The World Bank

ASTAE

Asia Sustainable and Alternative Energy Program

Greenhouse Gas Emissions Mitigation in Road Construction and Rehabilitation

A Toolkit for Developing Countries

ROADEO Toolkit User Manual

User Manual : Model Framework and Assumptions

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Abbreviations and Acronyms

AAU	Assigned Amount Unit
BAU	Business As Usual
CBR	Californian Bearing Ratio
CDM	Clean Development Mechanism
CER	Certified Emission Reduction
CRRAP	Cold Recycling of Reclaimed Asphalt Pavement
DNA	Designated National Authority
EIRR	Economic Internal Rate of Return
EPA	Environmental Protection Agency
ERU	Emission Reduction Unit
ESA	Equivalent Standard Axles
ETS	Emission Trading Scheme
EU	European Union
FIRR	Financial Internal Rate of Return
FUND	Framework for Uncertainty, Negotiation, and Distribution
GHG	Green House Gas
HMA	Hot Mix Asphalt
HMAM	High Modulus Asphalt Material
IPCC	International Panel on Climate Change
IRR	Internal Rate of Return
ITL	International Transaction Log
JI	Joint Implementation
NPV	Net Present Value
ODA	Official Development Assistance
ORN	Overseas Road Notes
PDD	Project Design Document
PPD	Perpetual Pavement Design
PPM	Parts Per Million
RGGI	Regional Greenhouse Gas Initiative
SC	Stage Construction
TRL	Transport Research Laboratory
UNFCC	United Nations Framework Convention on Climate Change
SCC	Social Cost of Carbon
WMA	Warm Mix Asphalt

Chapter 1 - Introduction

1. Purpose of this Document

This User Manual has been developed as part of an effort to prepare a toolkit for the evaluation and reduction of GHG emissions in the road construction industry. This is an abridged version of the User Manual. For a complete version that includes a more detailed overview of assumptions made and the development of equations used to estimate the various parameters of quantities of road works items within the algorithm, the user is referred to the complete User Manual on the CD that accompanies this document.

The User Manual is intended to provide guidance to the user of the GHG emissions evaluation and reduction tool "Greenhouse Gas Emission Mitigation Toolkit for Highway Construction and Rehabilitation" (ROADEO, ROADEO toolkit, the Toolkit), which takes the form of software.

The purpose of this document is to

- Describe the structure of the software and explain the logic behind its development, so that users may successfully implement it, and
- Detail the assumptions made to assist ROADEO users who may not have the comprehensive information required to assess GHG generators.

The modelling of GHG emissions is not covered by this document. The user may reference Annex 1- Introduction to GHG Emissions in Road Construction and Rehabilitation" for information and guidance on this aspect. This information is found on the CD that accompanies this document.

These assumptions, as will be evident from further reading, are not expected to provide accurate results. However, in the absence of information, and especially at early stages of projects (planning and early feasibility study stages, for example) the model can provide orders of magnitude.

The model is highly empirical; it has very little interface with engineering considerations, apart from some considerations of pavement. Therefore, it should be used with great care.

It is expected that feedback from experience will allow major improvements.

2. Structure of the Document

This document first presents the structure of the ROADEO toolkit, then describes the overall model principles, and finally, details estimation of GHG generators, in terms of materials, equipment, and transport. Practical guidance is also given in a specific section on best practices.

A report on the calibration of the model used in ROADEO appears in an appendix.

3. Notice

The following facts should be noted by the reader and ROADEO users:

- The tool is the result of a somewhat contradictory effort to
  - Make it as open as possible, so users can adjust most of the parameters affecting GHG emissions calculations and integrate their specific project conditions into the considerations and calculations, and
  - Make it easy to use and accessible to a wide range of users who are not GHG or road construction specialists;
- The decisions made by users in selecting values for the calculation parameters may have a major impact on the results. ROADEO provides guidance and orders of magnitude to assist in this difficult task. However, the current status of calculation parameters selection and available information still leave space for major uncertainties. As discussed in the review of GHG provided with the Toolkit, sources sometimes disagree significantly on values to be considered.
- Some parameters cannot be precisely assessed at upstream stages; any calculation should be accompanied by a short note summarizing the assumptions made and the limits or risks of the calculation.
- Engineering or empirical results available from ROADEO may not represent the specific condition of the user's project, and careful consideration should be given before using the default values. These are provided to help users identify main issues and their orders of magnitude.

Chapter 2 - Calculation Tool Architecture

1. General Requirements

1.1. Objective

ROADEO, along with this User Manual and the manual on GHG emissions and best practices, comprises a toolkit for the evaluation and reduction of road construction GHG emissions.

The ROADEO Toolkit is intended to perform the following tasks.

- **Evaluate GHG emissions** generated by a road project at three stages:
  - Planning / feasibility studies;
  - Detailed design; and
  - Works implementation / completion.
- **Assess alternative construction practices to limit GHG emissions:**
  - Identify technically relevant options based on the project's characteristics;
  - Evaluate GHG emissions of these options; and
  - Generate reports that provide useful information to the designer and planner (breakdown by type of work) to optimize the GHG-relevant design and implementation of the project.

ROADEO does not perform road engineering designs,. However, it enables identification of relevant alternatives to be further explored by users, with the support of the User Manual of best practices and through additional engineering studies as required.

Though ROADEO can be used at all stages of a project, it is most useful at upstream stages (planning and design) where other tools—those available and those under development—do not offer comparable functionality.

1.2. Programming Environment

The programming environment was selected on the basis of the following criteria.

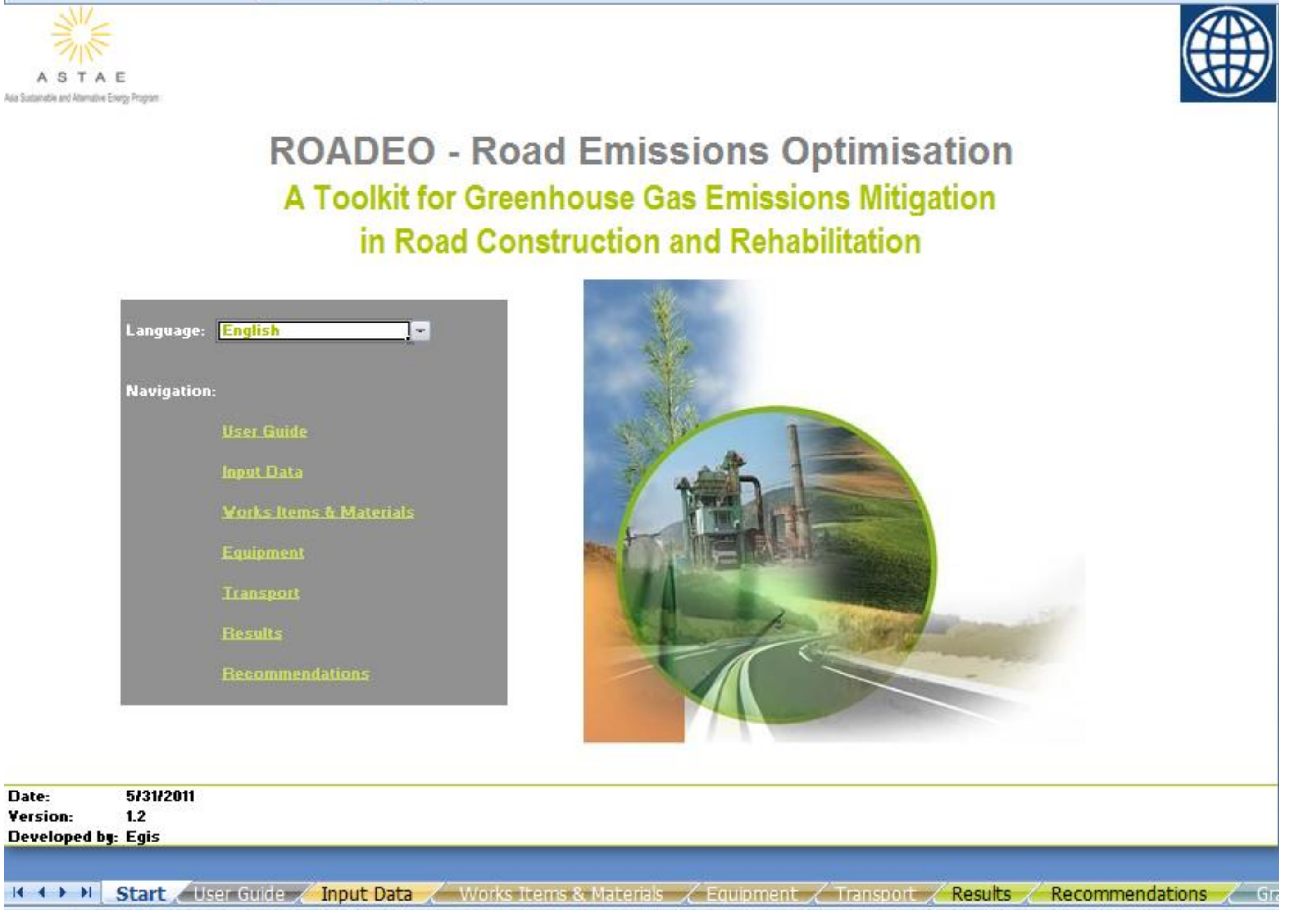
ROADEO spreadsheet version

ROADEO was also developed as a standalone spreadsheet.

This version provides all functionalities included in the original .NET/Access tool under a basic yet more familiar, flexible and transparent user interface.

This version is compatible with most versions of Microsoft Excel and Open Office, regardless of the OS platform.

Figure 1. Screenshot of Start tab (spreadsheet version)



1.3. User Interface Language

The default language is English.

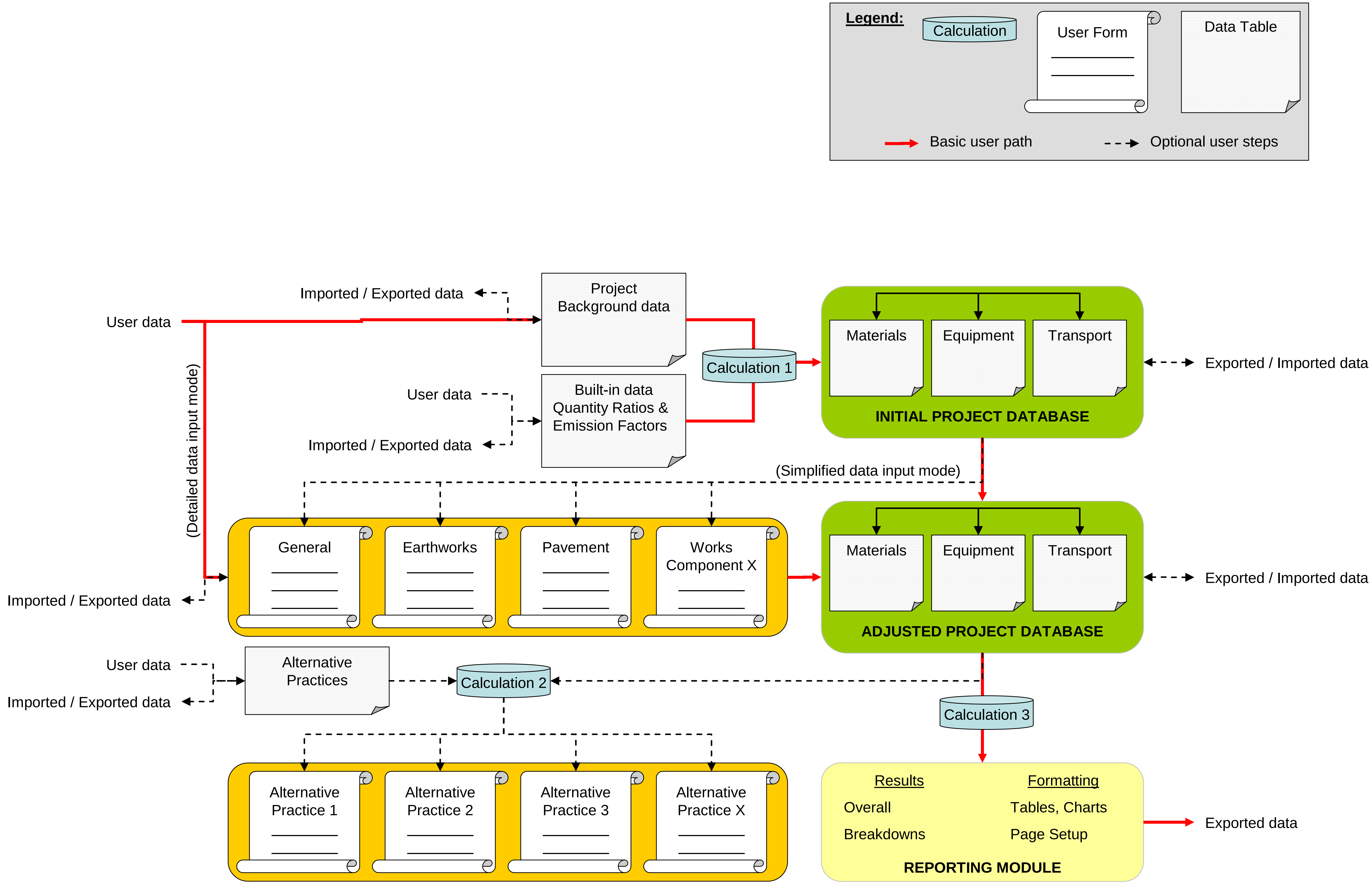
The initial version of the Microsoft Excel version features English, Chinese (simplified), Vietnamese, and Bahasa Indonesian.

The spreadsheet has been designed to allow translation into other languages, which may be implemented and made available to users at a later time.

1.4. Tool Organization

The following figure shows the general organization of the tool, including main user steps, data inputs / outputs and calculation protocols.

Figure 2. ROADEO Tool Organization



2. Data Arrangements

2.1. Data Transparency and Flexibility

ROADEO is based on transparent assumptions. Each variable is accessible to users and its value can be customized.

Data used for calculations comes from either

- **Built-in values** initially proposed within the tool for selected tables and variables;
- **Suggested values** proposed by the tool based on built-in values and calculations; or
- **User-defined values** imported by users or directly set by users (through user forms or table editing) to replace built-in or suggested values.

2.2. Database Structure

The database structure cannot be modified by users, but its contents may be adjusted—users can add or remove items and change corresponding values.

The database structure consists of one predefined table for each GHG generator:

- Materials;
- Equipment; and
- Transport.

Each GHG Generator has multiple associated variables falling into four groups:

1. **Works Components**: These are predefined tables. Each works component has multiple associated variables, allowing users to specify their project's characteristics and quantities.
2. **Characteristics**: Variables providing basic information on each GHG generator (designation, material's physical composition, type, transport mode, origin-stops-destination, and the like);
3. **Quantifying Data**: Measurement variables used for emissions calculations for each GHG generator (volume, weight, capacity, distance, fuel / electricity consumption, and so on), each one to be filled in with a predefined measurement unit.
4. **GHG Emission Factors**: kg CO_2 equivalent / selected measurement unit.

The table below shows a simplified view of the database structrure.

Table 1. Combination of GHG Generators and Works Components

GHG Generators Works Components	Materials	Equipment	Transport
Earthworks			
Drainage			
Utilities			
Pavement			
Structures			
Furniture			
Landscaping/Land Use			
Management			
Others			

Each column and each row has multiple associated variables. GHG emissions are calculated by combining (factoring and aggregating) these variables together.

Chapter 3 - General Model Framework

1. Architecture

The model included in ROADEO to assist users at upstream stages of projects (when all detailed information is not available) works in two stages.

1. In the first stage, the user is able to calculate quantities of road works items based on general characteristics of the project. The output of this stage is a "bill of quantities" at the feasibility study stage, and the works items are broken down into "works series" reflecting the types of works.
2. In the second stage, the user can calculate GHG emissions for each generator, based on the quantities of items of road works and on general characteristics of the project. These generators have been broken down into materials, transport and equipment.

2. Parameters / Background Data

The purpose of the model is to provide outputs as close as possible to reality, while keeping the need for user inputs minimal, as a high level of need for inputs may lead to:

- Lack of interest among nontechnical users, and
- High costs or an overly long period for data collection.

The background data that the user is required to enter in ROADEO are as follows.

2.1. User Inputs

The following table summarizes the 29 model parameters to be initially defined by users when detailed project quantities are not readily available. The model uses this data to suggest project quantities that can be further reviewed and customized.

In case detailed information on the project quantities has already been collected, it is not necessary for users to fill in all the information in the following table.

Table 2. Parameters to be Defined by the User

Parameter	Description	Unit
%ECD	length of existing cross-drainage as a percentage of requirement	%
%ELD	length of existing longitudinal drainage as a percentage of length of road	%
%EWB	parameter reflecting the balance between cut and fill	%
%GLP	general longitudinal profile	%
%MNT	length of road in mountainous terrain as a percentage of road length	%
%RCK	volume of rocky soil as a percentage of volume of soil	%
%URB	length of the road project crossing urban areas as a percentage of road length	%
%VET	volume of embankment treatment	%
%WDB	number of bridges to be widened as a percentage of number of bridges	%
CBR	California Bearing Ratio	%
EAL	equivalent standard axle (8.2t) loading – ESAL	u
ECS	existing cross-section	m
ILCT1	Initial land cover type I	list
ILCT1%	% of project alignment covered with initial land cover type I	%
ILCT2	Initial land cover type II	list
ILCT2%	% of project alignment covered with initial land cover type II	%
L	road project length	m
LW	lane width	m
MW	median width	m
MT	median type	list
NBL	number of lanes	u
OST	overlay structure type	list
PST	pavement structure type	list
RTP	road type	list
STH	area where subgrade has to be treated with hydraulic binders	%
SW	shoulder width	m
ST	shoulder type	list
TBM	type of barrier material	list
TSB	type of structure (standard bridges)	list
TSM	type of structure (major bridges)	list
TSW	type of structure (wall)	list
TUN	length of tunnel	m
WTP	works type	list

The next table shows a screenshot of the corresponding “Input Data” tab included in ROADEO (spreadsheet version).

Table 3. Screenshot of "Input Data" tab (spreadsheet version)

Designation	Unit	Quantity / Value Toggle Default Values
Country	list	General
Project Name		Default
Work Type	list	New alignment
Road type	list	Expressway
Alignment length	m	100,000
Number of lanes	u	4
Lane width	m	3.50
Median width	m	3.00
Median type	list	Paved
Shoulder width	m	3.00
Shoulder type	list	Paved
Existing cross section width	m	0.00
General longitudinal profile	%	30.00%
Length of road in mountainous terrain as a percentage of road project length	%	20.00%
Length of road in urban areas as a percentage of road project length	%	10.00%
Length of existing longitudinal drainage as a percentage of road project length	%	0.00%
Length of existing cross drainage as a percentage of requirement	%	0.00%
Parameter reflecting the balance between cut and fill	%	60.00%
Volume of rocky soil as a percentage of volume of soil (in %)	%	25.00%
Area where subgrade has to be treated with hydraulic binders	%	0.00%
Volume of embankment to be treated as a percentage of the volume of cut reused	%	20.00%
Number of bridges to be widened as a percentage of number of bridges	%	0.00%
Subgrade strength class	list	Standard Soil [5%-8%]
Expected traffic volumes	list	Medium traffic [10 to 17 Million ESA]
Pavement structure type	list	Bituminous pavement on granular materials
Overlay structure type	list	0.00
Type of barrier material	list	Steel
Type of structure (standard bridges)	list	Concrete (reinforced / prestressed)
Type of structure (major bridges)	list	Concrete (reinforced / prestressed)
Type of structure (wall)	list	Reinforced concrete
Length of tunnel	m	5,000
Select Inital Land Cover Type I	%	50%
Select Inital Land Cover Type II	%	20%

2.2. Stage 1

The table below shows the parameters used in calculations during Stage 1. The assumptions made and equations used to estimate quantities for each item of works are elaborated in chapter 4 of the full-length User Manual. The user is invited to refer to it for a detailed overview of the Stage 1 inputs.

Table 4. List of Parameters Used in Calculations of Stage 1

Parameter	Description	Unit	Comment and Explanation
%ECD	length of existing cross-drainage as a percentage of requirement	%	user input ○ 0%: no existing cross drain ○ 100%: all required drains exist
%ELD	length of existing longitudinal drainage as a percentage of length of road	%	user input ○ 0%: no existing longitudinal drain (also value for new project) ○ 100%: all required drains exist
%EWB	parameter reflecting the balance between cut and fill	%	○ user input 100%: cut is wholly reused in fill 0%:cut is wholly evacuated
%GLP	general longitudinal profile	%	user input ○ -100%: cut only ○ +100%: fill only
%MNT	length of road in mountainous terrain as a percentage of road length	%	user input
%RCK	volume of rocky soil as a percentage of volume of soil	%	user input
%URB	length of the road project crossing urban areas as a percentage of road length	%	user input
%VET	volume of embankment to be treated as a percentage of the volume of cut reused	%	user input
%WDB	number of bridges to be widened as a percentage of number of bridges	%	user input
A1	parameter		
A2	parameter		
A3	parameter		
A4	parameter		
A5	parameter		
A6	parameter		
A7	parameter		
A8	parameter		
A9	parameter		
A10	parameter		
CGA	area of clearing and grubbing	m^2	
CUE	volume of cut evacuated	m^3	

Parameter	Description	Unit	Comment and Explanation
CUR	volume of cut reused as fill	m^3	
CUT	volume of cut	m^3	
DSA	direction sign area	m^2	
ECS	existing cross-section	m	user input ○ width of existing road, including shoulders ○ 0 for new projects
FBP	volume of fill from borrow pit	m^3	
FIL	volume of fill	m^3	
HCF	average height of cut and fill	m	
HRE	volume of hard rock evacuated	m^3	
HRRP	volume of hard rock reused for pavement	m^3	
HRRF	volume of hard rock reused for fill	m^3	
IBA	interchanges bridge deck area	m^2	
ILCT	Dry metric tons / ha for selected initial land cover types	ton/ha	Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Values for Continental Asia)
L	road project length	m	user input
LBC	length of box culverts	m	
LBR	length of barriers	m	
LED	length of earth longitudinal drain	m	
LLD	length of lined longitudinal drain	m	
LPC	Length of pipe culverts	m	
LW	lane width	m	user input
MBA	deck area of major bridges on main section	m^2	
MW	median width	m	user input
NBL	number of lanes	u	user input
NCS	new cross-section	m	
NPA	new pavement area	m^2	
NPS	number of vertical signs (police)	u	
NSL	number of streetlights	u	
OPR	area of other paved roads	m^2	
POA	pavement overlay area	m^2	
RTP	road type	list	user input ○ expressway ○ national road ○ provincial road ○ rural road
SBA	deck area of standard bridges on main section	m^2	
SGP	area of subgrade preparation	m^2	
SW	shoulder width	m	user input
TEA	tunnel excavation volume	m^3	

Parameter	Description	Unit	Comment and Explanation
TLV	tunnel lining volume	m^2/m	area of wall lined per length of tunnel
TUN	length of tunnel	m	user input
VET	volume of embankment treatment	m^3	
WAL	area of walls	m²	
WBA	wayside amenities area	m²	
WPA	wayside amenities pavement area	m²	
WTP	works type	list	user input ○ new alignment ○ widening ○ rehabilitation

2.3. Stage 2

The table below shows the parameters used in calculations during Stage 2.

