CHAPTER II

หอสมุดกลาง สถาบันวิทยบริการ
จุฬาลงกรณ์มหาวิทยาลัย

LITERATURE REVIEW

2.1 General Economic Principle :

Winfrey (1969) considered engineering economy as a special phase of engineering devised to help guide the engineer toward the most economic design for specific tool, equipment, work, construction, and processes.

Pignataro (1973) considered highway economics, distinguished from engineering economy. The highway economics in his sense is concerned not only with the justification for certain improvement, but also with other factors that are of vital importance to highway development. The field of highway economics includes all elements and factors that affect the cost of transportation.

2.2 Introduction of Definitions, Concepts, Procedures and Formulas those employed in the HDM Model.

2.2.1 Traffic : as defined by NATIONAL ASSOCIATION OF AUSTRALIA STATE ROAD AUTHORITIES (NAASRA, 1976) is travelling of vehicles, persons or animals on a road.

The traffic is generally divided into six important types as follows.

i) Normal traffic : The traffic which will take place on the existing road, arising from the natural increase in population and economic activities independent of the improvement.

ii) Generated traffic: The traffic created on the road due to development of land use.

iii) Diverted traffic : A component of traffic which has changed its route but not its origins, destinations, or mode of travel.

iv) Converted traffic : A component of traffic which has changed its mode of travel., eg. from train to car.

v) Induced traffic : An added component of traffic which did not previously exist in any form but results from some roadway improvement.

vi) Potential traffic : The total volume which would move between two terminals assuming ideal transmission conditions.

The other types of traffic are shifted traffic and special traffic.

In the HDM model, traffic volumes are classified as either "normal" or "generated ". "Normal" traffic is defined as equal to the total traffic in the "base" or "without project" alternative. "Generated" traffic is defined as the traffic induced or diverted to the link due to improvements relative to a baseline alternative. According to these definitions, if the alternative being analysed is the baseline alternative, then generated traffic volumes are zero for the alternative.

2.2.2 Equivalent Standard Axles: The total number of equivalent standard axles on the link for the current year is computed as the sum over all vehicle groups. For each vehicle group, the total number of equivalent standard axles is computed as the product of the annual traffic in the vehicle group and the "equivalent standard axle load factor" specified by the user for the vehicle group. The equivalent standard axle load factor is defined as the number of applications of an axle carrying a standard load which would cause the same damage to a road as one application of the axle in question. The standard load used here is 18,000 lbs (8,200 kgs). The equivalent standard axle load factor of an axle, which is assumed to be independent of the strength or condition of the road to which it will be applied, is given by

$$AF = \left\{ \frac{LOAD}{8.2} \right\}^{4.5} \qquad \ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

Where AF is the equivalent standard axle load factor; and LOAD is the actual load on the axle, in metric tons. The equivalency factor for the vehicle is then the sum of the factors for the axles on the vehicle.

2.2.3 Modified Structural Number

In the analysis of pavement performance a convenient index of pavement strength is needed. This index must satisfy the condition that two pavements of the same type having the same index will perform identically. The concept of structural number developed during the AASHTO Road Test satisfied this requirement; the strength of subgrade, the impact of the environment, and the drainage characteristics of the base and subbase are incorporated, resulting in a modified structural number. The structural number of a pavement (SN) is defined by an empirical relationship in which the thickness and strength of each pavement layer are combined as follows:

$$SN = \sum_{i=1}^{n} a_i D_i \quad \dots\dots\dots\dots\dots\dots (2.2)$$

where a_i the strength coefficient of the i^{th} layer; D_i is the thickness of the i^{th} layer, in inches; and the summation is over all pavement layers, n.

The recommended values of strength coefficient for various materials are shown in Table 2.1 and Table 2.2.

A satisfactory way of taking into account the strength of the subgrade, the environmental impact and the drainage characteristics of the base and subbase is to modify the structural number of the pavement so that it is equal to the structural number of a road of the same type which behaves in the same way, but was built in a standard environment on a standard subgrade with standard drainage characteristics. This has been done in both TRRL and AASHTO studies.

