# MINIMUM STANDARD FOR ROAD CONDITIONS DURING ROAD REHABILITATION FOR OPTIMIZING ENERGY, ENVIRONMENT AND ECONOMIC IMPACTS

---

## Progress Report -01


*Prepared by*

Transportation Engineering Division

Department of Civil Engineering

University of Moratuwa



*Prepared for*

Vehicle Emission Trust Fund

Department of Motor Traffic

Sri Lanka

# TABLE OF CONTENTS

# List of Tables



# List of Figures

# 1 BACKGROUND TO THE RESEARCH PROJECT

## 1.1 Introduction

Sri Lankan Governments over the past decade has undertaken major investments on transportation infrastructure projects such as Expressways, Highways, and Railways with the intention of uplifting the living conditions of the general public and attracting foreign investments, tourists, etc.

Rehabilitation of urban roads are a part of this effort carried out with the objective of reducing the congestion in urban road networks. The Road Development Authority and the respective Municipal Councils or Urban Councils are the undertaking these projects for the roads under their purview. However, it has been observed that, there are several issues that arise during the construction period that affect the road users and the general public due to poor management and standards maintained at the work zones of highway construction projects in urban areas.

## 1.2 Highway work-zone

Highway work-zone is an area of a traffic way with highway construction, maintenance, or utility-work activities. A work zone is typically marked by signs, channeling devices, barriers, pavement markings, and/or work vehicles. It extends from the first warning sign or flashing lights on a vehicle to the "End of Road Work" sign or the last traffic control device.

During the time of rehabilitation, there are many inconveniences caused to the general public. It includes road users and nearby residents, shops, hospitals, courts, etc. Specifically, the following have been identified as the major inconveniences caused by a highway rehabilitation work zone.

- Safety issues
- Air, Water, and noise pollution
- Vibrations causing damages nearby structures
- Social issues due to land acquisition
- Mismatch between bi-roads and main road (Access gradient, texture, roughness, width)

- Condition of the provided by roads and the part of the road open for traffic
- Issues in traffic management and on site traffic controlling
- Drainage issues
- Increase of vehicle operating cost

This is more pertinent in urban areas where traffic volumes on roads are high and there is high pedestrian flow and road side development prevalent.

### 1.2.1 Current Guidelines on Work-zone Management in Sri Lanka

***Manual on Traffic Control Devices****; Part II, Road Work Areas- Second Edition by Ministry of Transport and Road Development Authority, Sri Lanka* is the widely adopted manual in Sri Lankan context. From 1992, Road development authority of Sri Lanka (RDA) was aware of the need of a manual for traffic signs and markings. First guideline on traffic signs and road markings was introduced in 1997 and was prepared in accordance with the stipulations provided in Vienna convention. In 1999, the National Road Safety Secretariat (NRSS) was requested to conduct a revision on the above manual to identify its relevance, particularly to the proposed Expressways, by Ministry of Transport and Highways. During the process of revision, amendments and additions were made to the original document, including amendments to diagrams to ensure the applicability of them to the proposed expressways. The conformity to Vienna convention, 1995 was further ensured as well.

The traffic control devices recommended in the above report are:

- Traffic Signs
- Traffic Cones
- Barricade Boards
- Road Humps with markings
- Rumble Strips
- Lamps/ Lighting Devices
- Temporary Traffic Light Signals
- Flagmen

Some measures that should be constantly checked in work Zones

- Work zone planning, even if it is a small one
- Signing of road work areas should be uniform and consistent all over the road network
- All traffic control devices should be in good operating condition and checked for low light performance
- The behavior of workmen should be decent enough to maintain a good relationship with road users
- Ensure the removal of all temporary traffic signs after completion of the road
- Someone should be appointed to hold the responsibility of traffic control devices in the work site
- Use as few traffic control devices as possible but as many as necessary.

Factors that impact the quality and safety of the work zone

- Average daily traffic
- The capacity of the temporary lanes and existing roads
- The speed limits
- Availability of detours
- Any other projects in the area (pipe laying, telephone lines, etc.)

However, there are several limitations that will discussed further in the following section that are prevailing in the current guidelines which fails to minimize the impacts on the road users and the environment.

## 1.3 Current issues and practices in highway work-zones in urban roads in Sri Lanka

### 1.3.1 Inconveniences Caused to the Public

It was identified that the road users and the nearby residents face enormous difficulties during the road rehabilitation projects. As described in the above chapters, the critical issues identified are;

- Air pollution
- Noise pollution
- Travel time increase and unreliability
- Disturbances to the accessibility to pedestrians
- Interruptions to the utility lines

- Safety

The most of the above inconveniences could have been minimized with proper planning prior to the commencement of the construction process.

