Life cycle analysis of transport modes

Final report
Volume II – Summary of literature reviews and primary questionnaires used for data collection

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Abbreviations[1]

AC	Alternating Current
AEI	Auroville Earth Institute
Al	Aluminium
AMC	Ahmedabad Municipal Corporation
APL	Aretefact Projects Ltd.
ARAI	Automotive Research Association of India
ASS	Annual Statistical Statements
B.G.	Broad Gauge
BEE	Bureau of Energy Efficiency (India)
BIS	Bureau of Indian Standards
BoQ	Bill of Quantities
BRTS	Bus Rapid Transit System
Btu	British thermal unit
CEA	Central Electricity Authority
CEPT	Center for Environmental Planning and Technology University
CO_2	Carbon dioxide
CS	Carbon Sequestration
CWR	Continuous Welded Rail
DBFOT	Design, Build, Finance, Operate and Transfer
DMRC	Delhi Metro Rail Corporation
ELV	End-of-Life Vehicles
ERC	Elastic Rail Clips
FRP	Fibre Reinforced Plastic

[1] Abbreviation for Volume I and II

g	gram
G.I.	Galvanized Iron
GHG	Greenhouse as
GIDB	Gujarat Infrastructure Development Board
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
HPEC	High Powered Expert Committee
HVAC	Heating, Ventilation, and Air Conditioning
HYSD	High Yield Strength Deformed (steel)
IRC	Indian Roads Congress
IRS	Indian Railway Standard Specification
KEPL	Kurukshetra Expressway Pvt. Ltd.
kg	kilogram
kJ	kilo joule
kl	kilo litre
km/kms	kilo metre
kV	kilo Volt
l	litre
lb	pound
LCA	Life Cycle Analysis
LDO	Light Diesel Oil
LPG	Liquefied Petroleum Gas
LWR	Long Welded Rail
m/mts	Metre
Mg	Magnesium
MIPS	Material Input Per Service unit

MMU	Mobile Maintenance Units
MoEF	Ministry of Environment and Forests (India)
MoRTH	Ministry of Road Transport and Highways (India)
MRTS	Mass Rapid Transit System
MS	Mild Steel
MUPB	Mobility-Umwelt-Belastungs-Punkte
NEWNE	Northern, Eastern, Western, and North-Eastern grid
NH	National Highway
NHAI	National Highway Authority of India
NHDP	National Highway Development Programme
NMV	Non-motorized vehicle
NR	Northern Railways
NRCO	Northern Railways Construction Organization
OMU	On-track Machines Unit
PDD	Project Design Document
PIU	Project Implementation Unit
PKM/PKT	Passenger kilometres travelled
PVC	Polyvinyl chloride
PWD	Public Works Department
RCC	Reinforced Cement Concrete
ROW	Right of Way
SIAM	Society of Indian Automobile Manufacturers
SRTU	State Road Transport Undertaking
T	tonne
TBM	Tunnel Boring Machine

TERI	The Energy and Resources Institute
TJ	Tera joule
UIC	International Union of Railways
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
vkm	Vehicle kilometre
WBM	Water Bound Macadam

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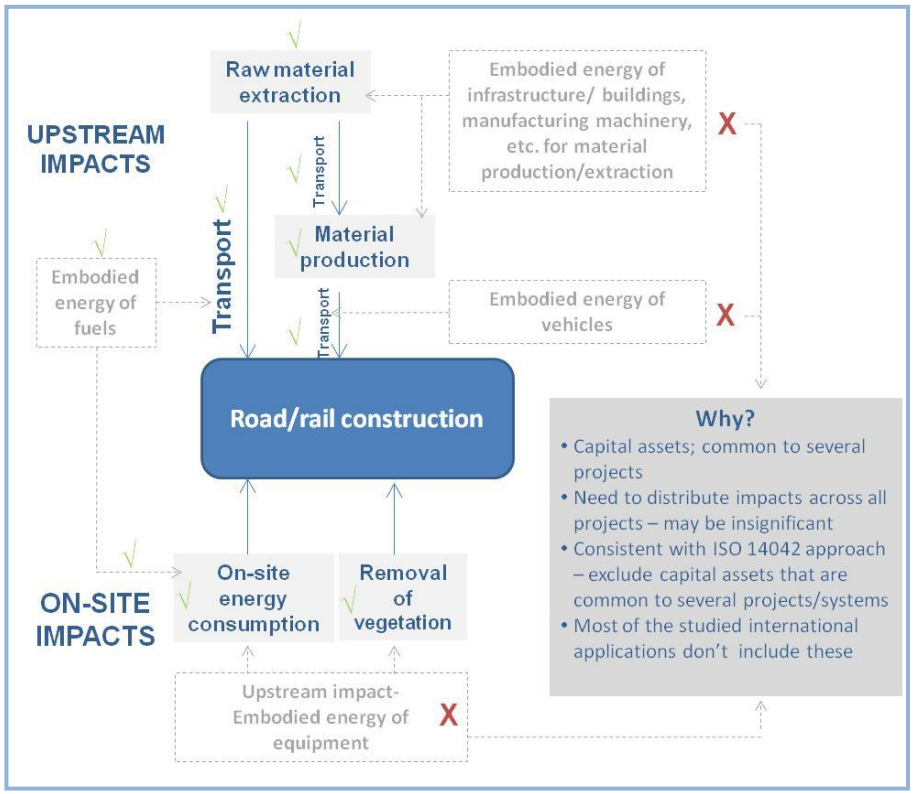
1. Literature review: Construction of transport infrastructure

India is witnessing massive construction activities in infrastructure sectors. Transport sector in particular has seen significant construction of highways, roads, ports, railways, and airports over the last decade. Undoubtedly, creation of transportation infrastructure has had an important role in the fast pace of economic growth being observed in the country but not without its impact on environment. Although large scale transport projects are subjected to techno-economic feasibility and environmental impact analysis, energy and climate change considerations do not particularly form the basis of decisions regarding which transport projects/modes to be promoted. In today's times, when the sensitivity towards energy security and climate change concerns has grown, it is important that the decisions related to transport sector growth take due consideration of these for all stages of transport infrastructure creation. Construction and maintenance stages of transport projects are usually ignored while understanding the energy impacts; focus typically being on the tail-pipe impact of transport operations.

As stated in the Volume I, this study is aiming to estimate the energy and CO_2 emissions impacts of transport infrastructure for all its life stages: construction, operations and maintenance so that these results can be used in decisions related to mode choice in addition to the economic and environmental criteria existing today. The study has selected five types of transport infrastructure – National Highways (NH), long-distance rail, urban roads, Bus Rapid Transit System (BRTS) and metro rail system. This section is aiming to highlight the construction stage impacts of all these five modes in terms of material and energy consumption. Figure 1.1 describes the scope of impact analysis for construction stage of transport infrastructure projects considered in this study.

Figure 1.1 Scope of construction stage impact analysis



1.1 Upstream impacts of construction – Material production and transportation

Manufacture of construction materials involves several processes. For manufacturing construction materials, raw materials are extracted from the earth and transported to a processing facility. Processed materials are then transported to a manufacturing facility where different materials from different sources are used together to manufacture a finished product. The finished product is then transported to the site and used in construction. Towards the end of its life-cycle, the material is demolished and disposed. Energy is used and emissions generated in each and every step of this process i.e. raw material extraction/mining, transportation, processing, manufacturing, construction/installation and disposal.

Embodied energy of materials is defined as the sum total of all energy sequestered in construction materials during all processes of production, on-site construction and final demolition and disposal.[2]

Embodied energy of construction materials can be divided into following stages:

- Energy used during extraction, processing and manufacturing of materials;
- Energy used in transportation of finished materials from manufacturing/ prefabrication plant to site;

Once construction materials reach the site, energy consumption occurs in:

- Installation of materials/construction on site;
- Maintenance over the life cycle of the material; and
- Disposal.

It is expected that embodied energy of construction materials forms a significant proportion of the overall energy consumed during the lifecycle of a given mode of transport. Therefore, it becomes critical to understand the embodied energy values of the key construction materials used in the transportation sector.

1.1.1 Calculation of embodied energy of construction

There are two broad methods of calculating embodied energy of construction materials:

- Process based analysis, and
- Input-output based analysis.

Process based analysis: In the process based analysis, the construction material is considered to be the final product. Then one works backwards, upstream in order to identify the various processes involved in contributing to the manufacturing of the final product and accounts for all possible energy inputs to those processes. This is one of the most commonly used methods to calculate embodied energy as it delivers reliable results. This method, however, has a limitation; since there can be numerous upstream processes, for practical considerations, a system boundary is usually defined and energy inputs of all processes within that system boundary are considered. This renders the calculation incomplete since there are several processes which get eliminated.

[2] Manish Kumar Dixit, Jose L. Fernandez-Solis, Sarel Lavy, Charles H. Culp, Identification of parameters for embodied energy measurement: A literature review, Energy and Buildings, Elsevier,2010

Input-output based analysis: In the input-output based analysis, economic data pertaining to the overall money flow across various sectors of the industry is considered. This is then converted into energy flows across various sectors of the economy using the average energy tariffs. The embodied energy of the product is then calculated by multiplying the cost of the product with the energy intensity of the product.[3] This method is expected to be more accurate and complete than the process based method; but this also has certain limitations. This method assumes that the entire economy is homogenous and is susceptible to uncertainty of data like energy tariffs, etc. Another aspect of error with this analysis is that it assumes calculations based on aggregation and grouping of various sectors which might deviate from the actual scenario.

Due to the various limitations of both the processes, hybrid analysis methods are used to estimate the embodied energy of materials. Hybrid analysis methods can be either process based hybrid analysis or input-output based hybrid analysis. Besides the system boundaries and analysis methods, several other factors influence the embodied energy calculations and may result in inaccuracies. Some of these factors below:

- **Differing system boundaries:** During embodied energy calculations, different researchers consider different system boundaries to enable them to collect data and calculate the embodied energy. This system boundary could be cradle to grave, cradle to site or cradle to cradle. Each researcher might select a different system boundary depending upon the complexity of the various processes involved in the manufacture of the product and availability of data. Inaccuracies occur when during the embodied energy calculation of various constituents of a product, numbers derived from different system boundaries are considered together. Inclusion of the certain upstream and/or downstream processes in one component and exclusion of the same in the other might lead to inaccurate results if both such numbers are used together. System boundary definition, therefore, becomes one of the most important factors to be considered while considering various embodied energy numbers.
- **Data source with respect to different countries or regions:** Different countries have different manufacturing sectors, different technologies, raw materials, energy sources, consumption patterns, technology of transportation modes, etc. The energy source itself may vary in different countries, for example, in some countries electricity is primarily generated by coal based thermal power plants, while in others, nuclear power may be the main source for electricity generation. This leads to significant deviation in embodied energy of materials between different countries. Even within each country, different geographic locations and energy and transportation sources can lead to different overall embodied energy numbers for a given material.
- **Data sources from different time periods:** While calculating the embodied energy number of a given product, embodied energy numbers of its constituent parts are also considered. In case the embodied energy numbers of the constituent parts do not belong to the same year/time period, they might result in inaccuracies during the overall embodied energy calculation. Old embodied energy data might not account for newer modifications in manufacturing and processing technologies, improvements in transportation modes, etc. Therefore, it is important to select

[3] Manish Kumar Dixit, Jose L. Fernandez-Solis, Sarel Lavy, Charles H. Culp, Identification of parameters for embodied energy measurement: A literature review, Energy and Buildings, Elsevier,2010

embodied energy numbers for all the materials from as common a timeline as possible in order to reduce the level of inaccuracy.

- **Source and completeness of data:** Often the data sources selected in different embodied energy studies may vary from one another. Some researchers collect primary data while others derive numbers from secondary sources. The differing choice of data source tends to impact the final output. Majority of the researchers carry out secondary research to establish sources for embodied energy numbers. In such cases, incompleteness of data, since data depends upon the method used by the researcher to gather information, impacts the final outcome of the embodied energy study.
- **Selection of appropriately representative technologies:** For a given time and location, a product can be manufactured using different technologies which would result in varying embodied energy numbers due to efficiencies of different manufacturing technologies. In such a scenario, selecting the most appropriate and representative technology becomes critical. Additionally, different regions might be using different technologies. Therefore during the calculation of an overall country common embodied energy number, the most appropriate and representative technology should be considered.
- **Consumption of sources like oil etc.:** Oil and gas products are used in the manufacture of several products used in the transportation sector. Here, these are used as raw materials instead of an energy source. This energy used as an ingredient in the manufacturing process is known as Feedstock Energy.[4] Feedstock energy needs to be considered during the embodied energy calculation of materials.

1.1.2 India specific embodied energy and CO_2 numbers for construction materials

In India, over the last decade, certain amount of research is being carried out in order to arrive at embodied energy and CO_2 numbers for construction materials. Given the construction and manufacturing scenario in India, lack of monitoring and data collection are the major stumbling blocks with respect to embodied energy calculations.

Over the last decade, a few researchers/institutes have worked on establishing embodied energy and CO_2 numbers for different materials commonly used during the construction processes. The number of such studies however is limited and doesn't leave much choice for selection of embodied energy numbers.

After literature review on the subject, the calculations for embodied energy and CO_2 done by Auroville Earth Institute (AEI) were found most relevant and comprehensive (AEI, 2009). AEI (2009) covers a range of construction materials and estimates India-specific[5] embodied energy and CO_2 values for the same. The scope of embodied energy and CO_2 numbers considered from AEI (2009) includes energy and CO_2 on account of:

- Raw material extraction/processing
- Processing of raw materials to produce finished material

[4] Manish Kumar Dixit, Jose L. Fernandez-Solis, Sarel Lavy, Charles H. Culp, identification of parameters for embodied energy measurement: A literature review, Energy and Buildings, Elsevier,2010

[5] In some instances, where India-specific data is not available, AEI (2009) relies on international literature for embodied energy and CO_2 values.

In case, embodied energy and CO_2 coefficients were not available from AEI (2009) for some materials, international literature was refereed for the same. Table 1.1 gives the embodied energy and CO_2 coefficients considered for some key construction materials in this study.

For the data on transportation of finished materials from manufacturing plants/retail outlets to the construction site, TERI collected primary data for specific projects studied. As described in Chapter 1 (Volume I), following information was collected from project contractors/implementing agencies to estimate energy and CO_2 for transportation of materials to site.

- Source from where finished material is being brought (location)
- Distance from site (average lead)
- Mode of transporting material to site (vehicle type, its fuel type and fuel efficiency, average loading, number of trips made to transport the total quantity of material used on-site)

In addition to the above listed data on transportation details for materials, data related to on-site energy consumption for construction processes was also collected.

Table 1.1 Embodied energy and CO_2 coefficients of some key construction materials

Material	Embodied energy coefficient	Unit	Embodied CO_2 coefficient	Unit
Coarse aggregate	0.2200	MJ/kg	0.0216	kg/kg coarse aggregate
Cement	9.7800	MJ/kg	0.8800	kg/kg cement
Fine aggregate	0.0204	MJ/kg	0.0020	kg/kg fine aggregate
Bitumen[1]	44.7000	MJ/kg	0.4800	kg/kg bitumen
Steel	33.3300	MJ/kg	3.0000	kg/kg steel
Galvanized steel (sheet or wire)	50.8000	MJ/kg	4.9780	kg/kg galvanized steel
Bitumen emulsion[2]	31.2900	MJ/kg	0.3360	kg/kg bitumen emulsion
Earthwork	0.0132	MJ/kg	0.0010	kg/kg earthwork
Brick[3]	3.4600	MJ/brick piece	0.3400	kg/brick piece
Rubber[1]	120.0000	MJ/kg	4.2500	kg/kg rubber
Cast iron[1]	20.5000	MJ/kg	1.3100	kg/kg cast iron
Glass[4]	26.2000	MJ/kg	2.5670	kg/kg glass

Material	Embodied energy coefficient	Unit	Embodied CO_2 coefficient	Unit
Aluminium	260.0000	MJ/kg	25.4800	kg/kg aluminium

[1] Source: Hammond and Jones (2008) (Embodied energy and CO_2 numbers for UK)

[2] Bitumen emulsion: Embodied energy and CO_2 has been estimated assuming it contains 70% bitumen, 1.5% chemical additives and rest water

[3] Kiln fired brick

[4] Source: Baird et al (1997) (Embodied energy and CO_2 numbers for New Zealand)

1.2 Road construction (National Highways and urban roads)

Government of India has been promoting the growth of roads sector during the past decade and has launched several programmes to channelize the same. The scale of road construction activities being undertaken in the country can be gauged from the fact that the road sector expenditures have gone up from 3% of the total Plan expenditure in the Ninth Five Year Plan (1997-2002), to almost 12% today[6]. The central sector outlay for road transport sector for the Eleventh Five Year Plan at current prices was Rs. 11.31 billion[7]. Considering that typically 95% of the road sector budget is used for civil works, about Rs. 10.75 billion is expected as being utilized in construction of roads in the current Plan period. A large portion of this investment is being utilized for the construction of National Highways.

The current phases of the National Highway Development Programme (NHDP) of the government target improving about 48,000 km of arterial routes of NH Network to international standards.[8] This has translated into massive construction activities being undertaken throughout the country. Table 1.2 gives the status of road construction activities undertaken by the National Highways Authority of India (NHAI) as on 29 February, 2012; NHAI had completed four-laning of more than 17,000 kms of highways and aims to undertake additional construction of about 19,900 kms under its flagship initiatives.

