AUSTRALIAN ROAD AND HIGHWAY ASSET MODEL

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Abstract: Australian road assets are estimated at about 100 billion dollars. The asset value is constantly changing due to new investment in road infrastructure and continuous deterioration from use and climatic effects. Knowledge of total expenditure on roads and bridges including new construction, minor and major upgrading and refurbishments, and maintenance are essential inputs into the assessment of the road system. Gross capital stock is based on retirements while the net capital stock is affected by depreciation. Net and gross capital stock is estimated for the period 1968-69 to 1997-98. This study uses the conventional Perpetual Inventory Model approach. The output from the asset model confirms that it is an appropriate technique for estimating the value of road assets. It also shows that a 50% retirement function is suitable for representing the pattern of retirement of road assets in Australia. The asset value may be used to devise road pricing and investment policies.

Key Words: Road assets, Capital stock, Depreciation, Retirement functions, Australia

1. INTRODUCTION AND BACKGROUND

Capital refers to the total investment of owners in a business that is available for reinvestment in the production of goods (Barnhart 1975). Capital stocks are reproducible, tangible assets used as factors of production in combination with other inputs such as labour, energy and other natural resources or materials. When considering the economy of a country, capital stock investments include health, education, defence, social security and welfare, housing, recreation and culture, fuel and energy and transport and communications, among others. The transport and communications sector is segregated into road, water, air, rail and communications.

The Australian road system is an important economic asset. It consists of roads, bridges, intersections, tunnels, and other forms of road infrastructure. The system has evolved over decades over which millions of dollars have been invested each year in its construction, maintenance, rehabilitation and management. Like all assets, the road system renders service throughout its life and depreciates from use, obsolescence and environmental factors.

Economic performance studies are essential to gain insights into how transportation infrastructure services should be priced, delivered, managed and financed. Charging for infrastructure increases the efficiency of road and highway infrastructure capital stock. Therefore, to devise policies on investment and pricing, the estimation of asset value of road infrastructure is essential.

1.1 Asset Value

The asset value of the Australian Road and Highway system is based on the public and private sector investments in the system. Three variations of asset value can be determined: the Book value, the Replacement value, and the Market value.

Book value is an accounting concept. It is based on the cost of acquiring the asset which is adjusted for depreciation.

Replacement value of an asset is the cost today to replace the asset in new condition. This is always higher than the book value, but is a useful concept for insurance purposes. It is recommended by insurance companies that a house or a building be insured for its replacement value so that in the event of destruction, the insurer is not out of pocket in replacing the asset.

Market value is the value that the asset will fetch if sold on the market in its current condition. The market value may be less or greater than the book value and may depend on the depreciation model used, the current condition of the asset, and the history of its use. If the asset cannot be easily sold in the market place, as is the case with the Australian Road and Highway system, the present value of all benefits that the asset may provide in its lifetime may be taken as its worth and hence, the market value.

This paper only aims to provide estimates of the book value of road and highway infrastructure. No attempt has been made to estimate the replacement or market value. This is considered to be compatible with the financial statements produced by government agencies which show the value of the road assets after accounting for depreciation.

1.2 Depreciation Models

Depreciation may be time-based and/or activity-based. Since a proportion of deterioration of roads takes place from weather and environmental factors, some part of depreciation has to be based on elapsed time.

Activity-based depreciation: An asset may be depreciated on the basis of its usage (activity) and/or the passage of time. In case of highway and road assets, the activity-based depreciation charge in a period will be a fraction of the asset value which is the ratio of travel task undertaken during the period to the life-time travel task that can be undertaken on the asset. The difficulties in basing the depreciation charge on activity levels include the following:

Non-homogeneity of tasks: The road and highway system is used for the movement of people (expressed in vehicle-km) and for the movement of goods (expressed in tonne-km). It would be necessary to convert the task performed into a homogeneous product.

Non-homogeneity of users: The system is used by vehicles of varying sizes and axle weights. Vehicles cause varying degree of wear and tear of the system based, primarily, on their weight. It is well known that a semi-trailer causes more wear and tear than a dozen sedans. Passenger car equivalents may need to be developed to convert the total traffic using the system to a homogeneous quantity. Remember that the well-known concept of pcu in traffic flow is based on the effect of vehicles on the relative degree of difficulty in manoeuvring and is inappropriate in the case of assessing their relative effect on wear and tear of the road system.