### 1.3.2 Impact on Air Quality

#### 1.3.2.1 Dust Generation

During the study of the considered rehabilitation/ improvement projects, it was found that the most critical issue was air pollution, mainly due to the excessive dust generation. Dust generation occurs in;

- Aggregate crusher, quarry operations
- Roadway excavation
- Sub-base/ base construction
- Concrete and asphalt batching plant operations
- Stockpile operations
- Rock drilling and blasting

In addition, air pollution increases due to poor maintenance of the existing carriageway. Potholes and similar distresses cause dust generation. In addition to the main road rehabilitated under the project, contractors often neglect the pavement conditions of the bi-roads, which are used for transportation purpose. Roads leading to the crushers, asphalt plants etc. often deteriorate beyond usable limit due to excessive axel loads imposed on them by trucks and other machinery.

Another major activity in which excessive dust generation experienced is the stockpile operation. Most of the soil stockpiles were note properly covered, nor wetted. Therefore, the dust particles were blown through the wind, and the most of the nearby properties were covered by a layer of dust witch would be harmful for the health.

#### 1.3.2.2 Harmful Emissions

Hazardous emissions such as $CO_2$, CO, $NO_2$, are emitted to the atmosphere during machinery and plant operations. In addition, these emissions become excessive during the slow moving traffic especially when single pile traffic is allowed during construction activities. All those harmful emissions would be hazardous for the health, which could cause lung diseases and cancers as well. And some of the emission gases would be harmful for the environment as well.

### 1.3.3 Emission Cost

Transport activities lead to air pollution directly from emission and indirectly from refining petrol and diesel. Some pollutants and their harmful results are mentioned below.

- Ozone - This is formed from the reaction of volatile organic compounds (from motor vehicle or industrial sources) and Nitrogen oxide (from motor vehicles). Effects are coughing, painful breathing, respiratory disease and reduction in crop yields.
- CO - This comes mainly from motor vehicle and can cause headache and low-level health effects. It irreversibly binds with Hemoglobin and cause Oxygen shortage in the body.
- Particulate Matter - This includes Carbon and Sulphates from motor vehicle exhaust and particles from break and tire wear. Effects are coughing, asthma, respiratory disease, restricted activity, hospitalization and premature death.
- Lead - This is a toxic heavy metal that comes through the usage of leaded petrol. It can damage the nervous system, reduce brain function of children and cause heart diseases among adults.
- $CO_2$ & $CH_4$ - This contributes to the global warming.

Summary of the factors affecting vehicle emission are summarized in Table 2-2, some of which are relevant to highway workzones.

**Table 1-1: Factors affecting vehicle emission**

| Roadway Characteristics | Traffic Characteristics | Driver Characteristics | Vehicle Characteristics | Weather Characteristics |
|---|---|---|---|---|
| Number of lanes<br>Lane width<br>Sight distance<br>Horizontal curves<br>Vertical curves<br>Grades<br>Roadway type<br>Speed limits<br>Pavement quality | Volume<br>Capacity<br>Volume/ Capacity ratio<br>Vehicle composition<br>Vehicle Speed | Attitude<br>Experience<br>Gender<br>Age<br>Aggressiveness<br><br>Driving modes | Age<br>Mileage<br>Weight<br>Fuel type<br>Engine size, type<br>Air to fuel mass ratio<br>Catalyst Maintenance | Temperature<br>Humidity<br>Visibility |

| | | | | |
|---|---|---|---|---|
| Signal coordination<br><br>Other traffic control measures | | | Aerodynamics<br>Emission control devices<br>Acceleration and deceleration characteristics | |

#### 1.3.3.1 Proposed Air Pollution Mitigation Measures

Some mitigation measures that can be adopted by the contractor are mentioned below.