Table 1.2 Construction of Highways by the National Highways Authority of India (status as on 29 February, 2012)

	NHDP	Port Connectivity	Others	Total by NHAI
Total Length (km)	48,254	380	1390	50,412
Already 4-Laned (km)	16,069	349	946	17,380

[6] The International Bank for Reconstruction and Development/The World Bank (2008)- Indian Road Construction Industry: Capacity Issues, Constraints & Recommendations

[7] Planning Commission of India (2007) 11th Five Year Plan, Volume III, Chapter 9

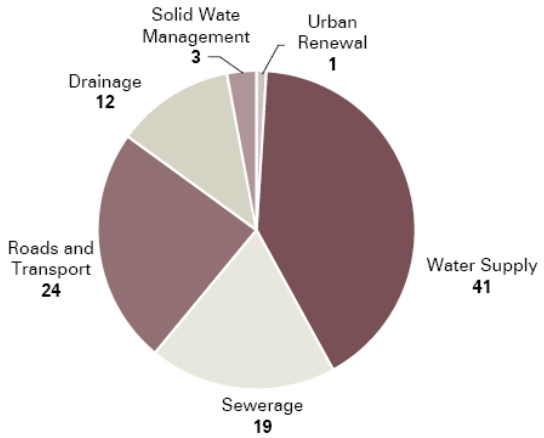
[8] http://www.nhai.org/WHATITIS.asp, last accessed on 29 March, 2012.

	NHDP	Port Connectivity	Others	Total by NHAI
Under Implementation (km)	12,416	31	424	12,967
Contracts under Implementation (No.)	143	4	4	153
Balance length for award (km)	19,611	0	20	19,907

Source: National Highways Authority of India (NHAI)[9]

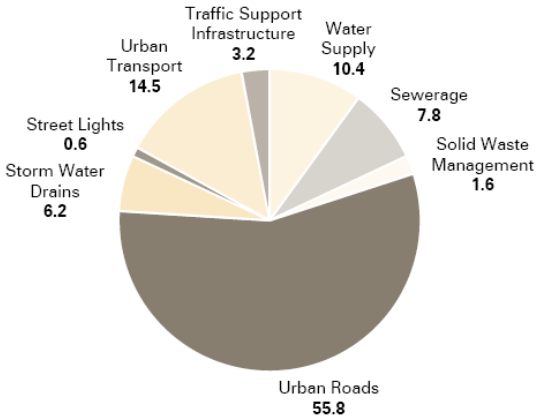
In addition to giving impetus to the development of National Highways, the Government of India has also been promoting growth of urban transport infrastructure including urban roads. The Jawaharlal Nehru National Urban Renewal Mission (JNNURM), which was launched in 2005 is assisting 65 cities in the country to upgrade their infrastructure and services. A large number of these cities have undertaken road construction activities as part of their city development agenda. As on December, 2010, about 24% of the JNNURM funds had been spent in urban transport sector (figure 1.2). The 'Report on Indian Urban Infrastructure and Services (2011)'[10] estimates investment requirement of about Rs. 31 lakh crores[11] from 2012 to 2031 for development of urban infrastructure in the country; urban roads constitute the highest share (56%) of this investment requirement (figure 1.3).

Figure 1.2 Sector-wise spending under JNNURM (% share) (Status as on 1 December, 2010)



[9] http://www.nhai.org/WHATITIS.asp, last accessed on 29 March, 2012.
[10] Report (2011) of the High Powered Expert Committee (HPEC) set up by the Ministry of Urban Development for estimating the investment requirements for urban infrastructure services
[11] At 2008-09 prices

Figure 1.3 Sector-wise shares of total investment requirements (Rs. 31 lakh crores) for urban infrastructure development from 2012 to 2031



Source for figures 2.2 and 2.3: Report on Indian Urban Infrastructure and Services, 2011[12]

The discussions above highlight the emphasis being given on the construction of National Highways and urban roads through the flagship programmes of the government. This translates into massive on-going and future road construction activities. As stated earlier, these construction activities would be accompanied with environmental impacts, which are typically ignored in conventional decision-making processes. The subsequent section highlights the key construction practices for National Highways and major urban roads (based on literature review) in order to understand the material and energy inputs for road construction activities.

The structure of National Highways and major urban roads is typically similar, except a few components like sidewalks, parking lanes, cycle tracks, etc. that are present in urban roads/urban sections of National Highways. Hence, the construction details for both, National Highways and major urban roads are dealt here in unison. Major differences in components have been highlighted in the description wherever applicable.

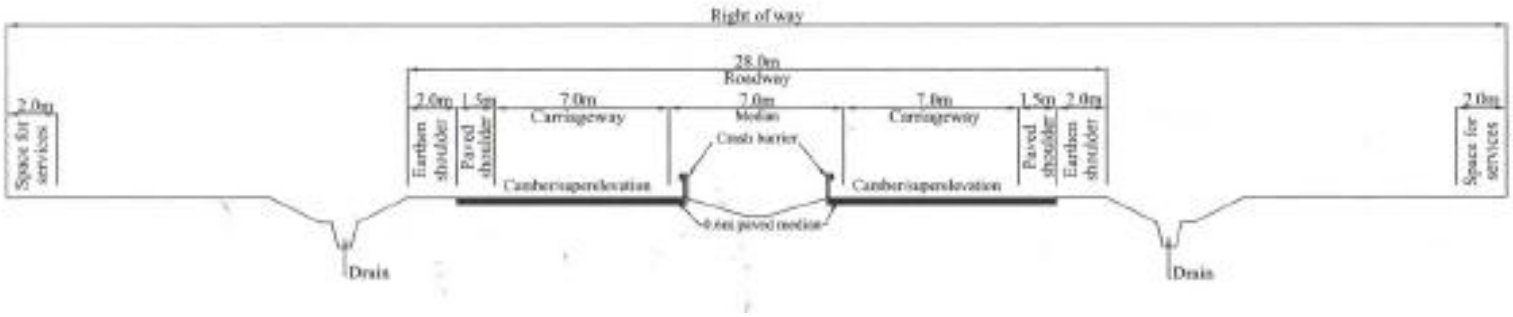
1.2.1 Design elements of roads

Typically, the horizontal cross-sectional elements of a road include (figures 1.4 and 1.5):

- Pavement/carriageway
- Median and kerb (traffic separators)
- Shoulder (paved and unpaved) and embankment slope (road margins)
- Parking lane, frontage road, cycle track, footpath, guard rail (more common in urban roads/urban sections of highways)
- Space for utilities
- Storm water drains

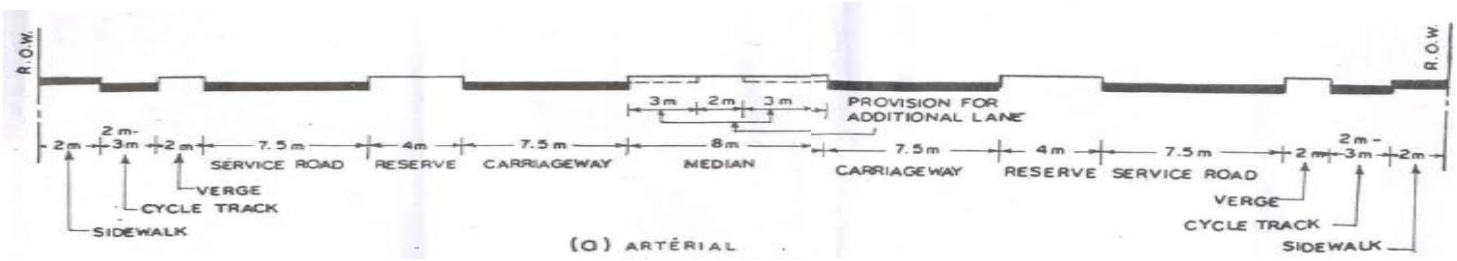
[12] Report (2011) of the High Powered Expert Committee (HPEC) set up by the Ministry of Urban Development for estimating the investment requirements for urban infrastructure services

Figure 1.4 Typical cross section of a 4-lane divided highway



Source: Four-laning of Highways through Public Private Partnership, Manual of Specifications & Standards, NHAI

Figure 1.5 Typical cross section of an urban arterial road



Source- Indian Roads Congress (IRC) code 86-1983

1.2.2 Construction stages

The construction of roads may be divided into the following stages:

- **Pre-construction**: Reconnaissance, preliminary surveys, decisions on final alignment, detailed surveys, material surveys and designing of sections at several points.
- **Construction**: Site clearance (removal of vegetation/shifting of utilities), earthwork (cut/fill); works related to drainage system and utilities; and construction of embankments, pavement (subgrade, sub-base and surface courses), median, kerb, footpath, cycle track, and other cross sectional elements.
- **Post construction:** Quality check for finished surface, camber, super elevation; installation of signages, street lights, traffic lights; and painting of road markings, kerbs, rails, etc.

1.2.3 Construction of carriageway

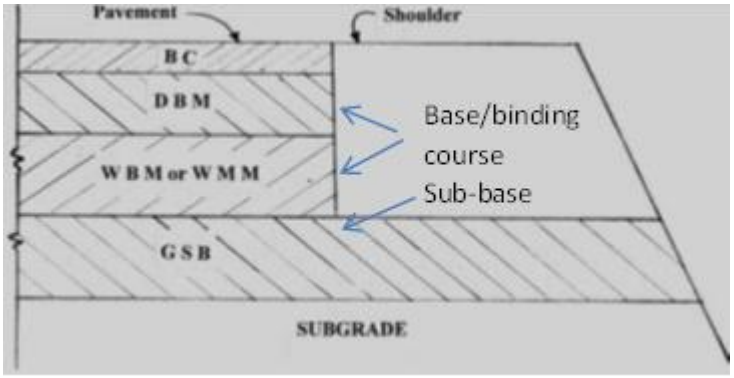
Carriageway/pavement is the most important component of the cross section of both NH and urban road. Based on the structural behaviour, pavements are generally classified into two categories:

- Flexible pavements
- Rigid pavements

The thickness of each layer and the mix of materials to be used for different pavements depends on factors like design life of the pavements, load factors, drainage conditions, soil type, environmental factors and availability of local materials[13].

Typically, pavements consist of the following layers: soil subgrade, base course, sub base course and the pavement course. Depending on the type of pavement, the mix for base, sub base and pavement course may vary as shown in figures 1.6 and 1.7. In India, most of the National Highways and urban roads have flexible pavements. However, advances in concrete technology and reduced life cycle costs are encouraging construction of rigid pavements.

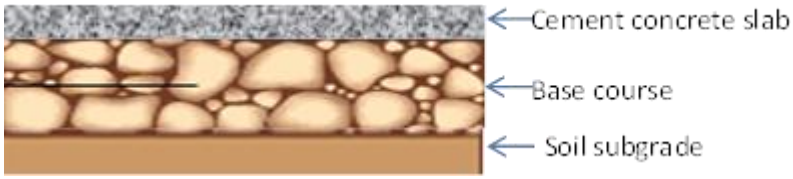
Figure 1.6 Typical cross section of flexible pavements in India



BC- Bituminous Concrete, DBM- Dense Bituminous Macadam, WBM- Water Bound Macadam, GSB- Granular sub base

Source: Kandhal et al (2008)[14]

Figure 1.7 Components of rigid pavement in India



Source: Khanna et al (2010)[15]

The current study is limiting its scope to bituminous pavements only, the primary reason being that most of the National Highways and urban roads in the country have bituminous pavements. Though cement concrete technology for pavements has seen some penetration, the bituminous pavements will continue being the dominant pavement technology. The stages for constructing bituminous pavements are discussed below:

Earthwork[16]

Earthwork is the process wherein the subgrade soil is prepared by bringing it to the desired grade and camber by compacting adequately. Depending on the proposed alignment of the

[13] S.K. Khanna and C.E.G. Justo (2010) Highway Engineering, Chapter 7
[14] P. S. Kandhal, V. K. Sinha, and A. Veeraragavan (2008), A Critical Review of Bituminous Mixes Used in India, Journal of the Indian Roads Congress, Volume 69-2, July-September 2008, Paper No. 541
[15] S.K. Khanna and C.E.G. Justo (2010), Highway Engineering, Chapter 7
[16] Ibid.

road below or above the ground level, excavation or embankment may be needed. Granular soil is generally preferred as highway embankment material. At times, it may be necessary to improve the stability or bearing capacity of the soil by use of controlled compaction, proportioning or addition of suitable admixtures or stabilizers. Use of cementing agents like portland cement, lime or lime-fly-ash, bituminous materials, etc. is done for stabilization.

Preparation of subgrade[17]

The preparation of subgrade includes all operations before the pavement structure could be laid over it and compacted. This includes site clearance, grading (embankment and cut section) and compaction.

Preparation of granular sub base (optional)

A layer of aggregates/broken stone is utilized for preparation of sub base.

Construction of water bound macadam (WBM) roads with bituminous pavements

The following process is followed for the construction of WBM bituminous pavements:

- **Preparation of base/binder course-** This includes spreading coarse aggregate uniformly, compacting using rollers, application of screenings, sprinkling and grouting, and application of binding material, rolling, setting and drying.
- **Application of tack coat-** Bitumen tack coat is applied over bituminous base or binder course.
- **Preparation and laying of pavement course-** Depending upon the type of bituminous pavement desired, the mix is prepared using hand drum mixer or hot mixer and is laid or spread using a mechanical paver. Material for the mix is usually bitumen, aggregate, stone chippings and sand. Rolling commences soon after the pavement mix is laid.
- **Application of seal coat-** A seal coat of sand and bitumen is applied as a seal coat and rolled.

Materials[18]

The main materials utilized for construction of bituminous pavements include bitumen, sand and aggregate/stone chippings.

1.2.4 Construction of sidewalk/parking lane (urban roads/urban sections of National Highways)

The minimum width of a sidewalk as prescribed in the IRC standards is 1.5 meters[19]; sidewalks can be with or without handrails. Parking lanes typically provided on sub-arterial, collector and local roads (in residential, institutional and shopping areas) have a width of 3 meters[20]. Various materials can be utilized for construction of pavements of sidewalks and parking lane like, precast concrete slabs, sand stone, etc.; the most common material utilized is the interlocking concrete paver blocks[21]. Recommended grade of paver blocks is M25-M30[22].

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[17] Ibid.

[18] Only major materials are described here. BoQs of relevant projects have been referred to in order to identify main materials.

[19] IRC:86-1983, Geometric Design Standards for Urban Roads in Plains

[20] Ibid.

[21] IRC:SP:62-2004, Guidelines for the Use of Interlocking Concrete Block Pavement

[22] IS:15658-2006 on "Precast Concrete Blocks for Paving (Specification BIS)

Construction of pavement of sidewalk/parking lane using interlocking concrete blocks[23]

The cross section of sidewalk/parking lane consists of the subgrade, base course, bedding and paving blocks. Although, local availability and economics generally dictate the choice of base material at the design stage, the materials considered suitable for base courses are unbound crushed rock, water-bound macadam, wet mix macadam, cement bound crushed rock/granular materials, and lean cement concrete/dry lean concrete.

The construction involves levelling and compaction of sub grade; laying of the base course; installation of edge restraints (kerb); placing of sand bedding and compaction; placing of blocks and interlocking; and filling of empty portions especially near restrains by cement concrete.

Materials

Main materials used include cement concrete pavement blocks, cement, aggregate, sand, crushed stone/gravel, curing compound and iron/steel guard rails.

1.2.5 Construction of medians/traffic islands

Medians/traffic islands are raised and kerbed at the perimeter and the enclosed area is filled with earth and suitably covered with grass turf/shrubs. The width of the median depends on the available right of way (ROW), terrain, etc. As per IRC codes, the minimum width of median is 1.2 metres (desirable width is 5 metres); for highways, it is 2 metres for built up area and 4.5 metres in open country areas[24]. Construction of medians/traffic islands involves laying of kerb stones at the perimeter. The confined area in the kerb is filled with local earth or granular material and compacted. The compacted area is finished with grass/shrubs in case of earth fill, whereas tiles/slabs/paving in case of granular fill. Paving can be concrete blocks, sand stone, etc. and construction is similar to that of sidewalk/parking lane pavements.[25]

Materials

Main materials used include kerb stones (cement, aggregate, sand), earth and granular material.

1.2.6 Mounting kerbs[26]

Kerbs are usually present alongside the central median and/or along the footpath in case of urban roads. These are usually pre-cast or cast-in-situ in M20 cement concrete. Kerbs are laid on existing pavement or M15 cement concrete and painted with two coats of synthetic enamel paint and primer.

Materials

Main materials used include kerb stones (pre-cast or casted in-situ), cement, aggregate, sand, water, paint and primer.

[23] Sharma S D (2009), Interlocking Concrete Paver Blocks: An Easy Approach for Road Construction, New Building Material and Construction Work (September 2009)
[24] IRC:SP:84- 2009 Manual for Specifications & Standards for Four Laning of Highways through Public Private Partnership
[25] MoRTH Specifications on Road and Bridge Works, Clause 407
[26] MoRTH Specification on Road and Bridge Works Clause 408

1.2.7 Installing roadside/median safety and noise barriers (highway)[27]

Roadside barriers provide safeguard against two types of roadside hazards- embankments and roadside obstacles and preventing the vehicles from veering off the sharp curves. Median safety barriers are provided on highways with narrow medians to avoid accidents. Recently noise barriers are being provided along highways passing through inhabited areas.

Steel or concrete (cast in situ or pre-cast) barriers are typically used. Steel barriers are erected using channel sections, whereas concrete barriers are laid on grout bed and joints are made using HYSD bars.

Materials

Main materials used include cement, aggregate, sand, water, and steel.

1.2.8 Installing lighting poles

Lighting on the roads is supported on G.I. poles which in turn are held in reinforced cement concrete (RCC) foundation. RCC M20 foundation is constructed with PVC pipe for cable entry and anchor plate. G.I. poles are mounted on the foundation using base plate and bolt.[28]

Materials

Main materials used include cement, sand, aggregate, reinforcement, steel, iron, and lighting fixtures.

