a close representation of the true magnitude based upon values selected with engineering judgment and knowledge of the asset being valued. Second, a measure of desirability is required, that is, the asset must provide value to someone or something and that value is relative depending upon the desirability of ownership and productivity of the asset. For example, buildings in an area to be flooded out will only have scrap value unless someone invests in moving them to a new site where they can continue to be used for their original purpose. In the highway context, the ‘someone’ are the owners and users as the road provides safe, smooth, convenient access to the public (the users) and an important component for economic growth to the province or state (the owner). Roads lose value through deteriorated condition (where vehicle operating costs increase as condition decreases), congestion (where travel times increase as saturation flow is reached or exceeded), utilization (where through network expansion and the addition of a link, a road is demoted to a lower functional classification and reduced usage occurs as drivers are diverted) and safety (where geometrics, road condition and environmental factors contribute to a high crash rate). An example of an asset providing value to ‘something’ is a pipeline which provides a transport means for natural gas or oil in a reservoir to be moved to refining facilities and/or market. The pipeline only has value to the owners, as long as the oil reserves exist and as the reservoir is depleted, the pipeline's value diminishes. Value is not always positive, for example, a contaminated works yard that requires soil remediation prior to disposal or sale is a negative or undesirable asset. Usually, the negative value is captured through estimation of the salvage value of the asset at decommissioning or disposal. Third the asset value is tied to useful service during an expected life which requires an understanding of the historical and future performance of the asset. Assets that are reaching the end of their expected service life and/or a threshold level of service have a reduced value to the owner which can be expressed as a reduced value or as an increased liability. Reduced value is an indication of the loss of past investment as the service life is consumed: increased liability is an indication of the future expense that will be incurred to return the asset to a higher condition and to regain service life.

Value to The Agency (*owner*)

A scan of provincial and state mission statements provides some insight into the value of the highway network to DOT's. Most agencies include provision of a highway/road network that is 'safe', 'smooth', 'sustainable' or 'efficient' as part of their mission and many see the road network as an economic driver for the province/state as a whole. Value therefore is defined in terms of increased productivity and prosperity, a fact recognized in a study of the impact of road network size on the gross national product. It is because of this connection that the International Bank for Reconstruction and Development (The World Bank) invests in road infrastructure in developing countries as part of their loan agreements. While there is a strong correlation between network length and GNP/GDP, using this as a measure of engineering asset value is problematic for several reasons. First, the GNP/GDP is affected by non-engineering factors, such as whether the economy is industrial, agrarian or resource based, the availability of an educated work force, and resource availability to name a few. Second, quantification of the proportion of the value that is solely a result of the road network is difficult and may be complicated by secondary benefits. Third, the low level of sensitivity of GNP/GDP to changes in the network condition, capacity, safety or utilization. In a developing network, such as in the third world, addition of network links can have a dramatic and relatively immediate impact on GNP/GDP as new opportunities develop as a result of the new roads. In a mature road network where little network expansion is occurring, most of the effort is towards maintaining the road network and changes in network condition have a limited impact on the GNP/GDP. Asset value as a function of GNP/GDP therefore is of limited use.

Humplick and Paterson [1994] defined several performance indicators, related to value, that can be used at a macro, sectoral, institutional or functional level to describe and/or monitor road assets, as summarized in Table 1.

Cost-benefit analysis is an accepted way to evaluate individual project. Haas [1994] identified the costs and benefits that can be assigned to implementation of pavement management and there is some potential to use the benefits as a measure of value to the owner as benefits can be realized at multiple levels. Costs of pavement management system implementation are relatively easy to quantify as they include tangible (or near tangible) items such as software acquisition, equipment and/or data collection costs, consultant services etc.

Benefits are much more difficult to quantify as they generally fall into soft categories that are 'value' benefits, such as "being able to defend/justify programs of maintenance and rehabilitation" or "having assurance that programs represent best expenditure of tax funds". Tangible benefits such as the savings in real highway expenditures as a result of decisions based upon cost-effectiveness should be easier to quantify, however; many problems exist in documenting the costs associated with the highway investment, as accounting procedures vary from agency to agency (such as the inclusion or exclusion of overheads in unit costs) and over time. Also the actual highway investment may be difficult to assess because the construction costs have occurred over a long time span without a common basis for comparison.

Benefits can accrue to three separate groups:

- The road user who receives a benefit through reduced travel time, vehicle operating, accidents and discomfort costs.
- The agency benefits from improved life cycle costs as a result of timely and appropriate maintenance and rehabilitation - selecting the 'right alternative at the right time'.
- The public in general through objective, consistent, transparent and repeatable decision-making.

Benefits to the user can be realized with smoother pavements and resulting vehicle operating costs; benefits to the agency (and the public in general) are realized through improved decision-making using accurate engineering models. These models are used to model the pavement performance over time to determine when a pavement requires rehabilitation and / or maintenance (contributing to the 'right strategy and the right time").

Several studies have attempted to quantify the costs and benefits of pavement management (Cowe Falls et al 1994, Visser et al 2001), however both of these studies have related the benefits to savings in agency costs or user costs, in an attempt to illustrate the benefits of using a management system to optimize agency program expenditures. The argument is made that agency expenditures based upon consistent, objective decision making, result in reduced life-cycle cost for the network and maintain the value, referred to in Cowe Falls (1994) as "agency savings in value". Several assumptions were made in that study that require further examination, most notably the use of a straight line performance prediction model that equated value to pavement quality.

Value to The User (public)

To the user, value is defined as convenience, safety and satisfaction. Convenience relates to the availability of a road network, (i.e., is there a road from A to B) and the total travel time of a trip (which relates to capacity). Safety is a function of the road geometrics (i.e., narrow low speed, two lane road or high-speed, multi-lane freeway) and condition as well as, the traffic characteristics and volume (i.e. all trucks, low volume, etc.). Customer satisfaction is the basis for many annual surveys by cities who commission customer satisfaction surveys to assess how well they are providing services of all types to the taxpayers. Many surveys ask about the value of the road and/or transportation network and most of the comments (>95% in Calgary [Andreason 2003]) relate to travel time issues, rather than safety or asset condition.

User value is most often calculated as costs, rather than value, with cost being the inverse of value. The argument is that low user costs as a result of a smooth, safe, trouble-free road network are equal to high value. The FHWA [FHWA 1998] guidelines for Life Cycle Cost Analysis identify three main components of user costs: Vehicle Operating Costs (VOC), Crash Costs and User Delay. Vehicle operating costs were first studied in the 1970's in The World Bank Brazil Study. In that study a direct correlation between pavement roughness and vehicle operating costs was developed for a closed road network where fleet characteristics (tyres, suspension etc.), and costs (fuel consumption, repairs, etc.) could be clearly related to pavement characteristics (grade, smoothness, etc.) [Bein 1989]. Crash costs are the domain of the safety analyst and actuary who develop costs for property damage only, injury and fatalities crashes that are used to set insurance rates.

