ROAD NETWORK DEVELOPMENT & MANAGEMENT
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Acknowledgement
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**Summary:**
Like any producer of goods or services, providers of road infrastructure have to determine the quality, quantity, availability and other so-called service levels of their product, the road networks. Typical service levels of a road network relates to the traffic capacity in relation to traffic demand, road safety characteristics, road length in relation to built-up area and measures to mitigate negative effects of road infrastructure like noise pollution.

According to the consumer surplus theory, providers of road infrastructure should aim to minimize the combined costs for road users, the road provider and the environment. The costs for road users are the direct costs of transportation like fuel, depreciation of vehicle, operation and maintenance of vehicles. Furthermore road users face all kinds of indirect costs, like travel time loss due to congestion and damages due to traffic accidents. The road providers have to pay for the construction and maintenance of road infrastructure. A break down of these costs would present the costs of the organization, costs of interests of loans in addition to actual construction and maintenance costs. The environmental costs are the costs caused by road users to the environment and third parties.

In a ringfenced system, the road users have to pay for the costs of the road provider and have to compensate the environment and third parties for damages caused by the road users. Road agencies can generate revenues through fuel taxes, taxes on car sales, licensing number plates, operating road tolls and collecting of other special taxes. The Road Agencies have to determine the level of these taxes and road tolls. Revenue generation should at least be high enough to finance the construction and maintenance of the road networks; alternatively the government (treasury) may choose subsidizing the provision of road networks. Ideally this subsidy has the form of sector-support and is not provided in the form of project support. Ideally the revenue collection should also compensate the damages to the environment and third parties and finance projects to minimize negative effects from road users, like subsidizing public transport, provided that such levels of revenue collection can be generated.
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1 INTRODUCTION

Road Authority
In most countries different public organisations manage different road networks. National Road authorities manage the National Road network. This road network consists of corridors that connect the national administrative, economic and cultural centres of the country. Usually the National Roads run through several provinces.

The Provincial road authority manages the provincial road network. The roads of the provincial road network usually connect the administrative, economic and cultural centres of the province. It usually also connects and makes use of some National roads.

The District authorities are responsible for the District Road network. This road network connects the administrative, economic and cultural centres in the district. And often it connects and integrates some of the provincial or national roads in its network.

Municipal roads usually run within the municipal borders.

Scope of document
This document deals with planning systems for national, provincial and district road networks.
This document does not include maintenance planning systems.
2 PROVIDING ACCESS

Access

The main objective of road providing organisations is to provide access within their financial and legislative framework. But what does access entail?

Hansen & Martellato

A general definition of accessibility is that it is the potential of opportunities for interaction (Hansen 1959 and Martellato et all, 1998). Related definitions use terms like 'ease of spatial interaction', or 'potentiality of contacts with activities or suppliers'.

Edmonds

Geoff Edmonds summarises lack of access as:" Lack of access deprives people of the opportunity to improve their lives. Access is composed of two elements. Mobility, reflecting the ease or difficulty in travelling to a service or facility and Proximity, of those services and facilities."

Roads are typical mobility interventions.

Equity

Most governments find it important that everybody has equal opportunities to reach certain facilities, the so-called equity ideology. Access is also seen as a key element in providing the opportunity for social and economic growth.¹

Accessibility, but for whom and for what? These basic questions indicate that accessibility is specific per type of user and per purpose. Therefore, when describing the accessibility situation, these aspects should be specified. An implication is that accessibility becomes purpose specific. There are different clients that have a demand for road infrastructure. Members of households want to travel to fetch water, schools, education, health facilities, telecommunication facilities, religion facilities, family and friends, markets, the work place. Businesses are in demand for roads for the collection of inputs and the distribution of products to customers, storage and other production facilities or other distribution networks like rail, water or air. The public sector is not only the main facilitator of roads but also a user of the road network. Think of the police, fire brigade, and ambulance, to name a few.

Willingness to pay

Not only the demand for transport/travel is purpose specific but also the willingness to pay is purpose specific. One would hope to travel less frequent to the hospital than to school, family, friends etc, but one would also hope that transport to the hospital is always available. The willingness to pay for life saving trip purposes is very high and almost price inelastic. The prevalent norms and values in society also influence the transport cost limits. These norms and values on the other hand are highly dependent on the normal practices in society. If the population is used to a situation where every village has its own primary school, they will frown upon a district where primary education is only provided in

¹ Geoff Edmonds: Wasted Time: The price of Poor Access, ILO, 1998
every other village.

2.1 **ROAD NETWORKS**

It is possible to describe the road network in different ways. The nine statements presented below can all be used to describe the performance of the road network in terms of accessibility.

1. A node has access to a network if a link exists between the node and the network
2. The accessibility of a node with respect to a network is the distance one has to travel to the nearest node on the next hierarchy network
3. The accessibility of a node in a network is the total number of direct connections with other nodes
4. The accessibility of a node in a network is the total number of links connected to this network
5. The accessibility of a node to another node is measured as the travel cost between these nodes
6. The accessibility of a node in a network is the weighted average travel cost between particular node and all nodes in the network
7. The accessibility of a node in a network is the expected value of the maximum utility of a visit to any node
8. The accessibility of a node in a network is (proportional to) the spatial interaction between the node and all other nodes
9. The accessibility of a node in a network is the total number of people one can reach from a node with in certain transport cost limit\(^2\).

To describe the road network based on one or more of these phrases information is needed about:

- The location of nodes (centres)
- The length of the links
- Data on transport costs, travel time, fares

And sometimes information about spatial patterns may be required, e.g. travel frequencies and traffic volumes.

**Price-elasticity**

As explained earlier, the price-elasticity for roads depends on the travel destination. Nobody wants to visit health facilities, but when necessary we are all grateful that both facility and road to access the facility are in good shape. Thus it is not always correct to assume that the actual traffic flow represents the demand for a certain road link. This is in particular the case in areas with low population densities and low motorised traffic. In more urbanised areas or in richer countries, it is more likely that the traffic is a good representation of the demand for certain facilities. Also keep in mind that traffic counts and origin-destination surveys are costly, if they have to be carried out on every road link.

\[^2\text{Transport cost limit can be formulated in any dimension: distance, travel time, expenditures, etc}\]
Statements 6, 7 and 8 are all difficult to quantify and therefore not suitable in the context of most countries. Statement 9 relates best to earlier presented definitions of Edmonds, Martellato and Hanssen. It also reflects best the equity principle of most governments.

Note that people may travel to the node (facility/ service/ entry point of transport network) even when it is outside this transport cost limit. However the number of people willing to travel to a certain destination decreases as the travel costs (travel time) to that destination increases. This process is stronger when the facility is located outside the travel limits.

Legend

- Area within transport limit, the norm.
- Influence area: Although outside the norm, there is still a demand for the infrastructure. The demand has an inverse relationship to transport costs

Typical road projects

Accessibility can thus be improved, among others, through the following road interventions:

1. Expansion of the road network, inclusion of new nodes.
2. Reduction of the distance between the node and the nearest entry of road network
3. Increasing the amount of direct connections between a node and the other nodes
4. Increasing the number of links accessing the node
5. Reduction of travel costs of road users, travel time, fares, toll fees, vehicle operation costs, accidents, congestion

Connectivity

The first improvement option is clearly focussed on the expansion of the existing road network; it results in additional access to isolated nodes. The other four improvement options are improving the performance of the existing road network.

Financial feasibility

But road organisations also would like to increase their financial
feasibility and therefore could implement projects to raise their income
and/or reduce their costs.

Environment

It should also be noted that road networks can also be improved
through reducing its negative environmental impacts. Roads are often
physical obstacles for wild life. Wild life reserves may be split in two or
more pieces due to roads running through it. It may be possible that
these pieces are too small to sustain certain species’ population. Road
authorities in the wealthier countries are already implementing
mitigating interventions. These mitigating interventions allow game to
cross the roads safely.
3 FINDING VERIFIABLE OBJECTIVE INDICATORS

Economic growth and social development requires transport infrastructure. Governments have the difficult tasks to find out which transport interventions are needed and what their contributions towards their development goals are.

Planners in the road sector should therefore develop verifiable objective indicators that are expressions of these development goals and relevant to the transport sector.

**Multiple objectives**

But the road sector also has a number of objectives. It would like to improve its financial capacity. At the same time it wants to provide more access to isolated (still disconnected villages), it also would like to improve the accessibility on its existing road networks and last but not least it would like to reduce the negative environmental impacts of the existing and future road network.

**One indicator?**

Thus the road-providing organisation has a number of sub-objectives. If all activities aiming at these different sub-objectives are financed from one source, the planners need to formulate one aggregate verifiable indicator. In such situations, the different interventions contributing to different sub-objectives are competing with each other for resources. If there are different sources for each and separate sub-objective, these sub-programs do not compete with each other and therefore it is not necessary to define one aggregate verifiable objective indicator. The latter situation is obviously the easier situation.

The first step is to identify the most common interventions and their impacts. The Table below provide a summary of the most common situations:

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Primary Impacts</th>
<th>Secondary Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road openings</td>
<td>Reducing transport costs/time to facility</td>
<td>Increasing maintenance costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Affecting competitiveness region</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase of vehicle emissions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase of vehicle energy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase of noise pollution</td>
</tr>
<tr>
<td>Congestion reduction</td>
<td>Reducing transport time/costs</td>
<td>Affects competitiveness region</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Reduction vehicle emissions</td>
</tr>
<tr>
<td>Road accident prevention</td>
<td>Reducing causalities, injuries and damages, = reducing transport costs</td>
<td>Affects competitiveness region</td>
</tr>
<tr>
<td>Road smoothening</td>
<td>Reducing vehicle operation costs (transport costs)</td>
<td>Less emissions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Less noise pollution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Affects competitiveness region</td>
</tr>
<tr>
<td>Road surface upgrading</td>
<td>Reducing vehicle operation costs</td>
<td>Affects maintenance demand and budget requirements</td>
</tr>
<tr>
<td>Road length reduction</td>
<td>Reduction of transport costs</td>
<td>Affects maintenance demands</td>
</tr>
</tbody>
</table>
### 3.1 SOCIAL INDICATORS

**Problems**
It is not only useful to indicate likely impacts of infrastructure interventions, but is also interesting to define simple Objective Verifiable Indicators to measure the problems it tries to address.

**Congestion**
Congestion problems are usually expressed in travel time delays. These are the delays due to the congestion.

**Accidents**
Accidents are usually recorded in three classifications:
1. Fatal accidents
2. Injuries
3. Damage only accidents

**Environment**
Environmental problems usually concentrate on themes like emissions, energy use and noise pollution.

**Isolation**
Isolated areas deprive people from access to all sorts of facilities, services, and destinations. Access could be measured in terms like transport time or costs to reach a certain facility, service or destination. Because isolation relates to opportunities and not to real behaviour, it is not necessary to collect information about travel frequencies and patterns.

### 3.2 FINANCIAL INDICATORS

**Generating income for transport infrastructure**
Ideally, transport utilities will charge road users for their use of the transport infrastructure, through road tolls, petrol levies and vehicle specific taxes. The revenues should cover all the costs for making transport infrastructure available (investments, administration, operation & maintenance), otherwise the government has to subsidise the provision of transport infrastructure from generic taxes and other sources of income. In more advanced economies, road users may be required to bear (some of) the costs to the society, like damages due to traffic accidents and pollution of the environment. In most low and middle-income countries, the society subsidises these “social” costs.

In general, national development improves when the total transport costs reduce. The total transport costs have three main components:
1. Cost of the transport utility to make transport infrastructure available
2. Cost to the society
3. Direct cost of transport itself
4. Indirect cost of transport due to inefficiencies in the transport infrastructure (i.e. waiting time due to congestion)

The revenue system should be designed in such a way that it covers all the costs of the transport system in the country, not just that of the airport, harbour, road network, waterways or railway. Often certain infrastructure systems or links of the system are more profitable than others. Therefore it is necessary to set up a system in which cross-subsidisation between transport infrastructure systems and different parts of the network. The transport infrastructure agencies usually do
not charge pedestrians and often non-motorised transport for the use of the transport infrastructure. The agency may finance the specific infrastructure for these target groups from a surplus generated from motorised traffic and from subsidies from generic taxes.