1.2.9 Installing road signs

Road signs are either kerb mounted or overhead signs that are placed on a structurally sound gantry or cantilever structure made of G.I. pipes. Overhead signs are supported by civil foundation in M15 cement concrete. The road signs are typically made of retro-reflective sheeting of high intensity grade with encapsulated lens fixed over aluminium sub-strata.

Materials

Main materials used include cement, sand, aggregate, water, and aluminium sheeting.

1.2.10 Road Markings (highway and urban roads)

Road markings comprise of carriageway markings and markings on intersections, hazardous locations, parking areas, etc. The markings can be done by thermoplastic paint or can be in the form of plastic sheet flushed with the pavement surface. Raised pavement markers (cat eyes/road studs) are used to improve visibility of the roads in the night. These are prismatic retro reflective type.

Materials

Main materials used include paint and primer.

[27] IRC:SP:84- 2009 Manual for Specifications & Standards for Four Laning of Highways through Public Private Partnership

[28] Delhi Transco Limited (2006) Standards for Integrated Street Lighting Project for Delhi

1.3 Construction of Bus Rapid Transit Systems (BRTS)[29]

BRTS is a public transportation system that uses buses to provide faster and more efficient service. This is often achieved by improvements in infrastructure like providing dedicated bus lanes and enhancing vehicle technology. Significant amount of time is consumed in pre-construction activities like planning of the BRTS including identification of corridors, feasibility studies, social and environmental impact studies, etc.

As being witnessed in many cities of the world, BRTS can make an important contribution towards promoting sustainability of urban transport systems. It is more energy efficient than conventional bus systems (on a per passenger km basis) due to the higher speeds and higher capacity buses[30]. From the construction perspective, most of the cross sectional elements of BRTS are same as that for urban roads. The width of each element/presence may be decided by the design and right-of-way (ROW) available.

1.3.1 Design elements of BRTS[31]

The design elements of BRTS are as follows (figures 1.8 and 1.9):

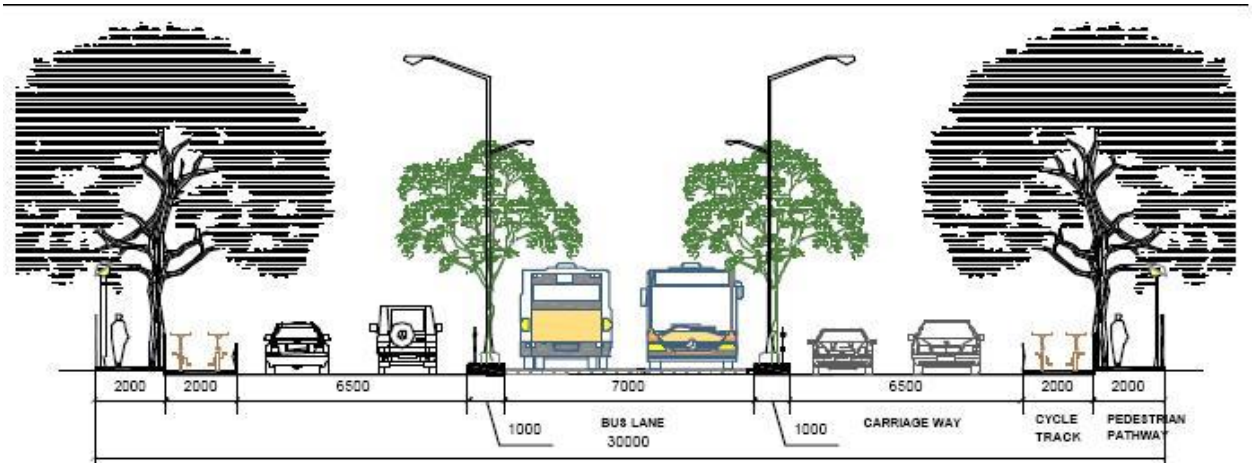
- Bus lane
- Motor vehicle lane
- Non-motorized vehicle (NMV) lane (cycle and cycle rickshaws)
- Pedestrian pathway
- Service lane/parking lane/hawker zone
- Median/edge treatment
- Traffic signages and road markings
- Street furniture
- Street lighting
- Bus stops, etc.
- Rolling stock- Buses

[29] There is no specified code/standard that guides the construction of BRTS in India, however for construction of traditional elements like carriageway and sidewalks, medians, etc. MoRTH Specifications for Bridge and Road works are utilized with certain modifications.

[30] ClimateTech Wiki, Bus Rapid Transit Systems, http://climatetechwiki.org/technology/brt, last accessed on 19th August, 2011

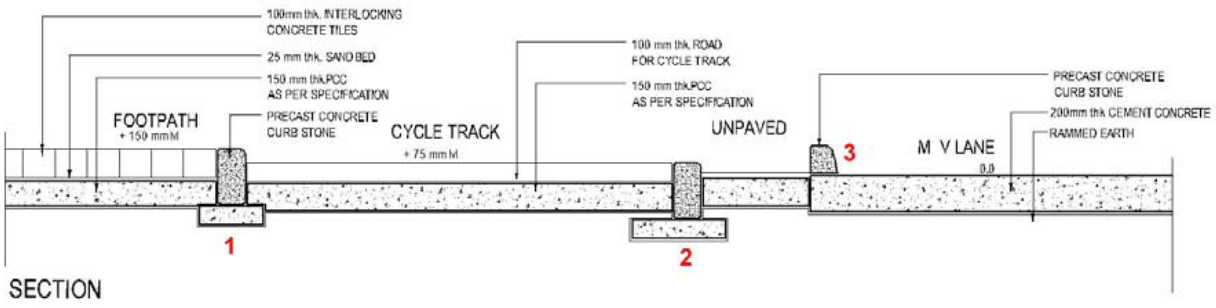
[31] Ahmedabad Municipal Corporation (2010), Bidding Document for Construction of Phase II BRTS Corridors for the City of Ahmedabad – Package 1

Figure 1.8 Typical cross section of BRTS for ROW of 30 metres



Source: - Bus Rapid Transit (BRT): Toolkit for Feasibility Studies by Asian Development Bank[32]

Figure 1.9 Detailed BRTS section showing segregated footpath, cycle track and motor vehicle lane



Source: First Delhi BRT Corridor- A Design Summary, Transportation Research and Injury Prevention Program, 2005

1.3.2 Construction of bus lane and motor vehicle lane

On new corridors, bus lanes are usually constructed in plain concrete, laid in situ by pavers on existing road surface with 50 to 100mm wide expansion joints. These joints are connected using dowel bars[33]. Bituminous pavements have also been used as bus lanes (which is what has been done in India), in which case, the construction process consists of earthwork, laying of granular sub base, bituminous base and surface coat according to MoRTH Specifications for Road and Bridge Works[34]. Construction processes and materials used in bituminous pavements are similar as described in 1.2.3.

[32] http://sti-india-uttoolkit.adb.org/mod2/index.html, last accessed on 19th August, 2011.

[33] Transportation Research and Injury Prevention Program (2005) First Delhi BRT Corridor- A Design Summary

[34] Ahmedabad Municipal Corporation (2010) Bidding Document For Construction of Phase II BRTS Corridors for the City of Ahmedabad – Package 1

1.3.3 NMV lane (cycle and cycle rickshaws)

NMV lane consists of cement concrete pavements with plain cement concrete base. The sub base and subgrade structure is the same as that for highway and urban road pavements (section 1.2.3).

Materials

Main materials used include cement, sand, aggregate, and reinforcement.

1.3.4 Pedestrian pathway

Pedestrian pathway is paved with interlocking concrete tiles over a sand bed and Portland cement concrete (PCC) base. The sub base and subgrade structure is the same as that for highway and urban road footpath.

Materials

Main materials used include cement, sand, aggregate, brick bat, and pavement blocks.

1.3.5 Service lane/parking lane/hawker zone

The pavement varies from asphalt to concrete to block pavers (such as interlocking cement tiles and rough stone pavers).

Materials

Cement, sand, aggregate, bitumen, crushed stone, paver blocks, and limestone dust.

1.3.6 Median/edge treatment

Kerb stones, bollards and rumble strips made of cement concrete are used for segregation and edge treatment. Bollards can also be MS hollow section. For construction of kerb and median, refer to National Highways and urban road section (sections 1.2.5 and 1.2.6). Rumble strips and concrete bollards are installed during the construction of carriageway, whereas, MS section bollards are installed after the construction using adhesives/ mortar.

Materials

Main materials used include cement, sand, aggregate, paint, and kerb stones.

1.3.7 Traffic signages and road markings

Markings and signages are installed on pavements, kerbs, and pedestrian pathways according to IRC standards. For details of construction and materials, refer to sections 1.2.9 and 1.2.10.

Materials

Main materials used include paints, cement, sand, aggregate, aluminium sheeting, and steel sections and angles.

1.3.8 Street lighting and lighting of bus shelters

Street lighting is installed to illuminate bus lanes, motor lanes, pedestrian pathways, and bus shelters. For construction details refer to section 1.2.9.

Materials

Main materials used include concrete, sand, reinforcement, steel, iron, and lighting fixtures.

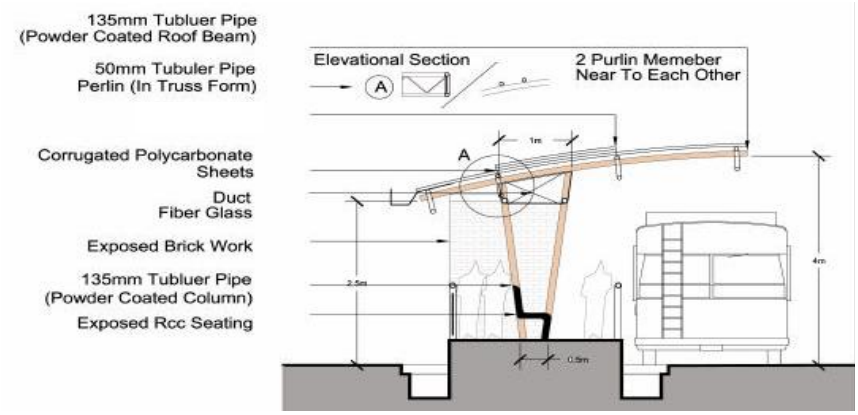
1.3.9 Bus stations[35]

The bus stations may vary from a simple structure with shelter and seating to an elaborate structure with space for facilities, vending, etc. The bus stations in Delhi BRTS include basic shelter and are modular in nature. The structural frame of the bus stations in Delhi BRTS is essentially prefabricated mild steel sections. The roofing system of the station consists of lightweight material such as FRP (Fibre Reinforced Plastic) or Asbestos sheet. The seating arrangement also consists of fibre seats. The plinth is constructed out of reinforced cement concrete and column pedestals are made of cement concrete.

Materials

Main materials used include cement, sand, aggregate, reinforcement and structural steel.

Figure 1.10 Typical BRTS bus station



Source: Ahmedabad BRTS Working Paper 4 on Station Design by AMC, CEPT and GIDB[36]

[35] Ahmebad Municipal Corporation, Center for Environmental Planning and Technology, Gujarat Infrastructure Development Board (2005), Ahmebad BRTS Working Paper 4 on Station Design

[36] Ahmedabad Municipal Corporation (AMC), Center for Environmental Planning and Technology, Gujarat Infrastructure Development Board (2005), Ahmedabad BRTS Working Paper 4 on Station Design

1.4 Construction of inter-city rail

Indian Railways (IR) has a network of more than 64,000 route kilometres, primarily broad gauge (1676 mm), with an average traffic density per running track kilometre of 12.67 million gross tonne kilometres on the Broad Gauge, twice the level in 1960/61. Railway tracks, the basic infrastructure for rail movement, constitute about 40% of the total capital investments of IR and are the most important asset of Indian Railways (both functionally and financially). Over time, Railways have evolved the technologies and practices to design, construct and maintain tracks, with an aim to move faster and heavier traffic.

Starting in 1853, when the first Railway line was opened, IR has constructed a country wide network of 64,460 route kilometres (till March, 2011) which has around 13,500 trains running on it every day.[37] The track construction works are carried out by all Zonal Railways themselves. The Railway budget announced for 2010/11 targeted an addition of 1,000 km of new lines, 800 km of Gauge conversion and 700 km of doubling, all of which has translated into substantial construction activities being undertaken by the Railways to meet the target. This section discusses the key elements of track construction and the processes and materials involved in the same.

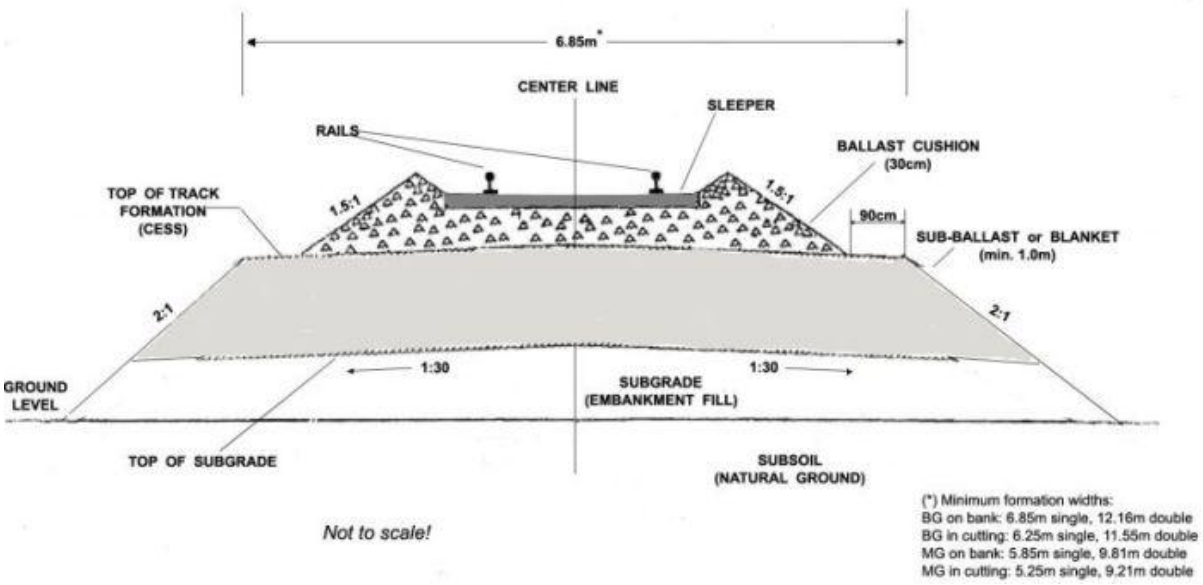
1.4.1 Key elements of a track

Track or Permanent Way is the rail-road on which train runs. It consists of two parallel rails having a specified distance in between and fastened to sleepers, which are embedded in a layer of ballast of specified thickness spread over the formation. Rails are joined to each other by fish plates and bolts or welding and then fastened to the sleepers by various fittings like keys and spikes, etc. (Agarwal, 2011)[38]. The key elements of a track therefore include (figure 1.11 and table 1.3):

- **Rails** – act as girders to transmit the wheel loads of trains to the sleepers
- **Sleepers** – hold the rails in proper position and provide a correct gauge; transfer the load to the ballast
- **Fittings and fastenings** – fasten sleepers to rails
- **Ballast** – gives a uniform level surface, provides drainage and transfers the load to a larger area of formation
- **Formation** – gives a level surface, where the ballast rests and takes the total load of the track and that of the trains moving on it

[37] Indian Railways Year Book (2010-11)
[38] M. M Agarwal (2011), Indian Railway Track

Figure 1.11 Key components of a Broad Gauge (B.G.) track



Source: http://www.irfca.org/, last accessed on 28 September, 2011

Table 1.3 Key dimensions of and materials used in a B.G. track

Track component	Key dimensions	Key materials
Formation	Width - 6.1 mts	Earth, stone dust and sand (primarily stone dust is used for blanketing; sometimes sand mixed with stone dust is also used)
Ballast	20 cm to 30 cm cushion below the bottom of sleepers	Broken stone ballast is most common. (Sand/*moorum* and coal ashes have been used in some cases in the past.)
Sleeper	2750X250X210 mm (PSC sleeper)	Pre-stressed concrete (PSC) sleepers are most common in B.G. (56%). Others used include cast iron sleepers (29%), steel sleepers (12%), and wooden sleepers (3%)
Rails	13 m length	Steel (60 kg and 52 kg rails standardized for B.G.)
Fastenings	Fish plates, bolts/screws, rail spikes, keys, elastic fastenings like elastic clips and IRN 202 clips	

Source: Indian Railways Permanent Way Manual (2004) and Agarwal (2011)

1.4.2 Construction of track

The key stages in construction of a railway track are discussed in table 1.4.

Table 1.4 Railway track construction- key stages

Construction stage	Primary activities
Laying of track formation	▪ This primarily involves earthwork (cut or fill) to form a subgrade, followed by laying of stone dust (sometimes mixed with sand/*moorum)* blanket, also referred as sub-ballast ▪ Trucks, dumpers, vibrator rollers, graders and manual labour are used
Laying of ballast cushion	▪ Trucks, dumpers and manual labour are used to lay ballast cushion
Placing rails and sleepers	▪ Sleepers are laid on the track; primarily manual effort ▪ Parallel step involves welding of rails to form longer rails that are progressively laid on the ballast/sleepers. Rails are welded in three rail panels in depots normally by flash-butt welding method to form short welded rails[39]. ▪ Sleepers and rails are fastened together
Tamping	On-track tamping machines/ tampers are used for packing of track, correcting alignment (lining) and correcting longitudinal and cross levels (levelling)
Signalling	Signalling works on track primarily involve lying of cables, putting up signal posts and location boxes.

