HDM-4 Road User Effects
• Most models in use draw on HDM-III
• No major RUE studies since HDM-III
• Several studies addressed HDM-III calibration or investigated single components - e.g. fuel
Key Changes to HDM-III

- Unlimited number of representative vehicles
- Reduced maintenance and repair costs
- Changes to utilization and service life modeling
- Changes to capital, overhead and crew costs
- New fuel consumption model
- New oil consumption model
- Changes to speed prediction model
- Use of mechanistic tire model for all vehicles
New Features in HDM-4

- Effects of traffic congestion on speed, fuel, tires and maintenance costs
- Non-motorized transport modeling
- Traffic safety impact
- Vehicle emissions impact
Representative Vehicles

Motorized Traffic
- Motorcycle
- Small Car
- Medium Car
- Large Car
- Light Delivery Vehicle
- Light Goods Vehicle
- Four Wheel Drive
- Light Truck
- Medium Truck
- Heavy Truck
- Articulated Truck
- Mini-bus
- Light Bus

Non-Motorized Traffic
- Bicycles
- Rickshaw
- Animal Cart
- Pedestrian

- Medium Bus
- Heavy Bus
- Coach
Road User Costs Components

Vehicle Operating Costs
- Fuel
- Lubricant oil
- Tire wear
- Crew time
- Maintenance labor
- Maintenance parts
- Depreciation
- Interest
- Overheads

Time Costs
- Passenger time
- Cargo holding time

Accidents Costs
Vehicle Speed and Physical Quantities

Roadway and Vehicle Characteristics

- Vehicle Speed
  - Physical Quantities
  - Unit Costs

Road User Costs
## Physical Quantities

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantities per Vehicle-km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>liters</td>
</tr>
<tr>
<td>Lubricant oil</td>
<td>liters</td>
</tr>
<tr>
<td>Tire wear</td>
<td># of equivalent new tires</td>
</tr>
<tr>
<td>Crew time</td>
<td>hours</td>
</tr>
<tr>
<td>Passenger time</td>
<td>hours</td>
</tr>
<tr>
<td>Cargo holding time</td>
<td>hours</td>
</tr>
<tr>
<td>Maintenance labor</td>
<td>hours</td>
</tr>
<tr>
<td>Maintenance parts</td>
<td>% of new vehicle price</td>
</tr>
<tr>
<td>Depreciation</td>
<td>% of new vehicle price</td>
</tr>
<tr>
<td>Interest</td>
<td>% of new vehicle price</td>
</tr>
</tbody>
</table>
Free-Flow Speeds Model

Free speeds are calculated using a mechanistic/behavioral model and are a minimum of the following constraining velocities.

- **VDRIVEu** and **VDRIVEd** = uphill and downhill velocities limited by gradient and used driving power
- **VBRAKEu** and **VBRAKEd** = uphill and downhill velocities limited by gradient and used braking power
- **VCURVE** = velocity limited by curvature
- **VROUGH** = velocity limited by roughness
- **VDESIR** = desired velocity under ideal conditions
Free-Flow Speeds Model

\[ Vu = \frac{\exp(\sigma^2/2)}{1 + \frac{1}{\beta} + \frac{1}{\beta} + \frac{1}{\beta} + \frac{1}{\beta} + \frac{1}{\beta}} \]

\[ Vd = \frac{\exp(\sigma^2/2)}{1 + \frac{1}{\beta} + \frac{1}{\beta} + \frac{1}{\beta} + \frac{1}{\beta} + \frac{1}{\beta}} \]

\[ V = 2 \div \left( \frac{1}{Vu} + \frac{1}{Vd} \right) \]

\[ Vu = \text{Free-flow speed uphill} \]
\[ Vd = \text{Free-flow speed downhill} \]
\[ V = \text{Free-flow speed both directions} \]
\[ \sigma = \text{Sigma Weibull parameter} \]
\[ \beta = \text{Beta Weibull parameter} \]
Free-flow Speed and Gradient