Time-based depreciation: The harsh climatic and environmental factors (like frozen roads in Canada, and cyclonic rains in North Queensland) have dramatic impact on the deterioration of roads. Therefore, some proportion of depreciation of highway assets has to be time-based. Hutchinson (1991) found that 50% of road network deterioration could be attributed to environmental factors alone in Canada.

Models of time-based depreciation: It is easier and more common to use time-based depreciation models only. Three common variations of time-based depreciation models are identified: the linear or straight line model (constant depreciation charge), the geometric or declining balance model (accelerated depreciation) and sinking fund model (delayed depreciation). The declining balance model is more commonly used in capital stock models, although for road and highway assets, the deterioration is slower in the earlier periods and accelerates as the asset ages. This points to the appropriateness of the delayed model. However, most road authorities in Australia use the straight-line method of depreciation.

1.3 Investment in Roads and Highway Systems

Investment in the Australian Roads and Highway system is made by public sector (Commonwealth, State and local governments) and by private sector (toll roads, Harbour tunnel, and private roads). The amount and proportion of funding by various levels of government has been changing over time. Figure 1 shows the sources of investment in the Australian road infrastructure system.

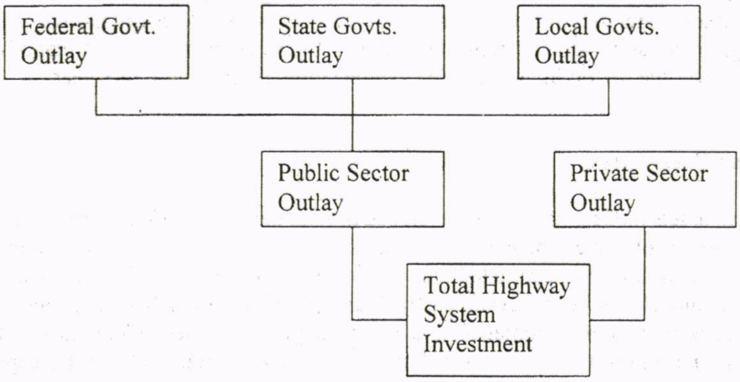

Figure 1: Sources of Highway System Investment

Investment in new road and bridge construction and major upgrading and refurbishments is considered to increase the asset value while land acquisition, research and development and minor renovations and alterations are not included in updating the asset value. Where possible, the expenditure on bridge construction and rehabilitation has been separated from the road and highway construction to develop separate models for bridge assets and road/highway assets.

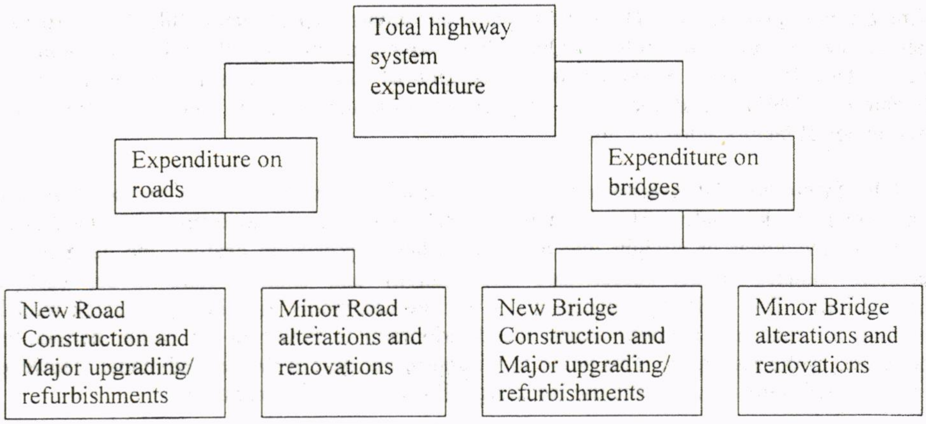

Figure 2: Structure of Highway System Expenditure

2. METHODOLOGY

The asset value of the road system is increased by new investments and reduced by depreciation or retirements. The structure of an asset model is based on a typical inventory or reservoir model with inflow and outflow. The inventory or quantity of water in the reservoir is a level while inflow and outflow are rates over the relevant period. Figures 3 and 4 show the inputs and outputs of an asset model in terms of stocks (levels) and flows. Stocks are measured at the end of the period (eg. gross capital stock), in million dollars. Flows are measured as a rate of change in the constituent over the period in question (eg. depreciation, retirements), in $/year.