Source: Indian Railways Permanent Way Manual (2004) and Agarwal (2011)

1.5 Construction of metro rail system

A metro rail system is an intra-urban passenger railway system with high capacity, speed and frequency, and grade separation from other traffic[40]. It can either be underground or elevated. Kolkata was the first city in India to start a metro rail system in 1984. Delhi is the second city in the country which has constructed a city-wide metro rail infrastructure. The success of Delhi metro rail has inspired cities like Mumbai, Bangalore and Hyderabad to undertake construction of metro rail systems in their respective cities.

Metro rail systems are estimated to have lower energy consumption, 20% less, as compared to road transport (on a per passenger km basis)[41]. At tail-pipe, they are a clean mode of transport. However, construction of metro rail systems is a highly resource and energy intensive exercise. The overall 'cleanliness' of the mode also depends on the source of electricity[42] being used for rail operations. The shifting of underground utilities, construction

[39] Short welded rails are also being progressively introduced on various routes; thermit welding is done to convert short welded rails into long welded rails.
[40] American Public Transportation Association (2008), Glossary of Transit Terminology
[41] Projects Info (2010), Cities Need to Move to MRTS
[42] Coal-based, gas-based or hydro/renewable energy sources

of tunnels and other facilities with traffic flow, resettling and rehabilitating affected families, etc. are some of the challenges in the construction of a metro rail system.

The sections given below provide a brief description of the components of a metro rail system, their construction processes and materials utilized. Apart from the ones described below, the metro rail system consists of other supporting facilities like workshops, warehouses, etc. which are outside the purview of the study.

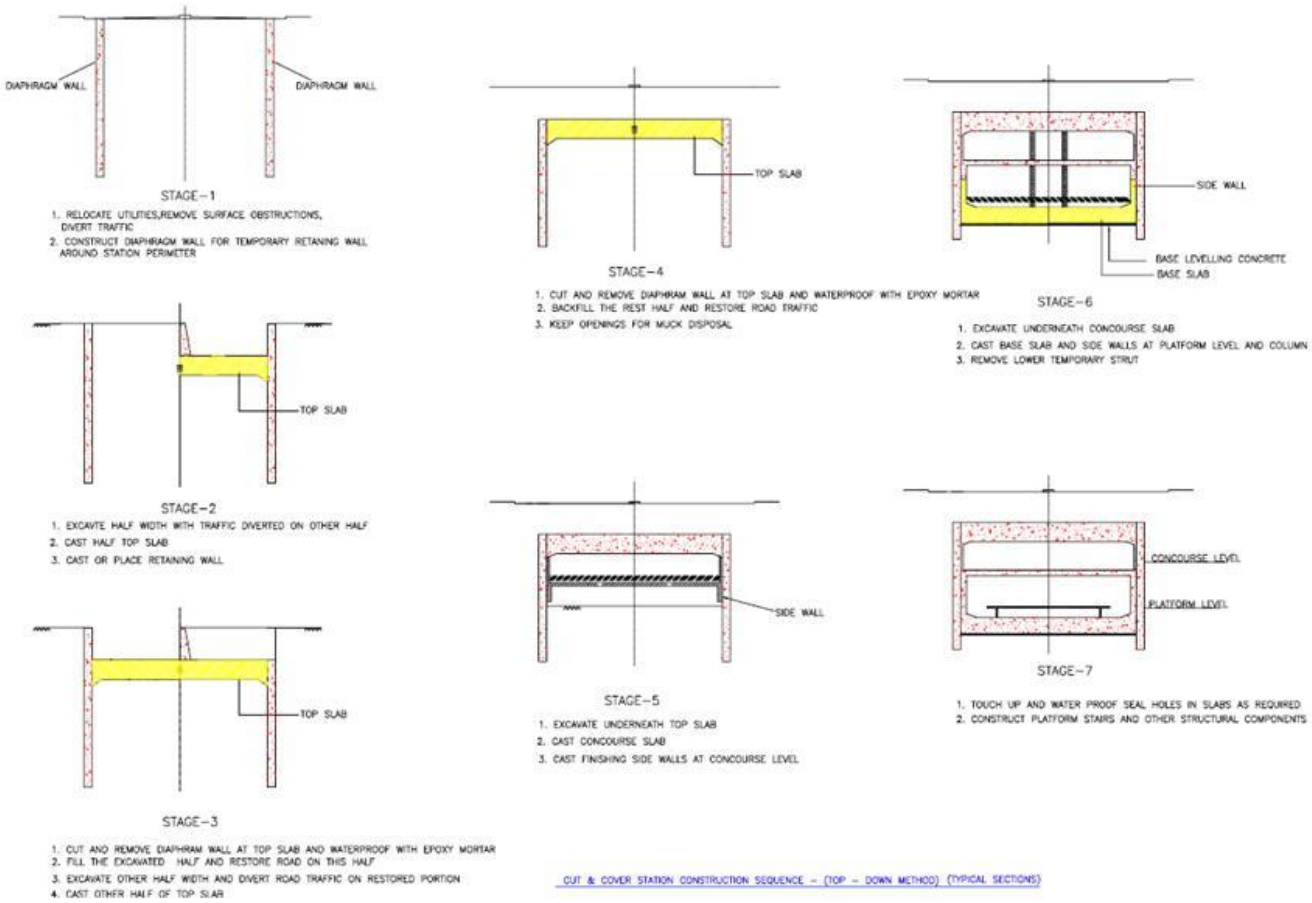
1.5.1 Design elements of MRTS

The important design elements of a metro rail system are as follows:

- Underground tracks and metro station
- Elevated viaduct and metro station
- Tracks
- Traction system
- Rolling stock

1.5.2 Construction of underground track and metro station

Figure 1.12 Cut and cover method for underground construction of metro rail system



Source: Detailed Project Report for Jaipur Metro Prepared by Delhi Metro Rail Corporation

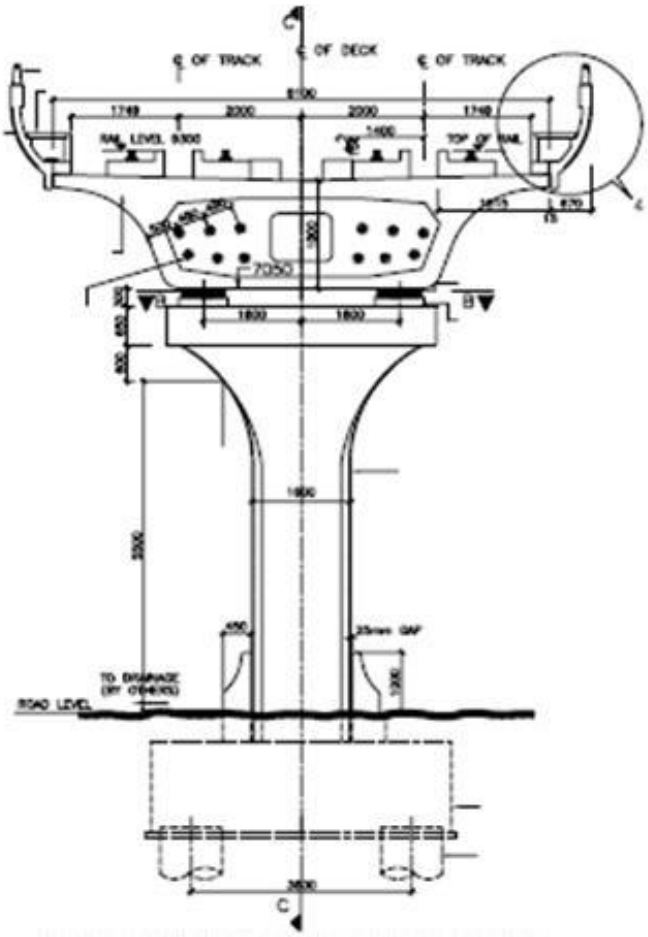
Tunnelling using Tunnel Boring Machine (TBM) is the most common method to begin underground construction. Top down, cut and cover method as described in figure 1.12 is utilized for later stages of construction. This consists of construction of support wall that is either a RCC diaphragm wall, sheet piles, retaining casing piles, soldier piles, secant piles or anchors. Piles are precast concrete. The top slab is constructed after which the diaphragm wall is cut to make it flush with the ground level. The top slab is water proofed and excavation continues underneath the top slab. The concourse slab is cast along with side walls. Excavation continues underneath concourse slab wherein the base slab and side walls for the platform and column are cast. This is followed by construction of platform and other structural components like elevator pit, escalator platforms, utility rooms, etc.

Materials

Main materials used include cement, aggregate, sand, G.I sheets, MS steel H or I sections, reinforcement, epoxy, bricks, and brick bats.

1.5.3 Construction of elevated viaduct and metro station

Figure 1.13 Typical cross-section of an elevated metro rail span



Source- Detailed Project Report for Jaipur Metro Prepared by Delhi Metro Rail Corporation

The elevated viaduct consists of sub structure and super structure. The sub structure consists of pile and pile cap and the super structure consists of pier, pier cap, pedestal, box girder, concourse and platform structures.

The construction of elevated viaduct begins with boring of cast-in-situ or precast piles. A concrete pile cap is casted on a PCC bed. The construction for superstructure begins with construction of pier starter followed by formwork, reinforcement and concreting of pier and pier cap. Concrete pedestals are constructed on pier cap.

Pre-cast pre-stressed box girders are launched using segmental construction. Girders are supported on pedestals through elastomeric bearings. Parapet is constructed and hand rails are fixed. For construction of station extra piers are constructed to support the double storied station complex.

Materials

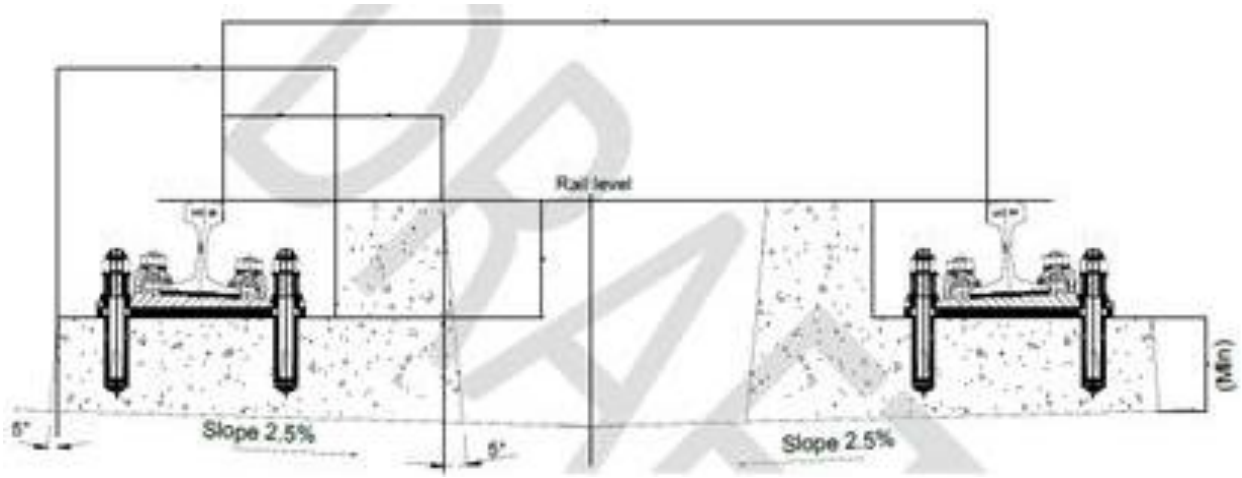
Main materials used include cement, aggregate, sand, admixtures, water, structural and reinforcement steel, bentonite, granular filling material for open foundation, PVC pipes, elastomeric bearings, steel tendons for pre stressing, MS steel tubes, polyethylene tubes, epoxy, G.I sheets, aluminium, polycarbonate sheets, bricks, galvanized mild steel for HVAC ducts.

It should be noted that as stated in Volume I, the study is limiting its scope to an elevated metro rail track and station.

1.5.4 Laying of tracks

Ballasted track for at-grade sections and plinth type ballast-less tracks for viaducts and inside tunnels are used in metro rails.

Figure 1.14 Ballast-less track at elevated viaduct



Source- Detailed Project Report for Jaipur Metro Prepared by Delhi Metro Rail Corporation

Materials

Main materials used include UIC 60, 1080 head hardened as per IRS-T- 12-96, steel, crushed stone for ballast (if tracks with ballast), pre-stressed concrete sleepers (cement, concrete, sand), reinforcement (RCC derailment guard swith plinth), elastomeric pad, steel fittings and fastenings.

1.5.5 Traction system

25KV AC overhead traction system is used.

Materials

Main materials used include structural steel section, cables.

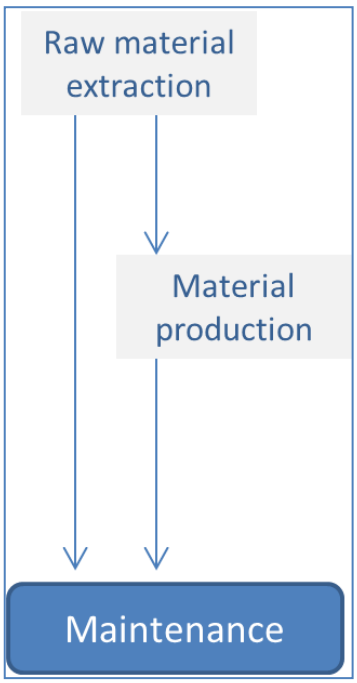
2. Literature review: Maintenance of transport infrastructure

As stated in the previous section, India is in the course of developing huge amount of transport infrastructure. Large scale investments are being made to create/improve transport infrastructure in the country. This translates into huge maintenance requirements of the assets that are being created; the amount of focus given on maintaining these assets will have a significant role in deciding the longevity of these investments/life of the assets being created.

Conventionally, maintenance has been a neglected subject; especially in the roads sector. According to the Asian Development Bank's recent paper on transport sector,[43] 'for every $1 of essential maintenance that is postponed the operating costs of vehicles increase by more than $3.' Due to shortcomings in maintenance of road infrastructure in India[44], there is more emphasis on new road construction over road maintenance, as a result of which maintenance backlogs get built up, which also forces early re-construction. Maintenance hence is a key component in the life cycle of transport infrastructures and needs due attention.

Similar to construction, maintenance activities also have a huge impact on the material and energy consumption. Since the focus of this study is to understand these impacts for full life cycle of transport infrastructures, this section aims to understand the typical maintenance practices followed for the five selected modes of transport in order to understand material and energy inputs for the same. Figure 2.1 gives the scope of LCA for maintenance stage.

Figure 2.1 Scope of maintenance stage impact analysis



[43] Asian Development Bank (2010), Sustainable transport initiative operational plan.
[44] Gupta D P (2005), Road funds: a case study of sustainable road maintenance in India, Transport and Communications Bulletin for Asia and the Pacific

2.1 Road maintenance (National Highways, urban roads and BRTS)

Road maintenance includes all those works, or activities, which are performed to maintain the pavement, shoulders, and other facilities provided for road users, as nearly as possible in their constructed conditions under given conditions of traffic loading and forces of nature[45]. All components of the road pavement require maintenance as they are subjected to traffic and environmental effects. Maintenance requirements are dependent on design standards, traffic loading, terrain, soil type, local environmental phenomenon, etc.[46]

Road maintenance activities can be categorized into following:

- **Routine maintenance** – Routine maintenance involves day to day repair of minor defects in existing facilities that need to be done quickly to arrest further deterioration and to ensure the safety of road users.[47] [48] These works are undertaken on an annual basis and are funded from the recurrent budget; these can be grouped into cyclic and reactive works types. Cyclic works are those undertaken where the maintenance standard indicates the frequency at which activities should be undertaken. Examples are verge cutting and culvert cleaning, works after monsoons, all of which are dependent on environmental effects rather than on traffic levels. Reactive works are those where intervention levels, defined in the maintenance standard, are used to determine when maintenance is needed. An example is patching, which is carried out in response to the appearance of cracks or pot-holes.[49]
- **Periodic maintenance** – Periodic maintenance activities are undertaken at intervals of several years to ensure structural integrity of the road to enable it to carry increased axle loads. Periodic maintenance is usually programmed as regular long-term maintenance works (carried out regularly but at long intervals) and its periodicity depends on factors like pavement design, traffic loads, environmental impacts, etc. Periodic maintenance activities usually exclude works that change the geometry of a road by widening or realignment. Works can be grouped into the works types of preventive, resurfacing, overlay and pavement reconstruction. Examples of periodic works include resealing and overlay works/provision of renewal coat to the wearing surface.[50] [51] [52]
- **Emergency maintenance or Special works** – These works cover those situations which call for a rapid response to restore the road pavement in order to ensure the safety of the road users. These works cannot be planned/estimated in advance. The

[45] Lea Associates South Asia Pvt. Ltd., India (2008), Technical Assistance for Implementation of Institutional Reforms in Road Sector of Uttar Pradesh, Review Report on Implementation of Upgraded Maintenance Practices and Standards for Core Network
[46] Ibid.
[47] Ibid.
[48] Ministry of Road Transport and Highway, MoRTH, Guidelines for Maintenance and Management of Primary, Secondary and Urban Roads
[49] http://www.worldbank.org/transport/roads/con&main.htm#maintenance, last accessed on 25 September, 2011.
[50] Ibid.
[51] Lea Associates South Asia Pvt. Ltd., India (2008), Technical Assistance for Implementation of Institutional Reforms in Road Sector of Uttar Pradesh, Review Report on Implementation of Upgraded Maintenance Practices and Standards for Core Network
[52] Ministry of Road Transport and Highway, MoRTH, Guidelines for Maintenance Management of Primary, Secondary and Urban Roads

works could involve pavement restoration after heavy rains/flood, cyclone, landslides, or winter maintenance works of snow removal or salting.