- Roughness = 3 IRI m/km
- Curvature = 25 degrees/km

Speed (km/hr) vs. Gradient (%) graph

- VCURVE
- VROUGH
- VDESIR
- VDRIVE
- VBRAKE
- Speed
Roughness = 3.50 m/km
Gradient = -3.5 %
VDRIVE

Drive Force

Grade Resistance
Air Resistance
Rolling Resistance

- Driving power
- Operating weight
- Gradient
- Density of air
- Aerodynamic drag coef.
- Projected frontal area
- Tire type
- Number of wheels

- Roughness
- Texture depth
- % time driven on snow covered roads
- % time driven on water covered roads
For uphill travel, VBRAKE is infinite. For downhill travel, VBRAKE is dependent upon length of gradient. Once the gradient length exceeds a critical value, the brakes are used to retard the speed.

- Braking power
- Operating weight
- Gradient
- Density of air
- Aerodynamic drag coef.
- Projected frontal area
- Tyre type
- Number of wheels
- Roughness
- Texture depth
- % time driven on snow covered roads
- % time driven on water covered roads
- Number of rise and fall per kilometers
VCURVE is calculated as a function of the radius of curvature.

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

\[ R = \text{Radius of curvature} \]

\[ R = \frac{180,000}{(\pi \times \max(18/\pi, C))} \]

\[ C = \text{Horizontal curvature} \]

\[ a_0 \text{ and } a_1 = \text{Regression parameters} \]
VROUGH is calculated as a function of roughness.

\[ VROUGH = \frac{ARVMAX}{a0 \times RI} \]

RI = Roughness

ARVMAX = Maximum average rectified velocity

a0 = Regression coefficient
VDESIR is calculated as a function of road width, roadside friction, non-motorized traffic friction, posted speed limit, and speed enforcement factor.

\[ V_{DESIR} = \min (V_{DESIR0}, PLIMIT \times ENFAC) \]

- **PLIMIT** = Posted speed limit  
- **ENFAC** = Speed enforcement factor  
- **VDESIR0** = Desired speed in the absence of posted speed limit  
- **VDES** = Base desired speed  

\[ V_{DESIR0} = VDES \times XFRI \times XNMT \times VDESMUL \]

- **XFRI, XNMT** = Roadside and NMT factors  
- **VDESMUL** = Multiplication factor  
- **VDES** = Base desired speed
Speeds Computational Logic

• Calculate Free-Flow Speed for each vehicle type

• Calculate the following for each traffic flow period:
  - Flow in PCSE/hr
  - Vehicle operating speed (Speed flow model)
  - Speed change cycle (Acceleration noise)
  - Vehicle operating costs
  - Travel time costs

• Calculate averages for the year
To take into account different levels of traffic congestion at different hours of the day, and on different days of the week and year, HDM-4 considers the number of hours of the year (traffic flow period) for which different hourly flows are applicable.
To model the effects of congestion, mixed traffic flow is converted into equivalent standard vehicles. The conversion is based on the concept of ‘passenger car space equivalent’ (PCSE), which accounts only for the relative space taken up by the vehicle, and reflects that HDM-4 takes into account explicitly the speed differences of the various vehicles in the traffic stream.

<table>
<thead>
<tr>
<th>Vehicle Type</th>
<th>PCSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motorcycle</td>
<td>0.50</td>
</tr>
<tr>
<td>Small Car</td>
<td>1.00</td>
</tr>
<tr>
<td>Medium Car</td>
<td>1.00</td>
</tr>
<tr>
<td>Large Car</td>
<td>1.00</td>
</tr>
<tr>
<td>Light Delivery Vehicle</td>
<td>1.00</td>
</tr>
<tr>
<td>Light Goods Vehicle</td>
<td>1.00</td>
</tr>
<tr>
<td>Four Wheel Vehicle</td>
<td>1.00</td>
</tr>
<tr>
<td>Light Truck</td>
<td>1.30</td>
</tr>
<tr>
<td>Medium Truck</td>
<td>1.40</td>
</tr>
<tr>
<td>Heavy Truck</td>
<td>1.60</td>
</tr>
<tr>
<td>Articulated Truck</td>
<td>1.80</td>
</tr>
<tr>
<td>Mini-bus</td>
<td>1.20</td>
</tr>
<tr>
<td>Light Bus</td>
<td>1.40</td>
</tr>
<tr>
<td>Medium Bus</td>
<td>1.50</td>
</tr>
<tr>
<td>Heavy Bus</td>
<td>1.60</td>
</tr>
<tr>
<td>Coach</td>
<td>1.70</td>
</tr>
</tbody>
</table>
Difference Between PCSE and PCU