2.1 Estimation Procedures

Numerous road assets models have been developed around the world. Most of these models have been in the domain of government departments. Almost every road/transport authority at a provincial or national level has estimated the value of their road assets. The Canadian Road and Highway Asset model has been developed by Transport Canada (Richardson, 1996) and uses three models of depreciation – geometric, linear and delayed. The net capital stock in highways declined as a proportion of total stock as well as a percentage of total public sector capital stock. Government investment in highway capital has been displaced by other public sector priorities. Hofman (2000) applied the Perpetual Inventory Method (PIM) for estimating the capital stock of Latin American highway system. This method is currently used by most OECD countries. The Australian Bureau of Statistics (Walters and Dipplesman, 1985) also used PIM to estimate Australia's capital stock in several sectors of the economy including transport. As a part of the road network asset modelling, the Queensland Main Roads Department has used a computeraided design package called Paminet SCENARIO for developing a decision support tool for its road assets maintenance system (Muir and Gordon, 1999).

2.2 Perpetual Inventory Model

The method used for determining the asset value and average age of the Australian road and highway system is through the use of the Perpetual Inventory Method (PIM). PIM is used to estimate gross capital stock as a weighted sum of cumulative historic investment flows (or capital formation expenditures) appropriately adjusted for discards. Net capital stock, depreciation flows, retirement flows and the average age of the capital stock for 1968-69 to 1997-98 are also determined using PIM. PIM is chosen over other methods of measuring capital stock that include surveys of physical assets, book values and insured values, composite physical indices, accumulated savings models, and stock exchange values. In general, PIM is advantageous as it uses available historic data on investment expenditure that is generally timely, uniform and comparable. The model is relatively flexible where certain variables and assumptions can be included or excluded from the model and it is easy to test its sensitivity to varying definitions and hypotheses. Also, statistical transformation from current to constant dollar values is easily obtainable.

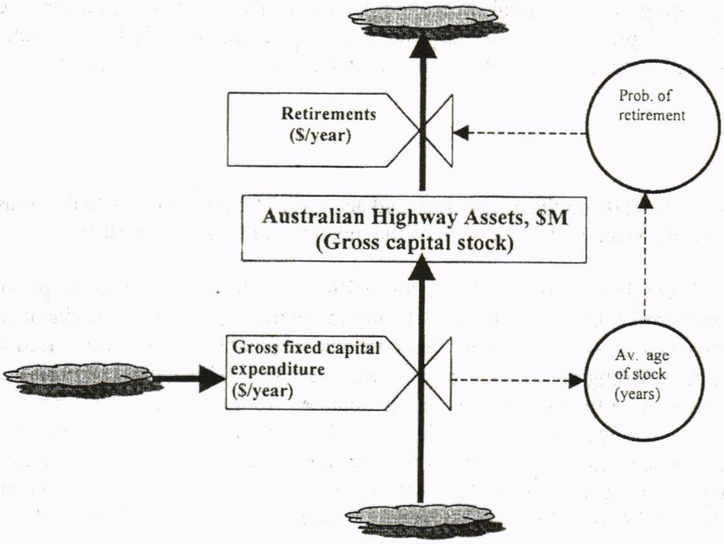

Figure 3: Basic Structure of Gross Capital Stock Model

Gross capital stock is updated by adding gross fixed expenditure on road infrastructure and subtracting retirements. Net capital stock is obtained by subtracting depreciation charge.

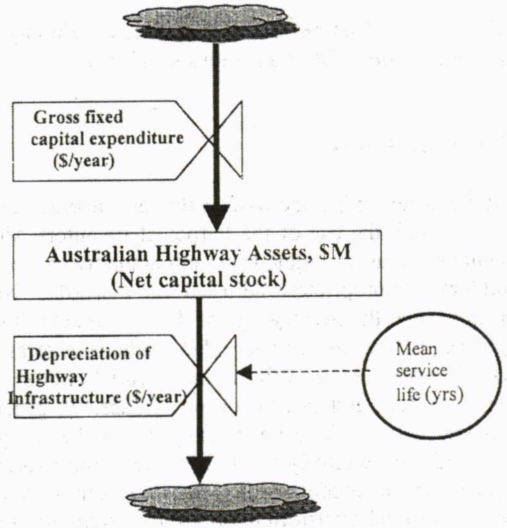

Figure 4: Basic Structure of a Net Capital Stock Model

PIM requires the accumulation of past capital investment flows, appropriately adjusted for asset retirement flows and annual depreciation amounts. Therefore, model inputs include gross fixed capital expenditure, assumed service life, a depreciation model and the retirement function.

