PRODUCTIVE HIGHWAY CAPITAL STOCK MEASURES

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PREFACE

Recent advances in economic analysis of the relationship between highway capital stock and economic performance provide important empirical assessments of the contribution of our nation's highways to economic growth. The focus of this project is to improve measures of highway capital stock, and thus further refine economic analysis of the stock's contribution to economic growth.

This report summarizes project efforts. Chapter I describes the basis for productive highway capital stock measures. Section I of Chapter I describes the methodology and relevant capital stocks concepts. Section II describes existing highway and other public capital stock studies and the methodologies employed. Chapter II details recommendations for construction of a quality adjusted public capital stock. These recommendations were presented to the project's Select Advisory Committee (SAC) for comments on December 10, 1997. Chapter III lists recommendations for future work. These recommendations were presented to the SAC for comments on October 27, 1998. Also at this meeting, methodologies employed in the construction of the highway capital stocks were described, the Fraumeni highway capital stock series was presented, and comparisons were made with other highway capital stock estimates. Finally, Chapter IV details the construction of the stocks to facilitate updates by FHWA and the adoption of relevant assumptions and methodologies by other researchers.

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CHAPTER I

METHODOLOGIES, CONCEPTS, AND STUDIES

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SECTION I: METHODOLOGY AND GENERAL CONCEPTS

INTRODUCTION

A specific terminology is used by economists to describe capital stock estimates and their construction. Relevant methodologies and concepts are presented in this Section to facilitate subsequent exposition. Definitions are listed alphabetically in Appendix to this chapter.

Capital stock is a measure of the amount of capital in existence at a particular point of time, e.g. December 31, 1997. Investment, a flow concept, is a measure of the additions to capital stock over a particular time period, e.g. from January 1, 1997 through December 31, 1997. An asset must be durable to be classified as capital. The convention is that any asset expected to be in service for at least one year is categorized as capital, if an asset is expected to be in service for less than one year it is categorized as a consumption good.[1]

Most, if not all, estimates of U.S. public capital stock include only fixed tangible assets. Fixed assets are non-financial produced assets which are used in a production process. Fixed tangible assets are best defined by example as the adjective "tangible" is not sufficiently definitive. Tangible assets include dwellings, other buildings and structures, machinery and equipment and cultivated assets, such as livestock, vineyards and orchards. In the case of public capital, fixed tangible assets include among other assets highways and streets, bridges, water and sewer systems, and conservation and development assets, including dams and reclamation assets. [2] [3]

Capital stocks are measured by the census method or by the perpetual inventory method. Under the census method, capital stock is counted. The sheer magnitude of the

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[1] Exceptions to this rule exist. For example, consumer durables, such as cars and refrigerators, are classified as consumption in our national accounts by the Bureau of Economic Analysis (BEA), but are treated as capital in the construction of wealth estimates by BEA.

[2] Intangible assets include computer software, mineral exploration expenditures, entertainment, literary or artistic originals, research and development and human capital.

[3] See System of National Accounts, 1993, Commission of the European Communities, International Monetary Fund, Organization for Economic Co-operation and Development, United Nations, World Bank, Brussels, Luxembourg, Paris, New York, Washington, D.C., 1993 pp. 305-310. The above examples of tangible and intangible assets are only illustrative; the list is not intended to be exhaustive. Also, see Table 3 pp. 18-19 of Fraumeni, Barbara M., "The Measurement of Depreciation in the U.S. National Income and Product Accounts," Survey of Current Business 77, July 1997.

enumeration task makes this an unattractive option. The task is further complicated by the need to devise a methodology sufficient to count or aggregate heterogeneous assets. Virtually all researchers who have constructed estimates of public capital stock for the U.S. have used the perpetual inventory system.

To construct net capital stocks with the perpetual inventory method, information on investment and asset deterioration is needed at a minimum.[4] Expenditures on public assets are investments. Since assets frequently last 60 years or more and expenditures are often not available over the entire time period, a benchmark or starting point for the capital stock, is also commonly needed. Gross capital stock is calculated by simply adding up investment or expenditure on public capital and deducting retirements or assets withdrawn from service. Net capital stock, which is the stock concept used in all of the studies described in this chapter, requires that the stock or investment be reduced by the amount of wear and tear on the asset as it ages and asset retirements. The sum of wear and tear, which is termed loss in efficiency, and retirements is deterioration.[5] [6]

There are two major difficulties associated with the construction of public capital stocks that serve as the focus of this project. The first is the estimation of deterioration. The

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[4] In this chapter, unless otherwise specified, the terms net capital stock and capital stock refer to productive capital stock.

[5] Even among those who specialize in economic accounts, there is substantial variation in terminology. In general, those individuals who do not specialize in economic accounts refer to deterioration as depreciation. Depreciation is a term used by virtually all economists when describing a wealth and income concept. Use of depreciation as a production or productivity concept leads to a great deal of confusion. It is common for researchers to not understand or even be aware of the distinction between a wealth stock and a productive stock. As a result, many employ the wrong type of capital stock. Further explanation is provided later in this Section. See Table 1 and the next Section for an indication of which studies have made this error.

Depreciation is also a term used to describe tax depreciation or the depreciation that income tax authorities allow a business to deduct from taxable income. Some of the terms for depreciation in a productive capital stock context, such as straight-line, double-declining and sum-of-the-years digit depreciation, originate from tax regulations and literature.

[6] Denote K_t as capital stock, I_t as investment, and d_t as the rate of deterioration in time t. Under the perpetual inventory method, net capital stock in year t is:

$$K_t = I_t + (1-d_t)K_{t-1},$$

In the first year, $K_t = I_t$ or $K_t = B_t$, where B_t is a capital stock benchmark.

second is the quantification of quality change and obsolescence. The two difficulties are interrelated.

EFFICIENCY DECLINE AND DETERIORATION

The purpose of constructing a public capital stock series is to estimate the productivity of the nation's infrastructure. As such, it is desirable to measure capital stock in efficiency adjusted units to reflect the decline in the productive services of an asset as it ages.[7] It is also desirable for assets to be deducted from the capital stock as they are retired to reflect the productive potential of the measured stock. Only then will public capital stock measures form a reasonable basis for economic analysis and policy decisions.

Economists heretofore have assumed that public capital stock conforms to a particular pattern of decline in efficiency or deterioration without any significant empirical evidence to support the choice of a particular pattern. The assumed patterns include the following: [8]

1. One-hoss shay,
2. . 9 hyperbolic,
3. Straight-line, and
4. Geometric.

Under one-hoss shay, which is a pattern typically used to describe efficiency loss, an asset suffers from no efficiency loss until it is retired. A light bulb is an example of one-hoss shay efficiency loss. The productive services from a light bulb are constant over its lifetime; they do no diminish until the moment the light bulb burns out.

A hyperbolic efficiency function is a general function that can be used to mimic numerous patterns. In general, researchers using hyperbolic functions assume a particular efficiency pattern. Retirements are included by assuming that different investment cohorts have different service lives. A .9 hyperbolic deterioration function is the form used by a number of researchers to construct estimates of public capital stock. With a .9 hyperbolic deterioration function, assets do deteriorate but the rate is very slow in early years. Deterioration in the first year is less than deterioration in the second year, which in turn is less than deterioration in the third year, and so on.

A straight-line function may be used to describe efficiency loss. With a straight-line efficiency function, the amount of efficiency decline is constant in every period. For example, with a straight-line efficiency function, efficiency loss in the first year is equal to

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[7] Productive capital stock is by definition a net stock concept, therefore, it is not necessary to include 'net' as an adjective when describing productive capital stocks.

[8] Mathematical formulas for a hyperbolic and a geometric pattern are provided in the Appendix.

efficiency loss in the second year, which is equal to efficiency loss in the third year, and so on. As in the case of a hyperbolic efficiency function, retirements are included by assuming that different investment cohorts have different service lives. As a result of the added effect of retirements, the productive stock declines at a faster rate than would be indicated by a straight-line efficiency loss once retirements begin.

Other researchers use a geometric function for deterioration. With geometric deterioration, the rate of deterioration is constant in every period. A geometric deterioration pattern captures the effect of retirements and loss in efficiency. A geometric pattern is a specific type of an accelerated pattern. An accelerated pattern assumes higher deterioration in the early years of an asset's service life as compared to later years. For example, with accelerated deterioration, deterioration in the first year is greater than that in the second year, which is in turn greater than that in the third year, and so on. Although all geometric patterns are accelerated, the curvature of the actual pattern depends on the declining balance rate.[9]

The following table illustrates the different types of patterns. The numbers refer to the percentage of an initial investment that remains in the productive capital stock under each assumption for an asset of a certain age with a physical life of 10 years[10]. In the geometric example, retirements have been deducted; in the one-hoss shay, hyperbolic and straight-line examples, retirements have not been deducted. Retirement deductions reduce the percentage of an initial investment that remains in the productive capital stock.

[9] In the following table, a double declining balance rate was used which results in a constant rate of decline in efficiency of .2. For the formula found in the Appendix, R is set equal to 2 for a double declining balance rate.

[10] The various lifetime concepts are discussed later in this Section.

AGE	ONE-HOSS-SHAY EFFICIENCY	.9 HYPERBOLIC EFFICIENCY	STRAIGHT-LINE EFFICIENCY	GEOMETRIC DETERIORATION
0	100.0	100.0	100.0	100.0
1	100.0	98.9	90.0	80.0
2	100.0	97.6	80.0	64.0
3	100.0	95.9	70.0	51.2
4	100.0	93.7	60.0	41.0
5	100.0	90.9	50.0	32.8
6	100.0	87.0	40.0	26.2
7	100.0	81.1	30.0	21.0
8	100.0	71.4	20.0	16.8
9	100.0	52.6	10.0	13.4
10	0.0	0.0	0.0	10.7

As these numbers indicate, the pattern used may significantly affect the measured level of public capital stock and the resulting measured productivity of that stock. Design specifications, actual practices, materials, load factors, and intensity of use are some of the factors that affect the following: asset durability or efficiency loss, service lives, retirement patterns, and the flow of services available from them. In addition, these factors are not constant; they change over time.

The objective of this project is to measure the productive public capital stock, in particular the productive highway capital stock. The results will serve as an important component of economic studies of the relationship between public infrastructure investments and private sector economic performance.

LIFETIMES AND RETIREMENTS

Part and parcel of the determination of the efficiency pattern of the public capital stock is the determination of asset lives. There are three types of lifetimes: physical life, service life and economic life.[11] Physical life is the number of years before an asset has declined in efficiency to the point at which it is retired due to the efficiency loss. Service life is the number of years that an asset is maintained in service or in use. Economic life is the number of years that the benefits from an asset are at least as great as the cost of maintaining the asset in service. The concept of physical life is relevant for determination of an efficiency pattern as it is a parameter in virtually all efficiency loss functions.

Retirement patterns may be totally independent of physical lives. An asset’s service life and physical life may be identical or the service life may be less than the physical life. An asset may reach the end of its service life before reaching the end of its physical life due to obsolescence, e.g. because highway specifications have changed or a higher quality

[11] There is not a standard set of lifetime terms used by economists.

highway can be built. The highway being retired[12] is able to still perform the service it was built to perform, but a different or higher quality highway replaces it. Similarly, an asset's economic life and physical life may be identical or the economic life may be less than the physical life, e.g. because demand patterns have changed. For example, a road leading to a desolate town has reached the end of its economic life, but its physical life may persist.[13] It follows that retirement patterns can be independent of efficiency patterns, as physical lives and efficiency patterns are interrelated.

Groups of assets typically have retirement distributions. That is, not all assets, even those of a particular type and vintage,[14] will have the same number of years until retirement or the same service life. Demand factors alone can create this phenomena as illustrated in the desolate town example. Budget and climatic factors, among others, may also affect when an asset is retired. Load and intensity of use factors can result in assets of the same type and vintage having different efficiency patterns, and thus different physical lives which can result in different retirement dates.

When a retirement distribution is used, a cohort approach is applied. Under the cohort approach, all assets that belong to the same asset group and vintage are assigned to a cohort. Each cohort has a different service life and/or physical life. For example, consider an asset with a mean service life of ten years. If 25% of the assets of the same group and vintage are retired after 9 years of service, 50% after 10 years of service, and 25% after 11 years of service, there are three cohorts.

Just as efficiency patterns can change over time, lifetimes, retirements, and retirement patterns can also. The same factors that impact efficiency patterns-- e.g. design specifications, actual practices, materials, load factors and intensity of use-- can also impact lifetimes, retirements and retirement patterns. The factors which impact economic lives, such as the economic vitality of an area, are numerous.

QUALITY CHANGE AND OBSOLESCENCE

The qualities or attributes of new assets frequently change over time, e.g. a highway built or reconstructed in 1950 is not identical to a highway built or reconstructed in 1990. When this phenomenon, termed quality change, occurs, it should be reflected in capital stock measures. A new asset is better than an old asset when for a specified amount of expenditure the quantity of the new asset is higher (and the price lower) than the quantity

[12] In the context of a highway, reconstruction is the equivalent of retirement.

[13] The concept of an economic life overlaps with the concept of a service life because economic or benefit/cost considerations may lead to retirement of an asset prior to the end of its physical life.

[14] A vintage of assets includes all assets that were purchased at the same time, e.g. during 1997.

of the old asset. If a new asset is different, but not better or worse than the old asset, there is no change recorded in the quantity of the new versus the old asset for a specified amount of expenditure. A new asset is worse than the old asset when for a specified amount of expenditure the quantity of the new asset is lower (and the price higher) than the quantity of the old asset. Quality adjustments are made to the investment flows of new assets, not to the quantity of the old capital stock. It is the new asset that has different attributes; nothing has occurred to change the attributes or quality of the old asset. If there are no adjustments to the quantities and prices of new investment and the “not better or worse” scenario is irrelevant, an assumption of no quality change is implicitly made.

Under the constant quality methodology, prices and quantities are adjusted when quality change occurs such that adjusted quantities at different points of time, e.g. 1960 versus 1990, possess the same potential productive capacity per unit. The product of unadjusted price times quantity must equal the product of adjusted price times quantity.

Obsolescence refers to the loss in value of an old asset resulting from new asset quality improvement or other demand factors, such as changes in income, tastes or preferences.[15] When obsolescence occurs it has no impact on the efficiency of the old asset. The old road is just as good as it was before the new road was built. For the purpose of constructing a productive capital stock, the relevant concern is not the value of the old asset, e.g. the price at which one could sell it, but how obsolescence affects asset deterioration. Obsolescence may affect efficiency of the old asset through changes in usage patterns over time, e.g. a highway may be impacted through intensity of use and load factors. In addition, obsolescence can result in a decision to retire an old asset before its physical life has ended. As a result, obsolescence may significantly affect the level of public stock.

PRODUCTIVE VS. WEALTH CAPITAL STOCK

Productive capital stock is the appropriate concept for estimating the productivity of capital stock or measuring the contribution of capital stock to economic growth. Wealth capital stock is the appropriate measure of the market value of capital. Productive capital stock is adjusted for current and past declines in efficiency. Wealth capital stock in addition is adjusted for future declines in efficiency. To explain the difference between the two types of capital stocks, economists favor the light bulb example for its simplicity. Assume a light bulb is capable of shining for 12 months. At any point in time over that 12 months, until the bulb stops shining, it is 100% productive as the intensity of light is constant. However, if one sold the light bulb after 6 months of use, a rational buyer would

[15] An interpretation of this definition of obsolescence provides justification for the example of a road leading to a desolate town under the guise of a change in tastes or preferences. Travelers choose not to travel on the road because they do not want to go to the town. Changes in income, tastes or preferences apply when the source of value reduction is not a new asset but rather other factors.

only be willing to pay approximately half of the original purchase price. In stock measurement, at the 6-month point, a productive capital stock of the light bulbs is approximately double the wealth capital stock.

The concept of wealth capital stock can be expanded upon by noting that the purchase price paid by an individual for an asset depends on the current and future stream of services expected from the asset. The purchase price is determined by a present value calculation which recognizes that an individual would pay more for an asset returning $100 in services today as compared to an asset returning $100 in services two years from today. As wealth capital stock depends upon the current and future efficiency of an asset, construction of a wealth capital stock from an efficiency function requires an assumed interest rate or discount rate to calculate present value.

Given any efficiency function, the corresponding concept for wealth capital stock, termed the relative price function, may be constructed using the following formula:

$$R_t = \frac{\Sigma_{\tau=t} E_\tau (1-r)^{\tau-t}}{\Sigma_{\tau=0} E_\tau (1-r)^{\tau}},$$

where R_t is the relative price at time t, τ-t is the number of years remaining until retirement, τ is the service life of the asset, E is the efficiency of the asset from the efficiency function, t is the current age of the asset, r is the discount rate or interest rate and all summations are until retirement of the asset.

Due to the discounting of the future efficiency of an asset, the relative price is always less than efficiency in period t except for the year the investment is made and the asset retired, and in the case of a geometric efficiency pattern. For example, the relative price pattern for an asset under one-hoss-shay efficiency is a concave pattern lying below the one-hoss-shay 100% efficient line. The following table lists the relative prices for the same patterns given in the earlier table. The numbers refer to the percentage of an initial investment that remains in the wealth capital stock under each assumption for an asset of a certain age with a physical life of 10 years at a discount rate of 4%.[16]

[16] The source for the term relative price and the numbers presented in the following table is Harper (1982). The relative price formula is also found in Bureau of Labor Statistics, “Trends in Multifactor Productivity, 1948-81,” U.S. Department of Labor, Bulletin 2178, September 1983.

AGE	ONE-HOSS-SHAY EFFICIENCY	.9 HYPERBOLIC EFFICIENCY	STRAIGHT-LINE EFFICIENCY	GEOMETRIC DETERIORATION
0	100.0	100.0	100.0	100.0
1	91.7	90.1	82.9	80.0
2	83.1	79.9	67.1	64.0
3	74.2	69.5	52.9	51.2
4	64.8	59.0	40.2	41.0
5	55.1	48.2	29.1	32.8
6	44.9	37.4	19.6	26.2
7	34.4	26.8	11.9	21.0
8	23.4	16.5	6.1	16.8
9	11.9	7.9	2.0	10.7
10	0.0	0.0	0.0	0.0

A comparison with the earlier efficiency and deterioration pattern table confirms that except in the case of a geometric pattern, a productive capital stock is larger than its corresponding wealth capital stock.

SECTION II: PUBLIC CAPITAL STOCK STUDIES

INTRODUCTION

There exist more than twenty studies published over the last twenty-five years that have constructed or applied estimates of at least one component of U.S. public capital stock. These studies are listed in Table 1 at the end of this Section. Some studies utilize the estimates of prior researchers, most notably the estimates of Munnell (1990). Other studies utilize the assumptions of prior researchers, most notably the assumptions of the Bureau of Economic Analysis (BEA, 1993) or Faucett and Scheppach (1974). This section begins with a brief description of those studies listed in Table 1 and then proceeds with a comparison of study methodologies.[17]

DESCRIPTION OF CAPITAL STOCK STUDIES

MAJOR STUDIES

Five major studies constructed estimates of U.S. public capital stock. The studies include:

BEA (1993, 1997),
Faucett and Scheppach (1974),
Munnell (1990),
Bell and McGuire (1994, 1997)/Dalenberg and Eberts (1994), and
Holtz-Eakin (1991, 1993).

In addition, Transport Canada estimated capital stocks for the Canadian road and highway system (Richardson 1996). The Canadian study is of interest because of the assumptions made regarding asset deterioration.

BEA (1993, 1997)

Bureau of Economic Analysis (BEA) studies[18] are a common source for investment data, capital stock data and capital stock benchmarks. BEA methodology is frequently used by

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[17] Table 1 is at the end of this chapter before the Appendix.

[18] U.S. Department of Commerce, Bureau of Economic Analysis, Fixed Reproducible Tangible Wealth in the United States, 1925-89, U.S. Government Printing Office, Washington, D.C., January 1993 (FRTW) describes the methodology used in the BEA study prior to the most recent benchmark revision of the National Income and Product Accounts (NIPAs). Fraumeni, Barbara M. “The Measurement of Depreciation in the U.S. National Income and Product Accounts,” Survey of Current Business, 77, July 1997, pp. 7-23 and Katz, Arnold J. and Shelby W. Herman, “Improved Estimates of Fixed

studies regardless of whether or not BEA data is used, The BEA capital stock data, which is currently available from 1925-1996, is a measure of tangible wealth and not productive capital stock.[19] The capital stock data, which detail investment and capital stocks by asset type, are compiled using information from numerous sources.

In the 1993 study, investment and capital stock were constructed for 15 types of nonresidential equipment and 15 types of nonresidential structures. Nonresidential equipment includes 6 types of Federal national defense nonresidential equipment, 8 types of Federal nondefense nonresidential equipment, and 1 type of state and local nonresidential equipment. Nonresidential structures include 1 type of Federal defense nonresidential structures, 6 types of Federal nondefense nonresidential structures, and 8 types of state and local nonresidential structures.

In the 1997 study, investment and capital stock are constructed for 76 types of nonresidential equipment and 19 types of structures. Nonresidential equipment includes 37 types of Federal national defense nonresidential equipment, 10 types of Federal nondefense nonresidential equipment, and 29 types of state and local nonresidential equipment. Structures includes 2 types of Federal defense nonresidential structures, 1 type of defense Federal residential structures, 7 types of Federal nondefense nonresidential structures, 8 types of state and local nonresidential structures and 1 type of state and local residential structures.

FAUCETT AND SCHEPPACH (1974)

The Jack Faucett Associates, Inc. study[20] is summarized in a five-volume report on transportation capital stock, investment needs and capacity measures commissioned by the U.S. Department of Transportation. The study examined 21 transportation modes between 1950-70 and based on that analysis projected investment needs through the year 1980. Capital stock estimates were constructed for commercial and noncommercial

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Reproducible Tangible Wealth, 1929-95," Survey of Current Business, 77, May 1997, pp. 69-92 describe the current methodology.

[19] It is common for researchers not to understand the difference between productive capital stock and wealth capital stock. Accordingly, many researchers utilize wealth capital stock or assumptions used to construct wealth capital stock when productive capital stock is clearly the appropriate measure. See Section I for further discussion of the difference between the two concepts and Table 1 for a listing of the studies that have used BEA estimates or assumptions.

[20] Faucett, Jack G. and Raymond C. Scheppach, Jack Faucett Associates Capital Stock Measures for Transportation, A Study in Five Volumes, U.S. Department of Transportation, Assistant Secretary for Policy, Office of Transportation Planning Analysis, Washington, D.C., December 1974.

modes, including public transportation, structures, equipment and land.[21] The modes examined are:

1. Automobiles,
2. Noncommercial aircraft,
3. Recreational boats,
4. Not-for-hire boats,
5. Airports,
6. Airways,
7. Waterways,
8. Highways,
9. Railroads,
10. For-hire trucks,
11. Intercity buses,
12. Oil pipelines,
13. Domestic air carriers,
14. Domestic water carriers,
15. Freight forwarders,
16. International air carriers,
17. International water carriers,
18. Local buses,
19. Taxicabs,
20. Rail transit, and
21. School buses.

The study reports gross and net investment, gross investment and gross capital stock deflators, gross and net capital stock, efficiency loss, retirements, service lives, stock vintage distributions for selected years. Separate estimates for structures, equipment, and, in some cases, land are also presented. Estimates of market value, depreciation, cost of capital services, projections of investment need and capacity are also included. Many data sources were used.

MUNNELL (1990)

The Munnell study constructed public capital stock for the 48 contiguous states over the period 1969-1988. State estimates were constructed using expenditure data from Government Finances coupled with BEA retirement, lifetime, and depreciation assumptions. The state estimates were then controlled to the national estimates of public

[21] Land estimates were constructed for four transportation systems: 1. Airports, 2. Highways, 3. Oil pipelines, and 4. Railroads. In the case of highways, the land estimates were allocated across seven modes: 1. Automobiles, 2. Local bus, 3. Intercity bus, 4. School bus, 5. Commercial trucking, 6. Private trucking, and 7. Taxicab (Faucett and Scheppach, 1974, Volume I, pp. 2-12 - 13, 4-9 - 14).

capital from BEA. Since BEA capital stocks are wealth estimates, Munnell's estimates are wealth estimates and not estimates of productive capital stock which is the desired measure.

BELL AND MCGUIRE (1994, 1997)/DALENBERG AND EBERTS (1994)

The Bell and McGuire (1994,1997)/Dalenberg and Eberts (1994) study was undertaken on behalf of the National Cooperative Highway Research Program (NCHRP). This study registers as the most extensive data collection effort since the 1974 Faucett and Scheppach study. The data series compiled as part of the study for at a minimum the 48 contiguous states include:[22]

1. Gross state product (1969-1992),
2. Earnings by industry (1969-1994),
3. Employment by industry (1969-1994),
4. Private capital stock estimates by industry, national totals (1947-1994),
5. State-level infrastructure spending for six categories of infrastructure (1977-1992),
6. National infrastructure spending by state and local governments on six categories of infrastructure (1902-1991),
7. State-level public capital stock estimates for six categories of infrastructure (1977- 1992),
8. Highway capital and maintenance outlays by state from the Federal Highway Administration (1960-1994 all levels; 1921-1995 state administered),
9. Highway capital stock estimates by state using Federal Highway Administration data (1931-1992),
10. Highway characteristics by state (1970 or later to 1995)
11. Transit characteristics by state (1984-1992), and
12. Airport and airways characteristics by state (1972-1994).

[22] The source for the list of data series is the draft February 1997 Appendix. In general, investment and capital stock data is included for Alaska, Hawaii and the District of Columbia for time series, such as State-level public capital stock estimates for six categories of infrastructure (1977-1992), which begin after Alaska and Hawaii became states. However, there are exceptions to this general rule. There are three differences in categories of coverage between the draft February 1997 Appendix and the September 1994 Final Report. First, for some series the initial and terminal years of the data compiled as reported in the draft 1997 Appendix differs from that in the September 1994 Final Report Appendix. Second, the Appendix to the September 1994 Final Report includes two series that are not listed in the draft February 1997 Appendix: state level private capital stock estimates by using employment allocators (1970-1989) and state-level private capital stock estimates by using GSP-IBT shares as allocators (1970-1989). Third, items 9-12 listed above are not included in the September 1994 Final Report.

The six categories of infrastructure are: highways, mass transit, air transportation, water transportation, water supply and sewerage. A multitude of data sources were employed.

