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DESIGN AND EVALUATION OF HIGHWAY PROJECTS

AND A CASE STUDY

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Part II

DESIGN AND EVALUATION OF HIGHWAY PROJECTS
AND A CASE STUDY

INTRODUCTION

The paper which I will deliver today is mainly concerned with the design and evaluation of rural road projects, be they trunk roads, intermarket centre roads, feeder roads or penetration roads. Many of the points which will be discussed will, however, also be applicable to the appraisal of Urban Roads.

This paper is divided into two parts. This first part discusses the types of costs and benefits which have to be considered, gives details of the method of determination of these costs and benefits and the significance of them in an economic analysis. Reference is also made to the significance of other factors which have to be taken into account and/or just borne in mind when conducting an appraisal. Guidelines are given for the organisation of studies together with indication of the road standards to be considered for the initial construction of, or the reconstruction of a road. In part 2 the analysis of a particular project will be considered.

It should be noted that there is still a considerable variance of opinion throughout the world on the method of appraisal which should be used for both high and low cost road projects. In addition the terminology which is used not only changes from country to country but also from individual to individual. In order, therefore, to try and avoid any ambiguity, I have attempted to define the terms which I have used within each section.

Where any reference is made in this paper to economic analysis, I will be referring to discounted cash flow techniques.
For the economic analysis of a project it is necessary to calculate:

a. The costs, and
b. The benefits.

The main costs to be considered in the analysis of a road project are the capital costs which are taken to include:

a. The Capital construction costs.
b. Engineering design costs.
c. Land acquisition and compensation costs, and
d. Supervision of construction costs.

Of the above, the most important are the 'capital construction' costs. The significance of the other 'capital costs' will vary from project to project. For example, land acquisition and compensation costs may vary from nothing for constructing a road across savanna scrubland which is already owned by a Government to £15,000 for a road through a coffee estate.

Other costs which may or may not be of significance are these, which I shall refer to as 'continuing yearly costs' and include:

a. Road maintenance costs.
b. Vehicle accidents costs.

In respect of these costs it should be noted that in some cases the improvement of a road facility may lead to either an increase or decrease in the costs. Where there is an increase then the cost difference is still classified as a cost but where there is a decrease in these costs, the difference will accrue as a benefit or negative cost. For example, where a single carriageway bitumen road is upgraded to a dual carriageway road there will be an increase in road maintenance costs but a decrease in vehicle accident costs, we hope. On the other hand where a gravel road is upgraded to a bitumen road, there will be a decrease in discounted road maintenance costs and possibly a decrease in vehicle accident costs.
costs. The actual result in each case analysed will depend upon the result of calculations for costs on the old and new facility.

There are two main types of benefits to be calculated:

a. Direct benefits, and
b. Induced benefits.

Direct benefits are those benefits which are directly attributable to an improvement in the road facility and which accrue to the users of that facility and the community as a whole through lower transport charges and easier marketing facilities.

This reduction in transport charges will be related to one or other of the following:

a. Shorter journey distance.
b. Lower vehicle operating costs per unit distance.
c. Passenger time savings.
d. Shorter transit times for goods, and
e. Less breakages.

The annual benefits (Bd) resulting from a shorter journey distance are obvious and are given by the expression:

\[ Bd = ADT \times (\text{vehicle operating cost on new facility}) \times (\text{reduction in length}) \times 365. \]

Where ADT = average daily traffic, and the term 365 is for the number of days in a year, Vehicle operating costs being expressed in the form of cost/km. It should be noted, however, that while the benefits to be gained from shortening journey distance can be very high, they are usually only significant at high traffic levels where the large volume of traffic will be sufficient to justify the additional capital construction costs which will be incurred in effecting a route shortening. In some cases, it may be preferable
to increase the journey distance to lower vehicle operating costs and avoid high capital construction costs.

The annual yearly benefits (Bv) to be obtained from a lowering of vehicle operating costs over a length of road are given by the expression

\[ Bv = ADT \times (Oe - On) \times \text{distance} \times (d) \times 365 \]

Where: \( Oe \) = Vehicle operating cost per unit distance on existing facility, and
\( On \) = Vehicle operating cost on new facility.

The factors affecting vehicle operating costs besides the type of vehicle can be classified as:

- a. Type of road surface.
- b. Vehicle speed.
- c. Rise and fall of the road (gradients).
- d. Curvature of the road.
- e. Congestion.

Some of these factors are interrelated and the importance of each will vary from project to project. For example, factors c, d and e all effect vehicle speed but the effect of each of these factors can also be assessed separately, but in one project a reduction in rise and fall of the road may generate higher benefits than any savings due to a reduction in congestion especially where traffic volumes are low. Suggested methods for calculating vehicle operating costs are given in Section 6.

The inclusion of driver and passenger time savings as a benefit has been a subject of much discussion, especially in relation to the appraisal of road schemes in countries where wage rates are low and there is considerable unemployment. Recent studies have demonstrated, however, that people who have to travel in such countries are prepared to pay for savings in time. Providing, therefore, the value of personal time savings are correctly
assessed for a particular project then it is considered perfectly valid to include these savings as benefits in an economic appraisal. This excludes any savings in wage costs for paid drivers, the benefits from which should be included under vehicle operating benefits. Methods for assessing the value of passenger time saving are also given in Section 6.

Shorter transit times for goods means that capital which is invested in the goods while in transit can be released at an earlier stage for investment elsewhere. Thus the value of this benefit can be assessed as the interest that would be paid on that capital over the reduction in time achieved. A classical example of this, are the benefits to be gained from air freighting high cost equipment such as computers and other scientific apparatus. The relevance of this to road schemes is not so marked but where high value goods, such as petrol and coffee, are regularly carried on a particular route, there may be some benefit.

The benefits to be obtained from 'less breakages' are easily seen when thought of in terms of manufactured goods and especially where such goods represent a high foreign exchange cost. Attention must also be paid to benefits which will accrue where damage to agricultural produce is reduced through a better road facility, thus enabling these crops to fetch a higher market price. A good example of this latter case is given where the transport of such fruits as strawberries, avocado pears and pineapples are involved, especially where such produce is destined for an export market. These fruits, if bruised or damaged, are virtually valueless in these markets. Benefits will also accrue where these fruits are sold on a local market and there will also be benefits in respect of other lower priced produce, such as bananas, potatoes and cabbages.

Induced benefits are direct monetary benefits generated by the construction or improvement of a road facility and which could not or would not have been generated without investment in such a facility. These benefits and the assessment of them are discussed in Section 3 and 4.
Section 2

PRESENT TRAFFIC AND COLLECTION OF
PRESENT TRAFFIC DATA

In an appraisal of a road project, traffic information is required for two reasons. First, as an input to the economic calculations where benefits to traffic are being assessed and secondly for the purpose of ascertaining the standard to which a new road facility should be designed.

There are two types of traffic in which we are interested and upon which information has to be obtained in respect of volume and growth rate and these are referred to simply as present traffic and future traffic. Present traffic is that traffic which at present uses a facility, while future traffic is that which will use the facility in the future. In respect of both of these types of traffic we have to collect or calculate information on some or all of the following:-

a. Volume.
b. Composition or Classification
   i. Light Vehicles - Cars
      - Light goods vehicles (vans and Landrovers)
   ii. Heavy Vehicles - Medium goods Vehicles (six tyres)
      Heavy goods Vehicles (six or more tyres)
      Buses.
c. Growth Rate.
d. Origin and destination.
e. Number of axles and axle loading.
f. Load capacity and load carried of both goods and passengers.

The above information is listed in order of general importance, the volume of traffic being the factor that must be known, while the relevance of the remainder of the data to a particular project will vary. The remainder of this section is now devoted to the collection of this data in respect of present traffic.
Collection of Present Traffic Data
Ideally there should be available within each country a data bank in either paper or computer form of the volume, composition and growth of past and present traffic on all classified roads for the use of planners at all levels in Government. Such data is then available for periodic analysis to select schemes for inclusion in a development plan or to provide information for the traffic analysis of a particular project. Inspection of such data can be very informative as to not only which roads require upgrading because of increased volumes traffic, but also as to which roads may require improvement through their being no or negative growth which might be indicative of their deteriorating condition.