User delay costs have been evaluated in the context of the FHWA [1998] guidelines for life-cycle analysis. Tighe [2000a,b] examined the total daily user delay costs incurred as a result of construction in a rural freeway and developed a methodology for selecting temporary traffic control measures to minimize those costs. Cowe Falls [2003] followed the same approach for an urban construction site and attempted to understand the issue of consumer surplus within a city network where consumers have multiple options in route selection. In this latter study, it was found that when drivers are forced through a detour provided by construction, some loss of traffic occurs as a result of drivers choosing another route. The amount of the surplus is this study was in excess of 1500 vehicles per hour. Consumer surplus in this case indicates that the value of this road to the drivers is diminished when travel times increase as a result of construction even if the detouring drivers may have chosen a longer route instead of waiting in a queue. While this study had many assumptions (including vehicle occupancy and unit costs), it nonetheless illustrates the difficulty of assigning value to a road network when the users have multiple choices.

The clearest measure of user value is the toll booth, particularly when alternative routes are available. In Ontario, Highway 407 provides an alternative route to Highway 401, across the City of Toronto. Highway 407 is a toll road operated by a private consortium that charges a distance-based toll. Users are billed monthly for the use of the road and travel time guarantees to the users drive response times to crashes, maintenance or repairs, and snow and ice control. Toll roads are used extensively in Europe however in Canada only three toll roads exist (Highway 407, the Coquihalla in B.C. and Hwy 104 in Nova Scotia) and as they are only a small part of the total road network it is difficult to translate the user value generated by these routes to the larger network.

Condition as a Measure of Value

Given the above discussion, the simplest way to equate the user and the owner to the value of the road network is through condition. In the case of pavements, this can be a composite pavement quality index or a component measure such as roughness, strength or distress. Condition is a robust measure which has been in use since the early 1970's when the initial pavement management implementations began which relates to the vehicle operating costs of the user and the agency costs expressed as historical program expenditures for construction, rehabilitation and maintenance.

Asset Valuation

Within the framework of asset management, asset valuation is used to calculate the current and future value. Whatever methodology is used, it must be based upon robust values that can be predicted with some degree of accuracy. If a parameter within the method cannot be predicted into the future with comfortable levels of certainty, as a result of a large statistical variance, the accuracy of future predicted values will be too inaccurate to be of use. Table 2 lists the most commonly referenced asset valuation methods and basic definitions, plus some associated terms. These are presented as a starting point for the next section which explains how each valuation method is calculated. Before calculating any asset values, there should be clear recognition of the features plus the advantages and disadvantages of the various asset valuation methods as summarized in Table 3, adapted from (Lemer 1997a).

The two most commonly referred to methods asset valuation methods are (historical cost based) book value and written down replacement cost (WDRC). Both of these methods are backward-looking in that they rely on historical costs for construction, rehabilitation and maintenance. However, there are other methods which should be identified and which can be quite relevant in certain situations and/or for certain asset items. For example, market value would be associated with the sale of a highway to a consortium (as was the case in 1999 in Canada with Highway 407 bypass of Toronto which sold for $3.1 Billion Cdn.). As another example, landscaping and vegetation within the right-of-way may not fit either a historical cost or WDRC base.

Amekudzi[2002] classified valuation methods into past- based and future based approaches according to the time frame for asset valuation as shown in Table 4. Past-based approaches use historical expenditures to determine value and include book value and equivalent worth in place. Future-based valuation methods use future data and include market value, productivity realized value and salvage value. A combination of past and future based approaches can be found in the replacement cost and written down replacement cost valuation methods as these require historical data (i.e. performance data) and current replacement costs to calculate the value. In addition to the five methods in Table 3 is the valuation method of GASB 34 (the Government Accounting and Standards Board Statement 34). This is a past-based approach that uses historical data to calculate the value of the assets. Calculating current or past value is relatively straight-forward; the difficulty comes when selecting a valuation method that will be used to project future value using any of the methods in the last two categories

Book Value (BV or HC)

Book value is defined as the value of an [asset] based upon historical costs less any allowance for depreciation. It is a backward looking approach to asset value as it includes the cost to build (or acquire) the asset, adjusted for consumption of that asset and in that sense is actually book cost. In the case of civil infrastructure, consumption is based upon the condition of the asset (which is equated to depreciation of the asset) to adjust the historical costs to current value. Depending on the age of the asset, actual cost data may be available, or the historical value is calculated by adjusting current replacement cost by historical price factors. That is, for recently built or acquired assets, the actual cost data is used, while older assets for which actual costs are not readily available, the historical cost is an estimated cost calculated. Book Value can be carried forward to future value through prediction of the condition of the asset using performance models.

Book value is calculated as follows:

BV = HC

where, BV = Book Value

HC = Historical Cost

= CC + RehC + MC

where, CC = Construction Cost

= Average construction cost per square metre for year of construction * pavement area

RehC = Rehabilitation Cost

= Average rehabilitation cost per square metre for year of rehabilitation * pavement area

MC = Maintenance Cost

= Number of maintenance treatments since last major rehabilitation * average cost of maintenance treatment * area * 0.01

Replacement Cost (RC)

Replacement cost is the price, at current market value, required to return an asset to new condition. In publicly-owned civil infrastructure systems, where rehabilitation and maintenance work is done by competitive bids, replacement cost is based upon current market forces. Replacement cost can be predicted using trend lines, but as a monitoring tool, it may be subject to too much variation to be reliable. It is calculated as follows:

RC = AC * Area

Where, AC = Average cost of construction per square metre.

Written Down Replacement Cost (WDRC)

Written Down Replacement Cost is the price, at current market value, required to return an asset to new condition, adjusted for the deteriorated condition of the asset at the time of replacement. The condition of the asset is used to adjust the replacement cost as a means of acknowledging that some assets are in better or worse condition at the time of replacement and therefore not all replacement costs will be the same on a square metre basis. The calculation is as follows:

WDRC = (AC*MRC) * area

Where, AC = Average condition of the asset, reduced to a decimal fraction of 1 (i.e., if the asset condition is 5 on a scale of 10, then Ac = 0.5)

MRC = Average replacement cost per square metre

As with replacement cost, this is a difficult method to use for future predictions, due to the difficulty in estimating future replacement costs. However, good performance modeling can predict future asset condition and it is for this reason, that some highway agencies (Manitoba and Saskatchewan being the most notable users) use WDRC.

Net salvage Value (NSV)

The recent Transport Canada blueprint *Straight Ahead* identified net salvage value as the preferred method for valuation of rail assets in Canada. NSV is defined as the difference between the cost to replace the asset and the cost to rehabilitate it. As rail lines are linear assets similar to road networks, this can be translated to the highway setting using the following calculation:

NSV = RC – RehC

Where, RC = Average cost of construction per square metre.

RehC = Average cost of rehabilitation per square metre * area

The rehabilitation cost can be calculated in two ways. In the first case, rehabilitation cost is calculated as the cost for a standard overlay times the section area for all sections below a defined condition threshold and is referred to as NSVa. In the second case, a simple decision tree is used to include maintenance activities such as crack sealing and patching for sections in relatively good condition and overlays for those below a defined threshold. The latter is referred to as NSVb.