- **Rehabilitation works** – These works cover those activities that restore or increase the structural strength of the road pavement to extend its life and safety for the road users. These works do not generally require any removal of the existing pavement. Example of rehabilitation works could be increasing the structural strength of the pavement by adding material, such as crushed stone on top of the existing pavement and then laying a base course and wearing course on top of the crushed stone. [53]
- **Reconstruction and upgrading** – These works include those activities which restore, and generally improve the structural and other aspects of the existing road. E.g.: widening of pavement around a curve, realignment of a small length of a road, sealing gravel shoulders, replacement of an existing structure, enlarging an existing culvert, improving an intersection layout and the bituminous surfacing of a short length of gravel road.[54]

2.1.1 Common maintenance treatments and materials used

- Pothole filling and patching on bituminous surfaced roads

  Materials - Cold premix for pothole filling, bitumen and aggregate, and stone chippings as blotting material to avoid bleeding of pavements

- Surface dressing, a simple, inexpensive and highly effective treatment capable of extending the life of an existing pavement and avoiding structural failure

  Materials - Bitumen and stone chippings

- Fog seal, a light spray application of dilute bitumen to seal narrow cracks on bituminous pavements

  Materials - Bitumen, stone chippings, and sand

- Slurry seal, a cold mix paving system that can correct a broad range of problems like filling cracks and voids, sealing the surface to make it impervious to water, etc. Existing distresses in older pavements, such as surface cracking, ravelling, loss of matrix, increased water and air permeability and lack of friction due to flushing or aggregate polishing can be corrected through a slurry application.

  Materials - Bitumen, aggregate, and fillers

- Reconstruction- Many times the existing pavements are so extensively damaged that their rehabilitation may cost as good as for a new one. Hence, whenever the existing pavements are in badly distressed conditions these are reconstructed.

  Materials - Sand, aggregate, admixtures, reinforcement, bitumen, and epoxy

- Other common maintenance treatment includes painting of kerbs, signages, road markings, etc.

  Materials - Synthetic enamel paint

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[53] Ministry of Road Transport and Highway, MoRTH, Guidelines for Maintenance Management of Primary, Secondary and Urban Roads and http://www.worldbank.org/transport/roads/con&main.htm#maintenance, last accessed on 25 September, 2011.
[54] Ibid.

- In addition to the materials mentioned, several new repair materials are emerging for flexible pavements; e.g. sand asphalt base course, bituminous cold mixes including gravel mix and stone mastic. [55]

2.2 Rail maintenance (inter-city rail)[56]

For over a century, rail track maintenance in India has been done by manual effort. Gradually, the Railways have moved to mechanized maintenance, which deploys track machines for day to day maintenance and track renewal works. Mechanized maintenance is typically done with the help of various 'off Track' and 'on Track' machines. A three-tier system of mechanized track maintenance consisting of the following components is followed:

- On-track Machines Unit (OMU)
- Mobile Maintenance Units (MMU)
- Track maintenance by 'Sectional Gangs'

2.2.1 On-track machines Unit (OMU)

Heavy on-track machines including tie-tamping machines for plain track and Points and crossings, shoulder ballast cleaning machines, ballast regulating machines, ballast cleaning machines, dynamic tack stabilizers, etc. are used for:

- Systematic tamping of plain tracks and Points and crossings
- Intermediate tamping of plain tracks and Points and crossings
- Shoulder ballast cleaning, ballast profiling/redistribution, track stabilization, periodical deep screening, etc.

2.2.2 Mobile Maintenance Units (MMU)

MMUs are used for picking up slacks, spot tamping, overhauling of level crossings, minor repairs, etc. Two types of MMUs are used:

- MMU-I (Rail-cum-Road vehicle based) for:
  - Need-based tamping
  - Casual renewal and repairs (except planned renewals)
  - In-situ rail welding
  - Overhauling of level crossings
  - Replacement of glued joints
  - Rail cutting/drilling and chamfering
  - Permanent repairs to fractures
  - Creep or gap adjustments
  - Distressing of LWR/CWR

[55] Seehra S.S. (2007), Operational Maintenance Strategies for Roads and Highways, New Building Material and Construction Work

[56] Indian Railways Permanent Way Manual (2004) and Agarwal (2011), Indian Railway Track

- Loading/unloading of material

- MMU-II (Road vehicle based) for:
  - Reconditioning of Turnouts
  - Minor repairs to the equipments of MMU

Both MMU-I and MMU-II consist of several equipments like track tampers and lifting jack, rail cutting and drilling equipments, rail welding equipments, rail tensors, welding generator, spanners, etc.

2.2.3 Track maintenance by 'Sectional Gangs'

The 'Sectional Gangs' perform the following functions as part of the three-tier mechanized maintenance of tracks.

- Patrolling of track (daily patrol, hot/cold weather patrol, monsoon patrol)
- Watching vulnerable locations
- Need-based attention to bridges, turnouts, approaches of level crossings
- Greasing of ERCs, lubrication of joints, casual changing of rubber pads and other fittings
- Minor cess repairs, cleaning of drains and boxing of ballast
- Attention to loops
- Creep and gap adjustment not involving use of machines
- Cleaning of crib ballast for effective cross drainage
- Pre and post tamping attention
- Assistance to MMU and OMUs, as required

2.2.4 Annual maintenance of concrete sleepers

Heavy on-duty track tampers are used for maintenance of concrete sleeper tracks. Specifically for spot attention/slack picking, multipurpose tampers and off-track tampers are used regularly. The annual maintenance programme for concrete sleeper tracks is outlined in table 2.1.

Table 2.1 Annual maintenance programme for concrete sleeper tracks

Period	Work
Post monsoon attention (for 6-7 months after the end of monsoon)	▪ Attention to run-down stretches ▪ Systematic attention by track machines ▪ Overhauling of level crossings ▪ Distressing of LWRs ▪ Spot renewals of rails and sleepers ▪ De-weeding ▪ Cold weather patrolling

Period	Work
Pre-monsoon attention (for 2 months prior to the onset of monsoon)	▪ Picking of slacks ▪ Cleaning and repairs to side and catch water drains ▪ Attention to yards drainage ▪ Spot renewals of rails, sleepers ▪ Shallow screening of specified lengths ▪ Hot weather patrolling
Attention during monsoon	▪ Picking of slacks, as required ▪ Normal track maintenance of yard lines ▪ Cleaning - removal of loose boulders from cuttings and tunnels ▪ Maintenance of side and catch water drains ▪ Repairs to cess and bank ▪ Monsoon patrolling

Source: Agarwal (2011) and Indian Railways Permanent Way Manual (2004)

In addition to the annual maintenance programme outlined in table 2.1, spot renewals, distressing of LWRs, main tamping, pre-post tamping works are carried out as per requirements and schedules. Sectional gangs are also required to carry out systematic attention to track from one end of gang beat to the other during work season. This primarily involves examination of rails, sleepers and fastenings; measurement of toe load of ERCs; inspection of and attention to insulated joints/switch expansion joints; packing of approaches of bridges, level crossings, breathing lengths of LWRs, bad formation areas, etc.; shallow screening of track; minor repairs, replacement of damaged/missing rubber pads, liners, etc. Periodic renewals may involve replacement of rails, sleepers, blast screening, etc. at pre-defined intervals or based on traffic conditions.

2.3 Rail maintenance (metro rail)

Consultations held with the Delhi Metro Rail Corporation officials to understand the maintenance practices adopted for Delhi Metro indicated that there are no significant annual maintenance practices that may lead to material and energy consumption. Periodic renewal/maintenance will primarily involve replacement of rails, once in 30 years.

3. Literature review: Life cycle energy and CO_2 impacts of rolling stock

This section focuses on understanding various approaches adopted to estimate life cycle impacts of transport rolling stock in terms of energy consumption and CO_2 emissions. A literature review was carried out for the same; key highlights of the literature review are discussed in the subsequent sections.

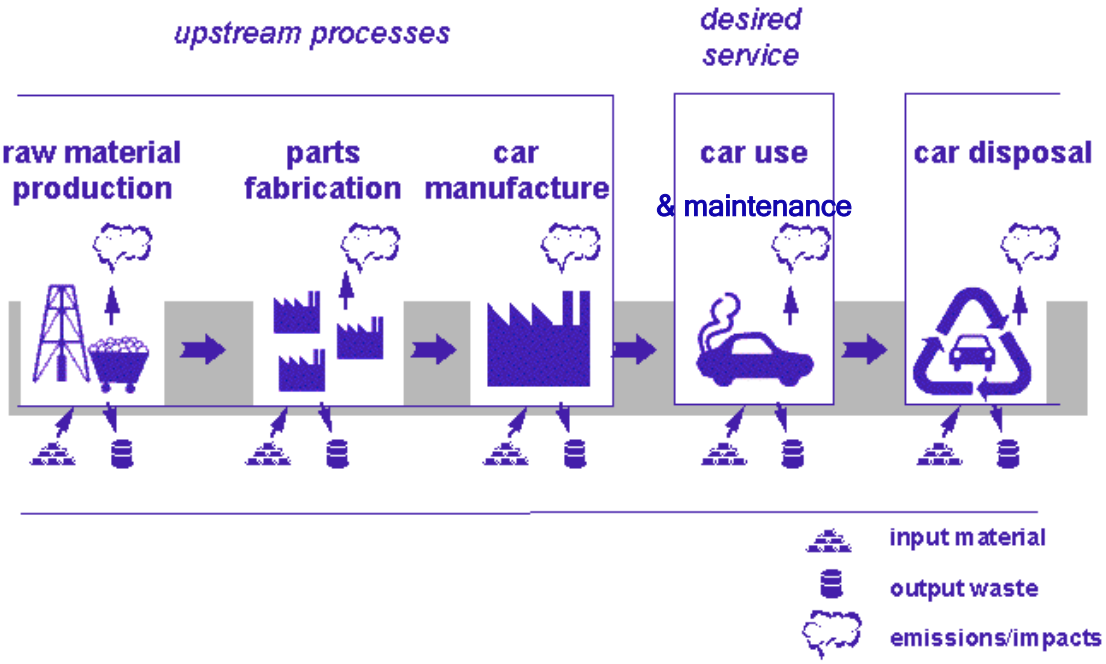
To understand the life cycle energy consumption and CO_2 emissions for rolling stock/vehicles[57], it is important to identify all stages in the life cycle of rolling stock, from raw material production to ultimate product disposal that consume energy (figure 3.1); these would typically include:

- **Raw material production –** Materials used include steel, plastics, non-ferrous metals such as aluminium, glass, rubber and composites such as glass fibre. All these materials require energy for their production.
- **Fabrication of parts** - Fabrication of parts of a vehicle also requires energy; this can be referred as the process energy. For e.g. fabrication of some major components like engine, body, tyres, windows, battery, etc. would require energy (process energy)
- **Vehicle assembly –** Energy is required to assemble the vehicle parts/components and operate the manufacturing plant.
- **Vehicle distribution –** Energy is consumed in transportation of vehicles from manufacturing plants to retail outlets.
- **Vehicle use –** Direct energy consumption takes place when vehicles are used.
- **Vehicle maintenance –** Maintenance and repair over the lifetime of the vehicles also requires energy.
- **Vehicle disposal –** As an ideal practice, the end-of-life vehicles (ELVs) should be shredded and a proportion of some materials should be recycled for further use. In Indian context, this may not, however, be the case. Vehicle disposal and recycling of components is not so far practiced in India.

As may be observed from above, the energy consumption during full life cycle of rolling stock can be divided into two categories: direct energy consumption due to use of fuels for vehicle use/operation, and indirect energy consumption due to manufacture, maintenance and disposal of the vehicle. This section aims to focus primarily on the approaches used to estimate the embodied energy of vehicles/indirect energy consumption. The following sections will focus on the methodologies for life cycle analysis of 'vehicles' based on literature review and the processes involved in vehicle life cycle.

[57] Please note that the terms rolling stock and vehicles will be used interchangeably. Rolling stock that is of interest in this study includes car, bus, truck, inter-city train/locomotive, and metro rail.

Figure 3.1 Life cycle of a car



Source: Mobility CarSharing, Switzerland[58]

3.1 Vehicle life cycle analysis: Literature review of methodologies adopted for LCA

Compared to the life-cycle analysis of fuel production and use (fuel life cycle), the importance of taking into account the 'vehicle life cycle' has been recognized only more recently.[59] In order to understand the methodology and assumptions for evaluating the vehicle life cycle, few case studies have been discussed as follows.

In a study done by **Eriksson et al. (1996)**[60] for Chalmers Industriteknik, a LCA was carried out for road transportation including activities such as production of vehicles, after-use treatment of the vehicles, fuel production, and fuel combustion at operation & maintenance stages. A software program, KRABAT, was developed and used for calculation of the environmental impacts; which were measured on per vehicle kilometre basis (vkm). The model considered consumption of non-renewable fuels & electricity to assess the impacts. For analysis, the following processes were studied and the most dominant contributors to the total environmental impact were identified:

- Production of fuel
- Production of vehicles
- Service and maintenance of vehicles
- Treatment of vehicles after-use

[58] www.doka.ch/DokaMobilitySTRCproc01.pdf, last accessed on 12 September 2011
[59] Weiss, M.A. et al. (2000) *On the Road In 2020: A life-cycle analysis of new automobile technologies*, Massachusetts Institute of Technology, Cambridge, Massachusetts available at http://web.mit.edu/energylab/www/
[60] Eriksson, E. et al. (1996) 'Life cycle assessment of the road transport sector', *The Science of the Total Environment* 189/190 pp. 69-76 available at http://www.sciencedirect.com/science/article/pii/0048969796051923

It was found that the production, maintenance and after-use treatment of the vehicle contributes significantly to the total environmental impact. For example, for passenger cars, the amount of fossil fuel used for production of the vehicle was found to be about 10% of the total amount used during the whole life time of the car, even when fuel life cycle impacts were also taken into account. However, "*this share is generally much smaller for trucks, since they are used more frequently than passenger cars*" (Eriksson et al. 1996)[61]. Moreover, the environmental impact of maintenance and after-use treatment of vehicles was found to be dependent on the total distance driven during the lifetime and treatment of the components and materials of the vehicle after use.

In **1998, Argonne National Laboratory**[62] carried out a LCA for heavy vehicles for the U.S. Department of Energy with an aim to evaluate the reduction in fuel use and emissions based on changes in materials and design of trucks. Total energy use and emissions were evaluated over the entire life cycle of the trucks, including:

- their production, use, maintenance, and recycling of components after use; and
- fuel production, transportation, and use.

The trucks were characterized and several types of potential improvements that could be made were identified. Accordingly, the energy and emissions implications of these changes were estimated based on a spreadsheet model. Argonne's Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model was used to generate per-vehicle fuel cycle impacts: fuel-cycle energy use (Btu/mile) and emissions (g/mile). Energy use and emissions for materials manufacturing and vehicle disposal were estimated by means of materials information from Argonne studies (Argonne National Laboratory, 1998). As in case of Eriksson et al (1996), it was found that "*direct impacts of the vehicle cycle -- producing the truck itself -- were determined to contribute only modestly to the totals, in contrast to results of similar studies with automobiles. The main reasons are the long distances traveled by trucks at low fuel economy.*"[63] Change in material composition of the trucks was found to lead to a significant reduction (3%) in the energy use per ton-mile.

A life cycle assessment of new automobile technologies was conducted by the Massachusetts Institute of Technology to explore their potential to emit lower greenhouse gas emissions (**Weiss et al. 2000**).[64] The focus of the study was to compare energy use & GHG emissions for different automobile technologies over the entire life cycle of a vehicle (both fuel & vehicle life cycles) and also to evaluate consumer cost per unit of distance driven for conventional vehicles (1996 baseline) and alternative cleaner options. Computer simulations, using previously published works were used to estimate fuel economy of various technology combinations. The study assumed a recycling rate of 95% for all metals and 50% for plastics and window glass. The assessment found that the production of vehicle materials accounts for the largest share in energy use of the vehicle cycle, ranging from two-thirds to three-fourth of total energy of the vehicle life cycle.

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[61] Eriksson, E. et al. (1996) 'Life cycle assessment of the road transport sector', *The Science of the Total Environment* 189/190 pp. 69-76 available at http://www.sciencedirect.com/science/article/pii/0048969796051923

[62] Argonne National Laboratory (1998) 'Life-Cycle Analysis for Heavy Vehicles', Conference Paper presented at *Air & Waste Management Association Annual Meeting*, San Diego, available at http://www.transportation.anl.gov/pdfs/TA/102.pdf

[63] Ibid.

[64] Weiss, M.A. et al. (2000) *On the Road In 2020: A life-cycle analysis of new automobile technologies*, Massachusetts Institute of Technology, Cambridge, Massachusetts available at http://web.mit.edu/energylab/www/

Mobility CarSharing,[65] a leading car sharing cooperative in Switzerland commissioned a study to analyze the total life cycle impacts of the vehicle models in its fleet. The assessment included:

- material use for car and road infrastructure,
- fuel consumption and exhaust emissions,
- health damages from road noise and motor vehicle accidents, and
- environmental burdens from land use and landscape fragmentation.

A new method called MUPB'97 was devised for this study. MUPB'97 stands for 'Mobility-Umwelt-Belastungs-Punkte' or 'Mobility-Ecoscarcity'. *"The suffix '97' indicates that the valuation weights were derived from the Swiss environmental situation in 1997."*[66] The results were reported in environmental load per vehicle kilometer. It was found that compared with an average Swiss passenger car in 1999, the car models of Mobility CarSharing Switzerland showed up to 39% reduction in overall energy use and emissions per vehicle kilometer over its full life cycle. This was primarily due to difference in the vehicle technology (use of lightweight materials) and the carsharing model adopted that resulted in behavioural change in modal choice by users. The analysis also showed that for Mobility CarSharing's car fleet, tailpipe emissions were a very small share in the overall environmental impact of the car. Moreover, roughly 50% of the total environmental burdens were 'indirect burdens' during the whole car life cycle e.g. in fuel manufacture and in material consumption.