Nevertheless, even where a data bank of information is available, it is most probable that when a detailed appraisal of a road project is required, the most recent historical information will not be sufficiently up to date for use in such a study. Thus it is necessary to execute at least:

a. A Traffic Count Survey, and possibly
b. An origin and destination survey.

Traffic Count Surveys
A traffic count survey as its name implies, is merely a count of the traffic passing in each direction along a road. A survey of this type can vary in its complexity and may be of the following type:

"A 24 hour, seven day, hourly, classified, directional survey" which description gives a full account of a survey executed. A typical manual count sheet is given in Figure 1. The number of vehicle axles may also be recorded. The time and length over which such a survey is executed will be dictated by the time and manpower available. A full count survey of the type described above is, however, to be fully recommended to ensure some sort of accuracy but even a 24 hour, seven day will not take into account seasonal variations.
If a count is being executed it is not difficult to obtain the information on hourly volumes, vehicle classification and direction and so a decision only has to be made on the time and duration of the survey. Where suitable manpower is short and time is limited, it is recommended that as a minimum "A 36 hour, two day, hourly, classified, directional survey" is made with one of the count days occurring on the local market day. A study has been made in Kenya by the R.R.L. U.K. of the likely counts of different durations on rural roads with varying traffic volumes and some of the results are given in Figure 2.

Where there is a large volume of traffic it may be necessary for the enumerators to use mechanical hand tallies and to record the results at fixed intervals on a form of the type shown in Figure 3. In such cases, results may be recorded at, hourly, half hourly or quarter hourly intervals. Where a survey is being executed for the design or re-design of a junction in an urban area, then quarter hourly results would be recorded to determine the peak hour and the peak quarter within that hour.

In order to economise slightly on manpower and to obtain some additional information on present traffic movements without much additional work, count surveys can be made at junctions, with an enumerator positioned on each leg of the junction recording the directional taken by vehicles going from his particular side. The results can then be summarised on a form of the type shown in Figure 4, thus enabling data at 3 points to be recorded.

Using a manual count form, a good enumerator can record up to 750 vehicles per hour, classified, in one direction, or 500 vehicles per hour classified in two directions. For 12 hour classified directional counts, one enumerator per 3,500 vehicles is recommended. With mechanical hand tallies, the above figures can be double. If using untrained staff, halve the above appropriate figures.

Where good staff is in short supply, or there is plenty of time for the study or long term data on traffic trends is required, particularly in respect of growth and seasonal variation,
consideration should be given to the use of automatic counters. These can either be of a mechanical or an electro-mechanical type which are operated in both instances by the passage of a vehicle over a hollow rubber tube placed across the road.

The action of the wheels of a vehicle passing over the tube causes an air pressure change in the tube which operates a diaphragm and which in turn operates a counter. Such instruments are normally set to record a pair of axles and thus on a road where vehicles with two or more axles are operated, the number of pairs of axles recorded have to be related to the number of vehicles by a manual classified survey. In any case, a classified vehicle count will be necessary at some stage.

Automatic counters can be used in a number of ways. For example, where a short term survey of a long road is being made, up to seven counters can be placed at strategic points along the route and then one traffic survey team can either execute a classified count at each point for seven days continuously or at each point for one day just once or once every seven days for the period of the study. Alternatively, a counter can be placed permanently at one location with a local person paid a nominal amount to read the counter once or twice a day and to record the figures on a preprinted post paid card or form which is sent to road headquarters once a month. Once an existing road has been selected for inclusion in a development plan it is to be recommended that at least one automatic counter is placed on the road in order that some long term continuous traffic data is available for the detailed appraisal stage.

There are a number of makes of automatic counter on the world market, some of which are very sophisticated and give hourly printouts either in digital or punched form on paper tape for computer analysis. For rural road schemes, however, a simple reliable mechanical type is recommended.

It must be mentioned in conclusion to this sub-section, that the organisation and collection of long term traffic data in an efficient and statistical correct manner has now developed
into minor science. The organisation of such data collection is to be fully recommended.

As a last resort, where it is required to collect a lot of traffic data in a very short time for a number of roads, as in a feeder road study, the questioning of local inhabitants who reside along the route as to the number of vehicles passing along the road should be considered as a method of data collection. Where traffic volumes are low, not more than 25 vehicles per day, this method can yield fairly accurate results.

**Origin and Destination Surveys**

Origin and Destination Surveys are executed basically for the purpose of ascertaining:

- a. Where a vehicle has come from (its origin), and
- b. Where it is going to (its destination).

As this type of survey entails stopping the traffic and asking questions of the occupants of the vehicles, further data of relevance to a particular study might also be collected on such points as:

- c. Vehicle type (see previous classification)
- d. Journey purpose - Travel to or from work
  - Business
  - Tourist
  - Leisure
  - Personal
- e. Intermediate stops.
- f. Purpose of Intermediate stops
- g. Carrying capacity (passengers and/or goods)
- h. Volume filled.
- i. Type of load carried
- j. Monthly earnings of
  - i. Driver
  - ii. Passenger.

In addition, where it is required to assess local vehicle operating costs, the following information can also be noted:
k. Vehicle registration number.

1. Vehicle mileometer reading.

The use of such information will be described in Section 6.

The merits and de-merits of carrying out an "origin and destination" survey for a particular project should be carefully considered. While this type of survey can yield a lot of useful information it can only be a success if carefully planned and executed and plenty of time is available for the proper analysis of the data collected. Wherever such a survey is executed, it will be necessary to recruit and train the interviewers, arrange for transport and in some instances, provide rations.

The method which it is proposed to use to analyse the data must be given careful thought before the survey is executed and the interview form drawn up in such a way as to permit easy analysis by hand or computer. No two studies are alike and it is difficult, therefore, to have a standard computer program for the analysis of the data although we are now trying to write a specification for such a program. However, where a study is of a very short duration, say 3 months, the time taken for the writing of the program could well exceed the study period and thus where the number of interviews to be analysed is small, hand sorting and analysis may provide the faster solution.

Given in Figures 4A to 4C are three sample interviews forms. Figure 4A illustrates a form which was specifically for computer analysis of the data with up to ten interviews being recorded on each form. The other two forms only allow for the recording of one interview per form and this enables hand sorting to be executed. The data recorded on the form illustrated in Figure 4B was, however, coded and punched on cards in free format and subsequently analysed by computer.

No definite guidelines can be given for the organisation of these surveys as the number of interviewers required will depend on the length of the interview, the volume of the traffic and the percentage of vehicles it is required to interview and the ability of the interviewers.
If in doubt as to the proper organisation required, it is worth executing a pilot study for about two hours, a few weeks before the full study.

Q & D studies are normally executed during the 12 daylight hours although they may be continued throughout 24 hours of a day in special cases. Four other important points to be noted are:

a. Good information signs to drivers.
c. Courtesy, and
d. Efficiency of Operation,
all of which will ensure the best co-operation from drivers and passengers alike.

Present Traffic Growth Rates
Traffic growth is normally of a compound form. Where there are more than two historical results available regression analysis has to be used for the analysis of the growth rate. If data is available for say, the preceding 20 years, then some judgment must be applied as to which of this data should be used, for many changes in the economic growth of a country or of a region in which the road is situated, may have taken place over that period. It is sometimes useful, therefore, to plot out the historical data on semi-log paper, as shown in Figure 6, to locate the break points in the varying growth rates which may have occurred over that period and then to calculate the present growth rate for the last period of steady growth. In addition to, or as an alternative to this procedure, it may be useful to quote a number of present growth rates, as for example:

1950 to 1972 = 18% p.a. compound.
1959 to 1972 = 14.5% p.a. compound.
1963 to 1972 = 22.0% p.a. compound.
1970 to 1972 = 29% p.a. compound.
Where there are abnormal growth rates, say greater than 10% or negative, then the reasons for this should be investigated.