In the TRRL Kenya study, Kenya is assumed to be the standard environment and only the effect of subgrade strength is taken into account explicitly in the modification of structural number, producing the following relationship:

$$\overline{SN} = SN + 3.51 \log CBR - 0.85 (\log CBR)^2 - 1.43 \qquad \ldots\ldots\ldots\ldots\ldots (2.3)$$

where $\overline{SN}$ is a modified structural number; SN is a structural number of the pavement; CBR is the subgrade CBR. The relationship above assumes adequate drainage of the pavement.

For the AASHTO Road Test, a regional and drainage factor and the subgrade strength are incorporated in the modified structural number:

$$(1 + \overline{SN}) = (1 + SN)(REGFAC)^{-0.10684} \left(\frac{CBR}{CBR_o}\right)^{0.14744} \qquad \ldots\ldots\ldots\ldots\ldots (2.4)$$

where $\overline{SN}$ is the modified structural number; SN is the structural number of the pavement; REGFAC is the regional-and-drainage factor; CBR is the CBR of subgrade; and CBR_o is the CBR of the AASHO subgrade (=2.69). A higher regional-and-drainage factor indicates a weaker effective pavement. The values of REGFAC range from 0.1 in a frozen subgrade condition to 5.0 in a saturated subgrade condition.

TABLE 2.1

STRUCTURAL LAYER COEFFICIENTS PROPOSED BY TRRL

PAVEMENT COMPONENT	COEFFICIENT
Surface Course (a_1)	
Surface Dressing	0.10
Asphalt Concrete (premix-low stability)	0.20
Base Course (a_2)	
Granular Materials 1/	
CBR = 30	0.07
CBR = 50	0.10
CBR = 70	0.12
CBR = 90	0.13
CBR = 110	0.14
Cement-Stabilized Materials 2/ Compressive strength of	
100 psi	0.10
300 psi	0.15
500 psi	0.20
700 psi	0.24
Subbase Course (a_3) 3/	
CBR = 5	0.06
CBR = 15	0.09
CBR = 25	0.10
CBR = 50	0.12
CBR = 100	0.14

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1/ $a_2 = (29.14CBR - 0.1977CBR^2 + 0.00045CBR^3)\ 10^{-4}$

2/ $a_2 = (750 + 2.66\ PSI - 0.00042\ PSI^2)\ 10^{-4}$

3/ $a_3 = 0.01 + 0.065\ \mathrm{Log}_{10}CBR$

SOURCE: HDM Model Description and User's Manual, 1979.

TABLE 2.2

STRUCTURAL LAYER COEFFICIENTS PROPOSED BY AASHO COMMITTEE ON DESIGN October 12, 1961

PAVEMENT COMPONENT	COEFFICIENT 1/
Surface Course	
Roadmix (low stability)	0.20
Plantmix (high stability)	0.44 2/
Sand Asphalt	0.40
Base Course	
Sanday Gravel	0.07 3/
Crushed Stone	0.14 2/
Cement-Treated (no soil-cement)	
Compressive strength at 7 days:	
650 psi or more (4.48 MPa)	0.23 3/
400 to 650 psi (2.76) to (4.48 MPa)	0.20
400 psi or less (2.76 MPa)	0.15
Bituminous-Treated	
Course-Graded	0.34 3/
Sand Asphalt	0.30
Lime Treated	0.15-0.30
Subbase Course	
Sandy Gravel	0.11 2/
Sand or Sandy-Clay	0.05-0.10

1/ It is expected that each state will study these coefficients and make such changes as experience indicates necessary.

2/ Established from AASHO Road Test Data.

3/ This value has been estimated from AASHO Road Test data, but not to the accuracy of those factors denoted by footnote 2/.

SOURCE: HDM Model Description and User's Manual, 1979.