The transport infrastructure agency has the task to set the physical infrastructure requirements, minimizing the aggregate costs for all road users and the agency (government). From an economic point of view, projects are justified when it lowers the aggregate cost through upgrading the transport network. However from a financial point of view, most projects increase the expenditures the transport providing institution. The transport infrastructure providers have to evaluate if they can afford the extra costs or the project will also generate additional revenues. Otherwise the government has to subsidise the provision of transport infrastructure. This means that all the road users together pay less than the costs of the transport infrastructure agency to provide transport infrastructure. It also means that the road users receive more in terms of access and infrastructure physical standards than they pay for.

When governments want to reduce subsidy levels they have the following choices:

- Increase aggregate income from road users
- Reduce expenditures through reduction of road network or lower physical standards
- Combination of the above

**Maintenance demand**

Most of the traffic runs over the highways, between the economic centres and of course within the urban areas. Thus these roads gain a lot of financial resources for the organisation. At the same time there is a positive correlation between traffic volumes and maintenance demands. Therefore these links with high traffic volumes have also high maintenance demands.

**Corridor**

It should be noted that usually these links are part of a corridor. If one link fails to deliver, the attractiveness of the corridor as a whole is affected, resulting in lower traffic demand. When the total length of the road network increases the maintenance demands increases too.

**Upgrading**

The maintenance demands not only depend on the traffic volume but also on the surface type. It is obvious that earth roads are more sensitive to deterioration than concrete roads. It may therefore be possible to reduce the maintenance demands through upgrading of the road surface.

**Bank Financing**

When road projects are to be financed by the Development Banks, like the World Bank, Asian Development Bank, the organisation has to prove that the project is financially viable. Too often the Banks are not concerned if the network (organisation) is financially viable, but are only interested in the financial feasibility of the project itself. The Development Banks express the financial feasibility in terms of economic rate of return. In brief there are two ways the Banks may assess the economic rate of return:
1. Producers surplus  
2. Consumer surplus

**Consumers’ Surplus**  
*Because it is close to impossible to estimate the producers’ surplus, the Banks prefer to use the consumer surplus methodology. The basic assumption of the consumer surplus methodology is that savings of the road users (as an impact of the project) will be transferred to the government and the government will use this fund to repay the loan. Although most loans are repaid, these assumptions are incorrect. The assumption in the producers surplus is that project will result in additional economic growth and that a part of the surplus, via tax systems, will go to the government. The assumptions made for the producers surplus system are correct, but it is very difficult to make reliable predictions of the producers’ surplus in the road sector.*

*Note that both techniques are economic and not financial feasibility assessments.*

*Financial assessments would focus on the impacts of the project on the road network, in terms of income and expenditures. For example: will the project generate more traffic on the whole road network and/or will the project reduce the required expenditures for operating, maintaining, improving and developing the road network? It should be noted that even if a project will result in a higher traffic demand over a certain link, the total traffic demand on the road network usually remain the same. The traffic demand is not so much determined by characteristics of the road network, but by social-demographic and economic factors. If the road project is accompanied with the reallocation of an industrial estate or the opening of new mining or tourist areas, or other economic activities. It is more likely that the project will result in a net traffic demand and therefore in additional income for the organisation.*

### 3.3 ECONOMIC INDICATORS

Many interventions have impacts on the transport costs and/or vehicle operation costs. It should be clear that the road user is the main beneficiary of these interventions. In theory these transport costs reductions and vehicle operation costs reductions could affect the economic situation of a country and/or region.

**Consumer surplus models**  
The economic impacts of road improvement interventions are usually predicted with consumer surplus models. Although the consumer surplus methodology is more acceptable to the economists, it must be noted that it does not predict the economic growth of a certain country, region etc. Reduction of transport costs may actually lead to emigration of certain businesses or strengthen the competitiveness of other regions/countries.

**Demand for data**  
Even consumer surplus models may be difficult to develop, because in
many countries data with regard to travel frequencies and patterns are not available, in particular for non-motorised travel. There are some more difficulties with these economic approaches. First of all the real economic costs of travel time delays, road accidents have to be established. Secondly road users and governments have other (social and environmental) objectives as well. These objectives may be conflicting. Although the travel frequency to health facilities should ideally be low, most people are willing to pay considerably for the infrastructure facilitating the health services.
4 ISOLATION & CONNECTIVITY

Isolation is perhaps the opposite of access. Its major cause is of course the lack of roads or transport infrastructure. Isolation is seldom caused due to irregularities in the existing road network.

Access Indicators

The International Labour Organisation has developed so-called access indicators to quantify access or isolation. It took it also a little further by formulating indicators describing the effects of road interventions in terms of access or isolation.

Simple access indicator

The simplest form to identify and rank road projects is respectively the number of people living in a settlement not connected by and the numbers of people served by the road projects (benefits) divided by the expenditures of the project. In this case it is assumed that every road has the same standard, which of course is unrealistic. Therefore the beneficiaries (the inhabitants of the connected settlements) are multiplied with a quality indicator. The quality indicator distinct different quality levels of the road. As described later in more detail, it is possible to describe the service level of the road in terms of:

- Periods when it is not accessible
- To what kind of vehicles it is accessible
- Speed
- Comfort
- Safety

Equation

In equation the benefits are calculated with the following formula:

\[ \sum (\text{Population connected per road type} \times \text{Quality score of the road}) \]

Traffic flow

In this analysis it assumed that traffic flows in one direction from lower hierarchy settlement to a higher hierarchy settlement. For example from a hamlet to the nearest village, from the village to the nearest town, from the town to the nearest city, or from the settlement to the district capital, from the district capital to the province capital and from the province capital to the capital of the country. Another, a little more complicated indicator is the travel time from a particular settlement to a road link with a certain quality belonging to a certain road network. Many road projects may not actually connect the
settlement, but the inhabitants of the settlements may require less time to reach the road network and therefore its destination. Often the quality standard of the road link and road network, all year sedan vehicle accessible road networks. It is possible to formulate higher standards by incorporating a speed component.

**Transport costs**

Some will ask why the travel time is taken and not the transport costs. First of all because most people walk in rural areas, it is difficult to estimate the transports costs. To measure or predict the transport costs, it is necessary to obtain data about the frequency of travel to certain destinations. As argued in previous chapters, the frequency of travel/transport is not necessarily an indication of the demand for road infrastructure to a certain destination. The IRAP tool as originally designed therefore measures or predicts the transport costs for one single or return trip (depending on the destination). Because in most situations it is difficult to measure the transport costs and therefore in most countries the Integrated Rural Accessibility Planning tool uses travel time instead.

**Different road qualities**

It is possible to make the indicator more complete to measure the travel time to different quality roads. If the settlement is located near to a high quality road, then in all cases the travel time to this road is taken.

**Equation**

\[
\sum \text{Settlement populations} \times (W_{q1} \times TT_{to \ q1} + W_{q2} \times TT_{to \ q2} + \ldots + W_{qn} \times TT_{to \ qn})
\]

Where

- \( TT_{to \ qn} \): travel time from settlement to the nearest road that at least meet quality standard \( n \)
- \( W_{qn} \): The weight factor showing the relative importance the particular road very often expressed as a percentage or as a ratio. (Thus all the weight factors together make 100 % or 1.)

**Transporters needs**

All weather sedan vehicle accessible roads allow transporters to provide transport for goods and services. And nowadays in most countries most transporters operate motorised vehicles. However non-motorised vehicles are still operating in parts of the world and often non-motorised transport has other requirements to the road network. The table below presents the different transport modes and their road requirements.
### INDEVELOPMENT:

#### Road Network Development & Management

<table>
<thead>
<tr>
<th>Mode of transport</th>
<th>Terrain</th>
<th>Typical load (Kg)</th>
<th>Average speed (km/hr)</th>
<th>Daily range (km)</th>
<th>Transport capacity (tonne km/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walking</td>
<td>All</td>
<td>25 – 30</td>
<td>4 – 5</td>
<td>15.20</td>
<td>0.12</td>
</tr>
<tr>
<td>Wheelbarrow</td>
<td>Rolling, narrow tracks</td>
<td>90</td>
<td>3 to 4</td>
<td>5 to 6</td>
<td>0.31</td>
</tr>
<tr>
<td>Handcart</td>
<td>Hilly, all weather roads</td>
<td>200</td>
<td>3 to 4</td>
<td></td>
<td>0.7</td>
</tr>
<tr>
<td>Cycle with carrier</td>
<td>Rolling, narrow tracks and hilly all weather &gt; 1.5 m wide tracks</td>
<td>60 – 40</td>
<td>10</td>
<td>40-50</td>
<td>0.5</td>
</tr>
<tr>
<td>Cycle trailer</td>
<td>Rolling, 1.5 meters wide smooth roads</td>
<td>150</td>
<td>8</td>
<td>30-40</td>
<td>1.2</td>
</tr>
<tr>
<td>Pack donkey</td>
<td>Hilly rough tracks</td>
<td>50-80</td>
<td>4 to 5</td>
<td>20</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Rolling, narrow rough tracks</td>
<td>50-100</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ox-drawn sledge (2 oxen)</td>
<td>Hilly, all weather roads &gt; 1.5 m wide</td>
<td>150 – 250</td>
<td>2 to 3</td>
<td>15</td>
<td>0.63</td>
</tr>
<tr>
<td></td>
<td>Rolling Medium smooth tracks 1 – 1.5 m wide</td>
<td>300 – 1000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Donkey cart</td>
<td>Hilly, all weather roads &gt; 1.5 m wide</td>
<td>300</td>
<td>4 to 5</td>
<td>20</td>
<td>1.35</td>
</tr>
<tr>
<td>Ox-cart</td>
<td>Hilly, all weather roads &gt; 1.5 m wide</td>
<td>800</td>
<td>3 to 4</td>
<td>20</td>
<td>2.8</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>Rolling, wide smooth tracks</td>
<td>50</td>
<td>40</td>
<td>150</td>
<td>2</td>
</tr>
<tr>
<td>Motor cycle trailer</td>
<td>Rolling, wide smooth tracks</td>
<td>300</td>
<td>20</td>
<td>80</td>
<td>6</td>
</tr>
<tr>
<td>Single-axle tractor</td>
<td>Road 3 m wide</td>
<td>800</td>
<td>10</td>
<td>40</td>
<td>8</td>
</tr>
</tbody>
</table>

Source: Ron Dennis, Rural transport and Accessibility

The next best option to an all weather sedan vehicle accessible road is a so-called fair weather sedan vehicle accessible road. These roads are not accessible during the monsoon. Trucks, busses, four-wheel drive cars and also pick-up vehicles have fewer requirements towards the road than the sedan drivers. They may still be able to operate during the monsoon season, even if the road is closed for sedan vehicles.

Of course to the inhabitants of the “isolated” settlement, the road link will only be of use when certain transport services are available. The most obvious transport needs is the provision of public transport. But the producers in the settlement also would like transporters to collect their produce with regular intervals. And sometimes they have special requirements to the frequency of delivery of inputs or the collection of products, e.g. milk producers. However for most road infrastructure providers it is very difficult to influence the transport services provided on the road network.

In many low and middle-income countries it is equally difficult to connect each settlement to the all/fair weather sedan vehicle road network. However it is often possible to improve the road network by upgrading tracks into trails and upgrading trails to allow
- Bicycle access
- Bicycle trailer access
- Motorcycle trailer access
- Single axle tractor trailer access
- Etc. Depending on the local transport equipment in use.