GASB 34

GASB 34 is a past based approach that estimates the historical cost using construction cost trends. The estimated historical cost can be calculated, under the GASB34 guidelines, as deflated replacement cost adjusted for the remaining service life and useful life as follows:

GASB = HC((UL – RSL)*D)

Where, HC = historical cost (determined by deflating replacement cost by a construction deflation factor)

UL = Useful life (year when section reaches a threshold level – year of construction)

RSL = year when section reaches a threshold level – year of performance data

$$D = (HC – SV) / UL \quad \text{(depreciation)}$$

Useful life is calculated using the following:

Useful Life = Current age + remaining life

Where, Remaining life = Trigger Year – Current Year

This method is different to written-down replacement cost in that the replacement cost is deflated using a price index, rather than a deterioration model [Cowe Falls and Haas 2001]. The calculation is the same as Book Value, with the estimated deflated historical cost being used. The deflation factor has a 25 year horizon which means that any asset older than 25 years has zero value, due to the combined effect of inflation and discount factors. Because GASB34 is mandated to be implemented by 2005, the horizon year is set for 1980.

If historical costs are not available, the historical cost of the section is determined by deflating current replacement costs per square foot (differentiated by functional classification) to the construction/rehabilitation year using the FHWA Highway price index. This is referred to a "Deflated GASB".

Data Requirements for Valuation

The data required to calculate current and future value using the valuation methods described above is summarized in Table 7.

The City of Edmonton Asset Valuation Base Case

The City of Edmonton began implementation of Municipal Pavement Management Application in 1988 with the first performance data collection survey. Using this database, inventory, historical work activities and costs and, performance data were extracted from the database. Approximately 7,000 road sections are in the database and all arterial and collector road sections that had actual performance data (as opposed to predicted from previous years' measurements) for a defined year were removed. From that set, all sections that had complete records of rehabilitation and maintenance activities and costs, as well as inventory elements, such as pavement type, structure, traffic etc. were extracted into the analysis subset, creating an analysis set of 113 sections. Each section in the analysis set was selected for completeness of these data elements and all sections have actual (not estimated or extrapolated data). This is particularly important for the historical rehabilitation and maintenance cost values.

Using this dataset and the above methods, the value for each section was calculated and a total network value calculated. GASB 34 value was further differentiated into three subgroups; in the first, the horizon year is negated and the actual year of construction is used (in this case the useful life of the pavement section can be greater than 25 years), the 1980 horizon year is used (in this case, no pavement is older than 15 years) and a horizon year of 1968 is used (in this case the maximum age of any pavement is 25 years). NSV a and b are differentiated as described above.

The 1993 total asset value for the network for each of the valuation methods is presented in Table 6 and Figure 1. The GASB valuation method is repeated three times using different remaining service life estimates to illustrate the difference between using straight-line depreciation (with two horizons, e.g. GASB (80) or GASB (25)) or engineering based deterioration (e.g. GASB(S)) to determine Remaining Service Life. The range of values is $46M to $154M, with the lowest calculated value in 1993 being WDRC and the highest being BV. The values are sorted by increasing amount and there is a clear division between the past-based valuation methods and future-based methods. The difference between past based values and current based values is primarily because of the large number (and area) of sections that are in the 10-15year age bracket. These sections were constructed in Edmonton during the construction boom of the 1980s, when unit construction prices were >$100/ sq. m. By comparison, the current-based valuation methods rely upon 1993 replacement cost (RC) which is <$70 sq.m. As expected RC is higher than all of the methods that use Replacement Cost and adjust for rehabilitation needs (in the case of NSVa or b) age (in the case of Deflated GASB) or condition (in the case of WDRC).

The mean asset value and 95% confidence intervals for each method is presented in Figure 2 in order to understand the distributions of each group. As with the total value presented in Table 6, the mean value for past-based values are substantially higher than the future based values. As can be seen, there is a large range of values depending upon which method is used and a large range of statistical variance as indicated by the confidence interval error bars in Figure 2. The high variance of the past based methods is because of a distortion in historical costs found in the Edmonton data set. Edmonton is built on a resource economy that has been subject to wild cycles of boom and bust, which are reflected in the historical construction costs. Unit costs for arterial roadways have varied from a low of $63/sq.m. to a high of $138/sq.m. within a ten year period. As the calculations use real data (rather than extrapolated or indexed unit costs) this has affected not only BV but also the historically based GASB methods by inflating the total asset valuation.

To test for significant difference between the total network values by method, analysis of variance was done for each combination of the methods. ANOVA compares the variance for each pair (BV-WDRC, BV-NSV etc.) to test for statistically significant differences between the values. The value for each section using each method was compared and the f values calculated as presented in Table 7. None of the methods are considered to be statistically similar as seen by the fact that none of the pairs result in a $F_{observed}$ value that is less than the $F_{critical}$. It should be noted that the associated p-values for these results are relatively high, which presents the possibility that the results are in error. When the confidence intervals are compared, it is possible to conclude that the GASB methods (S, 80 or 25) are statistically the same and also that the Deflated GASB, NSV (a and b) and RC methods are the statistically the same due to overlapping confidence intervals. The four methods that are most commonly used (WDRC, Deflated GASB, GASB (80) and BV) are plotted with 99% confidence intervals in Figure 4.

Characterizing Uncertainty in Asset Valuation using Monte Carlo Simulation

Monte Carlo simulation uses probability theory to estimate the uncertainty inherent in analyses where some of the parameters have built-in variability. To do this, variables are characterized by probability distributions and statistical criteria which are then used in multiple iterations of calculations. The distributions can be many forms, including normal, Poisson's, lognormal, binomial, triangular, etc. depending on the variability of the parameter being described and actual distribution observed or deduced. By inputting a distribution, rather than a mean value, some accounting is being made for variability in the field as a result of actual conditions, data collection tolerances, best estimates and the like. For example, asphalt overlay costs vary in any given year because of several factors, such as, contract quantity, time of year, haul distance from plant, capacity and competitiveness of the contracting environment. Yet, most agencies will only use an average unit cost for historical record keeping and/or budget projections. Similarly, surface distress rating systems, have tolerances built into quality control and acceptance procedures [Landers 2001], that are used to accept data from field personnel. These tolerances are designed to ensure data accuracy and repeatability from year to year and within any data collection season, but they also mean that the recorded distress value can be +/- the tolerance threshold. A rating of 7.2 in a system with a +/- tolerance of 0.5 means that the actual rating can be anywhere from 6.7 to 7.7. When these numbers are used to calculate asset value by reducing the unit replacement (with its own distribution accuracy and precision), the uncertainty is amplified. The variability of each of the data types used to calculate value is the result of different factors and these are summarized in Table 8.

The Monte Carlo Simulation process requires identification of the parameters in the analysis that have valid probability distributions rather than discrete values. This is done through analysis of the data to characterize what type of distribution and criteria to be used. Each distribution has different criteria, such as a normal distribution is defined as mean plus one standard deviation; a triangular distribution is defined as the minimum, maximum and most likely values. Once the distributions are defined the simulation begins by selecting values numbers randomly from the distribution(s) and repeating the calculation for many runs (the number of which is defined by the analyst). The output is a cumulative frequency plot of calculated values from which can be determined the calculated value at 90, 95, 97.5 and 99 percentile. The data is interpreted as " a 95% probability that the calculated value is X".

Asset Valuation at the 97.5th percentile

Using the parameters and probability distributions presented in Table 9, the total network value was calculated again at the 97.5 percentile. The criteria differ for each probability distribution, however, for the most part, triangular distributions are used for each parameter, and therefore, the minimum, maximum and most likely value are used. The results are presented in Table 10 and Figure 3.