2.3 Data

The precision of the model depends on the availability and accuracy of expenditure data that must extend over the lifetime of the stock and as far back as the most durable asset in existence.

A complete set of expenditure data is only available for 1970-71 to 1986-87. This is the period when the State Road Authorities and other agencies began to submit reports on their financing and expenditure procedures. It was, in this time, that cost recovery policies were recognised as an important ingredient in providing an efficient road transport system. This data is necessary as input into the model to determine the asset values and is obtained from the Bureau of Transport Economics (1982, 1989). The information includes expenditure figures for each of the three levels of government and is segregated according to whether the expenditure is for construction, maintenance or planning and research. Values for total expenditure for each level of government are available from 1987-88 to 1997-98 from the Bureau of Transport Economics (1998, 1999).

The model, used to determine the asset value requires that expenditure data be extended to cover the assumed service life of the stock. The earlier data is for total expenditure by all levels of government and is obtained from Butlin (1962), Keating (1973), Australian Bureau of Statistics and the Bureau of Transport Economics (1979, 1979a). As suggested by the Commonwealth Bureau of Roads (1975), maintenance expenditure is assumed to be 25% of the total expenditure.

2.4 Price Indices

Various data sources provided expenditure data in either current dollars or in an earlier year constant dollars. For consistency, all data was converted to constant 1998-99 dollars by using appropriate road construction price indices published by the Bureau of Transport Economics.

2.5 Mean Service Life

The service life of an individual capital item is "the interval between the date it enters productive activity and the date it ceases to be employed in productive activity" (Bailey 1981). The mean asset life for a class of assets, as in the case of road infrastructure, is the weighted average of the mean asset lives of the individual members of the class. Although asset lives are an important requirement for the effective use of the Perpetual Inventory Method, the available asset life data is limited. A study on the measurement of capital by Ward (1976) described mean service lives as the "weakest aspect" of the Perpetual Inventory Method.

Austroads (2000) lists the assumed mean service life for roads and bridges according to their construction material. It is known that timber bridges have a much lower expected service life in comparison to stronger, more reliable materials such as concrete or steel. Hence, by applying a weighting factor according to the probability of occurrence of the different building materials, the average service life is determined. The road infrastructure capital stock service lives are likely to show considerable variation over time due to increasing pace of technological and economic change and the relative costs of constructing new stock and maintaining the old stock. To accommodate this variance, it is wise to assume a distribution around the mean to accommodate the youngest and oldest service lives in the stock.

3. ROADS AND HIGHWAYS ASSET MODELLING

3.1 Road Infrastructure Gross Capital Stock

Gross capital stock represents the total volume of the existing physical stock available to a country. This is a measure of cumulated past investment flows still remaining in the current period stock, valued at the prices of some base year. This measure takes account of retirements of the stock that are made each year as the asset nears the end of its expected service life.

Following the calculation of investment, retirement and service life, the gross capital stock value for all roads in Australia has been determined. The initial starting value of the gross capital stock (1968-69) is taken from Walters *et al* (1985) who used PIM to determine the asset value of all stock in the Australian economy. The remaining gross capital stock figures from 1969-70 to 1997-98 are easily obtained by:

$$GCS_t = GCS_{t-1} + GI_{(t-1,t)} - R_{(t-1,t)} \quad (1)$$

where GCS_t = Gross Capital Stock at end of year t ($)
GCS_{t-1} = Gross Capital Stock at end of year t-1 ($)
$GI_{(t-1,t)}$ = Gross investment during year (t-1,t) ($/year)
$R_{(t-1,t)}$ = Retirements made during year (t-1,t) ($/year)

3.2 Retirements

Once a mean asset life is assumed, it is necessary to apply a distribution that represents the retirement pattern of the asset. This distribution may be expressed as either a survival or a retirement function. Survival functions refer to the proportion of investment in a particular asset category in a year that will survive a given number of years. Retirement functions, on the other hand, refer to the proportions of the investment that are retired in each year. As values of annual asset retirements are required in the Perpetual Inventory Method, retirement functions are of most use in this study.

Three variations of the retirement functions are assumed for this model. These represent varying assumptions regarding the probabilities of retirements of assets at the end of their mean service life. This requires determining the probability of retirement in each year from new (zero years) until the mean service life is reached, assuming that by the end of that year, the asset would be 50, 75 and 100 % retired. The first two assumptions allow for variances of service life around the mean while the last assumes that the entire asset existing in year 1 would be retired by the end of the service life year.