- PCU
  - consider two factors:
    - space occupied by vehicle
    - speed effects
  - used in highway capacity calculations

- PCSE (HDM-4)
  - considers only space occupied
  - speed effects considered separately through speed model
PCSE

Length

Gap

Space (m)
To consider reduction in speeds due to congestion, the “three-zone” model is adopted.
Speed Flow Model

Qo = the flow below which traffic interactions are negligible
Qnom = nominal capacity
Qult = ultimate capacity for stable flow
Snom = speed at nominal capacity (0.85 * minimum free speed)
Sult = speed at ultimate capacity
S1, S2, S3…. = free flow speeds of different vehicle types

### Speed-Flow Model Parameters by Road Type

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Width (m)</th>
<th>Qo/Qult</th>
<th>Qnom/Qult</th>
<th>Qult (PCSE/h/lane)</th>
<th>Sult (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single Lane Road</td>
<td>&lt; 4.0</td>
<td>0.0</td>
<td>0.70</td>
<td>600</td>
<td>10</td>
</tr>
<tr>
<td>Intermediate Road</td>
<td>4.0 to 5.5</td>
<td>0.0</td>
<td>0.70</td>
<td>900</td>
<td>20</td>
</tr>
<tr>
<td>Two Lane Road</td>
<td>5.5 to 9.0</td>
<td>0.1</td>
<td>0.90</td>
<td>1400</td>
<td>25</td>
</tr>
<tr>
<td>Wide Two Lane Road</td>
<td>9.0 to 12.0</td>
<td>0.2</td>
<td>0.90</td>
<td>1600</td>
<td>30</td>
</tr>
<tr>
<td>Four Lane Road</td>
<td>&gt;12.0</td>
<td>0.4</td>
<td>0.95</td>
<td>2000</td>
<td>40</td>
</tr>
</tbody>
</table>
Speed Flow Types

- Four Lane
- Two Lane
- Wide Two Lane

Speed (km/hr) vs Flow (veh/hr) graph
Roadside Friction
• Replaced HDM-III Brazil model with one based on ARRB ARFCOM model
• Predicts fuel use as function of power usage
Implications of New Fuel Model

• Lower rates of fuel consumption than HDM-III for many vehicles
• Effect of speed on fuel significantly lower for passenger cars
• Considers other factors – e.g. surface texture and type -- on fuel
• Model can be used for congestion analyses
Effect of Speed on Fuel Consumption

![Graph showing the effect of speed on fuel consumption for different regions: India-1, India-2, India-3, Caribbean, and Kenya. The graph plots speed in km/h on the x-axis and fuel consumption in L/1000km on the y-axis. The data points and lines indicate a decrease in fuel consumption as speed increases, with each region having a distinct curve.]
Congestion - Fuel Model

- 3-Zone model predicts as flows increase so do traffic interactions
- As interactions increase so do accelerations and decelerations
- Adopted concept of ‘acceleration noise’ -- the standard deviation of acceleration
Congestion Modelling

Acceleration in m/s/s

Uncongested

Congested
Effects of Speed Fluctuations (Acceleration Noise)

• Vehicle interaction due to:
  - volume - capacity
  - roadside friction
  - non-motorised traffic
  - road roughness
  - driver behaviour & road geometry

• Affects fuel consumption & operating costs
## dFUEL Values by Acceleration Noise and Vehicle Speed