The difference in total value between the base case and Monte Carlo case, shown in Figure 5, indicate that the greatest difference, and therefore uncertainty in the valuation, is in the Deflated GASB method. Deflated GASB is additive (replacement cost adjusted for age, plus salvage value calculated using NSVa). The method with the least difference is the RC, which has variability of replacement cost (+/- 10%) only.

An analysis of variance was repeated for the sections as in the base case to determine if similar results were found at the 97.5th percentile as shown in Table 10. With the application of Monte

Carlo simulation to the valuations, the results are quite different. All of the past based methods (with the exception of WDRC) are statistically similar as seen by the overlapping confidence intervals and the Fvalues in the ANOVA. The past based GASB values appear to be similar because of overlapping confidence intervals; however the ANOVA results indicate the contrary

Valuation methods that rely on current and/or future values (i.e. replacement cost based calculations of RC, WDRC and NSV) result in lower levels of uncertainty as indicated by the tighter confidence interval error bars in Figure 3.

Conclusion

Total network asset value has been calculated for five valuation methods using a subset of the City of Edmonton arterial and collector network. Using real, not extrapolated, historical costs, the Book Value, Written Down Replacement Cost, Net Salvage Value, and GASB34 methods produced large variations in total and mean asset value for the network. Book Value produced the highest total network value, primarily because of the inclusion of historical construction cost and accumulated rehabilitation and maintenance costs.

To understand the level of uncertainty in each of the methods, Monte Carlo simulation was used to characterize the cost variables using probabilistic distributions. For each method, the value at the 97.5th percentile was compared to the base valuation case and the difference plotted. The current based methods of RC, WDRC, Deflated GASB and NSV are statistically similar when variability in the input data is characterized using Monte Carlo simulation. The difficulty with current or future based valuation methods is in predicting value in the future using a unit replacement cost. Monte Carlo simulation is a good way to characterize valid variability in the performance and cost data and should be considered as part of the valuation process.

Of particular concern is the large difference (in both total and mean asset value, as well as confidence interval error bars at 95%) of the four most commonly used methods (WDRC, Deflated GASB, GASB(80) and Book Value). Based upon a survey of agencies (TRB 2002), most state DOT's are using Deflated GASB as the starting point for their initial valuations. Because of the requirement to report asset value, more attention is being given to retaining historical costs within the asset management systems and as such, future valuations will be done with either Book Value or GASB(80). In the case of this data set, that will result in a substantial change in the total asset value. Also, as demonstrated in this case, the potential exists for distortion in the value because of economic factors inflating construction costs. The high variance of all of the past based methods indicates the degree of variability resulting from varying historical costs.

Agencies that are in the process of developing asset values should also recognize that despite the variability in the method, what really is important is the change over time of the asset being valued. As asset valuation has the potential to become a performance measure or indicators, it is important that agencies be able to report how well they are retaining asset value as a result of proper management. One approach would be to report the Replacement Cost and the Written Down Replacement Cost. The former indicates the cost to replace the asset and the latter provides an indication of how well the asset is being managed. WDRC also incorporates engineering performance models and recognizes good management rather than consumption as in the case of straight line depreciation (used in GASB). The difference between RC and WDRC should not change if proper management of the asset is in place, whereas an increase in the difference would indicate that the network is losing value. Regardless of which valuation method is used, the important point is to select a valuation method that can be easily sustained and managed, is not data and/or analytically burdensome and that proper asset management should result in retention of asset value. What matters most is the change in the asset over time and proper management will preserve asset value.

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Table 1 Value Related performance indicators and indicator components for road assets (adapted from Humplick & Paterson [1994])

Level	Indicator	Component	Remarks
Macro	Asset Value	a) replacement value	By component or indicator of network size.
		b) book value or written down replacement cost	
Productivity & Efficiency	Expenditure productivity	a)total expend.	All work, and by category
		b)expansion and betterment expend.	Extensions, betterments, expansions
		c)preservation expenditure	a) – b) – d) and e)
		d)operations expenditure.	Traffic and safety management, etc.
Institutional Effectiveness	Economic returns	a)Program B/C or cost effectiveness	Benefits or effectiveness of annual program divided by total expenditures
		b)Ave NPV or benefits per km	Total annual NPV or benefits/length of network
		c)Network depreciation	Depreciated/current value of roads divided by replacement cost

Table 2 Basic Definitions of Asset Valuation Methods and Associated Terms [after Cowe Falls and Haas 2001]

Asset Valuation Methods	
Book value	Current value based on historical cost adjusted for depreciation (commonly used for financial accounting purposes)
Written down replacement cost	Current value based on replacement cost depreciated to current condition of the asset (commonly used for management accounting purposes)
Replacement Value	Current value based on cost of replacing/rebuilding the asset
Net Salvage Value	a) Cost to replace the facility less the cost of returning it to 'new condition' b) Cost of materials
GASB 34	Current value based upon actual or estimated historical cost
Associated Terms	
Historical cost	Original purchase price or as-built cost
Replacement cost	Cost of replacing/rebuilding the asset
Capital stock	Physical assets from which a flow of capital services is derived
Investment	Capital expenditure on new assets or major refurbishing of existing assets
Depreciation	Declining value of the asset with time, which may be straight line based, curved or stepped
Performance	Change of condition or status of the asset with time, which may be straight line based, curved or stepped (depreciation and performance may or may not be directly linked, depending on the asset item)

Table 3 Asset Valuation Methods: Features, Pros and Cons (after Lemer 1997a)

Method	Features	Advantages	Disadvantages
Book Value, BV Historical Cost, HC	Commonly used for financial accounting purposes. Uses historical records of procurement (first cost plus any subsequent costs), depreciated to present worth. Provides direct comparisons in time series progressions.	Data generally available. Relatively simple.	Does not account for changes in prices. Neglects usage. Neglects technology and service standard changes. Most models include a ‘horizon’ beyond which inflation and discount costs negate any retained value. Results can be misleading for older assets such as bridges, land. Value is related to age of asset (misleading).
Replacement cost, RC	Commonly used by public agencies for underground services (water distribution, storm and sanitary sewers), and various public infrastructure	Quite straightforward to calculate. Can be communicated and understood easily.	Can be misrepresentative (eg. Relatively new asset in good condition would be worth the same as an old, deteriorated asset).
Written Down Replacement Cost, WDRC	Commonly used for management accounting purposes. Uses current market prices to rebuild/replace. Current condition used to establish write down value.	Reflects current prices & technology. Requires good performance modeling. Easily understandable to technical staff. Enables comparison of assets. Provides for future budgeting.	Conjectural on replacement costs (subject to external market forces). Requires good performance modeling. Question of how to handle an upgraded /improved replacement.
Net Salvage Value, NSV	Represents value of materials including disposal costs	Uses generally available data.	Difficult to predict future construction prices. Subject to market forces, in particular, supply and demand if parallel service exists.