- Cover the stockpiles properly
- Frequently spray water on the dust prone surfaces of the road (eg. Unpaved sections)
- Cover dump trucks during transportation
- Spray water to the soil stockpiles before being transported to site
- Maintaining the existing roads and by-roads in motorable condition
- Promote latest technologies in asphalt plants and concrete batching plants to minimize dust generation
- Construct dust traps around the perimeter of the crusher plant
- Implementing entrance/outlet tyre wash for vehicles
- Maintain machines and equipment properly to minimize emission of harmful gases
- Retain mobility of traffic within the work-zones with proper traffic handling

### 1.3.4 Noise Pollution

Noise generation is another major concern to the road users. The residents around the work zone will be exposed to high noise levels during the road rehabilitation/ improvement projects. Activities such as;

- Movement an operation of heavy machinery and equipment
- Sub-base and base construction
- Aggregate crushing activities
- Pre-cast pile driving
- Sheet pile driving
- Bored pile socketing and hacking

- Excavation works
- Rock blasting activities
- Asphalt and concrete batching plant operations
- Electrical generators and air compressor operations

Excessive noise in residential areas is not ideal. Especially schools, pre-schools, elderly homes and religious places would require a low noise level from the surrounding. Therefore following mitigation measures have been proposed to overcome excessive noise levels

#### 1.3.4.1 Proposed Mitigation Measures for Excessive Noise Levels

It is suggested to prepare a 'Noise Pollution Mitigation Plan' before the commencement of construction, ideally during the planning stage. In preparation of this report, the locations and types of machineries and equipment to be used should be identified. The probable noise levels should have to be estimated from the past data and from other sources. If the probable noise levels exceed the regulations at the sensitive locations such as schools, temples, courts etc. then alternative mitigation measures should be proposed. It may require some alternative techniques or machinery to be used for those identified locations.

Most of the construction machinery and plants used in Sri Lanka are not state of the art and used. Most of the contractors hesitate to invest on latest machinery because of the lack of initial capital. However, most of the conventional machineries have been developed to increase the efficiency while the heat and noise generation are reduced. This results in less usage of machinery with improved noise levels and efficiency.

Attention should be given when locating Quarries, Mixing plants, and crushers. At the road construction works, it is suggested to use temporary noise barriers to minimize the noise passed into sensitive locations. They can easily be made from plastics, fibers etc. and can be re used as well.

### 1.3.5 Travel time increase

It is not possible to eliminate delays but delays can be minimized through proper planning. Delays occur due to;

- Improper Traffic management plans

- Pavement condition during rehabilitation
- Roadside friction due to temporary storage and construction activities
- Lack of advance signs and notices
- Unavailability of bi-roads and alternate links

#### 1.3.5.1 Proposals to Minimize Traffic Delays

Alternative routes should have been identified at the initial stages of the project, and the road users and the general public should have been informed about the proposed road rehabilitation/ improvement works to be executed. By means of electronic media and printed media, the alternative routes should have been published, and the road users should have been advised to avoid the project road as much as possible. The traffic patterns should have been studied together with an origin-destination survey. Then the related construction plan should be implemented to minimize the disturbances to the public.

Care should be taken to keep the pavement as motorable as possible during the construction period. If the traffic volume is very high, a new temporary road can be built and opened for traffic.

### 1.3.6 Disturbances to the Accessibility

Business places and residences become the victims of access restrictions during road rehabilitations. These kinds of disturbances to the accesses could be occurred mostly due to the grade (elevation) difference due to the improvement of the vertical profile of the road. At most of the times, the road finish levels would be raised. In addition, during the side drain construction, sub-base and base construction, asphalt paving could be identified as the major construction activities that could cause disturbances to the existing property access. In some of the locations, even a pedestrian access had not been provided during the construction.

#### 1.3.6.1 Proposals to Minimize Inconveniences due to Accessibility Restrictions

Most of the times, access disturbance is unavoidable for a given period of time. Planning in advance to commencement of rehabilitations can minimize it. For example, avoiding business areas during day times etc. can be done.

The most ideal solution for the disturbances of the accesses is the use of pre-cast drain sections especially for the accesses. The drain type, width and wall height could be determined beforehand and suitable drain sections can be constructed beforehand and brought to the site. This could complete the access rapidly by providing the suitable cover-slabs on top of the drain walls. Adopting and practicing this method could drastically reduce the time duration of the accesses closure.

The existing access should be disturbed only if all the required resources are ready, and only if there is an assurance that the access could be reinstated with the minimal disturbances to the users. If the existing access is already damaged for the construction works, the contractor should be enforced focus on reinstating it at the earliest possible. If the access is damaged for an unavoidably long period of time, it is suggested to provide temporary access by means of steel plates or suitable material.

Another important suggestion is to construct the private property access in two halves, at two stages. This strategy would be ideal for the commercial places where the width of the existing access is 6m or more. During the construction of one half of the access, the remaining half could be used in this method.

It is also suggested to discuss with the property owners about their convenient time for the access constructions. Weekends and public holiday would be ideal for the access construction of business places.