2.2.4 Cost of highway transportation may be divided into two broad categories, as follows;

a) Road User Costs is the costs incurred to the user in the operating of their vehicles. They are dependent on many variables (such as type of vehicle, type of area (rural or urban), type of highway, type of operation, running speed, gradient class, type of surface and alignment).

b) Road Costs may be defined as the annual costs accruing from the construction, maintenance, and operation of an individual highway or highway system. Annual road cost is the sum of the annual capital cost plus annual highway maintenance and operation cost, included pertinent structures maintenance cost. The annual capital cost is the yearly amount required to amortize the total cost of the improvement plus interest. The capital cost for the highway improvement is the total first cost or initial invesment, including the cost of engineering, land acquisition, administration, and construction. Maintenance cost may be calculated based on the expenditure on maintenance, staff, materials, equipments and the cost of various types of repairs and maintenance works in the highway system. Service lives of road surfaces and salvage value are necessary to the economic calculation for highway purposes. The average service lives of highway surfaces are shown in Table 2.3.

TABLE 2.3

Average Lives of Highway Surfaces

SURFACE TYPE	AVERAGE LIFE (Yrs)
Soil surface	4.0
Gravel or stone	7.5
Bituminous surface treated	11.7
Mixed bituminous	12.5
Bituminous penetration	18.5
Bituminous concrete	20.3
Portland cement concrete	27.0
Brick or block	19.6

SOURCE: HIGHWAY ENGINEERING, third edition, Ritter, Jr and Paquette, 1967. p 38.

Both costs, usually expressed on an annual basis, are of primary importance to the highway engineer. This is true because it is an axiom of highway economics that, in general, since the same people pay both the road costs and the road user costs, maximum economy is secured only when the sum of these costs is a minimum consistent with convenience and safety.

2.2.5 Vehicle Operating Costs:

The economic justification of road improvement projects is, first, that a better road is cheaper to maintain and secondly that vehicle operating costs on a better road are lower.

The basic components of vehicle operating costs are as follows:

a) Running costs : The components of running costs are fuel, oil, tires, maintenance and repairs, and depreciation costs.

b) Fixed costs : These are those that vary with the time taken for a particular journey. These consist of crew, variable overhead, and interest.

c) Passenger time costs : These are the value of vehicle passengers' travel time. The loss or gain in travel time should be reasonably included in computing the operation cost. The delays in travel time are likely to affect the economy in several ways.

Vehicle operating costs, as stated in HDM user's manual, are those costs incurred through owning and operating the vehicle, and include fuel, oil, tires, maintenance parts and labor, depreciation, interest, over head and crew costs. Travel time costs are related to the time value of passengers and cargo holding.

2.2.6 Exogenous costs and benefits

Exogenous or "other" costs and benefits are organized into sets similar to traffic sets. Other costs/benefits sets are defined as streams of costs and benefits applicable to specific links, with the streams being either "normal" or "generated." Accident costs may be both normal and generated. Increased agricultural production consumed on the farm caused by provision of an all weather access road should be entered in the model when applicable, as a "normal" exogenous benefit for computational purposes, although conceptually it may be classified as a "generated" benefit. An example of an exogenous cost would be environmental pollution.

2.2.7 Road Deterioration and Maintenance

Road deterioration is a function of the original pavement design, material types, volume and axle load configuration of traffic, climate and the maintenance policy specified.

Although maintenance is normally a small portion of total costs, the HDM model considers road deterioration and maintenance policies in some detail because vehicle operating costs are significantly affected by road surface condition, and the life of the investment and future rehabilitation costs are heavily dependent on the timeliness of maintenance. Maintenance options for paved road include patching, surface dressing, overlaying and reconstruction, and for unpaved road, grading and regravelling, in addition to other routine maintenance (drainage, shoulders and vegetation control).

Maintenance unit costs for various operation were obtained by short informal interviews of several maintenance officials in Thailand. An effort was made to break away from the standard lumpsum costing technique of ฿ 10,000 to ฿ 12,000 per kilometer unpaved, ฿ 15,000 per kilometer paved; and to instead estimate the actual use of these sums. It was important to disaggregate these costs because the computerized submodel for maintenance attempts to simulate the impact of specific maintenance actions on the deterioration of the pavement. The economic unit costs of maintenance appear as Table 2.4.