Table 4 Valuation Methods classified by Past, Current and Future Approaches (after Amekudzi [2002])

Past-Based Valuation	Current-Based Valuation	Future-Based Valuation
• Book Value • Historical cost • GASB 34	• Replacement Value • Written Down Replacement Value • Deflated GASB	• Salvage Value (or Net Salvage Value) • Replacement Value • Written Down Replacement Value

Table 5 Data Needs for Valuation Methods

Valuation Method	Pavement Type	Year of Construction (Age)	Traffic *	Pavement Thickness *	Most Recently Measured Performance	Maintenance Activity		Rehabilitation Activity		Initial Construction Costs	Current Construction Costs
						$	Yr	$	Yr		
Book Value		⌘				⌘		⌘		⌘	
Replacement Value	⌘										⌘
Written Down Replacement Value	⌘				⌘						⌘
Net Salvage Value	⌘	⌘		⌘							
GASB 34		⌘				⌘		⌘		⌘	
Deflated GASB		⌘									⌘

Table6 Comparative Total Network Value

Method	1993 Value	Past / Current Based Method
WDRC	$ 45,977,668	Current
Deflated GASB	$ 60,562,950	Current
NSVb	$ 68,422,673	Current
NSVa	$ 74,487,286	Current
RC	$ 81,391,410	Current
GASB (s)	$102,683,860	Past
GASB (25)	$110,810,325	Past
GASB (80)	$117,861,874	Past
BV	$ 154,692,968	Past

Table7 ANOVA results for base case.

Fcrit	***3.926***							
	RC93	**NSVa**	**NSVb**	**BV**	**GASB(s)**	**GASB(80)**	**GASB(25)**	**Defl GASB**
WDRC	196.502	165.515	64.941	157.610	87.030	123.875	93.046	42.433
RC93		252.606	21.986	113.843	20.381	55.029	30.524	164.232
NSVa			4.777	122.248	31.607	67.997	41.546	87.023
NSVb				140.032	60.000	105.759	73.809	8.548
BV					151.023	150.905	152.872	176.292
GASB(s)						73.792	28.198	78.826
GASB(80)							36.545	134.699
GASB(25)								91.043

p values	**RC93**	**NSVa**	**NSVb**	**BV**	**GASB(s)**	**GASB(80)**	**GASB(25)**	**Defl GASB**
WDRC								
RC93								
NSVa			0.031					
NSVb								0.004
BV								
GASB(s)								
GASB(80)								
GASB(25)								

Table 8 Variability Factors for Monte Carlo Parameters

Parameter	Variability a function of:
Surface Condition (PDI)	❑ QA / QC Tolerance of PDI data collection method ❑ Pavement type ❑ Prediction model / performance class ❑ Age
Unit Costs ❑ Replacement ❑ Rehabilitation ❑ Maintenance	❑ Quantity of material in contract ❑ Size of total contract ❑ Length of road ❑ Pavement structural design (layer thicknesses) ❑ Materials ❑ Time of year ❑ Capacity of suppliers ❑ Prior condition of road
Remaining Service Life	❑ PDI ❑ Maintenance practices ❑ Age
Section Maintenance Costs	❑ Area of road to be maintained (maximum area assumed, otherwise work would be rehabilitation) ❑ PDI ❑ Unit costs

Table 9 Monte Carlo Parameters

Parameter	Sub-Parameter	Sub-Parameter	Distribution	Criteria		
Surface Condition Index (SDI)	Pavement Type	Range	Triangular	Min	Max	Most Likely
	Rigid (COM & MCO)	10-8		-0.3	+0.3	Measured value
		8-6		-0.4	+0.4	
		<6		-0.5	+0.5	
	Flexible (BGB & BSC)	10-8		-0.25	+0.25	
		8-6		-0.4	+0.4	
		<6		-0.5	+0.5	
Unit Replacement Cost ($/sq.m)	Pavement Type		Triangular	Min	Max	Most Likely
	Rigid (MCO)			68.58	83.82	76.20
	Rigid (COM)			74.93	91.58	83.25
	Flexible (BGB & BFD)			$57.15	69.85	63.50
Remaining Service Life	All pavement types: Sigmoidal prediction models only	Years	Triangular	Min	Max	Most Likely
		<0		-1	+1	predicted
		0-4		-2	+2	
		5-9		-3	+3	
		10-14		-4	+4	
		>14		-5	+5	
Unit Rehabilitation Cost	75 mm Overlay	1993	Triangular	-10%	+10%	$5.80
Unit Maintenance Cost (NSV)	Crack Sealing (per linear metre)		Triangular	-10%	+10%	$2.24
	Patching		Uniform	-10%	+10%	$7.72
	Area crack sealed			5%	10%	7.5%
	Area Patched			10%	20%	25%
Unit Maintenance Cost (BV)	All pavement types		Triangular	$2.02	$7.72	$2.24

Table 10 ANOVA results for Monte Carlo Simulation results at the 97.5% level

Fcrit ***3.926***

	RC93	NSVa	NSVb	BV	GASB(s)	GASB(80)	GASB(25)	Defl GASB
WDRC	184.435	184.858	120.650	174.758	116.216	147.958	107.855	105.391
RC93		**0.001**	**1.026**	146.879	60.907	99.289	52.891	**0.297**
NSVa			**1.232**	149.342	60.803	100.363	53.450	**0.326**
NSVb				156.938	73.534	116.970	64.967	**2.698**
BV					166.885	167.149	241.324	140.540
GASB(s)						53.411	**2.684**	116.216
GASB(80)							87.459	147.958
GASB(25)								107.855

p values	RC93	NSVa	NSVb	BV	GASB(s)	GASB(80)	GASB(25)	Defl GASB
WDRC								
RC93		**0.977**	**0.313**					**0.587**
NSVa			**0.269**					**0.569**
NSVb								**0.103**
BV								
GASB(s)							**0.104**	
GASB(80)								
GASB(25)								

Table 11 Comparative Total Network Value versus Monte Carlo Simulation at 97.5%

Method	**1993 97.5th Percentile Value**	**1993 Base Value**	**Difference (97.5th percentile – base)**		**Current / Past Based Method**
			Absolute	**%**	
WDRC	$ 54,830,934	$ 45,977,668	$8,853,266	19%	current
Defl GASB	$ 97,073,448	$ 60,562,950	$36,510,498	60%	current
NSVb	$ 92,885,509	$ 68,422,673	$24,462,835	36%	current
NSVa	$ 95,333,251	$ 74,487,286	$20,845,965	28%	current
RC	$ 95,310,117	$ 81,391,410	$13,918,707	17%	current
GASB (s)	$141,197,291	$102,683,860	$38,513,430	38%	past
GASB (80)	$155,040,688	$117,861,874	$37,178,813	32%	past
GASB (25)	$136,762,626	$110,810,325	$25,952,301	23%	past
BV	$199,766,843	$ 54,692,968	$45,073,874	29%	past