Table 5. List of Parameters Used in Calculations of Stage 2 of the Model

Parameter	Description	Unit	Comment and Explanation
ASO	area of surface dressing for overlay	m²	
CBR	California Bearing Ratio	%	user input ○ to be homogeneous for the whole road
DAS	distance asphalt plant–site	km	
DBS	distance batching plant–site	km	
DCB	distance cement plant–batching plant	km	
DCF	distance cut on site–fill on site	km	
DCS	distance cement plant–site	km	
DQA	distance quarry–asphalt plant	km	
DQB	distance quarry–batching plant	km	
DRA	distance refinery–asphalt plant	km	
DRS	distance refinery–site	km	
DSB	distance site–borrow pit	km	
DSD	distance site–disposal site	km	
DSS	distance steel plant–site	km	
EAL	equivalent standard axle (8.2t) loading–ESAL		user input: ○ basic traffic ○ truck rate ○ traffic growth ○ design life
MHB	mass of hydraulic binder	t	
OST	overlay structure type	list	user input ○ bituminous ○ gravel ○ surface dressing

Parameter	Description	Unit	Comment and Explanation
ASO	area of surface dressing for overlay	m^2	
PST	pavement structure type	list	user input ○ cement concrete pavement ○ bituminous pavement on granular materials ○ bituminous pavement on hydraulic bound materials ○ bituminous pavement on bituminous bound materials ○ surface dressing ○ gravel
STH	area where subgrade has to be treated with hydraulic binders (as a % of subgrade preparation area)	%	user input
TBM	type of barrier material	list	user input ○ concrete ○ steel ○ timber
Ti	thickness of pavement layer No i	mm	thickness of pavement layers calculated by the model on the basis of EAL, CBR and PST
TSB	type of structure (standard bridges)	list	user input ○ Composite (steel / concrete) ○ Concrete (reinforced / prestressed)
TSM	type of structure (major bridges)	list	user input ○ Composite (steel / concrete) ○ Concrete (reinforced / prestressed) steel
TSW	type of structure (wall)	list	user input ○ steel (sheet pile) ○ reinforced concrete ○ reinforced earth
VBO	volume of bituminous concrete for overlay	m^3	
VGO	volume of gravel for re-gravelling	m^3	

Chapter 4 - GHG Generators

This chapter focuses on ROADEO's Stage 2 output—identification of GHG generators, based on the quantities of works for various components of the road project as defined in Stage 1.

1. Materials

ROADEO focuses on the following main materials (currently) including:

- Granular materials,
- Hydraulic binder treated materials (currently including cement and lime),
- Bitumen-treated materials,
- Metals (copper, steel),
- Rammed soil, and
- Timber.

The next table shows a screenshot of the “Works Items & Materials” tab used in ROADEO (spreadsheet version) to define the types of works items and materials involved in the project, as well as the corresponding quantities, densities, intensities and GHG emissions.

Table 6. Screenshot of "Works Items / Materials" tab (spreadsheet version)

Works Component	Works Item / Material	Unit	Quantity		Density (kg/qty)		Intensity ($kgCO_2eq/kg$)		Emissions (tCO_2eq)
Earthworks	Area of clearing and grubbing	m²	3,594,800	Override Quantity		Override Density		Override Intensity	
Earthworks	Area of subgrade preparation	m²	2,403,500	Override Quantity		Override Density		Override Intensity	
Earthworks	New cross section	m	23	Override Quantity		Override Density		Override Intensity	
Earthworks	Average height of cut and fill	m	8	Override Quantity		Override Density		Override Intensity	
Earthworks	Volume of cut	m3	9,607,920	Override Quantity		Override Density		Override Intensity	
Earthworks	Volume of soil evacuated	m3	2,882,376	Override Quantity	1,600	Override Density		Override Intensity	
Earthworks	Volume of soil reused as fill	m3	4,323,564	Override Quantity	1,600	Override Density		Override Intensity	
Earthworks	Volume of hard rock evacuated	m3		Override Quantity		Override Density		Override Intensity	
Earthworks	Volume of hard rock reused as pavement layer	m3	1,265,000	Override Quantity	1,600	Override Density		Override Intensity	
Earthworks	Volume of hard rock reused as fill	m3	1,136,980	Override Quantity	1,600	Override Density		Override Intensity	
Earthworks	Volume of fill	m3	17,843,280	Override Quantity		Override Density		Override Intensity	
Earthworks	Volume of fill from borrow pit	m3	12,382,736	Override Quantity	1,600	Override Density		Override Intensity	
Earthworks	Volume of embankment treatment	m3	864,713	Override Quantity		Override Density		Override Intensity	
Earthworks	Volume of subgrade treatment	m3	721,050	Override Quantity		Override Density		Override Intensity	
Earthworks	Mass of hydraulic binder	t	17,294	Override Quantity	1,000	Override Density	0.74	Override Intensity	12,797.7
Pavement	New pavement area	m²	2,530,000	Override Quantity		Override Density		Override Intensity	
Pavement	Pavement overlay area	m²		Override Quantity		Override Density		Override Intensity	
Pavement	Area of other paved roads	m²	700,000	Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Double surface dressing	mm		Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Flexible bituminous surface	mm		Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Bituminous surface	mm	125	Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Bituminous roadbase, RB	mm		Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Granular roadbase, GB1 - GB6	mm	125	Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Granular subbase, GS	mm	225	Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Granular capping layer or selected subgrade fill, GC	mm	175	Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Cement or lime stabilised roadbase 1, CB4	mm		Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Cement or lime stabilised roadase 2, CB5	mm		Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Cement or lime stabilised subbase, CS	mm		Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Cement Concrete with dowels, JPCP	mm		Override Quantity		Override Density		Override Intensity	
Pavement	Thickness of Cement Concrete (lean Concrete), LCB	mm		Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Double surface dressing	m3		Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Flexible bituminous surface	m3		Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Bituminous surface	m3	276,250	Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Bituminous roadbase, RB	m3		Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Granular roadbase, GB1 - GB6	m3	293,750	Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Granular subbase, GS	m3	528,750	Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Granular capping layer or selected subgrade fill, GC	m3	411,250	Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Cement or lime stabilised roadbase 1, CB4	m3		Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Cement or lime stabilised roadase 2, CB5	m3		Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Cement or lime stabilised subbase, CS	m3		Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Cement Concrete with dowels, JPCP	m3		Override Quantity		Override Density		Override Intensity	
Pavement	Quantity of Cement Concrete (lean Concrete), LCB	m3		Override Quantity		Override Density		Override Intensity	
Pavement	Bituminous Emulsion	m3		Override Quantity	1,400	Override Density	0.19	Override Intensity	
Pavement	Quarried Aggregate	m3		Override Quantity	1,600	Override Density	0.01	Override Intensity	
Pavement	Asphalt Concrete (General)	m3	276,250	Override Quantity	2,350	Override Density		Override Intensity	
Pavement	Volume of Bitumen in Asphalt Concrete (General)	m3	13,813	Override Quantity	1,400	Override Density	0.48	Override Intensity	9,282.0
Pavement	Volume of Aggregates in Asphalt Concrete (General)	m3	262,438	Override Quantity	1,600	Override Density	0.01	Override Intensity	4,199.0

1.1. Earthworks

For earthworks, materials do not represent a significant input, except for hydraulic binders (which can be a major contributor).

MHB = STH x SGP x 0.3 x 0.05 + VET x 0.02

Where
MHB: Mass of hydraulic binder (in t)
STH: Area where subgrade has to be treated with hydraulic binders (as a % of subgrade preparation area)
SGP: area of subgrade preparation (in m^2)
VET: volume of embankment to be treated (in m^3)

This assumes treatment of:

- the required area over a thickness of 30 cm, for a soil density of $2t/m^3$ and for a hydraulic binder proportion of 2.5 percent, and
- the required volume of embankment, for a soil density of $2t/m^3$ and for a hydraulic binder (lime) proportion of 1 percent.

The quantity and binder type can be adjusted manually by the user to reflect other conditions (treatment thickness, proportion of binder).

Soil densities can be considered as follows.

Table 7. Soil Densities for Binder Mixing with Soil

Materials Dry Density (t/m^3)	Min	Max
Silt	1.6	1.8
Clay	1.7	1.8
Sand		
Homometric sand	1.4	1.6
Graduated sand	1.6	1.9
Granular soil	1.8	2.2

Other binders can be considered (either as an alternative or as a combined solution, for example, treatment with 3 percent lime and 2 percent cement), with the emissions factors in table 6.

Table 8. Emissions Factors of Hydraulic Binders

Binder	CO_2 Impact (kg CO_2 eq. / t)	Source
Cement CEM I	868	ATILH
Cement CEM II	650	ATILH
Hydraulic road binder HRB 70% slag	294	ATILH
Hydraulic road binder HRB 50% slag	459	ATILH
Hydraulic road binder HRB 30% slag	625	ATILH
Hydraulic road binder HRB 30% limestone	614	ATILH
Hydraulic road binder HRB 30% fly ash	613	ATILH
Quicklime	1059	Union of Lime Producers (France)

1.2. Pavement

1.2.1. New Pavement

The model considers six types of pavement structures. For each of these, a pavement catalogue has been used.

Table 9. Typical Pavement Types and Designs

Pavement Type (PST)	Catalogue Used
Cement concrete pavement	California Department of Transportation Highway Design Manual, Tables 623 F and 623G
Bituminous pavement on granular materials	Transport Research Laboratory Road Note 31, Chart 3 and 5
Bituminous pavement on hydraulic bound materials	Transport Research Laboratory Road Note 31, Chart 4
Bituminous pavement on bituminous bound materials	Transport Research Laboratory Road Note 31, Chart 7
Surface dressing	Transport Research Laboratory Road Note 31, Chart 1
Gravel	Transport Research Laboratory Road Note 31, Chart

The following materials have been considered.

Table 10. Materials Considered in Typical Pavement Designs

Material	Reference
Double surface dressing	Transport Research Laboratory Road Note 31
Flexible bituminous surface	
Bituminous surface (usually a wearing course WC and a base course BC)	
Bituminous road base, RB	
Granular road base, GB1 - GB6	
Granular sub-base, GS	
Granular capping layer or selected subgrade fill, GC	
Cement- or lime-stabilized road base 1, CB4	
Cement- or lime-stabilized road base 2, CB5	

Material	Reference
Cement- or lime-stabilized sub-base, CS	
Cement concrete with dowels, JPCP	California Department of Transportation Highway Design Manual, Tables 623 F and 623G
Cement concrete (lean concrete), LCB	

ROADEO requires the following input from the user.

- Traffic data, in ESAL (10^6 equivalent standard axles to 8.16t); and
- Surface strength, as a CBR result.

Data are then converted according to the following tables, to find the corresponding pavement layer types and thicknesses in the above catalogues.

For cement concrete pavement:

Table 11. Traffic Classes for Cement Concrete Pavement

$TI=9x(ESA\ 8t/10^6)^{0.119}$	Traffic Indexes
0	TI1
9.5	TI2
10.5	TI3
11.5	TI4
12.5	TI5
13.5	TI6
14.5	TI7
15.5	TI8
16.5	TI9
17	TI10

Table 12. Subgrade Class for Cement Concrete Pavement Structures

CBR (%)	Subgrade Classes
40	Type 1
10	Type 2

For all other structures:

Table 13. Traffic Classes for All Pavement Structures Except Cement Concrete

ESA (8.16) ($x10^6$)	Traffic Classes (ORN 31)
0.3	T1
0.7	T2
1.5	T3
3	T4
6	T5
10	T6
17	T7
30	T8

Table 14. Subgrade Class for All Pavement Structures Except Cement Concrete

CBR (%)	Subgrade Classes (ORN 31)	Comments
2	S1	Poor soil: Contains appreciable amounts of clay and fine silt. (50percent or more passing -200) P.I. over .20
5	S2	
8	S3	Normal soil: Retains a moderate degree of firmness under adverse moisture conditions. Loams, salty sands, sand gravels with moderate amounts of clay, and fine silt. P.I. 15-20
15	S4	
30	S5	Good soil: Retains a substantial amount of load bearing capacity when wet. Sands, sand gravels, materials free of detrimental amounts of plastic material. P.I. less than 15
>30	S6	

If CBR Values are not available, the Overseas Road Note provides the following table.

Depth Of Water Table from Formation Level (Meters)	Subgrade Strength Class				
	Non-Plastic	Sandy Clay PI*=10	Sandy Clay PI*=20	Silty Clay PI*=30	Heavy Clay PI*>40
0.5	S4	S4	S2	S2	S1
1	S5	S4	S3	S2	S1
2	S5	S5	S4	S3	S2
3	S6	S5	S4	S3	S2

*PI=Plasticity Index

Note: Overseas Road Notes are prepared principally for road and transport authorities in countries receiving technical assistance from the British Government.

Quantities of material are then calculated according to the following table, depending on the type of works (in the formulas, Ti is the thickness of type i resulting from the above catalogue consideration).

Table 15.Quantities of Materials for Typical Pavement Layers

Layer Definitions		Unit	Calculation	
			New Alignment	Widening
1	Double surface dressing	m^2	(NBL*LW)*L* T1 (1)	((NBL*LW)-POA)*L* T1
2	Flexible bituminous surface	m^3	(NBL*LW+2*0.8*A8+ A9+0.30)*L*T2/1000	((NBL*LW+2*0.8*A8+A9+0.30) - POA)*L*T2/1000
3	Bituminous surface (usually a wearing course WC and a base course BC)	m^3	(NBL*LW+2*0.8*A8+ A9+0.30)*L*T3/1000	((NBL*LW+2*0.8*A8+A9+0.30) - POA)*L*T3/1000
4	Bituminous road base, RB	m^3	(NBL*LW+SW*2+MW +0.50)*L*T4/1000	((NBL*LW+SW*2+MW+0.50) - POA)*L*T4/1000
5	Granular road base, GB1 - GB6	m^3	(NBL*LW+SW*2+MW +0.50)*L*T5/1000	((NBL*LW+SW*2+MW+0.50) - POA)*L*T5/1000

6	**Granular sub-base, GS**	m^3	(NBL*LW+SW*2+MW +0.50)*L*T6/1000	((NBL*LW+SW*2+MW+0.50) - POA)*L*T6/1000
7	**Granular capping layer or selected subgrade fill, GC**	m^3	(NBL*LW+SW*2+MW +0.50)*L*T7/1000	((NBL*LW+SW*2+MW+0.50) - POA)*L*T7/1000
8	**Cement- or lime-stabilized road base 1, CB4**	m^3	(NBL*LW+SW*2+MW +0.50)*L*T8/1000	((NBL*LW+SW*2+MW+0.50)- POA)*L*T8/1000
9	**Cement- or lime-stabilized road base 2, CB5**	m^3	(NBL*LW+SW*2+MW +0.50)*L*T9/1000	((NBL*LW+SW*2+MW+0.50) - POA)*L*T9/1000
10	**Cement- or lime-stabilized sub-base, CS**	m^3	(NBL*LW+SW*2+MW +0.50)*L*T10/1000	((NBL*LW+SW*2+MW+0.50) - POA)*L*T10/1000
11	**Cement concrete with dowels, JPCP**	m^3	(NBL*LW+2*0.8*A8+ A9+0.30)*L*T11/1000	((NBL*LW+2*0.8*A8+A9+0.30) - POA)*L*T11/1000
12	**Cement concrete (lean concrete), LCB**	m^3	(NBL*LW+SW*2*+M W+0.50)*L*T12/1000	((NBL*LW+SW*2*+MW+0.50) – POA)*L*T12/1000

Notes:
(1): The double surface-dressing value from the catalogue has no thickness and is just equal to 1 when it is present, and 0 otherwise.
(2): Thicknesses are expressed in mm in the catalogue
Where:
A8=Shoulder width if shoulders are paved, and 0 otherwise;
A9=Median width if the median lane is paved, and 0 otherwise; and
POA=Pavement Overlay Area (m^2).

Quantities of each layer are then converted into quantities of basic materials with the following table.

Table 16. Composition of Pavement Layers

Layer	Bituminous Emulsion	Quarried Aggregate	Asphalt General	Soil General (rammed soil)	Cement General (typical)	Concrete Road & Pavement	Steel
Layer 1	9%	91%	0%	0%	0%	0%	0%
Layer 2	0%	0%	100%	0%	0%	0%	0%
Layer 3	0%	0%	100%	0%	0%	0%	0%
Layer 4	0%	0%	100%	0%	0%	0%	0%
Layer 5	0%	100%	0%	0%	0%	0%	0%
Layer 6	0%	0%	0%	100%	0%	0%	0%
Layer 7	0%	0%	0%	100%	0%	0%	0%
Layer 8	0%	94%	0%	0%	6%	0%	0%
Layer 9	0%	96%	0%	0%	4%	0%	0%
Layer 10	0%	0%	0%	98%	2%	0%	0%
Layer 11	0%	0%	0%	0%	0%	92%	8%
Layer 12	0%	0%	0%	0%	0%	100%	0%

For both asphalt and cement concretes, quantities of basic materials are then calculated on the basis of the following percentages:

Table 17. Composition of Asphalt and Cement Concrete

Layer	Bitumen	Cement General (Typical)	Quarried Aggregate	Sand
Cement Concrete		7.10%	31.75%	45.70%
Asphalt Concrete	5.00%	0%	95.00%	0%

In rehabilitations, it is considered that the only works conducted consist of the application of an overlay on the existing pavement (see section 1.2.2 Overlay). Hence, quantities of new pavement are nil. Similarly, for a widening, an overlay is applied on the existing cross-section, and the calculated pavement structure is applied only on the new pavement area. That is why the factor (1-POA) is applied to all of the formulas in the aforementioned table13.

For both types of work (rehabilitation and widening), the quantities of overlay are calculated as follows.

1.2.2. Overlay

Three types of overlay have been considered: bituminous, surface dressing, and gravel. These are addressed by the parameter OST, overlay structure type.

VBO = POA x 0.12 if OST = bituminous

Where
VBO: Volume of bituminous concrete for overlay (in m^3)
POA: Area of pavement overlay (in m^2)

Assumed thickness is 12 cm for material type 2 of new pavement catalogue.

ASO = POA if OST = surface dressing

Where
AST: Area of surface dressing for overlay (in m^2)
POA: Area of pavement overlay (in m^2)

for material type 1 of new pavement catalogue.

VGO = POA x 0.2 if OST = gravel

Where
VGO: Volume of gravel for re-gravelling (in m^3)
POA: Area of pavement overlay (in m^2)

for material type 5 of new pavement catalogue.

1.2.3. Other Roads

For other roads, the calculation for new pavement is used, based on 30 percent of the ESAL of the main road, the same pavement structure type, and the same CBR. The quantities of materials can be calculated by multiplying by the values of OPR resulting from stage 1.

1.3. Drainage

For drainage, the main GHG contribution results from the use of reinforced concrete or masonry for the construction of drains and culverts.

Table 18. Quantities of Materials for Drainage Works

Material Structure	Steel	Concrete
Lined drains	0.019 t/m	0.27 m^3/m
Pipe culverts	0.018 t/m	0.22 m^3/m
Box culverts	0.145 t/m	1.4 m^3/m

The quantities of materials (represented in tons of steel or m^3 of concrete per linear meter of drainage type) can be directly calculated by multiplying the above ratios by LPC, LBC, and LLD resulting from stage 1.

1.4. Structures

The main materials considered for structures are steel and cement concrete.

The following charts have been used for bridges, extracted from "An environmental comparison of bridge forms, D Collings, *Bridge Engineering*, Vol.159, December 2006, Issue BE4, Pg 163-168.

Figure 3. Quantities of Steel (kg/m²) for Bridges, Depending on Span

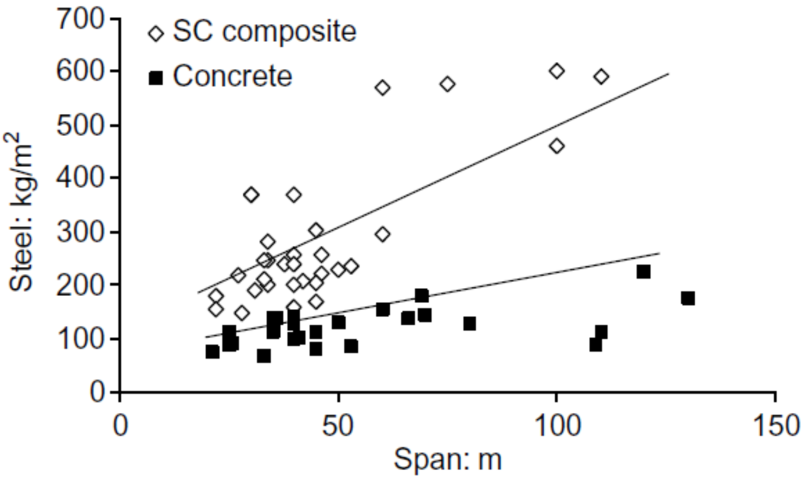
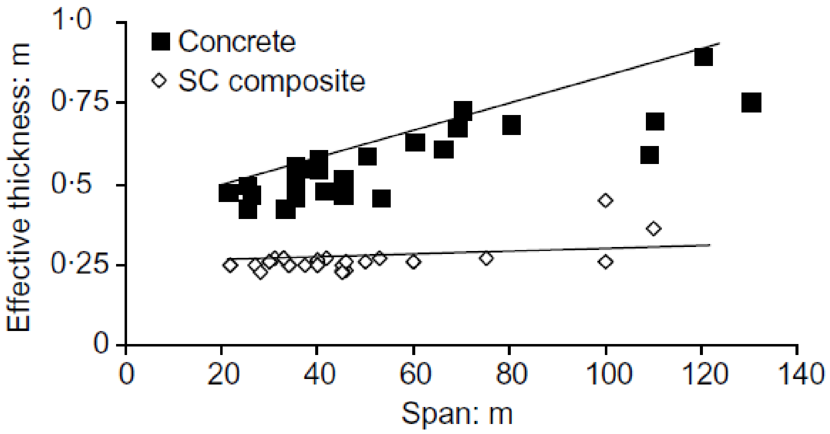


Figure 4. Effective Thickness—thus Quantities of Cement Concrete—for Bridges, Depending on Span



Three parameters are required for this stage.

1. TSW: Type of structure (wall), which can be
   - steel (sheetpile),
   - reinforced concrete, or
   - reinforced earth.
2. TSB: type of structure (standard bridges), which can be
   - composite (steel / concrete), or
   - concrete (reinforced / prestressed).
3. TSM: type of structure (major bridges), which can be
   - composite (steel / concrete),
   - concrete (reinforced / prestressed), or
   - steel.

It has been assumed that tunnels are constructed with a cement concrete lining.

1.4.1. Walls

Table 19. Quantities of Materials for Walls

Quantity Of Material Type of Wall	Steel	Cement Concrete	Rammed Soil
Steel	0.108 t/m²		
Reinforced concrete	0.045 t/m²	0.40 m^3/m^2	
Reinforced earth	0.012 kg/m²	0.07 m^3/m^2	1.5 m^3/m^2

Note: Quantities provided in mass of steel or volume of cement concrete, or rammed soil per area of wall.