It should be noted that not all vehicles are serving the same kind of services. The distance range and transport capacity (passengers and goods) may vary considerable. Although the road-providing organisation may not be able to influence actual vehicle use it does facilitate the process of increasing the service level and possibly reducing the transport costs. The table below presents on overview of the service levels and related transport costs.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Running costs (US$/km)</th>
<th>Load (kg)</th>
<th>No of passengers of 5 km</th>
<th>Cost per passenger/km per trip length (US$ cents/km)</th>
<th>Cost per tonne per km per trip length (US$ cents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle</td>
<td>0.015</td>
<td>60</td>
<td>1</td>
<td>4</td>
<td>3.7</td>
</tr>
<tr>
<td>Bicycle trailer</td>
<td>0.018</td>
<td>150</td>
<td>2</td>
<td>2.4</td>
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<tr>
<td>Motorcycle trailer</td>
<td>0.066</td>
<td>250</td>
<td>4</td>
<td>7.7</td>
<td>6.8</td>
</tr>
<tr>
<td>Single axle tractor trailer</td>
<td>0.11</td>
<td>800</td>
<td>14</td>
<td>1.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Diesel pick up</td>
<td>0.15</td>
<td>1000</td>
<td>6</td>
<td>6.4</td>
<td>4.9</td>
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<tr>
<td>7 tonne truck</td>
<td>0.8</td>
<td>7000</td>
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</tbody>
</table>

Source: Ron Dennis; Rural transport and accessibility

**Non-motorised transport** Such upgrades also facilitate the use of all kinds of non-motorised transport, which equally contribute in a reduction of transport costs.

<table>
<thead>
<tr>
<th>Mode</th>
<th>Operating costs for 500 hrs per year (US$)</th>
<th>Running (not including depreciation)</th>
<th>Per tonne/km</th>
<th>Cost of transporting 100 tonne per km per year (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wheelbarrow</td>
<td>10.00</td>
<td>0.136</td>
<td>0.057</td>
<td>57.6</td>
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<td>Handcart</td>
<td>10.00</td>
<td>0.136</td>
<td>0.057</td>
<td>30.20</td>
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<td>Bicycle trailer</td>
<td>48.00</td>
<td>0.15</td>
<td>0.15</td>
<td>48.8</td>
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<tr>
<td>Pack donkey</td>
<td>30.00</td>
<td>0.26</td>
<td>0.26</td>
<td>73.4</td>
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<tr>
<td>Ox-drawn sledge</td>
<td>30.00</td>
<td>0.11</td>
<td>0.11</td>
<td>35.30</td>
</tr>
<tr>
<td>Donkey cart</td>
<td>31.30</td>
<td>0.095</td>
<td>0.095</td>
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<td>Ox-cart</td>
<td>75.00</td>
<td>0.082</td>
<td>0.082</td>
<td>49.30</td>
</tr>
<tr>
<td>Single axle tractor trailer</td>
<td>550.00</td>
<td>0.26</td>
<td>0.26</td>
<td>503.5</td>
</tr>
</tbody>
</table>

Source: Ron Dennis; Rural transport and accessibility

**Locations of goods and services** It often equally important to analyse the actual locations of the goods and services, people would like to obtain. It is usually assumed that these goods and services are grouped together at certain centres and that is possible to distinct hierarchy levels between the centres on basis of the availability of the services and goods. For example it is very likely that daily goods, like water, rice, vegetables and meat is made
available near to most homes, regardless whether they are located in the capital or in a small hamlet. It is equally likely that heavy equipment items to be used for large-scale production activities are only sold in a few places in the country, if at all. Similar patterns we can find in the education and health sector. It is likely to find primary schools and some form of primary health services in every village and neighbourhood, but it is equally likely that universities and hospitals are only situated in cities. And then there are usually some levels, e.g. secondary schools and dental services located in towns. It is equally likely that the road network is connecting these centres. Very often it is possible to analyse the accessibility of a particular settlement in terms of its travel time to the nearest centre of a certain level. A village located near the capital can obtain all the services and goods at the capital and usually has no interest in access roads/trails/tracks to secondary or tertiary levels of centres. This methodology can only be used when it is possible to identify typical centres with certain service/goods levels. It is important that is very likely that each centre belonging to a certain centre category meets these service and goods levels. Otherwise it is more correct to split the goods and services in particular sectors and levels of hierarchy. Typical sectors of interest are water, health, and education but there are many other sectors of interest. An ILO project in Orissa (India) identified the following 28 access sectors:

1. Primary School
2. Upper Primary School
3. Secondary School
4. Upper Secondary School
5. Vocational Training Centres
6. Library:
7. Drinking Water
8. Health Care Sub-Centre
9. Primary Health Centre
10. Community Health Centre
11. G.P. Headquarter
12. Block Headquarter
13. District Headquarter
14. Bank
15. Post Office
16. Telephone
17. Minor Forest Produce collection centre
18. Retail Market
19. Agricultural Service Centre
20. Livestock centres
21. Ice Factory
22. Milk Route
23. Jetty
24. Cyclone Centre
25. Common Facility Centre (Industrial Cooperative)
26. Whole sale Market
27. Agricultural Input Centre
28. Cold Storage
It is needless to say that this approach can be very labour intensive and requires sufficient human and computer resources.

**Comparing facilities**

Some facilities in low and middle-income countries are of inferior quality. It is therefore difficult to compare the benefits of roads to destinations of different qualities. It is assumed that the transport costs are measured over the road that runs to the nearest facility that meets certain minimum standards. Facilities that are closer to the beneficiaries, but are of inferior quality, are just disregarded in the analysis. The beneficiaries may not even travel to the nearest facility that meets the set quality standards, because the distance or the costs are too far or too high.

**Weight factor**

Different destinations have different beneficiaries. Scholars travel to schools but everybody travels to health facilities. Certain households wish to travel to the mosque, where others prefer the church. Different people may give different value to access to different destinations. To compare the access situations to certain destinations, it is necessary to multiply the access situation with a weight factor. Thus this weight factor expresses the relative importance of the different destinations.

Usually the weight factors are expressed as a percentage or as a ratio. That means that sum of values of all weight factors result in respectively 100% or 1. There is also lively discussion about the value of access to services and goods needed by different economic sectors. Some argue that road infrastructure projects that benefit certain economic sectors should be given additional brownie points. Such arguments are in particular used when the government wants to support certain business sectors. Reasons for such additional support could be

- Diversification of local products
- Certain business sectors generate a lot of employment
- Additional economic income/growth
- Redistribution of income
- Without support business sector is expected to go bankrupt
- Import substitution
- Expected export opportunities
- Etc.

The weight factor gives the government the opportunity to express the relative importance of the destination.

**Beneficiaries differ**

It is also important to distinct the beneficiaries. The main discussion is always who are the beneficiaries of the businesses. The most common applied approach is to consider the persons employed by these businesses as the beneficiaries.

**Equation**

In formula:

\[ \sum \text{Settlement's beneficiaries} \times (W_{D1} \times \text{TT}_{to \, D1} + W_{D2} \times \text{TT}_{to \, D2} + \ldots + W_{Dn} \times \text{TT}_{to \, Dn}) \]

Where
TT to Dn: travel time from settlement to the nearest destination that at least meet a certain quality standard
W_Dn: The weight factor showing the relative importance the particular destination.

**Combined effects**

Because most road projects will improve the accessibility to different destinations at the time, even when they were initiated for only one purpose, the analysis is often quite complex. The next table only focuses on a limited number (6) of destinations and excluded weight factors.

<table>
<thead>
<tr>
<th>Benefiting Village</th>
<th>Population</th>
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<tbody>
<tr>
<td>Primary School</td>
<td>Before</td>
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<td>Travel Time</td>
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<tr>
<td>Upper Primary School</td>
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<td>Travel Time</td>
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<td>Health Subcentre</td>
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<td>Travel Time</td>
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<td>Primary Health Centre</td>
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<td>Community Health center</td>
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<td>Travel Time</td>
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<td>Drinking water</td>
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<td>Travel Time</td>
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<td>Total effect</td>
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<td>Population*Effect</td>
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</table>

Step plan

The first step is to identify which settlements are benefiting from the project and subsequently it is necessary to indicate for each settlement, which sectors will benefit.

Road quality requirements

This more detailed approach not only allows the road infrastructure provider to improve access to facilities, goods and services that are not located in the typical centre (where it is expected to be found), but also to differentiate in the road requirements. Because most children are walking and at best cycle to schools they do not require four-lane motorway to their schools. Livestock farmers produce milk the whole year and therefore they require all weather access roads. And because many farmers use equipment items during the harvest season they want their land to be accessible with these heavy equipment items during that season. And we all want to reach the hospital quickly when it is necessary; many therefore appreciate a smooth and high-speed road to the nearest hospital.

Multi-criteria analysis

If the road quality is incorporated in the analysis, it becomes necessary to develop a multi-criteria analysis. The multi-criteria analysis will have at least two components. Travel time to the destination and walking time to the road link meeting a certain quality standard. Because of its complexity often the indicator is broken down in two steps. The first step is to calculate the score per destination and subsequently the sum.
of the scores of all destinations multiplied with their respective weight factors is calculated

In formula:

$$\sum (W_{D1} \times D1 + W_{D2} \times Dd + \ldots + W_{Dn} \times Dn)$$

Where

$W_{Dn}$; Weight factor for destination (n)

$Dn$; The score for destination which calculated with the following formula:

$$\sum \text{beneficiaries} \times (W_{TT} \times \text{TT score} + W_{WT} \times \text{WT score})$$

Where:

TT score is the score depending on the travel time to destination (n)

WT score; the score belonging to the walking time to the connecting road link that meeting at least a certain quality standard

$W_{TT}$; the weight factor present the relative importance of the travel time in relation to the walking time to the road

$W_{WT}$: the weight factor presenting the relative importance of the walking time to the road in relation to the travel time to the destination (n)

The sum of $W_{TT}$ and $W_{WT}$ is either 100% or 1. The maximum TT score or WT score is 100 points. The more worse the situation to higher the score. The table below provides a framework for analysing access situations for only 6 sectors.
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<th>Benefiting Village</th>
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<td></td>
<td></td>
</tr>
<tr>
<td>Destination scores</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Like stated earlier still many funding organisations insist on quantifying the economic impacts in monetary terms. If so the access impacts, as calculated above have to be multiplied with a financial figure.

The financial figure could represent the willingness to pay of the population and in reality the government to provide access to the certain destinations. And thus includes the weight factor.

Note that this is a socio-economic analysis and the outcome is does not represent real economic growth in economic terms.
5 IMPROVING EXISTING ROAD NETWORKS

Problems on roads

Problems on the existing roads may have social, economic, environmental or combined negative impacts. The most prominent problems on the existing roads are:

- Travel Time Delays
- Traffic Accidents
- Noise nuisance
- Splitting nature reserves
- Vehicle emissions
- Energy use
- Road user costs

5.1 TRAVEL TIME DELAYS

Causes of travel time delays

Travel time delays are often related to congestion, but travel time delays may also be caused by certain road conditions, factors such as:

- Horizontal curvature
- Vertical gradient
- Pavement roughness
- Road width
- Sight distance

Archilla and Bennet

Studies of Archilla and Bennet show that vertical gradients that are shorter than 2.8 km or 1.5 km respectively hardly affect the travel time.

Free Speed

If it is assumed that there is no traffic on the road, these road condition factors determine the maximum speed possible (Free Speed). HDM 4 defines free speed “Free speeds are the speeds vehicles travel when unaffected by other traffic, but affected by road alignment. The Free Speed differs from the desired speed. The Desired Speed is the “ideal” speed that vehicles would travel at when unconstrained by other traffic or the geometry but affected by the overall alignment of the road and the road environment. Thus when the Free Speed is lower than the Desired Speed, the vehicles travel less fast and therefore have longer journeys, resulting in higher transport costs.