2.2.8 Maintenance Policy and Standard

Maintenance policy is consisted of a set of maintenance standard, where one or all standards may be included, and maintenance standards are composed of activity frequency schedule applicable to a specific surface type and traffic range. Maintenance standard can be divided into two types as follows:

a) Scheduled maintenance activities are done at specific time, regardless of the state of roadway deterioration.

b) Responsive maintenance activities are done when the roadway has deteriorated to a specific condition, regardless of the time at which that condition is reached.

TABLE 2.4

MAINTENANCE UNIT COSTS (1977 ₿)

ACTIVITY	UNITS	ECONOMIC	FINANCIAL
UNPAVED ROADS			
Light Grading	KM	1,544	1,715
Spot Regravelling	M^3	60	67
Gravel Resurfacing	M^3	42	45
Unspecified Others	KM/year	11,594	12,856
PAVE ROADS			
Surface Patching	M^2	18	20
Surface Dressing	M^2	36	38
Asphalt Overlay	M^3	2,268	2,400
Unspecified Others	KM/year	13,920	15,300

SOURCE: LOUIS BERGER INTERNATIONAL, INC. VOL.2., 1979 (Table E-2)

2.2.9 Thailand Maintenance Standards

Maintenance standards were established for all road surfaces defining with what annual frequency the various maintenance activities should occur. The standards were taken from Thailand Department of Highways guidelines for maintenance (Road Maintenance Planning Program of the Department of Highways. Presented to : The subcommittee of Road Maintenance Evaluation, The National Economics and Social Development Board. Prepared by : Maintenance Division, Department of Highways, September 1977.) are summarized below.

a) Gravel Road. The maintenance of gravel road are divided into three activities.

i) Grading depends on Average Daily Traffic (ADT) as follow:

ADT	Time of grading per year	Grading cycle (week)
0 - 150	2.5	20
150 - 400	9	6
400 - 750	18	3
> 750	30	1.5

ii) Regravelling 10 cm. for every 4 years.

iii) Routine maintenance (include drainage, vegetation, shoulder, and miscellaneous activities) for every year.

b) Surface Treatment (ADT less than 1,000 use single bituminous surface treatment, SBST, and ADT more than 1,000 use double bituminous surface treatment, DBST) has three maintenance activities as follows:

i) Surface patching for every year.

ii) Surface dressing (seal coat or surface treatment) for every 5 years.

iii) Routine maintenance for every year.

c) Asphaltic Concrete and Penetration Macadam have four maintenance activities as follows:

i) Surface patching for every year.

ii) Surface dressing, only for penetration macadam surface, for every 5 years.

iii) Overlay 50 mm. of asphaltic concrete for every 7 years.

iv) Routine maintenance for every year.

2.3 Economic Terms used in Economic Analysis

2.3.1 Discount Rate is used to transfer the yearly net earning for the remaining year of life expectancy to present worth should be based upon what money is worth to the individual.

2.3.2 Net Present Value is the algebraic difference in the present worth of both outward cash flows and inward flows of incomes or benefits. The alternative which having the greater net present value is the one with greatest economy.

In the HDM model, the net present value of one alternative related to another is computed as:

$$NPV^{(x-y)} = \sum_{t=1}^{T} \frac{NB_t^{(x-y)}}{(1+r)^{t-1}} \qquad \text{............ (2.5)}$$

where $NB_t^{(x-y)}$ is net economic benefit of alternative X relative to alternative Y in year t,

r is the annual discount rate, in fraction,

T is the user-specified analysis period in years.

2.3.3 Internal Rate of Return is vestcharge rate or discount rate which will equalize the negative costs and the positive returns or benefits. The rate of return method in highway proposals usually compare two alternatives in order to develop a differential benefit. The higher the rate of return the greater the economy.

The internal economic rate of return, in simple definition, as defined in HDM user's manual, is the discount rate at which the net present value as defined above equals zero.

$$\sum_{t=1}^{T} \frac{\Delta NB_t^{(x-y)}}{(1+r^*)^{t-1}} = 0 \qquad \ldots\ldots\ldots\ldots\ldots (2.6)$$

The above equation is solved for r* by evaluating the net present value at five percent intervals of discount rates between - 95 and + 500 percent, and determining the zero(s) of the equation by linear inter-polation of adjacent discount rates which net present values of opposit signs. It is possible to fine one or multiple solutions or none at all, depending on the nature of net benefit stream, $\Delta\ NB_t^{(x-y)}$.