Negative Growth Rates

At this point mention should be made of nil or negative growth rates. One cannot be specific about the reason for such happenings but they will generally indicate malfunctioning of some part of the system. For example where a country is in economic decline then there will be less need for people to travel or business and where there is a decline in per capital income, people will have less money to spend on food produce, manufactured goods and travel and hence there will be decline in the demand for these commodities and services with a corresponding decline in the demand for transport to carry the commodities and provide transport services.

In a Rural area a nil or negative growth rate might be indicative of maximum possible agricultural output, a more efficient transport system or more usually a decline in agricultural output due to a decline in agricultural advisory services, lack of seed or high transport costs making the produce grown competitive in the nearest local market with the result that no attempt will be made to grow anything more than subsistence crops the following year. In this case we have a self perpetuating decline which can usually be attributed to deterioration in the the road conditions.

Unless this fact is realised, there will be cries for increased agricultural output from the Central Government Offices, new production targets will be set, the District agricultural officer will be replaced as being inefficient and the local Agricultural Statistician or Economist in an effort to retain his job will merely double the production figures from those of the previous year, when writing his annual report. Where this deterioration of road standards occurs in a large feeder road network, with a consequent drop in agricultural output then inevitably the cost of the produce in the main local market will increase by the law of supply and demand, but this increase will not be sufficient to overcome the higher transport costs from the outer agricultural
areas and retail market costs will continue to escalate.

The above description may sound dramatic but such chains of events have occurred in a number of countries and thus to obtain high and higher agricultural outputs it must be ensured that all of the necessary basic infrastructure is of the required standard. I would respectfully suggest, therefore, seeing that many of you are connected with agricultural, that correct balance is obtained in the provision of such infrastructure.

It is of no use doubling the number of agricultural extension officers if first they are not able to move around their respective areas and secondly the additional produce which they encourage farmers to grow cannot be marketed and has to be destroyed.
Section 3

FUTURE TRAFFIC AND ASSESSMENT OF FUTURE TRAFFIC VOLUMES

Future Traffic is composed of the following:


b. Generated Traffic (Induced and Development Traffic).

c. Diverted Traffic.

The differentiation between the categories of future traffic is made for two reasons. First, the volume of each category has to be assessed differently and secondly the economic benefits to each of these categories may also have to be assessed differently depending on the method chosen for the appraisal of the project benefits.

Normal Traffic is traffic which will occur as a result of the normal growth of present traffic. That is, the traffic which will be present on a road in the future irrespective of whether the road is improved or not. The benefits to this traffic, as the result of an improvement to the facility, are normally taken as 100% of the accrued benefits from reductions in vehicle operating costs.

Generated Traffic of both types, induced and development will occur on the improvement of a road directly as a result of the road improvement caused by a reduction in journey distance or time, reduction in vehicle operating costs or the removal of some deterrent to travel such as a poor road. The induced traffic will normally occur within a short time (two or three years) of the completion of an improvement to a facility and is a once and for all increase, although after its generation it will continue to increase at the same growth rate as normal traffic. The volume of generated traffic is often related in some way to the volume of part or whole of the present traffic.
As indicated, there can be considered to be two parts to 'generated Traffic', 'induced' and 'development' traffic. **Induced traffic** consists of new trips created by the existence of an improved facility but not attributable to any change in land use. For example if, as the result of an improved road a local Administrative Officer found it worthwhile due to shorter journey time, to visit more often the sub-divisions of his area, then his additional trips would be termed 'induced traffic'.

**Development Traffic** on the other hand is additional traffic which will be created due to 'increased development of existing or new land adjacent to a new or improved facility, over and above that which would have taken place normally with the road in its present condition.' For example if, as a result of an improvement to a facility resulting in reduced vehicle operating costs, it became worthwhile due to lower transport charges, to market marginal costs produce, then the additional vehicle trips created in carrying this produce would be termed 'development traffic.' Development traffic is also associated with penetration roads. What are the benefits to 'generated traffic'. These are normally assessed as being equal to a percentage of the benefits accruing to normal traffic through reduced vehicle operating costs together with any savings due to shorter journey distances. The reasoning behind this assessment is based on the concept of consumer surplus as indicated on the following diagram.
Assessment of Future Traffic

The assessment of future traffic can be done by three basic techniques, namely:

a. Quantification of the volume based on assessments of the future demand for transport in respect of both commercial and personal needs.

b. Overall forecasts using some of functional relationships and/or gravity model techniques.

c. Application of straight compound or simple growth rates to the present traffic with possible adjustment for generated and/or diverted traffic.

The assessment of the volume of future traffic is regarded by some authorities as a complex function of a lot of unknown variables which are best not considered. However, with the advance of knowledge and our ability to quantify more of the events which occur in our everyday lives the assessment of future traffic does not provide insurmountable problems which should be avoided by taking a straight compound or simple projection of present traffic.

Traffic is analogous to water supply. Just as we are able to make an estimate of the future water supply requirements of a city and the size of pipes which will be required to carry this demand based on increases in population and higher living standards, so it is possible to make an estimate of the volume of future traffic. In an urban area, as may have been outlined to you yesterday, present traffic volumes can be related to land use, population, levels of car ownership, income levels and other parameters such as tourism, which can be shown to have an effect on the number of vehicles and the daily number of trips made by these vehicles.

In rural areas the estimating of future traffic will vary in complexity according to the type of road being assessed. This is due to the different types of traffic which will occur on a road. Where investigations are made of a rural 'trunk road' then the growth of the following types of traffic may have to be considered:
a. Import and export commercial traffic.
b. Inter-city commercial traffic.
c. Market centre (agriculture produce) to city traffic.
d. Local Agricultural traffic movements.
e. To and from work traffic (commuter traffic).
f. Light business traffic - Commercial Agriculture Administrative.

g. Tourist traffic.
h. Leisure traffic.
i. Personal trip traffic.

Before the future traffic can be estimated some quantification of the motivation of the present traffic must be made and this is where the information collected in an origin and destination survey would be used to calibrate some form of model which would describe these movements in whole or individually.

It will be appreciated that the future gross domestic product and per capital incomes will also play an important part in the determination of future traffic. The future gross domestic product will be indicative of future industrial and agricultural output which will require to be transported and per capita income in a rural area will reflect people's ability to pay for personal or semi-business transport. Studies in the past have shown that 'the growth rate of the volume of transport is often between two and three times the growth rate of the gross national product'*. In the Federal Republic of Germany the following models have been derived which relate in the first instance the gross national product to the demand for transport by an exponential function of the form:

\[ Y_{1t} = C_1 X_{1t}^a e^{bt} \]

where: \( Y_{1t} = \) goods transport in tons/km in year \( t \)

\( X_{1t} = \) gross national product in year \( t \)

* Introduction to Transport Planning - United Nations.
e = the number e
t = the year considered
a, b = parameters, which express the influence of
X_{1t} and t respectively on Y_{1t}.

This model was calibrated by a fit to time series data for the periods 1925 to 1937 and 1950 to 1960.

For the relationship between the production and/or import of some selected categories of goods (coal, cement, iron ore, iron and steel, mineral oils and wood) and the demand for goods transport the following linear function was fitted to data of the same period:

\[ Y_{2t} = a + b X_{2t} + c t \]

Where: 
- \( Y_{2t} \) = goods transport in tons/km in year t
- \( X_{2t} \) = production and import of selected goods in year t
- t = the year considered
- a = constant
- b & c = parameters which express the influence of \( Y_{2t} \) and t respectively on \( Y_{2t} \).

In this example, the parameters were estimated by a least squares fit and were highly significant. Thus by inserting in these formulae the gross national product or the production and/or import of the selected goods in a future year a reliable estimate of the demand for transport in the year concerned may be obtained. In these examples we are dealing with traffic at a macro level, whereas in the analysis of individual rural road schemes it is necessary to work at the micro level and to be far more specific especially at low traffic volumes. We will be assessing the types of future traffic discussed in the previous section but I would ask you to appreciate once again that this field is also becoming very specialised dominated in part by a new breed of people termed transportation engineers and that in the time available I can only give a broad insight into some of the current methods at present adopted.
Normal Traffic

The assessment of the present part of normal traffic has been discussed earlier. Where there is a positive present traffic growth rate then the future normal growth traffic can be assessed by one of two methods. First, the present traffic growth rate can be correlated to past increases in any one or a combination of the following factors:

a. population
b. increased agricultural output
c. increase in local per capital incomes

and the rate of future traffic growth calculated from any mathematical relationships so derived based on estimated future changes in these factors.