Free Speed models

The Kenya Road User Cost Study (Hide, et al., 1975), the Caribbean Study (Morosiuk and Abaynayaka, 1982) and the India Study (CRRI, 1982), all developed multivariate models with the same fundamental structure to determine the Free Speed. The models were of the form:

\[ S = a_1 + a_2 RS + a_3 F + a_4 CURVE + a_5 ALT + a_6 BI + a_7 PWR + a_8 WIDTH \]
Where:
RS is the rise in m/km
F is the fall in m/km
CURVE is the horizontal curvature in degrees/km
ALT is the altitude in meters above sea level
BI is the roughness in BI mm/km
PWR is the power to weight ratio in kW/t
WIDTH is the pavement width in m
a1 to a8 are regression coefficients

<table>
<thead>
<tr>
<th>Study</th>
<th>Vehicle</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
<th>A5</th>
<th>A6</th>
<th>A7</th>
<th>A8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kenya</td>
<td>Passenger car</td>
<td>102.6</td>
<td>-0.372</td>
<td>-0.076</td>
<td>-0.111</td>
<td>-0.0049</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>LCW</td>
<td>86.9</td>
<td>-0.418</td>
<td>-0.050</td>
<td>-0.074</td>
<td>-0.0028</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>CV</td>
<td>68.1</td>
<td>-0.519</td>
<td>0.03</td>
<td>-0.058</td>
<td>-0.004</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bus</td>
<td>72.5</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Desired Speed**

The desired speed is highly influenced by the road environment. For example, traffic travelling in mountainous and hilly terrain are usually less eager to travel fast than when they travel over flat or rolling roads. The road alignment, width, separation between slow and motorised traffic are also parameters that influence the desired speed.

**Speed limits**

Most countries have adopted speed limits for urban and rural areas. There may also be special speed limits for specific roads. For example, the Netherlands adopted the following set of speed limits:

- Urban areas: 50 km/hr
- Rural roads: 80 km/hr
- Motorways: 120 km/hr

**Road design handbooks**

The travel time delay due to the difference between the Free Speed and Desired Speed can easily be calculated with the help of road design handbooks. For example, if the radius of curvature is less than 200 meters it is possible to increase the Free Speed drastically through curvature improvement projects. In other words, the free speed in curves with a smaller radius than 200 meters is a constraint. HDM4 calculates the free speed in a curve with the following formula:

\[ V_{\text{CURVE}} = a_0 \cdot R^{a_1} \]

The following table presents the parameter variables a0 and a1:
### Rough roads

The design speeds (v) of course do only apply on smooth roads. Smoothness or its opposite roughness is usually expressed in IRI. Studies have indicated that the decrease in Speed (km/hr) per increase in IRI (M/km) varies between 0.64 and 2.57. To predict the real speed (maximum average rectified velocity), the maximum speed that a vehicle will travel at a given roughness level, Watanatada, *et al.* (1987b) developed the following equation for predicting the average rectified velocity at any speed:

\[
ARV (v) = a_2 * IRI * v^{[v/22.2]}^{[a_0 + a \ln(a_2 * IRI)]}
\]

<table>
<thead>
<tr>
<th>Surface Type</th>
<th>A0</th>
<th>A1</th>
<th>A2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt concrete</td>
<td>0</td>
<td>0</td>
<td>1.15</td>
</tr>
<tr>
<td>Surface treatment or gravel</td>
<td>1.31</td>
<td>-0.291</td>
<td>1.15</td>
</tr>
<tr>
<td>Earth or Clay</td>
<td>2.27</td>
<td>-0.529</td>
<td>1.15</td>
</tr>
</tbody>
</table>

HDM4 uses the following formula to calculate/predict the speed that a vehicle will drive given a certain pavement roughness/smoothness (VROUGH).

\[
VROUGH = \frac{ARV_{MAX}}{(1.15 * IRI)}
\]

### Maximum Average Rectified Velocity by Vehicle Class (mm/s)

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Brazil</th>
<th>Australia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger cars</td>
<td>259.7</td>
<td>203</td>
</tr>
<tr>
<td>Light Commercial Vehicles</td>
<td>239.7</td>
<td>200</td>
</tr>
<tr>
<td>Heavy busses</td>
<td>212.8</td>
<td>-</td>
</tr>
<tr>
<td>Medium Commercial Vehicles</td>
<td>194</td>
<td>200</td>
</tr>
<tr>
<td>Heavy commercial vehicles</td>
<td>177.7</td>
<td>180</td>
</tr>
<tr>
<td>Articulated Trucks</td>
<td>130.9</td>
<td>160</td>
</tr>
</tbody>
</table>

Roadside Friction usually influences the design speed. Roadside Friction is basically a combination of pedestrian flow, vehicle stops and parking manoeuvres, vehicles entering and exiting roadside premises, slow moving vehicles. Therefore the Design Speed has to be multiplied by a Roadside Friction Factor (XFRI).
INDEVELOPMENT:

$\text{XFRI} = 0.9615 + 0.0270 \text{ WIDTH} - 0.0297 \text{ SFCL} \quad \text{Four-Lane Divided}$

$\text{XFRI} = 0.9598 + 0.0290 \text{ WIDTH} - 0.0317 \text{ SFCL} \quad \text{Four-Lane Undivided}$

$\text{XFRI} = 0.9555 + 0.0350 \text{ WIDTH} - 0.0403 \text{ SFCL} \quad \text{Two-Lane Undivided}$

Where

$\text{WIDTH}$ is the pavement width in meters

$\text{SFCL}$ is the side friction class where 0 = Very Low; 1 = Low, 2 = Medium, 3 = High, 4 = Very High.

<table>
<thead>
<tr>
<th>Frequency of events (both sides)</th>
<th>Typical Condition</th>
<th>Side Friction Class</th>
<th>Side Friction Class Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50</td>
<td>Rural, agriculture or undeveloped; almost no activities</td>
<td>Very Low</td>
<td>0</td>
</tr>
<tr>
<td>50 – 149</td>
<td>Rural, some roadside buildings and activities</td>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>150 – 249</td>
<td>Village, local transport and activities</td>
<td>Medium</td>
<td>2</td>
</tr>
<tr>
<td>250 – 350</td>
<td>Village, some market activities</td>
<td>High</td>
<td>3</td>
</tr>
<tr>
<td>&gt; 350</td>
<td>Almost urban, Market/business activities</td>
<td>Very High</td>
<td>4</td>
</tr>
</tbody>
</table>

**Accelerate and breaking**  
Because of traffic behaviour it is not possible to drive with a constant speed. In reality traffic accelerate and break all the time. This affects the free speed drastically.

**Taking over**  
For example on single or two lane roads, it is not possible to take over immediately when the situation arises. Often traffic has to wait for oncoming traffic. That means that the instead of overtaking, the traffic has to slow down and drive at the same speed as the traffic it wants to overtake.

**Shoulder use**  
On narrow roads, traffic may have to move to the shoulder to let oncoming traffic pass. It is therefore appropriate to include passing places in the design of narrow roads. Narrow roads in the rural areas usually cater for low traffic volumes, but unfortunately there are also many narrow roads in urban areas.

**Bunching**  
On two-lane roads speeds are influenced through the mechanism of bunching. A stream of traffic is comprised of a population of vehicles each with their own desired speed. As the traffic volume increases faster vehicles catch up to slower ones. If there is an overtaking opportunity the faster vehicle will often pass and become free again, otherwise it will become a following vehicle until such a time as an overtaking opportunity presents itself. Thus, the speed of vehicles is dependant upon the volume and the available gaps in the opposing traffic stream. Multi-lane roads have a similar effect, although the ability of users to change lanes greatly increases the ability to overtake. This is reflected in the capacities of multi-lane vs. two-lane roads where multi-lane roads usually have on the order of a 50 per cent higher per lane capacity than two-lane roads.
5.1.1 Non-motorised traffic

Non-motorised transport (NMT) is a significant component of the traffic volume in many low and middle-income countries. NMT does not only affect the capacity of the road and therefore reduces the speed of the motorized vehicles, but it is hindered likewise. Shoulders were only used when they were firm, with smooth/minor-rutted surfaces, and when they were not more than 10 cm lower than the road surface.

<table>
<thead>
<tr>
<th>Shoulder width (m)</th>
<th>Shoulder type</th>
<th>Shoulder condition</th>
<th>Average Elevation</th>
<th>Useable?</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>-</td>
<td>No Shoulder</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>-</td>
<td>-</td>
<td>No Shoulder</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>-</td>
<td>Soft</td>
<td>-</td>
<td>-</td>
<td>No</td>
</tr>
<tr>
<td>&gt; 1</td>
<td>Firm</td>
<td>Smooth/Minor Rutting</td>
<td>Higher/Level/Below Road Surface</td>
<td>Yes</td>
</tr>
<tr>
<td>&gt; 1</td>
<td>Firm</td>
<td>Smooth/Minor Rutting</td>
<td>&gt; 10 cm Below Road Surface</td>
<td>No</td>
</tr>
<tr>
<td>&gt; 1</td>
<td>Firm</td>
<td>Severe Rutting</td>
<td>-</td>
<td>No</td>
</tr>
</tbody>
</table>

Road Characteristics influencing speed of NMT

There are a number of road characteristics influencing the speeds of NMT:

- MT traffic volume and speed;
- NMT traffic volume;
- Roadside activities;
- Roadway grade;
- Rolling resistance;
- Road width (where NMT can safely travel) and/or number of lanes;
- Method of separating NMT/MT traffic (eg, markings, physical separation, NMT-only Street);
- Roughness of road surface (particularly shoulder roughness);
- Inclement weather.

HDM 4

HDM-4 proposes to calculate the speed of NMT with the following formula:

\[ v = XMT \text{ max}[0.14, \min(V\text{DESIR}, V\text{ROUGH}, V\text{GRAD})] \]

Where

- \( V\text{GRAD} \) is the speed limited by gradient in m/s
- \( XMT \) speed reduction factor due to motorised traffic and roadside activities, allowable range: min 0.4 to max 1.0 (default = 1.0)
The limit of 0.14 m/s corresponds to a speed of 0.5 km/h.

The following describes how the speeds are calculated.

**DESired SPEED (VDESIR)**
Typical values of VDES for NMT (in km/h) are

<table>
<thead>
<tr>
<th>NMT</th>
<th>VDES Paved</th>
<th>VDES Unpaved</th>
<th>roughness</th>
<th>Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian</td>
<td>5.1</td>
<td>4.6</td>
<td>-0.048</td>
<td>-9.2</td>
</tr>
<tr>
<td>Bicycle</td>
<td>21.3</td>
<td>18.0</td>
<td>-0.225</td>
<td>-49.0</td>
</tr>
<tr>
<td>Cycle-Rickshaw</td>
<td>18.6</td>
<td>15.4</td>
<td>-0.197</td>
<td>-47.0</td>
</tr>
<tr>
<td>Bullock Cart</td>
<td>3.8</td>
<td>3.2</td>
<td>-0.036</td>
<td>-6.0</td>
</tr>
<tr>
<td>Farm Tractor</td>
<td>30.0</td>
<td>24.0</td>
<td>-0.250</td>
<td>-63.0</td>
</tr>
</tbody>
</table>

**ROUGHNESS SPEED (VROUGH)**
The effect of roughness on NMT speed is calculated as follows:

\[
V_{ROUGH} = V_{DES} + a_0 R_I
\]

**VGRAD**
The effect of gradient on NMT speed is calculated as follows:

\[
V_{GRAD} = V_{DES} + a_1 G_R
\]

5.1.2 Congestion
Congestion is not only a social nuisance to the road users, but also is an economic cost to the nation and in addition results in air pollution and fuel consumption.

**Measuring congestion**
Congestion is usually measured in duration and length. Most countries know the composition of its traffic, like trucks, busses, mini-busses, motorbikes, cars, etc. On basis of this information it is easy to estimate the number of cars involved in a congestion of a certain length. On basis of these data it is possible to assess the travel time delays.

It is also possible to calculate the travel time delays due to congestion with the help of a few simple formulas.

**Bottleneck**
Congestion occurs when the traffic demand is higher than the road capacity. That section that has the lowest capacity determines the road capacity, the bottleneck.

**Congestion development**
Thus if the traffic demand is higher than the capacity of the bottleneck, downstream the bottleneck, congestion will develop, while upstream the traffic continues its route freely, without travel time delays.