The quantities of materials can be directly calculated by multiplying the above ratios by WAL after the selection of TSW.

Quantity of cement concrete is then divided into basic material as indicated in table 16.

1.4.2. Standard bridges

Table 20. Quantities of Materials for Standard Bridges

Quantity of Material Type of Structure	Steel	Cement concrete
Composite	0.220 t/m²	0.30 m³/m²
Concrete	0.115 t/m²	0.5 m³/m²

Note: Quantities provided in tons of steel or cubic meters of cement concrete per area of bridge deck.

The quantities of materials can be directly calculated by multiplying the above ratios by the sum of SBA and IBA after the selection of TSB.

Quantity of cement concrete is then divided into basic material as indicated in table 16.

1.4.3. Major bridges

Table 21. Quantities of Materials for Major Bridges

Quantity of material Type of structure	Steel	Cement concrete
Steel	0.650 t/m²	0.15 m³/m²
Composite	0.518 t/m²	0.35 m³/m²
Concrete	0.225 t/m²	0.85 m³/m²

Note: Quantities provided in tons of steel or cubic meters of cement concrete per area of bridge deck.

An average span of 125 m has been considered.

The quantities of materials can be directly calculated by multiplying the above ratios by MBA after the selection of TSM.

Quantity of cement concrete is then divided into basic material as indicated in table 16.

1.4.4. Tunnel

The temporary and permanent lining of the tunnel have been assumed to be of cement concrete, with reinforcement or steel arches.

Table 22. Quantities of Materials for Tunnels

Material	Quantity
Steel	0.14 t/m³
Cement Concrete	1 m³/m³

Note: Quantities provided in tons of steel or cubic meters of cement concrete per volume of tunnel.

The quantities of materials can be directly calculated by multiplying the above ratios by TLV.

Quantity of cement concrete is then divided into basic material as indicated in table 16.

1.5. Equipment and Road Furniture

1.5.1. Barriers

For barriers, the parameter TBM (type of barrier material) is considered, which can be steel or timber (except on national roads and expressways).

Table 23. Quantities of Materials for Barriers

Quantity of Material Type of Structure	Timber	Steel	Cement concrete
Steel		0.012 t/m	
Concrete		0.002 t/m	0.25 m^3/m
Timber	0.019 t/m	0.008 t/m	

Note: Quantities provided in tons of timber or steel or cubic meters of cement concrete per linear metre of barrier.

The quantities of materials can be directly calculated by multiplying the above ratios by LBR once TBM has been selected.

Quantity of cement concrete (if any) is then divided into basic material as indicated in table 16.

1.5.2. Signs

Police signs and their supports are assumed to be in galvanized steel. Signs are supposed to be 0.8 m^2, 3mm thick, with a 2.5m high support of 6 kg/m.

The quantity of galvanized steel for police signs is therefore assumed as 35 kg/unit, and can be directly calculated from the value of NPS resulting from Stage 1.

Directional signs are supposed to be supported by steel (steel pole, except for expressways, where they are gantries). The quantities in the following table are given for 1 m^2 of directional sign.

Table 24. Quantities of Materials for Directional Signs

Type of Road	Quantity of Steel for Support	Quantity of Steel for Sign	Total Quantity of Steel	Quantity of Cement Concrete
Expressway	0.070 t/m²	0.025 t/m²	0.095 t/m²	0.3 m^3/m²
National / provincial / rural	0.018 t/m²		0.043 t/m²	0.2 m^3/m²

Note: Quantities provided in tons of timber or steel or cubic meters of cement concrete per square meter of sign.

Concrete for foundation is not taken into account. Aluminum has not been taken into account, although it is used in several countries for supports and sign panels.

The quantities of materials can be calculated directly by multiplying the above ratios by DSA resulting from Stage 1, based on road type (RTP).

Quantity of cement concrete is then divided into basic material as indicated in table 16.

1.5.3. Lighting

Materials are calculated for 15m-high steel supports and for the power cable (50m for one pole).

Table 25. Quantities of Materials for Lighting Works

Quantity of Steel for Support	Quantity of Cement Concrete	Copper
0.420 t/u	0.6 m^3/u	0.0225 t/u

Note: Quantities provided in cubic meters of cement concrete or tons of copper per number of lights

The quantities of materials can be calculated directly by multiplying the above ratios by NSL resulting from Stage 1.

Quantity of cement concrete is then divided into basic material as indicated in table 16.

1.6. Wayside Amenities

Materials are concrete (for pavement and buildings), steel (for buildings) and bituminous materials (for pavement).

For pavement, the calculation is made for the same structure as for the pavement of the main section for the WPA area.

For buildings, materials have been assumed to be steel and cement concrete (reinforced concrete).

Table 26. Quantities of Materials for Wayside Amenities

Quantity of steel	Quantity of cement concrete
0.08 t/m²	0.55 m^3/m²

Note: Quantities provided in tons of steel or cubic meters of cement concrete per square metre of wayside amenity

The quantities of materials can be calculated directly by multiplying the above ratios by WBA resulting from first stage.

Quantity of cement concrete is then divided into basic material as indicated in table 16

2. Works Equipment

The following characteristics have been considered for works equipment:

Table 27. Characteristics of Typical Construction Equipment included in ROADEO

Equipment	Works components	Type of Road	Capacity	Capacity Unit	Data Source for Capacity	Consumption /Hour	Consumption Unit	Data Source for Consumption	Emission factor (kg CO_2 eq. / Hr)
Aggregate crushing plant	Pavement; Structures; Drainage	Expressway	115	m^3 / hr	Shanghai Zenith Company	145	Liters / hr	IVL Report	426.89
		National road	70	m^3 / hr		87	Liters / hr	IVL Report	256.07
		Provincial road	46	m^3 / hr		58	Liters / hr	IVL Report	170.52
		Rural road	23	m^3 / hr		29	Liters / hr	IVL Report	85.26
Aggregate crushing plant (electricity)	Pavement; Structures; Drainage	Expressway	115	m^3 / hr	Shanghai Zenith Company	11 454	KW	IVL Report	depending on country
		National road	70	m^3 / hr		6 872	KW	IVL Report	
		Provincial road	46	m^3 / hr		4 582	KW	IVL Report	
		Rural road	23	m^3 / hr		2 291	KW	IVL Report	
Asphalt mixing plant	Pavement	Expressway	50	m^3 / hr		10 480	KW	IVL Report	depending on country
		National road	35	m^3 / hr		7 336	KW	IVL Report	
		Provincial road	20	m^3 / hr		4 192	KW	IVL Report	
Asphalt paver	Pavement	Expressway; National road	1 300	m^2 / hr	IVL Report	22	Liters / hr	IVL Report	64.68
		Provincial road	1 200	m^2 / hr	IVL Report	20	Liters / hr	IVL Report	58.80
Backhoe loader	Pavement	All roads	520	m^3 / hr	IVL Report	16	Liters / hr	IVL Report	47.04
Bitumen sprayer	Pavement	Expressway; National road	22 800	m^2 / hr	IVL Report	3	Liters / hr	IVL Report	8.82
	Pavement	Provincial road; Rural road	19 125	m^2 / hr	IVL Report	3	Liters / hr	IVL Report	8.82
Bulldozer	Earthworks	Expressway, National road, Provincial road	500	m^3 / hr	Caterpillar	25	Liters / hr	Caterpillar	73.50
Soil compactor	Earthworks; Pavement	Expressway; National road	1 006	m^2 / hr	IVL Report	18	Liters / hr	IVL Report	52.92
		Provincial road; Rural road	791	m^2 / hr	IVL Report	12	Liters / hr	IVL Report	35.28
Asphalt	Pavement	Expressway; National	791	m^2 / hr	IVL Report	18	Liters / hr	IVL Report	52.92

Equipment	Works components	Type of Road	Capacity		Capacity Unit	Data Source for Capacity	Consumption /Hour	Consumption Unit	Data Source for Consumption	Emission factor (kg CO_2 eq. / Hr)
compactor		road								
		Provincial road; Rural road	460		m^2 / hr	IVL Report	7	Liters / hr	IVL Report	19.70
Crane	Structures	Expressway; National road						Liters / hr		0.00
Crane	Structures	Expressway; National road						KW		depending on country
Drilling machine	Structures	All roads			m^3	IVL Report		Liters / hr	IVL Report	0.00
Dumper	Earthworks; Pavement	All roads	flat	140	m^3/h*km	IVL Report	20	Liters / hr	IVL Report	58.80
Dumper	Earthworks; Pavement	All roads	broken	140	m^3/h*km	IVL Report	28	Liters / hr	IVL Report	80.85
Dumper	Earthworks; Pavement	All roads	hilly	140	m^3/h*km	IVL Report	35	Liters / hr	IVL Report	102.90
Emulsion appliers	Pavement	All roads			m^2/hr			Liters / hr		0.00
Excavator (< 5% stones)	Earthworks	All roads	450		m^3/hr	IVL Report	34	Liters / hr	IVL Report	99.96
Excavator (< 25% stones)	Earthworks	All roads	430		m^3/hr	IVL Report	34	Liters / hr	IVL Report	99.96
Excavator (< 50% stones)	Earthworks	All roads	360		m^3/hr	IVL Report	34	Liters / hr	IVL Report	99.96
Excavator (> 50% stones)	Earthworks	All roads	300		m^3/hr	IVL Report	34	Liters / hr	IVL Report	99.96
Excavator (hydraulic)	Pavement; Structures; Drainage	All roads	360		m^3/hr	IVL Report	45	Liters / hr	IVL Report	132.30
Motor grader	Earthworks; Pavement	Expressway; National road	15 385		m^2 / hr	Caterpillar	42	Liters / hr	Caterpillar	123.48
		Provincial road; Rural road	14 240		m^2 / hr	Caterpillar	35	Liters / hr	Caterpillar	102.90

Equipment	Works components	Type of Road	Capacity	Capacity Unit	Data Source for Capacity	Consumption /Hour	Consumption Unit	Data Source for Consumption	Emission factor (kg CO_2 eq. / Hr)
Hydraulic hammer	Earthworks	All roads	40	m^3/hr	IVL Report	18	Liters / hr	IVL Report	52.92
Wheeled Loader (< 5% stones)	Earthworks	All roads	520	m^3/hr	IVL Report	23	Liters / hr	IVL Report	67.62
Wheeled Loader (< 25% stones)	Earthworks	All roads	470	m^3/hr	IVL Report	23	Liters / hr	IVL Report	67.62
Wheeled Loader (< 50% stones)	Earthworks	All roads	410	m^3/hr	IVL Report	35	Liters / hr	IVL Report	102.90
Wheeled Loader (> 50% stones)	Earthworks	All roads	370	m^3/hr	IVL Report	35	Liters / hr	IVL Report	102.90
Pile driver	Structures	All roads		m^2 / hr			Liters / hr		0.00
Pile driver	Structures	All roads		m^2 / hr			KW		depending on country
Pulvimixer	Earthworks	Expressway, National road	9 173	m^2 / hr	Caterpillar	46	Liters / hr	Caterpillar	135.24
Aggregate spreader	Pavement	Rural road (Surface treatment)	19 125	m^2 / hr	IVL Report	20	Liters / hr	IVL Report	58.80
Scrapper	Earthworks	Expressway, National road, Provincial road		m^3 / hr			Liters / hr		0.00
Slipform paver	Pavement; Structures; Drainage	Expressway, National road, Provincial road		m^3 / hr			Liters / hr		0.00
Pneumatic pick hammer	Earthworks	Provincial road; Rural road		m^3 / hr			Liters / hr		0.00
Tractor	Pavement	All roads		m^3			Liters / hr		0.00
Slipform for Barrier	Equipment (barriers)	Expressway, National road							
Hammer /	Equipment	Provincial road, rural							

Equipment	Works components	Type of Road	Capacity	Capacity Unit	Data Source for Capacity	Consumption /Hour	Consumption Unit	Data Source for Consumption	Emission factor (kg CO_2 eq. / Hr)
auger	(barriers)	road							
Water sprayer	Earthworks; Pavement	All roads	40 000	m^2 / hr	IVL Report	27	Liters / hr	IVL Report	79.38

The information in table 27 has been used to derive the following ratios / default values.

Table 28. Emissions Due to Equipment for Various Works Types

Works Item	Unit	Equipment	Unit Consumption (l/qty)	
			Exp/Nat	Prov/Rural
Earthworks				
Clearing and grubbing	m²	Bulldozer	0.083	0.083
Cut	m³	Excavator (< 5% stones)	0.076	0.076
	m³	Excavator (< 25% stones)	0.079	0.079
	m³	Excavator (< 50% stones)	0.094	0.094
	m³	Excavator (> 50% stones)	0.113	0.113
Reuse of hard rock as pavement layer	m³	Aggregate crushing plant	0.652	0.652
Reuse of hard rock as fill	m³	Aggregate crushing plant	0.652	0.652
Reuse of soil as fill	m³	Dumper	0.143	0.071
	m³	Backhoe loader (*2)	0.062	0.062
Fill from borrow pit	m³	Excavator (< 5% stones)	0.076	0.076
	m³	Backhoe loader	0.031	0.031
Evacuation of soil	m³	Backhoe loader	0.031	0.031
Preparation of subgrade	m²	Motor grader	0.003	0.002
	m²	Water sprayer	0.001	0.001
	m²	Soil compactor	0.030	0.030
Embankment treatment	m³	Pulvimixer	0.005	0.005
	m³	Water sprayer	0.001	0.001
	m³	Binder spreader	0.000	0.000
Subgrade treatment	m³	Pulvimixer	0.005	0.005
	m³	Water sprayer	0.001	0.001
	m³	Binder spreader	0.000	0.000
Pavement				
Double surface dressing	m³	Bitumen sprayer	0.030	0.030
	m³	Aggregate spreader	0.030	0.030
	m³	Soil compactor	2.865	2.865
Flexible bituminous surface	m³	Asphalt mixing plant	5.989	5.989
	m³	Asphalt paver	0.340	0.340
	m³	Asphalt	0.460	0.300

Works Item	Unit	Equipment	Unit Consumption (l/qty)	
			Exp/Nat	Prov/Rural
		compactor		
Bituminous surface	m^3	Asphalt mixing plant	5.989	5.989
	m^3	Asphalt paver	0.142	0.142
	m^3	Asphalt compactor	0.192	0.125
Bituminous road base, RB	m^3	Asphalt mixing plant	5.989	5.989
	m^3	Motor grader	0.020	0.013
	m^3	Asphalt compactor	0.153	0.100
Granular road base, GB1 - GB6	m^3	Motor grader	0.017	0.011
	m^3	Water sprayer	0.004	0.004
	m^3	Soil compactor	0.171	0.171
Granular sub-base, GS	m^3	Motor grader	0.013	0.009
	m^3	Water sprayer	0.003	0.003
	m^3	Soil compactor	0.133	0.133
Granular capping layer or selected subgrade fill, GC	m^3	Motor grader	0.015	0.010
	m^3	Soil compactor	0.150	0.150
Cement- or lime-stabilized road base 1, CB4	m^3	Pulvimixer	0.040	0.040
	m^3	Water sprayer	0.006	0.006
	m^3	Motor grader	0.024	0.016
	m^3	Soil compactor	0.240	0.240
Cement- or lime-stabilized road base 2, CB5	m^3	Pulvimixer	0.033	0.033
	m^3	Water sprayer	0.005	0.005
	m^3	Motor grader	0.020	0.013
	m^3	Soil compactor	0.200	0.200
Cement- or lime-stabilized sub-base, CS	m^3	Pulvimixer	0.000	0.000
	m^3	Water sprayer	0.000	0.000
	m^3	Motor grader	0.000	0.000
	m^3	Soil compactor	0.000	0.000
Cement concrete with dowels, JPCP	m^3	Concrete batching plant	1.682	1.682
	m^3	Slipform paver	0.101	0.101
Cement concrete (lean concrete), LCB	m^3	Concrete batching plant	1.682	1.682
	m^3	Slipform paver	0.153	0.153
General soil excavation **Rammed soil for sub-base layers excavation**	m^3	Excavator (< 5% stones)	0.030	0.030
	m^3	Backhoe loader	0.030	0.030
Surface dressing overlay	m^3	Bitumen sprayer	0.030	0.030
	m^3	Aggregate	0.030	0.030

Works Item	Unit	Equipment	Unit Consumption (l/qty)	
			Exp/Nat	Prov/Rural
		spreader		
	m^3	Soil compactor	2.865	2.865
Asphalt concrete overlay	m^3	Asphalt mixing plant	5.989	5.989
	m^3	Asphalt paver	0.142	0.142
	m^3	Asphalt compactor	0.192	0.125
Re-gravelling	m^3	Motor grader	0.015	0.010
	m^3	Soil compactor	0.150	0.150
Bituminous coating	m²	Emulsion applier	0.000	0.000
Drainage				
Lined/earth/pipe longitudinal drain	m	Excavator	0.045	0.011
Box culverts	m	Excavator	2.267	1.133
Concrete for lined drains / box culverts	m^3	Concrete batching plant	1.682	1.682
Structures				
Walls	m²	Pile driver	1.339	1.607
Cement concrete for walls (reinforced concrete)	m^3	Concrete batching plant	1.682	1.682
	m^3	Concrete pump - small	0.800	0.800
Excavation of rammed soil for wall (reinforced earth)	m^3	Excavator (< 5% stones)	0.030	0.030
	m^3	Backhoe loader	0.030	0.030
Standard/interchange bridges on main section	m²	Tower crane - small	8.925	16.227
Cement concrete for standard/interchanges bridges	m^3	Concrete batching plant	1.682	1.682
	m^3	Concrete pump - small	0.800	0.800
Major bridges on main section	m²	Tower crane - big	4.463	8.114
	m²	Drilling machine	1.339	2.434
Cement concrete for major bridges	m^3	Concrete batching plant	1.682	1.682
	m^3	Concrete pump - big	0.400	0.400
Excavation of tunnels	m^3	Hydraulic hammer	0.450	0.450
	m^3	Excavator	0.045	0.011
Cement concrete for tunnels	m^3	Concrete pump - big	0.400	0.400
	m^3	Concrete batching plant	1.682	1.682
	m^3	Tower crane -	0.400	0.400

Works Item	Unit	Equipment	Unit Consumption (l/qty)	
			Exp/Nat	Prov/Rural
		big		
Road furniture				
Barriers	m	Concrete barrier slipform	0.009	0.009
Directional sign area	m^2	Crane (mobile)	4.460	4.460
Streetlights	u	Crane (mobile)	11.156	11.156
Wayside amenities	m^2	Tower crane - small	4.463	0.000
Cement concrete for all road furniture	m^3	Concrete batching plant	1.682	1.682

The following table shows a screenshot of the "Equipment" tab used in ROADEO (spreadsheet version) to define the equipment involved in the project, as well as the corresponding type of energy, consumption, intensities and GHG emissions.

Table 29. Screenshot of "Equipment" tab (spreadsheet version)

Works Component	Associated Works Item / Material	Unit	Quantity	Equipment	Energy	Unit Consumption (l or kwh/qty)		Total Consumption (l or kwh)	
Earthworks	Area of clearing and grubbing	m²	3,594,800	Bulldozer	*Diesel*	0.0830	*Override Unit Consumption*	298,368	*Override Total Consumption*
Earthworks	Volume of cut	m3	9,607,920	Excavator (< 5% stones)	*Diesel*		*Override Unit Consumption*		*Override Total Consumption*
Earthworks	Volume of cut	m3	9,607,920	Excavator (< 25% stones)	*Diesel*		*Override Unit Consumption*		*Override Total Consumption*
Earthworks	Volume of cut	m3	9,607,920	Excavator (< 50% stones)	*Diesel*	0.0944	*Override Unit Consumption*	907,415	*Override Total Consumption*
Earthworks	Volume of cut	m3	9,607,920	Excavator (> 50% stones)	*Diesel*		*Override Unit Consumption*		*Override Total Consumption*
Earthworks	Volume of hard rock reused as pavement layer	m3	1,265,000	Aggregate Crushing Plant	*Diesel*	0.6522	*Override Unit Consumption*	825,001	*Override Total Consumption*
Earthworks	Volume of hard rock reused as fill	m3	1,136,980	Backhoe loader (*2)	*Diesel*	0.0615	*Override Unit Consumption*	69,968	*Override Total Consumption*
Earthworks	Volume of soil reused as fill	m3	4,323,564	Dumper	*Diesel*	0.1429	*Override Unit Consumption*	617,652	*Override Total Consumption*
Earthworks	Volume of soil reused as fill	m3	4,323,564	Backhoe loader (*2)	*Diesel*	0.0615	*Override Unit Consumption*	266,065	*Override Total Consumption*
Earthworks	Volume of fill from borrow pit	m3	12,382,736	Excavator (< 5% stones)	*Diesel*	0.0756	*Override Unit Consumption*	935,584	*Override Total Consumption*
Earthworks	Volume of fill from borrow pit	m3	12,382,736	Backhoe loader	*Diesel*	0.0308	*Override Unit Consumption*	381,007	*Override Total Consumption*
Earthworks	Volume of soil evacuated	m3	2,882,376	Backhoe loader	*Diesel*	0.0308	*Override Unit Consumption*	88,688	*Override Total Consumption*
Earthworks	Area of subgrade preparation	m²	2,403,500	Motor Grader	*Diesel*	0.0030	*Override Unit Consumption*	7,211	*Override Total Consumption*
Earthworks	Area of subgrade preparation	m²	2,403,500	Water Sprayer	*Diesel*	0.0007	*Override Unit Consumption*	1,682	*Override Total Consumption*
Earthworks	Area of subgrade preparation	m²	2,403,500	Soil Compactor	*Diesel*	0.0300	*Override Unit Consumption*	72,105	*Override Total Consumption*
Earthworks	Volume of embankment treatment	m3	864,713	Pulvimixer	*Diesel*	0.0050	*Override Unit Consumption*	4,324	*Override Total Consumption*
Earthworks	Volume of embankment treatment	m3	864,713	Water Sprayer	*Diesel*	0.0014	*Override Unit Consumption*	1,211	*Override Total Consumption*
Earthworks	Volume of embankment treatment	m3	864,713	Binder Spreader	*Diesel*	0.0003	*Override Unit Consumption*	272	*Override Total Consumption*
Earthworks	Volume of subgrade treatment	m3	721,050	Pulvimixer	*Diesel*	0.0050	*Override Unit Consumption*	3,605	*Override Total Consumption*
Earthworks	Volume of subgrade treatment	m3	721,050	Water Sprayer	*Diesel*	0.0014	*Override Unit Consumption*	1,009	*Override Total Consumption*
Earthworks	Volume of subgrade treatment	m3	721,050	Binder Spreader	*Diesel*	0.0003	*Override Unit Consumption*	226	*Override Total Consumption*
Pavement	Quantity of Double surface dressing	m3		Bitumen Sprayer	*Diesel*	0.0300	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Double surface dressing	m3		Aggregate Spreader	*Diesel*	0.0300	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Double surface dressing	m3		Soil Compactor	*Diesel*	2.8653	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Flexible bituminous surface	m3		Asphalt Mixing Plant	*Diesel*	5.9886	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Flexible bituminous surface	m3		Asphalt Paver	*Diesel*	0.3400	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Flexible bituminous surface	m3		Asphalt Compactor	*Diesel*	0.4600	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Bituminous surface	m3	276,250	Asphalt Mixing Plant	*Diesel*	5.9886	*Override Unit Consumption*	1,654,343	*Override Total Consumption*
Pavement	Quantity of Bituminous surface	m3	276,250	Asphalt Paver	*Diesel*	0.1417	*Override Unit Consumption*	39,135	*Override Total Consumption*
Pavement	Quantity of Bituminous surface	m3	276,250	Asphalt Compactor	*Diesel*	0.1917	*Override Unit Consumption*	52,948	*Override Total Consumption*
Pavement	Quantity of Bituminous roadbase, RB	m3		Asphalt Mixing Plant	*Diesel*	5.9886	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Bituminous roadbase, RB	m3		Motor Grader	*Diesel*	0.0200	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Bituminous roadbase, RB	m3		Asphalt Compactor	*Diesel*	0.1533	*Override Unit Consumption*		*Override Total Consumption*
Pavement	Quantity of Granular roadbase, GB1 - GB6	m3	293,750	Motor Grader	*Diesel*	0.0171	*Override Unit Consumption*	5,036	*Override Total Consumption*
Pavement	Quantity of Granular roadbase, GB1 - GB6	m3	293,750	Water Sprayer	*Diesel*	0.0040	*Override Unit Consumption*	1,175	*Override Total Consumption*
Pavement	Quantity of Granular roadbase, GB1 - GB6	m3	293,750	Soil Compactor	*Diesel*	0.1714	*Override Unit Consumption*	50,357	*Override Total Consumption*
Pavement	Quantity of Granular subbase, GS	m3	528,750	Motor Grader	*Diesel*	0.0133	*Override Unit Consumption*	7,050	*Override Total Consumption*
Pavement	Quantity of Granular subbase, GS	m3	528,750	Water Sprayer	*Diesel*	0.0031	*Override Unit Consumption*	1,645	*Override Total Consumption*
Pavement	Quantity of Granular subbase, GS	m3	528,750	Soil Compactor	*Diesel*	0.1333	*Override Unit Consumption*	70,500	*Override Total Consumption*
Pavement	Quantity of Granular capping layer or selected subg	m3	411,250	Motor Grader	*Diesel*	0.0150	*Override Unit Consumption*	6,169	*Override Total Consumption*
Pavement	Quantity of Granular capping layer or selected subg	m3	411,250	Soil Compactor	*Diesel*	0.1500	*Override Unit Consumption*	61,688	*Override Total Consumption*

3. Transport

3.1. Distances

The following distances have been considered.