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Speed (km/hr)</th>
<th>Acceleration Noise in m/s²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>Car</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>0.0063</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>0.0095</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>0.0083</td>
</tr>
<tr>
<td></td>
<td>90</td>
<td>0.1092</td>
</tr>
<tr>
<td></td>
<td>95</td>
<td>0.1133</td>
</tr>
<tr>
<td></td>
<td>100</td>
<td>0.1255</td>
</tr>
<tr>
<td>Bus</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Truck</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>
Effects Traffic Interactions on Fuel Consumption
Tire Consumption

• Tread wear
  □ amount of the tread worn due the mechanism of the tyre coming into contact with the pavement surface

• Carcass wear
  □ combination of fatigue and mechanical damage to the tyre carcass - affects number of retreads
Factors Influencing Tire Consumption

- Rubber
  - Composition Properties

- Pavement Texture
  - Microtexture
  - Macrotexture

- Temperature
  - Air
  - Road
  - Tyre

- Interface Contaminants
  - Water
  - Dust, Mud
  - Ice, Snow

- Vehicle
  - Tyre Load
  - Applied Force
  - Suspension Type

- Tyre
  - Type/Construction
  - Tread Pattern
  - Aspect Ratio
  - Inflation Pressure

- Temperature
  - Air
  - Road
  - Tyre

- Operating Conditions
  - Traffic Interactions
  - Road Alignment
  - Pavement Condition
  - Driver Behaviour

- Tread Wear Rate Per Unit of Energy
- Energy Per Unit Distance
- Tyre Consumption

Energy Per Unit Distance

Tread Wear Rate Per Unit of Energy

Tyre Consumption
Effect of Congestion on Tyre Consumption

- Speed in km/h
- dTYRE
- Acceleration Noise in m/s/s
Parts and Labor Costs

- Usually largest single component of VOC
- In HDM-III user’s had choice of Kenya, Caribbean, India and Brazil models
- All gave significantly different predictions
- Most commonly used Brazil model had complex formulation
- Few studies were found to have calibrated model
HDM-III (Brazil) Parts Consumption

Parts Consumption as % New Vehicle Price/1000 km

Roughness in IRI m/km

PC and LDV

HDM-4 Cars

HDM-4 Buses
Parts Model

- Estimated from HDM-III Brazil model
- Exponential models converted to linear models which gave similar predictions from 3 - 10 IRI
- Roughness effects reduced 25% for trucks
- For cars, roughness effects same as for trucks
- For heavy buses, roughness effects reduced further 25%
Utilisation and Service Life

- HDM-4 has either constant or ‘Optimal Life’ service life
- Utilisation function of hours worked for work vehicles; lifetime kilometreage for private vehicles
Optimal Life Method

- Underlying philosophy is that the service life is influenced by operating conditions, particularly roughness
- Relates life -- and capital costs -- to operating conditions
Optimal Life Method

Discounted Area = New Vehicle Price

RUN(OL)

Vehicle Age in years

Costs per year

Running Costs

OL
Roughness and Lifetime Utilisation

The graph shows the relationship between roughness in IRI m/km and optimal life as a percentage of baseline utilisation. As roughness increases, the optimal life decreases.
Constant Service Life

• Equations depend on the percentage of private use:

  $\text{LIFE}_\text{KM} = \text{LIFE} \times \text{AKM}$  \hspace{1cm} < 50%

  $\text{LIFE}_\text{KM} = S \times \text{HRWK} \times \text{LIFE}$  \hspace{1cm} > 50%
Capital Costs

• Comprised of depreciation and interest costs
• HDM-III used a simple linear model affected by operating conditions through the effects of speed on utilization and service life
• HDM-4 uses ‘Optimal Life’ method or constant life method
Depreciation in HDM-4

- Depreciation calculated multiplying the replacement vehicle price by the following equation:

\[ \text{DEP} = 1000 \cdot \frac{(1 - 0.01 \cdot \text{RVPLTPCT})}{\text{LIFEKM}} \]

- The replacement vehicle price is reduced by a residual value which can be a function of roughness.