HOLTZ-EAKIN (1991, 1993)

Holtz-Eakin constructed public capital stock for each of the 50 states, the District of Columbia and the United States between 1960-1988. Separate totals for states and localities were constructed as well as for functional categories-- education, higher education, local schools, streets and highways, sewerage, and utilities. Data sources utilized include Census publications Governmental Finances and State Government Finances.

RICHARDSON (1996)

The Richardson study estimated Canadian road and highway capital stock over the period 1961-1993. It differentiated among public and private highways[23] and calculated separate estimates of productive capital stock for highways and bridges by jurisdiction--Federal, provincial/territorial and municipal. Statistics Canada collected most of the source data.

OTHER STUDIES

There are a number of other studies that have estimated capital stocks which either did not undertake data construction efforts comparable in significance to the studies listed above or are lesser known than the above studies. These include:

1. Boskin, Robinson and Huber (1987),
2. Boskin, Robinson, and Roberts (1989),
3. Christensen, Christensen, Degen and Schoech (1989),
4. Costa, Ellson, and Martin (1987),
5. Cromwell (1988),
6. Dalenberg and Eberts (1997),
7. Duffy-Deno and Eberts (1989),
8. Eberts (May 1990),
9. Eberts, Park and Dalenberg (1986),
10. Garcia-Mila and McGuire (1992),
11. Nadiri and Mamuneas (1996), and
12. Wyckoff (1984).

There are also a number of studies listed in Table 1 that utilize data constructed by other researchers. The following list of these studies is not intended to exhaustive. The source of the data, either Munnell or BEA, is indicated next to the citation. These studies, which will not be discussed further in this chapter, include:

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[23] About 10% of highways are privately owned in Canada (Richardson, 1996, p. 7).

1. Aschauer (1989) – BEA,
2. Eisner (1991) – Munnell,
3. Garcia-Mila, McGuire and Porter (1996) – Munnell,
4. Holleyman (1996) – BEA,
5. Morrison and Schwartz (1996) – Munnell,
6. Ratner (1983) – BEA, and
7. Tatom (1993) – BEA,

BOSKIN, ROBINSON AND HUBER (1987)

Boskin, Robinson and Huber constructed estimates of state and local capital stock between 1927-85 for all 50 states and the District of Columbia. The nonresidential total was disaggregated into categories which match those found in the BEA (1993). The categories include total equipment and 8 nonresidential structure categories. The nonresidential structure categories are:

1. Educational buildings,
2. Hospital buildings,
3. Other buildings,
4. Highways and streets,
5. Conservation and development structures,
6. Sewer structures,
7. Water structures, and
8. Other.

Boskin, Robinson and Huber capital stock estimates are based on BEA investment data. The estimates are adjusted for intersectoral transfers and other possible statistical discrepancies by an amount equal to the difference between the stock produced by their attempt to reproduce BEA capital stock and actual BEA capital stock.

BOSKIN, ROBINSON AND ROBERTS (1989)

This later study estimated federal capital stock for 1927-1984. Nonresidential capital was categorized as either military or nonmilitary and equipment or structures which produced a total of eight categories. As in the previous study, the capital stock estimates are based on BEA investment data. The estimates are adjusted for intersectoral transfers and other possible statistical discrepancies by an amount equal to the difference between the stock produced by their attempt to reproduce BEA capital stock and actual BEA capital stock.

CHRISTENSEN, CHRISTENSEN, DEGEN AND SCHOECH (1989)

This study estimated investment and capital stock for the United States Postal Service. Detailed accounting records between were the basis for their 1949-1985 investment figures and other information needed to calculate capital stock. Capital stock was estimated for the following seven categories between 1963-1985:

1. Land,
2. Buildings,
3. Vehicles,
4. Customer service equipment,
5. Postal support equipment,
6. Mail processing equipment, and
7. Automated-processing equipment.

COSTA, ELLSON AND MARTIN (1987)

Costa, Ellson, and Martin estimated capital stock for the 48 contiguous states for 1937-72. Data sources for investment figures include Government Finances, State Government Finances and the Census of Government for selected years.

CROMWELL (1988)

Cromwell estimated bus retirement patterns for a 1979-84 sample of public and private local bus operators. The sample consisted of 112 local bus operators that had more than 5 busses over the period 1982-5 and provided only bus service over the same period. Although no corresponding capital stock was constructed, this study is described because the retirement information could be useful if a bus stock was estimated.

DALENBERG AND EBERTS (1997)

Dalenberg and Eberts estimated highway investment and capital stock for the 48 contiguous states between 1988-1992. These estimates differ from those presented in Bell and McGuire (1994, 1997)/Dalenberg and Eberts (1994).

DUFFY-DENO AND EBERTS (1989)

Duffy-Deno and Eberts estimated public capital stock for 28 Standard Metropolitan Statistical Areas (SMSAs) for the 1980-84 period. Public capital stock included in the study include:

1. Sanitary and storm sewers and sewage disposal,
2. Roadways, sidewalks, bridges, and tunnels,
3. Water supply and distribution systems,
4. Public hospitals, and
5. Public service enterprises, such as airports and ports.

This study is based on the methodology of Eberts, Park and Dalenberg (1986).

EBERTS (May 1990)

Eberts estimated investment between 1904-1977 and public capital stock between 1965-1977 between 36 SMSAs. The source of the investment data is City Government Finances and other Census publications. Categories of public capital stock similar to those reported in Duffy-Deno and Eberts (1989) were estimated. This study is also based on the methodology of Eberts, Park and Dalenberg (1986).

EBERTS, PARK AND DALENBERG (1986)

Eberts, Park and Dalenberg estimated investment and public capital stock between 1904-1981 for 40 SMSAs. The source of the investment data is City Government Finances and other Census publications. The data requirements for this project were extensive. The study identifies three major categories of public capital stock:

1. Water and Sewer,
2. Highways, and
3. Other.

These categories were disaggregated into subcategories which allowed differential treatment of assets according to their average service lives.

GARCIA-MILA AND MCGUIRE (1992)

Garcia-Mila and McGuire estimated highway and education capital stock for the 48 contiguous states between 1969-1983. The source of the investment data is Government Finances.

NADIRI AND MAMUNEAS (1996)

Nadiri and Mamuneas employed an estimate of total U.S. highway capital stock between 1950-1991 which was developed by Apogee Research, Inc. The investment data, which began in 1921, was based on Federal Highway Administration capital outlay data.

WYCKOFF (1984)

Wyckoff constructed estimates of highway investment and capital stock for 10 urban counties in the Midwest. The investment data began in 1941 and the capital stock data ranged between 1965-1976. Data sources included numerous Census documents, such as Local Government Finances in Selected Metropolitan Areas and Large Counties and city government finance annuals and compendiums.

COMPARISONS

DETERIORATION ASSUMPTIONS

The last column of Table 1 at the end of this section summarizes the deterioration assumptions for all studies described in this chapter.

MAJOR STUDIES

BEA (1993, 1997)

Since BEA studies relate to wealth, not production, BEA wealth capital stock estimates cannot be used in productivity analyses unless depreciation occurs at a geometric rate. Recently, BEA adopted a geometric rate of depreciation for almost all assets, including most public capital stock, except for missiles, computers and automobiles.[24] However, the BEA wealth studies that have influenced existing estimates of productive public capital stock were not based on a geometric rate of depreciation.[25] Researchers in several cases have adopted assumptions from BEA wealth studies or used BEA wealth capital stock as benchmark in analyses of productive public capital stock. These researchers either did not realize or ignored the inconsistency problem created by the use of BEA assumptions, wealth stocks or benchmarks to develop productive capital stock measures.

In its prior work, BEA assumed straight-line asset depreciation and a Winfrey asset retirement distribution. According to straight-line depreciation, the amount of depreciation, or change in the value of an asset associated with aging, is constant in every period. Use of BEA wealth capital stocks in lieu of productive capital stocks is equivalent to assuming a straight-line efficiency function which is inconsistent with BEA's depreciation assumption.[26] A one-hoss-shay efficiency function with a zero interest rate is consistent with BEA's straight-line depreciation function.

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[24] See Fraumeni, Barbara M. "The Measurement of Depreciation in the U.S. National Income and Product Accounts," Survey of Current Business 77, July 1997, pp. 7-23 and Katz, Arnold J. and Shelby W. Herman, "Improved Estimates of Fixed Reproducible Tangible Wealth, 1929-95," Survey of Current Business, 77, May 1997, pp. 69-92 for a description of the current methodology.

[25] U.S. Department of Commerce, Bureau of Economic Analysis, Fixed Reproducible Tangible Wealth in the United States, 1925-89, U.S. Government Printing Office, Washington, D.C., January 1993 describes the methodology used in the BEA study prior to the conversion to a geometric rate of depreciation for most assets.

[26] See the numerical example in Section I (Efficiency Decline and Deterioration) for a comparison of the patterns discussed in this Section. Regardless of whether the pattern relates to efficiency, depreciation or deterioration, the pattern will be the same.

A modified S-3 Winfrey curve was used by BEA to estimate the pattern of retirements around the mean for public capital stock. The modified S-3 curve is a bell-shaped distribution centered at the mean service life of the asset with retirements starting at 45 percent and ending at 155 percent of the service life. For each asset cohort, the service life is defined by the retirement distribution and a straight-line depreciation pattern applies. For example, suppose only three cohorts exist for a particular group of assets of the same vintage. Assume that the first cohort retires at 50% of the 10 year average service life, the second retires at 100% of the average service life, and the third retires at 150% of the average service life. The first cohort has a 5 year life, the second has a 10 year life, and the third has a 15 year life. The first cohort depreciates per year a constant amount equal to 20% of the initial investment, the second cohort depreciates per year a constant amount equal to 10% of the initial investment, and the third depreciates per year a constant amount equal to 6.67% of the initial investment. When BEA stocks are used as productive capital stocks, the net effect of the straight-line assumption and the retirement distribution is a convex deterioration pattern for the group of assets once retirements begin to occur.[27]

As previously noted, BEA assumes a geometric depreciation pattern for nearly all assets. With a geometric depreciation pattern, the rate of depreciation is constant and identical to the rate of deterioration. Productive and BEA wealth stocks are identical for almost every asset. Several questions remain regarding the use of BEA wealth public capital stocks. Is a geometric pattern appropriate?[28] Since the geometric rate of depreciation depends on the service life of the asset, are the service lives appropriate?

FAUCETT AND SCHEPPACH (1974)

Faucett and Scheppach used a .9 hyperbolic efficiency function in their construction of a productive transportation capital stock.[29] Retirements are assumed to be normally

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[27] See Section I for an example of a convex deterioration pattern (a geometric pattern).

[28] A geometric rate of depreciation was applied to assets for which no specific empirical evidence existed. This included most public assets. The analysis herein will determine the deterioration pattern most appropriate for highway capital stock.

[29] The .9 hyperbolic function, illustrated in Section I, is termed an efficiency depreciation function in Volume II of the Faucett and Scheppach report. Other alternatives discussed that could have been used to construct a productive capital stock (straight-line, double declining balance and sum of the years' digits) were termed depreciation functions also (Faucett and Scheppach, 1974, Volume I, Figure 2.1, p. 2-8). Depreciation is defined as "the loss in the value of a currently held asset" (Faucett and Scheppach, 1974, Volume I, p. 2.5), a definition consistent with that advocated in this analysis. However, in Volume IV economic depreciation is defined as "the loss in the current and future service value of the stock which by definition affects the price a purchaser is willing to pay for the stock, i.e. the market value" (Faucett and Scheppach, 1974, Volume IV, p. 2). This definition of

distributed with a standard deviation equal to 25% of the service life. The retirement distribution is vertically truncated at .5 and 1.5 of the service life. Further, the measure is adjusted for the distribution truncation loss of 4.5%. The retirement distribution is used to determine the service life and size of the cohorts of assets within the same group and vintage. Productive capital stock for each cohort of the same group and vintage is constructed using the .9 hyperbolic function with the service life dependent on the age of the asset at retirement.[30] As a result of the retirement distribution, the deterioration pattern for a group of assets, which is initially concave, becomes convex.[31]

MUNNELL (1990)

Munnell adopted the BEA (1993) wealth study assumptions. A pseudo capital stock was constructed using state data by accumulating investment flows and then applying a straight-line depreciation function and a modified S-3 Winfrey distribution to calculate net capital stock. Since the investment data was limited to only recent years, 1958-present, it was necessary to produce a capital stock benchmark or to somehow apportion capital stock at the national level among states. Munnell apportioned BEA wealth net stock estimates among individual states by using each state's pseudo capital stock share of the total across all 48 contiguous states. Therefore, the Munnell estimates are contaminated through the adoption of the BEA wealth study methodology and through the apportionment of BEA wealth capital stocks. Unless productive capital stock is best described by a straight-line efficiency function and a modified S-3 Winfrey distribution, the

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economic depreciation is equivalent to the operational definition of depreciation. According to Fraumeni (1997, p. 8):

"Depreciation is the change in value associated with aging of an asset. As an asset ages, its price changes because it declines in efficiency, or yields fewer productive services, in the current period and in all future periods. Depreciation reflects the present value of all such current and future changes in productive services."

In spite of the fact that the Faucett definition of depreciation and economic depreciation refer to the same concept, a .9 hyperbolic function is used to estimate efficiency depreciation and a straight-line economic depreciation function is used to estimate market values. Efficiency depreciation is used by Jack Faucett Associates to construct the measure termed in this chapter productive capital stock.

[30] Applying the cohort example in the BEA (1993, 1997) section above, the Faucett and Scheppach methodology is equivalent to rendering the service life in the hyperbolic function equal to 5, 10 and 15 years respectively for the first, second, and third cohort.

[31] An example of a concave deterioration pattern (a hyperbolic pattern) is provided in Section I. As noted previously, a geometric pattern is an example of a convex pattern.

Munnell estimates should not adopted in studies of productivity or economic performance.[32]

BELL AND MCGUIRE (1994, 1997)/DALENBERG AND EBERTS (1994)

This study adopted Faucett and Scheppach's (1974) or Holtz-Eakin's (1991, 1993) assumptions. Faucett and Scheppach's (1974) assumptions were used in constructing state highway capital stock estimates (number 9 in the list above) and a U.S. total. A .9 hyperbolic function and a normal truncated retirement distribution were employed to calculate productive capital stocks. The standard deviation of the normal retirement distribution was assumed to be equal to 25% of the service life. Further, the measure was vertically truncated at .5 and 1.5 of the service life and adjusted for the truncation loss of 4.5% of the distribution. As noted earlier with this cohort approach, the deterioration pattern for a group of assets, which is initially concave, becomes convex. The state-by-state and total U.S. highway series were constructed by extending the investment series backwards to 1935 and then employing the perpetual inventory method.

Bell and McGuire/Dalenberg and Eberts used Holtz-Eakin's assumptions to construct the capital stock for state level capital by six categories of infrastructure (number 7 in the list above). State capital stock benchmarks for 1976 were created by apportioning the U.S. total across the 48 contiguous states in proportion to the average share of total expenditures on the infrastructure category from 1977 to 1992. Finally, the perpetual inventory method was applied to extend the state capital stock series through 1992 using Holtz-Eakin geometric rates of deterioration. As a result, criticisms of Holtz-Eakin methodology apply to estimates for the six state categories of infrastructure.

HOLTZ-EAKIN (1991, 1993)

Holtz-Eakin adopted BEA wealth capital stock estimates to benchmark public capital stock in the initial year and to calibrate the measure of the geometric rate of depreciation. In each case, a state's share of the BEA aggregate wealth capital stock was assumed to be equal to that state's or locality's share of total current expenditure for that category in 1960. The perpetual inventory method was employed. The constant geometric depreciation rate was selected so that the aggregate capital stock for the state-local sector across all states and the District of Columbia was identical to the BEA aggregate net wealth capital stock in 1985. The state and local public capital stocks produced are estimates of wealth, not productive capital stocks. The estimated geometric rate of depreciation approximates the wealth capital stock which results from assuming a straight-

[32] Munnell does note that her estimates are estimates of wealth, but clearly the author did not realize that wealth estimates are not appropriate inputs to productivity or economic performance studies.

line depreciation and a S-3 Winfrey retirement function as the initial and terminal wealth stock are identical to the BEA's.

RICHARDSON (1996)

The Richardson study of highway capital stock is of interest because its assumptions regarding deterioration differ from those previously discussed. In addition, as service lives were allowed to vary over time, deterioration, which is dependent on average service lives, also varied over time. The retirement distribution used was the same as that used by Faucett and Scheppach and several other researchers (truncated normal at .5 and 1.5 of the average service life, adjusted for the truncated loss, and standard deviation equal to 25% of the service life). The efficiency function used was an average of a straight-line efficiency function and a hyperbolic efficiency function.[33] However, when comparing highway productive capital stock to other capital stocks, highway productive capital stock was constructed using a geometric deterioration function.

OTHER STUDIES

All remaining studies employed a deterioration pattern previously described, as deterioration assumptions were generally adopted from other studies. Of the twelve studies described previously, five applied a geometric rate of deterioration: 1. Boskin, Robinson and Huber (1987), 2. Boskin, Robinson, and Roberts (1989), 3. Christensen, Christensen, Degen and Schoech (1989), 4. Garcia-Mila and McGuire (1992), and 5.Wyckoff (1984). Five applied Faucett and Scheppach (1974) assumptions: 1. Dalenberg and Eberts (1997), 2. Duffy-Deno and Eberts (1989), 3. Eberts (May 1990), 4. Eberts, Park and Dalenberg (1986), and 5. Nadiri and Mamuneas (1996). One study, Munnell (1990), applied BEA assumptions. The Cromwell study (1988) made no assumptions about deterioration as a hazard model was used to estimate retirements from data on actual retirements.

Note that the Garcia-Mila and McGuire study implicitly assumed that all roads are equally efficient, or that the efficiency pattern is one-hoss-shay, by allocating the total U.S. highway capital stock to states on the basis of a state's share of total highway mileage to benchmark its state estimates.

The Dalenberg and Eberts study (1997) re-estimated state highway investment based on the previous year's capital stock and the increase in highway miles for that year. The adjusted investment was used to calculate an adjusted capital stock. Although this method had no impact on asset deterioration, it certainly impacted the capital stock estimates.

INITIAL YEAR FOR INVESTMENT AND BENCHMARKS

[33] Richardson called the hyperbolic function a delayed depreciation schedule.

The level of capital stock is affected by the initial year of investment data availability and by whether or not a benchmark is used. Some studies benchmark their capital stock by controlling estimates to another capital stock estimate. The implicit assumption that follows if a benchmark is not used is that there was no pre-existing productive capital in the initial investment year. Note that this is not a problem if any pre-existing capital stock was retired before the initial year of economic analysis. Many researchers employ Faucett and Scheppach (1974) service lives. For public capital, these range from 8 years for airport furniture and office equipment and local county and township road pavements to 80 years for highway grading.[34] Other researchers have used BEA (1993) service lives. For public capital, these range from 10 years for several categories of military nonresidential equipment to 60 years for all other nonmilitary and state and local nonresidential structures.[35] Therefore, if there is no benchmark, the capital stock should not be used for economic analysis for up to eighty years after the initial year for the investment data.

Of the eighteen studies described in this chapter, ten did not use a benchmark, five benched their capital stock to BEA (1993) wealth estimates, one benchmarked the capital stock and for two the written description did not provide enough information to determine which procedure was used.[36] The ten that did not bench their estimates include 1. BEA (1993, 1997), 2. Bell and McGuire (1994, 1997)/Dalenberg and Eberts (1994)…the state highway estimates, 3. Boskin, Robinson and Huber (1987), 4. Boskin, Robinson, and Roberts (1989), 5. Dalenberg and Eberts (1997), 6. Eberts (May 1990), 7. Eberts, Park and Dalenberg (1986), 8. Faucett and Scheppach (1974), and 9. Nadiri and Mamuneas (1996), and 10. Wyckoff (1984).[37] The five that benched their estimates to the BEA (1993) wealth estimates include 1. Bell and McGuire (1994, 1997)/Dalenberg and Eberts (1994)…the six types of infrastructure estimates through the use of Holtz-Eakin geometric rates of deterioration, 2. Costa, Ellson, and Martin (1987), 3.Garcia-Mila and McGuire (1992), 4. Holtz-Eakin (1991, 1993) and 5. Munnell (1990). Christensen, Christensen, Degen and Schoech (1989) benchmarked their estimates. Neither Duffy-Deno and Eberts (1989) nor Richardson (1996) provide enough information in their articles to determine if a benchmark is used.

[34] Faucett and Scheppach (1974) Table 3.3, p. 3-38 – 42.

[35] BEA (1993) Table B, p. M-17.

[36] Since Bell and McGuire (1994, 1997)/Dalenberg and Eberts (1994) produced two different sets of public capital stock estimates, the study is counted twice. Cromwell (1988) is not counted since a stock was not constructed.

[37] Dalenberg and Eberts (1997) is benched to the unbenched estimates of Bell and McGuire (1994, 1997)/Dalenberg and Eberts (1994).

Of the eleven studies that did not benchmark their capital stock estimates, BEA (1993, 1997) and Faucett and Scheppach (1974) are the only studies in which post-World War II estimates are not affected.[38]

The problem with benchmarking estimates to BEA (1993) is that it benchmarks estimates to wealth stock, which is not the correct stock for productivity or economic growth analysis.

The absence of benchmarks and benchmarking to the wrong stock are two serious shortcomings associated with current public capital stock estimates.

JURISDICTIONAL AND GEOGRAPHICAL COVERAGE

In general, more detail is preferred to less. More detailed estimates or their benchmarks are frequently produced by allocating an aggregate capital stock across subaggregates. However, it is frequently unclear how this allocation should be done. A summary of some of the issues involved with constructing state estimates is provided by Holtz-Eakin (1991). A second issue concerns the extent to which more detailed estimates reflect more detailed information. The existence of more detailed estimates create a false impression that researchers know more about the subaggregates then they actually do. Accordingly, several researchers have indicated the need for more work on state estimates of public capital stock.[39]

Of the U.S. studies described in this chapter, six constructed state public capital stock estimates. These include: 1. Bell and McGuire (1994, 1997)/Dalenberg and Eberts (1994), 2. Costa, Ellson, and Martin (1987), 3. Dalenberg and Eberts (1997), 4. Garcia-Mila and McGuire (1992), 5. Holtz-Eakin (1991, 1993) and 6. Munnell (1990). All of the public capital stock estimates for individual cities were constructed by Eberts and his co-authors: 1. Duffy-Deno and Eberts (1989), 2. Eberts (May 1990), and Eberts, Park and Dalenberg (1986).

Wyckoff (1984) produced the only estimates for counties.

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[38] Although BEA is publishes data only from 1925, historical investment data exists from as early as 1871 for nonresidential structures and 1890 for producer's durable equipment. These serve as the initial investment years for Faucett and Scheppach (1974), as well.

[39] Recommendations for future work in a later chapter as a part of this project call for improvements in state capital stock estimates and the use of price indices. The latter recommendation results from comments made by Randall Eberts on the need for state specific price indices during the October 27, 1998 Select Advisory Committee meeting.

OTHER TYPES OF ASSET DETAIL

Other types of asset detail are developed, as well. BEA(1997) presents data for up to 95 different types of public assets. Bell and McGuire (1994, 1997)/Dalenberg and Eberts (1994) constructed state and local estimates for six types of infrastructure, as listed earlier. Boskin, Robinson and Huber (1987) and Boskin, Robinson, and Roberts (1989) detail capital stock by the eight BEA nonresidential structure categories, which are listed above under Boskin, et. al. Faucett and Scheppach (1974) developed public capital stock by twenty-one transportation modes, for structures, equipment, and in some cases, land, as described earlier. Information for even more detailed asset categories was developed to assist in the transportation capital stock construction.[40] Holtz-Eakin (1991, 1993) constructed separate capital stock totals at the state and local levels for six functional categories, as listed above. Christensen, Christensen, Degen and Schoech (1989) estimated capital stock by seven Post Office related categories, as listed above. The Duffy-Deno and Eberts (1989) municipal categories listed above are functional categories, therefore, they are distinct from the eight BEA/Boskin et. al. categories. In the Eberts, Park and Dalenberg (1986) municipal study, several categories were aggregated to form three functional categories which are listed above.

With particular reference to highway capital stock, a number of researchers separated investment into expenditures on pavement, grading, and structures following the lead of Faucett and Scheppach (1974), however none distinguished new construction or reconstruction expenditures from other investment expenditures. All construction was implicitly assumed to be new construction. As the detailed worksheets underlying the 1997 Cost Allocation Study exhibit, the percentage of expenditures devoted to grading versus pavement is significantly different for new construction and reconstruction as compared to other types of construction.[41]

[40] See Faucett and Scheppach (1974) Table 3.3, p. 3-38 – 42.

[41] The unpublished worksheets (Jacoby) present the percentage that grading outlay is of grading plus pavement outlay for new construction, reconstruction, restoration and rehabilitation and resurfacing by rural and urban functional categories, such as Interstates, freeways and expressways, arterials, collectors and local. The percentage that is grading varies from 0% for resurfacing to 36.8% for new construction.