Table 30. Default Transport Distances

From	To	Value	Comment / Material Transported
Cut on site	**Fill on site**	Expressway: 2.5 km National road: 2 km Provincial road: 15 km Rural road: 1 km	Used for earthworks and tunnel
Borrow Pit	**Site**	Expressway: 25 km National road: 20 km Provincial road: 15 km Rural road: 10 km	Used for earthworks (fill from borrow pit)
Site	**Disposal site**	Expressway: 25 km National road: 20 km Provincial road: 15 km Rural road: 10 km	Used for earthworks (evacuated cut)
Quarry	**Batching plant**	Expressway: 30 km National road: 20 km Provincial road: 10km Rural road: 7 km	Aggregates
Quarry	**Site**	Expressway: 30 km National road: 20 km Provincial road: 10km Rural road: 7 km	Aggregates
Quarry	**Asphalt plant**	Expressway: 30 km National road: 20 km Provincial road: 10km Rural road: 7 km	Aggregates
Asphalt plant	**Site**	Expressway: 20 km National road: 10 km Provincial road: 7 km Rural road: 3 km	Bituminous bound materials
Batching plant	**Site**	Expressway: 20 km National road: 10 km Provincial road: 7 km Rural road: 3 km	Cement bound materials
Cement plant	**Batching plant**	250 km	Cement
Borrow pit	**Batching plant**	Expressway: 25 km National road: 20 km Provincial road: 15 km Rural road: 10 km	Sand for concrete
Refinery	**Asphalt plant**	250 km	Bitumen
Cement plant	**Site**	250 km	Used for soil treatment

			Cement Lime
Refinery	**Site**	250 km	Used for surface treatment Bitumen
Steel plant	**Site**	250 km	Steel No workshop assumed
Prefabrication plant	**Site**	150 km	Concrete prefabricated elements
Sawmill	**Site**	150 km	Timber barriers
Copper plant	**Site**	500 km	Electric cables for lightning and other road facilities

3.2. Fleet Vehicles

Road transport has been assumed by default.

A suboptimal use of transport fleet has also been assumed, involving the use of some medium trucks (15 percent) for long distance transport (over 25 km).

Although they are believed to reflect general actual conditions, these are important assumptions. They are not optimal and may trigger suggestions to use alternatives. Therefore, the user may have to check and adjust them.

Table 31. Default Transport Fleet Characteristics

Distance	<25 km	25 – 50 km	>50 km
Transport	30%: Truck 6.1 – 10.9 t – diesel 70%: Truck 11 - 19 t - diesel	Truck 11 - 19 t - diesel	Truck 21.1 – 32.6 t - diesel

In the 25–50 km range, only 11–19 ton diesel trucks were considered.

The following table shows a screenshot of the “Transport” tab used in ROADEO (spreadsheet version) to define transport activities involved in the project, as well as the corresponding origins, destinations, distances, quantities, intensities and GHG emissions.

Table 32. Screenshot of “Transport” tab (spreadsheet version)

Works Component	Works item / Material	Unit	Quantity	Density (t/qty)	Tons	Origin	Destination	Distance (km)	
Earthworks	Volume of soil reused as fill	m3	4,323,564	1.60	6,917,702	*Site*	*Site*	3	*Override Distance*
Earthworks	Volume of hard rock reused as fill	m3	1,136,980	1.60	1,819,168	*Site*	*Site*	3	*Override Distance*
Earthworks	Volume of fill from borrow pit	m3	12,382,736	1.60	19,812,378	*Borrow pit*	*Site*	25	*Override Distance*
Earthworks	Volume of soil evacuated	m3	2,882,376	1.60	4,611,802	*Site*	*Disposal area*	25	*Override Distance*
Earthworks	Mass of hydraulic binder	t	17,294	1.00	17,294	*Lime Plant*	*Site*	250	*Override Distance*
Pavement	Volume of hard rock reused as pavement layer	m3	1,265,000	1.60	2,024,000	*Site*	*Site*	3	*Override Distance*
Pavement	Asphalt Concrete (General)	m3	276,250	2.35	649,188	*Asphalt Plant*	*Site*	20	*Override Distance*
Pavement	Volume of Bitumen in Asphalt Concrete (General)	m3	13,813	1.40	19,338	*Refinery*	*Asphalt Plant*	250	*Override Distance*
Pavement	Volume of Aggregates in Asphalt Concrete (General)	m3	262,438	1.60	419,900	*Quarry*	*Asphalt Plant*	30	*Override Distance*
Pavement	Bituminous Emulsion	m3		1.40		*Refinery*	*Site*	250	*Override Distance*
Pavement	Cement General (Typical)	m3		2.20		*Cement Plant*	*Site*	250	*Override Distance*
Pavement	Concrete Road & Pavement	m3		2.20		*Batching Plant*	*Site*	20	*Override Distance*
Pavement	Volume of Cement in Concrete Road & Pavement	m3		2.20		*Cement Plant*	*Batching Plant*	250	*Override Distance*
Pavement	Volume of Aggregates in Concrete Road & Pavement	m3		1.60		*Quarry*	*Batching Plant*		*Override Distance*
Pavement	Volume of Sand in Concrete Road & Pavement	m3		1.85		*Borrow pit*	*Batching Plant*	30	*Override Distance*
Pavement	Quarried Aggregate	m3		1.60		*Quarry*	*Site*	30	*Override Distance*
Pavement	Soil General (rammed soil)	m3	1,116,250	1.60	1,786,000	*Borrow pit*	*Site*	25	*Override Distance*
Pavement	Steel General (average of all steels)	m3		7.85		*Steel Plant*	*Site*	250	*Override Distance*
Pavement	Quantity of bitumen for surface dressing overlay	m3		1.40		*Refinery*	*Site*	250	*Override Distance*
Pavement	Quantity of aggregate for surface dressing overlay	m3		1.60		*Quarry*	*Site*	30	*Override Distance*
Pavement	Quantity of asphalt concrete for overlay	m3		2.35		*Asphalt Plant*	*Site*	20	*Override Distance*
Pavement	Volume of Bitumen in asphalt concrete for overlay	m3		1.40		*Refinery*	*Asphalt Plant*	250	*Override Distance*
Pavement	Volume of Aggregates in asphalt concrete for overlay	m3		1.60		*Quarry*	*Asphalt Plant*	30	*Override Distance*
Pavement	Quantity of gravel for regravelling	m3		1.60		*Quarry*	*Site*	30	*Override Distance*
Pavement	Bitumen General for other roads	m3		1.40		*Refinery*	*Site*	250	*Override Distance*
Pavement	Quarried Aggregate for other roads	m3		1.60		*Quarry*	*Site*	30	*Override Distance*
Pavement	Asphalt Concrete (General) for other roads	m3	35,000	2.35	82,250	*Asphalt Plant*	*Site*	20	*Override Distance*
Pavement	Volume of Bitumen in Asphalt Concrete (General) for other roads	m3	1,750	1.40	2,450	*Refinery*	*Asphalt Plant*	250	*Override Distance*
Pavement	Volume of Aggregates in Asphalt Concrete (General)l for other roads	m3	33,250	1.60	53,200	*Quarry*	*Asphalt Plant*	30	*Override Distance*
Pavement	Soil General (rammed soil) for other roads	m3	227,500	1.60	364,000	*Borrow pit*	*Site*	25	*Override Distance*
Pavement	Cement General (Typical) for other roads	m3		2.20		*Cement Plant*	*Site*	250	*Override Distance*
Pavement	Concrete Road & Pavement for other roads	m3		2.20		*Batching Plant*	*Site*	20	*Override Distance*
Pavement	Volume of Cement in Concrete Road & Pavement for other roads	m3		2.20		*Cement Plant*	*Batching Plant*	250	*Override Distance*
Pavement	Volume of Aggregates in Concrete Road & Pavement for other roads	m3		1.60		*Quarry*	*Batching Plant*		*Override Distance*

4. Land-Use Changes

ROADEO takes into account GHG emissions due to land-use changes and subsequent removal of above ground biomass caused by the implementation of road construction and rehabilitation projects.

The assessment of these emissions is made on the basis of the following data:

- Initial land cover type (two types of vegetation can be selected by users among a pre-defined list) reflecting the typical land use observed along the project alignment before its implementation;
- Area affected by land-use change (to be entered by users as a % of the project alignment for each initial land cover type);
- Above ground biomass quantities (in dry metric tons / hectare) depending on land cover types found in Continental Asia (these values, shown in the table below, are based on data from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories); and
- Average density of CO_2 per dry metric ton of above ground biomass (set to a commonly used value of 1.72 tons of CO_2 per dry metric ton)

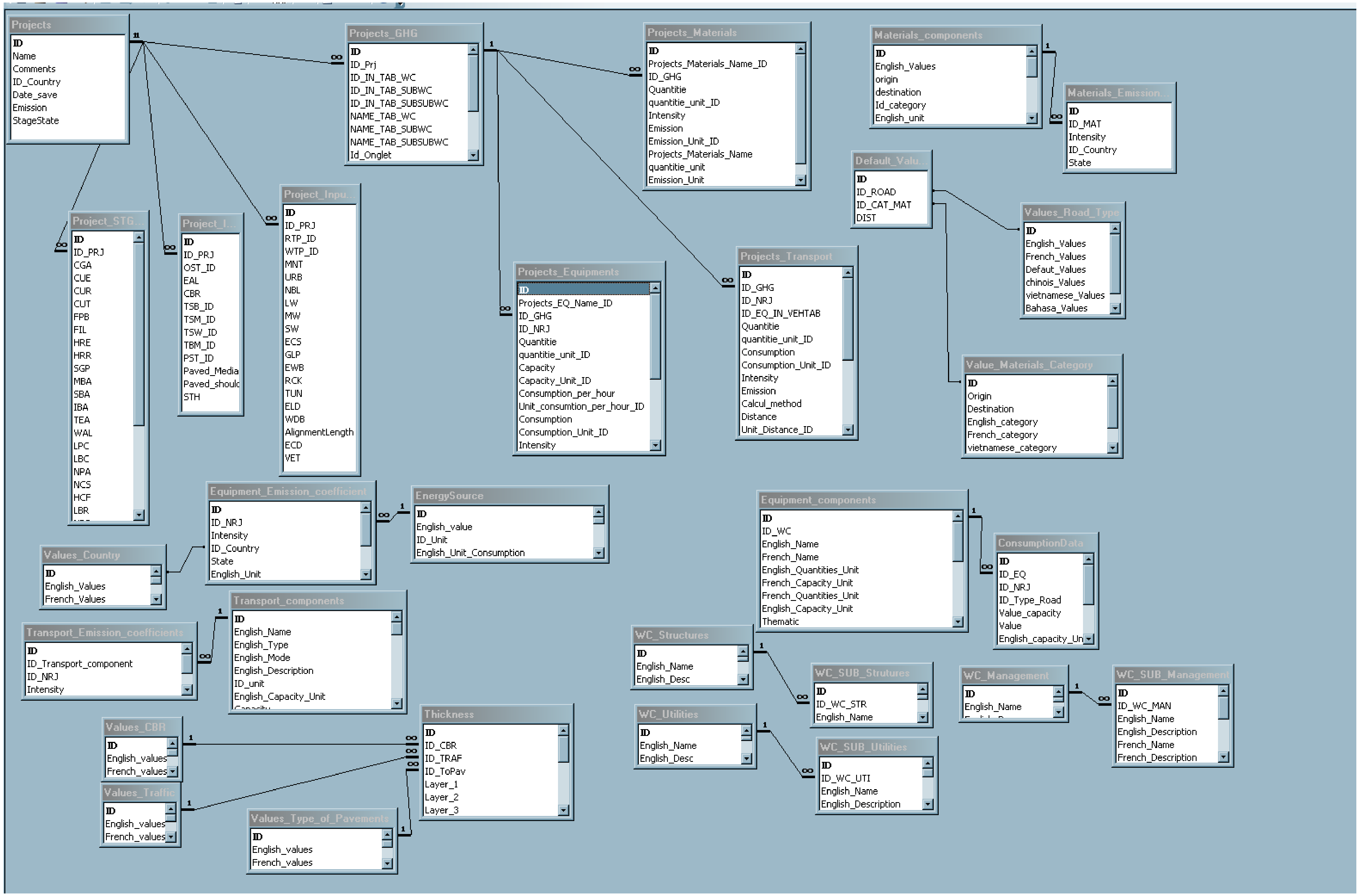
Table 33. Above Ground Biomass depending on Land Cover Types in Continental Asia (Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories)

Land Cover Type	Dry metric tons / ha		
	Low	Average	High
Tropical Rain Forest	120	280	680
Tropical Moist Deciduous Forest	10	180	560
Tropical Dry Forest	100	130	160
Tropical Shrubland	60	60	60
Tropical Mountain System	50	135	220
Subtropical Humid Forest	10	180	560
Subtropical Dry Forest	100	130	160
Subtropical Steppe	60	60	60
Subtropical Mountain System	50	135	220
Temperate Continental Forest (<20 years)	20	20	20
Temperate Continental Forest (>20 years)	20	120	320
Temperate Mountain System (<20 years)	20	100	180
Temperate Mountain System (>20 years)	20	130	600
Boreal coniferous forest	10	50	90
Boreal tundra woodland (< 20 years)	3	3.5	4
Boreal tundra woodland (> 20 years)	15	17.5	20

Boreal mountain systems (< 20 years)	12	13.5	15
Boreal mountain systems (> 20 years)	40	45	50

The resulting values of GHG emissions, which may be significant especially for greenfield projects in tropical and/or mountainous areas, are reported in the results tab of ROADEO and on the graph showing the distribution of project emissions according to the type of work component (tCO_2eq).

Appendix 1 – Overall Database Structure



Appendix 2 – Alternative Practices Data Sheets

egis	Alternative Practice	
	EAW002 – Use labor intensive techniques for excavation	
Related Work Components	Earthworks	Landscaping
Description	General principle: The purpose of this section is to review various techniques employed to excavate hard soil in open earthworks, including mechanical and manual methods.	

General principle:

The purpose of this section is to review various techniques employed to excavate hard soil in open earthworks, including mechanical and manual methods.

Technical description:

The use of heavy equipment to break **rocky materials** includes a hydraulic hammer, a hydraulic excavator and trucks to transport excavated materials, as shown on the picture below.

According to the equipment manufacturer's catalogue, a hydraulic hammer with a theoretical output of 40 m^3/h reduced to a practical 20 m^3/h, uses 18 Lt of fuel for one hour. Inputs required by this technique at a 1,000 m^3 daily rate are summarized in the following table.

The following table summarizes the relative impacts of the methods on the case study of the Hyderabad outer ring road.

Comparison of GHG emissions from earthworks techniques in hard soil

			Heavily Mechanized		Mechanized		Manual	
		Unit	**Hard rock**	**Normal soil**	**Hard rock (mining)**	**Hard rock (hammer)**	**Hard rock**	**Normal soil**
Output		**m3/24h**	**2,500**	**1,000**	**1,250**	**1,000**	**10**	**10**
quantities for 100 m3	Excavators (200 capa.)	Hr	1.92	1.2	1.92	1.92		
	Trucks	Hr	9.6	12	9.6	7.7		
	Rig bore	Hr	2.9					
	Compressor (Tractor)	Hr			48			
	hammer	Hr				24		
	Labor	man days	2.5	0.2	4.85	4.85	130	170
	Explosives	Kg	40		40			
	Fuel	Lt	161	58	117	168		
	GHG emissions	**kg CO_2 eq/100m^3**	**424**	**145**	**314**	**420**		

Conclusions

From the above it can be concluded that:

Excavation in hard soil generates 2 to 3 times more GHG than in ordinary soil.

The use of drilling rigs rather than light drillers is twice as productive, but produces 35% more GHG per m^3 of rock excavated

Productivity of labor intensive methods is 250 times lower, while involving 3 times more labor. If labor emissions are considered neutral, this is a significant reduction in emissions.

Explosives represent only 5 to 7% of the emissions of the excavation process.

The use of explosives for excavation seems indeed to produce less GHG as shown in the table below:

Relative importance of explosives in GHG emissions from earthworks techniques

Excavation method	Output (m^3/day)	Fuel Consumption (l)	Explosives (kg)	GHG (kg CO_2eq)	GHG (kg CO_2eq/m^3)
Hammer	1,000	864		2,160	2.2
Mining (light driller)	1,250	480	500	1,469	1.2
Mining (drilling rig)	2,500	1,725	1,000	4,851	1.9

Excavation and loading / transport to fill are of the same order of magnitude at around 2 kg CO_2eq/m^3 of excavated rock.

Interestingly, and in spite of the health and safety aspects which are less satisfactory than with other methods, the local lightly mechanized technique is the most efficient in terms of GHG emissions.

Life-Cycle data:

The Use of labor intensive technique for excavation has a direct impact on GHG emissions during the construction phase, and all works of maintenance or rehabilitation that require additional aggregates from quarry (overlay, widening, new alignment, repair of structures…).

Illustrations (pictures, drawings):

Hydraulic excavator feeding a truck to transport excavated materials

Excavation of ordinary soil using mechanized equipment

<table>
<tr><td rowspan="2"></td><td colspan="3">Alternative Practice</td></tr>
<tr><td colspan="3">EAW002 – Use labor intensive techniques for excavation</td></tr>
<tr><td></td><td colspan="3">
Manual excavation
</td></tr>
<tr><td rowspan="4">Documentation</td><td>Standards, guidelines, methodologies:</td><td colspan="2">• Travaux (n°864 – September 2009), Synduex (French national union of contractors, quarries and explosive specialists)
• ASIST Information Service, Technical Brief No 2, “Productivity Norms for labour-based construction”, 1998, ILO
• Applicable labor law</td></tr>
<tr><td>Involved organizations:</td><td colspan="2">• Labor authorities
• Mines and Quarries authorities
• Environmental authorities</td></tr>
<tr><td>Websites:</td><td colspan="2">• www.ilo.org</td></tr>
<tr><td>Other Reference documents:</td><td colspan="2">• •Jobs or machines – comparative analysis of rural road works in Cambodia – Paul Munters, ILO – 2003
• •Technology choice – man or machine – including case studies from Lesotho and Zimbabwe – Maria Lennartson and David Stiedl, ILO – 1995</td></tr>
<tr><td>Conditions for implementation</td><td colspan="2">Requirements:
•</td><td>Incompatible with:
•</td></tr>
<tr><td>GHG efficiency</td><td>Comparison with standard practice</td><td colspan="2">Order sof magnitude of the reductions which could be brought by labor intensive technique for excavation are shown in the table</td></tr>
</table>

	Alternative Practice
	EAW002 – Use labor intensive techniques for excavation

below for different types of roads:

Reduction in construction emissions (in t eq CO_2)	Transport	Machines	Materials		Total reduction (in t eq CO_2)	Reduction (in% of total emission of equipment based technology)
	On-site	Machines	Crushing	Mixing (incl. concrete excl. prefabricated items)		
Expressway	81.71	10.85	N/A	N/A	92.57	2.94%
National Road	9.97	7.23	N/A	N/A	17.20	2.27%
Provincial Road	3.38	11.58	22.24	5.59	42.79	22.11%
Rural Road - Gravel	0.53	10.85	28.56	2.32	42.26	47.05%
Rural Road - DBST	0.53	13.57	30.75	3.69	48.53	47.24%

Costs

Comparison with standard practice

According to available literature, costs of labor based works for rural roads are slightly lower than costs of equipment based works.

Filing information	Version: 0	Date: September 13, 2010

egis	Alternative Practice	
	EQU001 - Location of safety barriers	
Related Work Components	Earthworks Drainage Structures	Furniture Landscaping Management Other

Description

General principle:

Construction of safety barriers is responsible for a significant share (upto 25%) of GHG emissions in a road project. These emissions vary depending on the barriers' type and materials.

The principle of the alternative practice is to:

- Limit the construction of safety barriers to the strict minimum required for safety purpose by optimizing the project
- Select, where possible, lower emitting materials

An assessment of emissions by barriers showed that:

- Over a life cycle, the relative importance of emissions due to barriers is about]:
  - from 4 to 23% of GHG emissions due to pavement in the case of steel or concrete barriers
  - from 2 to 12% in the case of wood barriers
- There may be a significant interest in limiting the use of steel and concrete barriers where possible through adequate and safe design (safety zone cleared of obstacles, removal of aggressive spots, etc.), or to replace it by wood barriers when traffic volumes and loads are low enough. The potential impact could be upto 50% of the length of barriers, or from 2 to 12% of the emissions of pavement (depending on the selected structure). This requires anticipation in the geometric design, and efforts during the design phase.

Technical description:

The location of places where barriers is ruled by standards, and sometimes by the designer' experience or more specific studies. Barriers are required to isolate road side hazards.