When the traffic demand decreases again to a level below the capacity of the bottleneck, after some time the congestion will disappear again. Basically the congestion will have resolved when the last vehicle arriving the queue during over demand passes through the bottleneck. This process is usually visualised in a graph presented below. The so-called 'arrival' curve is a line with demand D as slope. The 'departure' curve has the capacity C as slope.
The graph describes the situation in which from Moment $t=0$ demand is higher than capacity until moment $t = t_1$. After that moment the demand becomes smaller than the capacity $C$ but has a constant value. This means from $t=0$ until $t = t_1$ the queue grows and after that time it decays.

**Limitations of the graph**

The model estimates the joint delay correctly. However it cannot be used to describe how the queue stretches over the road upstream of the bottleneck.

**Notation**

- $n =$ cumulative number of vehicles
- $C =$ capacity
- $t_1 =$ moment until over saturation lasts
- $q_1 =$ demand intensity from $t=0$ till $t=t_1$
- $q_2 =$ demand intensity for $t>t_1$
- $T =$ moment at which queue disappears, duration of congestion
- $N =$ number of vehicles experiencing congestion
- $R =$ delay (extra travel time)
- $R_{\text{mean}} =$ mean delay ($R/N$)
- $R_{\text{max}} =$ maximum delay

**Arrival curve:**

\[
\begin{align*}
n &= q_1 t \quad \text{for } 0<t<t_1 \\
n &= q_1 t_1 + q_2 (t - t_1) \quad \text{for } t > t_1
\end{align*}
\]
Departure curve:

\[ n = C \, t \]

The intersection of both curves occurs at moment \( t = t_2 = T = \) duration of queue (or congestion). It can be easily derived that:

\[ T = t_1 \, (q_1 - q_2) / (C-q_2) \]

Number of vehicles involved:

\[ N = C \, T \]

Delay:

\[ R = 0.5 \, (q_1-C) \, t_1^2 \, \frac{q_1-q_2}{C-q_2} \]

Mean delay per vehicle involved:

\[ R_{\text{mean}} = \frac{R}{N} = 0.5 \, (q_1 - C) \, t_1 / C \]

It is remarkable that \( R_{\text{mean}} \) is independent of \( q_2 \).

If \( q_2 \) is only a little smaller than \( C \), then:

- The queue will have a long life;
- There will be many vehicles involved
- Delay \( R \) will become large but
- The mean delay will not become larger

The maximum delay \( R_{\text{max}} \) will be experienced by the vehicle arriving at moment \( t = t_1 \)

\[ R_{\text{max}} = (q_1 - C) \, t_1 / C \]

It follows that \( R_{\text{max}} / R_{\text{mean}} = 2 \)

Thus in short, congestion depends on traffic demand and road capacities. Planners and designers have several models at their disposal to try to limit congestion. This subject will be discussed in a separate paper.

When the travel time delays are known, this figure could be calculated with a monetary figure.
5.1.3 Estimating economic effects of travel time delays

In economic appraisals, travel time delays are usually multiplied with a certain unit cost of time. This unit cost of time represents the economic costs for the society of the travel time delays. Establishing a value of time is considered extremely difficult.

Economic costs
Timesavings on a journey could be used for other productive work. But time delays are also a waste of resources to employers, who would like to use its employees in productive work. In theory an employer may be willing to pay up to an hour’s wages to reduce travel time by one hour.

Wage figures
HDM-4 argues that it is not correct to use the average national wages. It firstly argues that national statistics do not include the wages of the highest earning workers, like CEO or those who work in the informal sector. Furthermore it argues that in most low and middle-income countries there are large differences in wages between the regions.

Equity
In some countries, average regional wages have been established and thus it is possible to carry out more precise economic appraisals. However it should be noted that such pure economic appraisals are in conflict with the equity principles of the government.

Bank financed projects
Thus for pure economic appraisals, like in World Bank projects, it is correct to use regional data, but most countries would like to appraise their projects on basis of socio-economic analysis and should therefore use national averages.

Leisure time
Employers are of course not willing to pay additionally for personal trips of its personnel. However that does not mean that the travellers themselves are not willing to pay for timesavings. The amount depends mostly on the income and wealth of the traveller.

Goods
Goods held in inventory may be reduced when goods spent less time in transit. However not all goods benefit of timesavings. For example, if it arrives before the business opens, it cannot be unloaded.

Value of Time
IT Transport produced a must read document on this topic. The document can be downloaded from the following website: [http://www.ittransport.co.uk/publications.htm](http://www.ittransport.co.uk/publications.htm)

5.2 ACCIDENTS

Classification of accidents
Like congestion it is easy to record traffic accidents. They are usually classified in three categories:
1. Damage only accidents
2. Accidents with injured persons
3. Fatal accidents.

No models
However past research did not result in models estimating impacts of different road design criteria on traffic accidents. It is often difficult to quantify the effects of road improvements in terms of accidents. In most cases engineers only make guesses about the impacts.

ORN 10
The Overseas Note no 10 (ORN 10) of TRL presents different ways to calculate the economic costs of road accidents. The document can be downloaded from the following website:

5.3 VEHICLE OPERATION COSTS

5.3.1 Fuel consumption
Fuel consumption may account for 20 to 40% of the vehicle operation costs. Traffic congestion, road alignment and conditions may have negative impacts on the fuel consumption of the vehicles. Fuel consumption is not only a cost for the road user but is also considered an environmental hazard. Fuel consumption is often related to vehicle speed and is either expressed in mL/s or L/1000km.

Road conditions like roughness, rise and fall have also large impacts on the fuel consumption. A common equation for determining fuel consumption is presented below.

![Graph showing fuel consumption vs speed](image)

Formula

\[ FC = a_0 + a_1/S + a_2 S^2 + a_3 \text{RISE} + a_4 \text{FALL} + a_5 \text{IRI} \]

Where
- FC is the fuel consumption in L/1000 km
- S is the vehicle speed in km/h
- IRI is the roughness in IRI m/km
- RISE is the rise of the road in m/km
- FALL is the fall of the road in m/km
- a0 to a5 are constants
<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Country</th>
<th>Fuel Model Coefficients</th>
<th>other variables</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>a0 a1 a2 a3 a4 a5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passenger Cars</td>
<td>India</td>
<td>10.3 1676 0.0133 1.39 -1.03 0.43</td>
<td></td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>21.85 504 0.0050 1.07 -0.37 0.47</td>
<td></td>
<td>IRC (1993)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>49.8 319 0.0035 0.94 -0.68 1.39</td>
<td></td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>Caribbean</td>
<td>24.3 969 0.0076 1.33 -0.63</td>
<td>+ 0.00286 FALL²</td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>Kenya</td>
<td>53.4 499 0.0059 1.59 -0.85</td>
<td></td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td>Light Commercials</td>
<td>India</td>
<td>30.8 2258 0.0242 1.28 -0.56 0.86</td>
<td></td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>21.3 1615 0.0245 5.38 -0.83 1.09</td>
<td></td>
<td>IRC (1993)</td>
</tr>
<tr>
<td></td>
<td>Caribbean</td>
<td>72.2 949 0.0048 2.34 -1.18</td>
<td>+ 0.0057 FALL² + 1.12 (GVW - 2.11)RISE</td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>Kenya</td>
<td>74.7 1151 0.0131 2.91 -1.28</td>
<td></td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td>Heavy Bus</td>
<td>India</td>
<td>33.0 3905 0.0207 3.33 -1.78 0.86</td>
<td></td>
<td>IRC (1993)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>-12.4 3940 0.0581 0.79 2.00</td>
<td>+ 0.0061 CKM</td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td>Truck</td>
<td>India</td>
<td>44.1 3905 0.0207 3.33 -1.78 0.86</td>
<td></td>
<td>IRC (1993)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>141.0 2696 0.0517 17.75 -5.40 2.50</td>
<td></td>
<td>IRC (1993)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>85.1 3905 0.0207 3.33 -1.78 0.86</td>
<td>- 6.24 PW</td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>266.5 2517 0.0362 4.27 -2.74 4.72</td>
<td>-6.26 PW</td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>India</td>
<td>71.70 5670 0.0787 1.43</td>
<td>- 9.20 PW - 3.98 WIDTH</td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>Caribbean</td>
<td>29.2 2219 0.0203 5.93 -2.60</td>
<td>+ 0.85 (GVW - 7.0) RISE + 0.013 FALL²</td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
<tr>
<td></td>
<td>Kenya</td>
<td>105.4 903 0.0143 4.36 -1.83 -3.22 PW</td>
<td></td>
<td>Chesher &amp; Harrison (1987)</td>
</tr>
</tbody>
</table>
Fuel consumption increases when vehicles have to stop and wait, e.g. in front of traffic lights. Poor coordinated traffic lights may result in a 25% increase of fuel consumption.

5.3.2 Tyre consumption

In particular for heavy trucks, tyre consumption can be a major part of the Vehicle Operation Costs.

<table>
<thead>
<tr>
<th>Types of tyre consumption</th>
<th>HDM 4 distinguishes two types of tyre consumption:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Tread Wear</td>
</tr>
<tr>
<td></td>
<td>• Carcass Wear</td>
</tr>
</tbody>
</table>

Tread wear

Because the tyres come into contact with pavement a part of tread is worn.

Carcass wear

Carcass wear is a combination of fatigue and mechanical damage to the tyre carcass. It is defined as the number of retreads (recappings) to which a tyre carcass can have before the carcass is unsuitable for further retreads. In many countries, blowouts or ablative wear—i.e. the ‘tearing’ of the tread caused by surface material—are significant factors governing tyre life.

Rethreading

Every kilometre travelled has consequences in the loss in tread but also in terms of stresses and strains to the tyre carcass. After a while the tyre tread reaches its unacceptable depth and the tyre is either replaced or rethreaded. The latter option is only valid when the carcass is still in adequate condition. Rethreading is a common practice in many low and middle-income countries.

Road characteristics

Tyre consumption among others depend on three road characteristics:

1. Pavement condition
2. Road alignment
3. Traffic conditions

Pavement condition

The roughness of the pavement affects the tyre consumption drastically. Not only does it wear the tread but also it can have major impacts on the carcass.

Road alignment

Road alignment like horizontal curves also have major impacts on the tyre life.

Traffic conditions

Accelerations and decelerations depend on traffic volume and these manoeuvres give rise to the tyre consumption.

Pavement types

Claffey (1971) found that asphalt pavements and gravel pavements with thick spreading of loose stones resulted in respectively 75% and 460% increase in tyre wear over a concrete pavement.

Roughness

Findlayson and du Plessis (1991) analysed the costs for trucks from a forestry transport operation. The following equation was developed for predicting tyre life:

$$KMT = 166.47 - 31.83 \ln(13 \ IRI)$$

where KMT is the tyre life in '000 km

This model shows very high tyre wears on rough roads that were "thought to be caused by the higher incidence of premature tyre failures..."
and the increased ablative wear on unimproved logging roads” (Findlayson and du Plessis, 1991).

### 5.3.3 Vehicle maintenance and repair costs

#### HDM models

The HDM-3 and HDM-4 maintenance models distinguish two maintenance components:

1. Parts
2. Labour

The HDM-3 model is largely based on a study carried in Brazil. This study found that parts consumption largely depend on criteria like road roughness and vehicle age, while the labour hours was found to be a function of parts consumption and road roughness.