A bell-shaped curve best describes the retirement pattern of roads and bridges. The curve suggests that the probability of retirement (P_j) in the first few years (for road stock, approximately 10 years) is zero or close to zero. The probability increases along the bell-shaped distribution as the mean service life approaches the maximum value (50, 75 or 100%).

After determining the probability of retirement each year after acquisition (P_j), the retirement value can be determined, Walters (1985).

$$R_{(0,t)} = \sum_{j=1}^{ML} P_j \, GI_{(t-1,t)-j} \qquad (2)$$

where $R_{(0,t)}$ = Accumulated retirements to end of period t ($/year)
$GI_{(t-1,t)}$ = Gross investment in period t ($/year)
P_j = Probability of retirement j periods after acquisition
ML = Mean service life (years)

This produced the total amount of retirements made from acquisition of the stock to that date. Repeating the procedure using a Microsoft Excel spreadsheet package determined all retirement values from 1969-70 to 1997-98. However, PIM requires the amount retired in each year to correspond with annual investment data. Defined as the difference in the total retirements made from one year to the next, the amount retired in each year was:

$$R_{(t-1,t)} = R_{(o,t)} - R_{(0,t-1)} \quad (3)$$

where $R_{(t-1,t)}$ = Retirements made during year (t-1,t) ($/year)
$R_{(o,t)}$ = Accumulated retirements from acquisition to year t ($/year)
$R_{(0,t-1)}$ = Accumulated retirements from acquisition to year t-1 ($/year)

The Perpetual Inventory Model employs these values in equation (1) to determine the gross capital stock.

3.3 Net Capital Stock

Net capital stock is the cumulated depreciated value of the existing gross capital stock. Net capital stock estimates reflect the declining value of an asset through its reduced potential capacity to generate future earnings, as its remaining lifetime becomes progressively shorter.

In the same manner as gross capital stock, the required starting value of net capital stock for 1968-69 was taken from Walters *et al* (1985). The net capital stock values for 1969-70 to 1997-98 are determined by:

$$NCS_t = NCS_{t-1} + GI_{(t-1,t)} - D_{(t-1,t)} \quad (4)$$

where NCS_t = Net capital stock at end of year t ($)
NCS_{t-1} = Net capital stock at end of year t-1 ($)
$GI_{(t-1,t)}$ = Gross investment in year (t-1,t) ($/year)
$D_{(t-1,t)}$ = Depreciation in year (t-1,t) ($/year)

3.4 Depreciation

Estimates of capital consumption are derived by applying the straight-line depreciation function while assuming the road stock asset declined with age from the initial cost to zero at the end of its service life. Hence, the salvage value at the end of the service life was assumed to be zero. This scenario would be true if there were no investments on capital formation and maintenance. However, for the case of Australia's road and highway stock, existing gross fixed capital expenditure in each year increased the depreciated value to the new capital stock value. The depreciation is calculated by using straight-line method as shown in Equation 5. Net asset value is calculated from 1969-70 to 1997-98 using Equation 4.

$$GCS_{t-1} / MRL = D_{(t-1,t)} \quad (5)$$

where GCS_{t-1} = Gross Capital Stock in year t-1 ($)
$D_{(t-1,t)}$ = Depreciation in year (t-1,t) ($/year)
MRL = Mean remaining service life of the asset (years)

4. RESULTS

4.1 Investment in Road Infrastructure

Investment data is available since 1885-86 and a summary is presented in Table 1. During 1885-97, the total expenditure by all levels of governments increased from $223.6 M to $7,014 M.

Table 1: Total Government Expenditure on Roads in Australia, $M

Year	Construction	Maintenance	Planning & Research	Total Expenditure
Local Government				
1970-71	393.9	337.7	0.0	731.6
1997-98	1033.9	965.8	0.0	1999.7
State Government				
1970-71	659.5	308.9	1.6	970.0
1997-98	2122.5	1213.3	42.7	3378.5
Commonwealth Government				
1970-71	937.2	70.9	14.3	1022.4
1997-98	1330.0	213.5	0.0	1543.5
Total Public Sector				
1885-86	167.7	55.9	0.0	223.6
1970-71	1990.7	717.4	15.9	2723.9
1997-98	4603.5	2367.8	42.7	7014.0

Source:- Bureau of Transport Economics (1979, 1982, 1989, 1998, 1999), Commonwealth Bureau of Roads (1975).