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TABLE 1 PUBLIC CAPITAL STOCK ESTIMATES				
	Time Frame of Study	**Coverage**	**BEA dependent**	**Deterioration**
Aschauer (1989)	I & K: 1949-1985	all nonmilitary public capital	yes, BEA net wealth stocks	straight-line, Winfrey see BEA (1993)
Bell and McGuire (1994,1997)/ Dalenberg and Eberts (1994)	I: 1902-1990 or 1992 for total; 1977-1990 or 1992 for state detail K: 1931 or 1977-1990 or 1992 for state detail	up to 50 states, DC, national total across states for 6 categories of infrastructure, state-level detail for 6 categories of infrastructure	yes, as benchmarks for state level infrastructure by 6 categories; otherwise no	.9 hyperbolic, Winfrey; Faucett assumptions, see Faucett and Scheppach (1974); geometric for state-level detail for 6 categories of infrastructure, see Holtz-Eakin (1991, 1993)
Boskin, Robinson, and Huber (1987)	I & K: 1927-1985	total nonresidential state and local across all 50 states and D.C.	no	geometric
Boskin, Robinson and Roberts (1989)	I & K: 1927-1984	federal nonresidential (including military)	no	geometric
Bureau of Economic Analysis (1993)	I: as early as1820-1989, K: 1925-1989	national, asset, industry and legal form of organization detail including private and government (including military)	yes	straight-line, Winfrey

Bureau of Economic Analysis (1997)	I&K: 1925-1996	national, asset, industry and legal form of organization detail including private and government (including military)	yes	geometric for most assets
Christensen, Christensen, Degen and Schoech (1989)	I: 1949-1985, K: 1963-1985	United States Postal Service (USPS)	no	geometric
Costa, Ellson and Martin (1987)	I & K: 1937-72	48 states	yes, BEA assumptions, controlling	straight-line, Winfrey see BEA (1993)
Cromwell (1988)	I & K: 1979-1984	bus operators (both public and private)	no	
Dalenberg and Eberts (1997)	I & K: 1988-1992	highway, 48 states	no	.9 hyperbolic, Winfrey; Faucett assumptions, see Faucett and Scheppach (1974)
Duffy-Deno and Eberts (1989)	I & K: 1980-1984	28 SMSAs	no	.9 hyperbolic, Winfrey; Faucett assumptions, see Faucett and Scheppach (1974)
Eberts (1990)	I & K: 1904-1977	36 SMSAs	no	.9 hyperbolic, Winfrey; Faucett assumptions, see Faucett and Scheppach (1974)
Eberts, Park and Dalenberg (1986)	I & K: 1904-1981	40 SMSAs	no	.9 hyperbolic, Winfrey; Faucett assumptions, see Faucett and Scheppach (1974)

Eisner (1991)	I & K: 1970-1986	48 states	yes, Munnell data	see Munnell (1990)
Faucett and Scheppach (1974)	I: as early as 1871 for NRS, 1890 for PDE, to 1970, K: 1950-1970	transportation capital stocks (private and public)	no	.9 hyperbolic, Winfrey
Garcia-Mila and McGuire (1992)	I & K: 1969-1983	48 states	yes, BEA net wealth stocks	geometric
Garcia-Mila, McGuire and Porter (1996)	I & K: 1970-1983	48 states	yes, Munnell data	see Munnell (1990)
Holleyman (1996)	I & K: 1969-1986	total Federal, state and local	yes, BEA net wealth stocks	straight-line, Winfrey see BEA (1993)
Holtz-Eakin (1991, 1993)	I & K: 1960-1988	50 states, DC, localities and total US	yes, as benchmarks and to calibrate the geometric deterioration rate	geometric
Morrison and Schwartz (1996)	I & K: 1970-1987	48 states	yes, Munnell data	see Munnell (1990)
Munnell (1990)	I & K: 1969-1988	48 states	yes, controls and BEA assumptions	straight-line, Winfrey see BEA (1993)
Nadiri and Mamuneas (1996)	I 1921-1991, K: 1950-1991	total U.S. highway	no	Faucett assumptions
Ratner (1983)	I & K: 1949-1973	total US non-military	yes, BEA net wealth stocks	see BEA (1993)
Richardson (1996)	I&K: 1961-1993	highway capital stock, public and private, by jurisdiction and municipal	no	average of straight-line and hyperbolic, retirement distribution, see Faucett and Scheppach (1974)
Tatom (1993)	I: 1947-1992 K: as early as 1947 to 1992	various, including all public capital, nonmilitary total & state & local total	yes, BEA net wealth stocks	see BEA (1993)
Wyckoff (1984)	I: 1941-1976 K: 1965-1976	10 counties	no	geometric

APPENDIX DEFINITION GLOSSARY[42]

Capital is a durable asset. The convention is that any asset which is expected to last at least one year is called capital, if an asset is expected to last less than one year the asset is termed a consumption good.

Capital stock is a measure of how much capital you have at a particular point of time, e.g. December 31, 1997.

Census method. Under the census method, capital stock is measured by being enumerated.

Constant quality prices and quantities. Under the constant quality methodology, prices and quantities are adjusted when quality change occurs such that adjusted quantities at different points of time, e.g. 1960 versus 1990, have the same potential productive capacity per unit. The product of unadjusted price times quantity must equal the product of adjusted price times quantity. If the adjusted quantity is 25% higher than the unadjusted quantity, the adjusted price must be 20% lower than the unadjusted price. For example, if both unadjusted price and quantity are equal to 1.0 and the adjusted quantity is set to 1.25, the adjusted price must equal .8 (=1/1.25).

Decay is a synonym for efficiency decline. See the definition for efficiency decline below.

Depreciation is the change in the value of an asset associated with aging.

Deterioration is the decline in the potential productive services of an asset as it ages. Deterioration includes the effects of efficiency decline or decay and retirements.

Economic life is the number of years that the benefits from an asset are at least as great as the cost of keeping the asset in service.

Efficiency decline is the decline in the potential productive services of an asset still in service as it ages.

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[42] The idea for a glossary of terms and several of the definitions come from Triplett, Jack E., "Concepts of Capital for Production Accounts and for Wealth Accounts: The Implications for Statistical Programs," paper presented at the International Conference on Capital Stock Statistics, Canberra, Australia, March 10-14, 1997. Others come from System of National Accounts, 1993 Commission of the European Communities, International Monetary Fund, Organization for Economic Co-operation and Development, United Nations, World Bank, Brussels, Luxembourg, Paris, New York, Washington, D.C., 1993. The remainder are the sole responsibility of the author.

Fixed tangible assets are non-financial produced assets which are used in a production process. Fixed tangible assets include dwellings, other buildings and structures, machinery and equipment and cultivated assets such as livestock, vineyards and orchards. In the case of public capital, fixed tangible assets also include highways, bridges, roads, dams, water and sewer systems, and conservation and development assets.

Geometric deterioration. With geometric deterioration, the rate of deterioration is constant in every period. The rate of deterioration, d, is:

$$d = R/T,$$

where R is the estimated declining balance rate and T is the average service life of the asset.

Gross capital stock is the sum of investments minus retirements.

Hyperbolic function A hyperbolic function is a specific mathematical form:

$$S(a)=(L-a)/(L-Ba), \quad 0<a<L \text{ or } a=0$$
$$S(a)=0, \quad a>L \text{ or } a = L$$

where S(a) is the relative efficiency of an asset of age a, L is the service life, and B is the parameter allowing the shape of the curve to vary, set to .9 by JFA.

Investment, a flow measure, is the addition to the capital stock over a particular time period, e.g. from January 1, 1997 through December 31, 1997.

Net capital stock is the sum of investment minus deterioration (productive concept) or the sum of investment minus depreciation (wealth concept).

One-hoss-shay. With one-hoss-shay deterioration there is zero deterioration until the asset is retired.

Obsolescence is the loss in value of an old asset resulting from new asset quality improvement or other demand factors such as changes in income, tastes or preferences.

Perpetual inventory method. Under the perpetual inventory method, capital stock is estimated by summing up investment to produce gross capital stock or by summing up investment and reducing the resulting total by an estimate of asset deterioration to produce net capital stock.

Physical life is the number of years before an asset has declined in efficiency to the point where it is retired because of efficiency loss.

Productive capital stock is the capital stock which has been adjusted for the effects of deterioration, e.g. efficiency decline and retirements. Productive capital stock is a net capital concept.

Quality adjustments are made when new assets are significantly different than old assets. Quality adjustments affect the constant quality investment quantity and constant quality price of an asset.

Quality change is a term used when new assets are significantly different from old assets.

Retirements are assets withdrawn from service.

Service life is the number of years that an asset is kept in service or in use.

Wealth capital stock is the capital stock evaluated at its market value.

CHAPTER II

RECOMMENDATIONS FOR CONSTRUCTION OF A QUALITY ADJUSTED PUBLIC CAPITAL STOCK

SUBMITTED TO THE SELECT ADVISORY COMMITTEE

DECEMBER 10, 1997

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RECOMMENDATIONS FOR OTHER PUBLIC CAPITAL STOCK MEASUREMENT…………………………...……………………………………49

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INTRODUCTION

Capital stock information is an important component of economic studies examining the relationship between public infrastructure investments and private sector performance. In order to determine the productivity of public infrastructure, more broadly all forms of public capital, an accurate measure of public capital is needed. There are several studies which have estimated highway or other types of public capital stock (Faucett and Scheppach (1974), Munnell (1990), Dalenberg and Eberts (1994)/Bell and McGuire (1994, 1997) and Holtz-Eakin (1991, 1993)), but none has focused on measuring productive capital stock and adjusting that stock for both deterioration and quality change. As a result, the current study may have a significant impact on estimates of public capital stock, which in turn may have a significant impact on estimates of public capital productivity.

This project measures productive capital stocks as productive capital is the appropriate measure for use in studies of productivity.[43] Most prior studies directly or indirectly utilized wealth capital stocks or concepts appropriate to wealth capital stock measurement, as opposed to productive capital stock. The Bureau of Economic Analysis (BEA, (1993)) publishes estimates of wealth capital stock. The BEA estimates or assumptions are frequently used by economists unaware that wealth estimates cannot be used to estimate productivity. Table 1 summarizes the extent to which previous studies have been contaminated by the use of wealth stocks.

Whereas productive capital stock is the appropriate measure for estimating the productivity of capital stock, wealth capital stock is the appropriate measure of the market value of capital. Productive capital stock is adjusted for current and past declines in efficiency. Wealth capital stock in addition is adjusted for future declines in efficiency. To explain the difference between the two types of capital stocks, economists favor the light bulb example for its simplicity. Assume a light bulb is capable of shining for 12 months. At any point in time over that 12 months, until the bulb stops shining, it is 100% productive as the intensity of light is constant. However, if one sold the light bulb after 6 months of use, a rational buyer would only be willing to pay approximately half of the original purchase price. In stock measurement, at the 6-month point, a productive capital stock of the light bulbs is about double the wealth capital stock.

The concept of wealth capital stock can be expanded upon by noting that the purchase price paid by an individual for an asset depends on the current and future stream of services expected from the asset. This illustrates the concept of present value, e.g. anyone would pay more for an asset returning $100 in services today versus an asset returning $100 in services two years from today.

[43] Triplett (1997, p. 3) and the Bureau of Economic Analysis (BEA) (1987, p. x, 1993, p. M-6).

This main body of this chapter is divided into two sections. The first summarizes recommendations for the construction of highway public capital stock. The second summarizes recommendations for the construction of other public capital stock. Both sets of recommendations were presented to the Select Advisory Committee (SAC) on December 10, 1997 for their consideration and comments. The emphasis of this report is on the construction of a pro forma estimate of highway public capital stock; no estimate of other public capital stock will be constructed. The actual methodology used in construction of highway capital stock reflects not only the comments of the SAC, but also data availability and research completed after the December 10th meeting.

There are two appendices to this chapter. The first appendix lists definitions of terms used in the text. The second appendix describes the results of interviews undertaken by Gedeon Picher to identify major highway design changes implemented during the 1950s to the present, as represented by those undertaken by the Maine Department of Transportation (MDOT).

RECOMMENDATIONS FOR HIGHWAY CAPITAL STOCK MEASUREMENT

PREFACE

Recommendations are clearly impacted by feasibility limitations. Previous research, which involved much more extensive data collection, serves as an indicator of possible efforts.

For highways, the most detailed data source is Faucett and Scheppach (1974). Faucett and Scheppach (JFA) present investment and capital stock data for five-subcategories: the Interstate system, the State system, local city streets, local county and township roads, and all other roads. In addition, investment is further divided for each category between structures and equipment. From a sample of six randomly chosen states over the 1961-69 period, JFA calculated the average percentage of total capital expenditures allocated to highway equipment.[44] Further, the structures category was subdivided into pavement, grading and other structures.   Constant percentages are applied to allocate expenditures among the subcategories.[45]

Not all highway capital stock estimates identify equipment capital. In BEA (1987, 1993), highway equipment capital stock is not distinguished from other types of government

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[44] Inspection of the data for the Interstate system, reported in Tables A.21 and A.23, (pp. 26 and 28, Volume II) reveals that equipment investment is a somewhat variable percentage of structure investment.

[45] JFA refers to weights or constant percentages only in the context of service lives. Analysts have assumed that these weights also apply to total expenditures on structures.

nondefense equipment capital stock. Dalenberg and Eberts (1994)/Bell and McGuire (1994, 1997) do not include highway equipment capital stock in their highway estimates.

RECOMMENDATIONS

The greater the available detail on highway expenditure or investment, the higher the potential quality of highway capital stock estimates. At a minimum, it is essential that expenditures be identified by administrative class or functional category and by new construction versus other. Administrative classes include Interstate, State, Local and Town. Functional categories include Arterial, Collector and Local.

If new construction expenditures are not differentiated from other expenditures, it is particularly undesirable to assume that the composition of highway investment is fixed over time.[46] The composition of new construction expenditures are significantly different from the composition of other construction expenditures, with the latter much more heavily weighted towards pavement than the former. In addition, during certain time periods in the U.S. new construction has been more widespread than in other periods, e.g. during the construction of the Interstate system. Ignoring these considerations results in misleading estimates of highway capital stock.

It would be easier to continue expenditure disaggregation by administrative class as JFA has done for years prior to 1971 than to disaggregate by functional category. However, there are arguments in favor of expenditure disaggregation by functional category. It may be less difficult to associate stocks by functional category with capital service flows than by administrative class. In addition, although functional category definitions may have changed over time, administrative categories have certainly changed with the implementation of ISTEA, e.g. the NHS vs. non-NHS designations.

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[46] JFA assumes that for the Interstate and State systems, 52% of expenditures are for pavement, 26.5% for grading and 21.5% for other structures, with service lives of 14, 80 and 50 years, respectively. With the additional assumption that total expenditures are the same every year, by the 80th year (and later years), the percentages of total highway productive capital stock that are pavement, grading and other structures change from the expenditure percentages to 18%, 54.5% and 27.5%, respectively. The productive capital stock percentages vary significantly from the expenditure percentages. Also, the components of a given highway capital stock critically depend on the year of that calculation, which impacts the measured efficiency of the stock as well.

PAVEMENT

AASHTO curves

AASHTO pavement curves, suitable for use as efficiency curves, may simply be constructed by making assumptions about the relevant parameters.[47] The following chart exhibits the Maine Department of Transportation (MDOT) Structural Numbers (SN) and terminal serviceabilities (Pt) for asphalt construction by pre-ISTEA highway and road administrative classes, as cited by the most recent cost allocation study (MDOT, 1989):

	Interstate	FAP	FAS/FAU	SA/LOC
SN	6.00	4.46	4.25	2.50
Pt	3.10	2.50	2.00	2.00

where FAP denotes Federal Aid Primary, FAS/FAU denotes Federal Aid Secondary/Federal Aid Urban, and SA/LOC denotes State Aid/Local. In general, the MDOT uses Interstate and FAP numbers for the NHS and the FAS/FAU numbers for the Surface Transportation Program (STP) - non-NHS.

AASHTO curves also exist for Portland Concrete Cement (PCC) construction. If expenditures can be separated by type of construction, e.g. asphalt versus PCC, efficiency curves could be specific to the type of construction.

Although AASHTO pavement curves can be determined from a Present Serviceability Index (PSI) of 5.0 to 0.0, clearly not all points on the curve are operational. For asphalt, a PSI of 4.2 is the average quality of a new road. According to AASHTO, Pt is the point at which a pavement should be treated (retired). Road treatments, e.g. reconstruction, rehabilitation, restoration and resurfacing, may occur at points distributed around the Pt point for a variety of reasons.

Core efficiency curves

It is recommended that the AASHTO curves for asphalt, from a PSI of 4.2 to the Pt point and possibly somewhat beyond, be used as the "core" efficiency curves for pavements.[48] [49] The curves should be normalized so that 4.2 represents 100% efficiency. A possible tactic is to use the AASHTO curves as the "core" efficiency curves up to a PSI level somewhat

[47] The majority of the SAC concluded that the efficiency curves should not be identical to the AASHTO pavement curves, although still a function of pavement condition as predicted by the AASHTO pavement curves.

[48] Sometimes pavement is not treated (retired) until a PSI below the Pt point. In addition, there is some potential productive capacity below the Pt point.

[49] This recommendation would be revised if expenditures on asphalt vs. PCC construction were available.

below the Pt point, e.g. 10% below. Under this proposal, the 10% point represents 0% efficiency. Additional considerations relevant to this recommendation include: the extent to which the MDOT SN and Pt numbers are representative of practices across the country, whether an attempt should be made to adjust for other construction types such as PCC, and how and when transition to other curves should be made given results of the Long-Term Pavement Performance (LTPP) studies currently underway.

The variable on the x-axis of AASHTO curves is Equivalent Single-Axle Loads (ESALs). The variable on the x-axis of an asset efficiency curve is age. To move from ESALs to age requires critical assumptions about ESALs per time period or Average Annual Daily Traffic (AADT) and the composition of AADT, including growth assumptions. MDOT regularly calculates total ESALs before replacement is needed for every design project from AADT plus composition of traffic. AADT PLUS composition of traffic specifies the makeup of the AADT by vehicle class. Expected service life can be determined by dividing TOTAL ESALs by ESALs per year for typical facilities by administrative or functional categories.

In the State of Maine, a pavement life of 20 years was expected, however 14 years is the typical pavement service life. This may be due to any one of a number of reasons: 1) higher than expected traffic, possibly as a result of unforeseen economic development, 2) unaccounted for swelling and frost heaves, 3) rutting or low skid resistance problems not captured in the AASHTO equation, 4) roadwork undertaken elsewhere in the area, 5) policy/political considerations as opposed to technical considerations, and 6) budgetary reasons.[50]

Retirement distribution

Even if there is agreement on the shape of the core efficiency curves, there may be disagreement on what the retirement distribution should be. The retirement distribution can have two major components, the first being the distribution of retirement dates along a given efficiency curve, including the core efficiency curves, and the second being the family of efficiency curves distributed about the core efficiency curves.

Pavement is commonly treated before it reaches the Pt point, as it is cost efficient to do so. This suggests that a retirement distribution along a given efficiency curve should be heavily skewed towards points before Pt.

Differences in initial SN provide a rationale for a family of efficiency curves. Initial SN differs according to whether pavement is laid during new construction and whether treatments are major or minor. Major treatments include rehabilitation, reconstruction and restoration. Minor treatments include resurfacing and Highway Maintenance Mulch

[50] Small and Winston have raised some questions about the AASHTO curve itself. See Small and Winston (1988) and Small, Winston and Evans (1989).

(HMM). The initial SN for new construction or major treatment is typically the same. The initial SN for minor treatment is typically below the SN for new construction and major treatment. An efficiency curve based on a lower initial SN will be different than the core efficiency curve. The distribution of capital outlays for major versus minor treatments could be used to weight the family of efficiency curves created by different SNs.

Differences between actual and expected AADT and traffic composition also provide a rationale for a family of efficiency curves. At a local level, development patterns affecting AADT and traffic composition are frequently not accurately predicted, e.g. knowing where a new shopping mall is going to be located, but at the state and national level it is argued that growth in AADT can be predicted with a higher degree of accuracy. Although it may be difficult to predict where and when a new shopping mall is going to be located, it is predictable that development will occur someplace in the country over a specific time period.

Accounting for the difference in design physical life and actual service life (20 vs. 14) remains an issue. It would be easiest to arbitrarily assume that the difference is due to higher than expected ESALs per year. However, such an assumption runs contrary to the message of the previous paragraph and ignores the other possibilities listed earlier. This formulation suggests a family of different efficiency curves clustered about and skewed to the left of the core efficiency curves. For those curves with ESALs per year greater than the core efficiency curves, efficiency would decline faster as indicated by the AASHTO PSI/ESAL relationship. This methodology is similar to the Winfrey curve approach, through which assets decline in efficiency faster or slower than the typical asset for one reason or another. In this case, the reasons are differences in ESALs or AADT and traffic composition sustained by a road.

Unless there is specific information about the family of efficiency curves, a false rigor is created by assuming a specific distribution for those curves. The recommendation is that only a "core" efficiency curve be adopted unless specific information about the family of efficiency curves can be obtained. A distinction between new construction and major or minor treatments seems most promising to develop a family of curves, however, expenditures categorized in this way may not be available.

Quality

If expenditures can be separated by type of construction, there is both a quality question and an efficiency curve question as posed above. A quality adjustment might be appropriate if the cost per "unit of quality" differs for an asphalt road versus a PCC road.

SUPERPAVE, which is just beginning to come on-line, seems to be a pavement of higher quality as compared to its predecessors. In order to incorporate SUPERPAVE quality adjustment into the highway capital stock measures, information on the relative quality and the relative cost of SUPERPAVE is needed.

GRADING

The physical life of grading is very long. Estimates vary from 80 years (JFA, 1974) to indefinite (Picher, interviews, 1997). Relatively little, if anything at all, is known about grading deterioration. Two possible contrasting assumptions are a geometric rate at the Hulten-Wykoff default rate for structures (Fraumeni, 1997) and a .9 hyperbolic rate.[51] [52] The geometric efficiency function includes retirements and the hyperbolic function does not. Accordingly, JFA retirement assumptions are used in conjunction with a .9 hyperbolic function in the construction of Figure 1. Figure 1 illustrates the difference between a .9 hyperbolic-JFA deterioration function and a geometric deterioration function for an asset with an average service life of 10 years. Under the JFA assumptions for an asset with an average service life of 80 years, retirements begin at age 40 and continue to age 120. Under a geometric assumption, retirements may continue on indefinitely. There exist an infinite number of possible deterioration curve shapes. Because of the long life of grading as compared to other components of highways, deterioration assumptions can have a significant impact on estimates of productive capital stock. The sensitivity of productive capital stock measurements to variations in the grading deterioration curve can be demonstrated with BEA or JFA data.

At this time, there are no plans to attempt an implementation of quality adjustment into the grading component of highway capital stock.

OTHER STRUCTURES

It is hypothesized that other structures consist of predominantly bridges. Examples of assets which are considered non-bridge other structures include culverts, pipe arches, pedestrian tunnels and bridges 20 feet or less in length. Other structures are much more similar to building structures in their characteristics than either paving or grading. As such, there is a stronger empirical basis for using a geometric rate of deterioration.[53] [54]

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[51] The Bureau of Economic Analysis considers highways structures.

[52] With a geometric rate of depreciation (wealth stock concept), the rate of deterioration (productive stock concept) is equal to the rate of depreciation.

[53] The Hulten-Wykoff study (1981a, 1981b) concluded by examining used asset prices that a geometric rate of depreciation is the best approximation to actual depreciation. Fraumeni (1997) agreed based on a survey of empirical studies of depreciation. BEA (Katz and Herman, 1997) has adopted a geometric rate of depreciation for most assets, including all highway assets.

[54] See footnote 8.

However, deterioration information specific to bridges would be very useful in this effort and might be available from bridge rehabilitation projects.[55]

The construction of bridges with higher load bearing capacity, as distinguished by the HS and H systems, is evidence of quality change in bridge construction. Even though load bearing is just one aspect of a bridge's characteristics, it would be extremely difficult to track quality changes using other characteristics, as bridges are highly heterogeneous assets.

EQUIPMENT

The major issue for capital stock measurement of highway equipment is data availability. As described in the preface, highway equipment is either excluded from highway capital stock estimates, created with a constant percentage of expenditure assumption, or not separately identified from other types of public capital equipment. The evidence from JFA (1974, p. 3-9) justifies that expenditures on highway equipment are a relatively small, but clearly not negligible, percentage (6%) of total highway capital expenditures. In addition, JFA concluded that 75% of highway equipment expenditures is reported as maintenance expenditures, the remainder is reported as structure expenditures.[56]

If information was available on the major types of equipment expenditures, reasonable assumptions could be made about equipment deterioration patterns and service lives. For example, if the majority of highway equipment was thought to be construction equipment, street cleaners, snow plows (in certain states) and other vehicles, then substantial empirical evidence exists to determine deterioration patterns (Fraumeni 1997; Hulten and Wykoff 1981a, 1981b). Of course, this information is useful only if an estimate of total expenditures on highway equipment is available.

OVERALL QUALITY

The discussion to this point has centered on a highway comprised of three components: pavement, grading and other structures. A sense of the highway as a package, including those characteristics not captured by the three components which have possibly changed over time, is missing. These characteristics include geometric design features, traffic maintenance, design of interchanges and intersections, safety features, and signage, to

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[55] PONTIS, a bridge management system, states the probability that individual elements of a bridge will make a transition among condition states as the result of deterioration and maintenance. The system is too detailed to serve as a source of deterioration information for a bridge as a whole.

[56] If JFA is correct that about 25% of equipment expenditures are included under structure expenditures, therefore a portion of equipment expenditures may be included in many highway capital stock estimates, but with inappropriate deterioration and service life assumptions.

name a few. The conclusion of Picher's study (Picher (1997); Fraumeni and Picher, Appendix II) is that there has been very little change or very little unidirectional change from 1950 to the present in major quantifiable MDOT system features such as design speed, maximum grade, lane capacity and minimum width. Other characteristics of highways definitely have changed, but these are difficult to quantify with respect to the extent of quality improvement and the cost per unit of quality change.

MAINTENANCE

There are competing theories concerning whether maintenance should be included in the capital stock.[57] Some of the theories involve judgements about whether an asset should be considered as a whole, e.g. a car includes the car body, engine, brakes and tires, or whether an asset should be taken as the sum of its parts, e.g. the car body, engine, brakes and tires as all independent assets. If an asset is taken as a whole, it is more likely that an expenditure will be considered maintenance and therefore not part of capital stock, as compared to the case in which an asset is taken as a sum of its parts.[58] Other issues relevant to this topic are whether the maintenance has a life of greater than a year and whether the maintenance changes the life or durability features of the asset. On face value, the definition of maintenance expenditures as

> "...costs... required to keep highways in usable condition. The service life of a highway is not extended beyond the original design" (Highway Statistics 1995, p. IV-5)

suggests that maintenance should not be included in the capital stock.

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[57] BEA does not consider maintenance as investment.

[58] For example, according to BEA the mean service life of an automobile owned by an individual is 8 years and the mean service life of tires, tubes, accessories and other parts is 3 years (Fraumeni, 1997, Table 3, p. 18). If the automobile is taken as a whole, the mean service life would be 8 years and expenditures for tires would be considered maintenance expenditures. If the automobile were taken as the sum of its parts, expenditures for tires would be considered a capital outlay.

RECOMMENDATIONS FOR OTHER PUBLIC CAPITAL STOCK MEASUREMENT

PREFACE

Other public capital stock consists of the entire public stock less highway public capital stock. Figures 2-4 depict the relative size of other public capital stock. Note that GOPO is defined as Government Owned Privately Operated capital stock. The "wrong" concept, wealth capital stock, is used in the figures. A measure using the "right" concept, productive capital stock, will not be available until productive capital stock is constructed later in this project.