The Brazil relationships have the following form $1$ (Watanatada, et al., 1987a):

$$
\text{PARTS} = C_{0SP} C_{KM} k_p \exp(C_{SPIRI} IRI) \text{ for } IRI < IRI_{0SP}
$$

$$
\text{PARTS} = C_{KM} k_p (a_0 + a_1 IRI) \text{ for } IRI > IRI_{0SP}
$$

$$
a_0 = C_{0SP} \exp(C_{SPIRI} IRI_{0SP})(1 - C_{SPIRI} IRI_{0SP})
$$

$$
a_1 = C_{0SP} C_{SPIRI} \exp(C_{SPIRI} IRI_{0SP})
$$

$$
\text{LH} = C_{0LH} \text{PARTS} C_{LHPC} \exp(CLHIRI IRI)
$$

where PARTS is the standardised parts consumption as a fraction of the replacement vehicle price per 1000 km

CKM is the vehicle cumulative kilometrage in km

IRI is the roughness in IRI m/km

IRI_{0SP} is the transitional roughness beyond which the relationship between parts consumption and roughness is linear

C_{0SP} is the parts model constant

C_{SPIRI} is the parts model roughness coefficient

LH is the number of labour hours per 1000 km

C_{0LH} is the labour model constant

C_{LHIRI} is the labour model roughness coefficient

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Parts Model Parameters</th>
<th>Labour Model Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$k_p$</td>
<td>$C_{0SP}$</td>
</tr>
<tr>
<td>Passenger Car</td>
<td>0.308</td>
<td>32.49</td>
</tr>
<tr>
<td>Utility</td>
<td>0.308</td>
<td>32.49</td>
</tr>
<tr>
<td>Large Bus</td>
<td>0.483</td>
<td>1.77</td>
</tr>
<tr>
<td>Light and Medium Truck</td>
<td>0.371</td>
<td>1.49</td>
</tr>
<tr>
<td>Heavy Truck</td>
<td>0.371</td>
<td>8.61</td>
</tr>
<tr>
<td>Articulated Truck</td>
<td>0.371</td>
<td>13.94</td>
</tr>
</tbody>
</table>

#### HDM4 model

The HDM4 model is given by:

$$
\text{PARTS} = \{K_{0pc} [C_{KM} k_p (a_0 + a_1 IRI)] + K_{1pc}\} (1 + CPCON \, dFUEL)
$$

where

CPCON is the congestion elasticity factor (default = 0.1)

dFUEL is the additional fuel consumption due to congestion as a decimal (default = 0.5)

K_{0pc} is a rotational calibration factor (default = 1.0)
K1pc is a translational calibration factor (default = 0.0)
a0 to a1 are model parameters

<table>
<thead>
<tr>
<th>No</th>
<th>Vehicle</th>
<th>CKM</th>
<th>kp</th>
<th>a0 x 10^-4</th>
<th>a1 x 10^-4</th>
<th>a0</th>
<th>a1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>MC</td>
<td>50,000</td>
<td>0.308</td>
<td>9.23</td>
<td>6.20</td>
<td>77.14</td>
<td>0.547</td>
</tr>
<tr>
<td>2</td>
<td>PC</td>
<td>115,000</td>
<td>0.308</td>
<td>36.94</td>
<td>6.20</td>
<td>77.14</td>
<td>0.547</td>
</tr>
<tr>
<td>3</td>
<td>LDV</td>
<td>120,000</td>
<td>0.308</td>
<td>36.94</td>
<td>6.20</td>
<td>77.14</td>
<td>0.547</td>
</tr>
<tr>
<td>4</td>
<td>LGV</td>
<td>120,000</td>
<td>0.308</td>
<td>36.94</td>
<td>6.20</td>
<td>77.14</td>
<td>0.547</td>
</tr>
<tr>
<td>5</td>
<td>4WD</td>
<td>120,000</td>
<td>0.371</td>
<td>7.29</td>
<td>2.96</td>
<td>77.14</td>
<td>0.547</td>
</tr>
<tr>
<td>6</td>
<td>LT</td>
<td>120,000</td>
<td>0.371</td>
<td>7.29</td>
<td>2.96</td>
<td>242.03</td>
<td>0.519</td>
</tr>
<tr>
<td>7</td>
<td>MT</td>
<td>240,000</td>
<td>0.371</td>
<td>11.58</td>
<td>2.96</td>
<td>242.03</td>
<td>0.519</td>
</tr>
<tr>
<td>8</td>
<td>HT</td>
<td>602,000</td>
<td>0.371</td>
<td>11.58</td>
<td>2.96</td>
<td>301.46</td>
<td>0.519</td>
</tr>
<tr>
<td>9</td>
<td>AT</td>
<td>602,000</td>
<td>0.371</td>
<td>13.58</td>
<td>2.96</td>
<td>301.46</td>
<td>0.519</td>
</tr>
<tr>
<td>10</td>
<td>MNB</td>
<td>120,000</td>
<td>0.308</td>
<td>36.76</td>
<td>6.20</td>
<td>77.14</td>
<td>0.547</td>
</tr>
<tr>
<td>11</td>
<td>LB</td>
<td>136,000</td>
<td>0.371</td>
<td>10.14</td>
<td>1.97</td>
<td>242.03</td>
<td>0.519</td>
</tr>
<tr>
<td>12</td>
<td>MB</td>
<td>245,000</td>
<td>0.483</td>
<td>0.57</td>
<td>0.49</td>
<td>293.44</td>
<td>0.517</td>
</tr>
<tr>
<td>13</td>
<td>HB</td>
<td>420,000</td>
<td>0.483</td>
<td>0.65</td>
<td>0.46</td>
<td>293.44</td>
<td>0.517</td>
</tr>
<tr>
<td>14</td>
<td>COACH</td>
<td>420,000</td>
<td>0.483</td>
<td>0.64</td>
<td>0.46</td>
<td>293.44</td>
<td>0.517</td>
</tr>
</tbody>
</table>

5.3.4 Service Life

Definitions

A vehicle, or any physical property, has three measures of its life, namely the:

- **Service life**: the period over which the vehicle is operated;
- **Physical life**: the period which the vehicle exists (even if it is not being used); and,
- **Economic life**: the period which the vehicle is economically profitable to operate.

The Service life is the optimal point in the life of a vehicle to be scrapped. The service life depends largely on the cost of operating the vehicle.

**HDM 4**

HDM 4 uses the following formula to estimate the optimal life of a vehicle under the condition of different road roughness values;

\[
\text{LIFEKM} = \text{LIFEKMPCT} \times \text{LIFEKM0}/100
\]

Where

- LFEKM is the optimal lifetime utilisation in km
- LFEKM0 is the average service life in km
- LFEKMPCT is the optimal lifetime kilometreage as a percentage of baseline life.

The average service life (or baseline life) is calculated from the expression

\[
\text{LIFEKM0} = \text{AKM0} \times \text{LIFE0}
\]

where

- AKM0 is the user defined average annual utilisation in km
- LIFE0 is the user defined average service life in years

The optimal life as a percentage of the user defined baseline vehicle life.

\[
\text{LIFEKMPCT} = \min(100,100/(1+\exp(a0 \times R_I^{a1}))
\]

where RI is the road roughness in IRI m/km

40
a0, a1 are regression coefficients (Default values for all vehicle types are: a0 = -65.8553, a1 = -1.9194)

<table>
<thead>
<tr>
<th>No</th>
<th>Vehicle Type</th>
<th>AKMO (km/yr)</th>
<th>LIFE (yrs)</th>
<th>HRWKO (hrs/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Motorcycle</td>
<td>10000</td>
<td>10</td>
<td>400</td>
</tr>
<tr>
<td>2</td>
<td>Small Car</td>
<td>2300</td>
<td>10</td>
<td>550</td>
</tr>
<tr>
<td>3</td>
<td>Medium Car</td>
<td>2300</td>
<td>10</td>
<td>550</td>
</tr>
<tr>
<td>4</td>
<td>Large Car</td>
<td>2300</td>
<td>10</td>
<td>550</td>
</tr>
<tr>
<td>5</td>
<td>Light Delivery Vehicle</td>
<td>30000</td>
<td>8</td>
<td>1300</td>
</tr>
<tr>
<td>6</td>
<td>Light Goods Vehicle</td>
<td>30000</td>
<td>8</td>
<td>1300</td>
</tr>
<tr>
<td>7</td>
<td>Four Wheel Drive</td>
<td>30000</td>
<td>8</td>
<td>1300</td>
</tr>
<tr>
<td>8</td>
<td>Light Truck</td>
<td>30000</td>
<td>8</td>
<td>1300</td>
</tr>
<tr>
<td>9</td>
<td>Medium Truck</td>
<td>40000</td>
<td>12</td>
<td>1200</td>
</tr>
<tr>
<td>10</td>
<td>Heavy Truck</td>
<td>86000</td>
<td>14</td>
<td>2050</td>
</tr>
<tr>
<td>11</td>
<td>Articulated Truck</td>
<td>86000</td>
<td>14</td>
<td>2050</td>
</tr>
<tr>
<td>12</td>
<td>Mini-Bus</td>
<td>30000</td>
<td>8</td>
<td>750</td>
</tr>
<tr>
<td>13</td>
<td>Light Bus</td>
<td>34000</td>
<td>8</td>
<td>850</td>
</tr>
<tr>
<td>14</td>
<td>Medium Bus</td>
<td>70000</td>
<td>7</td>
<td>1750</td>
</tr>
<tr>
<td>15</td>
<td>Heavy Bus</td>
<td>70000</td>
<td>12</td>
<td>1750</td>
</tr>
<tr>
<td>16</td>
<td>Coach</td>
<td>70000</td>
<td>12</td>
<td>1750</td>
</tr>
</tbody>
</table>

**Residual value**

Vehicles that operated over rough roads usually receive a lower residual value, because these vehicles suffered more. Bennett (1996) assumed that the residual values for all vehicles were 15 per cent at a roughness of 5 IRI m/km; five per cent at a roughness of 15 IRI m/km, and a minimum of two per cent.

RVPLTPCT = max[2, 15 - max(0, (RI - 5))]

where RVPLTPCT is the residual vehicle price in per cent.

The depreciation is calculated using the equation:

DEP = 1000 * (1 - 0.01 * RVPLTPCT) / LIFEKM

where

DEP is the depreciation cost as a fraction of the replacement vehicle price, less tyres

**5.3.5 Engine oil consumption**

Oil consumption depends on two factors: Oil contamination and Oil loss. For HDM-III Watanatada, *et al.* (1987a) proposed the following model for predicting oil consumption:

OC = a0 + a1 RI

where

OC is the oil consumption in L/1000 km

a0 and a1 are coefficients

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>a0</th>
<th>a1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passenger Cars and Utilities</td>
<td>1.55</td>
<td>0.15</td>
</tr>
<tr>
<td>Light Trucks</td>
<td>2.20</td>
<td>0.15</td>
</tr>
<tr>
<td>Medium and Heavy Trucks</td>
<td>3.07</td>
<td>0.15</td>
</tr>
<tr>
<td>Articulated Trucks</td>
<td>5.15</td>
<td>0.15</td>
</tr>
<tr>
<td>Heavy Buses</td>
<td>3.07</td>
<td>0.15</td>
</tr>
</tbody>
</table>
The India study (CRRI, 1982) is notable since it endeavoured to relate oil consumption to operating conditions. A series of equations were developed which related oil consumption to various road geometry parameters such as gradient, width and roughness. The study found that there were significant operator effects—i.e. the rate of oil consumption was highly dependent on the policies of the companies participating in the study. For example, when the individual operators were included through the use of dummy variables in the equation the R² was 0.75 compared to R² below 0.2 with pooled data. Not surprisingly, the vehicle operator effects mainly influenced the intercept, which represents the oil lost due to contamination.

Kadiyali (1991) in updating the CRRI (1982) costs adopted the following equation, which was from the original CRRI (1982) work.

This equation was adopted by IRC (1993) for economic appraisals in India.

\[ OC = a_0 + a_1 RF + a_2 RI/W \]

where RF is the rise and fall in m/km
W is the pavement width in m

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>a₀</th>
<th>a₁</th>
<th>a₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycles</td>
<td>0.39</td>
<td>0.00750</td>
<td>0.08</td>
</tr>
<tr>
<td>Passenger Cars</td>
<td>1.94</td>
<td>0.03769</td>
<td>0.43</td>
</tr>
<tr>
<td>Light Truck</td>
<td>1.00</td>
<td>0.02400</td>
<td>0.11</td>
</tr>
<tr>
<td>Medium and Heavy Trucks</td>
<td>2.48</td>
<td>0.06010</td>
<td>0.29</td>
</tr>
<tr>
<td>Heavy Buses</td>
<td>3.66</td>
<td>0.01271</td>
<td>0.48</td>
</tr>
</tbody>
</table>

5.4 ENVIRONMENTAL CONCERNS

Till now we could easily convert the negative or positive effects of roads and projects in monetary units. It is far more difficult to express the impacts on the environment in monetary terms. It is certainly more difficult to estimate the impact of the environmental changes on the GDP. The most common approach is either to establish willingness to pay and compensation figures. It is not always possible to establish the compensation figures precisely. It is possible to calculate the costs for replacing the felled trees, or the costs for breeding and setting out of deer and other animals, in case a road project cuts a nature reserve in two or more pieces. It is still possible to estimate the compensation costs for noise pollution. For example by assuming that every household living in the noise polluted areas is entitled to move to another location on cost of the government. However it is less easy to calculate the costs for compensating peoples lives, which were shortened due to vehicle emissions.