- The denominator is the lifetime utilisation which may be constant or predicted with the OL method to be a function of roughness.
Roughness on Depreciation
Interest Costs

• Interest costs are the replacement vehicle price multiplied by the following equation:

\[ INT = 0.5 \times \frac{\text{AINV} \times 1000}{100 \times \text{SHRWK0}} \]

• Function of speed and hours worked as well as the interest rate
Oil Consumption

- HDM-III only function of roughness
- Model contains two components
  - Fuel use due to contamination
  - Fuel use due to operation which is proportional to fuel use

\[
\text{OIL} = \text{OILCONT} + \text{OILOPER SFC}
\]
Travel Time Components

- **Passenger Working Hours**
  \[ PWH = \frac{1000 \text{ PAX PCTWK}}{100 \text{ S}} \]

- **Passenger Non-Working Hours**
  \[ PNH = \frac{1000 \text{ PAX} (100 - \text{PCTWK})}{100 \text{ S}} \]

- **Crew Hours**
  \[ CH = \frac{1000 (100 - \text{PP})}{100 \text{ S}} \]
Road Safety

• HDM-4 does not predict accident rates
• User defines a series of “look-up tables” of accident rates
• The rates are broad, macro descriptions relating accidents to a particular set of road attributes
  - Fatal
  - Injury
  - Damage only
Accident Groups

- Road type, class, use
- Traffic level
- Geometry, pavement type, ride quality, surface texture, presence of shoulders
- Non-motorised traffic
- Intersection type
Accident Rates and Exposure

• The accident rate is the number of accidents divided by the exposure
• It is typically expressed in number per 100 million vehicle-km

\[
\text{ACCRATE} = \frac{\text{ACCYR}}{\text{EXPOSURE}}
\]

\[
\text{EXPOSINT} = \frac{\text{AADT} \times 365}{10^6}
\]
## Accident Rates Examples

### Number per 100 million vehicle-km

<table>
<thead>
<tr>
<th></th>
<th>2 Lane Paved Road</th>
<th>4 Lane Divided Expressway</th>
<th>4 Lane Freeway</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>South Africa</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation</td>
<td>100.0 100%</td>
<td>93.0 100%</td>
<td>50.0 100%</td>
</tr>
<tr>
<td>Manual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Canada</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>British Columbia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>121.0 100%</td>
<td>93.0 100%</td>
<td>50.0 100%</td>
</tr>
<tr>
<td>Evaluation</td>
<td>1.9 2%</td>
<td>1.1 1%</td>
<td>0.5 1%</td>
</tr>
<tr>
<td>Manual</td>
<td>36.3 30%</td>
<td>30.0 32%</td>
<td>16.2 32%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>South Africa</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economic</td>
<td>230.0 100%</td>
<td>25.0 11%</td>
<td>8.0 8%</td>
</tr>
<tr>
<td>Evaluation</td>
<td></td>
<td>39.0 17%</td>
<td>27.0 27%</td>
</tr>
<tr>
<td>Manual</td>
<td></td>
<td>166.0 72%</td>
<td>65.0 65%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Sources:**
- South Africa: Economic Warrants for Surfacing Roads, 1989, SABITA and CSIR
VOC Calibration Procedure (Level 1)

- Vehicle mass & ESAL
- Road Capacity & Speed-Flow factors
- Vehicle service life
- Vehicle Utilisation (Annual KM & Hours)
- Desired speed
- Vehicle engine power, speed (rpm) & braking
- Tyre characteristics (type, rubber volume, etc)
- Vehicle depreciation
- Aerodynamic factors
Calibration Very Important

![Graph showing cost comparison for different types of trucks]

- **2-Axle Truck**
- **5-Axle Truck**
- **7-Axle Truck**

Cost in cents/km vs.
- Crew
- Interest
- Depreciation
- Maintenance
- Tires
- Fuel & Oil
Non-Motorised Transport (NMT)
NMT User Costs and Benefits

- Travel speed and time
- Wear and tear of some NMT vehicles and components
- Degree of conflicts with MT traffic
- Accident rates
- Energy consumption
Factors which influence NMT Speed