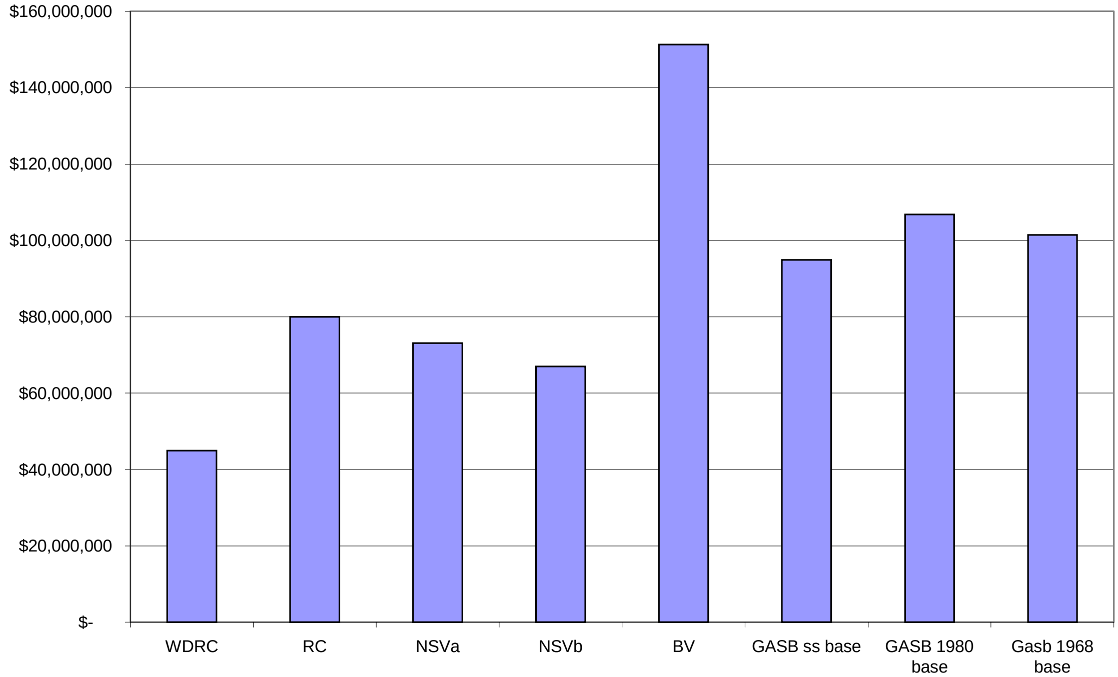

Figure 1 Total Network Value 1993

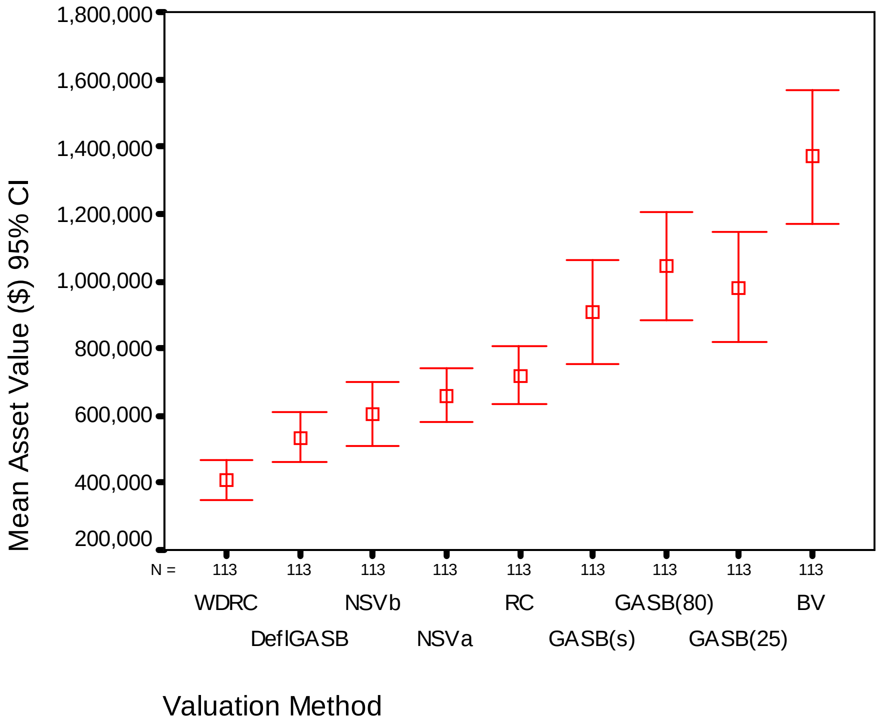

Figure 2 Mean Asset Value 1993 at 95% Confidence Intervals

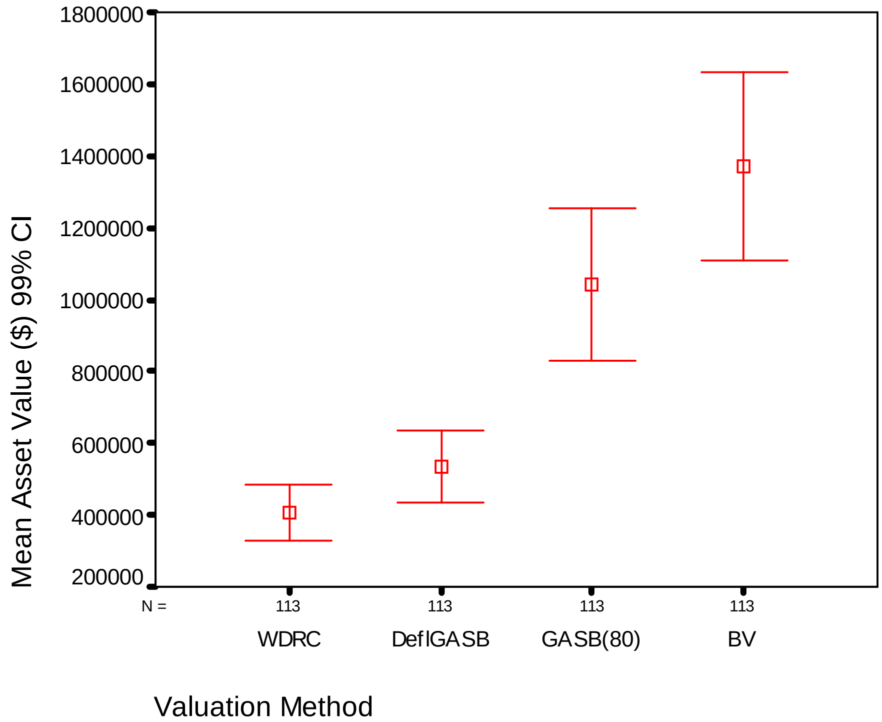

Figure 3 Mean Asset Value at 99% Confidence Intervals

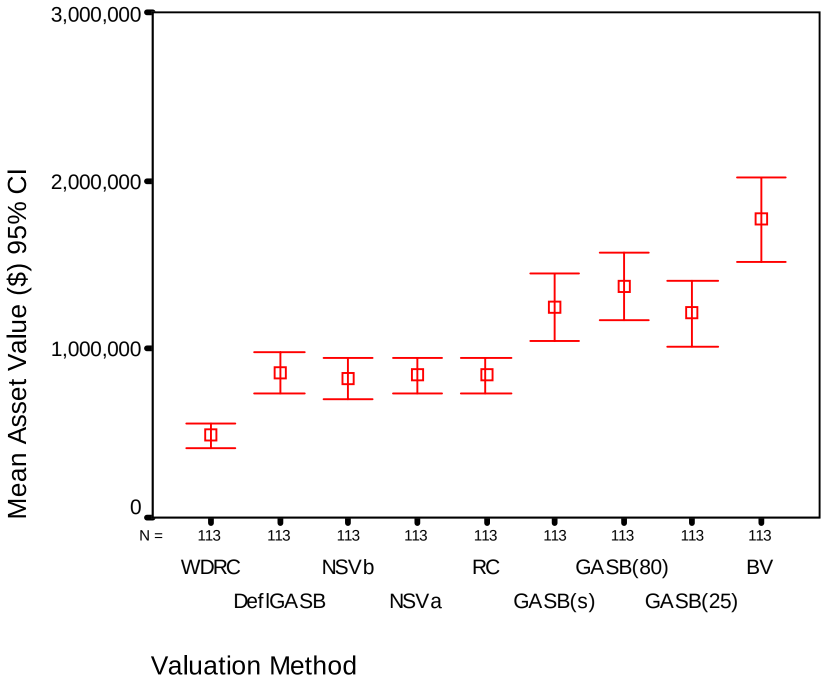

Figure 4 Mean Asset Value 1993 97.5th percentile - 95% Confidence Intervals