RECOMMENDATIONS

COVERAGE

Other public capital stock includes a diverse set of assets. Frequently analysts exclude military and GOPO stocks when the productivity of public capital stock is estimated.[59] Presumably, this exclusion is made because analysts have been unable to quantify the productivity of defense assets such as missiles, aircraft, tanks and ships. Other public capital stocks, excluding military and GOPO, consist of a wide variety of equipment stocks, building stocks, and specialized non-building structures such as sewer systems, water systems, and conservation and development assets. It is unclear whether the forthcoming BEA investment data will be available in categories corresponding to detailed service life and geometric rate of depreciation information.[60] As most analysts will continue to use BEA investment data to construct productive capital stock, the recommendation is that the level of detail be no greater than that allowed by the BEA investment data and service life information. In addition, it is proposed that little, if any, effort be directed towards determining an appropriate methodology for the construction of military and GOPO capital stocks.

DETERIORATION

There is limited information about asset deterioration of other public capital stock. However, if just the basic error of using the "wrong" concept, wealth capital, is corrected, measured other public productive capital stocks will be significantly different from BEA wealth stocks. Figure 5 illustrates the difference for non-residential stocks using a geometric rate of depreciation for productive capital stocks.[61] In 1925, the geometric

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[59] See, for example, Aschauer (1989) and Munnell (1990).

[60] See Fraumeni (1997) Table 3.

[61] Residential capital was not included in the comparison because residential investment is very small relative to nonresidential investment, only aggregate numbers are given by BEA, and lifetimes corresponding to unpublished detail have a wide range, e.g. from 20 to

productive capital stock is 13% higher than the BEA wealth capital stock; by 1994 it is 26% higher. The recommendation is that productive capital stock be calculated using a geometric rate of depreciation, with further asset specific investigation possible as part of a project extension.

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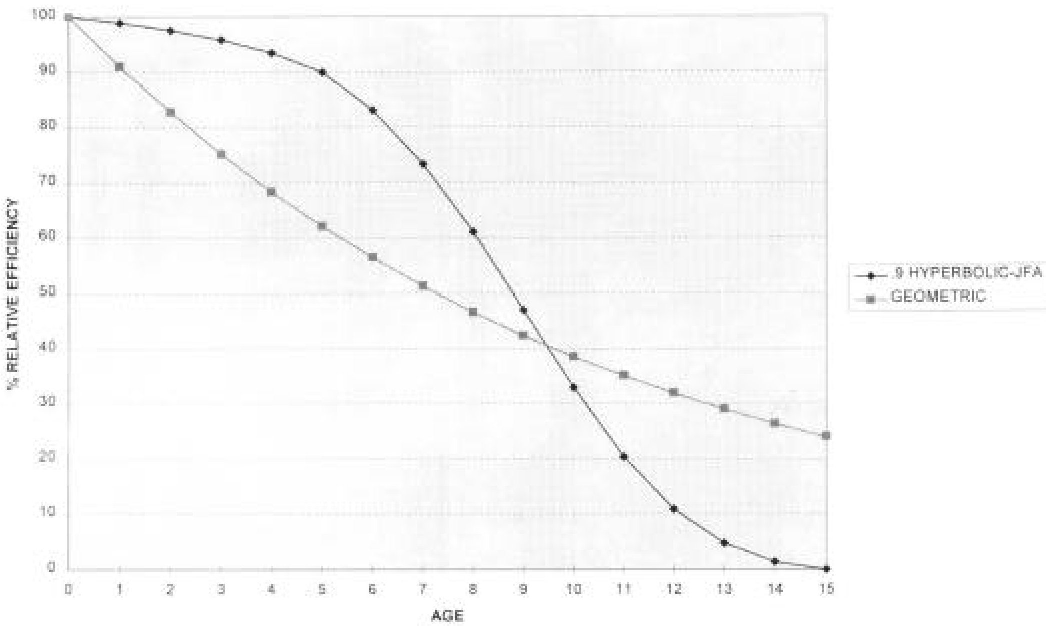
FIGURE 1



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.9 HYPERBOLIC-JFA
GEOMETRIC

APPENDIX I

DEFINITIONS

Benchmark. A benchmark is a reference point from which measurements can be made. Commonly a benchmark is used in the perpetual inventory method. The benchmark is typically set to an estimate of the capital stock in an initial year.

Capital is a durable asset. The convention is that any asset which is expected to last at least one year is called capital, if an asset is expected to last less than one year the asset is termed a consumption good.

Capital service flow is the productive input that flows from a capital good over a particular time period, e.g. from January 1, 1997 through December 31, 1997.

Capital stock is a measure of how much capital you have at a particular point of time, e.g. December 31, 1997.

Constant quality prices and quantities. Under the constant quality methodology, prices and quantities are adjusted when quality change occurs such that adjusted quantities at different points of time, e.g. 1960 versus 1990, have the same potential productive capacity per unit. The product of unadjusted price times quantity must equal the product of adjusted price times quantity. If the adjusted quantity is 25% higher than the unadjusted quantity, the adjusted price must be 20% lower than the unadjusted price. For example, if both unadjusted price and quantity are equal to 1.0 and the adjusted quantity is set to 1.25, the adjusted price must equal .8 (=1/1.25).

Deterioration is the decline in the potential productive services of an asset as it ages. Deterioration includes the effects of efficiency decline and retirements.

Efficiency decline is the decline in the potential productive services of an asset still in service as it ages.

Geometric deterioration. With geometric deterioration, the rate of deterioration is constant in every period. The rate of deterioration, d, is:

$$d = R/T,$$

where R is the estimated declining balance rate and T is the average service life of the asset.

Hyperbolic function. A hyperbolic function is a specific mathematical form:

$S(a)=(L-a)/(L-Ba), \quad 0<a<L \text{ or } a=0$

$S(a)=0, \quad a>L \text{ or } a = L$

where S(a) is the relative efficiency of an asset of age a, L is the service life, and B is the parameter allowing the shape of the curve to vary, set to .9 by JFA.

Investment, a flow measure, is the addition to the capital stock over a particular time period, e.g. from January 1, 1997 through December 31, 1997.

Net capital stock is estimated under the perpetual inventory method by summing investment and reducing the resulting total by an estimate of asset deterioration. The "net" concept is appropriate for productivity analysis.

Nominal value is the value of a good or asset enumerated in the dollars of the period of valuation, e.g. 1990 dollars are used to value assets purchased, sold or held in 1990. Frequently, nominal value is called current dollars or simply value.

Obsolescence is the loss in value of an old asset resulting from new asset quality improvement or other demand factors such as changes in income, tastes or preferences.

Perpetual inventory method. Under the perpetual inventory method, capital stock is estimated by summing investment to produce gross capital stock or by summing investment and reducing the resulting total by an estimate of asset deterioration to produce net capital stock.

Physical life is the number of years until an asset has zero efficiency or potential productive capacity.

Productive capital stock is the capital stock which has been adjusted for the effects of deterioration, e.g. efficiency decline and retirements.

Quality adjustments are made when new assets are significantly different from old assets. Quality adjustments affect the constant quality investment quantity and constant quality price of an asset.

Quality change is a term used when new assets are significantly different from old assets.

Retirements are assets withdrawn from service.

Service life is the number of years that an asset is kept in service or in use.

Straight-line function. With a straight-line function, efficiency decline is a constant percentage amount per period over the service life of the asset. In each period, the percentage efficiency decline is equal to 100/L, where L is the service life of the asset. For example, if the service life is 10, the asset declines in efficiency by the absolute amount of 10% per period. The efficiency sequence is 100%, 90%, 80%, 70%, 60%, 50%, 40%, 30%, 20%, 10%, 0%.

Wealth capital stock is the capital stock evaluated at its market value.

Winfrey retirement distributions were developed by Robley Winfrey (1967). Winfrey estimated and categorized retirement distributions based on assets retired in the 1920's and 1930's. Specific Winfrey retirement distributions, commonly distributions similar to a normal distribution with the mean service life as the central point, are frequently assumed to characterize retirement distributions of post-World War II assets.

APPENDIX II

SUMMARY OF MAJOR MDOT DESIGN CHANGES FROM 1950-PRESENT

Barbara M. Fraumeni and Gedeon G. Picher

Gedeon Picher identified major highway design changes implemented by the Maine Department of Transportation (MDOT) during the 1950s to the present.[62] In order to gain the necessary information, interviews were conducted with individuals from several organizations, including MDOT, FHWA, Maine Municipal Association, AASHTO, and its committees, as well as independent highway design engineers. In addition, relevant supporting materials were collected. The analysis focused on design standard changes and how these standards differ among the various components of the U.S. highway and road system. Federal Aid Highways were emphasized, but important features of State and Local facilities were included as well.

MDOT design standards from the 1950s to the present generally conform to AASHTO design standards. As such, the following discussion is relevant to any state which also adheres to AASHTO standards.

Picher's study finds that there is very little unidirectional change over the period considered in major geometric system features such as horizontal curvature, vertical curvature, maximum grade, lane capacity, and minimum lane and shoulder widths.[63] The horizontal curvature and maximum grade standards show little variation and those few variations that do occur are not consistent in direction. The 1994 lane capacity values for two-lane highways are essentially the same as previous values; the capacity of multi-lane highways is about 10% higher. The roadway minimum width specifications for two-lane, main, surfaced, rural highways for 1990 are essentially unchanged from the 1954 specifications and the 1994 values are very similar to the 1990 values. Recommended shoulder widths over the period, if anything, have narrowed slightly. Stopping sight distance was adjusted in the early 1960's, but has remained stable since then. As a result, vertical curve lengths increased.

From the 1960s through the 1980s, economic factors and aggregate material availability problems led to modifications in pavement thickness by the MDOT and its predecessor on Federal and State Highways. Prior to the advent of AASHO recommendations for the design of flexible pavement structures (dated 1965, but available in draft form in 1961), Federal Aid Highways were built with a 3" binder course with a 3" base course on either

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[62] Recent and anticipated changes in highway design and maintenance are described in MDOT 1995 and 1997 task force reports.

[63] The key documents on geometric design are the AASHTO write-ups for 1954, 1990 and 1994.

18" or 24" of gravel.   After that time, under the AASHTO procedures, 1" was deducted from the wearing surface on Federal and State Highways and the calculated thickness was rounded down to the nearest half inch when resurfacing. For resurfacing, the calculated thickness was rounded down to the nearest half inch. Since the late eighties, however, recommended thicknesses have been used.

Several changes, some of which have already begun, are expected to affect pavement design and features over the near future. These include the use of SUPERPAVE, the trend towards mechanistic pavement designs, and the adoption of new AASHTO design standards. The use of SUPERPAVE, which is just beginning in Maine, is expected to increase the life of new pavement by 5 years. Contractors are somewhat reluctant to make the investment necessary to produce SUPERPAVE until they are assured of a sufficient volume of continuing orders to justify the investment. Sometime after the year 2000 pavement design changes are expected as the AASHTO Pavement Design Guide, which has been substantially unchanged since 1961, is being revised, with the final draft available in 1999.

The Interstate System, launched in 1956, has distinct construction requirements which adhere to the highest standards. Pavement reliability values for Interstate and other National Highway System (NHS) categories are between 90-95% with a terminal serviceability of 3.1 PCR. In contrast, reliability values for collectors (non-NHS) are approximately 85%; terminal serviceability was 2.5 for former Federal Aid Primary roads and 2.0 for lesser roads.

State Aid standards are used for non-Federal collector roadways. Where appreciable flows of heavy trucks are anticipated, AASHTO pavement design procedures are followed.

In accordance with the provisions of the Intermodal Surface Transportation Efficiency Act (ISTEA), a tightening of pavements and shoulders will occur on non-NHS highways in Maine.

Few communities in Maine have pavement/design/construction standards. The standards that exist vary widely and are set by each town individually as the Maine Municipal Association does not promulgate standards. Nonetheless, many communities refer to MDOT specifications when designing and constructing roads. Arterial highways often have involvement of MDOT; at times, collectors may also have MDOT involvement. A Town Road Improvement Program (TRI) was in place until about 1980.   This program provided funding assistance to communities. TRI standards were less stringent than those for the State Aid System were. The Program resulted in the building of only gravel roads.

MDOT has consistently adopted methods from the forefront of bridge technology, using traditional, yet leading edge bridge designs. For example, it changed to HS25 when HS20 was still the standard. The employment of Load Resistance Factor Designs (LRFD) also serves as an example of MDOT embracing leading edge designs.

Cost and design considerations have resulted in a number of specification changes over time. The high cost of hazardous material containment procedures has resulted in a substitution away from materials which need painting, e.g. concrete and weathering steel. Membrane waterproofing for bridge decks has been provided since the 1970s. Other design changes have been implemented to minimize corrosion due to birds and precipitation. The compressive strength of some types of concrete has increased four-fold, but design has remained traditional with respect to allowable stresses. Fatigue has been a consideration in design since the early 1970s and is well controlled. In the unusual cases in which fatigue has been a problem, it has generally resulted from actual traffic loadings diverging upwards from those anticipated during design. There have been some design issues, e.g. in continuous bridges and pin and link truss designs. In general, prestressed and continuous designs provide more economic designs than traditional designs. Jersey barrier railings, which are as high as former guardrails, are being provided on new bridges. Finally, the cost of environmental mitigation is now included in systematic design processes.

Some changes are occurring concurrently with or as a result of ISTEA implementation. Reductions in overall width requirements lessens both right-of-way and environmental costs, expedites the project development process and concentrates capital expenditures between the extreme shoulder lines. Approximately 65% of expenditures are now directed between the extreme shoulder lines; previously this figure was approximately 40%. The FHWA no longer reviews plans for highways not within the NHS.[64] Plans for many of these roads were reviewed in the past under Federal Aid Primary, Federal Aid Secondary, and Federal Aid Urban funding programs. Federal funding continues to require conformation to AASHTO design standards for the NHS. Accordingly, NHS highways are still constructed to AASHTO standards, but non-NHS highways need not be. Traffic volumes tend to be the most important criteria for determining roadway configurations (MDOT 1995). The realization that reconstruction of non-NHS highways built before 1955 may never be possible has led to changes in maintenance and capital expenditures. For example, a reduced number of pavement treatments are being used in conjunction with streamlined engineering and inspection standards to realize economies of scale. Of the 8,300 miles of State and State Aid Highways, 6,600 miles have been constructed or reconstructed to modern standards; it is unlikely that the remaining 1,700 miles, not part of the NHS, will be reconstructed to modern standards.

MDOT is sensitive to highway and road management financial issues. A recent (January 1997) task force suggested that treatments for segments of highways address the specific distresses found in each individual segment, rather than using the most extensive treatment over the entire length of the project. Reducing overall width requirements is considered the most effective way to introduce cost savings through standards revision. For example, cost savings are achieved through the use of modern wider pavers which lay down enough

[64] The NHS/non-NHS categorization scheme was created by ISTEA.

width for both pavement and shoulders (if narrowed), eliminating the necessity for additional passes for shoulders alone.

There were a number of concerns expressed about pavement evaluation and management programs, which are both of more significance under budgetary pressures. Pavement design is based on one index, while project selection decisions are determined by another index. Empirical relationships linking state pavement condition surveillance data with usage do not fully account for the percentage of trucks and the loading and axle characteristics of trucks. No weigh-in motion data has been collected since the late 1980s. However, MDOT recently purchased a falling weight deflectometer and a portable core drill and re-initiated weigh-in motion programs to aid in pavement assessment and management.

Because of the availability of Federal money, projects on Federal Aid Systems (basically now the NHS) were designed to better standards. The higher standards affected slope ratios, guardrails, intersections, design speeds, shoulder paving, and railroad crossing grade separations. With scarce state dollars, the facilities on the few highway improvement projects funded only with state aid are generally designed for minimum safety conditions under reduced minimum design standards and design speeds. Desirable additions which are not critical are usually bypassed.

In recent years, corridors have generally been designed for a uniform design speed. Designers seek to avoid high construction/reconstruction costs associated with excavation through massive granite formations which may be necessary with higher uniform design speeds along a given route. Intrusion into pristine environments, particularly coastal environments, is also avoided in design as much as possible.

Safety was held up as a prime design and operating criterion by both the State and Federal personnel interviewed. Federal officials have actively pursued safety goals with AASHTO and the States and have achieved mutually acceptable adjustments in standards and guidelines from time to time.

There have been a number of other changes over the period 1950 to the present which are difficult to quantify. These changes include improved drainage features and components, crash-tested guardrails, full shoulders on bridges, streamlined preconstruction and construction engineering, better materials to avoid moisture trapping and frost problems, provision of a clear zone on Interstate roadsides to eliminate deadly fixed objects, longer acceleration lanes and more gradual curves on limited access roads, other guardrail improvements, and improved signing, interchanges, intersections and traffic maintenance. In addition, computers have been integrated into many aspects of the design and transportation management and delivery systems.

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CHAPTER III

RECOMMENDATIONS FOR FURTHER WORK

SUBMITTED TO THE SELECT ADVISORY COMMITTEE

OCTOBER 27, 1998

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INTRODUCTION

While accurate capital stock measures are recognized as a critical component of economic studies examining the relationship between highway investments and private sector performance, an improved understanding of this is achievable through further data development. Future work recommendations are classified within six broad categories: 1) highway capital service flows, 2) state estimates of highway capital stock, 3) methodological guidelines, 4) other transportation capital stocks and capital service flows, 5) Long-Term Pavement Performance (LTPP), and 6) price indices. This list incorporates measures deemed important by the Select Advisory Committee (SAC) at their October 27, 1998 meeting.

SPECIFIC RECOMMENDATIONS FOR FURTHER WORK

HIGHWAY CAPITAL SERVICE FLOWS

Capital service flows are the productive inputs that flow from capital stock. Previous studies of highway productivity used capital stocks as proxies for capital service flows (Aschauer, 1989; Munnell, 1990; Nadiri and Mamuneas, 1996). Although flows and stock are clearly related as there cannot be a flow without a stock, such measures are distinct for several reasons. These include, but are not limited to, intensity of use and type of use. For example, a machine may be idle or a building may be vacant. Under these circumstances, there is no productive input flowing from the stocks. A comparable example for highways is a desolate road leading to a ghost town. In addition, the productive input flowing from a stock depends upon its use. A personal computer might be used by children to play computer games or used by a business to maintain its accounting records. Clearly, in the latter case the productive input is greater than in the former. A comparable example for highways is an interstate used primarily by passenger vehicles versus one used primarily by five-axle combination vehicles. In sum, stock measures potential productive services and capital service flows measure actual productive services.

The primary difficulty with measuring capital service flows from highways or any public good is the absence of income flows, including profits, arising from the activities of governments. In the private sector, capital service flows may be estimated from income flows using the cost of capital approach pioneered by Jorgenson (1963). Without this possibility for public goods, capital service flows would have to be derived from proxies for the relative marginal products of various highway stocks. While some presently available information utilized in the construction of the stocks could be used, additional data would have to be collected. In addition, a theoretical and methodological basis for the construction of capital service flows for highways would need to be fully developed.

STATE HIGHWAY CAPITAL STOCKS

The Fraumeni project developed national estimates of highway capital stocks. Economists commonly examine the contribution of highways to productivity at the state level (Bell, and McGuire, 1994, 1997/Dalenberg and Eberts, 1994; Morrison and Schwartz, 1996). Accordingly, it would be a worthwhile endeavor to develop state estimates comparable to the existing national estimates. These state stocks would incorporate the significant methodological improvements of the national estimates. Previous researchers have identified additional methodological difficulties (Dalenberg and Eberts, 1994; Holtz-Eakin, 1991, 1993) that must be accounted for in the construction of state estimates.

METHODOLOGICAL GUIDELINES

Researchers will inevitably adopt assumptions used in the construction of the Fraumeni national highway capital stocks in their own work. Most of these researchers will not undertake the significant efforts necessary to replicate the methodology used in the Fraumeni study, rather, they will attempt to build an approximate measure of highway capital stock. Most of the major studies of highway or public capital stock productivity heretofore adopted the Faucett methodology (Faucett and Scheppach, 1974) to construct capital stock estimates. It is expected that the Fraumeni study will be used in the same way. As a result, it is imperative to develop methodological guidelines for the adoption of Fraumeni assumptions in an effort to promote accuracy and consistency in the future use of the research pursued herein. For example, it would be necessary to determine which truncated hyperbolic function best mimics the actual Fraumeni efficiency functions and how best to benchmark capital stock estimates.

OTHER TRANSPORTATION CAPITAL STOCKS AND CAPITAL SERVICE FLOWS

The relationship between any type of transportation investment and economic growth is of primary interest. Comparable estimates of all transportation capital stocks and capital service flows should be developed to assist future research on this topic. Jack Faucett Associates undertook such a study (Faucett and Scheppach, 1974), but the study is dated and its methodology is flawed. In addition, the study focused on capital stocks rather than capital service flows, but the latter are preferred for analysis of productivity and economic growth.

LONG-TERM PAVEMENT PERFORMANCE

The Department of Transportation recently completed an LTPP study. The SAC concluded that at some point it would be desirable to incorporate information from this study into the methodology used to construct highway capital stocks.

PRICE INDICES

The SAC concluded that price indices should be the focus of future research. The Fraumeni project did not investigate the methodology used in constructing Bureau of

Economic Analysis (BEA) highway deflators. The appropriateness of the BEA deflators for all components of highway capital stock, e.g. pavement, grading, structures and right-of-way, was also discussed along with the likelihood that state specific deflators would be needed in conjunction with estimates of state highway capital stock.

CONCLUSION

These recommendations for further study convey a sense of the substantial amount of work that remains to be done on capital stocks and capital service flows for highways and other transportation assets. Although much has been accomplished and improved upon with the Fraumeni highway capital stocks, it is hoped that further progress will be made in the efforts to improve our understanding of the sources of economic growth.

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CHAPTER IV

DOCUMENTATION FOR PRODUCTIVE HIGHWAY CAPITAL STOCK CONSTRUCTION

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INTRODUCTION

This documentation is sufficiently detailed to allow researchers to replicate the construction of productive highway capital stock. A list of abbreviations utilized in the main body of the text is contained in Appendix I to this documentation. Appendix II lists all Fraumeni data sources by Roman numeral section number. The development of the pavement AASHTO curves by Gedeon Picher of Mainesurf, Inc. is described in Appendix III. Appendix IV lists all Picher computer files. Appendix V details how AADT and traffic composition estimates are constructed. Appendix VI includes the original AADT curve and the equation for computing axle and axle group ESALs.

I. TOTAL CAPITAL OUTLAY

The majority of the capital outlay data comes from Table HF-210, "Funding for Highways, All Units of Government, 1921-1995," p. IV-7 – 38 of HST95. This table is available from the Office of Information Management, Department of Transportation web site and in printed form. The data is in current or nominal dollars.[65]

Under capital outlay, the "Total" category "On State-Administered Highways" less Interstate capital outlays are allocated to State.[66] Capital outlay for the "Total" category "On Locally Administered Roads" and "Not Classified by System" are allocated to Local.[67] The Interstate numbers for 1956-1986 are from HST85, Table HF-221, "Estimated Capital Expenditures by Federal Systems and Expending Agencies, 1956-1986," pp. 95-99, contained in the Excel file HF221ROW.xls. The Interstate numbers for 1987-1995 are from HST95, Table SF-212A "State Capital Outlay on Arterials and Collectors, by Improvement Type, 1981-1995," p. IV-97.[68] The Interstate number for 1996 is from HS96 Table SF-12, "State Highway Agency Capital Outlay and Maintenance - 1996, Total for All Areas - Classified by Functional System," p. IV-79. Once the Interstate capital outlay series is developed for 1956-1996, a State other than Interstate series is created.[69] The worksheet for creating the final capital outlay series is at the end of the Lotus file for HF-210, the main body of the latter pulled off the web.

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[65] All capital outlay source data is in current or nominal dollars, capital stock data is in constant dollars unless specified otherwise.

[66] Unless otherwise noted, the term "State" refers to Non-Interstate State.

[67] Unless otherwise noted, the term "Local" refers to other than Interstate or State.

[68] There are two SF-212A files, one in Lotus (SF212A.wk4) and one in Excel (SF212A.xls).

[69] The first capital outlays on the Interstate system occurred in 1956.

II. RIGHT-OF-WAY OUTLAYS

Right-of-way (ROW) outlays for 1956-1986 are collected from HST85, Table HF-221, "Estimated Capital Expenditures by Federal Systems and Expending Agencies, 1956-1986," pp. 95-99. The procedures used to estimate ROW for other years varied depending upon visual inspection of the data and the reasonableness of the results produced by alternative methodologies.

For Interstates, ROW outlays for 1987-1995 are estimated via several steps. First, outlays are collected from HST95 SF-212A, "State Capital Outlay on Arterials and Collectors," p. IV-97. Second, from SF-212A the percentage that new construction outlay is of capital outlay less bridge, ROW and engineering outlay is calculated. There are five years of overlap between the ROW HST85 Table HF-221 data and the HST95 SF-212A outlay data. The data for 1981-2 is not used because data for these years is frequently suspect.[70] Next, an ordinary-least-squares regression is run in TSP (see FHWA1.txt and FHWA1.lis) for 1983-1986 with the percentage ROW outlay is of capital outlay as the dependent variable, the percentage new construction outlay is of capital outlay less bridge, ROW and engineering outlay as the independent variable and an intercept term. The coefficients from this regression are used to estimate the percentage that ROW is of capital outlay. These percentages are then multiplied by the capital outlay data described in Section I above to determine ROW expenditures for 1987-1995.

For State, the 1921-1955 ROW outlay is estimated by assuming that the average percentage ROW is of capital outlay for 1956-1969 is constant over the earlier years. The procedure used to estimate the 1987-1995 data parallels that used for Interstates. An ordinary-least-squares regression is run in TSP (see FHWA3.txt and FHWA3.lis) for 1983-1986 with the percentage ROW outlay is of capital outlay as the dependent variable, the percentage new construction outlay is of capital outlay less bridge, ROW and engineering outlay as the independent variable and an intercept term. The coefficients from this regression are used to estimate the percentage that ROW is of capital outlay. These percentages are then multiplied by the capital outlay data described in Section I above to determine ROW expenditures for 1987-1995.

For Local, information from HST95 LGF-202, "Disbursements of Local Governments for Highways, 1921-1994," p. IV-108 is used to estimate ROW outlay for 1921-1955 and 1987-1995. This computer file version of this table is a Lotus file, LGF202.wk4. LGF-202 capital outlay is outlay by local governments. The HF-210 capital outlay used in this project is capital outlay on locally administered roads by any level of government. As a result, LGF-202 ROW outlay cannot be used directly for ROW outlay. Accordingly, all estimates are adjusted by the average percentage LGF-202 ROW is of HF-221 ROW. LGF-202 ROW outlays is available only from 1931. For 1921-1929, ROW is estimated as

[70] Unless noted otherwise, 1981-1982 data from HST or HS tables beginning in 1981 or 1982 are not used.