In order to estimate the vehicle life cycle emissions, **Zamel and Li (2005)**[67] estimated the emissions associated with the vehicle cycle on a per vehicle basis. Assuming certain lifetime mileages, a value for emissions per kilometer was calculated. The method used by Zamel and Li considers the energy use and emissions associated with the production of the vehicle materials, its assembly, distribution and disposal.

Another study to assess the life cycle environmental impacts of road transport fuels and technologies was carried out by the **London Borough of Camden (2006)**[68] with an aim to formulate the future transport policy. A comparison of the life cycle environmental impacts of conventional fuels/technologies was carried out with other cleaner options. The study considered only material production and vehicle assembly stages in vehicle cycle analysis, in view of the results highlighted by Zamel and Li (2005). The data used in this model was as follows:

- mass of the vehicle (kg),
- distribution of the material used in the vehicle by mass (kg) using a system of 12 material category types,
- emissions associated with the production of each material category (grams/kg), and
- total energy required for vehicle assembly (MJ).

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[65] Doka, G., & Ziegler, S. (2001) *Complete Life Cycle Assessment for Vehicle Models of the Mobility CarSharing Fleet Switzerland*, Mobility CarSharing, Switzerland available at www.doka.ch/DokaMobilitySTRCproc01.pdf

[66] Ibid.

[67] Zamel, N. & Li, X. (2005) 'Life cycle comparison of fuel cell vehicles and internal combustion engine vehicles for Canada and the United States', *Journal of Power Sources* Volume 162, Issue 2 pp. 1241-1253 available at doi:10.1016/j.jpowsour.2006.08.007

[68] *Life Cycle Assessment of Vehicle Fuels and Technologies*, London Borough of Camden, London, UK available at http://www.ecolane.co.uk/projectspublications.php

The results showed that vehicle size is strongly correlated to overall environmental impact. This was attributed to the fact that larger vehicles require more materials and assembly energy during manufacture. Moreover, they also tend to have higher fuel use and hence an increase in fuel production energy. The results of LCA also showed that "*the vehicle and fuel production stages account for around 20% of total lifetime greenhouse gas emissions – the emissions associated with fuel and vehicle production being roughly equal in magnitude.*"[69]

Saari et al. (2007)[70] calculated the natural resource use of road transport for different road categories and for different vehicle types. Life cycle wide consumption of materials by the roads and vehicles were determined and reported against vehicle-kilometers, person-kilometers and ton-kilometers transported. The results were indicated in form of Material Input Per Service unit (MIPS) that measures material and energy consumption of products and services throughout their whole life cycle. This methodology was developed by the Wuppertal Institute for Climate, Environment and Energy, Germany.

Chester and Horvath (2009a and 2009b)[71] [72] included the embodied energy of vehicles while doing life cycle assessment of road, rail and air travel. In this method, environmental performance was calculated for each component in the mode's life cycle and then normalized per Passenger-Kilometer-Traveled (PKT). The component energy or emissions were calculated based on the following formula:

$$E_M = \sum_c^C \frac{\mathrm{EF}_{M,c} \times U_{M,c}(t)}{\mathrm{PKT}_M(t)}$$

Where,
E_M is total energy or emissions per PKT for mode M;
M is the set of modes {sedan, train, aircraft, etc.};
c is vehicle, infrastructure, or fuel life-cycle component;
EF is environmental (energy or emission) factor for component c;
U is activity resulting in EF for component c;
PKT is PKT performed by mode M during time t for component c.

Results were reported in form of modal average occupancy per PKT performance. Occupancy rates were taken into consideration as "*per-PKT performance, which captures the energy and emissions intensity of moving passengers, is the result of occupancy rates. An evaluation of these occupancy rates with realistic low and high ridership illustrates both the potential environmental performance of the mode as well as the passenger conditions when modes are*

[69] *Life Cycle Assessment of Vehicle Fuels and Technologies*, London Borough of Camden, London, UK available at http://www.ecolane.co.uk/projectspublications.php
[70] Saari, A. et al. (2007) 'Influence of vehicle type and road category on natural resource consumption in road transport', Transportation Research Part D 12 pp. 23–32 available at http://www.sciencedirect.com/science/journal/13619209
[71] Chester, M. V. & Horvath, A. (2009a) 'Environmental assessment of passenger transportation should include infrastructure and supply chains', *Environmental Research Letters* 4 (024008) pp. 8 available at http://iopscience.iop.org/1748-9326/4/2/024008
[72] Chester M. V. and Horvath A. (2009b), 'Life-cycle Energy and Emissions Inventories for Motorcycles, Diesel Automobiles, School Buses, Electric Buses, Chicago Rail, and New York City Rail', UC Berkeley Center for Future Urban Transport: A Volvo Center of Excellence, Institute of Transportation Studies, UC Berkeley available at http://escholarship.org/uc/item/6z37f2jr

equivalent". It was found that the share of vehicle life cycle in total modal life cycle energy consumption was 3% for bus, 7–21% for rail, and 2–14% for air modes.

Chester and Horvath (2009b) was found out to be one the most recent and comprehensive study on life cycle analysis of vehicles. Estimated in the context of USA, the work provides embodied energy and CO_2 values for different types of private and public modes of transportation. As stated in Chapter 1 (Volume I), **in absence of data to estimate India-specific embodied energy and CO_2 values for rolling stock, the values provided in Chester and Horvath (2009b) have been considered in this study.**

4. Questionnaire for collecting construction data for a National Highway project

Questionnaire for collecting construction data for a National Highway project

About the project

Name of the project:			
City/State:			
Road start and end points:	From-	To-	Total distance between the two points (km):
Road length constructed as on date (km):			
Construction duration:	Start date- End date/expected end date-		
Design life of pavement (years):			
Cross-section details	ROW, No. of lanes, Carriage way width, Divided/undivided, median width, shoulder, service road, etc.		

Information on consumption of construction materials (as on date, for the road length constructed)									
Construction material	**Quantity used**	**Source from where construction material is/was brought**		**Typical mode used for transporting material from source**					
	(tonnes/ litres)	**Place**	**Distance from site/ lead (in kms)**	**Vehicle type (Truck, tempo, etc.)**	**No. of trips**	**Average loading on vehicle (tonnes/ litres)**	**Fuel type (diesel, CNG, etc.)**	**Fuel efficiency (km/l)**	**Avg. idling time while loading/unloading (hours)**
Aggregate/base material									
Cement									
Sand									
Bitumen/tar									
Steel reinforcement									
Other steel									
Bitumen emulsion									
Furnace oil									
LDO									
Diesel									
Fill (soil/earth, etc.)									
Concrete*									
Mix material/hot mix asphalt*									
** Is usually prepared on- site. In case, these are being prepared off-site, then the details should be filled.*									

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Construction material	Quantity used	Source from where construction material is/was brought		Mode used for transporting material from source					
	(tonnes/ litres)	Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (tonnes/ litres)	Fuel type (diesel, CNG, etc.)	Fuel efficiency (km/l)	Avg. idling time while loading/unloading (hours)
Bricks									
Water									
Cut (soil/earth, etc.)		**							
Limestone dust									
Admixtures									
Paint									
Primer									
Concrete curing compound									
Joint sealant									
Polymeric synthetic fibers									
*** Destination of cut*									

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Construction material	Quantity used	Source from where construction material is/was brought		Mode used for transporting material from source					
	(tonnes/ litres)	Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (tonnes/ litres)	Fuel type (diesel, CNG, etc.)	Fuel efficiency (km/l)	Avg. idling time while loading/unloading (hours)
Materials for formwork									
In case, NH section has sidewalk/ pavement (in urban areas), then: - Precast cement concrete slabs - Stone slabs - Others									
Others (if any)									

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Information on street furniture

Type of street furniture used/will be used (please specify the road length for which information is being provided)	Primary materials of which street furniture is made (steel, aluminum, etc.)	Weight of primary materials per fixture (if available)	If weight of primary materials per fixture is not available, then, give key dimensions/ features of a typical fixture (height, area, diameter, type)	Manufacturer	Source from where street furniture is/was brought				
					Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle	Fuel type of vehicle (diesel, CNG, etc.)
Signages									
Street lights									
Toll gates									
Bus stop shelter (if any)									
Road delineators									
Others									

Information on on-site electricity and fuel consumption (as on date for the road length constructed)

<table>
<tr><th colspan="4">Electricity consumption</th></tr>
<tr><td>1. What was the on-site electricity usage during project construction phase for on-site lighting, field offices, running machinery/equipment, etc.?</td><td colspan="3">Total electricity purchased from electricity distribution company/ state electricity board (as on date): _____ (Unit _____)
(In case month wise-data is available, please fill details in the Annex 1)

Which company? :_____</td></tr>
<tr><td>2. Was there on-site generation of electricity by using electric generators? If yes, then please give the details.</td><td colspan="3">No. of generators used: _____

Fuel type used in generators: _____

Total quantity of each fuel type used in generators (as on date):
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
(In case month wise-data is available, please fill details in the Annex 1)

What is the average daily use of generators?: _____hours</td></tr>
<tr><th colspan="4">Consumption of fossil fuels and biomass</th></tr>
<tr><td rowspan="11">3. What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)?</td><td>Fuel</td><td>Quantity</td><td>Unit</td></tr>
<tr><td>Diesel</td><td></td><td></td></tr>
<tr><td>Petrol</td><td></td><td></td></tr>
<tr><td>CNG</td><td></td><td></td></tr>
<tr><td>Furnace oil</td><td></td><td></td></tr>
<tr><td>LDO</td><td></td><td></td></tr>
<tr><td>Kerosene</td><td></td><td></td></tr>
<tr><td>LPG</td><td></td><td></td></tr>
<tr><td>Natural gas</td><td></td><td></td></tr>
<tr><td>Biomass</td><td></td><td></td></tr>
<tr><td colspan="3">(In case month wise-data is available, please fill details in the Annex 1)</td></tr>
</table>

	Type	Number	Fuel type
4. Type of vehicles/ machinery used on-site during construction			

Information on travel of construction staff/labour

Staff/labour	No. of staff/labour	Typical mode of travel (for coming to construction site daily)			Average daily distance travelled to reach construction site (kms)	Remarks
		Vehicle type	Fuel type	Average occupancy		
Contractors/engineers/ other staff						Are the vehicles owned by the contractor? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour						
Equipment opeartors						

Information on vegetation removed

Vegetation removed Was there any removal of vegetation during construction phase? If yes, then please give the details.	1. No. of trees removed during construction or hectares of forest area cut during construction _____ 2. What were the main species removed? _____ _____ 3. Were these trees burnt on site, or given to nearby villages to be used as fuel wood or given to forest department? _____ 4. Are there any photographs of the site before construction began showing the vegetation/tree cover? Please share the photographs. 5. Were you required to seek Forest Department's/Ministry of Environment's clearance for road construction? If yes, is it possible to share the reports/documents submitted for clearance?

Information on expected traffic on the road

1. Please share the DPR of the project. We need the traffic estimates for the entire design life of this road/road section from DPR/project feasibility report. Do these traffic estimates include the induced traffic effect? (please fill details in Annex 2)

2. In case, you don't have traffic estimates, please share the expected growth rate for vehicles, if available.

Annex 1

Month-wise electricity and fuel consumption for on-site construction activities

(In case the contractor has month-wise numbers)

Month, Year	Electricity purchased from power distribution company (specify unit)	Electric generators					Total fuel consumption									
		Diesel	Kerosene	Petrol	Natural gas	LPG	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

Annex 2

Traffic estimates for the entire design life of this road/road section from DPR/project feasibility report

Year	Cars	Two wheelers	Taxis	Jeeps	Buses	Mini buses	LCVs	HCVs	Others

5. Questionnaire for collecting construction data for an urban road project

Questionnaire for collecting construction data for an urban road project

About the project

Name of the project:			
City:			
Road start and end points:	From-	To-	Total distance between the two points (km):
Road length constructed as on date (km):			
Construction duration:	Start date- End date/expected end date-		
Design life of pavement (years):			
Cross-section details	ROW, No. of lanes, Carriage way width, Divided/undivided, median width, shoulder, service road, etc.		

Information on consumption of construction materials (as on date, for the road length constructed)										
Construction material	Quantity used (tonnes/cum/litres)		Source from where construction material is/was brought		Typical mode used for transporting material from source					
	Quantity	Unit	Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (tonnes/ litres)	Fuel type (diesel, CNG, etc.)	Fuel efficiency (km/l)	Avg. idling time while loading/unloading (hours)
Aggregate/base material										
Cement										
Sand										
Bitumen/tar										
Steel reinforcement										
Other steel										
Bitumen emulsion										
Furnace oil										
LDO										
Diesel										
Fill										
Concrete*										
Mix material/hot mix asphalt*										
** Is usually prepared on- site. In case, these are being prepared off-site, then the details should be filled.*										

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Construction material	Quantity used		Source from where construction material is/was brought		Mode used for transporting material from source					
	Quantity	Unit	Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (tonnes/ litres)	Fuel type (diesel, CNG, etc.)	Fuel efficiency (km/l)	Avg. idling time while loading/unloading (hours)
Bricks										
Water										
Cut (soil/earth, etc.)			**							
Limestone dust										
Admixtures										
Paint										
Primer										
Concrete curing compound										
Joint sealant										
Polymeric synthetic fibers										

*** Destination of cut*

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Construction material	Quantity used		Source from where construction material is/was brought		Mode used for transporting material from source					
	Quantity	Unit	Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (tonnes/ litres)	Fuel type (diesel, CNG, etc.)	Fuel efficiency (km/l)	Avg. idling time while loading/unloading (hours)
Materials for formwork										
Sidewalk/ pavement: - Precast cement concrete slabs - Stone slabs - Others										
Kerb stones										
Others (if any)										

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Information on street furniture

Type of street furniture used/will be used (please specify the road length for which information is being provided)	Number	Primary materials of which street furniture is made (steel, aluminum, etc.)	Weight of primary materials per fixture (if available)	If weight of primary materials per fixture is not available, then, give key dimensions/ features of a typical fixture (height, area, diameter, type)	Manufacturer	Source from where street furniture is/was brought				
						Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle	Fuel type of vehicle (diesel, CNG, etc.)
Traffic lights										
Signages										
Street lights										
Bus stop shelter										
Road delineators										
Guard rails										
Others										

Information on on-site electricity and fuel consumption for construction of road (as on date for the road length constructed)

<table>
<tr><th colspan="4">Electricity consumption</th></tr>
<tr><td>1. What was the on-site electricity usage during project construction phase for on-site lighting, field offices, running machinery/equipment, etc.?</td><td colspan="3">Total electricity purchased from electricity distribution company/ state electricity board (as on date): _____ (Unit _____)
(In case month wise-data is available, please fill details in the Annex 1)

Which company? :_____</td></tr>
<tr><td>2. Was there on-site generation of electricity by using electric generators? If yes, then please give the details.</td><td colspan="3">No. of generators used: _____

Fuel type used in generators: _____

Total quantity of each fuel type used in generators (as on date):
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
(In case month wise-data is available, please fill details in the Annex 1)
What is the average daily use of generators?: _____hours</td></tr>
<tr><th colspan="4">Consumption of fossil fuels and biomass</th></tr>
<tr><td rowspan="11">3. What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)?</td><td>Fuel</td><td>Quantity</td><td>Unit</td></tr>
<tr><td>Diesel</td><td></td><td></td></tr>
<tr><td>Petrol</td><td></td><td></td></tr>
<tr><td>CNG</td><td></td><td></td></tr>
<tr><td>Furnace oil</td><td></td><td></td></tr>
<tr><td>LDO</td><td></td><td></td></tr>
<tr><td>Kerosene</td><td></td><td></td></tr>
<tr><td>LPG</td><td></td><td></td></tr>
<tr><td>Natural gas</td><td></td><td></td></tr>
<tr><td>Others</td><td></td><td></td></tr>
<tr><td colspan="3">(In case month wise-data is available, please fill details in the Annex 1)</td></tr>
</table>

	Type	Number	Fuel type
4. Type of vehicles/ machinery used on-site during construction			

Information on travel of construction staff/labour

Staff/labour	No. of staff/labour	Typical mode of travel (for coming to construction site daily)			Average daily distance travelled to reach construction site (kms)	Remarks
		Vehicle type	Fuel type	Average occupancy		
Contractors/engineers/ other staff						Are the vehicles owned by the contractor? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour						
Equipment operators						

Information on vegetation removed

Vegetation removed Was there any removal of vegetation during construction phase? If yes, then please give the details.	6. No. of trees removed during construction _____ 7. What were the main species removed? _____ _____ 8. Were these trees burnt on site, or given to the forest department? _____

Information on expected traffic on the road

3. Please share the DPR of the project. We need the traffic estimates for the entire design life of this road/road section from DPR/project feasibility report. Do these traffic estimates include the induced traffic effect? (please fill details in Annex 2)

4. In case, you don't have traffic estimates, please share the expected growth rate for vehicles, if available.

Annex 1

Month-wise electricity and fuel consumption for on-site construction activities

(In case the contractor has month-wise numbers)

Month, Year	Electricity purchased from power distribution company (specify unit)	**Electric generators**					**Total fuel consumption**								
		Diesel	Kerosene	Petrol	Natural gas	LPG	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Others (if any)

Annex 2

Traffic estimates for the entire design life of this road/road section from DPR/project feasibility report

Year	Cars	Two wheelers	Taxis	Jeeps	Buses	Mini buses	LCVs	HCVs	Others

6. Questionnaire for collecting construction data for a BRTS project

Questionnaire for collecting construction data for a BRTS project

About the project

Name of the project:			
City:			
BRT start and end points:	From-	To-	Total distance between the two points (km):
BRT length constructed as on date (km):			
Construction duration:	Start date- End date/expected end date-		
Design life of pavements (years):	Bus lane: Private vehicle lane: Cycle track: Footpath:		
Cross-section details			

Information on consumption of construction materials (as on date, for the BRT length constructed)										
Construction material	**Quantity used (tonnes/cum/litres)**		**Source from where construction material is/was brought**		**Typical mode used for transporting material from source**					
	Quantity	**Unit**	**Place**	**Distance from site/ lead (in kms)**	**Vehicle type (Truck, tempo, etc.)**	**No. of trips**	**Average loading on vehicle (tonnes/ litres)**	**Fuel type (diesel, CNG, etc.)**	**Fuel efficiency (km/l)**	**Avg. idling time while loading/unloading (hours)**
Aggregate/base material										
Cement										
Sand										
Bitumen/tar										
Steel reinforcement										
Other steel										
Bitumen emulsion										
Furnace oil										
LDO										
Diesel										
Fill										
Concrete*										
Mix material/hot mix asphalt*										
** Is usually prepared on- site. In case, these are being prepared off-site, then the details should be filled.*										

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Construction material	Quantity used		Source from where construction material is/was brought		Mode used for transporting material from source					
	Quantity	Unit	Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (tonnes/ litres)	Fuel type (diesel, CNG, etc.)	Fuel efficiency (km/l)	Avg. idling time while loading/unloading (hours)
Bricks										
Brick bats										
Water										
Cut (soil/earth, etc.)			**							
Limestone dust										
Admixtures										
Paint										
Primer										
Concrete curing compound										
Joint sealant										
Adhesives										
Polymeric synthetic fibers										
*** Destination of cut*										

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Construction material	Quantity used		Source from where construction material is/was brought		Mode used for transporting material from source					
	Quantity	Unit	Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (tonnes/ litres)	Fuel type (diesel, CNG, etc.)	Fuel efficiency (km/l)	Avg. idling time while loading/unloading (hours)
Materials for formwork										
Sidewalk/ pavement: - Precast cement concrete slabs - Stone slabs - Kotta stone - Others										
Kerb stones										
Aluminum/ MS pipes										
Others (if any)										

Note: Please give the **TOTAL** quantity of materials consumed as on date (materials used for all construction purposes like pavements, medians/ dividers, sidewalks (if any), constructing sound barriers, etc.)