The estimates of the compensation costs depend on government norms and standards as well as on the willingness to pay for such compensations. Court cases, laws or policy documents may have created precedents in this respect and should be treated like norms and standards. For cases norms and standards are not available, you may analyse the decisions in the past. Often the history provides information.
about willingness to pay or to compensate for specific negative impacts.

5.4.1 Mitigating Nature Reserves

A possible question for road agencies is: How to identify and rank mitigating nature reserve projects? It is argued that roads cut nature reserves in two or more pieces affect the population of different species. For example, different groups of deer are not able to exchange any longer, resulting in breeding problems. Conservationists may have developed approaches to study the impact of roads on nature reserves. Such approaches should certainly be taken into account when developing systems for identifying and ranking of mitigation projects.

However if such expertise is not available the road authority may wish to record road accidents with animals. The records should present the location, species and amount of accidents. This information could be used for the identification and ranking of projects. However if conservationists have developed their models, it is probably more accurate to use these models.

5.4.2 Vehicle emissions

As a result of the combustion process, motor vehicles emit various chemical compounds, like Hydrocarbons (HC), Carbon Monoxide (CO), Carbon Dioxide (CO2), Nitric Oxides (NOx), Sulphur Dioxide (SO2), and Lead (Pb). The emissions are damaging the natural environment and subsequently human health.

The table below present average figures of emissions of different kind of vehicles:

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Pollutant</th>
<th>Average amount</th>
<th>Average/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G/km</td>
<td>kg/yr</td>
<td></td>
</tr>
<tr>
<td>Passenger car</td>
<td>Hydrocarbons</td>
<td>1.9</td>
<td>34.0</td>
</tr>
<tr>
<td></td>
<td>Carbon Monoxide</td>
<td>14.3</td>
<td>262.7</td>
</tr>
<tr>
<td></td>
<td>Nitrogen Oxides</td>
<td>1.0</td>
<td>17.7</td>
</tr>
<tr>
<td></td>
<td>Carbon Dioxide</td>
<td>225.5</td>
<td>3992.0</td>
</tr>
<tr>
<td></td>
<td>Gasoline</td>
<td>88</td>
<td>1561.3</td>
</tr>
<tr>
<td>Light Trucks</td>
<td>Hydrocarbons</td>
<td>2.5</td>
<td>57.2</td>
</tr>
<tr>
<td></td>
<td>Carbon Monoxide</td>
<td>19.9</td>
<td>447.7</td>
</tr>
<tr>
<td></td>
<td>Nitrogen Oxides</td>
<td>1.2</td>
<td>28.1</td>
</tr>
<tr>
<td></td>
<td>Carbon Dioxide</td>
<td>338.3</td>
<td>7620.5</td>
</tr>
<tr>
<td></td>
<td>Gasoline</td>
<td>123.5</td>
<td>2782.0</td>
</tr>
</tbody>
</table>

Road agencies can influence the vehicle emissions in two ways:

1. Reduction of the amount of motorized kilometres
2. Influencing the traffic speed

The first option can be achieved through reduction the lengths of the road links. However it should be noted that such interventions might increase the attractiveness to travel and therefore result in an increase of the vehicle emissions.

Road authorities set speed limits and therefore influence the vehicle emissions. Slow driving traffic emits more emissions. Thus projects reducing congestions also have a positive impact on the vehicle emissions.
The vehicle emissions like CO and CH increases when vehicles have to stop and wait and thus traffic lights affect the emissions of CO and CH considerably. It is possible to use an English model to estimate the emissions for CO and CH, but it should be noted that the model is not yet validated:

\[ CO = q \times (0.007D + 0.2F_s + 0.1) \]
\[ CH = q \times (0.009D + 0.3F_s + 0.25) \]

Where
- CO and CH are the emissions for respectively CO and CH [g/s]
- q number of vehicles per second
- D average delay per vehicle
- \( F_s \) Ratio of vehicles that has to stop
5.4.3 Noise pollution

The Noise level is strongly influenced by the traffic flow. The more motor vehicles run over a specific road segment the louder the noise production.

**Norms**

Most governments have adopted norms with regard the maximum noise levels. The norms are often related to the environment, through which the road runs. Roads in urban areas have to meet high/firm standards towards noise pollution. The norms in nature reserves are usually firmer than the norms for agricultural areas.

**Counting households**

In Urban areas, it is possible to quantify the noise nuisance through counting the number of households that are negatively affected or are living in noise levels that are exceeding the acceptable noise levels. To make it more complex it is possible to calculate the number of households living in noise conditions exceeding the norms with the following intervals:

- 0-3 dB
- 4-6 dB
- 7-9 dB
- More than 9 dB

To make it even more complex these groups can be multiplied with the number of hours per day in which the households live in these conditions.

In equation:

\[
\sum (HH_{\text{interval}} \times \text{Hours}_{\text{affected}})
\]

In which:

- \(HH_{\text{interval}}\), number of households living in certain noise conditions
- \(\text{Hours}_{\text{affected}}\), Number of hours, in which the noise level exceeded the norm.

**Influencing road characteristics**

Noise pollution depend on a number of road characteristics:

- Amount of traffic
- Average speed of traffic
- Amount of heavy traffic
- Gradient of traffic
- Road texture

**HDM 4**

HDM-4 developed a noise prediction model. It estimates the noise levels 10 meters away from the edge of the carriageway. It starts by calculating a basic noise level that needs to be corrected with certain factors like:

- Speed
- Gradient

The basic noise levels are calculated with the following formula:
\[ L_{10} = 42.2 + 10 \log_{10} Q \]
\[ Q = \text{vehicles per hour} \]
\[ L_{10} = \text{The noise level exceeded 10 per cent of the time over a measured time period.} \]

**Speed correction**

The speed correction depends largely on the percentage of heavy vehicles. HDM-4 uses the following formula to calculate the speed correction:

\[
\text{DBSPEED} = 33 \log_{10} [S+40+500/S] + 10 \log_{10} [1+(5* \text{PCTHCV}/S)] - 68.8
\]

Where:
- DBSPEED is the correction due to speed in dB(A)
- PCTHCV is the percentage of heavy vehicles in the traffic stream.

**Gradient correction**

HDM-4 uses the following formula to calculate the gradient correction:

\[ \text{DBGR} = 0.3 \text{ GR} \]

Where:
- DBGR is the correction due to gradients in dB(A)
- GR is the gradient in per cent

**Road surface**

The noise level should also be corrected for noise generated by surface type and texture depths. The table below presents the relationship of the correction factors between speed, surface type and texture depth.

<table>
<thead>
<tr>
<th>Acoustic properties</th>
<th>Pervious Surfaces (Macadam)</th>
<th>Concrete</th>
<th>Bituminous</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 75 km/h</td>
<td>-3.5 dB(A)</td>
<td>10 log_{10} (90Tdsp + 30)-20 dB(A)</td>
<td>10 log_{10} (20Tdsp + 60)-20 dB(A)</td>
</tr>
<tr>
<td>&lt;75 km/h</td>
<td>-3.5 dB(A)</td>
<td>-1 dB(A)</td>
<td>-1 dB(A)</td>
</tr>
</tbody>
</table>

Besides emissions and the noise pollution there are a few other environmental problems related to road networks. Road user costs like fuel consumption, tyre consumption, maintenance and repair costs, engine oil and depreciation of the vehicles are also negative impacts for the environment. These items are grouped in one category Vehicle Operation Costs.

**Controlled intersections**

The noise pollution increases at intersections in particular at the controlled intersections. However the increase is negligible when the distance between the source (the centre of the junction) and the receiver (like surrounding houses) is larger than 150 meters.

Is the distance shorter the additional noise pollution can be estimated with the following equation:

\[ L_{\text{juntion}} = q(2.4-0.016a) \]

Where
- \( L_{\text{juntion}} \) noise increase [dBA]
- \( a \), distance between source and receiver [meters]
- \( q \) factor depending on the following criteria
When at least 3 legs carry a vehicle load of 2500 vehicles per twenty-four hours the intersection is classified as intersection type 1. Other intersections are classified as intersection type 2.

When the ratio between the traffic on the legs in different directions is between 1/3 and 3 the intersection is classified as “equal” in other situation the intersection is unequal.

All pedestrian crossings are unequal intersections type 2.

<table>
<thead>
<tr>
<th>Values for q</th>
<th>Intersection type 1</th>
<th>Intersection type 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equal</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Unequal</td>
<td>2/3</td>
<td>1/2</td>
</tr>
</tbody>
</table>
6 COMMON DENOMINATOR

Budget structure
The previous chapters discussed verifiable indicators of single problems. It possible to work with all these independent indicators if the interventions targeting the different problems are all financed from different sources. Thus the organization receives separate budgets to address each of the following issues:

- Isolation
- Travel time delays
- Accidents
- Emissions
- Noise pollutions
- Vehicle operation costs
- Mitigating interventions to reconnect nature reserves
- Etc

Block grant
However reality is often different. Most road authorities receive a block grant from which they finance all so-called development interventions. Often they receive another grant to finance all maintenance activities, including rehabilitation and reconstruction.

Monetary units
With the help of economics it is possible to compare different interests. Take this simple example. To compare the value of apples and pears, it is perhaps possible to count the apples and pears or to weigh them. However an economist and most people will compare them in terms of costs. If you are to buy some fruit and your options are either apples or pears you will base your decision partly on your preference, you may like apples better than pears, but if apples are triple the price of the pears you may opt for the pears. In other words you make a cost/benefit analysis. You compare the amount of pears or apples with the respective costs. Governments do the same. Although it is not very difficult to estimate the costs of projects, it far more difficult to estimate the benefits.

We are going through the same process if we want to develop an integrated management approach of the road network in a particular geographical area. We have seen that on existing road networks we have road user costs (time delays, fuel consumption, type consumption, car repairs, accidents, etc.). The road user costs are often expressed in monetary terms. However it less easy to calculate the economic costs of problems like vehicle noise, vehicle emissions and lack of access to education, health facilities, water, and other economic and social destinations.

Compensation for lost opportunities
In some countries econometric studies have been carried out, to identify the amount of economic costs of vehicle noise and emissions and people living in isolated areas with no access or very deprived access to the early mentioned destinations. If studies are not readily available the most common approach is to analyse government’s willingness to pay for corrective measures or to compensate the people living in these conditions.
An alternative way of estimating negative economic effects of living in isolated villages is based on the fact that most people in these villages are substance farmers and do not gain any formal income. In other words the GDP per capita in these villages is zero. The government may feel that it needs to compensate the inhabitants of the isolated villages and is willing to pay the difference between the average GDP per capita in the country or respective geographical area and the GDP per capita in the isolated village.

An economist will calculate the benefits with the following simple formula:

\[ \text{Benefits} = \text{Economic cost without the project} - \text{Economic cost with the project} \]

**An example**

Thus a road safety project that saves one fatal accident per year on a spot with one fatal accident per year and costs 1 million dollars, has the following economic benefits. It was calculated that the economic cost for one fatal accident is 0.5 million dollars.

We also assume that on basis of traffic volume predictions, the road will be completely overhauled in ten years time. During these ten years, the project saves 10 lives, resulting 5 million dollars. The project costs 1 million dollars.

Thus the economic benefits are:

\[ 4 \text{ Million} = 5 \text{ million (lives not saved)} - 1 \text{ million (project cost)} \]

The benefits and costs of a time delay reduction project are respectively 2 million and 0.4 million dollars.