### 1.3.7 Interruptions to the Utility Lines

Most of the residences and business places have suffered due to the interruptions to their utility lines such as water supply, electricity and telecommunication lines. These disturbances could occur due to;

- Utility line relocation process
- During construction activities by mistakes

In most road rehabilitation projects, the existing utility lines adjacent to the road edge would have to be relocated prior to the construction activities commence. Generally, this relocation would be carried out by directly by the respective utility organization (eg.Ceylon Electricity Board).

In addition to that, the existing utility lines could have been damaged accidently during road construction activities especially during the roadway excavations and side drain excavation processes.

#### 1.3.7.1 Strategies to Minimize Interruptions to the Utility Lines

The disturbances to the utility lines during the utility relocation process could not be avoided at all. However, the respective authorities or the contractor should inform the users about their relocation plan and schedule prior to the commencement. They should publish their schedule such that all the probable users are informed about the interruptions. Then the users could plan their activities accordingly.

The existing utility lines get damaged during excavations. The main reason for these kinds of damages is the lack of as-built drawings of the layout plans from the respective authorities. Under these circumstances, trial pits should have dug in pre-determined intervals to check the types and depths of each underground utility line. In addition, the adjacent residents could be consulted to get an initial idea of the types and locations of each underground utility line.

The metal detectors could be used to identity underground electricity cables, and GI pipes. In these cases, the exact location of the each line can be identified.

The construction team should be well equipped with necessary equipment to repair any damages to the utility lines like water and sewage.

Critically, experienced and well-trained operators can minimize the overall damages to the utility lines.

# 2 PROJECT PROPOSAL

## 2.1 Research Objectives

- Evaluate current condition of road rehabilitation project work zones with respect to condition of the roadway conditions and traffic management.
- Evaluate traffic operating conditions at road rehabilitation project work-zone considering the traffic volume and roadway characteristics.
- Estimate the increase in emission and fuel consumption and vehicular depreciation due to congestion and poor road conditions at work zones.
- Quantify the economic value of increase in vehicle operating cost, fuel consumption and pollution in road rehabilitation project work-zones.

## 2.2 Main deliverables and Outcomes of the study

### 2.2.1 Goal of the proposed project

Evaluate the increase economic cost (related to vehicle operating costs and emissions) due to roadway and traffic conditions at work zones of urban road rehabilitation projects and propose minimum standards that should be maintained during road construction projects to minimize the economic costs of such projects, while improving fuel economy and emissions.

### 2.2.2 Outcomes

- Existing road conditions of work zone roadway measured in terms of road roughness and travel speeds for traffic.
- Increase in fuel consumption and vehicular depreciations for selected vehicle types when travelling on work zone areas in road rehabilitation projects.
- Estimated emission levels of work zone areas.
- Methodology to compute economic cost of poor roadway conditions at work zones in road rehabilitation projects.
- Propose minimum standards for roadway conditions during road rehabilitation projects.

## 2.3 Intended Results

The study outcomes can be used to establish the effects of road conditions on energy and environmental performances of road vehicles, and thereby promote improved work zone management practices and standards in urban road rehabilitation projects to ensure the economic costs, with respect to pollution and vehicular operating costs are minimized. The findings can also be incorporated in the feasibility studies of such projects so that these external costs are considered in evaluating project feasibility.

## 2.4 Project Activities:

- Conduct surveys at road upgrading project sites to measure traffic volume, composition, travel speed, road condition (roughness, distresses) and traffic management methods.
- Estimate the fuel consumption, vehicular depreciation and emission levels based on the traffic composition, speed, and road conditions using methodologies available in literature (HDM4 software will be used, other methodologies will also be explored).
- Carry out surveys to estimate fuel consumption levels for different roadway conditions (measured in terms of road roughness only) for selected vehicle types. Develop methodology to estimate the economic cost of poor roadway conditions in work zones of road rehabilitation projects.

## 2.5 Indicators for Project Outcomes

- Guideline for minimum standard will be submitted to ICTAD, RDA and PRDA for implementation in the road construction projects  Guideline for minimum standard will be submitted to CEA for EIA and IEE approvals.
- Two technical papers will be published in reputed journals based on the outcome of the research work.
- A workshop will be conducted for the representatives of road agencies, road contractors and consultants.

### 2.5.1 Means of Verifications

- The relevant documents copies will be submitted with the comments from respective organizations
- Letter of acceptance / copy of reviewers’ comments will be submitted
- Participant list and the summary of feedback of the participants will be submitted.

Assumptions: Unit economic values existing in literature relevant to local conditions will be used to quantify the economic costs.