In some cases, however, it may be quite as accurate to project the present traffic at the present traffic growth to obtain the future normal traffic where the present growth rate is reasonable and no reason can be anticipated for any large changes in this rate. A reasonable rate is considered to be anything up to 10% p.a. compound which will give a doubling of the traffic in just over seven years. Any rate in excess of this must be carefully examined and if any exceptional events of only a temporary nature have recently occurred, then the future rate chosen must be adjusted to allow for this.

For example, on a road with about 100 v.p.d. the construction of a new tea factory or secondary school might well generate an extra 20 v.p.d. for a year or so giving a present growth rate for that period of 20% p.a. If this rate was then applied at a compound factor to the present traffic of 120 v.p.d. we would have in ten years time about 720 v.p.d. representing a sevenfold increase and in 20 years time 4,000 v.p.d. which is a surprisingly high number for what might only be a simple agriculture feeder road.

Where there occurs a high growth rate for which there is no logical explanation and which cannot either be substantiated or disproved then it is suggested that this high rate be applied at a simple interest rate as opposed to compound interest rate. Thus in our previous example a 20% simple growth rate would give 360 v.p.d. after 10 years and 600 v.p.d. after 20 years representing a 12%
and an 8.5% compound interest growth rate over the two periods respectively. This procedure may possibly lead to some under-design but it will prevent overinvestment while at the same time giving only slightly lower traffic in the first years which if discounted cash and flow techniques are being used will not greatly underestimate the benefits.

**Generated Traffic (Induced)**

The use of gravity model techniques is often the best way of assessing this traffic. A gravity model has a basic form of:

$$Q_{ij} = k \cdot A_i \cdot A_j \cdot f(Z_{ij})$$

where:

- $Q_{ij}$ = the flow from point i to point j
- $k$ = a constant
- $A_i$ & $A_j$ = some value of the drawing power of points i and j, such as population, and
- $f(Z_{ij})$ = some measure of resistance to travel from point i to point j.

On a rural road between two large urban centres, it might be modified to:

$$Q_{ij} = k \frac{A_i \cdot A_j}{(t_{ij})^n}$$

where:

- $t$ is the journey time between centres i and j, and the power $n$ determines the significance of the time $t$.

This model can be calibrated from the results of an origin and destination study and measurements made of $t$. Once calibrated, the potential generated traffic can be deduced by inserting for $t$ the calculated journey time for the proposed new facility. The generated traffic being equal to the difference between the present actual value of $Q_{ij}$ and the future calculated value of $Q_{ij}$.

While a gravity model of the above form may give reasonably accurate indications of generated traffic in the circumstances described, it is not considered to be very reliable in more rural circumstances where present traffic volumes are low.
(50 to 150 v.p.d.) as it does not take into account a sufficient number of variables which are known to affect traffic in these areas. A study made in Tanzania by the R.R.L., U.K. of methods to derive estimates of generated traffic produced a model of the form:-

\[ Q_{12} = k \left[ \frac{(H_1 D_2)}{(\Sigma i H_i - H_2) + (H_2 D_1)} / (\Sigma i H_i - H_1) \right] + C \]

Where: \( Q_{12} \) = traffic demand between centres 1 and 2 measured in daily vehicle trips.
\( k \) = constant
\( H \) = the attraction of a centre (GDP value weighted by service points score) indicated by subscript.
\( D \) = total estimated travel demand for the centre indicated by subscript and measured in total daily vehicle trips.
\( t_{12} \) = journey time between centres 1 and 2 measured in hours and weighted if required, to reflect the deterrent factor of the road between centres 1 and 2.
\( C \) = a constant.

The derivation of this model was based on the RRL's finding of what motivated traffic in the rural area studied. The basic input to this model are the gross domestic product of a centre, its attractiveness measured in 'service points score', the estimated demand for travel of a centre and the journey time between centres weighted, if required, to reflect the deterrent factor of the road. The purpose of 'service points score' is to give some weighting to a centre, other than GDP. The points scores can be calculated on the basis of services offered such as the ranking of the administration, medical services, banks, communications and agricultural extension services on a scale of 0 to 3. For example:-

- no medical services scores 0
- a dispensary 1
- a doctor 2
- a hospital 3
An inventory form for collecting details of a centre is shown in Figure 6. The basic structure of the model can be depicted as:

\[ \text{Attraction 1,500} \]
\[ \text{(G.D.P. 100 score 15)} \]

\[ \text{Attraction 350} \]
\[ \text{(G.D.P. 50 score 5)} \]

\[ \text{Attraction 125} \]
\[ \text{(G.D.P. 25 score 5)} \]

\[ \text{Attraction 50} \]
\[ \text{(G.P.D. 50 score 10)} \]

\[(n) = \text{deterrence to travel (distance x road quality = journey time)}\]
The volume of future traffic can then be calculated by inserting in a calibrated model a value for \( t \) based on estimates of journey time on a new facility between the centres studied. If only one road in a network is being improved then the model may demonstrate that the traffic volume on other links in the network may fall. The volume of generated traffic will then equal \( Q \) (estimated for future) minus \( Q \) (present).

In cases where a gravity model is not found to be applicable good judgement as to the effect of an improvement to a facility may give just as good indication of the volume of induced traffic. In the circumstances with which we are dealing the results of the origin and destination study combined with interviews with local haulage operators, bus companies and administrative officers, should provide sufficient guidance. Alternatively the volume of induced traffic can be taken as a percentage of the present traffic. This percentage can be assessed from earlier road improvements and will generally be found to be between 10% and 25%.

**Generated Traffic (Development)**

Development traffic is calculated by assessing the demand for transport caused by a change in land use which from the point of view of our discussion means increased agricultural output. A good example of development traffic is that which occurs upon the construction of a penetration road. Although no benefits can be assigned to the traffic generated in such a case it is necessary to know the probable volume in order to decide upon road standards. Let us take an example of this:

A new sugar factory is to be constructed and it is required to open an adjacent area for the cultivation of sugar cane by means of a penetration road.

The total area to be planted is 3,000 hectares
The yield is estimated to be 12 tonnes/hectare/month
(144 tonnes/hectare with 12 months maturing period)
Then the total tonnage to be carried to the factory = 36,000 tonnes/month
If 10 tonne trucks are to be used to carry the cane to the factory then the number of vehicle trips equals

\[
\frac{(36,000) \times 2}{10 \times 25} = 252 \text{ heavy vehicles per day (h.v.p.d.) on the road into the factory.}
\]

Where the factor 25 equals the number of working days in a month and the factor 2 allows for return trips. To this should be added cultivation and administrative traffic which might amount to another 50 light and/or heavy vehicles per day. Obviously the volume of traffic will decrease the further from the factory and the nearer to the end of the cultivated area the road penetrates. There may be more than one penetration road to serve the area in which case the traffic on each has to be separately calculated.

In addition to the main penetration road there will also be private estate roads which sub-divide the estate and give more efficient access to individual blocks for cultivation and harvesting.

In this example a yield of 12 tonnes per hectare/month has been used but as you will appreciate the yield may vary from 110 tonnes/hectare to 300 tonnes per hectare or more and maturing periods from 12 to 22 months.

The above example was related to estate production, but many of the penetration roads constructed are for the purpose of providing access and egress to already inhabited areas where there is existing subsistence farming and also for settlement schemes in order to encourage cash crop farming by providing access to markets and thus as a whole contributing to a country's food production programme. In these cases the assessment of the demand for transport is slightly more complex as the volume of produce to be marketed will be related to:

a. Available land
b. Percentage of land already under cultivation.
c. Yields per unit area - with and without access to advisory services, equipment and fertilisers.
d. Population.
e. Split of production into subsistence and cash crops.
f. Central Government agricultural programmes and statutory board diversification schemes.
g. Area of influence of the road.
h. Distance to market and marketing arrangements.
i. Availability of cash loans.