- MT traffic volume and speed
- NMT traffic volume
- roadside activities
- roadway grade
- rolling resistance
- inclement weather
- road width (where NMT can travel safely) and/or number of lanes
- method of separating NMT/MT traffic
- roughness of road surface
NMT Speed Model

\[ V_{Sk} = f (V_{DESk}, V_{ROUGHk}, V_{GRADk}) \]

- Desired speed (VDES)
- Speed limited by road surface roughness (VROUGH)
- Speed limited by road gradient (VGRAD)
NMT Time and Operating Cost

• Components:
  - Time-Related Cost: $f(\text{speed})$
  - Standing Cost: $f(\text{capital cost, average life, utilisation, interest charge})$
  - Repair and Maintenance Cost: $f(\text{IRI, NMT age and utilisation})$
## NMT Speeds (km/h)

### Road Gradient Effects, IRI = 4 m/km

<table>
<thead>
<tr>
<th>NMT type</th>
<th>Flat Terrain</th>
<th>Hilly Terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycles</td>
<td>18.0</td>
<td>5.4</td>
</tr>
<tr>
<td>Rickshaws</td>
<td>15.8</td>
<td>2.8</td>
</tr>
<tr>
<td>Animal Carts</td>
<td>3.3</td>
<td>2.0</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>4.4</td>
<td>2.3</td>
</tr>
</tbody>
</table>

### Road Surface Roughness Effects, RF = 10 m/km

<table>
<thead>
<tr>
<th>NMT Type</th>
<th>Roughness 3 IRI</th>
<th>Roughness 13 IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycles</td>
<td>18.83</td>
<td>10.73</td>
</tr>
<tr>
<td>Rickshaws</td>
<td>16.47</td>
<td>9.38</td>
</tr>
<tr>
<td>Animal Carts</td>
<td>3.43</td>
<td>2.13</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>4.59</td>
<td>2.87</td>
</tr>
</tbody>
</table>
## NMT Time and Operating Costs ($/km)

### Pavement Type Effects, IRI = 4 m/km, RF=10 m/km

<table>
<thead>
<tr>
<th>NMT Type</th>
<th>Bituminous</th>
<th>Gravel</th>
<th>Earth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycles</td>
<td>0.047</td>
<td>0.051</td>
<td>0.049</td>
</tr>
<tr>
<td>Rickshaws</td>
<td>0.055</td>
<td>0.060</td>
<td>0.058</td>
</tr>
<tr>
<td>Animal Carts</td>
<td>0.273</td>
<td>0.280</td>
<td>0.277</td>
</tr>
<tr>
<td>Pedestrians</td>
<td>0.096</td>
<td>0.096</td>
<td>0.096</td>
</tr>
</tbody>
</table>
Impact of NMT on MT

• MT Speed
  - modelled using the “side friction” or speed reduction factor (XNMT)
  - XNMT value is used in the Free Speed model

• MT Operating Costs
  - modelled using “acceleration effects” or speed-change cycles (acceleration noise)
Environment Models

- Environmental effects:
  - Emissions (hydrocarbons, NOx, ...)
  - Energy balance
  - Noise (forthcoming)

- Quantities computed but not included on the economic evaluation
Emission Models

• Developed by VTI in Sweden
• Conducted statistical analysis of emissions as function of fuel use
• Developed simple linear model
• Model will be changed in future
Emissions Model

Estimate quantities of pollutants produced as a function of:

- Road characteristics
- Traffic volume/congestion
- Vehicle technology
- Fuel consumption

- Hydrocarbon
- Carbon monoxide
- Nitrous oxides
- Sulphur dioxide
- Carbon dioxide
- Particulates
- Lead
Energy Balance Analysis

• Compares total life-cycle energy consumption of different transport policies
• Three energy use categories:
  - Motorised vehicles
  - Non-motorised vehicles
  - Road construction and maintenance
Energy Analysis Output

- Total energy consumption
- Total consumption of renewable and non-renewable energy
- Total national and global energy use
- Specific energy consumption (per km)