### 2.5.2 Sustainability Aspects

- ICTAD can include the guidelines in the specification for roads and bridge constructions.
- RDA and other road agencies implement the standard in road construction projects during the monitoring and evaluation of road projects.
- Propose to include the minimum standard in conditions of contracts.

Submit a copy the minimum standard to CEA to implement in EIA, IEE approvals

# 3 METHODOLOGY

## 3.1 Data collection

### 3.1.1 Roughness Data

Pavement condition is represented by international roughness index (IRR), a globally recognized parameter to represent the condition of a road pavement. A higher IRR value would represent a road in poor condition with surface irregularities, unevenness and distresses. Typically roads with IRR values of 6 above are considered to be in poor condition and IRR exceeding 10 are considered to be unsuitable for frequent movement of traffic (see Figure 3-1. IRR scales and pavement condition).

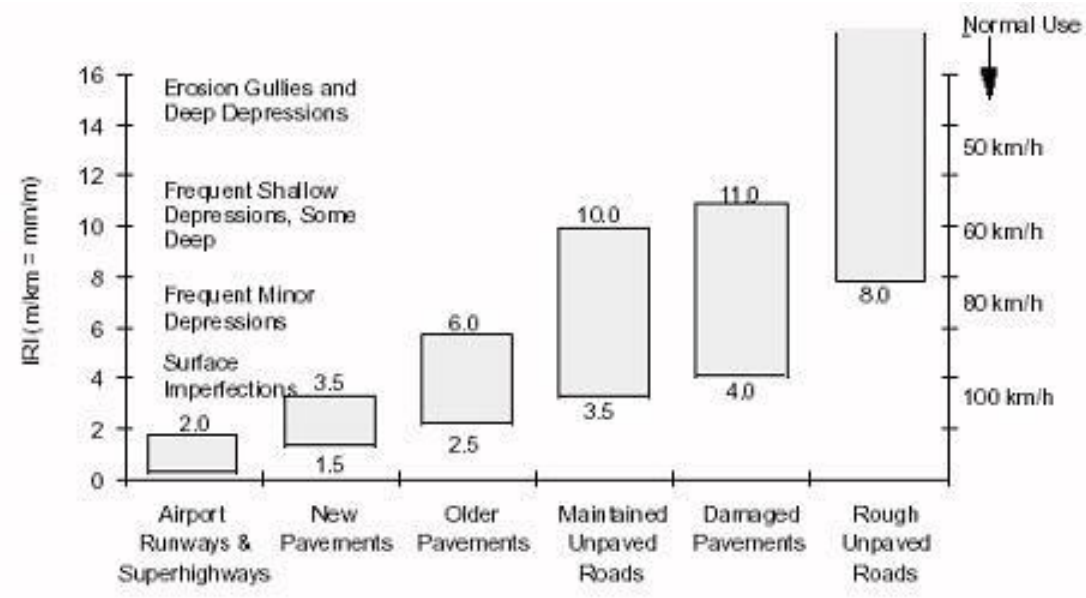



**Figure 3-1. IRR scales and pavement condition[1]**

Roughness data is collected for road segments near workzones to evaluate their condition and this data will be used to assess the vehicle operating cost variation due to the change in work zone pavement conditions.

### 3.1.2 Speed Survey

Speed survey was done in normal road segment, work zone & finished road segment in

[1] Sayers et al., 1986, source: http://www.pavementinteractive.org/roughness/ (retrieved: 1/7/2017)

peak and off-peak hours using GPS data loggers. This will give the distance and time at various road segments which can be used to calculate the travel speed.

The data will be used to calculate the travel time increase (delay) in the work zone area.