Much of the above information can be obtained from examination of local and central government records and discussions with other government officers. Where this information is not available, then other methods may have to be used or estimates made. As an aid to the identification of factors a, b and c, maps and aerial photographs are useful sources of information when combined with field inspection and measurement. Where the aerial photographs are to a sufficiently large scale, the area of existing individual crops can be identified though the estimation of existing yields is normally achieved with ground inspection. If new aerial photographs have to be taken then careful consideration must be given to the scale in relation to the crops to be identified and the time of year at which to execute the flying. Colour photography will help considerably with the identification of existing land uses and crops but this is considerably more expensive than black and white photography.

Population has two effects on output. First, if we have to predict the total volume of future output then it must be demonstrated that there are or will be sufficient persons of working age to achieve this output. Secondly, in estimating the volume of cash crops available for marketing allowance must be made for the subsistence requirements of the present and future population and the amount calculated deducted from the total gross output.
Factors (f) and (g) 'area of influence of the road' and 'distance to market and marketing arrangements' are interrelated. A number of studies of the affect of these factors on agricultural output from an area have been made in a number of countries but in nearly all of the cases examined the results obtained and expressions derived have been considered to be only applicable to precisely similar conditions.

In some cases the area of influence of a road has been found to parallel the road whilst in other cases a triangular effect has been created with the base of the triangle located at the nearest market centre. These two results are depicted below:
Although no precise relationships have been established it would appear that a parallel area of influence is created with a bitumen road or good gravel road and triangular area of influence with an earth road or jeep track. A study in Sabah, North Borneo by the RRL of the U.K. suggests that a kilometre of earth road in an agricultural area will on average induce the cultivation of 65 hectares giving an average penetration depth of between 600 and 700 metres although this depth of penetration will vary where a triangular distribution occurs. The variation in the area developed in Sabah was from 100 to 5 hectares per kilometre decreasing in proportion to the distance from the market. The crop produced was high value rubber and copra. Other authorities have suggested that for smallholding development one kilometre of road per 10 to 20 hectares of required development can be used as a rough guide, based on the optimum road layouts chosen for private estates. Population pressures will also have a considerable influence on development and for deeper penetration than these outlined above will occur in areas of high population density.

Thus in the Sabah study the three factors found to have the most significant affect on the volume of crops marketed were:

a. the standard of the road in relation to journey length, type (or value) of commodity and rainfall.
b. the location of the road in relation to its surrounding terrain.
c. the location of the road in relation to areas of population pressure and under-employment.

From a study of the factors the following model was derived to give an estimate of the area (A) of cash crops likely to be developed per kilometre of road.

\[
A = 411 a(0.80-0.0106D)\left[1 - \frac{(S - s \cdot L)^2}{K}ight] - \frac{L}{D}
\]

where: 
- \( A \) = area of cash crop development in hectares/km.
- 411 = mean area of influence of the road in hectares/km.
- \( a \) = the proportion of the area (hectares) of influence of one kilometre of road that is potential agricultural land.
D = the distance of the area from the main commercial centre in kilometres.
S = average speed in km/h of medium commercial vehicles on all weather roads.
α = average speed in km/h of medium commercial vehicles on the road being studied.
L = distance in km to be travelled over any length of inferior road.
K = some constant representing the importance attached to journey time in the local environment.
P = some constant reflecting comfort and uncertainty of travel.

This model in Sabah 'produced results very close to those obtained through observation, and for the nine districts examined the correlation coefficient was 0.84.'

Having ascertained the probable area of cash crop development it is then necessary to calculate the output based on known or calculated yields derived from studies of the soils and climate of the area. This may of course be complex where a number of different cash crops are produced in comparison to the example given earlier where there was only one crop to be considered. Once the probable increased output has been calculated as a volume or tonnage the volume of development traffic and number of trips can then be ascertained.

The quantification of development traffic where an improvement is to be made to an existing road is sometimes complex due to difficulties in distinguishing it from other types of future traffic, particularly normal growth traffic. Development traffic will generally occur, only where an earth road is improved or upgraded to a gravel or bitumen standard. There should not, therefore, be much difficulty in distinguishing it from other types of future traffic as the existing traffic volumes in such cases are low. Where difficulties are encountered then resort may have to be made to some form of
model or alternatively again a straight percentage taken of the present traffic which may be between 10% and 25% giving the total volume of generated traffic as somewhere between 20% and 50% of the present traffic.

It must be emphasised again, however, that the models given in these sections should not be applied directly to other situations and that is preferable to undertake similar studies in ones own country to obtain correct results. Pilot studies are to be preferred by taking two or more areas having similar population densities, topography and climatic conditions and then developing the roads within one of the areas and comparing its performance in terms of increased output with the area where no road development has been undertaken. Such a study was undertaken by the RRL (U.K.) in Uganda between 1948 and 1956 in respect of three potential cotton growing districts. The results in terms of volume and value of increased output are shown in Figure 8.

**Diverted Traffic**

The assessment of diverted traffic in a rural area should be relatively simple providing the correct surveys have been executed in the first place. For small traffic volumes, the assignment of traffic to alternative routes can be done manually based on a few simple factors such as time and/or distance. The number of trips created by persons and goods diverting to other models of transport will not be large in the circumstances under immediate discussion and the diverted traffic if any will come from other routes.

**Summary**

To summarise on the assessment of future traffic an example is given below based on percentage growths and relationships using a 10% p.a. compound growth rate.

<table>
<thead>
<tr>
<th>Year '0'</th>
<th>Present traffic</th>
<th>= 120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year '1'</td>
<td>Normal traffic = 120+10%(12)</td>
<td>= 132</td>
</tr>
<tr>
<td></td>
<td>Generated traffic = ½(20% of 120)</td>
<td>= 12</td>
</tr>
<tr>
<td></td>
<td>Diverted traffic</td>
<td>= 5</td>
</tr>
<tr>
<td></td>
<td>TOTAL</td>
<td>= 149</td>
</tr>
</tbody>
</table>
SECTION 4

INDUCED BENEFITS
(Induced Agriculture)

Induced benefits as previously indicated are net monetary benefits generated by the construction or improvement of a road facility and which could not and would not have been generated without investment in such a facility. These benefits can be classified into:

a. Induced agricultural benefits, or
b. Induced social benefits.

Induced agricultural benefits are the sole source of benefits in the justification of penetration roads and also are important in the justification of improvements to feeder roads and inter-market centre roads, where an upgrading is made of the road surface. Induced agricultural benefits (a) are equal to the net increase in the value of agricultural produce caused by the improvement which in turn equals:

The market price paid for the produce minus
i. Production costs
ii. Transport and marketing costs, &
iii. Other inputs.

Where there is an existing road, these benefits can be alternatively quantified by taking the benefits to road users, accruing through lower vehicle operating costs to traffic generated as a result of the increased agricultural output due to the improvement in the road facility as was previously discussed for development traffic.

The calculation of induced benefits is a particularly important subject as in the next decade, to achieve higher agricultural outputs, many countries will have to spend a substantial sums of money on penetration roads and improvements to existing earth roads to encourage the growing and marketing of more produce which
will also help to change subsistence economies into cash economies. Much of what has been stated in relation to the calculation of 'development traffic' applies equally to the calculation of induced benefits in which the following assessments have to be made.

a. Area of influence of the road
b. Land use, crops yields etc.,
c. Market prices for produce
d. Production costs
e. Transport costs
f. Other inputs.

For estate production all of the above factors are readily assessed although the 'market price' may for some crops depend on the World Market Prices. In such cases shadow prices to reflect the value of foreign exchange earned might be used. Where crops are grown for local markets the calculations may be very sensitive to daily or seasonal fluctuations. Local market prices are normally assessed as many of you will know, by visiting the local market with a spring balance or other weighing equipment and obtaining as large a sample of prices as possible from the various stall holders for the individual crops. In some countries this is done on a daily or market day basis at all the local markets and so all year road prices are readily available. Where all year prices are not available and a short road feasibility study is being executed then estimates may have to be made of seasonal fluctuations or such fluctuations allowed for in a sensitivity or risk analysis.