Each country usually has its own specific rules for application of safety barriers, albeit they are usually slight variations on the same general theme. It is sometimes possible to optimize and reduce the amount of barrier to be installed depending upon the specific country rules, by adjusting some of the other design parameters.

The requirement for implementing a safety barrier is related to other components of the road project (environment, utilities, drains, structures, landscaping, signs, lighting, geometry…).

The alternative practice consists in optimizing the project taking into account the minimization of length of barriers. This can be achieved during design through an in-depth review of all components. Example of actions to be taken include:

- Avoid locating obstacles such as signs, pillars, poles, trees, walls, drains,… which would have to be isolated from the road by barriers close to the road;
- Study the possibility of relocating such obstacles further from the road in case of existing roads;
- Avoid steep level differences in geometry (embankments, structures, accesses at exit or entrances. This may have consequences on land acquisition requirements though in a limited manner
- Avoid mixing high speed and low speed modes or locating their travel lanes close to each other

As an example, on a reasonably high speed road such as a new alignment rural expressway,

- If the specific rules are where sideslope of earthworks is 4H:1V on fill or more in normal circumstances - where no specific adjacent safety "obstacles" exist - a vergeside road barrier is not required, and

- if also normal practice is to add vergeside barriers when height of fill is greater than 3m [for any slope] and on slopes steeper than 4H:1 V at any height

then it may be cost (and environmentally - i.e. such as reduction in emissions during construction) effective, if land is available, to

- design all embankments height 3m or less with 4H to 1V slopes and avoid general use of vergeside barrier];
- provide the vergeside barrier at 3m embankment height or more - and steepen up the fill slope used (for example to 2H:1V)

but precise slope obviously depends on then the geotechnical slope characteristics.

<u>Life-Cycle data:</u>

From the pure point of view of GHG emissions, minimising the length of barriers to be constructed has an impact:

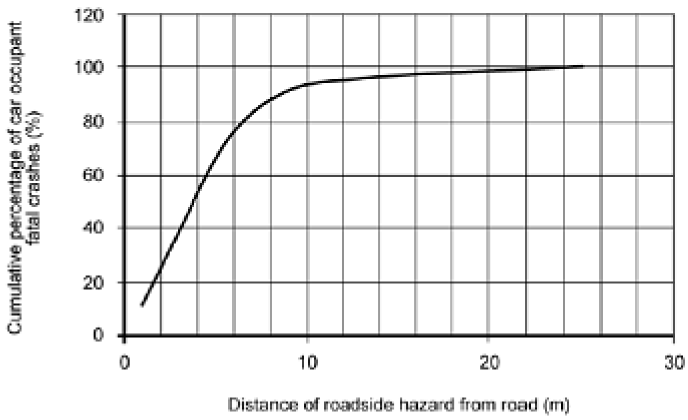
- During construction stage
- During operations: minimizing the repairs to be made following shocks and accidents, and the maintenance requirements (upgrading in case of pavement overlay, or replacement after 15 to 20 years).

The following can be used as a typical scenario:

- maintenance
  - Steel barriers: Replace 2% of length of barriers every year
  - Concrete barriers: rebuild 0.5% of length of barrier every year
- Rehabilitation
  - Steel barriers: adjust supports by 5 cm every 5 years (due to overlay of pavement)
  - Concrete barrier: no rehabilitation
  - Reconstruction
  - Steel barriers: replace all barriers every 25 years
  - Concrete barriers: replace all barriers every 25 years*
- dismantling   Included in reconstruction

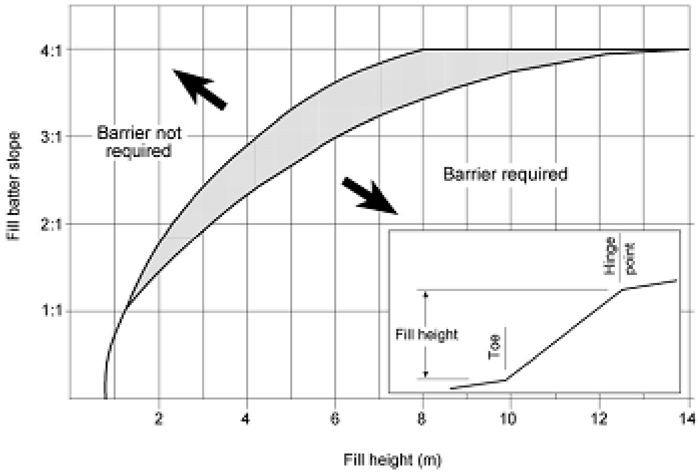
<u>Illustrations:</u>

Severity of car crashes versus distance of roadside hazard from road: concept of clear zone.



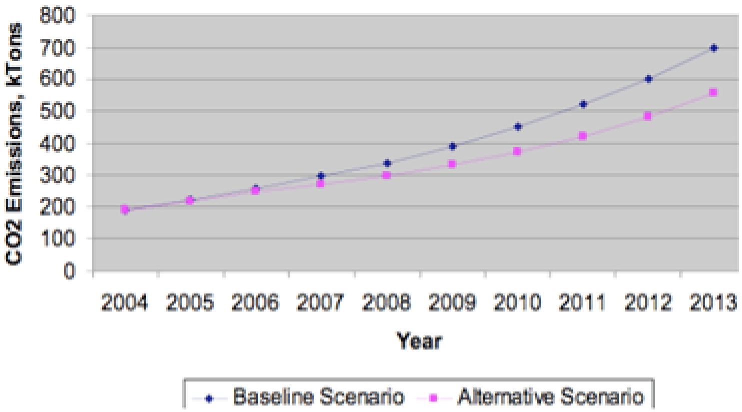
<![endif]>

Example: treatment of fill areas

	Alternative Practice		
	EQU001 - Location of safety barriers		
	 		
Documentation	Standards, guidelines, methodologies:	• Refer to applicable national standards • May involve adjustments in the design of other work components	
	Involved organizations:	• Transport authorities • Road safety authorities • Road operator	
	Websites:	• http://standards.mainroads.wa.gov.au/Internet/Standards/RTEms/roadside/ • http://safety.fhwa.dot.gov/	
	Other Reference documents:	• Traitement des obstacles latéraux sur les routes principales hors agglomeration guide technique (édition 2002) • Guide to the design of road safety barriers – Mainroads – 2009 • Assessment of Roadside Hazard – Mainroads – 2006 • Roadside Design Guide – AASHTO	
Conditions for implementation	Requirements: • Interesting in case road equipments/furniture represent a large share of total project emissions • Follow applicable standards and perform safety audit • Consider project's interfaces	Incompatible with: •	
GHG efficiency	Comparison with standard practice	Optimize location of safety barriers	
	• Materials:	For standard barriers: • About 22 kg / m of steel for steel barriers • About 0.25 m3 / m of concrete and 2 kg / m of steel for concrete barriers For wood barriers, about 20 kg/m of wood and 8 kg/m of steel	
	• Equipment:	Hammer for steel barrier, slipform for concrete barrier	
	• Transport:	Distance: • Steel plant to site • Batching plant to site Overall, GHG emissions for standard concrete and steel barriers are similar,	

	Alternative Practice	
	EQU001 - Location of safety barriers	
		and about 85 $kgCO_2eq$/ m, depending on the emission factors taken for the materials (especially steel, as barriers are usually recycled at the end of their life cycle). For wood barriers, GHG emissions can be taken as an order of magnitude as generating about 43 $kgCO_2eq$/m of barrier. Reductions can therefore be measured by the reduction of the length of barriers.
Costs	Comparison with standard practice	Costs depend on the industry and location.
Filing information	Version: 0	Date: September 2, 2010

Alternative Practice		
	EQU002 – Optimize public lighting	
Related Work Components	Earthworks Drainage Utilities	Furniture Landscaping Management Other
Description	General principle: Street lighting in parts of Asia can be characterized by low efficiency light sources housed within poorly designed luminaries and installed in inappropriate locations. Studies have shown that public lighting can be very inefficient. The alternative practice consists in: • Identifying real requirements for street lighting • Properly designing the street lighting system, including power supply, command and lighting technology • Take into account maintenance in the construction.	
	Technical description: While this toolkit does not focus on operations, this alternative practice has an impact on the operations through: • Adjustment of lighting to the areas which require it for comfort and safety reasons • Definition of a proper lighting level • Use of adequate lighting technology, with more efficient sources • Implementation of more efficient power sources, including the possibility to vary the lighting intensity • Implementation of maintenance systems which identify failing sources and allow their early replacement before their consumption increases. • Recycling of sources, whenever possible.	
	Life-Cycle data: This alternative practice has an impact during construction, but also during operation.	
	Illustrations (pictures, drawings): Emissions savings in Vietnam from Vietnamese Energy Efficiency Public Lighting Project	



In France, the road operator of the Parisian region expressway network established

Alternative Practice			
	EQU002 – Optimize public lighting		
	a lighting masterplan, which included the suppression of lighting on 128km of the previously existing 243 km.		
Documentation	Standards, guidelines, methodologies:	• Applicable standards	
	Involved organizations:	• Road operators, public works authorities, procurement authorities • Consultants • Contractors • Suppliers / vendors • Road safety councils	
	Websites:	• http://www.c40cities.org/bestpractices/lighting/vietnam_lighting.jsp	
	Other Reference documents:	•	
Conditions for implementation	Requirements: • Performance oriented standards		Incompatible with: •
GHG efficiency	Comparison with standard practice	Various actions to improve the efficiency of public lighting systems in Vietnam are estimated to result in a 25% decrease in GHG emissions. For a European power mix, the lighting of an expressway emits about 55 t CO_2/km /year	
Costs	Comparison with standard practice	The cost efficiency of the alternative practice depends on the envisaged action, and on the local cost of power.	
Filing information	Version: 0		Date: August 4, 2010

<table>
<tr><td rowspan="2">egis</td><td colspan="2">Alternative Practice</td></tr>
<tr><td colspan="2">GEN001 – Adopt adequate procurement procedures</td></tr>
<tr><td>Related Work Components</td><td></td><td>Management
Other</td></tr>
<tr><td rowspan="4">Description</td><td colspan="2"><u>General principle:</u>

While procurement and contractual activities do not directly contribute to major GHG emissions, their consequences in terms of organization, technology and therefore emissions of the construction activities can be high.

The principle of the alternative practice is to take into account GHG emissions in the upstream activities to provide an adequate set-up, through:

• Inclusion of environmental criteria in procurement
• Adoption of a packaging optimized in view of the project's requirements</td></tr>
<tr><td colspan="2"><u>Technical description:</u>

The alternative practice aims at implementing GHG emissions mitigation measures:

1. Packaging and implementation scheme

In the standard practice, the implementation plan, and more specifically the packaging of the works sometimes can result in breaking down the project into small components. Traditional construction contracts may be preferred, even with small size contracts to avoid international procurement constraints. Little freedom is left for the contractors to optimize the site organization. Major contributors to GHG emissions such as asphalt plant may therefore not be optimized, while the equipment suitable for smaller size contracts may be smaller and less efficient than for larger contracts.

In the alternative practice, more efficient schemes such as large-size and global packaging of the works, EPC (Engineering procurement construction), output / performance based, but also labour or community based contracts should be envisaged, and the size of the construction packages should be adapted to make the most efficient use of the production and construction resources.

2. Inclusion of environmental criteria in procurement

The requirements for the contractor to implement an environmental management plan are now somehow standard. However, requirements for specific actions to limit GHG emissions are not common.

This alternative practice consists in including such requirements in the contract specifications. This includes:

• Inclusion of the requirements related to the relevant more efficient practices in the contract specifications.
• Definition of a framework to optimize construction activities from GHG point of view, and allow methods and products which satisfy the quality criteria, but emit less GHG.
• Definition of the evaluation and monitoring framework. The baseline situation could be assessed with an emission calculation tool, such as the one included in the toolkit. This could be introduced in the design or supervision consultancy contract.

The requirement for the contractor to provide the information required to calculate actual GHG emissions.</td></tr>
<tr><td colspan="2"><u>Life-Cycle data:</u>

The impact of this alternative practice in terms of GHG is limited to the construction phase.</td></tr>
<tr><td colspan="2"><u>Illustrations (pictures, drawings):</u></td></tr>
</table>

	Alternative Practice		
	GEN001 – Adopt adequate procurement procedures		
Documentation	Standards, guidelines, methodologies:		
	Involved organizations:	• Public works authorities • Ministry of finance / audit authorities • Environmental authorities	
	Websites:		
	Other Reference documents:	• Environmental procurement – Practice guide - UNDP	
Conditions for implementation	Requirements: • Procurement guidelines compatible with environmental requirements • Existence of an evaluation and monitoring framework		Incompatible with: •
GHG efficiency	Comparison with standard practice	The impact of an adapted packaging can be quantified by comparing: • Standard medium/small size equipment based construction technology; with • A more optimal technology, which could be large / heavy equipment for a large size project, or a labor based technology for a smaller size rural road project. The impact of including environmental selection criteria in the procurement could be limited, as it is not directly linked to the performance of the contractor. However it could be expected that such a practice would support the contracting and consulting industries in progressively improving their performance.	
Costs	Comparison with standard practice	Impact on costs could be expected to be limited for this alternative practice. However, the most efficient packaging from GHG point of view would also be most efficient from the cost point of view.	
Filing information	Version: 0		Date: October 12, 2010

<table>
<tr><td></td><td colspan="2">Alternative Practice
GEN002 – Optimize transportation</td></tr>
<tr><td>Related Work Components</td><td>Earthworks
Drainage
Utilities
Pavement
Structures</td><td>Furniture
Landscaping
Management
Other</td></tr>
<tr><td>Description</td><td colspan="2">
<u>General principle:</u>

Transport represents a significant share of GHG emissions from road construction activities (20% to 30% depending on the road and works types). As soon as bitumen, steel, lime or cement are involved, the share of transport in overall road construction emissions exceeds 25%, and may even rise beyond 30% for major roads. It is lower for rural roads involving the use of only local materials, where it is still above 20% of overall GHG emissions.

The terminal sections of the transport process are generally constrained and have to be done by road. Heavy bulk materials are also largely transported by road, even though alternative modes may exist. This has two impacts:
• Road transport is obviously a higher GHG generator and therefore transport contribution increases
• More heavy vehicles ply on the roads, which results in shortening the duration of their life and increases the emissions linked to maintenance of these roads. It also possibly results in congestion of some of the sections.

This alternative practice focuses on the first aspect in order to reduce transport GHG emissions through:
• Improvement of efficiency of road vehicles
• Improvement of driving habits
• Change of transport mode (train, waterways, etc.)

The second aspect is more difficult to assess in general, but can be significant, as could be the case when large volumes of materials are moved over large distance
</td></tr>
<tr><td></td><td colspan="2">
<u>Technical description:</u>

The standard practice consists in:
• Limiting the use of gasoline and prefer diesel
• Use more efficient (per t.km transported) and therefore larger road vehicles (trucks with higher payload), and use latest technology fleets. Ensure that trucks are not too old.
• Improve driving habits: less idle time, less time over 1500 rpm, less time over 85 km/h, changing gears at lower regime
• Shift long distance transport to other modes: waterways, or train especially when the network uses electricity and when power generation emits less GHG (hydraulic or nuclear).
• Optimize on site transport

Related actions include:
• Considering transport mode when choosing a material source (i.e. select a material source close to railway or waterways). Promoting eco driving by truck drivers through training and awareness campaigns. Certification could accompany this action.
• Regulations to impose stricter emission standards on trucks
</td></tr>
</table>

	Alternative Practice
	GEN002 – Optimize transportation

	• Coordination and planning to make train and waterways transport available in a reliable manner for contractors. This may include actions on logistics black spots to ensure that there is no loss of efficiency at points where mode is changed or on sections which may lack capacity in the networks.	
	Life-Cycle data: This alternative practice has no impact on the life cycle.	
	Illustrations (pictures, drawings):	
Documentation	Standards, guidelines, methodologies:	•
	Involved organizations:	• Ministry of transport, traffic police authorities, environmental authorities • Transporters and their associations • contractors
	Websites:	• http://www.ecodrive.org/
	Other Reference documents:	•
Conditions for implementation	Requirements: • Railways and waterways networks in good condition	Incompatible with: •
GHG efficiency	Comparison with standard practice	**Impact of fuel within a mode** Gasoline emits more GHG than diesel depending on the type of vehicle as follows: • Truck < 1,5 t 15% • Truck 1,5 - 2,5 t 12% • Truck 2,51 - 3,5 t 46% For rail, the impact of the energy source is also very important. GHG emissions of electric railways depend on the energetic mix used for power production. **Impact of vehicle type and technology within a mode** For a given mode, unit emissions vary significantly: • By +/-47% for trucks of more than 5t • By +/-34% for vessels / push boats The higher the payload, the more efficient the transport mode is in terms of GHG emissions. A significant impact can therefore be expected from more efficient use of vehicle fleets. Specifically, the use of smaller trucks (6-10t with 0.5 kgCO_2eq/t.km instead of 11-21t with emission of 0.25kg CO_2eq/t.km) is still widespread, even for long distances. The potential impact of this change can be up to 22% when compared to a non optimized

transport fleet.

Similarly, use of modern push boats instead of smaller size vessels could be expected to result in significant increases of efficiency. The expected order of magnitude of this change is, however, much smaller than the improvement that can be expected from modal shift from road to rail or waterway.

Impact of driving habits (eco driving)

The order of magnitude of the reduction of GHG emissions due to eco driving is from 10 to 15% of the consumption of the vehicles and equipment. The emission factors of the concerned can therefore be decreased by 10 to 15%.

Safety is an additional benefit.

Impact of on site transport

On site transport can be optimized by:

- The use of road trucks instead of dumpers if the site tracks can be used by normal vehicles
- The use of conveyor belts in the case of specific localized transport (e.g. for tunnel excavation, on a quarry).

Impact of modal shift

While, depending on the energy source, unit emissions of waterways and railways are comparable, the average emission of trucks of payload more than 3.5t is about 17 times higher.

Therefore, significant savings in GHG emissions can be expected through an increased use, where possible, of transport by railways or waterways(emission factor 0.03 kg/t.km instead of 0.41). Modal shift (to rail or water) can be expected to have an impact on the long distance transport.

Costs

Comparison with standard practice

Costs to be taken into account include:

- Costs for training staff
- Costs for investing in trucks
- Transport costs by other modes

These costs may not systematically have to be borne by a specific project, as they can be amortized.

Savings could be expected from:

- Lower fuel consumption
- More efficient transportation

Filing information	Version: 0	Date: October 12, 2010

egis	Alternative Practice
	GEN003 – Implement adapted geometric standards

Related Work Components	Earthworks Drainage Utilities Pavement Structures	Furniture Landscaping Management Other

Description

General principle:

Road design standards provide engineers with requirements and guidance for the geometric design of roads. They often include desired values and required (and lower) values. International practices vary on that respect

The proposed alternative practice consists in selecting appropriate design parameters values:

- satisfying the safety and capacity requirements with an adequate level of comfort at the design horizons
- possibly lower than some indicative or prescribed values from the applicable road standards.

Technical description:

The proposed alternative practice includes:

- considering traffic demand levels at various horizons, and providing the required number of traffic lanes at these horizons. This may allow phasing of the construction activities or even avoid them for pavement, bridges, and even earthworks.
- Selecting adequate types of accesses at junctions, preferring more compact arrangements. This may have an impact on the pavement, bridges and earthworks at the corresponding locations.
- Selecting adequate basic parameters:
    - starting with the design speed) with due consideration of the constraints from the road environment (urban area, mountain…)
    - following with horizontal and vertical curves and slopes, which can have a significant impact on earthworks
    - also including cross section parameters such as lanes width, and left and right shoulders widths.

As an order of magnitude, on a standard section:

- reducing the number of lanes could, if applicable, reduce pavement area by 20 to 30%
- reducing lane width, if applicable, could reduce pavement area by about 5%

Depending on the widening strategy (build bridges initially for final cross section or not), the above also may also have a similar impact on bridges area on the main section.

Life-Cycle data:

The implementation of this alternative practice also has an impact on the rest of the life cycle, as:

- staging may result in additional maintenance or later construction activities
- reduced maintenance requirements as the extent of the initial construction is decreased

egis	Alternative Practice
	GEN003 – Implement adapted geometric standards

Illustrations (pictures, drawings):

Example: normal and reduced widths for 2x3 carriageway (French standards)

Widths in m		3 lanes					
		LS	LL	CL	RL	EL	total
	normal	1.00	3.50	3.50	3.50	2.50	14.00
HOV> 7%	1st reduction	0.75	3.50	3.50	3.50	2.50	13.75
	2nd reduction	0.75	3.00	3.50	3.50	2.50	13.25
	3rd reduction	0.75	3.00	3.25	3.50	2.50	13.00
	4th reduction	0.75	3.00	3.25	3.50	2.25	12.75
	5th reduction	0.50	3.00	3.25	3.50	2.25	12.50
	6th reduction	0.50	3.00	3.00	3.50	2.25	12.25
HOV ≤ 7%	1st reduction	0.75	3.50	3.50	3.50	2.50	13.75
	2nd reduction	0.75	3.00	3.50	3.50	2.50	13.25
	3rd reduction	0.75	3.00	3.00	3.50	2.50	12.75
	4th reduction	0.75	3.00	3.00	3.50	2.25	12.50
	5th reduction	0.50	3.00	3.00	3.50	2.25	12.25
	6th reduction	0.50	3.00	3.00	3.25	2.25	12.00

Documentation

Standards, guidelines, methodologies:	• applicable standards • "flexibility in highway design", ASHTO
Involved organizations:	• Transport authorities, Public works authorities • Road operators • Road research organizations • Consultants • Road safety councils
Websites:	
Other Reference documents:	

Conditions for implementation

Requirements:

- Especially interesting in the case of high level of service roads for low traffic
- Consultation with technical authorities in charge of design approval
- Good assessment of the traffic situation and forecasts

Incompatible with:

- congestion
- high level of demand
- strict standards and design review processes giving no flexibility to the designer

GHG efficiency

Comparison with standard practice

The alternative practice may result in reducing initial GHG emissions from pavement by reducing the quantities of materials, transport and equipment, by about 20 to 30% for staging, and about 5% for reduced cross section characteristics.

Costs

Comparison with standard practice

As an indication of the orders of magnitude, the impact

	Alternative Practice
	GEN003 – Implement adapted geometric standards

		of optimized geometric design have been assessed on a case study in the case of pavement as: • staged construction (adding lanes when required, with earthworks allowing future widening): 7.5% reduction in total construction costs • decrease lane width by 0.25 m: about 1% reduction in total construction costs Staged approaches may result in increased total costs, and require a detailed assessment of all construction and maintenance activities over the life of infrastructure.
Filing information	Version: 0	Date: October 11, 2010

	Alternative Practice
	GEN005 - Optimize workzone traffic management

Related Work Components	Earthworks Drainage Utilities Pavement Structures	Furniture Landscaping Management Other

Description

General principle:

This section provides information on traffic management practices limiting GHG emissions due to traffic congestion caused by rehabilitation, widening or maintenance work zones on existing road sections.