### 3.1.3 Traffic Surveys

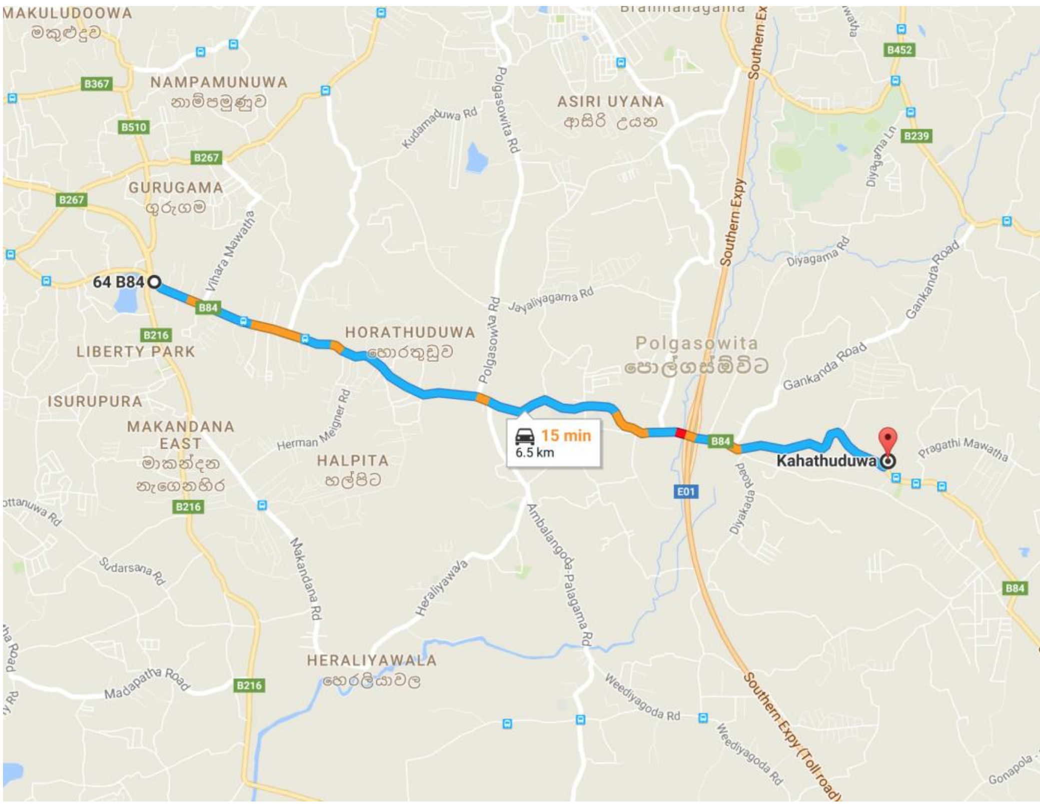
Manual classified counts will be carried out at work-zones to identify the volume and composition of traffic on the particular road where the surveys are carried out. This will be required to assess the total economic cost due to delays and vehicle operating cost increase due to work zone activities.

The traffic volume and speed survey data is also an input in the emission modelling process which will be elaborated in the following sections.