LGF-202 capital outlay multiplied times the 1940-1949 average percentage that LGF-202 ROW is of LGF-202 capital outlay, divided by the 1956-1969 average percentage that LGF-202 ROW is of HF-221 ROW. The 1940-1949 average is used in the numerator instead of an average from earlier years to avoid replicating the atypical relationships of the Depression years. The average used in the denominator is calculated from 1956 as 1956 is the first year of the HF-221 data. For 1930, ROW is estimated as LGF-202 capital outlay multiplied times the 1931-1934 average percentage that LGF-202 ROW is of LGF-202 capital outlay, divided by the 1956-1969 average percentage that LGF-202 ROW is of HF-221 ROW. For 1931-1955, ROW is estimated as LGF-202 ROW divided by the 1956-1969 average percentage that LGF-202 ROW is of HF-221 ROW. For 1987-1994, ROW is estimated as LGF-202 ROW divided by the 1970-1986 average percentage that LGF-202 ROW is of HF-221 ROW. For 1995, ROW is estimated as HF-210 capital outlay times the 1990-1994 average percentage that estimated ROW is of HF-210 capital outlay.

III. DEFLATORS

The Bureau of Economic Analysis (BEA) implicit deflators are used to convert current or nominal dollars to constant dollars.[71] The deflator is derived by dividing BEA historical cost investment by the chained quantity index for highways and streets. One deflator is derived for Federal, another for State and Local. All outlays are converted before capital stocks are created, as a result all capital stocks are in constant dollars. The deflator series for the most recent BEA investment data (BEA, 1997) begin in 1925. Since a deflator is needed beginning in 1921, implicit deflators are derived from the previous BEA investment data (BEA, 1993), which is available from 1918-1994 for Federal and 1881-1994 for State and Local. In both cases, the deflators are normalized to 1992, the bench year for the most recent BEA data. This procedure produced reasonable results for the 1921-1924 Federal deflator series, but not for the State and Local deflator series. This may be because the investments are very small in the early years such that rounding up or down can significantly affect the implicit deflators. As a result, the 1921-24 State and Local deflator is recalculated. In HIGHI96.xls, the State and Local deflators for years prior to 1925 are estimated backwards from 1924 to 1921. They are estimated by the ratio of the Federal deflator for the year to be estimated (e.g. 1924) to the Federal deflator for the next year (e.g. 1925) times the State and Local deflator for the next year (e.g. 1925).

[71] The BEA (1993) data is contained in the computer files 11IHI.txt and 12ICQ.txt. The BEA (1997) data is contained in the computer file WEALTH.txt.

IV. OUTLAYS FOR NEW CONSTRUCTION AND RECONSTRUCTION

Outlays excluding those for ROW are separated into outlays for new construction and reconstruction versus those for Other types of capital outlays.[72] This is done because the percentage of pavement, grading and structures differ significantly for new construction and reconstruction versus Other.[73]

Since all except for a small percentage of Interstates were constructed beginning in 1956 or after,[74] it is assumed that all nonROW Interstate capital outlays from 1956-75 are for new construction or reconstruction. Since the highway capital stock estimates relate to productive efficiency and no new Interstate is completed and open-to-traffic until approximately 1958, all capital outlays are lagged by two years during the initial construction or reconstruction phase, 1956-1975. In addition, it is assumed that all outlays beginning in 1976 are for Other. Although these are simplifying assumptions, the evidence is that they closely approximate reality.[75]

For State and Local, percentages of capital outlay representing new construction or reconstruction are estimated for the whole period—1921-1995. The percentage that new construction or reconstruction is of total capital outlay is estimated from data in HST95 SF-212A, "State Capital Outlay on Arterials and Collectors," p. IV-97. The actual percentages are used from 1983-1995; the average 1983-1995 percentage is used for all previous years. For Local, it is assumed that the percentage for new construction and reconstruction is equal to one-third of the State percentage. This figure is a rough approximation determined by looking at HST95 HM-210 "Public Road and Street Length, 1921-1995, Miles by Jurisdiction, National Summary," p. V-6, contained in the computer file HM210.wk4. For 1952-1965, years in which miles are added to roads under State and Local, County, Town and Municipal Control, the percentage of total miles for the Local, County, Town and Municipal category are 36.51% of the State category. The percentage is taken to be one-third, instead of 36.51%, as miles decreased more commonly for the Local category than for the State category.

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72 The word 'Other' will be used to refer to 'other than new construction and reconstruction'.

73 See the section below on the percentage breakout between pavement, grading and structures.

74 See Section VI for information on the Interstate benchmark.

75 America's Highways, 1776-1976 (Federal Highway Administration, 1977, pp. 481-2) states that in 1974 36,000 of the 42,500 mile Interstate System was in service, with another 2,800 under construction and only 400 miles on a "non-progress" status. The status report dated September 30, 1976 stated that of the 37,869 miles open to traffic, 24,242 miles required minor improvements (p. 473).

V. PERCENTAGE SPLIT BETWEEN PAVEMENT, GRADING AND STRUCTURES

The percentage split between pavement, grading and structure outlays depended essentially on the 1997 Cost Allocation Study (CAS) worksheet (Jacoby, undated).[76] This worksheet, reproduced below, is used to allocate total pavement and grading capital outlays for new construction and reconstruction versus Other between pavement and grading. To use the 1997 CAS splits, the percentage that structure outlays are of total capital outlays, excluding ROW, had to be determined. To determine the percentage that structures are of total capital outlays excluding ROW, the simplifying assumption is made that all structures are bridges. Differential bridge outlay splits are determined for new construction and reconstruction versus Other. The creation of new construction and reconstruction versus Other categories is validated by the typically significantly different percentages in the 1997 CAS for new construction and reconstruction versus restoration and rehabilitation and resurfacing. Different percentages are also created for Interstate, State and Local. The differential 1997 CAS worksheet data is reproduced below.

1997 CAS Grading/(Grading+Pavement)

	Rural Interstate	Rural Other Principal Arterial	Rural Minor Arterial	Rural Major Collector	Rural Minor Collector	Rural Local
New Construction	0.2580	0.3760	0.3760	0.3070	0.3070	0.2750
Reconstruction	0.2730	0.1990	0.1990	0.2430	0.2430	0.2510
Restoration & Rehabilitation	.01735	0.1310	0.1310	0.1500	0.1500	0.1500
Resurfacing	0.0740	0.0630	0.0630	0.0570	0.0570	0.0490

	Urban Interstate	Urban Freeways & Expressways	Urban Other Principal Arterial	Urban Minor Arterial	Urban Collector	Urban Local
New Construction	0.2780	0.3680	0.3680	0.3680	0.2680	0.2680
Reconstruction	0.2150	0.2710	0.2710	0.2710	0.2640	0.2640
Restoration & Rehabilitation	0.1075	0.1950	0.1950	0.1950	0.1930	0.1930
Resurfacing	0.0000	0.1190	0.1190	0.1190	0.1220	0.1220

For new construction or reconstruction, it is assumed that the structure percentage of Interstate capital outlays excluding ROW is a weighted average of the 1923-1931 State

[76] The original source of the worksheet data is unknown.

Eastman Report figure, 16.5%, (Section of Research, 1940, p. 58)[77] and the JFA figure, 21.5% (Faucett and Scheppach, 1974, Volume I, Table 3.3, p. 3-38).[78] This average is 19%. According to the Eastman Report (p. 58) grading is 30.6% of pavement plus grading for state highways in 1923-31. Weighting figures used in the1997 CAS by the 1994 center lane miles for rural and urban Interstates (HST95, Table HM-220, "Public Road and Street Length, Miles by Functional System, National Summary," p. V-9) resulted in an estimate of 26.4%. Most Interstate construction occurred in the late fifties, through the sixties, and into the seventies, a time period intermediate between the Report period and the 1997 CAS period. Accordingly, a weighted average of the Eastman Report figure and the 1997 CAS figure (((30.6+26.4)/2=28.5%) is used for the percentage that grading is of pavement plus grading for new construction or reconstruction. This results in an estimate of 23.1% for the percentage that grading is of pavement plus grading plus structure outlays (.285*(1.00-.19) =.231).

For Other, the structure percentage of Interstate capital outlays excluding ROW is calculated based on information in HS95, Table FA-6, "Obligation of National Highway System and Surface Transportation Program Funds by Improvement Type, Fiscal Year 1995," p. IV-38.[79] The percentage bridge outlays are of new construction and reconstruction non-bridge outlays is derived from the structure percentage described above (.19/(1.00.-.19)=.23) in the Other calculations. This percentage, 23%, is multiplied times new route and reconstruction obligations to estimate bridge obligations associated with new routes and reconstruction. Obligations for other than new route and reconstruction including bridges is estimated as total obligations minus new route, reconstruction and bridge obligations associated with new routes and reconstruction. Bridge obligations for other than new route and reconstruction is estimated by deducting the estimated new route and reconstruction bridge obligations from total bridge obligations. Finally, the percentage that other than new route and reconstruction obligations is of other than new route and reconstruction including bridges obligations is calculated. It is equal to 14.5%. This percentage is employed as the percentage that Interstate structure outlays are of total capital outlays, excluding ROW, for Other.

To calculate the percentage that Interstate Other grading is of pavement plus grading plus structures, additional information from Table FA-6 is employed. This data and the calculations are included in INTER.xls. It is assumed that the percentage that grading is of pavement plus grading for major widening is 50% of the 1997 CAS percentage for reconstruction and 50% of the 1997 CAS percentage for restoration and rehabilitation. The 1997 CAS percentage for restoration and rehabilitation is used as the percentage for minor widening. The 1997 CAS percentages are then weighted by the FA-6 obligations to

[77] This report will be referred to as the 'Eastman Report'.

[78] This report will be referred to as 'JFA'.

[79] The calculations based on FA-6 described in this section are detailed in the Excel file BRIDGE%.xls.

derive the percentage that grading is of pavement plus grading outlays. The percentage that grading is of pavement plus grading and structures is equal to the percentage that grading is of pavement plus grading only divided by (1-.145).[80] The percentage that pavement is of pavement plus grading plus structures is equal to 100 minus the grading and structure percentage.

The procedure employed to estimate the State percentages for pavement, grading and structures parallels the procedure used for Interstate Other.

The procedure employed to estimate the Local percentages for pavement, grading and structures parallels the procedure used for State and Interstate Other with one modification. For new routes and reconstruction, the percentage that bridge obligations are of pavement plus grading obligations is set equal to the Interstate percentage for the same times the ratio of the percentage Local bridge obligations are of total Local obligations to the percentage Interstate bridge obligations are of total Interstate obligations.[81]

VI. BENCHMARKS

Capital stock benchmarks are needed in 1958 for Interstate and 1921 for State and Local.

The Interstate benchmark represents highways transferred to the Interstate System from the State system at the inception of the Interstate system. According to America's Highways, 1776-1976 (Federal Highway Administration, 1977, p. 478) 2,102 miles of toll roads had been incorporated into the Interstate system as of August 21, 1957. According to HST95 Table HM-215 "Public Road and Street Length, 1923-1995, Miles by Federal-Aid Highways, National Summary", p. V-7, this represents .94% of the 235,114 miles of Primary Highway System which existed in 1955 just prior to the establishment of the Interstate System. Therefore, .94% of the State capital stock is transferred to the Interstate System as of 1958. This transferred stock is deteriorated as it would have been had it remained part of the State System.

The Eastman Report is the source for State and Local 1921 benchmarks. Calculations, relevant data, and documentation are in BENCH.xls. The Eastman Report calculates the cost of constructing roads by 10 road types in existence in 1921. This is estimated by multiplying the average cost per mile of Federal Aid roads in 1917-24 times the State or County and Local mileage in 1921. For County and Local, only structure cost is included as part of capital cost for the three lowest road types: Sand, Clay and Top Soil,

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[80] .145 is the percentage that structure outlays are of total capital outlays, excluding ROW; see the previous paragraph.

[81] See INTER.xls, STATE.xls and LOCAL.xls for computations related to the pavement, grading, and structures splits.

Nonsurfaced Improved and Nonsurfaced Unimproved. For State, only structure cost is included as part of capital cost for Nonsurfaced Unimproved.

State and County and Local roads are adjusted for differences in quality between these roads and Federal roads and roads built before 1921 and those built in 1921. For high type State roads an explicit quality adjustment is given, equal to 1.5625%. A number of assumptions are made in this project to estimate other quality adjustments. For lower type State roads, no explicit quality adjustment is given in the Eastman Report although a price plus quality adjustment is given. Accordingly, it is assumed that the proportion of quality reduction is double the proportion of quality reduction for the overall price plus quality reduction for high type roads. The quality adjustment for lower type State roads is calculated in two steps. First, the ratio of Eastman Report price plus quality adjustment for high type roads to the Eastman Report price plus quality adjustment for low type roads is calculated (=.50/.35=1.428571). Second, the low type quality adjustment is estimated by multiplying this ratio times the State quality adjustment times two (=1.5625*1.428571*2=4.4642%). The quality adjustment for Miscellaneous roads is a weighted average of the adjustments for high type and low type roads, the weights corresponding to the mix of high type and low type roads in the implicitly in the Eastman Report category Miscellaneous.

No explicit quality adjustment for County and Local roads is given in the Eastman Report, although a price plus quality adjustment is given. Accordingly, the ratio of the Eastman Report State price plus quality adjustment (66.7% for high type roads, 50% for low type roads) to the County and Local price plus quality adjustment (35% for high type roads, 25% for low type roads) is employed to revise the State quality adjustment. The quality adjustment so calculated for County and Local high type roads is 1.9057 times the State quality adjustment; the quality adjustment for County and Local low type roads is 2 times the State quality adjustment. Accordingly, the quality adjustment for County and Local high type roads is 2.297769% (=1.428571%*1.9057); the quality adjustment for County and Local low type roads is 8.9284% (=4.4642%*2.0). The quality adjustment for Miscellaneous County and Local roads is again estimated using the implicit weights in the Eastman Report, paralleling the treatment for Miscellaneous State.

These calculations produce a quality adjusted 1921 benchmark capital stock that has not been adjusted for deterioration.

Capital stocks are deteriorated using the methodology applied to post-1921 capital stocks. 1921-1940 State and Local efficiency functions and Eastman Report service lives are utilized (tables, pp. 59, 69).

VII. PAVEMENT AASHTO CURVES

The development of the pavement AASHTO curves by Gedeon Picher of Mainesurf, Inc. is described in Appendix III. AASHTO curves are a Pt or PSI versus ESAL relationship.[82] Picher converted the relationship of Pt versus ESALs to the relationship of Pt versus time, the latter needed for the development of efficiency functions. Two Interstate relationships are developed, the first covering the time period 1958-1977 and the second covering the time period 1978-1997. Five relationships each are developed for State and Local: 1921-1940, 1941-1960, 1961-1980, and 1981-2000. Information on AADT and traffic composition was constructed by a research assistant working for Barbara Fraumeni as detailed in Appendix V. The data sources are HS, various years, Table HM-57, "Average Daily Traffic - Rural – Year," pp. V-55 – 56 in HS95, HS, various years, Table HM-57, "Average Daily Traffic – Urban – Year," pp. V-57 – 58 in HS95, HST95, Table VM-201, "Annual Vehicle Distance Traveled in Miles, 1936-1995, by Vehicle Type and Highway Category," p. V-11 – 14. The files containing data collected from these tables and the calculations are contained in RURAL.xls and URBAN.xls for Interstate and RURAL2.xls and URBAN2.xls for State on the Picher computer disks. The final results of Picher's work is listed in INTER.xls, STATE.xls and LOCAL.xls.[83]

As the relationship between PSI and time is needed for whole number years, e.g. 1,2,3,…20, the Picher results are fitted with a curve to determine the PSI values for whole number years. The equations, estimated in Excel, and the corresponding R-squares, are as follows:

Interstate

1958-1977 y = 6.4878x3 - 57.362x2 + 141.8x - 64.256
$R^2 = 0.9999$

1978-1997 y = 3.5089x3 - 23.697x2 + 16.3x + 89.69
$R^2 = 0.9999$

State

1921-1940 y = 5.8013x5 - 91.328x4 + 571.08x3 - 1776.6x2 + 2743.7x – 1657.7
$R^2 = 1$

1941-1960 y = 1.3337x5 - 16.438x4 + 72.652x3 - 128.83x2 + 35.257x + 113.78
$R^2 = 0.9997$

---

[82] The abbreviations are as follows: Pt represents terminal serviceability, PSI represents Present Serviceability Index and ESAL represents Equivalent Single-Axle Load. The final AASHTO curves utilized to develop efficiency curves are denoted in terms of PSI vs. time.

[83] The results are located at the top of the INTER58, STATE21 and LOCAL21 worksheet respectively for Interstate, State and Local.

1961-1980 y = -3.403x5 + 57.531x4 - 380.64x3 + 1233.7x2 - 1975.4x + 280.2
$R^2 = 1$
1981-2000 y = -0.9638x5 + 17.762x4 - 125.74x3 + 432.87x2 - 745.37x + 542.92
$R^2 = 1$

Local
1921-1940 y = 3.5381x5 - 51.294x4 + 291.69x3 - 817.35x2 + 1128x - 592.63
$R^2 = 0.9999$
1941-1960 y = 2.5091x5 - 37.487x4 + 219.66x3 - 633.63x2 + 896.23x - 475.86
$R^2 = 0.9996$
1961-1980 y = 2.1727x5 - 31.138x4 + 175.1x3 - 486.06x2 + 663.14x - 334.22
$R^2 = 1$
1981-2000 y = 1.587x5 - 22.983x4 + 131.2x3 - 370.35x2 + 509.98x - 251.21
$R^2 = 1$

where y is the age of the asset, e.g. 0,1,2,..20, and x is the PSI. The final PSI versus whole year relationships are listed in the worksheets INTER58, INTER78, STATE21, STATE41, STATE61, STATE81, LOCAL21, LOCAL41, LOCAL61, and LOCAL81 in the corresponding Excel files INTER.xls, STATE.xls and LOCAL.xls.[84]

[84] All results described in this and later sections specific to 1958, 1978, 1921, 1941, 1961, and 1981 initial years are given in the corresponding listed worksheets and Excel files.

VIII. PAVEMENT EFFICIENCY CURVES

Once the PSI versus whole relationship is known, there are four remaining steps to estimating an efficiency curve for pavements:

1) convert PSI-AASHTO to PSR-HERS,[85]
2) calculate the time cost due to the loss in efficiency from PSR induced lower speeds,
3) calculate the vehicle operating cost due to the loss in efficiency from PSR induced changes, and
4) calculate the efficiency percentages.

Calculations for step 1-4 are contained in INTER.xls, STATE.xls and LOCAL.xls in the corresponding year worksheets.

1) CONVERT PSI-AASHTO TO PSR-HERS

Since AASHTO and HERS use different pavement condition indicators, it is necessary to convert one to the other. The translation equation for flexible pavements is:[86]

$$PSR = 5.0 - 3.5 * (4.2 - PSI)/2.7,$$

where PSR is the abbreviation for present serviceability rating.[87]

2) CALCULATE THE TIME COST DUE TO THE LOSS IN EFFICIENCY FROM PSR INDUCED LOWER SPEEDS

The design speed when PSR is at its maximum is needed to calculate the loss in efficiency from PSR induced lower speeds. For Interstate and State, this design speed is assumed to be 70 mph, for Local it is assumed to be 65 mph. Note that these design speeds reflect the

[85] HERS denotes the Highway Economic Requirement System. See Jack Faucett Associates (1971) for a description.

[86] This equation was derived by Gedeon Picher of Mainesurf, Incorporated. Picher discussed the form of this equation with Douglas Lee and others at the Volpe National Transportation Systems Center and consulted the HERS Technical Report. Picher utilized two constraints in deriving the given equation: AASHTO's 4.2 initial PSI being equated with the 5.0 initial PSR in HERS as the top rating achievable and the two scales being numerically equal at Pt= 1.5.

[87] The efficiency curve for flexible pavements is utilized for all roads whether they are surfaced with Portland Concrete Cement (PCC), some other material, or unsurfaced. A quality adjustment is developed as part of this to reflect the changing composition of the types of roads and highways in the United States. See Section XI of this data documentation for further information.

effect on pavement only, they do not reflect safety conditions or other considerations other than pavement conditions.

The speed equation utilized for all types of vehicles is:

$$VROUGH = 20 * PSR,$$

where VROUGH is maximum speed in miles per hour given the existing pavement conditions (HERS equation 8.10, p. 8.9, Jack Faucett Associates, 1991).

The maximum value of VROUGH is set to the design speed. The time cost of decreased speeds is measured by applying the HERS weighted average travel time rates (Exhibit 8.10, "Value of One Hour of Travel Time by Benefit Category and Vehicle Type," p. 8.36, Jack Faucett Associates, 1991). By using the same rates for all years, it is assumed that relative costs by vehicle class are constant. For example, the 5-axle combination rate ($26.09) is implicitly assumed to always be 2.72 times (=$26.09/$9.59) the automobile rate ($9.59). It is also assumed that the relationship between time costs and operating costs is constant. For example, if time costs are $.20 per minute and operating costs are $.10 per minute for a given speed and PSR, then time costs for that speed and PSR implicitly are always twice the operating costs (=$.20/$.10). The HERS weighted average value of one hour of travel time adjusts for business on-the-clock versus other travel, labor and fringe costs, vehicle costs, inventory costs and occupancy rates. The weighted averages are as follows:

Auto	$ 9.59
4-Tire Truck	$10.87
6-Tire Truck	$20.42
3-4 Axle Truck	$23.34
4-Axle Combination	$25.94
5-Axle Combination	$26.09.

Information on Vehicle Miles Traveled (VMT) by functional highway classes from the 1997 CAS, Table II-5, "1994 VMT by Vehicle Class and Highway Functional Class", p. II-9 is utilized to further weight the weighted HERS averages.

3) CALCULATE THE VEHICLE OPERATING COST DUE TO THE LOSS IN EFFICIENCY FROM PSR INDUCED CHANGES

The equation utilized to calculate operating costs is modified from HERS equation 8.39, p. 8.46 as it is assumed there is a zero grade to the road. The modified equation is:

$$OPCST1 = OCXR(vt) * (AES)^{OC1U(1,vt)}$$
$$EXP\ [OC1U(2,vt) + OC1U(3,vt) * PSR + OC1U(4,vt) * AES$$

where OPCST1 is constant-speed, zero grade operating costs per thousand vehicle-miles in 1988 dollars, AES is average effective speed determined from the VROUGH equation above, vt is vehicle type, OC1U(I,vt), I=1,4 is a set of operating cost coefficients, and OCXR(vt) is a set of ratios of operating-cost indexes used for converting the operating-cost estimates to 1988 dollars (HERS Exhibit 8.12, "Coefficients for Uphill and Zero-Grade Constant-Speed Operating Cost Functions," p. 8.48, Jack Faucett Associates, 1991). The specific operating cost equations by type of vehicle are:

Small Autos
OPCST1=.837*AES**-0.5212*EXP(6.558-.108*PSR+.0119*AES)
Medium Autos
OPCST1=.837*AES**-0.431*EXP(6.272-.1052*PSR+.0140*AES)
4-Tire Trucks
OPCST1=.837*AES**-0.443*EXP(6.142-.1084*PSR+.0187*AES)
2-Axle, 6-Tire Trucks
OPCST1=.999*AES**-0.434*EXP(6.831-.0731*PSR+.0145*AES)
3+ Axle Single-Unit Trucks
OPCST1=1.034*AES**-0.4084*EXP(7.389-.0868*PSR+.01229*AES)
3 & 4-Axle Combinations
OPCST1=1.042*AES**-0.415*EXP(7.311-.1122*PSR+.01313*AES)
5+ Axle Combinations
OPCST1=1.048*AES**-0.319*EXP(7.19-.114*PSR+.01096*AES).

Operating costs for each vehicle category are calculated employing the above equations.

As the operating cost equations differentiated between small and medium automobiles, the percentage of small autos on the road needs to be estimated in order to determine the percentage weights for the operating costs of different vehicle categories.[88] Several sources are employed to calculate this percentage. The first step is to estimate the percentage of small auto sales. Data on small auto sales for 1976-1996 is from the Transportation Energy Book, compiled by Stacy C. Davis, Edition 10, Table 3.9, "Model Year Sales, Market Shares, and Sales-Weighted Fuel Economies of Domestic and Import Automobiles, Model Years 1976-88," pp. 3-18 – 19 and Edition 13, Table 3.18, "Period Sales, Market Shares, and Sales-Weighted Fuel Economies of Domestic and Import Automobiles, Selected Sales Periods, 1976-1992," p. 3-30. Data on small auto sales, imports and total sales from 1956-1968 are imputed from a chart in an article by William S. Rukeyser, "Detroit's Reluctant Ride into Smallsville", Fortune, March 1969, p. 113. Data on total auto sales from 1970-1996 is from the Transportation Energy Book, compiled by Stacy C. Davis, Edition 17, Table 3.7, "New Retail Automobile Sales in the United States, 1970-96," p. 3-11. From these sources, a full set of data needed to calculate the percentage small autos are of total auto sales for the 1956-1968 and 1976 – 1996 periods are available. The data on the 1976-1977 percentage of small cars is not employed as it appears that a category redefinition occurred, as evidenced by the jump in

[88] Calculations described in the rest of this section are contained in SMALLCAR.xls.

the percentage. Between 1968 and 1973, the small auto percentage is assumed to increase by +2% a year. Between 1973-1978, the percentages are interpolated.

The next step, given estimates of the percentage that new small auto sales is of total new auto sales, is to estimate the percentage of small autos on the road. For this purpose, information on the average age of autos is needed. Data on the average age of autos in use is from the Transportation Energy Book, compiled by Stacy C. Davis, Edition 17, Table 3.5, “Scrappage and Survival Rates for Automobiles 1970, 1980 and 1990 Model Years,” p. 3.9. The average age data for other years are estimated via interpolation and backwards and forwards extrapolation. The average age estimates are employed to create an estimate of the percentage of small autos on the road in any year. As the percentage of new small automobiles sold is very small prior to 1961, it is assumed for State and Local that there are no small autos prior to 1961, the zero year of the third AASHTO curve. For Interstates, since the zero year of the first Interstate AASHTO curve is 1958, it is assumed that small autos existed from the beginning of the Interstate System.