Information on street furniture

Type of street furniture used/will be used (please specify the BRT length for which information is being provided)	Number	Primary materials of which street furniture is made (steel, aluminum, etc.)	Weight of primary materials per fixture (if available)	If weight of primary materials per fixture is not available, then, give key dimensions/ features of a typical fixture (height, area, diameter, type)	Manufacturer	Source from where street furniture is/was brought				
						Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle	Fuel type of vehicle (diesel, CNG, etc.)
Traffic lights										
Signages										
Street lights										
Bus stop shelter		Frame, roof, seating, sheets								
Road delineators										
Guard rails										
Others										

Information on on-site electricity and fuel consumption for construction of BRT (as on date for the BRT length constructed)

<table>
<tr><th colspan="4">Electricity consumption</th></tr>
<tr><td>1. What was the on-site electricity usage during project construction phase for on-site lighting, field offices, running machinery/equipment, etc.?</td><td colspan="3">Total electricity purchased from electricity distribution company/ state electricity board (as on date): _____ (Unit _____)
(In case month wise-data is available, please fill details in the Annex 1)

Which company? :_____</td></tr>
<tr><td>2. Was there on-site generation of electricity by using electric generators? If yes, then please give the details.</td><td colspan="3">No. of generators used: _____

Fuel type used in generators: _____

Total quantity of each fuel type used in generators (as on date):
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
(In case month wise-data is available, please fill details in the Annex 1)

What is the average daily use of generators?: _____hours</td></tr>
<tr><th colspan="4">Consumption of fossil fuels and biomass</th></tr>
<tr><td rowspan="11">3. What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)?</td><td>Fuel</td><td>Quantity</td><td>Unit</td></tr>
<tr><td>Diesel</td><td></td><td></td></tr>
<tr><td>Petrol</td><td></td><td></td></tr>
<tr><td>CNG</td><td></td><td></td></tr>
<tr><td>Furnace oil</td><td></td><td></td></tr>
<tr><td>LDO</td><td></td><td></td></tr>
<tr><td>Kerosene</td><td></td><td></td></tr>
<tr><td>LPG</td><td></td><td></td></tr>
<tr><td>Natural gas</td><td></td><td></td></tr>
<tr><td>Others</td><td></td><td></td></tr>
<tr><td colspan="3">(In case month wise-data is available, please fill details in the Annex 1)</td></tr>
</table>

	Type	Number	Fuel type
4. Type of vehicles/ machinery used on-site during construction			

Information on travel of construction staff/labour

Staff/labour	No. of staff/labour	Typical mode of travel (for coming to construction site daily)			Average daily distance travelled to reach construction site (kms)	Remarks
		Vehicle type	Fuel type	Average occupancy		
Contractors/engineers/ other staff						Are the vehicles owned by the contractor? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour						
Equipment operators						

Information on vegetation removed

Vegetation removed Was there any removal of vegetation during construction phase? If yes, then please give the details.	9. No. of trees removed during construction _____ 10. What were the main species removed? _____ _____ 11. Were these trees burnt on site, or given to the forest department? _____

Information on expected traffic on the BRT corridor

5. Please share the DPR of the project. We need the traffic estimates for the entire design life of this BRT corridor from DPR/project feasibility report. Do these traffic estimates include the induced traffic effect? (please fill details in Annex 2)

6. In case, you don't have traffic estimates, please share the expected growth rate for vehicles, if available.

Annex 1

Month-wise electricity and fuel consumption for on-site construction activities

(In case the contractor has month-wise numbers)

Month, Year	Electricity purchased from power distribution company (specify unit)	**Electric generators**					**Total fuel consumption**								
		Diesel	Kerosene	Petrol	Natural gas	LPG	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Others (if any)

Annex 2

Traffic estimates for the entire design life of this BRT corridor from DPR/project feasibility report

Year	Cars	Two wheelers	Taxis	Jeeps	Buses	Mini buses	LCVs	HCVs	Others

7. Questionnaire for collecting construction data for an inter-city rail track construction project

Questionnaire for collecting construction data for an inter-city rail track construction project

About the project

Name of the project:			
City/State:			
Rail start and end points:	From-	To-	Total distance between the two points (km):
Rail length constructed as on date (km):			
Construction duration:	Start date- End date/expected end date-		
Design life of rail (years):			
Cross-section details	Formation, ballast, broad/meter gauge, sleepers, etc.		

Information on consumption of construction materials (as on date, for the rail length constructed)										
Construction material		**Quantity used**	**Source from where construction material is/was brought**		**Typical mode used for transporting material from source**					
Track components	**Type**	**(tonnes/ litres/kms/ mts/number)**	**Place**	**Distance from site/lead (in kms)**	**Vehicle type**	**No. of trips**	**Average loading on vehicle (tonnes/litres)**	**Fuel type (diesel, CNG, etc.)**	**Fuel efficiency (km/l)**	**Avg. idling time while loading/ unloading (hours)**
Formation	Earth									
	Others (specify)									
Ballast*	Stone aggregate									
	Sand									
	Moorum									
	Coal ashes									
	Others (specify)									
Sleepers **	Pre-stressed concrete									
	Cast iron									
	Steel									
	Wooden									
	Others (specify)									
Rails	60 kg 90 UTS									
	52 kg									
	90 R									
Give specifications of: * Ballast used – (size) ** Sleepers used – (length, width, height, weight per sleeper)										

Note: Please give the **TOTAL** quantity of materials consumed as on date (

Construction material		Quantity used	Source from where construction material is/was brought		Mode used for transporting material from source					
Track components	**Type**	**(tonnes/ litres/kms/ mts/number)**	**Place**	**Distance from site/lead (in kms)**	**Vehicle type (Truck, tempo, etc.)**	**No. of trips**	**Average loading on vehicle (tonnes/litres)**	**Fuel type (diesel, CNG, etc.)**	**Fuel efficiency (km/l)**	**Avg. idling time while loading/unloading (hours)**
Track fittings and fastenings*	Fish plates									
	Bolts/screws									
	Keys									
	Spikes									
	Elastic fastenings									
	Others (specify)									
Others	Concrete		**							
	Cement									
	Sand									
	Water									
	Steel reinforcement									
	Other steel									
	Bricks									
	Paint/primer									
	Cut (soil/earth, etc.)		***							

** Give specifications of fittings and fastenings (material, weight per fitting/fastening)*
*** Is usually prepared on- site. In case, these are being prepared off-site, then the details should be filled.*
**** Destination of cut*

Note: Please give the **TOTAL** quantity of materials consumed as on date

Information on signals/signages

Type and number used/will be used (please specify the rail length for which information is being provided)	Primary materials of which fixture is made of (steel, aluminum, concrete, etc.)	Weight of primary materials per fixture (if available)	If weight of primary materials per fixture is not available, then, give key dimensions/ features of a typical fixture (height, area, diameter, type)	Manufacturer	Source from where fixture is/was brought				
					Place	Distance from site/ lead (in kms)	Vehicle type (Truck, tempo, etc.)	Average loading on vehicle	Fuel type of vehicle (diesel, CNG, etc.)
Signals									
Sign boards									
Gates on manned-crossings									

Information on built structures/buildings made along the track for operational purposes (not railway stations)

- No. of buildings
- Floor area
- No. of floors
- Concrete/brick structure or structure made of other materials

Note: Please give the **TOTAL** quantity of materials consumed as on date

Information on on-site electricity and fuel consumption (as on date for the rail length constructed)

<table>
<tr><th colspan="4">Electricity consumption</th></tr>
<tr><td>1. What was the on-site electricity usage during project construction phase for on-site lighting, field offices, running machinery/equipment, etc.?</td><td colspan="3">Total electricity purchased from electricity distribution company/ state electricity board (as on date): _____ (Unit _____)
(In case month wise-data is available, please fill details in the Annex 1)

Which company? :_____</td></tr>
<tr><td>2. Was there on-site generation of electricity by using electric generators? If yes, then please give the details.</td><td colspan="3">No. of generators used: _____

Fuel type used in generators: _____

Total quantity of each fuel type used in generators (as on date):
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
Fuel_____ Quantity_____ Unit_____
(In case month wise-data is available, please fill details in the Annex 1)

What is the average daily use of generators?: _____hours</td></tr>
<tr><th colspan="4">Consumption of fossil fuels and biomass</th></tr>
<tr><td rowspan="10">3. What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)?</td><td>Fuel</td><td>Quantity</td><td>Unit</td></tr>
<tr><td>Diesel</td><td></td><td></td></tr>
<tr><td>Petrol</td><td></td><td></td></tr>
<tr><td>CNG</td><td></td><td></td></tr>
<tr><td>Furnace oil</td><td></td><td></td></tr>
<tr><td>LDO</td><td></td><td></td></tr>
<tr><td>Kerosene</td><td></td><td></td></tr>
<tr><td>LPG</td><td></td><td></td></tr>
<tr><td>Natural gas</td><td></td><td></td></tr>
<tr><td>Biomass</td><td></td><td></td></tr>
<tr><td colspan="3">(In case month wise-data is available, please fill details in the Annex 1)</td></tr>
</table>

	Type	Number	Fuel type
4. Type of vehicles/ machinery used on-site during construction			

Information on travel of construction staff/labour

Staff/labour	No. of staff/labour	Typical mode of travel (for coming to construction site daily)			Average daily distance travelled to reach construction site (kms)	Remarks
		Vehicle type	Fuel type	Average occupancy		
Contractors/engineers/ other staff						Are the vehicles owned by the contractor? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour						

Information on vegetation removed

Vegetation removed Was there any removal of vegetation during construction phase? If yes, then please give the details.	12. No. of trees removed during construction or hectares of forest area cut during construction _____ 13. What were the main species removed? _____ _____ 14. Were these trees burnt on site, or given to nearby villages to be used as fuel wood or given to forest department? _____ 15. Are there any photographs of the site before construction began showing the vegetation/tree cover? Please share the photographs. 16. Were you required to seek Forest Department's/Ministry of Environment's clearance for rail construction? If yes, is it possible to share the reports/documents submitted for clearance?

Information on expected traffic on the rail section

1. Please share the DPR of the rail project. We need the traffic estimates for the entire design life of this rail section from DPR/project feasibility report.

Annex 1

Month-wise electricity and fuel consumption for on-site construction activities

(In case month-wise data is available)

Month, Year	Electricity purchased from power distribution company (specify unit)	Electric generators					Total fuel consumption									
		Diesel	Kerosene	Petrol	Natural gas	LPG	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

8. Questionnaire for collecting construction data for a metro rail track construction project

Questionnaire for collecting construction data for an elevated metro rail track and station

About the project

Name of the project:			
City:			
Metro rail start and end points: (for which construction details are being provided)	From-	To-	Total distance between the two points (km):
Metro rail length constructed as on date (km):			
Construction duration:	Start date- End date/expected end date-		
Design life of rails (years): Design life of sleepers (years): Design life of viaduct structure (years):			
Cross-section details:			

Information on consumption of construction materials (as on date, for the metro rail length constructed)									
Construction material	**Quantity used**	**Source from where construction material is/was brought**		**Typical mode used for transporting material from source**					
Type	**(tonnes/ litres/kms/ mts/number)**	**Place**	**Distance from site/lead (in kms)**	**Vehicle type**	**No. of trips**	**Average loading on vehicle (tonnes/litres)**	**Fuel type (diesel, CNG, etc.)**	**Fuel efficiency (km/l)**	**Avg. idling time while loading/ unloading (hours)**
Cut		*							
Fill									
Coarse aggregate									
Fine aggregate									
Concrete**									
Cast segments***									
Steel reinforcement									
Structural steel									
Elastomeric bearings									

* Destination of cut

** Is RMC being used? _____ (Please provide details). Does this concrete amount include concrete used for cast segments? _____

*** Material weight in one cast segment?

Concrete	Wax/cement used for grouting polyethylene tubes
Steel reinforcement	
Polyethylene tubes	Sand (for sand blasting on ends of segments)

Any other pre-case elements being used? Please provide details

Note: Please give the **TOTAL** quantity of materials consumed as on date

Construction material	Quantity used	Source from where construction material is/was brought		Mode used for transporting material from source					
Type	(tonnes/ litres/kms/ mts/number)	Place	Distance from site/lead (in kms)	Vehicle type (Truck, tempo, etc.)	No. of trips	Average loading on vehicle (tonnes/litres)	Fuel type (diesel, CNG, etc.)	Fuel efficiency (km/l)	Avg. idling time while loading/unloading (hours)
Rail									
Sleepers (PSC)*									
Fastenings**									
Electric cables									
Fiber optic cables									
Signal posts***									
PVC pipes									
Admixtures									
Primer									
Epoxy									
Shear keys									
Water									

* Sleepers used – (length, width, height, weight per sleeper)
** Give specifications of fittings and fastenings (material, weight per fitting/fastening)
*** Primary material of signal post? _____, Weight of material per post? _____

Note: Please give the **TOTAL** quantity of materials consumed as on date

Information on on-site electricity and fuel consumption (as on date for the metro rail length constructed)

Electricity consumption during construction			
1. What was the on-site **electricity** usage during project construction phase for on-site lighting, field offices, running machinery/equipment, etc.?	Total electricity purchased from electricity distribution company/ state electricity board (as on date): _____ (Unit _____) (In case month wise-data is available, please fill details in the Annex 1) Which company? :_____		
2. Was there **on-site generation of electricity** by using electric generators? If yes, then please give the details.	No. of generators used: _____ Fuel type used in generators: _____ Total quantity of each fuel type used in generators (as on date): Fuel_____ Quantity_____ Unit_____ Fuel_____ Quantity_____ Unit_____ Fuel_____ Quantity_____ Unit_____ Fuel_____ Quantity_____ Unit_____ (In case month wise-data is available, please fill details in the Annex 1) What is the average daily use of generators?: _____hours		
Consumption of fossil fuels during construction			
3. What was the quantity of fuels consumed on-site for running machinery and vehicles (as on date)?	**Fuel**	**Quantity**	**Unit**
	Diesel		
	Petrol		
	CNG		
	Furnace oil		
	LDO		
	Kerosene		
	LPG		
	Natural gas		
	(In case month wise-data is available, please fill details in the Annex 1)		
	Do these numbers include on-site energy used for constructing cast segments? If not, please provide details.		

	Type	Number	Fuel type
4. Type of vehicles/ machinery used on-site during construction			

Information on travel of construction staff/labour

Staff/labour	No. of staff/labour	Typical mode of travel (for coming to construction site daily)			Average daily distance travelled to reach construction site (kms)	Remarks
		Vehicle type	Fuel type	Average occupancy		
Contractors/engineers/ other staff						Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour						

Information on expected traffic and electricity consumption

- Please provide the estimates for traffic and ridership for the entire design life of this metro rail section.
- What will be the expected annual operational electricity consumption?
    - Traction
    - Non traction

Information on construction of an elevated metro station

- Please provide the quantity of key materials consumed for construction of one elevated metro station.