The trend in construction and maintenance expenditure is indicative of periods of economic downfall and uprise in Australia, as shown in Figure 5. Maintenance and construction expenditure remained relatively constant until the completion of World War I in 1918. The proportion increased slightly until the beginning of World War II, over which it decreased quite rapidly. Expenditure then increased until the 1970's after which it increased rapidly to 1997-98. Construction activity increased from $167.7M in 1885-86 to $4603.5M in 1997-98 and maintenance activity rose from $55.9M to $2367.8M over the same period. This means that maintenance formed 25% of total expenditure prior to 1970-71 after which it increased to 38% in 1997-98. Overall, expenditure on maintaining the road system became more important over the years while construction activity subsided. Planning and research expenditure also increased from 1970-71 at $14.2m to $29.8M in 1975-76. The highway investment as a proportion of Gross Domestic Product (GDP) has fallen dramatically up to 1980-81 but has remained steady at about 0.8% since then, as shown in Figure 6.

4.2 Private Sector Expenditure on Roads

Expenditure on construction by the private sector increased from $806.1M in 1983-84 to $4637.1M in 1998-99 as shown in Table 2. Of this, road construction attributes to 82% ($660.1M) in 1983-84 and increased to 95% ($4402.7M) in 1998-99. Bridges construction accounted for the remainder. (Australian Bureau of Statistics, catalogue no. 8762.0)

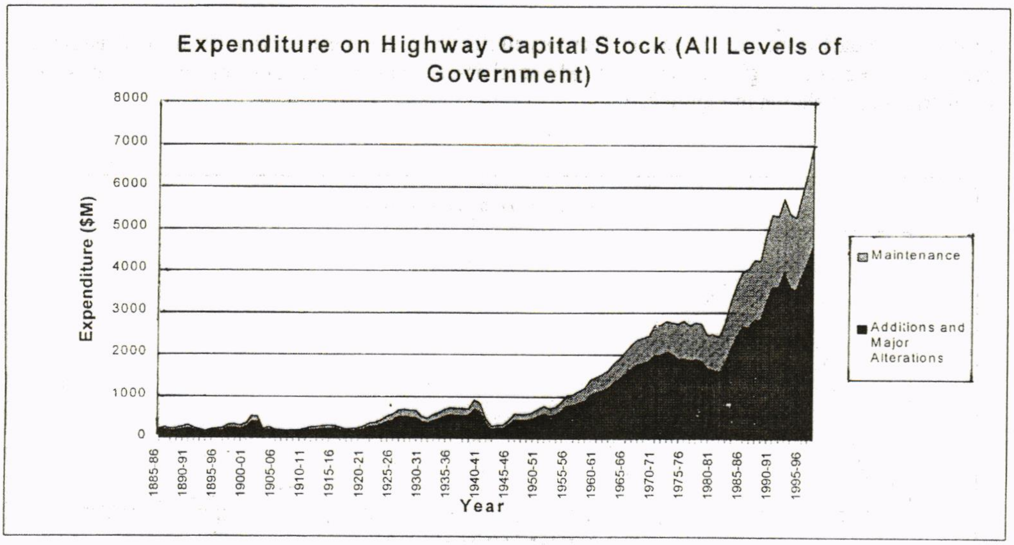

Figure 5: Expenditure on Highway Capital Stock

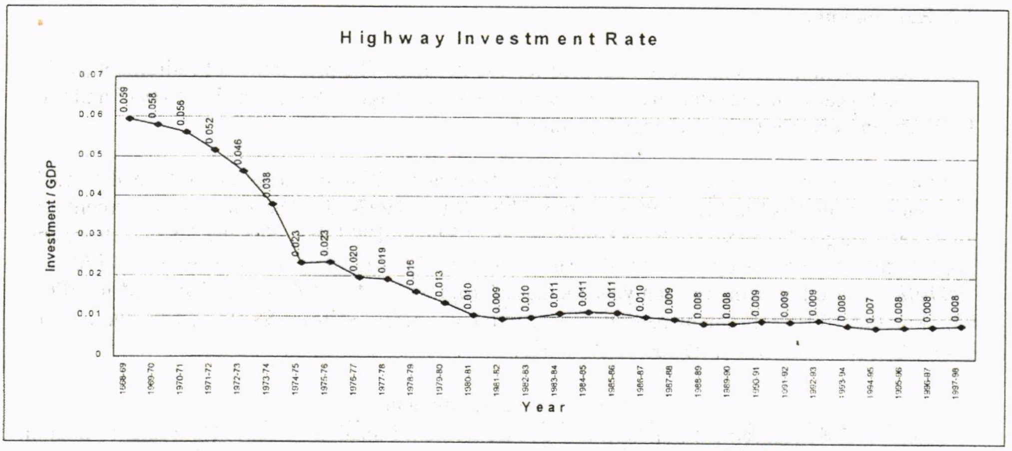

Figure 6. Highway Investment as a Proportion of Gross Domestic Product

Table 2. Private Sector Expenditure, $M

Year	Roads	Bridges	Total Expenditure
1983-84	660.1	146	806.1
1998-99	4402.7	234.4	4637.1