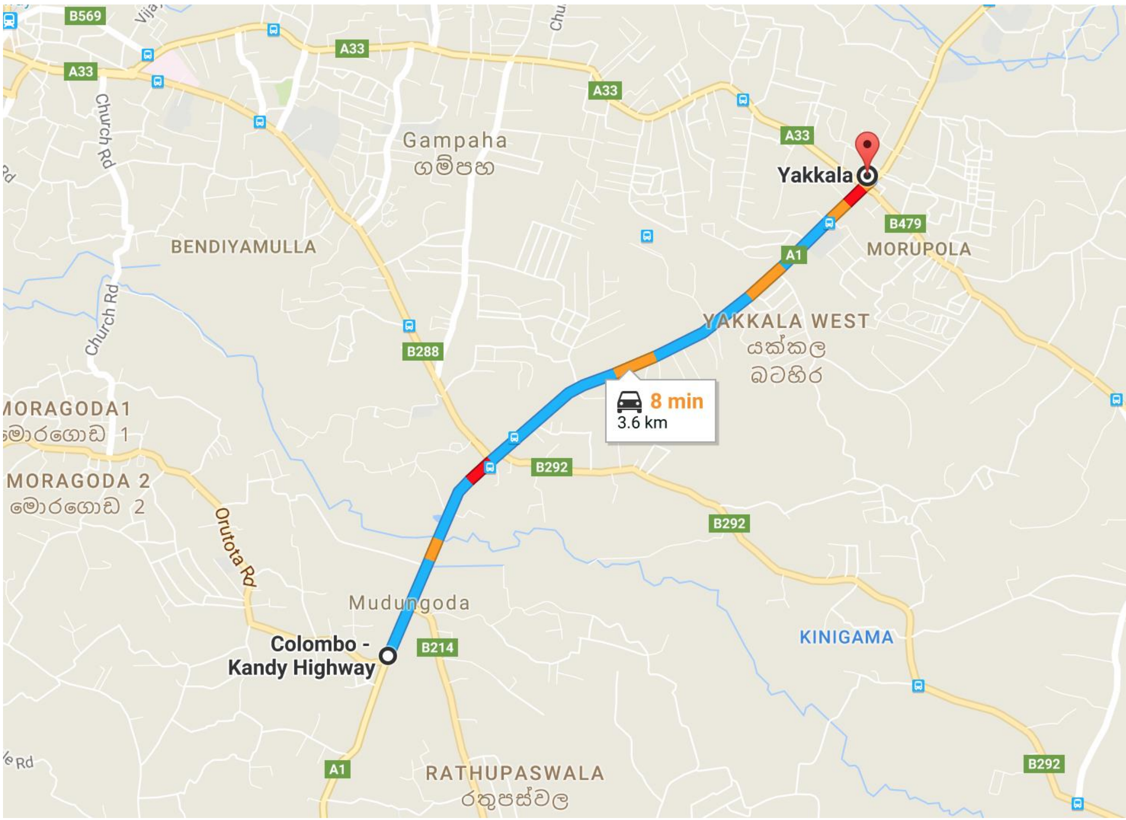
## 3.2 Survey Locations

The following sites where road rehabilitation work is being carried out have been identified for the detailed data collection. Additional sites will be considered based on the quality of the data collected from the given locations.

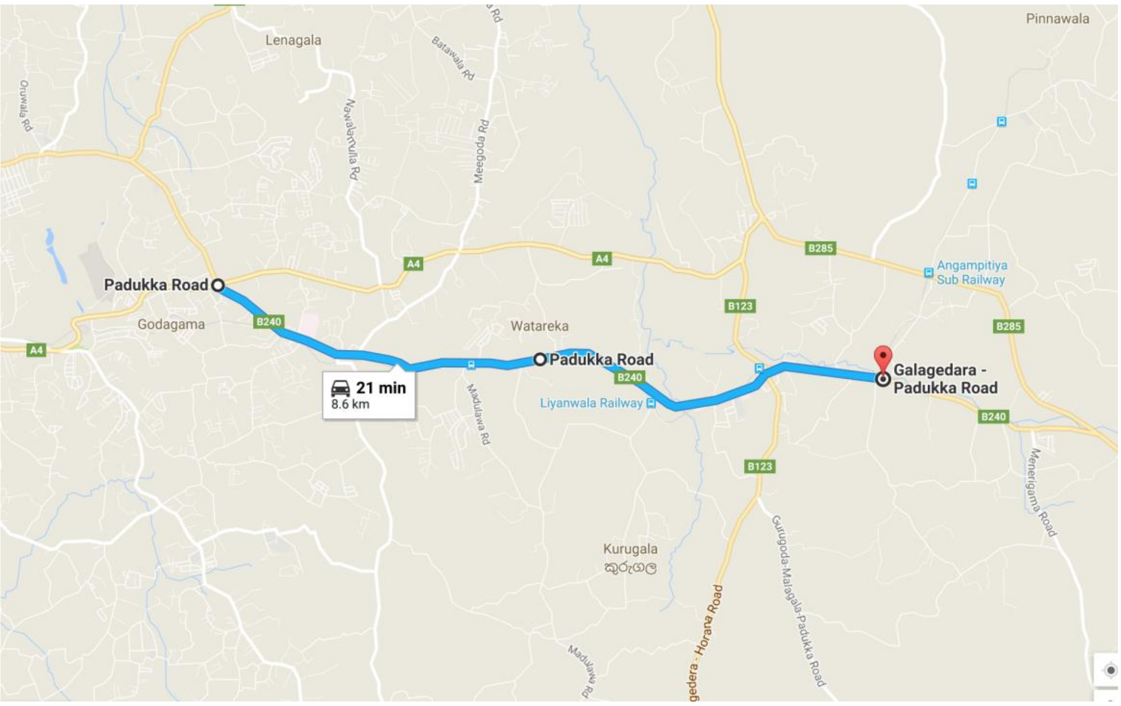
- B84 Horana Road:- Road stretch from Kesbewa junction to Kahathuduwa expressway entrance