Production costs in self employed smallholder farming should include for manpower, tools and any fertilizers used. Manpower costs can be valued in a number of ways. For instance the average minimum wage rate could form the basis for one type of valuation or alternatively an opportunity or shadow costs for the labour, which might well be zero, could be used. The value to be used for any particular project is best decided upon in consultation with the Government Treasury or the funding agencies.
Transport costs are the crucial question of the whole calculation for if they exceed the market price then it is not worthwhile marketing the produce. The accurate determination of transport costs is thus very important and as discussed earlier, these costs must not be allowed to rise in future years due to poor road maintenance, otherwise the agriculture production in an area might well revert to subsistence forming. Marketing costs may be taken as wholesalers', retailers and/or cooperatives costs.

The term other inputs refers to any costs which might be associated with a particular scheme such as: agricultural advisory officers, processing facilities or schools and social halls. It is considered by some authorities that even where say, schools are not built as a specific part of a project, but are built at a later date from individuals or a cooperatives' profits, that these future costs should be foreseen and allowed for in the economic evaluation.

The induced benefits to be gained from the construction or reconstruction of a road are illustrated by the Uganda Cotton Development Scheme referred to in the preceding sections. An example of an induced benefit calculation for the Kenya Sugar Roads - Phase II is given in Figure 8.

Induced social benefits are those which will accrue through increased social intercourse affected by the construction of a penetration road into an already inhabited area or by improvements to an existing road which will permit greater freedom of movement. Such benefits are often difficult to quantity and where such quantification is possible care must be exercised to avoid double counting of benefits. Where quantification is difficult and/or double counting may occur mention should nevertheless be made of possible induced social benefits in descriptive form.
I make no apology for talking about engineering in this discussion because the economic viability of a project depends for 50% of its success on what it is going to cost. We do not want a feeder road designed as a super highway but we do want a road that is going to serve the purpose for which it is intended and this in some cases may mean building to higher standard than what would appear to be the minimum cost solution.

One definition of an engineer 'is a person who can do for a shilling, what any fool can do for a pound', thus an engineer by his learning and experience has to produce an economic solution to each problem which he is given and will, therefore, have some understanding of economics. It is nevertheless essential that at the commencement of a project the engineer should be given some indication of the standard of road which will be required.

The main factors affecting the cost of a road are:

a. Pavement standard
   i. Earth
   ii. Gravel
   iii. Bitumen

b. Road width 3.5m to 7.5m for single carriageway roads

c. Type of Terrain
   i. Flat
   ii. Hilly
   iii. Mountainous, which in turn will affect

d. Geometric Design Standards
   i. Horizontal - minimum curve radius
   ii. Vertical - maximum gradient and sight distance

e. Availability of pavement Materials

f. Type of River Crossings

g. Future Maintenance Costs.

The pavement design standard and road width will be determined by the present or future traffic volume and in some cases by the type
of terrain. For example, in mountainous country where an earth road only is required on account of the low traffic volumes, it may be necessary to lay a bituminous pavement on steep gradients to permit travel in wet weather. The absolute minimum width of road to be recommended is 3.5m for a single lane road and 5.0m for a two lane road. The economics of constructing a 3.5m bitumen road must, however, be carefully examined for individual schemes as this form of road will be found to have a very high maintenance cost caused by the necessity for passing vehicles to be continuously running off and on the edge of the bituminous surface. It should also be noted that gravel roads are as rule constructed to a greater width than a bituminous road of equivalent standing.

The volume of traffic which can be carried on a particular width of road will also be affected by the terrain. Although congestion is not a problem on most agricultural roads, the effects of a large number of steep gradients and bends will considerably reduce the overtaking opportunities for vehicles and this may have to be compensated for by providing a greater road width than might otherwise be necessary on a flat level road, to allow more maneuverability for vehicles under hilly or mountainous conditions. Whereas in the past, a road in these latter circumstances with low traffic volumes of 50 to 100 v.p.d. might have automatically been constructed as a single 3.5m width road, it has been found preferable to construct such roads to a 5.0m or 6.0m width.

Geometric design standards are usually listed in terms of highway design speeds and cross referenced to type of terrain. For example, a road designed to a 100 k.p.h. design speed has to have a minimum curve radius of 600 m with 8% superelevation if a vehicle travelling at that speed is to safely negotiate a bend of that radius. Such a radius is often impracticable in hilly or mountainous country without incurring high capital costs of construction and in these circumstances a design speed of only 50 k.p.h. may be chosen which requires a minimum curve radius of 120 m. Gradients are also obviously affected by terrain but these can be minimized in many cases by designing the road to follow more closely the natural ground contours but this will generally increase the length of the road and so a compromise
has to be found in hilly or mountainous country between:

a. A straight road with steep gradients (no earthworks)
b. A twisty but level road (no earthworks)
c. A semi-straight road with gradients minimised by heavy earthworks.

Each of the above solutions may be used progressively as the volume of traffic on a road increased and the road is improved by stage construction from earth to gravel to bitumen. In each case higher direct benefits will accrue due to the higher traffic volumes which will be present at each stage of the development.

The availability or non availability of pavement materials is one of the reasons why road construction costs for two otherwise similar roads may vary considerably. The main naturally occurring materials in Africa are:

a. Quartzitic or lateritic gravels
b. Soft rock and
c. Hard rock.

Where good sources of these materials, especially types a & b are not readily available it may be necessary to use inferior sources and to stabilise them with cement, lime or bitumen. Countries that have large quantities of good quartzitic gravels are able to build many kms of excellent gravel roads very cheaply. Whereas, in other countries where these gravels are not so plentiful or non existent, the gravel road stage of development may have to be eliminated and improvements to existing earth roads delayed until such time as there are sufficient benefits to justify a bitumen road.

The type of river crossings to be employed are dictated largely by the standard of road to be constructed. The main types are:
In my opinion not enough advantage is taken of stage construction of bridges in advance of the road construction in order to permit easier access to outlying areas. Many areas are socially cut-off from development by only poor river crossings which deter motorists and vehicle operators but the inevitable solution is to construct immediately, for these areas, a new full scale road improvement when only a few new bridges would temporarily solve the access problem and enable the investment in the road to be delayed for five or ten years. In addition more use should be made temporary bridges which when they are replaced by more permanent structures can be used elsewhere.

Mention is made of future maintenance costs in this section because it is an engineering design consideration. Road maintenance costs can be considered under two parts:

a. Annual general maintenance and
b. Periodic regravelling costs for gravel roads, and periodic resealing costs for bitumen roads.

The factors affecting these costs are:

a. Road standard - width
b. Volume of the average daily traffic
c. Type of terrain, and
d. Rainfall.

The above factors are most significant in the assessment of gravel roads, as these roads normally have a higher annual general maintenance cost than bitumen roads and also require regravelling every three to five years as opposed to resealing a bituminous road about every eight to ten years. Thus where discounted cash flow techniques are being used for project evaluation the present discounted maintenance costs for a gravel road may exceed by a considerable amount those for a bituminous road, especially in mountainous areas of high rainfall.
where regravelling may be necessary once a year. A number of expressions have been derived relating road maintenance costs of roads to the average daily traffic but I consider these to be of doubtful validity unless they also take into account the additional factors listed above. The cost of road maintenance can be ascertained from local sources or the central government ministry dealing with roads. Otherwise expressions relating the costs to some or all of the above factors may be used. Simple expressions relating maintenance cost to average daily traffic which have been used in Tanzania are given below:

a. Earth Roads (40 to 100 v.p.d.)
Annual Cost = £(31.25 to 0.625Q) per kilometre

b. Gravel Roads (60 to 200 v.p.d.)
Annual Cost = £(31.25 + 1.25Q) per kilometre

c. Bituminous Roads (150 to 1,200 v.p.d.)
Annual Cost = £(187.5 to 0.31Q) per kilometre.
VEHICLE OPERATING COSTS

Mention was made earlier of the factors which affect vehicle operating costs. We will now look at the components which go to make up the total vehicle operating cost. These components can be listed as:

a. Standing Costs
   (i) Depreciation
   (ii) Interest on Capital Invested
   (iii) Insurance
   (iv) Wages (Commercial Vehicles)

b. Running Costs
   (i) Fuel and Lubricants
   (ii) Tyres
   (iii) Maintenance

c. Overheads (Commercial Vehicles)

d. Time Costs of Drivers and Passengers
   (Private Vehicles)

All of the above costs are normally calculated net of tax.