The operating costs are weighted by the vehicle category percentages calculated from the 1997 CAS, Table II-5, “1994 VMT by Vehicle Class and Highway Functional Class”, p. II-9, where the small versus medium auto percentage split just described is employed to further divide the auto category.

4) CALCULATE THE EFFICIENCY PERCENTAGES

Once time costs and operating costs are calculated, it is a simple matter to calculate the efficiency percentages which comprise the efficiency curve. The following formula is employed:

$$NETOT = (ITC + IOC)/(NTC + NOC),$$

Where NETOT is the net total efficiency in the current year, ITC is the initial time cost, IOC is the initial operating cost, NTC is the new or current year time cost, and NOC is the new or current year operating cost. NETOT is a percentage which starts at 100% in the initial year, representing pavement which is 100% efficient. The lower the percentage, the lower the efficiency of pavement.

IX. SERVICE LIFE AND EFFICIENCY ASSUMPTIONS

The four components of capital stock are pavement, grading, structures, and ROW.

Pavements are assumed to have a service life of 20 years. Pavement efficiency is calculated as described above.

Grading is assumed to have a service life of 80 years. It is assumed to be 100% efficient until it is retired (replaced) at the end of its service life.

Structures are assumed to have a service life of 50 years. As very little is known about the pattern of efficiency loss for structures, which disproportionately are bridges, it is assumed that efficiency loss is similar to that for buildings. Following the lead of Fraumeni (1997), a geometric rate of deterioration of 1.82% is utilized.[89] [90]

It is assumed there is no loss in the efficiency of ROW and that ROW lasts forever. Accordingly, efficiency is held constant at 100% forever.

X. CAPITAL STOCK CALCULATIONS

Capital outlays are apportioned into new construction and reconstruction versus Other capital outlay for pavement, grading and structures and total ROW capital outlay. All nominal capital outlays are deflated by the appropriate deflator, described above, before dollar capital stocks are calculated. Capital stocks thus constructed are constant dollar capital stocks. The formulas for accumulation of pavement, grading, structure and ROW outlays in construction of capital stock for a particular type, e.g. Interstate, State and Local, are:

Pavement and Grading

$$\text{Capital Stock}_{year} = \Sigma_{age}\Sigma_{vintage}\ (\text{Efficiency}_{age,vintage} * \text{Capital Outlay}_{year\text{-}age,\ vintage})$$

Structures

$$\text{Capital Stock}_{year} = \text{Capital Outlay}_{year} + (1.0 - 0.0182) * \text{Capital Stock}_{year\text{-}1}$$

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89 The pavement, grading and structure service life assumptions are identical to those employed by Faucett and Scheppach (1974) with the exception of other than Interstate pavements. See Faucett and Scheppach (1974, Table 3.3, “Average Life Assumptions – Structures”, pp. 3.38). Gedeon Picher of Mainesurf, Inc. presented convincing evidence that the design life for all pavements are best represented by an estimate of twenty years. However, note that the service lives for the 1921 benchmark are taken from the Eastman Report and may differ from those listed above.

90 Note that the service lives for the 1921 benchmark are taken from the Eastman Report and may differ from those listed above.

ROW

$$\text{Capital Stock}_{\text{year}} = \text{Capital Outlay}_{\text{year}} + \text{Capital Stock}_{\text{year-1}}.$$

Except for the grading formula applied to the 1921 Eastman Report benchmark, the formula for grading simplifies to the formula applied to ROW. With a grading service life equal to 80, any grading stock resulting from expenditures made in 1921 or after will be 100% efficient until 2001 or later. Accordingly, there is no vintage or age effect within the time period covered by this study and the efficiency term can be dropped. A simple capital accumulation formula, such as that applied to ROW outlay, applies.

In the pavement formula, age refers to the age of the pavement, which ranges from 0 to 20 years. As noted before, at age equal to 0, the pavement will be 100% efficient. At age equal to 20, the pavement is retired (replaced); therefore its efficiency is 0%. In between, the efficiency percentage depends on the specific efficiency curve. Vintage refers to the zero year of the efficiency curve. For Interstates, this is 1958 or 1978, for State and Local, this is 1921, 1941, 1961, or 1981. As the efficiency curves vary by Interstate, State, Local and by zero year, summation must occur over the various vintage types. For example, Interstate pavement capital stock created by a capital outlay in 1970 (using the zero year = 1958 efficiency curve) will still be efficient in 1985, when new capital outlays are governed by the zero year = 1978 efficiency curve. The summations appearing in the formula reflect this fact.[91]

A nominal or current dollar estimate of any capital stock can be obtained by multiplying the constant dollar stock by the appropriate deflators described above.

XI. ROAD-TYPE QUALITY INDEX

The section refers to four sources: the Eastman Report, HST75, chart entitled "Total Road and Street Mileage in the United States by Surface Type, 1900-1975;" p. 212, HST75, Table M-203, "Existing Mileage in the United States, by System, and Type of Surface, 1941-1975," pp. 205-211, and HST95, Table HM-212, "Public Road and Street Length, 1941-1995," p. V-5. Road type quality calculations are contained in QUALITY.xls, the chart data is contained in CRTNUM.xls, and Table M-203 is contained in M203.xls.

[91] As noted previously, detailed calculations appear on the INTER58 and INTER78 worksheets of the Excel file INTER.xls, on the STATE21, STATE41, STATE61, and STATE81 worksheets of the EXCEL file STATE.xls, and on the LOCAL21, LOCAL41, LOCAL61 and LOCAL81 worksheets of the Excel file LOCAL.xls.

The first step in constructing a road quality index is to develop road-type time series from 1921-1995. The HST75 chart is the sole source of information from 1921-1940.[92] Not all of the chart categories: 1) bituminous and Portland Concrete Cement, 2) soil-surfaced, gravel and stone, and 3) nonsurfaced mileage, match categories in M-203 or HM-212, the sources for 1941-on data. Category 2 plus 3 equals total unpaved mileage, a category which has a direct correspondence to categories in M-203 and HM-212, but category 1 needs to be disaggregated to match categories in M-203 and HM-212. The percentage that paved low type and intermediate type roads are of total paved roads is calculated from data in HM-212. As this percentage is relatively stable over the thirty-five year period 1941-1975, varying from 52.1% to 57.5%, the average percentage over that time period is used to estimate the miles of paved low and intermediate miles from 1921-1940. This average percentage is multiplied times category 1 miles to split the category 1 between low and intermediate type paved roads and high type roads. Two road quality categories are then created: 1) unpaved, paved low and intermediate type roads and 2) high type roads.[93]

Alternatively, three categories could be defined from 1921-1975: 1) nonsurfaced roads, 2) paved low and intermediate type roads, and 3) high type roads. This approach is not utilized for two reasons: 1) the difficulty of estimating nonsurfaced road miles post 1975 and 2) the extent to which nonsurfaced road quality is already captured in capital stock estimates. Unlike the percentage of low and intermediate type roads in all paved roads, the percentage of nonsurfaced roads in all unpaved roads varies considerably. The Eastman Report does not include grading for State, County and Local nonsurfaced unimproved roads and County and Local nonsurfaced improved in its costs estimates as associated outlays are thought to be maintenance, not capital outlays. To the extent that outlays on nonsurfaced roads are maintenance, not capital outlay, the lower quality of nonsurfaced roads compared to surfaced, unpaved is already captured in capital stock estimates.

The road quality index utilizing the two categories is constructed by normalizing the quality of a high type road to 1.0. Unpaved, low and intermediate type roads are assigned a quality index equal to .350146333, which is the relative high type to unpaved, low and intermediate type road Eastman Report adjustment. As described in Section VI, the quality adjustment for high type roads is 1.5625, for other roads it is 4.46242. The ratio of these two adjustments is .350146333, which is utilized as the unpaved, low and intermediate type road quality index. The unnormalized road quality index would be equal to 1.0 if all roads are of high type; it would be equal to .350146333 if all roads are unpaved, low and intermediate type roads. The unnormalized road type index varies from .3690 in 1921 to .5688 in 1995, representing more than a 50% improvement in road quality in 67 years. The final form of this index is normalized to 1.0 in 1992.

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[92] The chart data is contained in CRTNUM.xls.

[93] All high type roads are paved.

An alternative form of this index is the percentage of paved roads in all roads. This percentage ranges from 18% in 1921 to 61% in 1995, representing more than a 200% improvement in road quality in 67 years. The final form of this alternative index is also normalized to 1.0 in 1992.

XII. BRIDGE QUALITY INDEX

The National Bridge Inventory (NBI) contains information on all 600,000 plus highway-related structures of at least twenty feet in the United States from the early eighties to the present.[94] The NBI data can be combined with worksheet data obtained from James Saklas (undated)[95] of the Federal Highway Administration to estimate an index of bridge quality from 1983-1996.[96] For earlier years, general trends in the construction of bridges with higher bridge loading capabilities determined from the NBI and information collected by Gedeon Picher of Mainesurf, Inc. can be utilized to construct bridge quality indexes.

The Saklas data estimates cost of construction for standard bridge types by twelve HS or H types for three to thirteen bridge span length categories. A total of 960 categories are covered.[97] These categories account for approximately two-thirds of all NBI structures. The eleven types are as follows with the number of bridge span length categories indicated in brackets:

1. Reinforced concrete slabs (simple), [3]
2. Reinforced concrete slabs (continuous), [4]
3. Prestressed concrete slab (simple), [3]
4. Prestressed concrete slab (continuous), [5]
5. Reinforced concrete T-beam (simple), [5]
6. Reinforced concrete T-beam (continuous), [8]
7. Prestressed concrete beam (precast), [10]
8. Prestressed concrete multicell box girders, [10]
9. Steel I beam (rolled), [6]

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94 See the NBI codebook (FHWA, 1988) for further information.

95 James Saklas of the Office of Policy Development at the FHWA provided the information in spreadsheets. Saklas is listed as the only citation for the data as no other identifying information is available. The data was constructed in the eighties or nineties. It is contained in the Excel file BRIDGES.xlc.

96 The bridge quality index was not constructed as part of this project as FHWA personnel was unable to deliver information from the 1983 and 1996 NBI in time to allow its construction.

97 The twelve HS or H types include H2.5 bridges of three different widths: 38, 32 and 26 feet.

10. Steel I girder (simple), and	[13]
11. Steel I girder (continuous).	[13]

The quality indicator would be the HS and H gross weight loadings, which are as follows, in thousands of pounds:

1. HS 25	90
2. HS 22.5	81
3. HS 20	72
4. HS 17.5	63
5. HS 15	54
6. H 20	40
7. H 15	30
8. H 10	20
9. H 5	10
10. H 2.5	5.

Suppose for purposes of illustration that all new bridges built in 1995 are HS22.5 and all new bridges built in 1996 are HS25. For a one span reinforced concrete slab (simple) 30 foot span bridge, the construction cost of a HS25 bridge is $145,829 and the construction cost of a HS22.5 bridge is $140,767.[98] The cost ratio is 1.036. The gross weight loading ratio is 1.111 (=90/81). The quotient of the quality ratio to the cost ratio is 1.073, which indicates quality per construction dollar has increased.

The Saklas H or HS categories have a corresponding NBI category for six categories:

1) HS 25,
2) HS 20 plus HS 20+Mod,
3) H 20,
4) HS 15,
5) H 15, and
6) H 10.[99]

As the Saklas cost data is for one span, to construct cost for a complete bridge with possibly more than one span, it is necessary to calculate the average length of other than the maximum span. Average length of other than the maximum span can be estimated as structure length minus length of maximum span divided by the total number of spans in the bridge minus one.

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[98] Saklas spreadsheets.

[99] The NBI categories exist only for increments of 5. Accordingly, any bridge designed above an increment of 5 design category (e.g. HS 22.5) would be allocated to the loser category (e.g. HS 20)

The total cost for the bridge as a whole is the sum of the cost for the maximum span plus the total cost for the other spans.

The total cost for a bridge should be weighted by the gross weight loading. Total gross weight loading weighted costs then should be summed across all bridges and divided by the sum of the total cost of construction of all included bridges to produce an average gross weight loading per dollar of construction cost. This index, normalized to 1.0 in 1992, is the bridge quality index.

For years before 1983 two approaches should be attempted. The NBI data on year reconstructed and year built can be inspected to determine if there is a pattern in the adoption of particular H or HS design load. The problem with the year reconstructed and year built data is that the NBI design load information does not identify if the H or HS design load has changed since the bridge is built or if it is changed when the bridge is last reconstructed. As a result, this information needs to be supplemented or even totally replaced by information on adoption of H or HS design standards collected by Gedeon Picher of Mainesurf, Inc. If the NBI information is useful, the same procedure as described above for 1983-1996 should be utilized to create the bridge quality index. If the NBI information does not seem indicative of design changes, then the information collected by Picher should be utilized directly. As there is little or no cost data associated with the Picher information, either quality increases are assumed to be directly proportional to the increase in the gross weight loading of newly designed bridges or the Saklas cost data and the distribution of bridge types and span configurations is assumed to apply to all years prior to 1983. If the former methodology is utilized, it is implicitly assumed that higher gross weight loadings can be accomplished without any increase in construction cost.

The following is a summary of the Picher information, with supplementary information as noted:[100]

[100] Unless otherwise noted, the source of all information on MDOT practices is “The Impact of the LRFD Bridge Design Specification upon Bridge Live Loading in Maine,” MDOT Technical Report 95-1, December 1997.

1921	H 15[101]
1944	HS 20-44 design loading added by AASHTO
1969	HS 20 adopted by MDOT[102]
1977	permission to adopt HS 25 received by MDOT
1978	HS 25 design load adopted by the Pennsylvania Department of Transportation

A MDOT document "Truck Weights and Standard Design Truck for Bridges," (July, 1974) indicates that the average additional costs to design and construct a HS 25 bridge over a HS 20 bridge is 4%. In addition, it indicates that the average additional costs to design and construct a HS 25 bridge over an HS 20 bridge is 7%.[103]

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[101] A Picher email dated November 10, 1998, describes how James Tukey, the current MDOT Bridge Design Engineer, remembers seeing old plans with H 15 designs back to the late 1920's. America's Highways, 1776-1976, (Federal Highway Administration, 1977) indicates that in 1939 a study by the War Department indicated that 2,400 defense effort related bridges could not sustain a H 15 loading. This source stated further that H 15 was the American Association of State Highway Officials standard for bridges on the Federal-aid system (p. 142). It is unknown what percentage 2,400 bridges might be of all defense related bridges, the condition of bridges not categorized as defense related or their gross weight loading ability.

[102] The Picher email (November 10, 1998) categorized the adoption of HS 20 by the Maine Department of Transportation (MDOT) as being quite late in the game.

[103] Picher's email contains other design-related information, relating to Load Factor Design (LFD) and Load Resistant Factor Design (LRFD). This information is not summarized herein as these design features cannot be translated to equivalent H or HS categories.

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APPENDIX I ABBREVIATIONS

AADT Average Annual Daily Traffic

AASHTO American Association of State Highway and Transportation Officials

AES Average Effective Speed

BEA Bureau of Economic Analysis

CAS Cost Allocation Study

ESAL Equivalent Single-Axle Load

EASTMAN REPORT Section of Research, Federal Coordinator of Transportation, 1940.

FHWA Federal Highway Administration

FRTW Fixed Reproducible Tangible Wealth, 'YR' to 'YR', a BEA publication, various years

HERS Highway Economic Requirements System

HS Highway Statistics 'YR', various years

HST Highway Statistics, Summary Through 'YR', various years

JFA Faucett and Scheppach, 1974, a.k.a. Jack Faucett Associates

LFD Load Factor Design

LOCAL Other than Interstates or State

LRFD Load Resistance Factor Design

MDOT Maine Department of Transportation

OTHER Other than new construction or reconstruction.

PSI Present Serviceability Index

PSR Present Serviceability Rating

Pt Terminal serviceability.

ROW Right-Of-Way

STATE State excluding Interstates

TSP Time Series Processor, an econometric computer estimation package

VMT Vehicle Miles Traveled

VPD Vehicles Per Day

APPENDIX II LIST OF SOURCE DATA AND COMPUTER FILES

SOURCE	TABLE	TITLE	PAGES	SECTION	FORMAT	DISK
HST85	HF-221	"Estimated Capital Expenditures by Federal Systems and Expending Agencies, 1956-1986"	95-99	I, II	Paper, Excel (HF221ROW .xls)[104]	NA[105], Disk 1
HST95	HF-210	"Funding for Highways, All Units of Government, 1921-1995"	IV-7 – 38	I	Lotus (HF210.wk4)	Disk 1
HST95	SF-212A	"State Capital Outlay on Arterials and Collectors, by Improvement Type, 1981-1995"	IV-97	I, II,IV	Lotus (SF212A.wk4), Excel (SF212A.xls)[106]	Disk 1
HS96	SF-12	"State Highway Agency Capital Outlay and Maintenance - 1996, Total for All Areas - Classified by Functional System"	IV-79	I	Paper	NA
FHWA1.TXT, FHWA1.LIS		TSP program and listing to estimate the percentage right-of-way is of new construction expenditures for Interstates		II	Word Perfect TSP program	Disk1
FHWA3.TXT, FHWA3.LIS		TSP program and listing to estimate the percentage right-of-way is of new construction expenditures for States		II	Word Perfect TSP program	Disk1
HST95	LGF-202	"Disbursements of Local Governments for Highways, 1921-1994"	IV-108	II	Lotus (LGF202.wk4)	Disk 1
BEA (1993)	BEA DISKS	"11IHI EYBFNIT09" for Federal historical cost, "11IHI EYBSLIT11T" for State historical cost, both for highways and streets investment			ASCII (11IHI.txt)	Disk1

[104] The capital outlay data is not available on disk, but the ROW outlay data is available on disk.

[105] NA stands for not available on disk.

[106] Most data comes from the Lotus file. Some Interstate data comes from the Excel file.

BEA (1993)	BEA DISKS	"12ICQ QYBFNIT09" for Federal chained quantity index, "12ICQ QYBSLIT11T" for State chained quantity index, both for highways and streets investment		III	ASCII (12ICQ.txt)	Disk1
HIGHI96.XLS		Deflators derived from the BEA disk data listed above.		III	Excel	Disk1
BEA (1997)	BEA DISK 5	"6162" for Federal historical cost , "6188" for Federal constant cost, "6176" for State and Local historical cost, "6202" for State and Local constant cost, all for highways and streets investment		III	ASCII (WEALTH21 .txt)	Disk 2
HST95	HM-210	"Public Road and Street Length, 1921-1995, Miles by Jurisdiction, National Summary"	V-6	IV	Lotus (HM210.wk4)	Disk 2
HST95	HM-220	"Public Road and Street Length, Miles by Functional System, National Summary"	V-9	V	Paper	NA
HS95	FA-6	"Obligation of National Highway System and Surface Transportation Program Funds by Improvement Type, Fiscal Year 1995"	IV-38	V	Excel (BRIDGE%. xls)	Disk 2
INTER.xls		Core Excel worksheet employed to calculate the Interstate capital stocks		I-VIII	Excel	Disk 3
STATE.xls		Core Excel worksheet employed to calculate the State capital stocks		I-VIII	Excel	Disk 3
LOCAL.xls		Core Excel worksheet employed to calculate the Local capital stocks		I-VIII	Excel	Disk 3
HST95	HM-215	"Public Road and Street Length, 1923-1995, Miles by Federal-Aid Highways, National Summary"	V-7	VI	Paper	NA
HS, various years	HM-57	"Average Daily Traffic - Rural – Year"	V-55 – 56 in HST95	VII, Appendix V	Excel (RURAL.xls, RURAL2.xls)	Picher Disk

HS, various years	HM-57	"Average Daily Traffic - Urban – Year"	V-57 – 58 in HST95	VII, Appendix V	Excel (URBAN.xls, URBAN2.xls)	Picher Disk
HST95	VM-201	"Annual Vehicle Distance Traveled in Miles, 1936-1995, by Vehicle Type and Highway Category," p. V-11 – 14	V-11 - 14	VII, Appendix V	Excel (RURAL.xls, URBAN.XLS, RURAL2.xls, URBAN2.xls)	Picher Disk
BENCH.xls		Excel worksheet containing Eastman Report data, calculations and documentation for benchmarks		VI, XI	Excel	Disk 2
Jack Faucett Associates, "The HERS Technical Report"	Equation 8.10		8.9	VIII	Paper	NA
Jack Faucett Associates, "The HERS Technical Report"	Exhibit 8.10	"Value of One Hour of Travel Time by Benefit Category and Vehicle Type"	8.36	VIII	Paper	NA
1997 CAS (August 1997)	II-5	"1994 VMT by Vehicle Class and Highway Functional Class"	II-9	VIII	Paper, Excel (INTER.xls, STATE.xls, LOCAL.xls)	Disk 3

Jack Faucett Associates, "The HERS Technical Report"	Equation 8.39		8.46	VIII	Paper	NA
Jack Faucett Associates, "The HERS Technical Report"	Exhibit 8.12	"Coefficients for Uphill and Zero-Grade Constant-Speed Operating Cost Functions"	8.48	VIII	Paper, Excel (INTER.xls, STATE.xls, LOCAL.xls)	Disk 3
Davis, Transportation Energy Book, Edition 10	3.9	"Model Year Sales, Market Shares, and Sales-Weighted Fuel Economies of Domestic and Import Automobiles, Model Years 1976-88"	3-18 - 19	VIII	Paper, Excel (SMALLCAR. xls)	Disk 2
Davis, Transportation Energy Book, Edition 13	3.18	"Period Sales, Market Shares, and Sales-Weighted Fuel Economies of Domestic and Import Automobiles, Selected Sales Periods, 1976-1992	3-30	VIII	Paper, Excel (SMALLCAR. xls)	Disk 2
Rukeyser, Fortune		"Detroit's Reluctant Ride into Smallsville", March 1969, p. 113.	113	VIII	Paper, Excel (SMALLCAR. xls)	Disk 2
Davis, Transportation Energy Book, Edition 17	3.5	"Scrappage and Survival Rates for Automobiles 1970, 1980 and 1990 Model Years"	3.9	VIII	Paper, Excel (SMALLCAR. xls)	Disk 2

Davis, Transportation Energy Book, Edition 17	3.7	“New Retail Automobile Sales in the United States, 1970-96”	3-11	VIII	Paper, Excel (SMALLCAR. xls)	Disk 2
Davis, Transportation Energy Book, Edition 17	3.5	“Scrappage and Survival Rates for Automobiles 1970, 1980 and 1990 Model Years”	3.9	VIII	Paper, Excel (SMALLCAR. xls)	Disk 2
HST75		“Total Road and Street Mileage in the United States by Surface Type, 1900-1975”	212	XI	Paper, Excel (CRTNUM .xls)	Disk 2
HST75	M-203	“Existing Mileage in the United States, by System, and Type of Surface, 1941-1975,”	205-211	XI	Excel (M203.xls)	Disk 2
HST95	HM-212	“Public Road and Street Length, 1941-1995”	V-5	XI	Lotus (HM212.wk4)	Disk 2
QUALITY.xls		Excel worksheet used to calculate the road-type quality index		XI	Excel	Disk 2
BRIDGES.xlc		Excel worksheet from James Saklas of FHWA, input to a potential bridge quality index		X	Excel	Disk 2
National Bridge Inventory		Available on CD-ROMS from FHWA		X		NA

APPENDIX III DOCUMENTATION OF THE DEVELOPMENT OF THE Pt VS. TIME RELATIONSHIPS

INTERSTATE SYSTEM
1958-1977
1978-1997
NON-INTERSTATE STATE SYSTEM
1921-1940
1941-1960
1961-1980
1981-2000
LOCAL SYSTEM
1921-1940
1941-1960
1961-1980
1981-2000

Gedeon G. Picher, President
Mainesurf, Inc.

This paper documents the development of the Pt vs Time relationships used in the development of the efficiency curves for the above systems and time periods. Further, its objective is to allow the reader to reconstruct the relationships in the event he so chooses.

The most straightforward approach to doing the above is to follow the development of the Interstate 1958-1977 curve through its several steps to show the inter-relatedness of the steps.
Following that, each of the other remaining curves will be addressed by exception and similarity in detail enough to allow the reader to also reconstruct those relationships.

Pavement deterioration in terms of serviceability is calculated using the AASHTO flexible pavement design equation given in the AASHTO "Guide for the Design of Pavement Structures", page I-5. Equivalent (18,000 Pound) Single Axle Loads (ESALs) are derived through a spreadsheet which is developed for the purpose, based on AASHTO design equations. The values are further refined to recognize two-tired axles and unbalances among axles of an axle group.

The following steps are necessary in the development of any of the Pt vs Time relationships:

1. Development of AADT by year for the design period.

2. Development of Traffic Distribution by year in terms of passenger vehicles, single unit trucks and combination vehicles in the AADT.
3. Development of Annual Design Lane traffic level and lane distribution.
4. Computation of Structural Number (SN) for the given System and 20 year time period and computation of corresponding Equivalent Single Axle Loads (ESALs) for the computed SN, for the passenger vehicles, single unit trucks and combination vehicles in the traffic stream. Iteration is required for this step, as predicted ESALs over the 20 year period according to the AASHTO equation must equal ESALs expected of the roadway traffic over the same period.
5. Computation of the Environmental Factor, taken as equivalent to ten percent of accumulated ESALs.
6 6. Computation of Target ESALs for each 0.1 drop in Terminal Serviceability (Pt), starting from an Initial Serviceability (Po) of 4.2.
7. Computation of time in years to reach each Pt point.

We will now go through each of the above steps for each of the Pt vs Time relationships, starting with INTERSTATE SYSTEM 1958-1977, on the next page. The computer spreadsheet detailing the final resulting files is identified in the final section. The attachments and accompanying computer files on disk complete the formal documentation. Additional detail is available in specific computation packets resident in Mainesurf, Inc. files.

A. INTERSTATE SYSTEM 1958-1977

1. Development of AADT by year for the design period

The "Highway Statistics" (U.S.D.O.T.) editions from 1981 to 1995 are used to estimate AADT by AADT groups weighted by miles of highways/streets for both rural and urban (Table HM57). As 1981 and 1982 values are found questionable; they are adjusted during the visual fit process, described next. AADT figures earlier than 1981 are not available. See spreadsheets RURAL.XLS and URBAN.xls.