4.2 Mean Service Life

Based on the data from each State and Territory in Australia, the mean service life of road assets has been calculated as a weighted average of individual assets. This has been estimated as 43 years, and its distribution is shown in Figure 7.

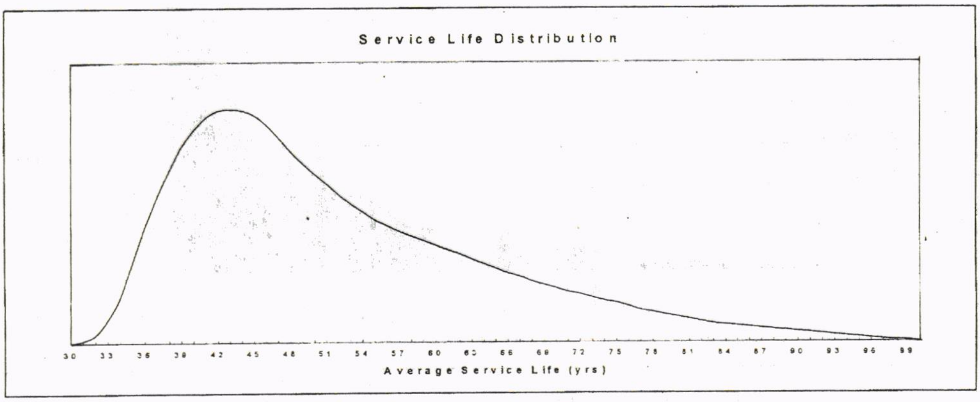

Figure 7. Mean Service Life Distribution

4.3 Retirements

Three retirement models have been adopted for use in PIM. The probability of retirement by the end of each year of the service life has been recorded and ranges from 0 to 0.5, 0 to 0.75 and 0 to 1.00 respectively, for the three models assumed.

For the 50% retirement rate, the amount retired from acquisition of the stock to the end of each year range from $4419.5M in 1969-70 to $12862.0M in 1997-98. The value of retirements *in* each year ranges from $7.3M in 1970-71 to $629.8M in 1997-98. For the 75 % retirement pattern, the retirements by the end of year range from $6911.7M in 1969-70 to $20545.6M in 1997-98. The retirements in each year increased from $15.7M in 1970-71 to $950.1M in 1997-98. For the 100% retirement pattern, the retirements increased from $8414.2M by the end of 1969-70 to $24468.1M by the end of 1997-98.

Table 3 Asset Retirements

Year	50% Retirement Function		75% Retirement Function		100% Retirement Function	
	Accumulated Retirements ($M)	Annual Retirements $M/year	Accumulated Retirements ($M)	Annual Retirements $M/year	Accumulated Retirements ($M)	Annual Retirements $M/year
1969-70	4419.5	7.3	6911.7	15.7	8414.2	61.9
1997-98	12862.0	629.8	20545.6	950.1	24468.1	1253.2

4.4 Gross Capital Stock

The initial value of gross capital stock, as taken from Walters *et al* (1985), is $24890.5M. The remaining gross capital stock figures are determined using Equation 3 and depend on the retirement of the stock and the three retirement patterns. The 50% retirement pattern gives the gross capital stock asset value that increases from $27809.6M in 1970-71 to $91502.4M in 1997-98. The 75 % retirement pattern results in a gross capital stock value of $27786.6M in 1970-71 to $86310.9M in 1997-98 and the 100 % retirement pattern gives asset values ranging from $27863.2M in 1970-71 to $83891.0M in 1997-98, as shown in Table 4.

Table 4. Gross Capital Stock $M

Year	50% Retirement Function	75% Retirement Function	100% Retirement Function
1970-71	27809.6	27789.6	27683.2
1997-98	91502.4	86310.9	83683.2

4.5 Depreciation and Net Capital Stock

Using the PIM equations 4 and 5, depreciation and net stock for each year from 1968-69 to 1997-98 have been determined.