Again it is preferable to assess these costs from basic principles when executing a detailed study rather than to apply generalised Costs which may have already been calculated for different types of vehicles in your respective countries. The justification of many road improvement projects, where an improvement made is in the type of running surface, is often done, purely on the savings in vehicle operating costs in changing from earth to gravel to bitumen. However, it is most probable that when such improvements are made there will also be changes to the width, rise and fall and curvature of the
road, which will also give rise savings in operating costs. When alternative schemes are being prepared account should be taken of these additional factors to ensure that the schemes are properly compared on an equal basis.

The assessment of the components of vehicle operating costs can be done by:

a. Scientific study using empirical methods
b. Collection of actual operating data from interviews with haulage operators, bus companies and private car owners combined with general observations.

c. A combination of a & b above.

In a feasibility study for a particular road project there is generally insufficient time for a full scale scientific study and it is then necessary to resort to the collection of existing local data. This method while possibly not so accurate will on the other hand reveal only special factors which affect vehicle operating costs in the area being studied. The main limitations on this method are threefold. First small operators often do not keep good records of their costs. Secondly, there might be kept two sets of accounts, one for the tax man and one for the operators own use and thirdly it is sometimes difficult to find vehicles that operate exclusively on one type of road surface. Once these difficulties are appreciated then by applying some known facts on vehicle operating costs a transport economist is able to obtain the costs required. An example of this would be to calculate the local vehicle running costs on only bitumen roads and then to apply the factors listed below for other types of surface:

<table>
<thead>
<tr>
<th>Surface</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bitumen</td>
<td>1.00</td>
</tr>
<tr>
<td>Gravel</td>
<td>1.10 to 1.20</td>
</tr>
<tr>
<td>Earth</td>
<td>1.84 to 2.10</td>
</tr>
</tbody>
</table>

These factors were obtained from studies made in Kenya and Zambia by the RRL, UK and have since been extensively used for many economic analysis, but as will appreciated there are
varying standards of earth and gravel roads and the full benefits to be gained from a particular project may not be realised if local running conditions are not fully investigated.

There are number of excellent papers and books on the assessment of vehicle operating costs. Two of particular interest are:

a. World Bank Staff Occasional Paper Number Two 'The Quantification of Road Use Savings' by Jan de Veille, and

b. Motor Vehicle Running Costs for Highway Economy Studies by Robert W

In this paper, therefore, it is only intended to cover briefly the assessment of the various components of operating costs and to suggest methods of collecting data for local appraisals.

DEPRECIATION

Depreciation is normally calculated on a 'straight line' basis over the life of the vehicle. The depreciable value being the purchase price new minus the value of the tyres with no residual value. The depreciation cost per kilometre will be determined by the total length of service of the vehicle, its annual mileage, average running speed, type of running surface and degree of maintenance. Speed affects depreciation in two ways. At high speeds, first there is greater wear and tear on the vehicle but secondly, increased vehicle utilisation, while at low speeds the converse applies. Vehicle depreciation costs per kilometre, irrespective of speed equal the depreciable value divided by the total lifetime mileage. Adjustments, where necessary they have to be made for the speed factor. Local information on vehicle life and annual mileage can be collected in an origin and destination study as previously noted, by taking the vehicle registration number and mileomter reading. The age can then be determined by comparing the registration number with lists giving the years in which blocks of numbers were issued. In countries where the vehicle registration plates are changed annually, this method will obviously not work. As
an alternative to this method but also for the purpose of collecting other information surveys may be made of second hand vehicle garages where the car log books are available for inspection and also by interviews with lorry and bus operators and private car owners. Survey farms for these purposes are given in Figures 10 and 11.

INTEREST ON CAPITAL INVESTED

Interest on capital invested can be calculated on half the depreciable value of the vehicle over its total lifetime at the local rate of interest. This assumes that the average age of vehicles on the road is half their total life and their value half their new value. This is in fact only true if the vehicle population is stationary and the individual vehicle is depreciated on a straight line basis. As this is not so, a calculation on this basis will underestimate the interest but adjustments can be made if thought necessary. The cost of interest on capital invested per kilometre can then be taken to equal the annual interest divided by the annual vehicle mileage with allowances for the speed factor.

INSURANCE

The cost of insurance can easily be determined from vehicle operators or insurance corporations. Where the insurance is through private companies then an allowance must be made for the tax element in the cost. The cost per kilometre is calculated as before by dividing the annual cost by the annual vehicle mileage with allowances for the speed factor. Insurance costs must not be included in vehicle operating costs if the specific cost of accidents is to be assessed separately.

WAGES OF PAID DRIVERS

The cost wages for paid drivers can be obtained from an origin and destination survey. After allowing for tax the cost per kilometre can be calculated with the speed factor also being taken into account if required.
These components of vehicle operating costs are affected to differing degrees by all of the factors previously mentioned. Extensive research has been executed on these costs and a lot of literature published. On a straight level road fuel consumption for the majority of vehicles is lowest at around 55 k.p.h. Above and below this speed fuel consumption increases per kilometre travelled. Fuel consumption can be measured directly by fitting a petrol meter in the fuel system of a vehicle and taking readings at different average speeds over set sections of road whose horizontal and vertical profiles are known or can be measured. These tests can be carried out for many combinations of vehicle type, percentage road, type of surface and horizontal and vertical profile at differing average speeds and expressions derived by regression analysis relating fuel consumption to each of the factors considered. On most rural roads congestion is not a problem and consequently vehicle speed is most affected by the rise and fall of a road and its curvature and fuel consumption is in some cases more directly related to these factors. However, as previously mentioned the significance of these factors will vary from project to project and in some cases the type of running surface may be the predominant factor affecting consumption.

Tyre wear is known to be affected by road surface type, speed, loading, altitude and temperature but little research has so far been done to assess the individual affect of each of these parameters. Most investigation into vehicle operating costs, usually obtain facts on tyre life in terms of kilometres per tyre with reference only to road surface type, where possible, and divide this distance into the cost of the tyre new, less tax and any rebates for use of the carcass for remoulds to give tyre costs per kilometre. In scientific studies which have been executed, tyre wear has been found to at least double with an increase in average speed from 24 k.p.h. to 80 k.p.h. and increase by 20% with a change in air temperature from 18°C to 30°C. Tyre wear is also known to increase with altitude and
load. Local information on tyre life can be obtained from private and commercial vehicle operators.

**MAINTENANCE**

The standard of vehicle maintenance varies appreciably in any country throughout the world. However, as a less well maintained vehicle will depreciate at a faster rate than one which is well maintained, the differing depreciation and maintenance costs should balance each other out providing the correct assessments are made in each individual case. Here again information can be collected from local vehicle operators and costs per kilometre obtained by dividing the annual maintenance cost less tax by the annual vehicle mileage. When collecting information on maintenance costs it is most important that as wide a range as possible of vehicles of differing age are covered in order that the varying maintenance costs known to occur with age are taken into account. It will be generally found that these costs are split 50/50 into cost of labour and cost of parts.

**OVERHEAD COSTS**

Some authorities may not agree on the inclusion of overheads in vehicle operating costs for the purpose of assessing road improvement schemes. By 'overheads' reference is made to administrative staff who may control and organize large vehicle fleets. However, such staff usually have a fixed cost and if vehicle utilization is improved by the provision of a better road then their cost per kilometre of vehicle operation will drop proportionately. The inclusion or exclusion of these costs and any resultant benefits must be decided upon for individual schemes.