Key materials	Quantity consumed	Unit (tonnes, kms, mts, number, sqm)	Remarks
Concrete			
Steel reinforcement			
Structural steel			
Material for roof truss			Please specify material
Material for roof sheet			Please specify material
Metal fabrications • Railings • Signages • Others (please specify)			Please specify material/s
Bricks			
Materials for flooring			Please specify material/s

Key materials	Quantity consumed	Unit (tonnes, kms, mts, number, sqm)	Remarks
Glass			
Paint			
Conveying systems			
Escalators			
Elevators			

- What is the operational electricity consumption of one elevated metro station (daily or monthly or annual)? _____
    - Source of electricity: Grid ____, Diesel generators _____
    - If both grid and diesel generators are source of electricity, what is the share of both in electricity supply? _____

Annex 1

Month-wise electricity and fuel consumption for on-site construction activities

(In case month-wise data is available)

Month, Year	Electricity purchased from power distribution company (specify unit)	Electric generators					Total fuel consumption									
		Diesel	Kerosene	Petrol	Natural gas	LPG	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

9. Questionnaire for collecting maintenance data for National Highways

Questionnaire for collecting maintenance data for National Highways

About the Highway

Road section maintained: (Road start and end points)	From-	To-	Total distance between the two points (km):
City/State:			
Cross-section details	Type of pavement – bituminous/cement concrete ROW, No. of lanes, Carriage way width, Divided/undivided, median width, etc. Width and type of shoulders, details of side drains, culverts		
When was the road constructed? (Completion date of road construction)	_____Month _____ Year		
What is the expected life of the road pavement?			

Routine maintenance of Highway (ordinary repairs)

1. What are the key routine maintenance activities? [e.g. patch repairs, crack sealing, repairing shoulders, painting (signs, km stones, road markings, etc.), vegetation removal]	

2. For routine maintenance activities, please share details for one year maintenance work as indicated below.

2a. Material consumption

Materials used for routine maintenance (for 1 year)	**Quantity used in one year**	**Source from where construction material/fuel was brought and mode of transportation**			
		Place	**Distance from site/ lead (in kms)**	**Typical vehicle type (Truck, tempo, etc.)**	**Fuel type of vehicle**
Bitumen					
Mix material/Hot mix asphalt					
Aggregate/base material					
Cement					
Sand					
Fill					
Paint					
Primer					
Water					
Others					
2b. Energy consumption (In case month wise-data is available, please fill details in the Annex 1)					
Electricity					
Diesel					
Petrol					
Kerosene					
Others					

3. Information on travel of construction staff/labour

For, routine maintenance work, give details of staff/labour travel (typical pattern)

Staff/labour	**No. of staff/labour involved in a year**	**No. of days in the year when maintenance work is carried out**	**Typical mode of travel** (for coming to construction site)	**Average distance travelled to reach site (kms)**	**Remarks**
Contractors/engineers/ other staff					Are the vehicles owned by the contractor/ authority? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour					
Workmen					
Equipment operators					

Periodic renewal/maintenance of Highway

(Renewal coat to the wearing course/surface done periodically at predetermined frequency)

1. What is the frequency of periodic renewal/maintenance i.e. putting renewal coat to the wearing course/surface?		_____years			
2. Who carries out the periodic maintenance?		NHAI or Contractor			
3. Please give details for one periodic renewal/maintenance work on the road					
3a. Material consumption					
Materials used for 1 full periodic maintenance work (Confirm the length of road for which this work was carried out)	**Quantity used**	**Source from where construction material/fuel was brought and mode of transportation**			
		Place	**Distance from site/ lead (in kms)**	**Typical vehicle type used (Truck, tempo, etc.)**	**Fuel type of vehicle**
Bitumen					
Mix material/Hot mix asphalt					
Aggregate/base material					
Cement					
Sand					
Paint					
Water					
Cut (soil/earth, bitumen, etc.)*		*Destination of cut			
Others					
3b. Energy consumption (In case month wise-data is available, please fill details in the Annex 2)					
Electricity					
Diesel					
Petrol					
Kerosene					
Others					

*Is any of the material that is removed from the wearing course recycled?

4. Information on travel of construction staff/labour

For, periodic maintenance work, give details of staff/labour travel (typical pattern)

Staff/labour	**No. of staff/labour**	**No. of days in which work was completed**	**Typical mode of travel** (for coming to construction site)	**Average distance travelled to reach site (kms)**	**Remarks**
Contractors/engineers/ other staff					Are the vehicles owned by the contractor/ authority? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour					
Workmen					
Equipment operators					

Annex 1

Month-wise electricity and fuel consumption for routine maintenance work

(In case month-wise numbers are available)

Month, Year	Electricity	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

Annex 2

Month-wise electricity and fuel consumption for periodic renewal/maintenance work

(In case month-wise numbers are available)

Month, Year	Electricity	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

10. Questionnaire for collecting maintenance data for urban roads

Questionnaire for collecting maintenance data for urban roads

About the road

Road section maintained: (Road start and end points)	From-	To-	Total distance between the two points (km):
City:			
Cross-section details	Type of pavement – bituminous/cement concrete ROW, No. of lanes, Carriage way width, Divided/undivided, median width, etc. Width and type of shoulders, details of side drains, culverts		
When was the road constructed? (Completion date of road construction)	_____Month _____ Year		
What is the expected life of the road pavement?			

Routine maintenance of road (ordinary repairs)

1. What are the key routine maintenance activities? [e.g. patch repairs, crack sealing, repairing shoulders, painting (signs, km stones, road markings, etc.), vegetation removal]	

2. For routine maintenance activities, please share details for one year maintenance work as indicated below.

2a. Material consumption

Materials used for routine maintenance (for 1 year)	**Quantity used in one year**		**Source from where construction material/fuel was brought and mode of transportation**			
	Quantity	**unit**	**Place**	**Distance from site/ lead (in kms)**	**Typical vehicle type (Truck, tempo, etc.)**	**Fuel type of vehicle**
Bitumen						
Mix material/Hot mix asphalt						
Aggregate/base material						
Cement						
Sand						
Fill						
Paint						
Primer						
Water						
Pavement blocks						
Kerb stones						
Others						
2b. Energy consumption (In case month wise-data is available, please fill details in the Annex 1)						
Electricity						
Diesel						
Petrol						
Kerosene						
Others						

3. Information on travel of construction staff/labour

For, routine maintenance work, give details of staff/labour travel (typical pattern)

Staff/labour	**No. of staff/labour involved in a year**	**No. of days in the year when maintenance work is carried out**	**Typical mode of travel** (for coming to construction site)	**Average distance travelled to reach site (kms)**	**Remarks**
Contractors/engineers/ other staff					Are the vehicles owned by the contractor/ authority? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour					
Workmen					
Equipment operators					

Periodic renewal/maintenance of road

(Renewal coat to the wearing course/surface done periodically at predetermined frequency)

1. What is the frequency of periodic renewal/maintenance i.e. putting renewal coat to the wearing course/surface?			_____years			
2. Who carries out the periodic renewal/maintenance?						
3. Please give details for one periodic renewal/maintenance work on the road						
3a. Material consumption						
Materials used for 1 full periodic maintenance work (Confirm the length of road for which this work was carried out)	**Quantity used**		**Source from where construction material/fuel was brought and mode of transportation**			
	Quantity	**Unit**	**Place**	**Distance from site/ lead (in kms)**	**Typical vehicle type used (Truck, tempo, etc.)**	**Fuel type of vehicle**
Bitumen						
Mix material/Hot mix asphalt						
Aggregate/base material						
Cement						
Sand						
Paint						
Water						
Cut (soil/earth, bitumen, etc.)*			*Destination of cut			
Others						
3b. Energy consumption (In case month wise-data is available, please fill details in the Annex 2)						
Electricity						
Diesel						
Petrol						
Kerosene						
Others						

*Is any of the material that is removed from the wearing course recycled?

4. Information on travel of construction staff/labour

For, periodic maintenance work, give details of staff/labour travel (typical pattern)

Staff/labour	**No. of staff/labour**	**No. of days in which work was completed**	**Typical mode of travel** (for coming to construction site)	**Average distance travelled to reach site (kms)**	**Remarks**
Contractors/engineers/ other staff					Are the vehicles owned by the contractor/ authority? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour					
Workmen					
Equipment operators					

Annex 1

Month-wise electricity and fuel consumption for routine maintenance work

(In case month-wise numbers are available)

Month, Year	Electricity	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

Annex 2

Month-wise electricity and fuel consumption for periodic renewal/maintenance work

(In case month-wise numbers are available)

Month, Year	Electricity	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

11. Questionnaire for collecting data on maintenance of BRTS

Questionnaire for collecting maintenance data for Bus Rapid Transit System (BRTS)

About the road

BRT section maintained: (Start and end points)	From-	To-	Total distance between the two points (km):
City:			
Cross-section details	Type of pavement – bituminous/cement concrete (Bus lane, Private vehicle lane, Cycle track, Footpath) ROW, No. of lanes, Carriage way width, Divided/undivided, median width, etc. Width and type of shoulders, details of side drains, culverts		
When was the BRT corridor constructed? (Completion date of BRT construction)	_____Month _____ Year		
What is the expected life of the pavement?	Bus lane: Private vehicle lane: Cycle track: Footpath:		

Routine maintenance of BRT (ordinary repairs)

1. What are the key routine maintenance activities? [e.g. patch repairs, crack sealing, painting (signs, kerbs, road markings, etc.), vegetation removal]	

2. For routine maintenance activities, please share details for one year maintenance work as indicated below.

2a. Material consumption

Materials used for routine maintenance (for 1 year)	**Quantity used in one year**		**Source from where construction material/fuel was brought and mode of transportation**			
	Quantity	**unit**	**Place**	**Distance from site/ lead (in kms)**	**Typical vehicle type (Truck, tempo, etc.)**	**Fuel type of vehicle**
Bitumen						
Mix material/Hot mix asphalt						
Aggregate/base material						
Cement						
Sand						
Fill						
Paint						
Primer						
Water						
Pavement blocks						
Kerb stones						
Others						
2b. Energy consumption (In case month wise-data is available, please fill details in the Annex 1)						
Electricity						
Diesel						
Petrol						
Kerosene						
Others						

3. Information on travel of construction staff/labour

For, routine maintenance work, give details of staff/labour travel (typical pattern)

Staff/labour	**No. of staff/labour involved in a year**	**No. of days in the year when maintenance work is carried out**	**Typical mode of travel** (for coming to construction site)	**Average distance travelled to reach site (kms)**	**Remarks**
Contractors/engineers/ other staff					Are the vehicles owned by the contractor/ authority? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour					
Workmen					
Equipment operators					

Periodic renewal/maintenance of BRT

(Renewal coat to the wearing course/surface done periodically at predetermined frequency)

1. What is the frequency of periodic renewal/maintenance i.e. putting renewal coat to the wearing course/surface?	_____years					
2. Who carries out the periodic renewal/maintenance?						
3. Please give details for one periodic renewal/maintenance work						
3a. Material consumption						
Materials used for 1 full periodic maintenance work (Confirm the length of BRT for which this work was carried out)	**Quantity used**		**Source from where construction material/fuel was brought and mode of transportation**			
	Quantity	**Unit**	**Place**	**Distance from site/ lead (in kms)**	**Typical vehicle type used (Truck, tempo, etc.)**	**Fuel type of vehicle**
Bitumen						
Mix material/Hot mix asphalt						
Aggregate/base material						
Cement						
Sand						
Paint						
Water						
Cut (soil/earth, bitumen, etc.)*			*Destination of cut			
Others						
3b. Energy consumption (In case month wise-data is available, please fill details in the Annex 2)						
Electricity						
Diesel						
Petrol						
Kerosene						
Others						

*Is any of the material that is removed from the wearing course recycled?

4. Information on travel of construction staff/labour

For, periodic maintenance work, give details of staff/labour travel (typical pattern)

Staff/labour	**No. of staff/labour**	**No. of days in which work was completed**	**Typical mode of travel** (for coming to construction site)	**Average distance travelled to reach site (kms)**	**Remarks**
Contractors/engineers/ other staff					Are the vehicles owned by the contractor/ authority? Is the fuel consumption of the vehicles included in numbers provided above?
Construction labour					
Workmen					
Equipment operators					

Annex 1

Month-wise electricity and fuel consumption for routine maintenance work

(In case month-wise numbers are available)

Month, Year	Electricity	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

Annex 2

Month-wise electricity and fuel consumption for periodic renewal/maintenance work

(In case month-wise numbers are available)

Month, Year	Electricity	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

12. Questionnaire for collecting data on mechanized maintenance of railway tracks (Broad Gauge)

Questionnaire for collecting data on mechanized maintenance of railway tracks (broad gauge)

Rail length maintained: Rail start and end points:	**From-**	**To-**	**Total distance** between the two points (km):
State/s in which the track is falling:			
Cross-section details of rail track maintained: (Please give a cross-section diagram also)	**Track component**	**Materials (put √)**	**Remarks (if any)**
	Formation	Earth ___ Others (specify) _____	
	Ballast	Stone aggregate ___ Sand ___ Moorum ___ Coal ashes ___ Others (specify) _____	
	Sleepers	Pre-stressed concrete ___ Cast iron ___ Steel ___ Wooden ___ Others (specify)_____	Life of sleepers ____years
	Rails	60 kg 90 UTS ___ 52 kg ___ 90 R ___	Life of rails _____years
When was this rail track constructed?			
When did rail operations start on this track?			
When the rails on this track were replaced last time?	_____ **When the rails on this track will be replaced next? _____**		
When the sleepers on this track were replaced last time?	_____ **When the sleepers on this track will be replaced next? _____**		
Traffic on this rail track (GMT)			

Description of activities in annual maintenance of the identified track

- Post monsoon maintenance works
- Pre-monsoon maintenance works
- Maintenance works during monsoon
- Spot renewal of rails and sleepers
- Distressing of LWRs
- Machine tamping - Main tamping, pre and post tamping works
- Annual systematic attention to track by gangs
- Need-based track maintenance (directed track maintenance)

Activities	**Mechanized equipments used**	**Fuels used by equipments** (Electricity, petrol, diesel, etc.)

Information on consumption of construction materials (for one year maintenance activities on the track)								
Type	**Quantity used**	**Source from where construction material is/was brought**		**Typical mode used for transporting material from source**				
	(tonnes/ litres/kms/ mts/ number)	**Place**	**Distance from site/lead (in kms)**	**Vehicle type**	**No. of trips**	**Average loading on vehicle (tonnes/litres)**	**Fuel type (diesel, CNG, etc.)**	**Fuel efficiency (km/l)**
Stone aggregate								
Sand								
Moorum								
Sleepers								
Rail								
Fish plates								
Bolts/screws								
Keys								
Spikes								
Elastic fastenings								
Concrete		*						
Cement								
Water								
Steel reinforcement								
Other steel								
Bricks								
Paint/primer								
Fill (soil/earth)								
Cut (soil/earth)		**						

** Is usually prepared on- site. In case, these are being prepared off-site, then the details should be filled.*
*** Destination of cut*

Information on electricity and fuel consumption (for one year maintenance activities on the track)

Electricity consumption
Total electricity purchased from electricity distribution company/ state electricity board: _____ (Unit _____) (In case month wise-data is available, please fill details in the Annex 1) Which company? :_____
No. of electric generators used: _____ Fuel type used in generators: _____ Total quantity of each fuel type used in generators (as on date): Fuel_____ Quantity_____ Unit_____ Fuel_____ Quantity_____ Unit_____ Fuel_____ Quantity_____ Unit_____ Fuel_____ Quantity_____ Unit_____ (In case month wise-data is available, please fill details in the Annex 1)

Consumption of fossil fuels		
Fuel	**Quantity**	**Unit**
Diesel		
Petrol		
Furnace oil		
LDO		
Kerosene		
Others (please specify)		
(In case month wise-data is available, please fill details in the Annex 1)		

Note: The fuel consumption numbers should be total for one year maintenance activities. They should include fuel consumption for all activities like running of on-track, off-track machines & equipments, welding, inspection activities, movement of gang men, etc.

Information on travel of gang men/staff/labour

Staff/labour	No. of gang men/ staff/labour involved in one year	Typical mode of travel to track maintenance site Vehicle type	Average daily distance travelled to reach maintenance site (kms)
Gang men			
Staff			
Labour			

No. of days in a year when maintenance works are carried out ____

Annex 1

Month-wise electricity and fuel consumption for one year maintenance activities

(In case month-wise data is available)

(Specify units for data)

Month, Year	Electricity purchased from power distribution company	Electric generators					Total fuel consumption									
		Diesel	Kerosene	Petrol	Natural gas	LPG	Diesel	Petrol	CNG	Kerosene	LPG	Natural gas	Furnace oil	LDO	Biomass	Others (if any)

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About Sustainable Habitat Division, TERI

The Sustainable Habitat Division at TERI is comprised of three research areas: the Center for Research on Sustainable Building Sciences (CRSBS), the Center for Research on Sustainable Urban Development and Transport Systems (CRSUDTS), and the Association for Development and Research on Sustainable Habitats (ADaRSH).

CRSBS is dedicated to all aspects of energy and resource efficiency in buildings and has been offering environmental design solutions for habitat and buildings of various complexities and functions for nearly two decades. It consists of architects, planners, engineers, and environmental specialists who specialize in urban and rural planning, low energy architecture and electromechanical systems, water and waste management and renewable energy systems. A regional center in Bangalore has been set up to facilitate development and mainstreaming of sustainable buildings, improve performance levels of existing buildings, and raise awareness on sustainable buildings in Southern India.

CRSUDTS works extensively on various urban issues with an aim to promote sustainable urban development. It was established in 1999 in response to the growing urban demands, particularly in the urban infrastructure sectors. CRSUDTS is involved in research related to urban transport and sustainability issues. It's activities range from carrying out energy-environment related analysis, giving inputs to policy and planning, improving urban service provision and governance, carrying out sustainability assessments, exploring climate change implications and carrying out capacity building for various stakeholders, all in the context of the transport and urban development sectors.

ADaRSH has been setup as an independent entity to promote GRIHA and its associated activities.