Interstate System AADT values for all years from 1958 to 19980 (rural) and to 1982 (urban) and for 1996 and 1997 (urban and rural) are visually fit/estimated to the "Highway Statistics" data above, assuming 15000 AADT in 1958 for urban and 6000 AADT for rural. The resulting values and the composite AADT using the average rural/urban mile ratio from 1983-1995 (2.802) are detailed in spreadsheet COMBR&U.WKS. Rural Interstate values are shown in spreadsheet WTAVGADT.WKS (Chart 4) and Urban Interstate values are shown in spreadsheet ADTURBAN.WKS (Chart 6).

2. Development of Traffic Distribution by year in terms of passenger vehicles, single unit trucks and combination vehicles in the AADT

The distribution of AADT into passenger vehicles, single unit trucks and combination vehicles for 1983 to 1997 is taken from Table VM 201 in "Highway Statistics Summary to 1995" (U.S.D.O.T.). Because the relative percentages are quite constant, they are used for the entire period 1998-1997. The resulting splits are:

Passenger Cars:	87.456%
Single Unit Trucks:	2.721%
Combination Vehicles:	9.823%

The values and computations are shown in the spreadsheet TRAFSPLIT.WKS and in its Chart 2.

3. Development of Annual Design Lane traffic level and lane distribution

For the Interstate System, it is necessary to (1) split the AADT by direction, (2) to determine the design lane and (3) to find the number of each vehicle type in the design lane.

A 50-50 directional split is assumed for the 24 hour period for both the AADT and vehicle loading conditions. It is recognized that hourly values may vary, but this effect is assumed to be averaged out over the course of the entire day.

The AADT values for the composite AADT over the 1958-1997 period comport to a four lane divided facility. Because most of the traffic occupies the right lane, as opposed to the median lane, it is chosen as the design lane. The direction is immaterial, as the design is the same in either direction under the directional assumption above. The following values are used for the percentage of AADT in the design lane by vehicle type:

Passenger Cars:	60%
Single Unit Trucks:	80%
Combination Vehicles:	90%

These values are chosen with reference to Page II-9 in the AASHTO Pavement Design Guide (1993).

Twenty year vehicle passages in the design lane are then computed by vehicle type.

4. Computation of Structural Number (SN) for the given system and 20 year time period and computation of corresponding Unit Equivalent Single Axle Loads

(ESALs) for the computed SN, for passenger vehicles, single unit trucks and combination vehicles -

A spreadsheet (REPESALS.WKS) is developed to compute representative ESALs for passenger vehicles, single unit trucks and combination vehicles. A 1980 (approx.) vintage electronic data set of vehicles (I4ALL.CSV) is obtained from Jim Saklas of the FHWA Office of Policy Development, Washington, D.C. Office which contained axle arrangement (spacing), axle operating weights and vehicle type for many vehicles at varying gross weights. Relative vehicle miles of travel by weight groups are obtained from Table II-7 in the 1997 Federal Highway Cost Allocation Study. Each vehicle classification is grouped into the three major groupings above (passenger cars, single unit trucks and combination vehicles). The spreadsheet allows the user to compute representative ESALs upon input of Structural Number (SN), Initial Serviceability (Pi) and Terminal Serviceability (Pt). The spreadsheet is modeled on similar LOTUS spreadsheets created by Maine DOT (ESALFAST.WK1 and IMBESAL.WK1). Like these two spreadsheets, adjustments for two tired axles and unbalance among axles in the axle groups are incorporated into the calculations and can be seen from the spreadsheet formulae. The formula for the computation of ESALs per axle group is shown in an attachment to this paper.

The computation of structural number is done by iteration using the spreadsheet ASPH.WKS, which is merely the computation of the AASHTO curve for flexible pavements on Page I-5 in the "AASHTO Guide for Design of Pavement Structures" (1993), and the summation of vehicle ESALs in the design lane over the full 20 year period. A 10% surcharge is assumed and added to the summation. The Structural Number is varied until ESALs predicted by the AASHTO equation is equal to the ESALs calculated by the passage of the vehicles plus 10%.

REPESALS.WKS and ASPH.WKS, with their proper inputs are used in developing all the Pt vs Time relationships.

5. Computation of the Environmental Factor, taken as equivalent to ten percent of accumulated ESALs

Once the Structural Number is determined for the pavement structure, environmental surcharges can be determined for each 0.1 drop from the Initial Serviceability. Because the ESALs as computed from ASPH.WKS do not generally exactly equal the summation of ESALs experienced by the pavement (plus 10% surcharge), target ESAL values take into account any variation so that the Pt vs Time curve is internally consistent. Structural Numbers are computed to two decimal places. SN is computed as 5.97 for the Interstate curve for 1958-1977. This computation is done within the YRESAL.XLS spreadsheet, which also develops the time value for each Pt value if successively used with the appropriate inputs. A brief description follows:

Col. B Terminal Serviceability (Pt)

Col. C Composition of Traffic by Vehicle Type
Col. D Percent of Traffic in Design Lane
Col. E ESAL equivalents for specific SN and Pt by vehicle class
Col. F Computes weighted ESAL for one vehicle in design lane of the AADT
Col. G Number of ESALs to reach Pt as determined by AASHTO curve and ASPH..WKS
Col. H Target ESALs after environmental reduction due to 10% surcharge and Adjustment mentioned above for internal consistency. Select the Pt desired for the analysis and place this value from Column J manually in cell AJ5.
Col. I First year's traffic (AADT)
Col. J First year's ESALs/day in design lane Select the Pt desired for the analysis and place this value from Column J manually in cell AJ4.

(Columns K through AG may be ignored as irrelevant and part of an earlier spreadsheet development supplanted by the Time Computation Table starting in cell AH12.)

Column AH
The computation of years to each Pt point is done in the table starting at this point. Annual AADT is input along with the appropriate ESAL target value. The time value is read by inspection of Column AP, where the residual turns negative. This is an early rudimentary form of the time computation in the spreadsheet. In a later version which is used for all the Pt vs Time curves for the Non-Interstate State and the Local Systems, time is computed from Col. AH and spreadsheet logic is applied to arrive at the appropriate time value in a conveniently located output cell.

It would be useful at this point to identify the input variables for the Pt vs Time computations. They are listed below:

a. An Initial Present Serviceability Index (Pi)
For asphaltic pavements, Pi is taken as 4.2, the maximum practical PSI which is obtainable in the field, and that which obtained at the original Illinois AASHTO Road Test. This value is used for all systems.
b. Terminal Serviceability for 20 year Design Life
Interstate System: 3.0
Non-Interstate State System: 2.5
Local System: 2.0

These values correspond well with design practice at Maine DOT and comport well with recommended AASHTO Design Guide values. Terminal Serviceability values at 0.1\intervals from the Pi of 4.2 are used to get intermediate year values all the way to the 20 year design period..

c. Combined Standard Error of the Traffic Prediction and Performance Prediction
Interstate System: 0.45
Non-Interstate State System: 0.43
Local System: 0.40
AASHTO road test equations correspond to 0.45 and Maine DOT uses 0.45 for major highways. Values for the lesser systems are taken as slightly less in recognition of the
fact that traffic volumes are less reliable than for the Interstate System.

d. Resilient Modulus
It is necessary to select a modulus representative of average conditions in the U.S. The Resilient Modulus associated with a well drained soil in the Mid-Atlantic Region lower Midwest/upper south is used. It is representative of a frozen season of one month in length, a spring thaw of two weeks, a wet period of 6 months with dry periods for the rest of the time. The Resilient Modulus is derived on Page H6 of the AASHTO Design Guide. It's value is 5700 psi, for all systems. If Pt vs Time curves specific to other regions are desired, computations specific to those regions should be done.

e. Reliability Level
Interstate System: 0.95
Non-Interstate State System: 0.90
Local System: 0.75
These values are in line with Table 2.2 of the AASHTO Design Guide. The Standard Normal Deviate (Zr) is found from Reliability Level from Table 4.1 in the AASHTO Design Guide.

f. Design Life
A period of 20 years is chosen for all Pt vs Time curves.

6. Computation of Target ESALs for each 0.1 drop in Terminal Serviceability (Pt), starting from an Initial Serviceability (Po) of 4.2

As indicated immediately above for Column H, target ESALs for each Pt is computed by YRESAL.XLS.

7. Computation of time in years to reach each Pt point

As indicated immediately above for Column AP, the time to reach each Pt is computed by YRESAL.XLS.

The above details the development of the Interstate System Pt vs Time curve. The remaining curves are discussed in turn in the following sections, by exception to the basic procedure outlined above.

B. INTERSTATE SYSTEM 1978-1997

1. Development of AADT by year for the design period

Traffic volumes developed under "INTERSTATE SYSTEM 1958-1977" above are used for the years involved in this computation.

2. Development of Traffic Distribution by year in terms of passenger vehicles, single unit trucks and combination vehicles in the AADT

The distribution of AADT into passenger vehicles, single unit trucks and combination vehicles for this period is the same as for 1957-1978.

The process for Steps 3 to 7 below paralleled those for 1958-1977, above.

3. Development of Annual Design Lane traffic level and lane distribution
4. Computation of Structural Number (SN) for the given system and 20 year time period and computation of corresponding Unit Equivalent Single Axle Loads (ESALs) for the computed SN, for passenger vehicles, single unit trucks and combination vehicles -
5. Computation of the Environmental Factor, taken as equivalent to ten percent of accumulated ESALs
6. Computation of Target ESALs for each 0.1 drop in Terminal Serviceability (Pt), starting from an Initial Serviceability (Po) of 4.2
7. Computation of time in years to reach each Pt point

C. NON-INTERSTATE STATE SYSTEM 1921-1940

As a general note for the Non-Interstate State System and the Local System, a series of three basic spreadsheets are used to develop the Pt vs Time curves, as follows:

1. REPESALS.WKS - develops representative ESALs for any SN and Pt (same as Interstate, above)
2. NICESALS.WKS - develops the annual number of ESALs by year
3. YRESAL9.WKS - An updated version of YRESAL.XLS, used above for the

Interstate System. Years are read directly in an output cell located near the input cell.

Representative ESALs for each traffic classification are "pasted special" from REPESALS.WKS into NISESALS.WKS. The resulting list of annual ESALs per year are in turn "pasted special" into the appropriate column in YRESAL9.WKS and Time in years is read in the output cell.

This represents a streamlining of the process used for the Interstate System, but the basic computations are the same.

NOTE CAREFULLY: The spreadsheets above are generic general process oriented analysis tools. Data for the specific system, the time period in question, and the desired target value for a specific Pt must be entered into the above spreadsheets at the start of the analysis.

1. Development of AADT by year for the design period

AADT for both rural and urban are developed from RURAL2.XLS and URBAN2.XLS which is developed by Barbara Fraumeni using "Highway Statistics Summary, 1995". The rural and urban curves are plotted for 1981-1996. They are extended visually to 1921, where an initial value of 200 is assumed for rural AADT and an initial value of 500 is assumed for urban AADT. An adjustment to estimate the effect of depression years is also made. Yearly AADT values are read directly from the plots. The rural /urban VMT ratio is computed for 1981, 1986, 1991 and 1996 as shown below from RURAL2.XLS and URBAN2.XLS.

Year	Rural/Urban VMT Ratio
1981	5.489
1986	4.621
1991	4.520
1996	4.071

From Table HM212 in "Highway Statistics Summary, 1995" and the AADT curves constructed, similar values for 1921, 1941 and 1961 are computed as shown below by association.

Year	Table HM212 Rural/Urban Mileage Ratio Eliminating unpaved roadways	Rural/Urban VMT Ratio Non-Interstate State System
1921	(3.25 - estimated)	3.25/3.06*6.612 = 7.436
1941	3.06	3.06/2.89*6.245 = 6.612
1961	2.89	2.89/2.54*5.489 = 6.245
1981	2.54	5.489
1991	2.19	4.520

The resulting composite Rural/Urban AADT is computed and is shown in spreadsheet R1NINTCO.WKS.

2. Development of Traffic Distribution by year in terms of passenger vehicles, single unit trucks and combination vehicles in the AADT

Traffic distribution is obtained from VM201 in "Highway Statistics Summary, 1995" for the years 1936-1940. Busses are aggregated with single unit trucks. The trend from 1936-1940 is projected backwards to 1921. The final split is developed and shown in spreadsheet TR213640.WKS. ESALs per year are computed and shown in spreadsheet RRNISESA.WKS.

3. Development of Annual Design Lane traffic level and lane distribution

All Non-Interstate facilities are of such AADT that they represented a two-lane roadway. As such, half of the traffic and all vehicles are in the design lane.

4. Computation of Structural Number (SN) for the given system and 20 year time period and computation of corresponding Unit Equivalent Single Axle Loads (ESALs) for the computed SN, for passenger vehicles, single unit trucks and combination vehicles

This computation is conducted similarly to that above for the Interstate System.

5. Computation of the Environmental Factor, taken as equivalent to ten percent of accumulated ESALs

Same as methodology as above.

6. Computation of Target ESALs for each 0.1 drop in Terminal Serviceability (Pt), starting from an Initial Serviceability (Po) of 4.2

Same methodology as above.

7. Computation of time in years to reach each Pt point

Same methodology as above.

D. NON-INTERSTATE STATE SYSTEM 1941-1960

1. Development of AADT by year for the design period

AADT for both rural and urban are read from the rural and urban curves developed in Section C above. The rural /urban VMT ratios previously derived for 1941 and 1961 are used to weight the rural and urban AADTs.

The resulting composite Rural/Urban AADT is computed and is shown in spreadsheet AUNI4160wks.

2. Development of Traffic Distribution by year in terms of passenger vehicles, single unit trucks and combination vehicles in the AADT

Traffic distribution is obtained from VM201 in "Highway Statistics Summary, 1995" for the years 1941-1960. Busses are aggregated with single unit trucks. An adjustment is made to refine the computation to add an urban VMT component to Single Unit Trucks and Combination Vehicles, as Passenger cars have it. The trend line from 1951-1960 is projected backwards to arrive at the figures. The final split is developed and shown in spreadsheet PERCEN41.WKS.

3. Development of Annual Design Lane traffic level and lane distribution

All Non-Interstate facilities are of such AADT that they represented a two-lane roadway. As such, half of the traffic and all vehicles are in the design lane.

4. Computation of Structural Number (SN) for the given system and 20 year time period and computation of corresponding Unit Equivalent Single Axle Loads (ESALs) for the computed SN, for passenger vehicles, single unit trucks and combination vehicles

This computation is conducted similarly to that above for the Interstate System.

5. Computation of the Environmental Factor, taken as equivalent to ten percent of accumulated ESALs

Same as methodology as above.

6. Computation of Target ESALs for each 0.1 drop in Terminal Serviceability (Pt), starting from an Initial Serviceability (Po) of 4.2

Same methodology as above.

7. Computation of time in years to reach each Pt point

Same methodology as above.

E. NON-INTERSTATE STATE SYSTEM 1961-1980

1. Development of AADT by year for the design period

AADT for both rural and urban are read from the rural and urban curves developed in Section C above. Rural and Urban AADTs are shown in spreadsheet R6180NIS.WKS. The rural /urban VMT ratios previously derived for 1961 and 1981 are used to weight the rural and urban AADTs. Results are shown in spreadsheet R2NINTCO.WKS.

2. Development of Traffic Distribution by year in terms of passenger vehicles, single unit trucks and combination vehicles in the AADT

As above, traffic distribution is obtained from VM201 in "Highway Statistics Summary, 1995" for the years 1961-1980. The final split is developed and shown in spreadsheet PERCEN61.WKS.

3. Development of Annual Design Lane traffic level and lane distribution

All Non-Interstate facilities are of such AADT that they represented a two-lane roadway. As such, half of the traffic and all vehicles are in the design lane.

4. Computation of Structural Number (SN) for the given system and 20 year time period and computation of corresponding Unit Equivalent Single Axle Loads (ESALs) for the computed SN, for passenger vehicles, single unit trucks and combination vehicles

This computation is conducted similarly to that above for the Interstate System.

5. Computation of the Environmental Factor, taken as equivalent to ten percent of accumulated ESALs

Same as methodology as above.

6. Computation of Target ESALs for each 0.1 drop in Terminal Serviceability (Pt), starting from an Initial Serviceability (Po) of 4.2

Same methodology as above.

7. Computation of time in years to reach each Pt point

Same methodology as above.

F. NON-INTERSTATE STATE SYSTEM 1981-2000

1. Development of AADT by year for the design period

AADT for both rural and urban are read from the rural and urban curves developed in Section C above. Values for Rural and Urban AADTs are shown in spreadsheet R6180NIS.WKS. The rural /urban VMT ratios previously derived for 1961 and 1981 are used to weight the rural and urban AADTs. Results are shown in spreadsheet R3NINTCO.WKS.

2. Development of Traffic Distribution by year in terms of passenger vehicles, single unit trucks and combination vehicles in the AADT

As above, traffic distribution is obtained from VM201 in "Highway Statistics Summary, 1995" for the years 1961-1980. The final split is developed and shown in spreadsheet PERCEN82.WKS.

3. Development of Annual Design Lane traffic level and lane distribution

All Non-Interstate facilities are of such AADT that they represented a two-lane roadway. As such, half of the traffic and all vehicles are in the design lane.

4. Computation of Structural Number (SN) for the given system and 20 year time period and computation of corresponding Unit Equivalent Single Axle Loads (ESALs) for the computed SN, for passenger vehicles, single unit trucks and combination vehicles

This computation is conducted similarly to that above for the Interstate System.

5. Computation of the Environmental Factor, taken as equivalent to ten percent of accumulated ESALs

Same as methodology as above.

6. Computation of Target ESALs for each 0.1 drop in Terminal Serviceability (Pt), starting from an Initial Serviceability (Po) of 4.2

Same methodology as above.

7. Computation of time in years to reach each Pt point

Same methodology as above.

G. LOCAL SYSTEM 1921-1941

1. Development of AADT by year for the design period

No local AADTs are available from Barbara Fraumeni, the yearly "Highway Statistics" publications and the "Highway Statistics Summary, 1995", so innovation and estimation is necessary. After exploring several ways of arriving at a composite AADT, one is finally selected. It involved adding rural Major Collector, Minor Collector, and Local miles in Table HM220 and dividing it into the total rural VMT for Other Rural Roads, all in the above publication. The result is divided by 365.25 to give AADT. Then the ratio of Urban AADT to Rural AADT of the appropriate years as used in the Non-Interstate State System AADT curves is used to find the urban Local AADT. The ratio of Rural to Urban miles as used above are used to weight the Rural and Urban AADTs to arrive at composite AADT. The results are computed on and are shown on spreadsheets RLOCAADT.WKS and LOCOMB.WKS. A value of 35 starting value for the rural 1921 AADT is arrived at by ratioing the rural Local AADT in 1980 to the value selected for the rural Non-Interstate State System. Again, an adjustment of AADT is made for depression years.

2. Development of Traffic Distribution by year in terms of passenger vehicles, single unit trucks and combination vehicles in the AADT

As above, traffic distribution is obtained from VM201 in "Highway Statistics Summary, 1995" for the years 1936-1940. The categories "other rural" and "all urban" are used for all three vehicle groupings. The trend for those years is back projected to 1921 for the other values. The final split is developed and shown in spreadsheet R213640.WKS. Annual ESALs per year are computed on spreadsheet LESAL.WKS.

3. Development of Annual Design Lane traffic level and lane distribution

All Non-Interstate facilities are of such AADT that they represented a two-lane roadway. As such, half of the traffic and all vehicles are in the design lane.

4. Computation of Structural Number (SN) for the given system and 20 year time period

and computation of corresponding Unit Equivalent Single Axle Loads (ESALs) for the computed SN, for passenger vehicles, single unit trucks and combination vehicles

This computation is conducted similarly to that above for the Interstate System and Non-Interstate State Systems. Duplicates of original files used in the Interstate and Non-Interstate Systems are made and used as working files for the local computations. REPESALS.WKS computes representative ESALs. LOC2WORK.WKS computes annual ESALs per year for each of the 20 years involved. LOC1WORK.WKS computes the Time to drop to each Pt value from 4.2 to 2.0 in 0.1 intervals.

5. Computation of the Environmental Factor, taken as equivalent to ten percent of accumulated ESALs

Same as methodology as above.

6. Computation of Target ESALs for each 0.1 drop in Terminal Serviceability (Pt), starting from an Initial Serviceability (Po) of 4.2

Same methodology as above.

7. Computation of time in years to reach each Pt point

Same methodology as above.

H. LOCAL SYSTEM 1941-1960

Weighted AADT is computed as above in LUNI4160.WKS.

Traffic composition is computed in L4160TC.WKS, back projecting SU and Combination vehicles for 1941 to 1950 by using 1951 to 1960 values.

Annual ESALs are found from RNISESAL6.WKS.

Years to Pt are found using YRESAL6.WKS.

I. LOCAL SYSTEM 1961-1980

Weighted AADT is computed as above in LUNI6180.WKS

Traffic composition is computed in L6180TC.WKS. "Other 2 axle, 4 tired" values for 1966
on are put into the SU category as it is done that way in the table before 1966.

Annual ESALs are found from RNISESAL5.WKS.

Years to Pt are found using YRESAL5.WKS.

J. LOCAL SYSTEM 1981-2000

Weighted AADT is computed as above in LUNI8100.WKS

Traffic composition is computed in L8100TC.WKS.

Annual ESALs are found from RNISESAL4.WKS.

Years to Pt are found using YRESAL4.WKS.

K. FINAL COMPUTER FILE SUMMARIZING RESULTS

The Pt vs Time curves by System and Time Interval are detailed in spreadsheet FINALRES.WKS included on the documentation disk..

L. ACCOMPANYING DISKETTES LABELED PICHER DISK 1 AND 2, AND SUPPLEMENTARY INFORMATION

All files mentioned in this documentation are contained in the accompanying diskettes, labeled Picher Disk 1 and Picher Disk 2. Filenames ending with the file extension ".WKS" are presented in their ".XLS" version, for the convenience of the EXCEL user. ".CSV" and LOTUS ".WK1" files are also given for completeness.

Additional material is attached to this document for clarity. Copies of the original AADT curves and the equation used for computing axle and axle group ESALs are attached.

Additional detail is available in specific computation packets resident in Mainesurf, Inc. files.

APPENDIX IV LIST OF PICHER COMPUTER FILES

ORIGINAL FILE	XLS VERSION
ADTURB.WKS	ADTURB.XLS
ASPH.WKS	ASPH.XLS
AUNI4160.WKS	AUNI4160.XLS
COMBR&U.WKS	COMBR&U.XLS
ESALFAST.FMT	XXXXXXXXXXXX
ESALFAST.WK1	XXXXXXXXXXXX
FINALRES.WKS	FINALRES.XLS
I4ALL.CSV	XXXXXXXXXXXX
IMBESAL.FMT	XXXXXXXXXXXX
IMBESAL.WK1	XXXXXXXXXXXX
L4160TC.WKS	L4160TC.XLS
L6180TC.WKS	L6180TC.XLS
L8100TC.WKS	L8100TC.XLS
LESAL.WKS	LESAL.XLS
LOC1WORK.WKS	LOC1WORK.XLS
LOC2WORK.WKS	LOC2WORK.XLS
LOCOMB.WKS	LOCOMB.XLS
LUNI4160.WKS	LUNI4160.XLS
LUNI6180.WKS	LUNI6180.XLS
LUNI8100.WKS	LUNI8100.XLS
NISESALS.WKS	NISESALS.XLS
PERCEN41.WKS	PERCEN41.XLS
PERCEN61.WKS	PERCEN61.XLS
PERCEN82.WKS	PERCEN82.XLS
R1NINTCO.WKS	R1NINTCO.XLS
R213640.WKS	R213640.XLS
R2NINTCO.WKS	R2NINTCO.XLS
R3NINTCO.WKS	R3NINTCO.XLS
R6180NIS.WKS	R6180NIS.XLS
REPESALS.WKS	REPESALS.XLS
RLOCAADT.WKS	RLOCAADT.XLS
RNISESA4.WKS	RNISESA4.XLS
RNISESA5.WKS	RNISESA5.XLS
RNISESA6.WKS	RNISESA6.XLS
RRNISESA.WKS	RRNISESA.XLS
RURAL.XLS	XXXXXXXXXXXX
RURAL2.XLS	XXXXXXXXXXXX
TR213640.WKS	TR213640.XLS
TRAFSPLT.WKS	TRAFSPLT.XLS

URBAN.XLS	XXXXXXXXXXXX
URBAN2.XLS	XXXXXXXXXXXX
WTAVGADT.WKS	WTAVGADT.XLS
YRESAL.XLS	XXXXXXXXXXXX
YRESAL4.WKS	YRESAL4.XLS
YRESAL5.WKS	YRESAL5.XLS
YRESAL6.WKS	YRESAL6.XLS
YRESAL9.WKS	YRESAL9.XLS

APPENDIX V STATISTICAL DATA GATHERING REQUIRED FOR DEVELOPMENT OF AADT AND TRAFFIC COMPOSITION

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April 14, 1998 [107]

The following indicates the statistical research needed to define the pavement deterioration functions for "Interstate", "State other than Interstate", and "Other than State", as related to AADT and vehicle miles of travel (vmt). The emphasis should be on gathering Interstate data as a primary function. The data for the other systems will be used as we examine those systems.

The data should be gleaned back in time as far as possible, but not for before 1920. In the case of Interstate, expect to run out of AADT and vmt in the late 1950s when going back in time. The Interstate system was established in 1956, and included by definition and law many existing toll facilities, especially in the northeast, mid-Atlantic and Midwest regions.

Please use the following approach for the two parameters above, as I have done for the year 1995, for the Interstate System.

A. AADT:

Reference: Highway Statistics -1995 Table HM-57 page V-55 for Rural Interstate
Table HM-57 page V-57 for Urban Interstate

Construct the following tables, for 1994, 1993, etc. stepping back a year in time each time. The values shown below are the 1995 figures.

I. Rural

AADT - Centerline miles of Rural Interstate System

AADT Group	<6000	6000-9999	10000-19999	20000 and over
Miles	4524	4745	11,143	12,168
Est.Reference AADT	3000	8000	15000	25000
AADT*miles	13,572,000	37,960,000	167,145,000	304,200,000

Total miles: 32,580

Total of AADT*miles: 522,877,000

Rural Weighted Average AADT = 522,877,000/32,580 = 16,049 vpd

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[107] This text is based primarily on an email dated April 4, 1998. It was revised on December 21, 1998 by Barbara Fraumeni to correct for typographical errors and to reflect minor refinements in the procedure employed.