The Benefit/Cost ratio is calculated with the following simple formula:

\[ \frac{\text{Benefit}}{\text{Cost}} = \frac{4 \text{ Million}}{1 \text{ Million}} \]

In this case the road accident project has a benefit/cost ratio of 4 (4 million/1 million) and

The Time Delay reduction project has a benefit/cost ratio of 5 (2 million/0.4 million) and therefore economist would consider the latter to be more attractive.

Because of the nature of the benefit formula used by economist, it is possible that projects are rejected, because the economic benefits are zero or negative. In those cases an economist will reject a project.

Many of the identified road problems are social in nature and rejection of such projects may be unacceptable to the government and its population. Economists have suggested multiplying the specific economic effects of the specific projects with a weight factor.
Weight factors

The government, sometimes through national census, determines weight values for all the different issues at stake:

- No or deprived access to education
- No or deprived access to health
- No or deprived access to post office, etc
- Travel time delays
- Accidents
- Other Vehicle Operating Costs
- Vehicle Noise
- Vehicle Emissions

By adding weight factors in the analysis, the analysis was transformed from an economic analysis into a socio-economic analysis. An economic analysis only works with the costs for society. Socio-economic analysis includes the social values about these costs.

If governments do not use a census it may question themselves, how much they are willing to pay to reduce one kilometre of congestion of a period of an hour, or to reduce the number of fatal accidents by one, etc, etc.

If the weight value for accidents is 2 and for travel time delays is one, the economic benefits change accordingly:

Road safety project.
The accumulated number of saved lives were 5, resulting in 5 million dollars. The project cost is 1 million dollars.

The benefit can be calculated by multiplying the 5 million dollars with the weight factor 2 and subsequently reducing it with the project cost.

Thus \((5 \text{ million} \times 2) - 1 \text{ million} = 9 \text{ million}\)

The Benefit/cost ratio increases to 9 (9 million/1 million).

Although now the road safety project will be given priority, projects still run the risk to be rejected because they generate no positive socio-economic benefits.

Some social scientists therefore urge to use a simpler formula to calculate the benefits, by neglecting the project costs in it. They may use weight factors to express the preference. (I like apples two times more than pears.)

In this case the benefit of the road safety project would increase to five million (in case without a weight factor) and 10 million dollars (with weight factor). To compare the different projects addressing different issues, the benefits are still expressed in dollars.

This approach is a little risky because it favours expensive projects.
The social benefit analysis seems to be more common when projects of one particular social sector is addressed or when it is possible to use one and the same unit to express the effects of projects. Such an unit could be X.

It is possible to assume that
1 kilometre congestion of 1 hour w1 X
and that
1 fatal accident equals w2 X

The challenge is to define X for each of the specific problems. The first step is usually writing down the units that can be measured like:

<table>
<thead>
<tr>
<th>Issue</th>
<th>X (example)</th>
<th>Weight factor (example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time delays</td>
<td>1 kilometre congestion of 1 hour per lane</td>
<td>1</td>
</tr>
<tr>
<td>Fatal accidents</td>
<td>1 fatal accident</td>
<td>20</td>
</tr>
<tr>
<td>Accident injury</td>
<td>1 injury</td>
<td>5</td>
</tr>
<tr>
<td>Accident damage only</td>
<td>1 accident damage only</td>
<td>1</td>
</tr>
<tr>
<td>Vehicle noise</td>
<td>Area affected</td>
<td>3</td>
</tr>
<tr>
<td>Isolated village</td>
<td>1 affected person * 10 minutes travel time beyond government norm</td>
<td>1</td>
</tr>
</tbody>
</table>

X does not reflect the importance given to a specific issue and therefore it is important to multiply X with a weight factor W.

It is not easy to express the effects of rural access improvement projects in economic terms. It is in theory possible to calculate the travel time delays and their respective costs of each village. However, this requires extensive data collection about travel patterns, frequency and the like. Usually Origin – Destination surveys are carried out. This process is often expensive and often time consuming for the organization, responsible. But more important, people in isolated villages tend to travel less. After all where would they go and for what reason? In that case, travel costs of an isolated village give the wrong indication. It is only fair to estimate the travel costs of village when that village is already connected by road to the road network and villages with more facilities.
7 FORECASTING TRAFFIC DEMAND

Planners need to have knowledge of the existing transport demands on specific links and are able to predict future transport demands deriving from various economic and social developments and potential transport projects.

In most advanced economies there is a stable relationship between GDP and traffic demand. Although these relationships may change due to cultural changes, as has happened when the female population entered the cash economy as employees. Low and middle-income countries going through industrialisation processes will learn that transport demands and GDP figures vary at the various stages of their development. All these countries are in an obvious need for transport interventions. When productivity grows in the agricultural sector transport is needed for supplies (tools, equipment, fertilisers, etc) to the farms in the rural areas and the products, mainly food have to be transported to the markets. Increasing industrial production means bringing together greater volumes of inputs and distribution of finished products. The number of goods exchanged will multiply with increasing specialisation and rising incomes. Thus the increase in freight movement is faster that the increase in GNP.

In the early stage of industrialisation, the transport demand of heavy materials increases. Thus transport requirements rise at a considerable higher rate than the rise in economic activity. Later, as development proceeds, the further processing of raw materials will result in greater values in product for given volumes of transport. In addition, services (nontradables) will contribute significantly to the GNP. Thus the traffic demand as a percentage of the GNP decreases as the development level progresses.

Transport surveys

Transport surveys should be based on what traffic can be expected to flow as a result of production trends, socio-cultural behaviour and implementation of development plans. Traffic volumes have to derive from studies of economic and social activities. A road by itself will seldom result in additional traffic demand.

In advanced economies, traffic engineers use route choice modals that depend on route characteristics. These models are of little use to most low and middle-income countries, where the number of alternative routes is limited. Transport needs are created by what takes place outside the transport field.

In many low income countries, the movement of mineral fuels (coal and oil), agricultural products (food & fibres), steel and cement together form a substantial proportion of the total freight demand. Plans to use alternative energy sources clearly affect the demand for freight transport. Distribution of electricity takes place through electric systems.
transmission lines. Distribution of gas can go through pipes.

Agricultural production is highly seasonal and generates seasonal peak flows in transport demand. Storage facilities, food processing plants, slaughter houses in rural areas bring more benefits to the farmers. These facilities also reduce the seasonal peak flows and thus the physical requirements for the transport infrastructure.

Government comprehensive, zoning and specific plans indicate locations of industrial, service, agriculture, recreation and areas to live in. In addition their development plans provide information about government investments in the other sectors. In addition plans of private developers are useful sources to forecast future traffic demands.
8 ORGANISATION STRUCTURE AND PROCESSES

8.1 STRUCTURE

The structure of the organisation includes the division of the organisation in groups (units/teams, departments, divisions, etc), the division of tasks, responsibilities and powers and the way co-ordination of activities take place. Usually the formal organisation structures are neatly described in the organograms. A simple but very effective organogram for road infrastructure provision is sketched below.

The organisation provides the following services:

- Planning section
- Emergency works
- Identification
- Design
- Preparation & Implementation

The organogram is designed on the basis of the following assumptions:

**Emergency**
Because emergency works cannot be delayed, this group have separated from the rest. They basically operate autonomous with exception that they inform the planning section and other sections about the repairs carried out. Both responsibility and authority is delegated to this section with respect to repair of emergency failures.

**Identification**
The section of identification undertake a number or tasks but all related to identification of new project, related to maintenance, financial improvement, or projects with environmental or socio-economic objectives. Depending on the size of the works, staff from the other sections may work for this section on a part-time basis. An important task of the manager of this section is to discuss with the (business-) community possible new development in the region, which may impact the demand for infrastructure.

**Design**
The design section designs the products. As these products may vary considerably in range, it will require different expertise, like:
1. Civil engineers
2. Traffic planners/engineers
3. Environmental engineers

**Preparation and implementation**
These sections is mainly filled with civil engineers and technicians, who are responsible to preparation of the contract documents, specifications and have to implement the works. Like the design section, this section organises itself in subsections with groups of staff with certain expertise, from which projects can draw resources.

**Planning**
The planning section ranks, phases and directs the projects. It also monitors the progress of the works. It requires information from the other four sections to do its work.
8.2 PROCESSES

Processes

A process is a sequence of activities/interlinked events that transforms inputs into outputs. Probably the most important processes are the financial mechanism.

Financial mechanism

As stated in the introduction of this document, maintenance does require financial means. The government (on different levels) usually finances maintenance of public infrastructure. The budget requirements for maintenance fluctuates considerable over the years. The income of the government has usually a more stable character. There different ways/procedures to determine maintenance budgets. The simplest option is that the income of road tolls and fuel levies are directly transferred to road agency. The road agency is given freedom to use this budget for all kinds of projects, on condition that the network is always in a minimum condition. The agency may also borrow and save money to shift funds to the years where it is most needed. Usually politics do want to intervene when it comes to projects with social/economic objectives. They therefore do want to control the funds allocated to these projects. The same procedures can be applied, with the exception that the budget can only be used for maintenance purposes. It has become a recurrent budget, which is stable over the years. In this case the agency and the government will have to negotiate about the height of the required maintenance budget. When data are not available about actual annual average maintenance requirements some rule of the thumbs can be applied, like:

- Earth roads 500 US$/year
- Gravel Roads 1500 US$/year
- Asphalt roads
- Concrete roads

However when the more time-based models are used, the more accurate the required maintenance sum can be determined. This system is also used when performance contracts are used, where a contractor receives a contract for 3 up to 10 years to keep a part of the road network all the time in a minimum condition. Unfortunately sometimes governments do want to keep the freedom of allocating budget in their own hands. In those situations maintenance is competing with other objectives/products. The recurrent budget is reduced to a level where it only can be used for periodic-, cyclical and emergency maintenance. Variable maintenance and not urgent corrective maintenance interventions are competing with projects with socio-economic objectives.

Financial procedures

Budgets and divisions

The different divisions have all their different budget requirements. From the previous paragraph it is clear that the emergency unit should have their own budget to carry out the tasks assigned to. Basically the budget should be large enough and based on the last ten years expenditures. To reduce the risks of collusion, corruption and inefficient use both financial and technical audits will be necessary. The identification carries out routine tasks, which means that their budget is unlikely to fluctuate over the years. The other

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4 See for definitions, paragraph 2.2 Objectives
sections are mainly project oriented and therefore will require two separate budgets. The first one is the recurrent budget for permanent expenditures and the second budget is the project specific budgets.

**Directing projects**

The planning section, with advice of the sections, has to direct the projects on basis of possible impacts, and costs. It therefore breaks down the project in stages. Each stage usually ends with semi-finished product, like a sketch design, detailed design, contract documents, completion/delivery of product. The semi-finished product includes usually information about costs and impacts. As the project develops, more and accurate information is gathered about these elements. The adjusted information may of course lead to new prioritisation and ranking of the different projects.

**Readjusting planning**

Note that the preparation of a new project requires a certain lead-time and budget. In addition information about new projects is usually less accurate as the information of already developed projects. If a new project is ranked above the already prepared project, it should be noted that during the preparation time, the network does not gain additional profitability, which should be counted as a loss.

**Corrective maintenance**

Corrective maintenance includes so-called emergency maintenance. Emergency maintenance results from failures with high unacceptable consequences. Whenever a failure occurs the organisation has basically three options of actions:

- Report the failure so that it will repaired at the first opportune moment
- Patch up the failure till the first opportune moment is there to overhaul it
- Overhaul the failure.

**Patching up**

It should be noted that the live of patching up is of course limited. It may be necessary to undertake another minor repair before the major overhaul will take place. Patching up is usually considered when the failure is small in impact but is expensive to repair. A major overhaul may exhaust available funds during that budget year and therefore it is forwarded to next year's budget. The overhaul may need resources (materials and sometimes equipment) not available and the delivery time takes too long. To avoid negative consequences like accidents or none availability of the infrastructure, the organisation may opt to patch up the damaged item. The overhaul itself may also have major negative consequences and therefore it may be wise to postpone it to first possible opportune moment.