Extensive research has been carried out on modeling congestion from work zones and developing tools to mitigate it. These tools generally rely on a set of assumptions regarding traffic (volumes, distribution, fuel consumption), capacity (geometry of standard section and layout of work zones) and on their relations (speed variations, delays). They allow users to perform the following calculations:
Assessment of the capacity for various alternatives of site arrangements
Optimization of the timing for works implementation to minimize traffic delays

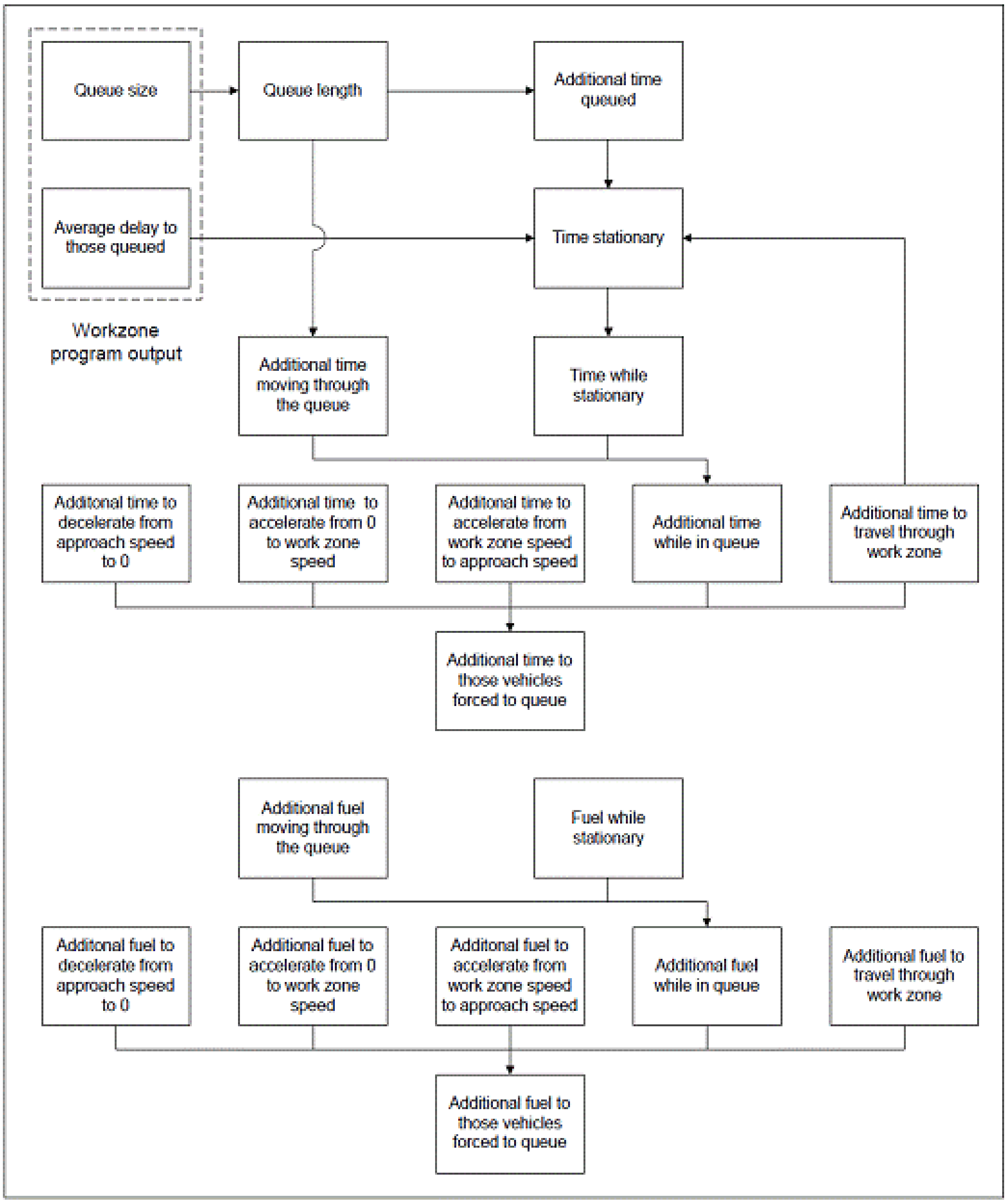
Technical description:

The HDM-4 software includes a specific model assessing the effects of road works on fuel consumption (cf. *HDM-4 Documentation Volume 7th, Modeling Road User and Environmental Effects, Section B13 - The Effects of Road Works on Traffic and User Costs*). Its analysis framework is summarized here below.

It should be noted that HDM-4 does not take into account the impacts of traffic diversion on fuel consumption. While detours by road users to avoid work zones usually result in additional fuel consumption, it may happen that the overall balance is negative (e.g. fuel consumption savings due to lower speed limits along the detours).

Tools have been developed by national road administrations to address these issues (e.g. 'Quickzone' developed by the US FHWA, 'CA4PRS' developed by Caltrans, the 'PROPICE' project in France which led to the development of 'OPTRA' - a simulation tool for roadworks congestion forecast and planning optimization).

	Alternative Practice
	GEN005 - Optimize workzone traffic management



HDM-4 Work Zone Analysis Procedure

A quantified assessment of additional GHG emissions depending on traffic conditions at work zones is provided by the following study:

1. "Impacts of road characteristics on atmospheric pollution by road transport", Philippe Lepert, François Brillet, LCPC

Based on an experiment conducted on a 2 x 2 lanes freeway with a speed limit of 90 km/h, the extra consumption of vehicles which run through a work site and experience disturbances or congestions has been assessed as follows.

Extra GHG emissions from vehicle consumption depending on traffic flow conditions at work zones

	Alternative Practice
	GEN005 - Optimize workzone traffic management

Data	Traffic flow condition Free	Disturbed	Stop & go	Congestion
Mean speed (km/h)	90	74	46	4
Standard deviation on speed (km/h)	1.1	8.9	23.0	3.7
Mean acceleration (m/s²)	0	0	0	0
Standard deviation on acceleration (m/s²)	0.1	0.4	0.4	0.3
Mean consumption (Liter/100 km)*	5.7	6.9	7.4	37.1
Mean GHG emissions (% of free flow) *	-	+ 21 %	+ 70 %	+ 555 %

* For an average sedan type vehicle

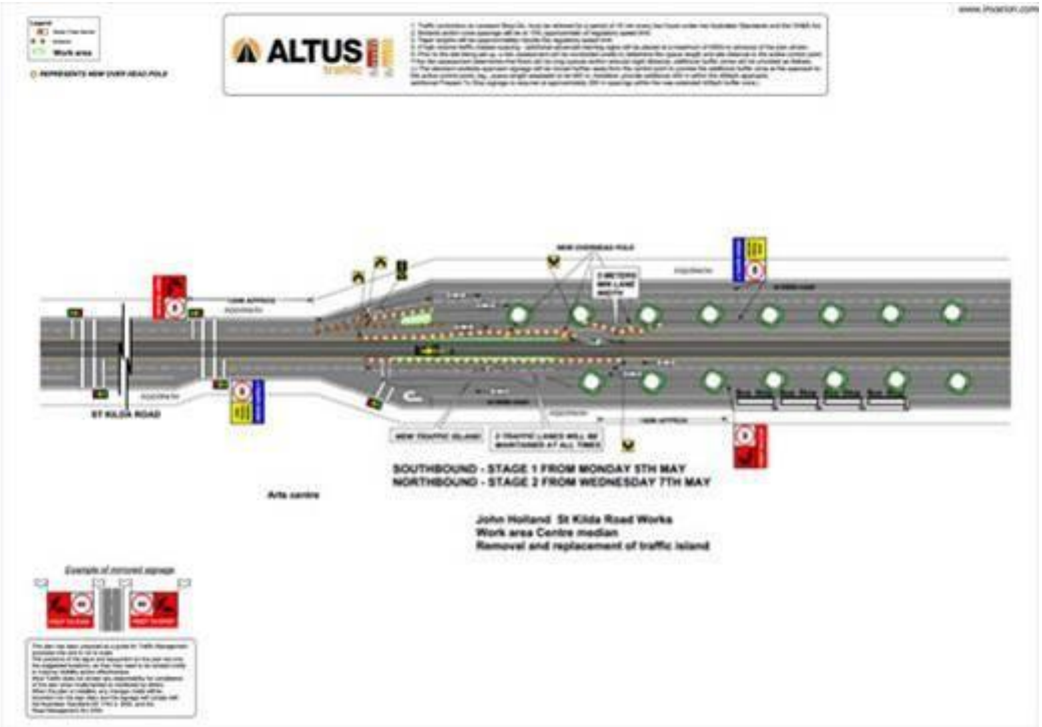
The above results show that congested situations may lead to major additional GHG emissions as compared with free flow traffic conditions.

Life-Cycle data:

Traffic management optimization has a direct impact on GHG emissions:

- During routine maintenance, rehabilitation, reconstruction and dismantling works of an existing road
- More generally, whenever the road is partially of totally blocked (accident, broken culvert, fallen tree…)

Illustrations (pictures, drawings):



Example of traffic management for the rehabilitation of a 4 lane road (from Altus Traffic, Australia)

Alternative Practice

GEN005 - Optimize workzone traffic management

Example of traffic diversion planning (from Altus Transport, Australia)

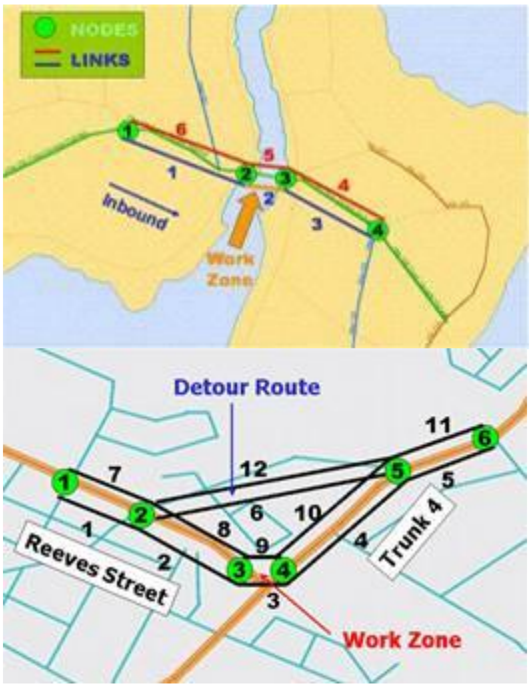


Figure 4 & 5 – Quickzone® solutions for different work zones

Documentation	Standards, guidelines, methodologies:	• Refer to applicable national standards
	Involved organizations:	• Transport authorities • Police authorities

	Alternative Practice		
	GEN005 - Optimize workzone traffic management		
		• Road safety authorities • Road operator	
	Websites:	• www.transport-research.info/ • www.th.gov.bc.ca/ • www.aitpm.org.au/	
	Other Reference documents:	• New-Zealand – Code of Practice for temporary Traffic Management • Traffic Management for land transport, Transport Research Knowledge Center • Traffic Management Guidelines for works on Roadways, Ministry of Transportation of British Colombia • Manuel du chef de chantier – volumes 1 to 6. SETRA, Ministry of Transport, France	
Conditions for implementation	Requirements: • Works Type = rehabilitation or widening; for new alignment: restricted to interfaces / junctions / crossings with existing roads. • Dense enough road network to allow diversion path • To be carefully considered on congested sections / regions		Incompatible with: •
GHG efficiency	Comparison with standard practice No.1:	Optimize workzone traffic management	
	• Materials:	N/A	
	• Equipment:	N/A	
	• Transport:	N/A	
	• Other variations (quantifiable or not):	Based on the findings of the Propice project / Optra tool in France, potential savings from optimized traffic management at work zones are generally assumed to range from 20 to 30% of overall GHG emissions due to congestion (for an expressway).	
Costs	Comparison with standard practice	In China, Indonesia and Vietnam, provisions for traffic management during construction in bidding documents are between 0.15% and 0.40% of the whole construction cost. In Europe, it can represent up to 8% of the project budget.	
Filing information	Version: 0		Date: September 13, 2010

	Alternative Practice
	PAV001 – Manage overloading

Related Work Components	Pavement Structures	Management Other

Description

General principle:

Current pavement design practices in East Asian countries may not always properly consider the impacts of overloading, which often results in premature pavement fatigue and subsequent additional maintenance requirements generating GHG emissions.

Damage to pavement increases very quickly with the axle load, approximately according to the 4^{th} power of axle load. Overloading can also result in severe bridge or structural damage.

Technical description:

The alternative practice consists in:

- At a first level, to properly assess the traffic load which the pavement will have to bear during its life. This includes an adequate assessment of overloading, which in turn may result in stronger (thicker) pavement structures than in the absence of overloading. The expected benefit is to avoid premature failure and reconstruction, which will be ineffective in terms of GHG emissions
- At a second level, to control overloading and prevent overloaded vehicles from using the network.

  At network level, this is complicated as it involves transversal institutional measures (mobilizing several ministries such as public works, transport, police / interior, justice, finance and possibly local authorities). These measures are not easy to decide, especially in developing economies where they may result in slowing down economic growth. They include information to sensitize main stakeholders, prevention (through actions on transporters, insurances, etc…) and repression (through control, fines, etc…).

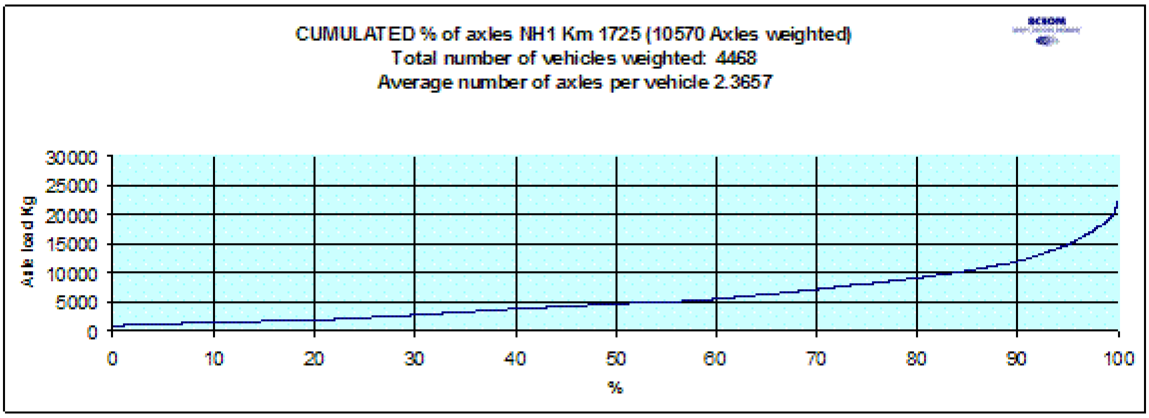
  At project level, measures can include arrangements made with authorities to implement the control, provision of infrastructure and equipment to control overloading (weighing stations).

Life-Cycle data:

This practice does not involve major emissions over its life cycle, although its consequences have an overall impact over the pavement (and bridges) life cycle duration.

Illustrations (pictures, drawings):

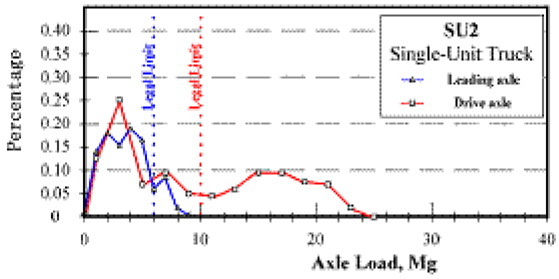
Axle load survey result – 2006, Vietnam

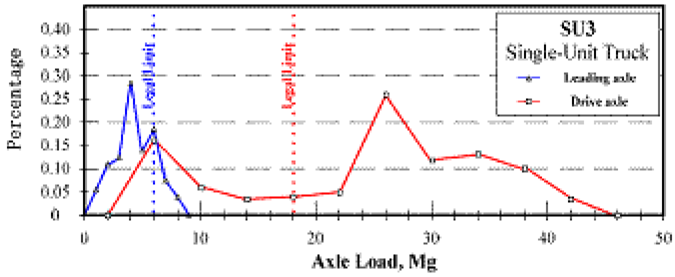


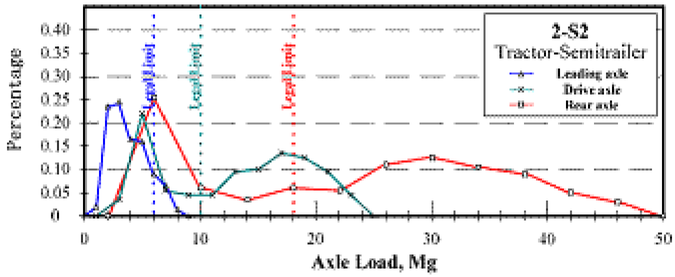
Axle load survey result – 2005, Anhui (China)

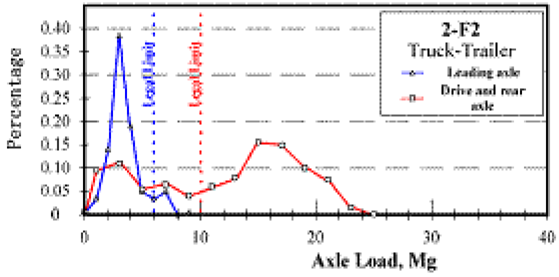
Alternative Practice

PAV001 – Manage overloading









Goods category	Proportion of freight volume (%)	Proportion of truck traffic (%)	Average GVW (Mg)	OLtP (%)	OLtR of laden trucks (%)
Coal	19.12	10.98	33.3	100.0	70.6
Metal ore	2.87	0.43	12.7	0.0	0.0
Steel	5.10	6.41	36.2	86.7	68.0
Building material	27.98	29.19	21.0	77.0	43.7
Nonmetallic ore	2.97	0.00*	-	-	-
Chemical material	9.82	13.25	20.2	80.0	49.6
Foodstuff	10.35	9.83	20.2	77.3	58.9
Farm byproduct	2.98	6.41	15.6	41.7	51.2
Daily industrial product	2.08	15.81	17.2	67.6	47.3
Other industrial product	5.92	5.98	16.6	38.5	51.1
Other goods	10.81	1.71	13.1	50.0	24.3

Note: the survey data about trucks carrying nonmetallic ore is not available.

	Alternative Practice		
	PAV001 – Manage overloading		
Documentation	Standards, guidelines, methodologies:	• Applicable road/traffic regulations • Applicable pavement design standards	
	Involved organizations:	• Public authorities: road operators (public, private), police, justice, finance, transport • Private authorities: Road operators, insurance companies • Transport companies	
	Websites:	• http://www.dft.gov.uk/vosa/repository/Vehicle%20Safety%20-%20The%20Dangers%20of%20Overloading.pdf • http://www.jis.gov.jm/trans_works/html/20100309T150000-0500_23190_JIS_TRAFFIC_AUTHORITY_FOCUSES_ON_OVERLOADED_VEHICLES.asp	
	Other Reference documents:	• Site survey and analysis of highway trucks overloading status quo in Anhui, Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 1790 - 1803, 2005 • Overseas road note N°40 – Axle load surveys and traffic counts	
Conditions for implementation	Requirements: • Institutional coordination, including adequate regulations • Proper design procedures • Enforcement procedures • Coordination with road safety		Incompatible with:
GHG efficiency	Comparison with standard practice	The extent of overloading greatly varies from one location to another, depending on economic patterns. However, significant levels of overloading can be observed in places with a proportion of 20% of axles (in number) over the legal limit. Depending on the design standards used, emissions due to the construction of the pavement structure (material, transport, equipment) for a given traffic may be from 20 to 50% higher for a road with overloading than emissions from the structure in the absence of overloading.	
Costs	Comparison with standard practice	Depending on the pavement design standards used, the unit cost of the pavement structure can be about 10 to 15% higher for a road with overloading than emissions from the structure in the absence of overloading.	
Filing information	Version: 0		Date: October 6, 2010

	Alternative Practice
	PAV002 - Use high modulus asphalt concrete

Related Work Components	Earthworks Pavement	Management Other

Description

General principle:

Referring to the perpetual pavement concept, one among the basic principles of a long life pavement is to increase the elastic modulus of road base layers. Providing more rigid road base layers by using HMAM materials can result in significantly reducing the potential of structural distresses by minimizing both:

- The tensile strain and fatigue at bottom of the road base asphalt concrete layers
- The compressive strain on top of sub-grade

Technical description:

Due to the use of hard grade bitumen, i.e. having a penetration value 20/30 or possibly 10/20, the dynamic modulus and corresponding rigidity of High Modulus Asphalt Materials (HMAM) are 50% higher than those of conventional asphalt mixes at the same temperature.

To improve the fatigue cracking potential of hard bitumen, new techniques such as vacuum distillation and propane-precipitated-asphalt have been applied. Thus the fatigue resistance of HMAM is about 50% higher than that of the conventional mix using softer 60/70 penetration bitumen value for thick asphalt pavements.

HMAM also provide higher rutting resistance under severe heavy solicitations. So HMAM can limit the rutting risk and corresponding maintenance needs in developing country where road pavements are frequently submitted to overloaded trucks under hot climate conditions.

Thanks to their higher elastic modulus and fatigue resistance, HMAM materials permit thickness reductions of about 30% to 40% in asphalt road base layers when compared to conventional asphalt materials for the same life span.

Life-Cycle data:

Maintenance scenarios can be assumed to be same as those for standard bituminous pavement

Illustrations (pictures, drawings):

Documentation		
	Standards, guidelines, methodologies:	• NF P98-140 – Couches d‟assises: enrobés à module élevé (EME), l‟Association Française de Normalisation (AFNOR), Paris, LaDefense, 1999.
	Involved organizations:	• Transport Research Laboratory • AFNOR • World Road Association
	Websites:	• www.piarc.org
	Other Reference documents:	• Caroff, G. and J.F. Corté, "Les enrobés á module élevé", Revue generale des routes et des aerodromes, Hors série 1-1994, 1994. • Nunn, M.E. and T. Smith, Evaluation of EME: A French high modulus roadbase material", Transport Research Laboratory Project Report

	Alternative Practice **PAV002 - Use high modulus asphalt concrete**		
			PR66, Transport Research Laboratory, Crowthorne, 1994. • Colas, Sustainable Development – the environmental road of future, 2003 • TRL Report TRL636 - The application of Enrobé à Module Élevé in flexible pavements ("EME2") • TRL Project Report 66 - Evaluation of "Enrobe a Module Eleve" EME : A French high modulus roadbase material
Conditions for implementation	Requirements: • Structural bituminous pavement		Incompatible with: •
GHG efficiency	Comparison with standard practice • Materials: • Equipment: • Transport: • Other variations (quantifiable or not):		The use of high modulus asphalt concrete enables to save about 20% in GHG emission, compared to traditional road base asphalt. (comparison based on Colas report *Sustainable Development – the environmental road of future* (September 2003)) Decreased quantities of materials also result in a decrease of the transport requirements.
Costs	Comparison with standard practice		Compared to projects using traditional road base asphalts HMA materials lead to savings of about 18% in cost for construction. (comparison based on Colas report *Sustainable Development – the environmental road of future* (September 2003))
Filing information	Version: 0		Date: September 16, 2010

egis	Alternative Practice
	PAV003 - Use warm and half warm asphalt mixes

Related Work Components	Earthworks Pavement	Management

Description

General principle:

In the framework of on-going research programs and starting larger scale applications on sites since 2005, the solutions proposed to improve the energy efficiency of hot asphalt mixing processes are categorized in warm and half warm, depending on whether their manufacturing temperature is above or below 100°C. The key element is to maintain a low viscosity of the mixture while decreasing the production and laying temperature.