2.3.4 First-Year Benefits

The first-year benefit, which can be used as a criterion in determining the optimal timing of stage construction, is defined in the HDM model as the ratio (in percent) of the net economic benefit realized in the first year after construction completion to the increase in total construction cost:

$$FYB^{(x-y)} = 100 \frac{\Delta NB_{t^*}^{(x-y)}}{\Delta TCC^{(x-y)}} \qquad \ldots\ldots\ldots\ldots\ldots (2.7)$$

where $FYB^{(x-y)}$ is first-year benefit of alternative X relative to alternative Y, in percent.

$\Delta NB_{t^*}^{(x-y)}$ is net economic benefit of alternative X relative to alternative Y in year t* where t* is the year immediately after the last year in which construction costs is incurred in alternative X.

$\triangle TCC^{(x-y)}$ is increase in total construction cost (undiscounted) of alternative X relative to alternative Y.

2.3.5 Salvage Value is the word commonly used to refer to the residue of property and materials from service. The word has the annotation of "something reduced or saved". Salvage value is the term most often used to express the monetary value of salvaged property.

2.3.6 Sensitivity of Factors

The analysis for economy produces an arithmatical answer, the magnitude of which depends partly upon engineering judgement in selecting factor and estimating the future. The solution of engineering economy may vary upto 300 percent depending upon the factors chosen by the analyst. To gain some understanding of how certain factors affect the solution a good practice is to solve for economy by using low, medium, and high values of the critical factors, and in different combinations. The sensitivity of each factors in controlling the result should be understood by each analyst and each decision maker.

2.4 Feeder Road (or Provincial Road) and their Effects

Feeder road, or provincial road, is a road that serve as a traffic feeder to a more important road (as a turnpike), it can be composed with a secondary road.

Because the economy of Thailand almost always depend upon agricultural activities then to serve agricultural needs feeder road play an important role. Feeder road can be described as a road that facilitate a delivery of farm products to market places.

The following paragraphs describe the effects of feeder road.

Effect on productivity: Transportation is becoming a primary factor in the food production process, for with the gradual disappearance of unused land in most part of the world, the principle means of increasing productivity is to apply fertilizer, seed, insecticides, and mechanical equipment to existing cultivable areas. Poor transport has the added effect of preventing farmers from specializing in the crops that offer the best return. Where transport is inadequate, each grower attempt to keep his family and livestock supplied with all their needs, an he retained more food than he may actually need. He knows that if he runs short it will be difficult to tap other sources, and more expensive because of high transport cost.

Effect on education and health: If the farm to market road was poor a very small percentage of high school age children are able to get to school. Therefore if we have good farm to market road, it will improve education (encourages teachers to come into a region) and also improve health (access to hospitals and doctors can get into a region.)

Effect on people: New road also created better lives in many other ways. In most cases the building of the road not only made if easier for rural dwellers locally through the building of community halls, mosques, schools, adult education centers, clinics, mobile post offices, and other government services, libraries, and road also being many things to people e.g., newspaper, electricity, television, etc.,. Beside these, jobs are also provided by road construction, maintenance and also road those generated by a new road e.g., transport services, motor repair, etc.

2.5 Road Investment Model

2.5.1 Models in general

Road investment models are computer model which, generally, used to evaluate alternatives design, construction, maintenance strategies and sensitivity to changes in many assumed parameters of the road (traffic growth, traffic composition, etc.,). The focus of the models are on project-level engineering decisions and their applications for total transport cost.

2.5.2 Models that come before Highway Design and Maintenance Standards Model (HDM)

2.5.2.1 The Highway Design Model

Moavenzadeh, 1971, studied highway design and presented the results in a prototype or experimental highway cost simulation model. The model consists of their functional submodels, a construction cost submodels, a roadway maintenance submodel, and a vehicle operating cost submodel. These súbmodels are used to simulate each year of roadway life. Each submodel estimates resource consumption first and estimates the money value of those resources using prices supplied by the analyst. Hence the model is adaptable to any economy regardless of relative cost of different resources.