II. Urban

AADT - Centerline miles of Urban Interstate System

AADT Group	<15000	15000-34999	35000-59999	60000-99999	100,000 and over	TOTAL
Miles	778	3132	3197	2871	3186	
Est.Reference AADT	7500	25000	47500	80000	125000	
AADT*miles	5,835,000	78,300,000	151,857,500	229,680,000	398,250,000	

Total miles: 13,164

Total of AADT*miles: 863,922,500

Urban Weighted Average AADT = 863,922,500/13,164 = 65,628 vpd

III. Interstate System Weighted Average Composite AADT:

(522,877,000 + 863,922,500)/(32,580 + 13,164) = 30,316 vpd

B, Vehicle Miles of Travel - Traffic Composition

Reference: Highway Statistics Summary to 1995 VM-201 Page V-14

Reference Vehicle	Millions of Vehicle Miles of Travel - Interstate System Rural	Urban	Total	Adjusted Percentage
Passenger Cars	115,991	205,497	321,488	57.0
Busses	711	580	1,291	0.2
Other 2 Axle-4 tire vehicle	63,329	109.811	173,140	30.6
Single Unit Trucks	6,708	7,148	13,856	2.4
Combinations	36,644	18,492	55,136	9.8
				100.0

It is not necessary to use the above table format. A spreadsheet format with one line for each year is preferable, as long as all the data and computations above are included. The tables above were shown for the sake of clarity.

For AADT s in the "State - other than Interstate System" category, the researcher must use all of the data included under "Other Principal Arterial", "Minor Arterial", and "Major Collector" for Rural. Similarly, for Urban, he must use "Other Freeways and Expressways", "Other Principal Arterials", "Minor Arterial" and "Collector", merging it all to arrive at a composite AADT for the categories as a whole, weighting each result by number of miles in each category. For "Other than State", no data is supplied. A separate estimate will be generated by the project principals.

For Vehicle Miles of Travel - Traffic Composition for "State other than Interstate", use Table VM-201 page V-14. Use only the categories shown for other than Interstate (i.e., "Rural Other Arterial", 'Other Rural Roads", and "Other Urban Streets"). Find the sum of the vmts of these categories and compute the percentage distribution for each vehicle class, as done above.

For Vehicle Miles of Travel - Traffic Composition for "Other than State", use Table VM-201 page V-14. Use only the categories "Other Rural Roads" and Other Urban Streets".

Finally, record the Interstate miles open to traffic from Table HM-30 page V-31 1995 Annual Highway Statistics for Urban, Rural and Total for all years back to 1956, the inception of the Interstate System. If the Annual Highway Statistics books take it beyond that, please report what they do.

APPENDIX VI SUPPLEMENTARY INFORMATION FROM PICHER

ESAL=(Wt/W18)

log(Wt/W18)=al*log((Lx+n) / 19)-a2*log(n)+Gt(1/B18-1/Bx)

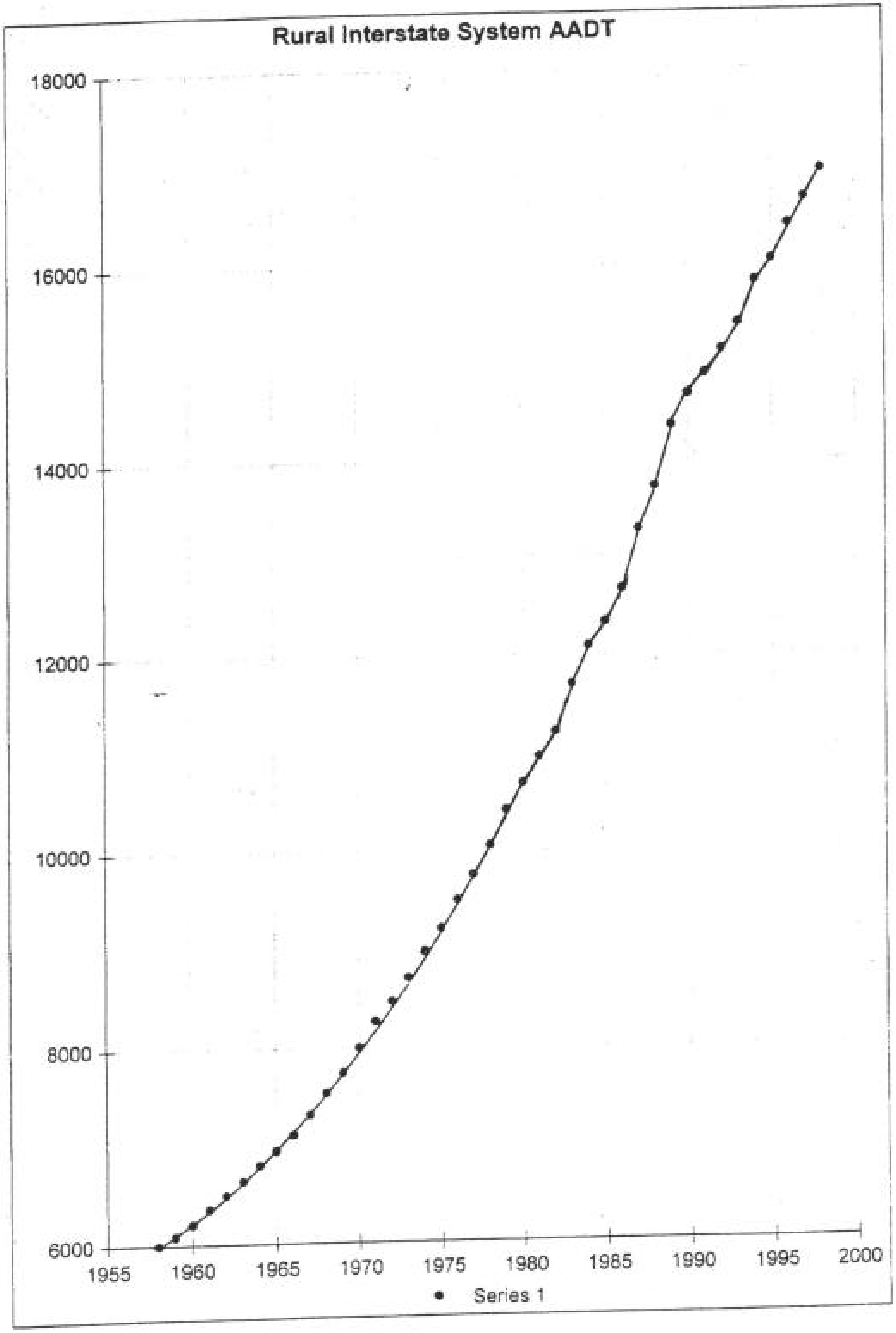
Lx=Load on axle or axle group in kips

N=# of axles in group

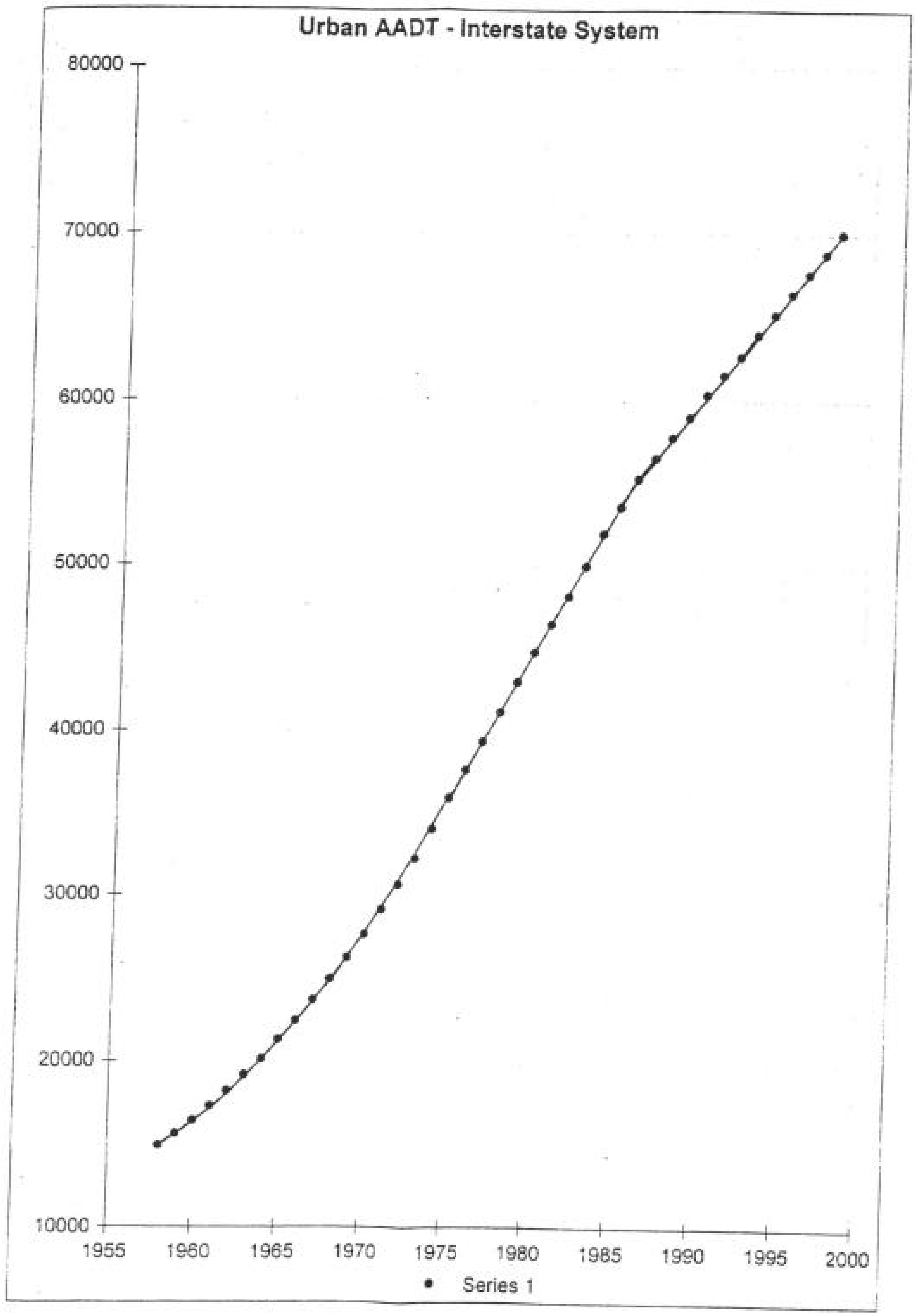
Gt=log ((Po-Pt)/(Po-1.5))
Po=4.2 for flexible pavement
Pt=acceptable terminal pavement serviceability =2.5

Bx=B1+[b2*(Lx+n)**b3/{(STR+1)**b4*(n)**b5}]
STR=structural number for flexible pavement (SN)=5

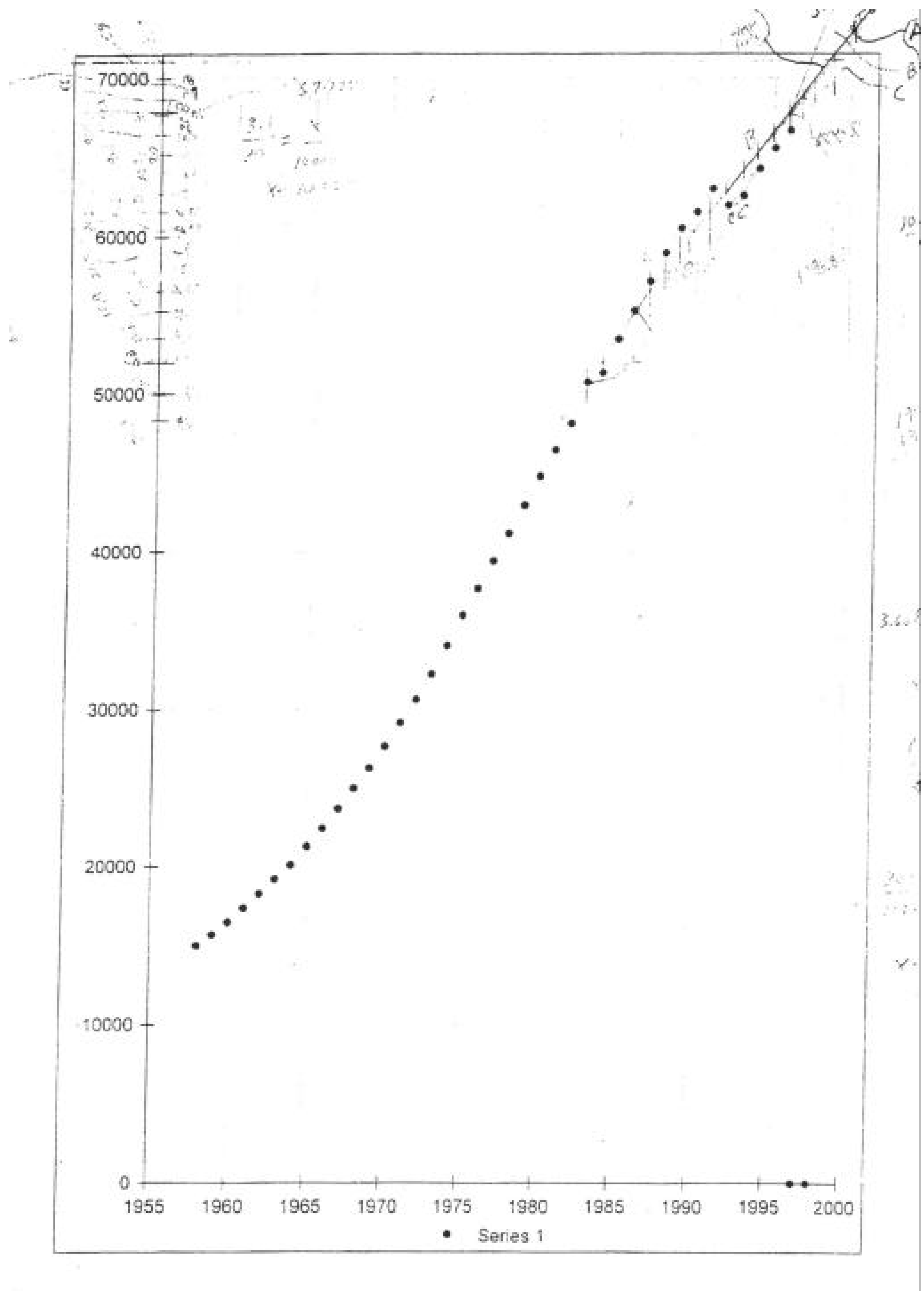
a1 = 4.79
a2 = 4.33
b1 = 0.40
b2 = 0.081
b3 = 3.23
b4 = 5.19
b5 = 3.23



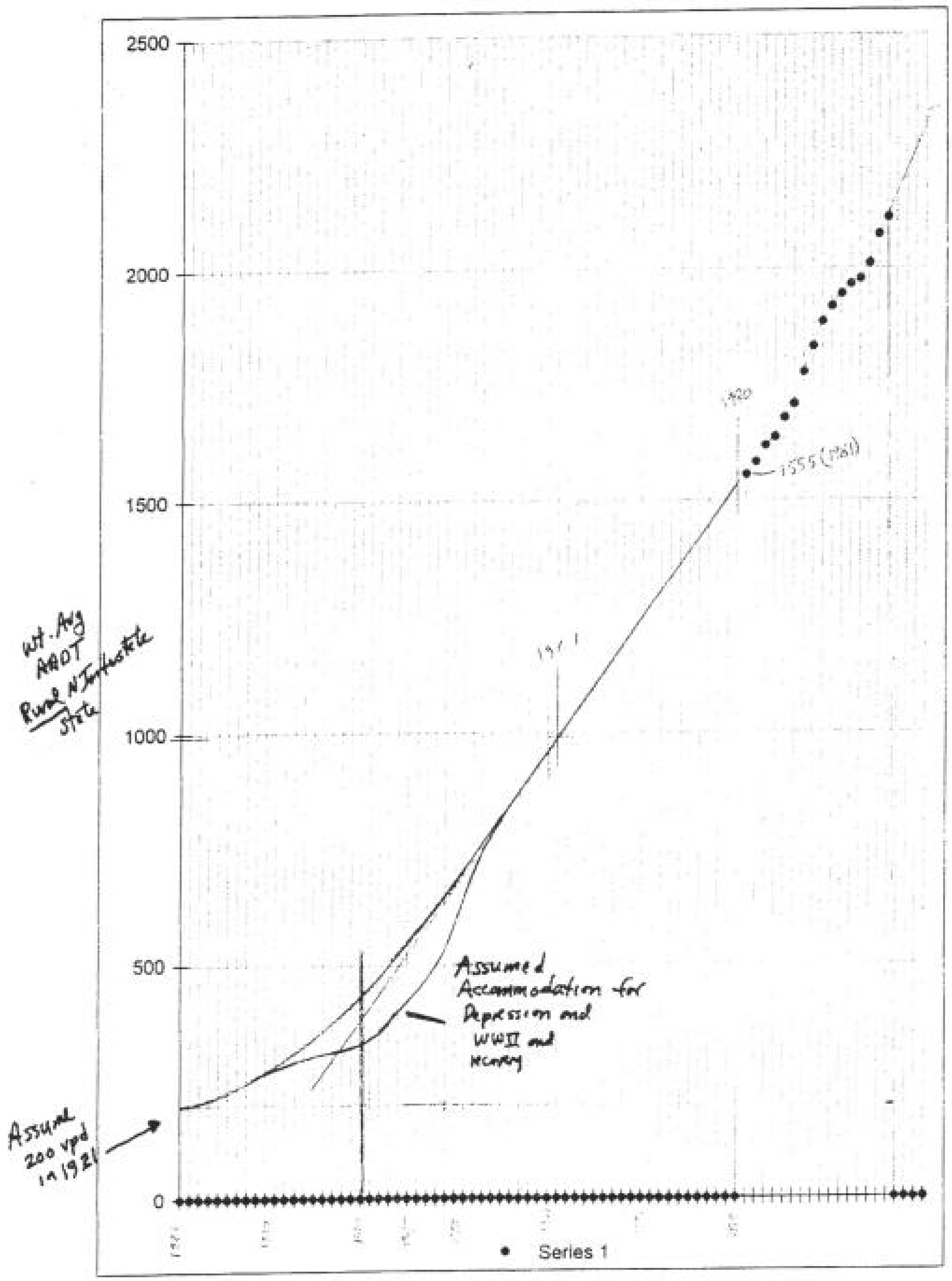
Rural Interstate System AADT
18000
16000
14000
12000
10000
8000
6000
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Series 1



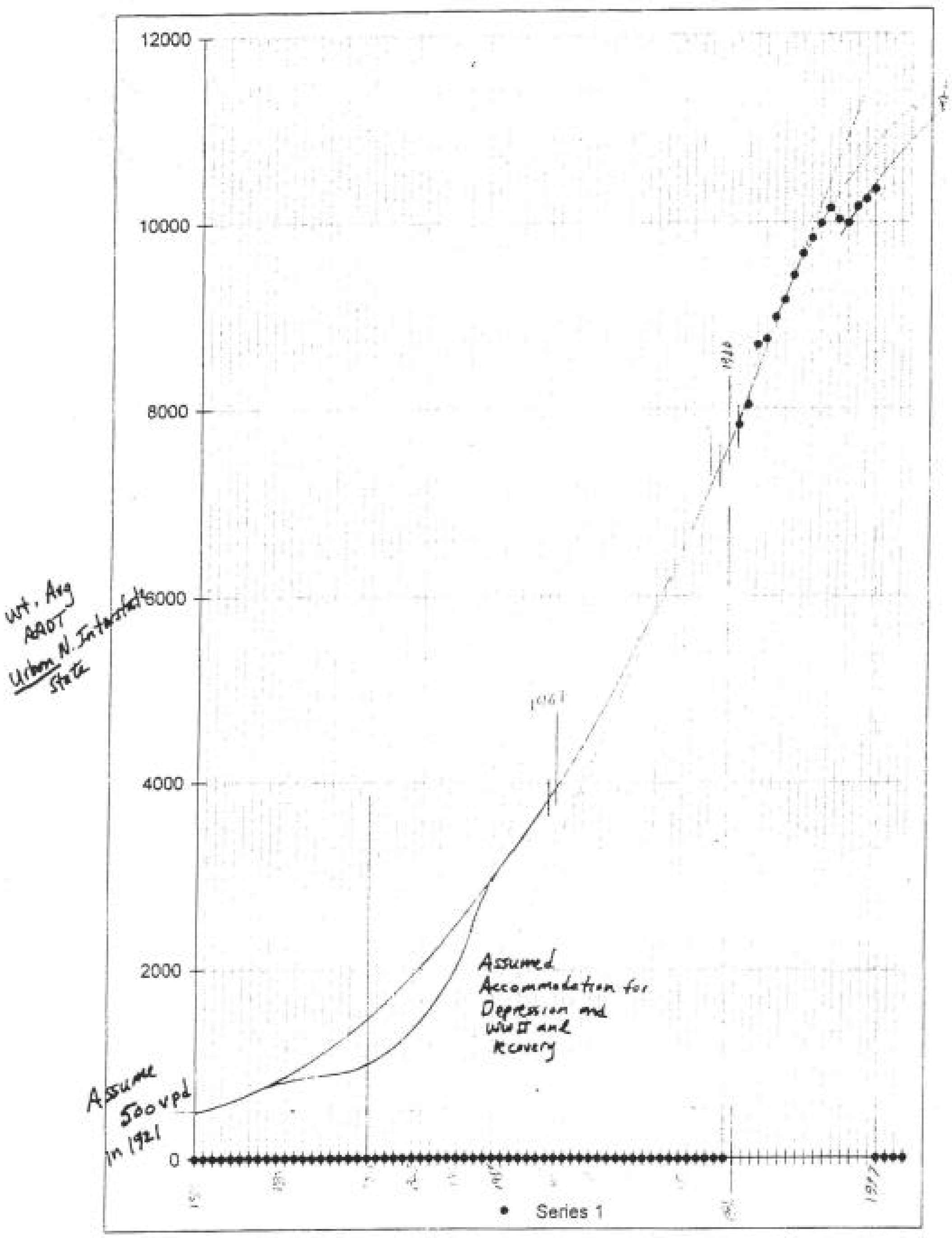
Urban AADT - Interstate System
80000
70000
60000
50000
40000
30000
20000
10000
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Series 1



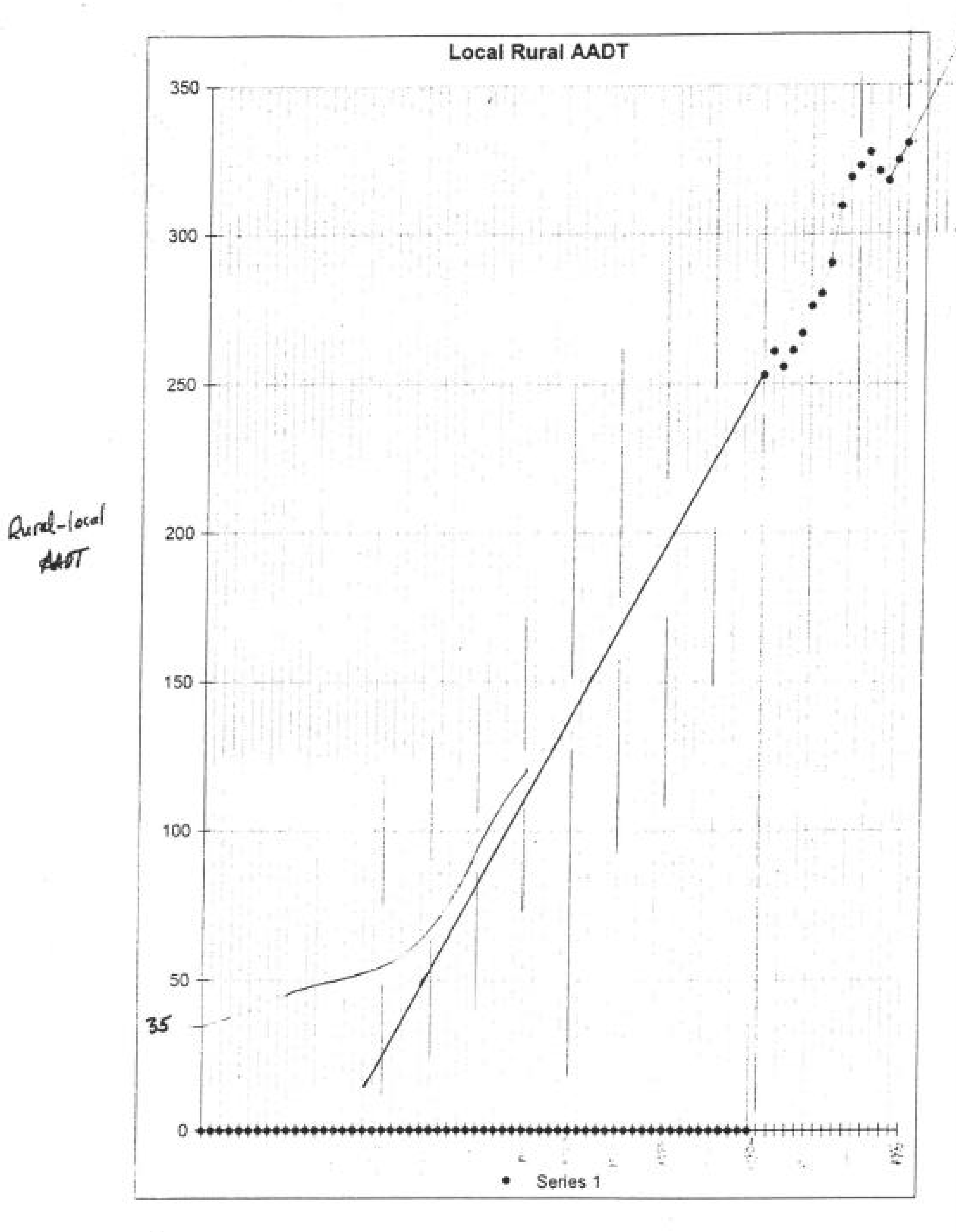
70000
60000
50000
40000
30000
20000
10000
0
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
Series 1



2500
2000
1500
1000
500
0
Series 1
Wt. Avg
AADT
Rural N Interstate
State
Assume
200 vpd
in 1921
Assumed
Accommodation for
Depression and
WWII and
recovery
1555 (1961)



12000
10000
8000
6000
4000
2000
0
Wt. Avg
AADT
Urban N. Interstate
State
Assume
500vpd
in 1921
Assumed
Accommodation for
Depression and
WWII and
Recovery
1967
Series 1


Local Rural AADT
350
300
250
200
150
100
50
0
35
Rural-local AADT
Series 1