Warm and cold aggregate processes are promising. Numerous construction firms have launched research and development projects on these processes which environmental balance seems favorable.

Technical description:

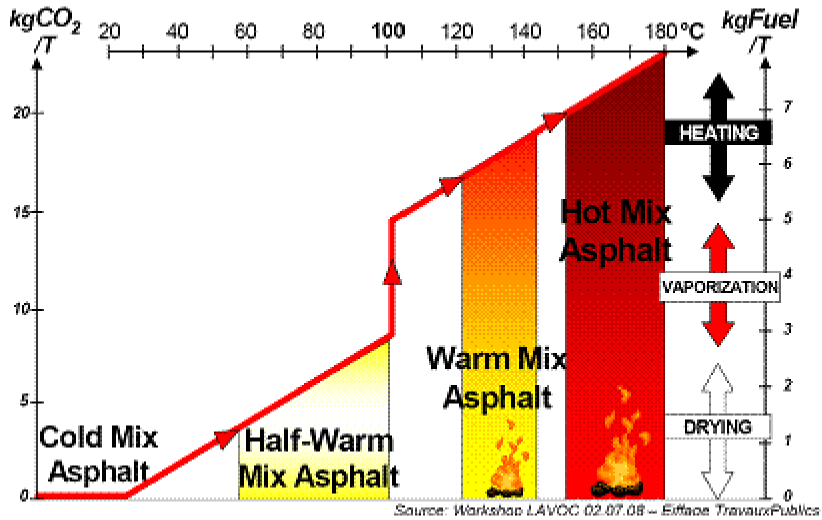
Warm mixed asphalt materials (WMA) make use of systems acting on the viscosity of the bitumen (wax, double coating, soft binder, hard binder, foaming agent) with an aggregate skeleton of uniform temperature maintained slightly over 100°C and thus entirely anhydrous.

Life-Cycle data:

Following first results, the total life-cycle of a pavement construction (binder, aggregate, mixing process, transport, processing) with a cold process could reduce GHG emissions from about 30-35%.

Illustrations (pictures, drawings):

WMA and HWMA technologies with regards to energy and CO_2 emissions.



HWMA technology (Fulton Hogan Coolpave with LEA®)

	Alternative Practice
	PAV003 - Use warm and half warm asphalt mixes
	 **WMA technology (HGrant Warm Mix System®)** 

Documentation	Standards, guidelines, methodologies:	
	Involved organizations:	• Asphalt pavement Alliance • National Pavement Association • World Road Association
	Websites:	• www.warmmixasphalt.com • www.fhwa.dot.gov
	Other Reference documents:	• The Asphalt Pavement Association of Oregon, “Warm Mix Asphalt Shows Promise for Cost Reduction, Environmental Benefit”; Centerline,

	Alternative Practice		
	PAV003 - Use warm and half warm asphalt mixes		
			The Asphalt Pavement Association of Oregon, Salem, OR, Fall 2003. • Brosseaud, Y. "Warm Asphalt – Overview in France." LCPC, France, Presentation to WMA Scan Team, May 2007.
Conditions for implementation	Requirements: • Low / medium traffic		Incompatible with: • High traffic
GHG efficiency	Comparison with standard practice		Use warm and half warm asphalt mixes Following first results, the total life-cycle of a pavement construction (binder, aggregate, mixing process, transport, processing) with a cold process could reduce GHG emissions from about 30-35%. This could be reflected by decreasing the materials coefficients by the same value
Costs	Comparison with standard practice • Unit cost for construction		WMA and HWMA require specific equipment and/or specific products to keep satisfactory conditions during the process of bitumen emulsifying, which slightly increase the final cost of the product. Nevertheless, this cost increase is globally compensated by the fuel savings due to lower heating temperatures. Potential of warm mix asphalt has been demonstrated and the use of WMA could be beneficial. However, the experience with HWMA is currently more limited and some issues still need to be addressed.
Filing information	Version: 0		Date: September 16, 2010

<table>
<tr><td></td><td colspan="2">Alternative Practice
PAV005 - Use Recycling</td></tr>
<tr><td>Related Work Components</td><td>Pavement</td><td>Management</td></tr>
<tr><td rowspan="3">Description</td><td colspan="2"><u>General principle:</u>
The existing road pavements should be thought as a deposit of materials similar to a quarry with the possible addition of new binder, rejuvenators or virgin aggregates (aiming at optimizing the mix grading curve). In this concept, the road materials should leave the recycling cycle only when they become an ultimate waste.</td></tr>
<tr><td colspan="2"><u>Technical description:</u>
The available recycling processes take place in the framework of the following techniques:
1. Cement concrete pavements can be recycled in place by breaking the existing concrete and overlaying it with a new asphalt or cement concrete surface. Alternatively, the existing concrete may be broken up, removed and crushed into aggregate sizes at the mixing plant and used as recycled concrete with additional cement.
2. Reclaimed Asphalt Pavements (RAP) can be recycled:
• In hot mixing plants at a recycling rate generally close to 10% in elevator foot, corresponding to the maximum acceptable threshold in most international specifications and standards. Nevertheless, this level in specifications is being updated by taking into account possible higher recycling rates that can possibly be reached now, depending on recent improvements in mixing plant technology:
    • Up to 25% into the mixer,
    • Up to 35% into dryer recycling ring,
    • Up to 50% in case of two drums in parallel, this is the most advanced technology for hot asphalt recycling, nevertheless available only for very few plants at the present time.
• In hot surface recycling/thermo-regeneration, this technology is usable only for wearing courses on a maximum thickness of 40 mm;
• Cold in mixing plant or on-site by adding as binder either bitumen emulsion (or foam bitumen), or cement or a mix of bituminous emulsion and cement. This technology is very attractive in terms of mitigation of GHG emissions as it permits a recycling rate up to 100% of in-site existing materials, which is significantly higher than recycling technology in hot mixing plants. Nevertheless, the elastic modulus and structural efficiency of these materials remain relatively weak and cause an increase in the thickness of the corresponding layer by about 30% when compared to traditional hot asphalt materials. Also in-site cold recycling requires a sufficient homogeneity of existing pavement structures, which is not the case for most job sites, causing quality defects.</td></tr>
<tr><td colspan="2"><u>Life-Cycle data:</u>
Recycling existing pavement for rehabilitation or widening operations, enables</td></tr>
</table>

significant savings in terms of GHG emissions, in materials production of course, but also in materials transport.

Illustrations (pictures, drawings):

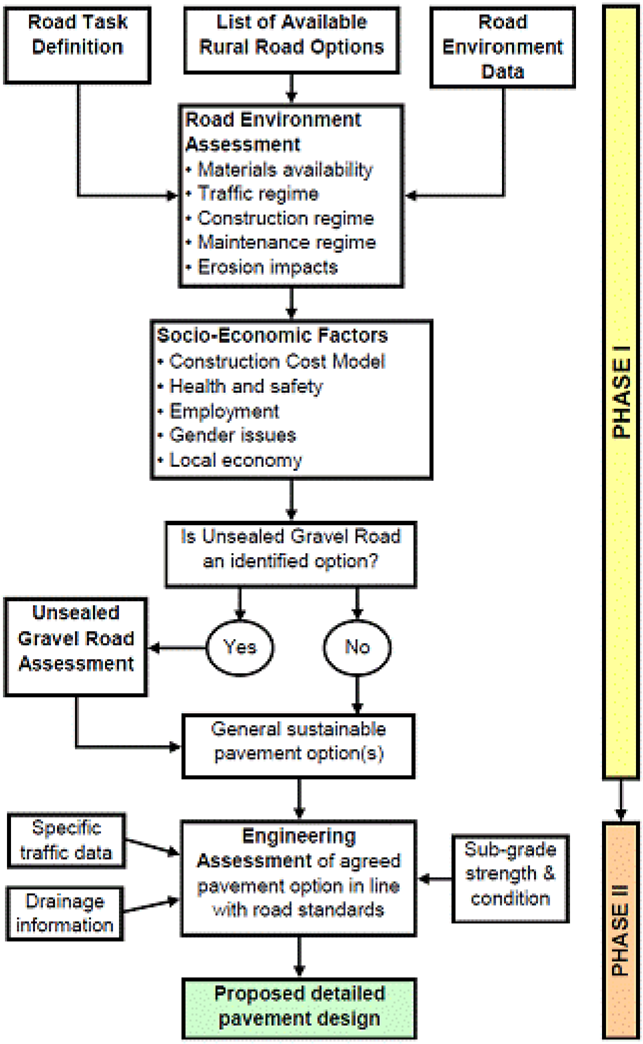
On-site recycling with bituminous emulsion and cement on Kiev/Chop road (Ukraine) (Source Egis Bceom International 2009)

Cold In-place Recycling (CIR) construction train and equipment. (Source: Ministry of Transportation of Ontario)

	Alternative Practice		
	PAV005 - Use Recycling		
Documentation	Standards, guidelines, methodologies:		
	Involved organizations:	• Asphalt Recycling & Reclaiming Association • National Asphalt Pavement Association • World Road Association • Asphalt Emulsion Manufacturers Association	
	Websites:	• http://www.aema.org • http://www.hotmix.com • http://www.piarc.org	
	Other Reference documents:	• *Asphalt Hot-Mix Recycling,* The Asphalt Institute, Lexington, KY, $8, (606) 288-4960. • A Study of the Use of Recycled Paving Material, Report to Congress as specified in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), Report No. FHWA-RD-93-147, EPA/600/R-93/095. • Recycling Book, Fayat	
Conditions for implementation	Requirements: • Especially relevant for rehabilitation or widening projects • Adequate Quality Assurance system	Incompatible with:	
GHG efficiency	Comparison with standard practice		
	• Materials:	• In the case of hot recycling, there is no significant difference between virgin and RAP recycled materials; • In the case of cold recycling with bitumen emulsion or cement, the situation is dependent on the specific local conditions (on-site recycling or mixing plant) with globally an advantage of about 40 to 50% in favour of cold RAP technology. This decrease can be taken into account by decrease the emission factors of the concerned materials.	
	• Transport:	If waste disposal sites are remote from the construction site, the reduction in transport (as recycled material is kept on site) can be significant and should be taken into account.	
Costs	Comparison with standard practice	Use Recycling	
	• Unit cost for construction	N/A	
	• Unit cost for maintenance	N/A	
	• Unit cost for rehabilitation	Based on information provided by road works companies, there is no significant cost difference	

egis	Alternative Practice	
	PAV005 - Use Recycling	
	• Unit cost for reconstruction	between raw aggregates and RAP, due to the additional cost for milling and crushing the recycled RAP materials.
	• Unit cost for dismantling	N/A
Filing information	Version: 0	Date: September 17, 2010

	Alternative Practice	
	PAV008 – Optimize pavement structure and surface types	
Related Work Components	Earthworks Drainage Pavement	Management Other
Description	General principle: A common practice especially on low volume roads, consists in addressing the social demand for higher level of service roads through structural paving (bituminous or cement concrete pavement). An alternative practice, which is promoted by funding institutions, consists in carefully selecting the surface and structural type of pavement to be provided and, for low traffic roads, to prefer whenever technically suitable, gravel roads or surface treatments.	
	Technical description: The alternative practice consists in proposing cost effective pavement designs, which can be achieved through: • Treatment of weak locations (lack of drainage, low points, lack of structures, steep slopes to be paved) to ensure all-weather connectivity • Proper gravel road design, whenever the local materials are suitable. This may also involve maintenance and operation arrangements to maintain low roughness and limit dust • When erosion is higher or the traffic level becomes higher, surface treatment (sandwich of thin layer of aggregates and bituminous binder laid and rolled on site) may become an effective solution with less material than a full bituminous concrete pavement.	
	Life-Cycle data: Life cycle information for gravel roads, surface treatment and structural pavement differ significantly.	
	Illustrations (pictures, drawings):	

egis	Alternative Practice
	PAV008 – Optimize pavement structure and surface types
	

Documentation	Standards, guidelines, methodologies:	• Design and appraisal of rural transport infrastructure: ensuring basic access for rural communities, World Bank technical paper 496 • International guidelines for low-cost sustainable road surfacing, PIARC (SEACAP)
	Involved organizations:	• Road planning authorities, communities • Planning / design consultants
	Websites:	• www.ruralroads.org
	Other Reference documents:	• Guidelines for low volume sealed roads, SADC, 2003

Conditions for implementation	Requirements: • Institutional organization and structured and performance oriented planning processes • Low traffic volumes	Incompatible with: • High erosion (high rainfall, steep slopes) • High traffic

	Alternative Practice
egis	**PAV008 – Optimize pavement structure and surface types**

GHG efficiency

Comparison with standard practice

The following table summarizes the result of a case study.

Materials emissions (t C02 – eq)	*Provincial Road)*	*Rural Road - Gravel*	*Rural Road – DBST*
Crushed Aggregates	7.8	5.8	5.8
Quarried Aggregates	47.8	38.1	41
Bituminous emulsion	1.9	0	6.8
Hot mix Asphalt	24.2	0	0
Reinforced Concrete 2%	13.3	9.2	9.2
Reinforced Concrete 3%	16.6	2.4	2.4

The table below compares global emissions of a road with structural pavement (provincial), and

Road type	*Provincial*	*Rural - Gravel*	*Rural - DBST*
Emission (t CO_2 eq./km)	191	83	115

For a given geometry, surface treatment emits about 20% more GHG than a gravel road.

Although geometry is slightly different, the use of structural pavement produces significantly more GHG than other surface types.

Costs

Comparison with standard practice

The table below provides typical orders of magnitude of costs for improvement of a rural road with a given initial status, resulting from a project in Sri Lanka.

Typical budget for the actions

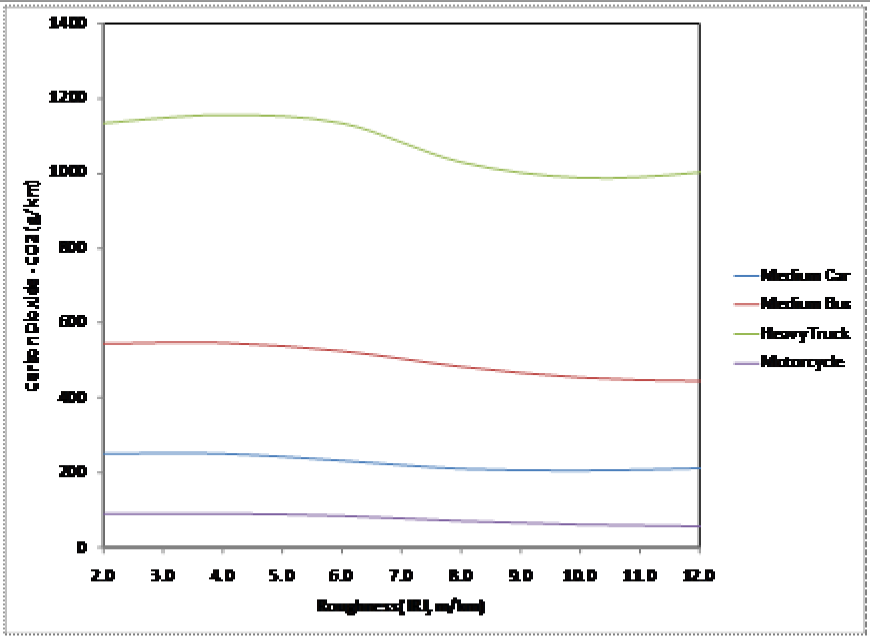
Road status	Light maintenance	Heavy maintenance	Upgrading
Earth	35	250	1100 (800 to 2050)
Gravel	110	170	
Bituminous	270	470	
Cement concrete			2050

Filing information | Version: 0 | Date: October 11, 2010

Alternative Practice		
	PAV009 – Ensure low roughness	
Related Work Components	Earthworks Pavement Structures	Management Other
Description	General principile: Fuel consumption of vehicles driving on a road depends, among others, on the roughness of road surface. This roughness is the result of geometric characteristics of several sizes, from surface texture to alignment geometry.	
	Technical description: The alternative practice consists in ensuring minimum roughness for a given road (alignment) geometry. This mostly requires careful implementation of the works, through: • The use of adequate construction equipment. This involves not only thick pavement layers (paving machine, compactor) but also earthworks (grader, compactor) • The mobilization of qualified workmanship • The proper management of material production and laying (avoiding unnecessary stops during laying operations) • The selection of adequate materials (to avoid deformation and rutting under traffic load) At design stage, care has to be taken while preparing the specifications for all the above aspects and indicating the performance targeted for roughness. Control during implementation shall also be planned, with measurements of this characteristics before the hand over.	
	Life-Cycle data: Proper maintenance planning and implementation is a requirement to maintain a reasonable level of roughness.	
	Illustrations (pictures, drawings):	

Alternative Practice

PAV009 – Ensure low roughness



This alternative practice focuses on the left part of this graphic, from 2 to 4 IRI)

Documentation	Standards, guidelines, methodologies:	HDM-4 Road Use Costs Model Version 2.00 Documentation February 18, 2010
	Involved organizations:	• Contractors • Design and supervision consultants
	Websites:	
	Other Reference documents:	"Impacts of road characteristics on atmospheric pollution by road transport", Philippe Lepert, François Brillet, LCPC
Conditions for implementation	Requirements: • Adequate material design • Proper specifications • Adapted control plan & quality organisation • Trained staff and modern equipment	Incompatible with: • Old technology equipment
GHG efficiency	Comparison with standard practice	The alternative practice is neutral in terms of construction, but has been added to the toolkit as it has an impact on the overall emissions of the road. This impact is especially important for trucks for which it can be upto 5% according to the HDM4 model. Improvements in pavement roughness, especially by reducing short-wavelength unevenness, could decrease fuel consumption by up to 4 liters/100 km as assessed using a mathematical "suspension model".
Costs	Comparison with standard practice	Impact on costs is expected to be limited or neutral.
Filing information	Version: 0	Date: October 6, 2010

egis	Alternative Practice
	PAV010 – Use soil stabilization

Related Work Components	Earthworks Drainage Pavement	Management Other

Description

General principle:

A current practice consists in opening borrow pits or quarries around the road site to extract materials needed for embankment, and pavement or structure aggregates.

The alternative practice consists in reusing materials from the site itself as embankment or subbase, after improving their quality by treating them with hydraulic binders.

Locally available materials which have insufficient characteristics for use in construction works (as subgrade, as pavement materials) may be improved by mechanical (blending) or chemical treatment (especially with hydraulic binders).

This avoids transporting valuable (and rare) materials over long distances.

Technical description:

The standard practice consists in using materials from a nearby quarry or borrow pit, which involves using natural resources and transport. In areas having good soil or rock and in the absence of stringent environmental requirements prohibiting opening of quarries / borrow pits, the transport component can be small and this technique may be cost effective and minimizing GHG emissions.

The alternative practice considers fine soil treatment with hydraulic binders to improve their mechanical and physical properties. A number of binders are available, including lime, cement, and hydraulic road binders containing slag. The existing soil is mixed by a powerful machine (pulvimixer) with a defined quantity of binder. This is the result of a design process involving geotechnical surveys and trials.

The user shall refer to available guidelines for design and construction considerations. As an indication:

- The first step is to assess the suitability of soil for treatment through physical and chemical tests. This involves observing the behaviour of treated soil (expansion…)
- The second step is to identify in laboratory the optimal treatment: type of binder or mix of binders, quantities and resulting improvement

The third step is to test the proposed treatment on a trial site.

Threshold quarry-site distance above which soil treatment becomes more GHG effective than bringing crushed aggregates on site

Distance from quarry to site (km)	**Binder proportion**		
Binder type	**1%**	**2%**	**3%**
CEM I	85	243	401
CEM II	45	164	282
Hydraulic road binder HRB 70% slag		34	88
Hydraulic road binder HRB 50% slag	11	94	178
Hydraulic road binder HRB 30% slag	41	155	268
Hydraulic road binder HRB 30% limestone	39	151	262
Hydraulic road binder HRB 30% flyash	39	150	262
Quicklime	120	312	505

These typical values are rather high, indicating that there is a high likelihood that adequate materials sources could be identified within the corresponding distance from the site.

egis	**Alternative Practice**
	PAV010 – Use soil stabilization

From a larger environmental perspective, this alternative, in spite of the high emissions due to the binder, also preserves existing natural resources.

Life-Cycle data:

In general, the improvement of embankment and the introduction of a capping layer improve the long term behaviour of the pavement. Treatment not only improves the characteristics of materials, but also makes them more homogeneous and less subject to variation (according to humidity among others). This in turn makes the infrastructure less subject to spot failure.

Illustrations (pictures, drawings):

Modern pulvimixer

Pulvimixer in Xi'an, China

Documentation		
	Standards, guidelines, methodologies:	• applicable soil treatment and earthworks guidelines
	Involved organizations:	• Public works authorities, environmental authorities • Design and supervision consultants • Contractors • Hydraulic binder producers, and construction equipment manufacturers
	Websites:	• http://www.infociments.fr/publications/route/collection-technique-cimbeton/ct-30gb
	Other Reference documents:	• COMPARATIVE STUDY IN ROAD ENGINEERING SOIL TREATMENT VS UNBOUND GRANULAR MATERIALS Graphic method for environmental and economic comparison, Cimbéton

	Alternative Practice
	PAV010 – Use soil stabilization

Conditions for implementation

Requirements:	Incompatible with:
• local material suitable for treatment • Trained personnel, adapted equipment • High and constant quality binder • Long sections	• Local soil not suitable for treatment • Inadequate equipment, unskilled labour • Low quality binder

GHG efficiency

Comparison with standard practice

- Materials: Treatment adds to the standard practice the emissions due to lime, cement or other hydraulic binders.

Binder	GHG emission (kg eq CO_2eq / t)	Source
Cement CEM I	868	ATILH - Technical Union of Hydraulic Binders Industry - France)
Cement CEM II	650	
Hydraulic road binder HRB 70% slag	294	
Hydraulic road binder HRB 50% slag	459	
Hydraulic road binder HRB 30% slag	625	
Hydraulic road binder HRB 30% limestone	614	
Hydraulic road binder HRB 30% fly ash	613	
Quicklime	1,059	Union of lime producers, France

The emissions due to production of material from a quarry or a borrow pit according to the standard practice (excavation) can be assessed as:

- 10 kgCO_2eq/t for crushed aggregates
- 2.5 kgCO_2eq/t for pit run aggregates

- Equipment: Treatment adds to the standard practice the placement of the binder. The corresponding emissions are shown below:

Type of soil	Emissions (kg eqCO_2 / m3 treated soil)
silty / sandy soil	1.75
Clay soil	2
Gravelly soil	2.25
Packed and difficult soil	2.5
Bouldery soil	3

The placement of materials according to the standard practice can be assumed as producing 0.3 kgCO_2eq/m^3 of placed materials

- Transport: Treatment adds to the standard practice the transport of binder from the factory, but decreases the transport of materials from the quarry or borrow pit to the site.