2.5.2.2 The Road Transport Investment Model (RTIM)

The description of this model which will describe below is taken from Robinson, Hide, Hodges, Rolt and Abaynayaka (1975).

The model was developed as an aid to decision - making within the road sector. It calculates cost to the road user only and does not taking into account either secondary economic effects (e.g. increase in mobility). In its simplest form, the model can be used to minimize the total cost of transport on a set of alternative road investment, i.e., it can be used to minimize the sum of construction, maintenance and road user costs over the 'life' of alternatives. Simple manipulation of the results will produce estimates of net present value for all the options.

The model calculates the cost of a road and predicts the condition of the road as timepasses and vehicles travel along it. Having predicted the condition of the road, the model estimates the costs of road maintenance and the vehicle operating costs for each year. All these costs are then discounted back to the base year and summed over the 'life' of the road to obtain the total cost.

The model requires basic input as follow:

a. route location
b. road design standrads
c. terrain information
d. properties of construction meterials
e. construction unit cost
f. environmental factors
g. vehicle operation unit costs
h. traffic volumes
i. traffic composition
j. vehicle loads and equivalence factors
k. maintenance policy
l. maintenance unit costs.

A typical run of the model will begin with the construction submodel. For each year in which construction or reconstruction occurs, the submodel calculates the quantities and thus the costs of earthworks, pavement, drainage and site clearance are known. Having estimated construction cost, the deterioration of the road is estimated in relation to the initial construction specification, the maintenance policy selected, the rainfall and the traffic flow. The submodel for estimating vehicle performance uses the details of the road condition obtained from the deterioration submodel together with details of the geometry of the road to predict vehicle speeds for each type of vehicle. Fuel consumption, tyre wear, vehicle maintenance and depriciation costs are then calculated and are used in conjunction with traffic forecasts to give the total vehicle operating costs for the year in question. Road maintenance costs are estimated for each year of the analysis period.

The costs calculated for each year of the analysis period are discounted back to the base year at the discount rate specified by the user and the total cost is obtained by summing these discounted costs.

The model can be used with different levels of data. There is a large amount of detailed data which can be obtained to be used as input to the model. However, it is not necessary to provide all data that the model is capable of handling. If certain information is not available, the model will assume appropriate values, with a possible resultant loss in accuracy.

An important characteristics of the model is that all estimates are made in terms of physical quantities.

The model can thus be used for any monetary system and for varying costs of any parameters.

The model has an additional facility which allows the economics of different stage constructions to be examined.

In addition, individual submodels can be used separately. For example, the construction submodel can be used to estimate costs and quantities for various projects, the deterioration and vehicle performance submodel can be used to determine the deterioration and vehicle operating costs on an existing road.

The model is extremely flexible and with very little effort can be used to investigate a large number of routes, maintenance programmes, stage construction options, and combination of these, which would otherwise be extremely time-consuming and costly to perform.

2.5.2.3 The Road Investment Analysis Model (RIAM)

The Road Invesment Analysis Model, RIAM, as described in Brademeyer (1977), is used in evaluating alternative design, construction, and maintenance strategies on low volume roads (a road where congestion on vehicle interaction effects may be ignored) at either the link or network level. The focus of the model is on project-level engineering decisions and then implication for total transport costs.

The types of decisions which are within the scope of the model include the choice of alignment, geometric standard, surface type, maintenance policy,and construction and maintenance methods. The costs considered included total construction costs, labor, equipment, materials, overheads (such as overhead in maintenance, etc.) and total maintenance costs, normal and generated traffic vehicle operating and travel time costs, and exogenous costs, all described in financial, economic, and foreign exchange costs. The model may be used at both the prefeasibility (a pilot study to help make decisions on which alternative road schemes should be built, and on what construction, geometric alignment) and feasibility (an economic assessment to determine whether the benefits to be obtained from a project justify the capital expenditure involved) stages of project evaluation, and has been structured so that it provides information useful in both budgetary and economic planning of low-volume roads, as well as the impacts of foreign exchange requirements and network configurations. The model can be applied to two types of road surface:

a) paved road (asphaltic concrete, bituminous),
b) unpaved road (earth and gravel road).