**VEHICLE SPEEDS**

In this section vehicle speeds have been demonstrated to play an important part in the assessment of vehicle operating costs. Vehicle speeds on existing roads can be assessed by three methods:

a. Registration Number Plate Method
b. Moving Car Observer Method
c. Use of Test Vehicle
In the registration number plate method observers are stationed at the beginning and end of the road section to be analysed and note down the registration numbers of vehicles using the road and the time at which they pass. Comparison is then made by manual or computer analysis of the two sets of observation and the time taken for individual vehicles to pass along the section calculated. Average speeds for different groups of vehicles can then also be calculated. This method has the advantage of enabling a large amount of data on all vehicles usung a road to be collected in a very short time.

The 'moving car observer' method can be executed in a number of ways. The main basis of the method is for an observer travelling in a vehicle to follow another vehicle chosen at random which is proceeding normally along the road to be analysed and noting the time taken for it to pass between various points. To obtain average vehicle speeds a number of runs may have to be made along the road for each vehicle class, but the number of runs made can be reduced by following one particular vehicle for say, only 5 kilometres and then randomly selecting another vehicle to follow for the next 5 kilometres and so on.

The use of a test vehicle is usually done for obtaining the speed of heavy commercial vehicles. By hiring a vehicle of this type, observation of speed on different gradients and road surface types can be made under a variety of load conditions while possibly at the same time making observation of petrol consumption.

**ROAD INVENTORIES**

In order to calculate the operating cost savings that will accrue through an improvement to a facility it is necessary to quantify the existing road characteristics and make some estimate of the characteristics of the future facility. This is done by compiling a road inventory of the existing road by making measurements of characteristics which are known to have an affect on operating costs. In compiling a road inventory the following may be noted usually on a kilometre basis:

a. pavement type
b. pavement condition
c. Road width
d. Drainage
e. Rise and fall
f. Curvature

g. sight distance

h. Percentage heavy vehicle

i. Traffic volume.

In a study carried out in Jamaica between 1962 and 1964 by the RRL, UK an expression was derived for the purpose of calculating car journey times (JT) in minutes per kilometre on bitumen roads over the range 0.40 to 1.13 minutes, as:

\[ JT = 2.503 - 1.2032W - 0.002110S + 0.000205Q + 0.00025U + 0.000491C + 0.001847P \]

Where:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>4.2 to 8.5</td>
</tr>
<tr>
<td>S</td>
<td>41 to 257</td>
</tr>
<tr>
<td>Q</td>
<td>13 to 544</td>
</tr>
<tr>
<td>H</td>
<td>1.4 to 42.6</td>
</tr>
<tr>
<td>C</td>
<td>0 to 795</td>
</tr>
<tr>
<td>P</td>
<td>0 to 75</td>
</tr>
</tbody>
</table>

The above expression can be used for gravel and earth roads by adding a further term to the equation to reflect the general average lower speeds on gravel and earth roads.
Road Accident Costs

Road accident costs can only be evaluated if national statistics are available for the average cost of different types of accidents together with data on accident rates for different road standards. Where such data is not available, then in a report it may only be possible to quote the accident rates on the existing facility from information compiled from police records.

Road accident rates are normally quoted either as the number of accidents per million vehicle kilometres or the number per 100 million vehicle kilometres. The overall accident rate for rural roads can vary between 1.0 and 13.0 per million vehicle miles. Accidents are generally classified into

a. Fatal
b. Serious Injury
c. Slight Injury, and
d. Damage Only.

The average cost of accidents in the United Kingdom at 1970 prices has been found to be £1,600 per injury accident ranging from £19,000 for a fatal accident to £100 for a damage only accident. The cost of serious and slight injury accidents were found to be £1,400 and £250 respectively.

In the valuation of the cost of accidents the following points are considered:
a. Loss of output
b. Cost of medical treatment
c. Damage to property
d. Administrative costs - police, insurance, etc.
e. Delay to other vehicles
f. Funeral costs
g. Suffering and bereavement.

In the case of fatal accidents, the discounted value of future consumption may or may not be deducted from the discounted resource costs of the future production of the person killed.

Tributary Roads
Where a road is constructed or improved for the development of an area, the cost of any tributary roads which also have to be constructed as part and parcel of the development must also be included in the capital costs for the purpose of the economic analysis.

Shadow Prices
At the present time the World Bank and other international funding agencies require the capital costs of a project to be estimated using both normal wage rates and low shadow wage rates for labour in countries having high unemployment. The main effect of the use of these shadow rates is obviously to lower the estimated capital construction costs.

This argument is now, however, being taken one stage further by giving to tenderers for a project shadow wage rates for estimating purposes
to see what effect it will have on the contractors decision regarding the balance between labour and plant to be used for construction. This idea is a variation on forced labour intensive methods but is one which allows contractors the freedom of economic choice. The use of shadow wage rates for tendering purposes is understood to be still at the experimental stage.

Tax Element of Construction Costs

To obtain the economic capital costs of construction to be used in the economic analysis allowance has to be made for tax element in the estimated financial capital construction costs. This tax element is normally expressed as a percentage of the financial costs and can be calculated from an examination of the tax element contained in the following items:

a. Machinery (customs duty)

b. Fuel (excise and sales taxes)

c. Wages (income tax etc., and also contributions to state medical and pension funds)

d. Vehicles (tax element on purchase price, running costs and maintenance)

e. Construction Materials (import duty and tax on distributors and manufacturers profit)

f. Construction Company's Profit (Company Tax)

Not all of the above items may be taxed in some countries while elsewhere there may be other taxes to be applied. For example, in Uganda no customs duty is payable on construction machinery imported for a specific project provided the machinery is exported on completion of
construction. In the three East African Countries of Kenya, Tanzania and Uganda the tax element was calculated in the East African Transport Study to be about 10%.

**Foreign Exchange Component of Construction Costs**

As you may know most international funding agencies only give grants or loans to cover the foreign exchange component of a project. Thus it is necessary to make an estimate of this component in order to make a loan application. It will be found that all of the items listed in the previous paragraph on tax also contain a foreign exchange cost and this can be fairly easily assessed. For road construction projects in Kenya the foreign exchange component of the financial construction costs has been found to be in the region of 65% to 70%. In Uganda this component has been variously estimated at between 50% and 70%.

**Sensitivity and Risk Analysis**

It is usual to execute sensitivity or risk analysis on the main inputs to an economic analysis. In the analysis of road projects sensitivity or risk analysis is executed on some or all of the following inputs:

- a. Capital costs
- b. Future traffic volumes
- c. Crop yields to allow for droughts
- d. Discount rates
- e. Road Maintenance Costs
In the past it has been our practice to use sensitivity analysis but we have now come to the conclusion that this can be meaningless. For example, if the most pessimistic view was taken and the estimated construction costs were increased by 25%, the estimated future traffic volumes were halved, the lowest estimated crop yields were used together with a drought every three years plus the highest imaginable discount rate and perfect road maintenance was budgeted for, then it would be virtually impossible to justify any road project. The chances of all such events occurring within one project have been estimated to have a low probability. We intend, therefore, in future projects to use risk analysis methods by employing Monte Carlo techniques to all variables with the results plotted as a cumulative frequency distribution.
Section 6
SUMMARY

In the previous sections all of the factors to be considered in an economic analysis have been discussed in very general terms. Mention has been made of traffic volumes, traffic growth rates, induced benefits, engineering design standards and vehicle operating costs. From the many economic analyses of road projects that have been executed in the past certain relationships have been found to exist between traffic volumes and road standards and also the traffic volume at which an improvement to a road facility can be economically justified through a reduction in vehicle operating costs and in some cases road maintenance costs caused by the improvement.

In Figure 12 I have attempted to define some of these relationships but as you will appreciate the traffic volumes and standards listed can only be a guide. The traffic volumes have been described in terms of equivalent passenger car units to allow for variations in the percentage of heavy vehicles. For most purposes all light vehicles can be taken as being equal to one passenger car unit and heavy vehicles to three passenger car units.

The 'present road standard' is the one which will be found to be present over the range of indicated traffic volumes. If a higher standard exists at these traffic levels then overinvestment may have occurred. If there is a lower standard then substantial vehicle operating costs are possibly being incurred which could be reduced by investment in an improved facility. Although no golden rules can be given investigations into providing 'improved road standards' should be started when the traffic volumes are in the upper third of the related range.
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