	Alternative Practice **PAV010 – Use soil stabilization**	
Costs	Comparison with standard practice This has to be the subject of a specific costing study for the project	
Filing information	Version: 0	Date: October 11, 2010

egis	Alternative Practice
	PAV012 -Take maintenance into account during design

Related Work Components	Pavement	Management

Description

General principle:

Maintenance works have a significant importance in the overall emissions of road construction (20 to 40%). Hence, it is pertinent to include maintenance strategies at the design stage to anticipate – and optimize – the life-cycle emission of the road project.

Various approaches to maintenance and their impact on GHG emissions (in terms of overall volume, and in terms of timing) have been reviewed:

- Standard / catalogue
- Progressive construction
- Deferred maintenance / perpetual pavement

Technical description:

Thicknesses of pavement layers at construction stage

Thickness (mm)	ORN31 Chart 5 – S3/T7	Stage construction	Perpetual pavement
Allowable cumulative traffic at initial construction (million ESA 8.16 tons)	**11.2**	**6.0**	**26.5**
Wearing / binding courses (bituminous)	125	90	175
Unbound granular base course	225	225	250
Sub-base Unbound gravel	250	250	250

Maintenance scenarios have been worked out for these initial pavement layers, as follows:

Maintenance scenario and life-cycle GHG emissions using standard design based on ORN31

ORN31 Chart 5 - T7/S3	Thickness (mm)	Emission ($kgCO_2eq$ /t)	Density	Emission ($kgCO_2eq$ /m²)	Year	GHG emissions over 40 years ($kgCO_2eq$ /m²)
Wearing / binding courses (bituminous)	125	54	2.25	15.19	0	15.19
Unbound granular base course	225	10	2.20	4.95	0	4.95
Sub-base Unbound gravel	250	10	2.20	5.50	0	5.50
AC Overlay	40	54	2.25	4.86	10; 20; 30	14.58
Milling	20	8	2.20	0.35	20	0.35
AC Overlay	100	54	2.25	12.15	40	12.15
Milling	60	8	2.20	1.06	40	1.06

	Alternative Practice
	PAV012 -Take maintenance into account during design

TOTAL						**53.78**

Maintenance scenario and life-cycle GHG emissions using stage construction

Stage construction	Thickness (mm)	Emission ($kgCO_2eq$ /t)	Density	Emission ($kgCO_2eq$ /m²)	Year	GHG emissions over 40 years ($kgCO_2eq$ /m²)
Wearing/binding courses (bituminous)	90	54	2.25	10.94	1	10.94
Unbound granular base course	225	10	2.20	4.95	1	4.95
Sub-base Unbound gravel	250	10	2.20	5.50	1	5.50
AC Overlay	60	54	2.25	7.29	5; 40	14.58
AC Overlay	40	54	2.25	4.86	10; 30	9.72
Milling	60	8	2.20	1.06	20; 40	2.11
AC Overlay	100	54	2.25	12.15	20	12.15
TOTAL						**59.95**

Maintenance scenario and life-cycle GHG emissions using perpetual pavement

Perpetual pavement	Thickness (mm)	Emission ($kgCO_2eq$ /t)	Density	Emission ($kgCO_2eq$ /m²)	Year	GHG emissions over 40 years ($kgCO_2eq$ /m²)
Wearing/binding courses (bituminous)	175	54	2.25	21.26	1	21.26
Unbound granular base course	250	10	2.20	5.50	1	5,50
Sub-base Unbound gravel	250	10	2.20	5.50	1	5.50
AC Overlay	40	54	2.25	4.86	15, 30, 40	14.58
Milling	40	8	2.20	0.70	30, 40	1.41
TOTAL						**48.25**

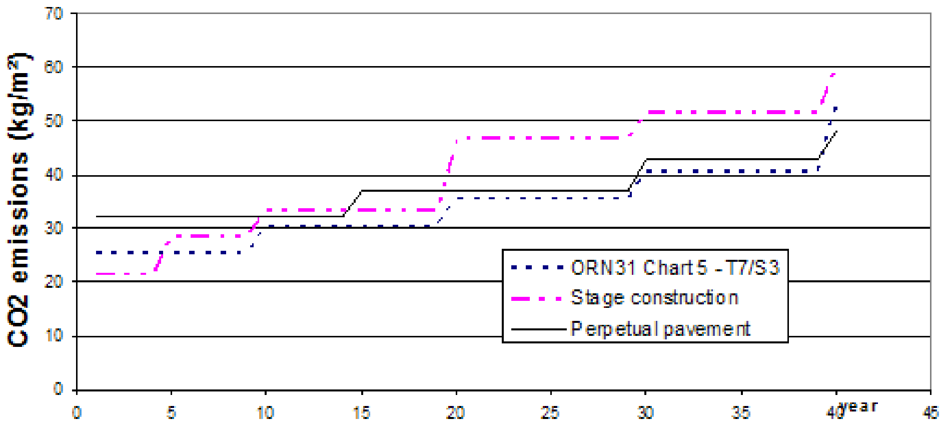
Life-Cycle data:

The following chart shows the cumulated emissions for construction and maintenance activities for each case:

Cumulated GHG emissions for construction and maintenance activities depending on pavement construction / maintenance strategy

Alternative Practice

PAV012 -Take maintenance into account during design

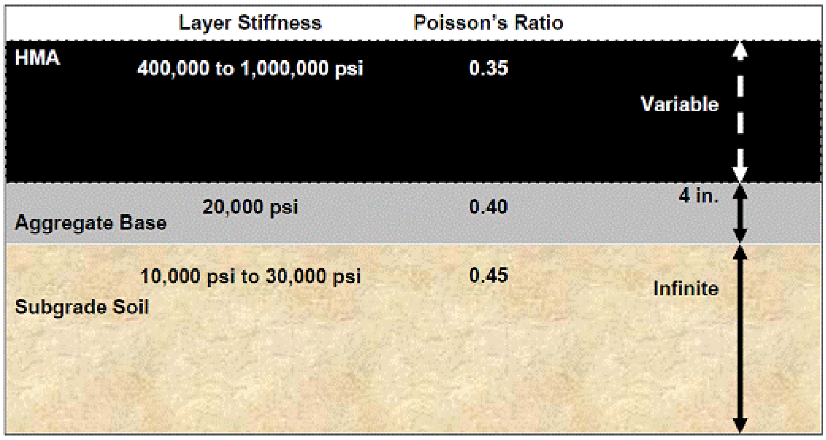


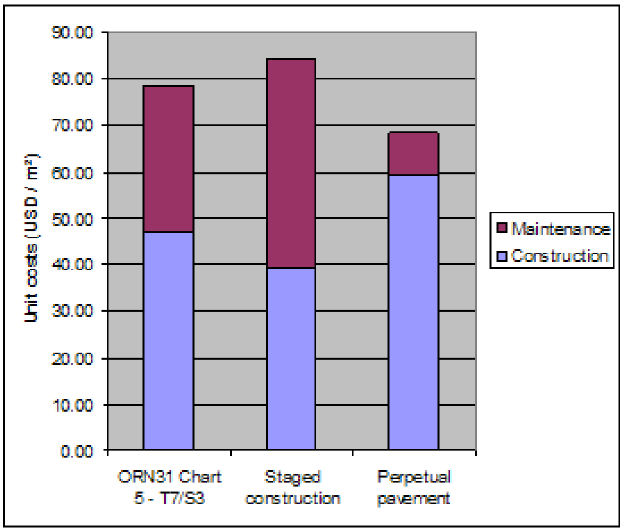
In that specific case, the impact of the various strategies on GHG emissions does not clearly appear to be significant over the whole life-cycle, except for stage construction which generates higher GHG emissions.

While the perpetual pavement method generates more GHG at initial construction, its maintenance is more GHG effective than that of other methods.

Illustrations (pictures, drawings):

Perpetual pavement on the Highway 406, Ontario, Canada (www.mto.gov.on.ca)

	Alternative Practice	
	PAV012 -Take maintenance into account during design	
	 **PerRoad® Software output: Structural cross section an material properties of a perpetual pavement**	
Documentation	Standards, guidelines, methodologies:	• ORN31 Chart 5 – S3/T7, Transport Research Laboratory • Long-life pavements, Transport Research Laboratory, 2001 • PerRoad mechanistic design software, Asphalt Alliance
	Involved organizations:	• Asphalt Pavement Alliance (APA) • World Road Association
	Websites:	• www.asphaltalliance.com • www.piarc.org • www.transport-links.org
	Other Reference documents:	• Asphalt Pavement Alliance (2001) Perpetual Pavement: Structured for the future. • Newcomb, E. D, Buncher, M., and Huddleston, I. J. (2001) Concepts of Perpetual Pavements, Transportation Research Circular No. 503, pp. 4-11. • Nunn, M. E., A. Brown, D. Weston, and J. C. Nicholls. (1997) Design of Long-Life Flexible Pavements for Heavy Traffic. TRL Report 250, Transport Research Laboratory, Crowthorne, U.K. • Von Quintus, H. L. (2001) Hot-Mix Asphalt Layer Thickness Design for Longer-Life • Bituminous Pavements, Transportation Research Circular No. 503, pp. 66-78.
Conditions for implementation	Requirements: • Heavy / high traffic	Incompatible with
GHG efficiency	Comparison with standard practice • Materials: • Equipment: • Transport:	Staged construction seems to lead to significantly higher total emissions and the perpetual pavement strategy seems to lead to slightly lower emissions than standard pavement structure after 40 years.

egis	Alternative Practice	
	PAV012 -Take maintenance into account during design	
	• Other variations (quantifiable or not):	It should however be noted that the damage factor after 40 years is significantly lower (i.e. better structural condition of the asset) in the case of perpetual pavement.
Costs	Comparison with standard practice	Take maintenance into account during design
		Without considering discount rate, although overall costs for perpetual pavement are lower than for the other options, its initial construction costs are significantly higher, and the corresponding financial impact may prevent project owners from selecting this option, especially in the case of private investors developing toll road projects under tight initial investment constraints. **Comparison of distributed costs between initial construction and maintenance activities depending on pavement construction / maintenance strategy** 
Filing information	Version: 0	Date: September 15, 2010

Alternative Practice		
egis	**STR001 – Make optimal use of materials (steel / concrete)**	
Related Work Components	Structures	Management Other

Description

General principle:

Construction industry practices, availability of standard industrial construction components or equipment (moulds) lead to standard design which may not be optimal in terms of GHG emissions.

The proposed alternative practice consists in comparing the relative merits, for the specific site conditions on the project, of:

- a reinforced / prestressed concrete structure
- a composite (steel / concrete) structure.

Technical description:

For more details the user may refer to applicable standards.

Life-Cycle data:

Existing studies indicate that the emission over the working life of the bridge is broadly similar for steel, concrete and steel–concrete composite structures at about 3.5 t CO_2/m^2. This is about as much as (slightly more than) the initial construction. Most of the maintenance emissions are from resurfacing of the bridge. The CO_2 from the traffic diversion will be dependent on the traffic volume, proportion of lorries and the diversion distance and may vary significantly

According to some studies, emissions during the life of the structure are significantly higher (between 3.5 and 4.8 times emissions due to construction) and mostly due to congestion due to closure of the bridge for maintenance purpose. This obviously has to be looked into as differences in maintenance planning and implementation may result is significant differences in terms of congestion and impact on traffic.

Sample maintenance scenario

Activity	Frequency (years)
Inspection	5
Joint replacement	20
Concrete Repair	30
Painting	25
Drainage cleaning	2
Bearing shelf cleaning	1
Water proofing	30

Illustrations (pictures, drawings):

Documentation

Standards, guidelines, methodologies:	• applicable standards
Involved organizations:	• Transport, Public works ministries • Road operators • Design consultants • contractors

<table>
<tr><td rowspan="2"></td><td colspan="3">Alternative Practice</td></tr>
<tr><td colspan="3">STR001 – Make optimal use of materials (steel / concrete)</td></tr>
<tr><td rowspan="2"></td><td>Websites:</td><td colspan="2"></td></tr>
<tr><td>Other Reference documents:</td><td colspan="2">• "an environmental comparison of bridge forms", Bridge Engineering 159 issue BE4, April 2010
• to "A model for appraising the sustainability of bridges" by A Amiri, C Arya & P R Vassie
• analysis of the life cycle of a bridge (Analyse du cycle de vie d’un pont) T87, Cimbéton</td></tr>
<tr><td>Conditions for implementation</td><td colspan="2">Requirements:
• flexibility in design</td><td>Incompatible with:
• Site specific constraints (highly corrosive environments, circulated roads…)</td></tr>
<tr><td>GHG efficiency</td><td>Comparison with standard practice</td><td colspan="2">Material type typically has an impact of less than 15% on GHG emissions for a given structure type.
However, there is no definite trend showing that a material type is less emitting than another.
It is therefore advised to perform a detailed assessment of the concrete and composite alternatives based on the site conditions (including distances to material sources).</td></tr>
<tr><td>Costs</td><td>Comparison with standard practice</td><td colspan="2">Costs depend on the status of the industry, and on the site conditions. A project specific assessment may also provide valuable information for decision makers.</td></tr>
<tr><td>Filing information</td><td colspan="2">Version: 0</td><td>Date: October 12, 2010</td></tr>
</table>

Alternative Practice

STR002 – Use fly ash in concrete

Related Work Components

Earthworks	Furniture
Drainage	Management
Utilities	Other
Pavement	
Structures	

Description

General principle:

Fly ash is a by product of coal power generation. It is available in large amounts, among others, in India and China. Production of fly ash is estimated to grow from 900 million tons in 2004 to 2 billion tons in 2020.

The principle of this alternative practice is to use this product, which would else have to be eliminated, as a cementitious binder to produce concrete.

Technical description:

From 2.2 billion tons in 2005, the cement production worldwide is expected to grow to more than 3.1 billion tons by 2015 and more than 3.5 in 2020. A large share of this increase is due to the development of Asia (mostly China, India) and Middle East. China is estimated to represent 45% of the demand, with an annual growth of 8.5%, while India's production was 145 million tons.

The coincidence of a large demand for cement, and of the availability of large quantities of fly ash makes this alternative practice interesting.

While it changes the material's behaviour, the replacement of cement by fly ash, for a proportion of up to 55% does not affect the long term performance of the concrete in a negative manner.

Life-Cycle data:

This alternative practice may increase the durability of concrete by reducing the requirement for water in the mix.

Illustrations (pictures, drawings):

Production and use of fly ash, 2004

Country	Production (million tonnes)	Utilization in Concrete %
China	>600	>15
India	>110	15%
U.S.A.	>60	10%
Russia	60	5
Germany	30	12
U.K.	10	10

Short term properties of concrete with fly ash

Fly ash trial group *	Slump, percent of initial slump minutes after completion of mixing				
	5 mins.	20	35	50	65
25% group average result	100	100	98	93	79
32.5% group average result	100	100	96	90	83
40% group average result	100	100	97	84	73

Medium term properties of fly ahs concrete

egis	Alternative Practice
	STR002 – Use fly ash in concrete

Compression strength MPa (480kg total cementitious)				
Age	1 day	3	7	28
25% group average result	21	48	63	85
32.5% group average result	13	43	59	78
40% group average result	8	39	54	75

Durability group compression strength MPa (incorporating microsilica)				
Age	1 day	3	7	28
25% Fly Ash, 520kg, 6% MS	20	52	75	114
40% Fly Ash, 500kg, 6% MS	16	44	65	97

C45 concrete mixes

≈ 380kg test group	Portland cement	Supplementary cement	C. AGG	F. AGG	Admix	Water	Density	WC ratio
Portland (ref)	380	0	1085	746	4	170	2385	0.45
Fly Ash (10%)	340	40	1093	726	4	170	2368	0.43
Fly Ash (25%)	285	95	1095	724	4	165	2368	0.43
Fly Ash (40%)	230	154	1111	727	4	159	2385	0.41
Fly Ash (55%)	170	208	1115	720	4	147	2364	0.39

Documentation	Standards, guidelines, methodologies:	
	Involved organizations:	
	Websites:	
	Other Reference documents:	• Role of fly ash in reducing greenhouse gas emissions during the manufacturing of protland cement clinker, V Mohan Malhotra
Conditions for implementation	Requirements: • Availability of fly ash • Proper mix design	Incompatible with:
GHG efficiency	Comparison with standard practice	The reductions in GHG emissions come from: • The replacement of cement by a binder which, as a by product, has a low GHG emission factor. This brings in a reduction of about 1 t eq CO_2/ton of cement replaced, or a reduction of 10 to 50% of the cement emissions. • The reduction of material transport. This materializes, when the source of fly ash is not too far from the batching plant and the

	Alternative Practice	
	STR002 – Use fly ash in concrete	
	site.	
Costs	Comparison with standard practice The impact of this alternative practice on cost is neutral.	
Filing information	Version: 0	Date: October 19, 2010

Egis	Alternative Practice	
	STR004 – Ensure recycling of steel	
Related Work Components	Drainage Utilities Pavement Structures	Furniture Management Other

Description	General principle: Along with lime and cement, steel is one of the main road construction materials contributing to GHG emissions from structures and road furniture (and pavement in the case of cement concrete pavement). Steel can be recycled, and in mature economies, recycled steel makes upto 50% of the input material for steel production. In developing economies, amounts of available steel to be recycled are not yet sufficient to make up similar proportions. Recycling steel at the end of life of the structure in which it is embedded can significantly reduce the emissions associated to the construction of the structure.
	Technical description: The alternative practice consists in ensuring recycling of steel products at the end of the structure life. Different industrial production processes exist for steel, including: • Production from ore in blast furnace • Production from recycled steel in electric furnace These processes result in different GHG emissions, and the producers optimize their production based on the available resources. Usually, "long products" which include reinforcement bars, cables, and beam or sheetpile profiles are made from recycled steel. The alternative practice aims at facilitating the recycling process, and to increase the proportion of recycled steel. The alternative practice does not consist in specifying the use of recycled steel. Industrials are responsible for this optimization, and the market of steel for recycling can be tense especially in emerging economies where little quantities of used steel are available for recycling so far. Unnecessary specifications may result in additional tensions on this market, and on significant transport emissions to source recycled steel from other countries.
	Life-Cycle data: This alternative practice has no impact on the life cycle apart from recycling at the end of life.
	Illustrations (pictures, drawings):

Documentation	Standards, guidelines, methodologies:	
	Involved organizations:	• Steel producers, steel manufacturers • Contractors • Design and supervision consultants
	Websites:	• http://www.worldsteel.org/
	Other Reference documents:	• The "CO_2 tool": CO_2 emissions and energy consumption of existing & breakthrough steelmaking

egis	Alternative Practice
	STR004 – Ensure recycling of steel
	routes, ULCOS
Conditions for implementation	Requirements: / Incompatible with:
GHG efficiency	Comparison with standard practice

The table below shows average GHG emission factors for various steel products used in construction. Factors are given for products taking recycling at the end of life into account or not.

The recycling at the end of life has a significant impact (between 25 and 50%) on the level of emissions and this practice can contribute to significant savings.

GWP in kg eq CO_2 per ton of steel	Sections (beams, billars)	Hot Dip Galvanised	Rebars (reinforcement)
cradle to gate data (excluding recycling at the end of life)	1 563	2 474	1 244
cradle to grave data (without use phase) with 90% recycling rate at the end of life	1 122	1 268	939

Costs	Comparison with standard practice This alternative practice has no impact on the costs.
Filing information	Version: 0 / Date: October 11, 2010

Alternative Practice

STR006 – Optimize alignment to minimize structures requirement

Related Work Components

Earthworks	Furniture
Drainage	Landscaping
Utilities	Management
Pavement	Other
Structures	

Description

General principle:

The construction of structures (tunnels, bridges, walls…) emits much more GHG than the construction of road on embankment.

The proposed alternative practice consists in optimizing the road alignment, for a given level of service and use, in order to minimize the requirement for structures.

Technical description:

The alternative practice consists in:

- Optimizing the alignment, for a given use, in order to reduce the number and dimensions of structures (walls, tunnels, bridges). Optimizations may include: shorter spans, better foundation ground, limited skew, shorter tunnels, lower and shorter walls. This may result in additional earthworks
- Optimizing the arrangement of some junctions where at grade crossings or junctions can provide a satisfactory level of service
- Defining optimal arrangements for the required structures minimizing their requirements (functional cross section, optimized start and end point, geotechnical surveys and design)

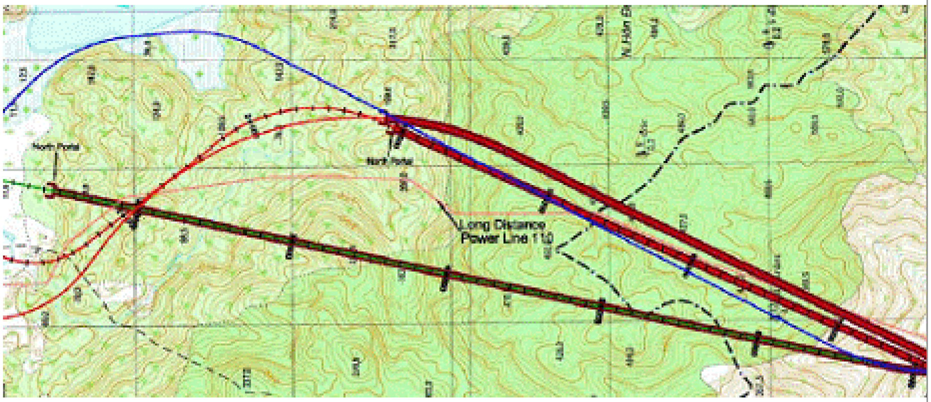
Life-Cycle data:

This alternative practice has an impact on the life cycle by decreasing the operation requirements, and affecting the maintenance requirements (replacing structure maintenance by pavement maintenance).

Operations of tunnels are likely to have a significant impact when compared to standard operations.

Illustrations (pictures, drawings):

Alignment optimization resulting in a significant decrease of the tunnel length



Documentation

Standards,	• Applicable road and structures standards

egis	Alternative Practice **STR006 – Optimize alignment to minimize structures requirement**	
	guidelines, methodologies:	
	Involved organizations:	• Transport and public works authorities • Design consultants
	Websites:	
	Other Reference documents:	• Flexibility in highway design, ASHTO • Overseas road note 6, TRL
Conditions for implementation	Requirements: • Possibility to optimize the design (time available, institutional arrangements)	Incompatible with: • Fixed design with no flexibility given to designer
GHG efficiency	Comparison with standard practice	The following table summarizes the orders of magnitude of GHG emissions from construction for various road configurations:

(tCO_2eq/km)	Embankment	Bridge	Tunnel
Expressway	2.971	74.397	75.547
National Highway	739	35.649	37.773
Provincial Road	191	27.899	30.219
Rural Road	100	20.127	23.608

Which is analyzed below in terms of comparison between the various configurations

Emissions ratio	Bridge / embankment	Tunnel / embankment
Expressway	25	25
National Highway	48	51
Provincial Road	146	158
Rural Road	201	236

This impact is obtained through the reduction of the quantities of materials (cement, steel) and their transport, as well as through the use of different construction equipment.

Costs	Comparison with standard practice	Costs are highly variable depending on a project's specific constraints. As an order of magnitude sections involving significant structures such as tunnels or bridges can be 5 to 10 times more expensive.
Filing information	Version: 0	Date: October 11, 2010