The RIAM is written in FORTRAN IV which is a computer language that can be transferred amongst a large number of different computers.

The RIAM is a large complex, yet flexible system consisting of a logic - controlling main program and several major submodels, each consisting of a main program and satellite service programs. Each program contains one or more FORTRAN procedures. Total length of all system programs at the present time is about 15,000 lines of code.

Analytic Framework:

The basic function of the model is to estimate construction, maintenance, exogenous, and user costs for a road or system of roads which are to be designed, constructed and maintained to specific standard, and subject to known predicted traffic demands.

This is done by simulating the life of each road from initial construction, through periodic upgrading, and through the annual cycle of use, deterioration, and maintenance.

The simulation is accomplished by determining construction and maintenance activities to be performed, and by estimating road conditions, traffic volumes, ancillary invesment, and all associated costs on a year-by-year basis throughout the analysis period. This Model consists of construction submodel, road deterioration and maintenance submodel, user cost submodel, traffic submodel, exogenous cost/benefit submodel, and economic evaluation submodel. The specific operation undertaken in each year are as follows:

A construction submodel schedules projects; allocates a percentage of construction costs to the current year, and updates the status of the link and activates generated traffic and/or cost/benefits (if any) as projects are completed. The various types of construction project which may be undertaken include new construction, overlaying, pavement reconstruction, widening, widening and reconstruction, realignment, and removal from service. Updating of the road includes the opening of sections to traffic and abandonment of older sections. All costs are input by the user, in financial, economic, and foreign exchange terms (both unit costs and total amount).

A road deterioration and maintenance submodel estimates the average and final surface conditions for the year as a function of the initial design standard, last year's surface conditions, the volume and composition of the traffic during the current year, the local environment (terrain, rainfall), and the specified maintenance policy. Surface deterioration may be estimated for both paved and unpaved roads. A range of typical maintenance activities may be specified for each surface type or either a scheduled or demand responsive basis, these are priced in financial, economic, and foreign exchange terms according to the amount of maintenance which is actually performed. The condition of the road is expressed in terms of roughness and rut depth (all roads), cracking and patching (paved road), and looseness and moisture content (unpaved road).

A user cost submodel estimates the costs of operating vehicles over each road as a function of surface type and condition, environment, design geometrics (grade, curvature, and width), and vehicle characteristics. The components of vehicle operating costs include running costs (fuel, oil, tires, maintenance pasts, and maintenance labor), annual fixed costs (depreciation, interest, crew costs, and overhead costs), and travel time costs (passenger time and cargo holding costs). Cost estimates are prepared for a fleet of vehicles representative of those which will actually be using the road, by vehicle type, in financial, economic, and foreign exchange terms.

A traffic submodel estimates the current year's traffic volumes based on the previous year's traffic normal and generated traffic. If the network option is used, the origin-destination demands are assigned to the system. Both the actual and perceived costs of travel are then recorded in financial terms, to measure the consumer surplus of the system.

An exogenous costs/benefits submodel estimates the current year's exogenous net costs based on the previous year's costs and benefits and anticipated growth, in financial, economic, and foreign exchange terms.

The results of the simulation include a record of the expenditures incurred by the Highway Authority for capital improvements and maintenance; a record of the costs incurred by road user, both normal and generated; a detailed history of the status and deterioration of each road; and a history of the traffic volumes and ancillary investments. All estimates, other than construction and ancillary investments, are made in terms of physical quantities; from which total costs are obtained by applying the appropriate unit rates. The model is therefore not dependent on the use of a particular monetary system, nor is it affected by changes in relative prices. All costs are estimated in financial, economic and foreign exchange terms.

An economic evaluation submodel produces the requested annual reports for maintenance quantities and costs, and road conditions. In addition, it performs the economic evaluation of the requested group-alternatives, producing costs stream histories and economic indicators for each comparison. Network performance reports are also produced.