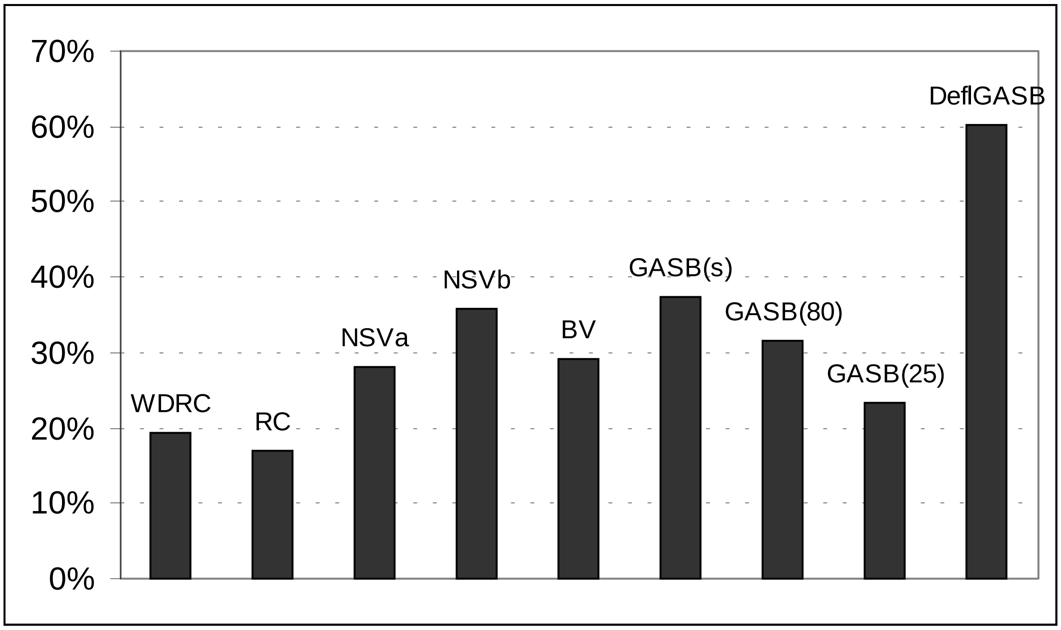

Figure 5 Percentage Difference between 1993 Asset Value Based upon Measured Condition and 97.5th Percentile Monte Carlo Value

Table 10 ANOVA results for Monte Carlo Simulation results at the 97.5% level

Fcrit ***3.926***

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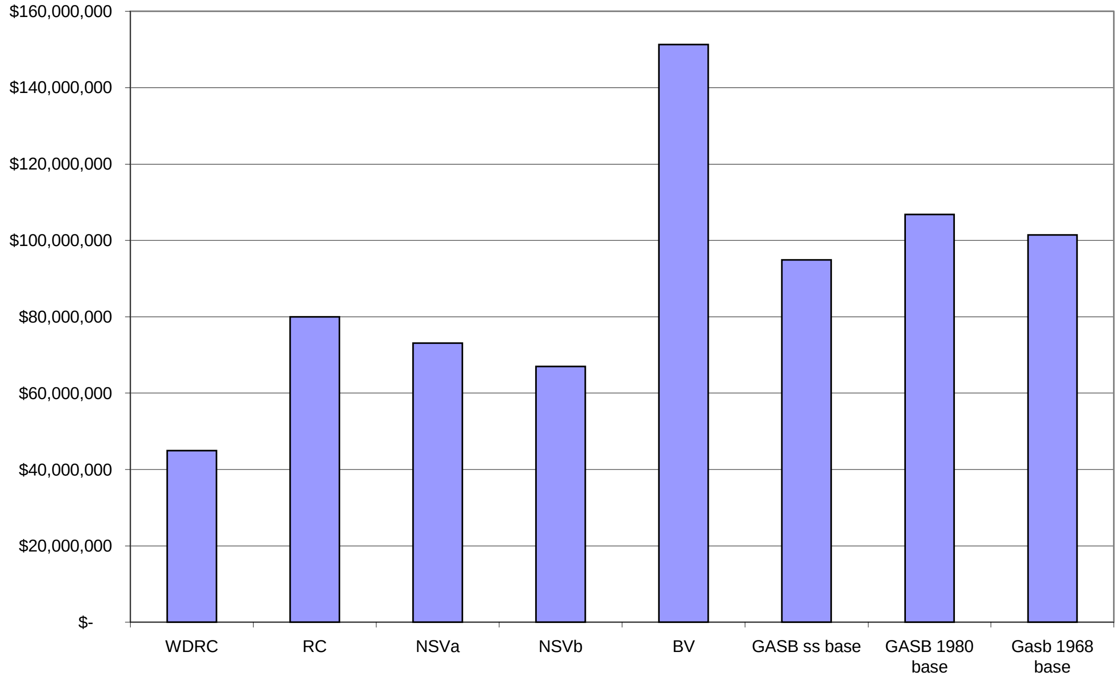