Comparison of Gross and Net Capital Stock Figure 8 shows a comparison of gross and net capital stock from 1968-69 to 1997-98 based on the values obtained by using PIM. The gap between gross and net stock appears to be widening representing the ageing of the highway infrastructure.

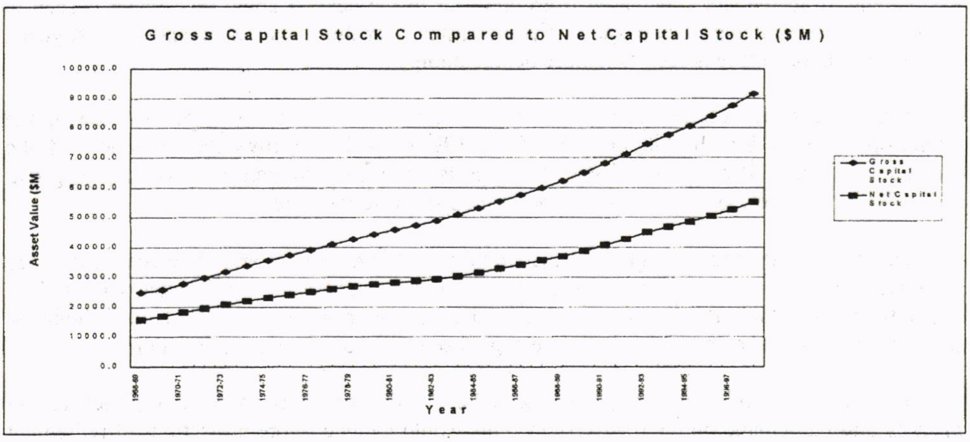

Figure 8. Gross and Net Capital Stock

4.7 Average Age

The average age of the road infrastructure capital stock is a ratio of past investment flows and gross capital stock in the year of question. For the 50 % retirement pattern, the average age of the stock decreases from 9.6 years in 1968-69 to 7.5 years in 1983-84 after which it increases to 7.9 years in 1988-89. It remains constant until 1992-93 after which it increases to 8.1 years in 1996-97. For the 75% retirement curve, the average age decreases from 14.3 years in 1968-69 to 11.6 years in 1980-81 after which it increases to 11.8 years in 1982-83 and decreases again to 11.6 in 1983-84. The average age then increases to 12.4 in 1997-98. The average age of the stock is 19.2 years in 1968-69 and decreases to 15.3 in 1980-81. It then increases to 15.5 in 1981-82 after which it decreases in 1983-84. Since that time, the average age of the stock greatly aged to 17.5 years in 1997-98. It is concluded that the capital stock became younger until the early 1980's after which the stock began to age.

Table 5. Average Age, years

Year	50% Retirement Function	75% Retirement Function	100% Retirement Function
1968-69	9.6	14.3	19.2
1997-98	8.0	12.8	17.5

5. DISCUSSION AND CONCLUSION

The Perpetual Inventory method has been used to determine the asset value and average age of the Australian road infrastructure capital stock. This model indicates that the gross and net capital stock steadily increased until 1997-98. The average age of the stock decreased slightly until 1983-84 after which it continues to increase suggesting that the stock is getting older. Retirements from the stock increased from one year to the next. Capital investment is seen to replace these retirements. Depreciation also increased over the study period and in most years, maintenance expenditure is seen to replace depreciation.

The estimated values of the road assets based on 50% retirement function is close to the published value of $91 billion in 1995 (Cox, 1997). This confirms the soundness of the methodology used. It may also be seen to supports the 50% retirement function implying that 50% of the road assets are retired by the end of their mean service life

The accuracy of the model could be further improved if construction and maintenance data are collected in an inventory system. Annual upgrading of a database including actual service lives and retirement values and investment distribution among bridges, roads and other highway infrastructure would be beneficial for future capital stock and average age estimation.

Further extension to this study could lead to the estimation of future asset value projections to meet increasing demand on the road system. This would include future projections of retirement values, capital investment, maintenance investment and depreciation. This information would allow governments to develop spending policies to meet the annual investment target and ensure that the system is maintained and the user's demands are met.

Policies leading to cost recovery could also be determined using the information obtained in this study. This would involve comparing road user charges with past investment to determine if the road users are getting what they pay for or, paying for what they are getting. The governments could then determine efficient methods of recovering costs in future years. The segregation of road user charges between rural and urban areas within Australia could be studied to determine appropriateness of funding distribution. In other words, are the available funds being fairly distributed to aid all communities? This is essential to maintain the existence of a sustainable road infrastructure system in Australia.

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