Figure 1 Total Network Value 1993

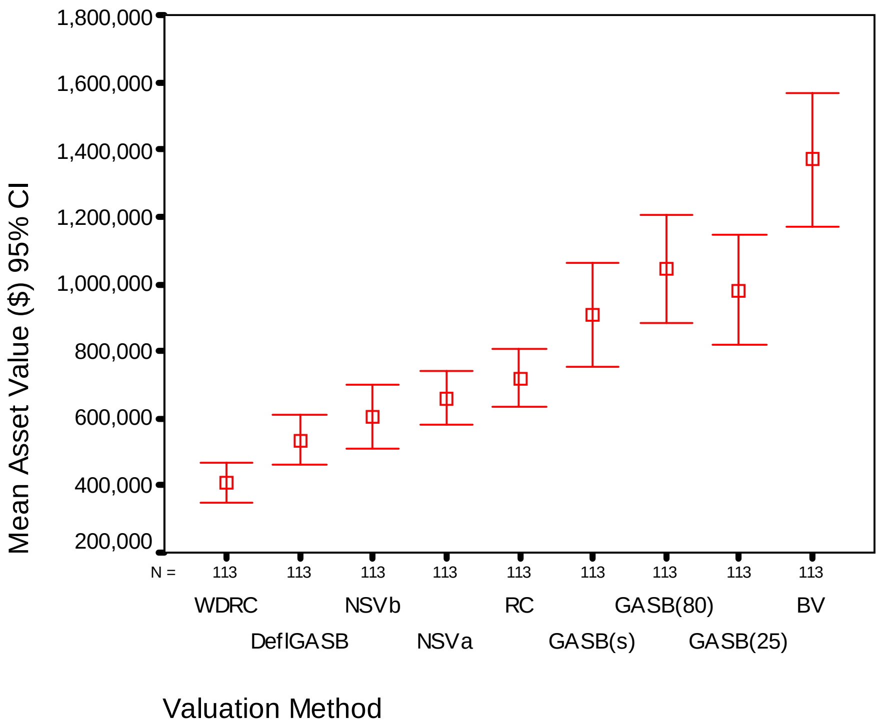

Figure 2 Mean Asset Value 1993 at 95% Confidence Intervals

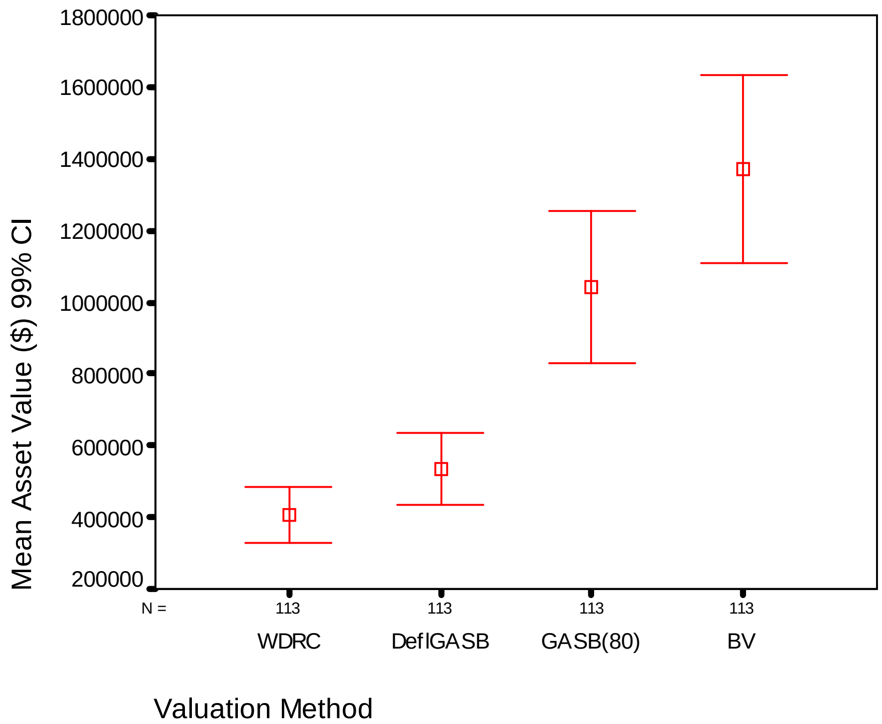

Figure 3 Mean Asset Value at 99% Confidence Intervals

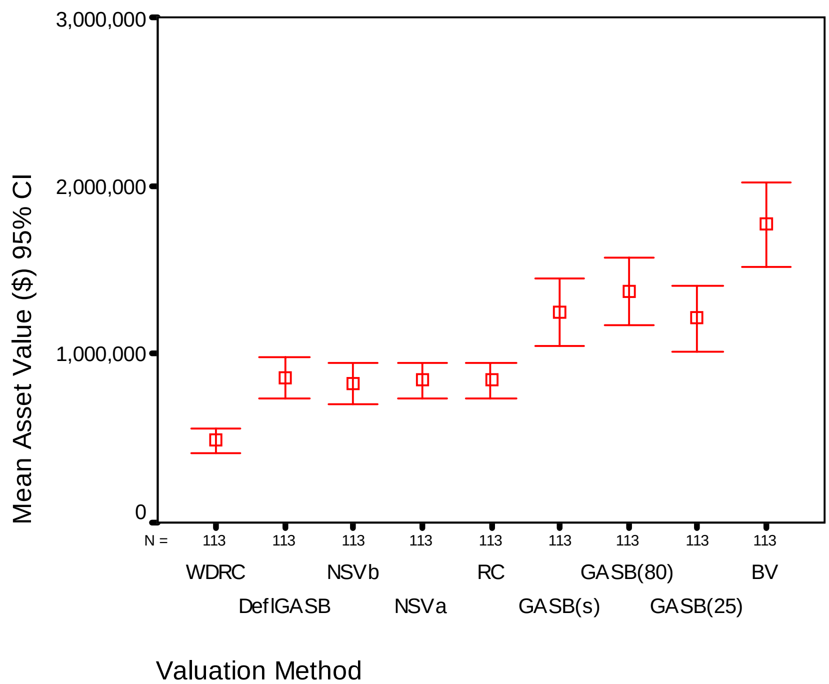

Figure 4 Mean Asset Value 1993 97.5th percentile - 95% Confidence Intervals

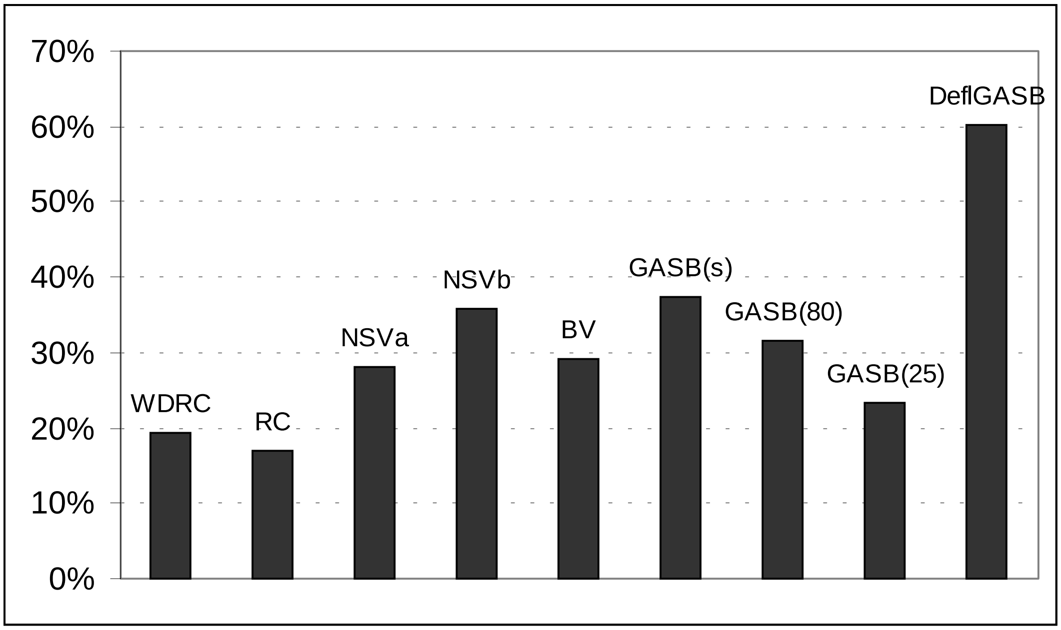

Figure 5 Percentage Difference between 1993 Asset Value Based upon Measured Condition and 97.5th Percentile Monte Carlo Value