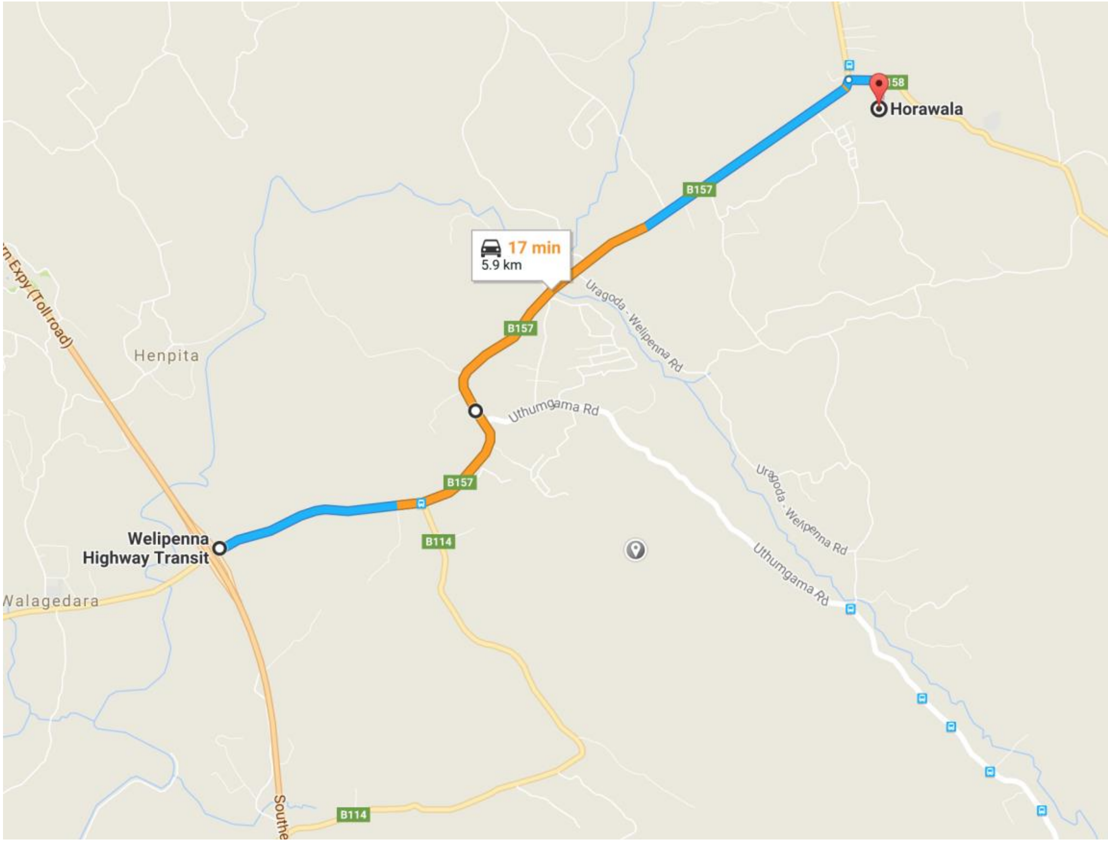
- A1 Kandy road:- Belummahara junction to Yakkala junction




- B40 Padukka road:- Godagama to Padukka



- B157  Aluthgama road:- Welipenna entrance to Horawala




## 3.3 Estimation of Road User Costs

The base values for toad user costs were estimated according to the guideline by Ministry of National Planning, 2000.  This includes, value of time of road users (by vehicle type, vehicle operating cost (for different speeds/ IRI values), emission cost.

The estimation methodology is included in Appendix I of the report.

# 4 ILLUSTRATIVE EXAMPLE – CASE STUDY FOR B295 ROAD (MORATUWA-PILIYANDALA ROAD)

## 4.1 Summary of Data collection and Analysis

This study has adopted an analytical approach using HDM-4 developed by World Bank to estimate the vehicle operating costs, Emission costs, delay costs etc. HDM-4 model is widely used to estimate vehicle operating cost for highway project economic evaluations and the model results have been validated by studies done in several countries.

The software was calibrated using data obtained from an internal study conducted by Transportation engineering division of Department of Civil Engineering, University of Moratuwa. Further, the monetary values for Value of Time of a person (VOT) are obtained from the report "Assesssing Public Investment in the Transport Sector," Ministry of Finance, Sri Lanka, 2000.

**Speed surveys were carried out on the road segment near the workzone and under normal operating conditions. As observed in Table 4-1, 4-2 and**

Figure 4-1, there is a significant reduction in speeds of all vehicle types, especially the heavy vehicles such as buses, trucks. This leads to the delays and economic loss due travel time increase. Furthermore, slow moving vehicles will also increase fuel consumption resulting in increase in vehicle operating cost increase.

**Table 4-1: Speed survey- Off peak**

| Off Peak hour 10.00 am - 11.00 am | | | | | |
|---|---|---|---|---|---|
| **Vehicle Type** | **Number** | **Percentage** | **Speed (kmph)** | | |
| | | | **Normal** | **Work zone** | **Finished road** |
| Car | 180 | 20% | 40 | 15 | 55 |
| Three Wheel | 283 | 31% | 35 | 20 | 40 |
| Motor Bike | 326 | 36% | 50 | 30 | 60 |
| Bus | 32 | 4% | 37 | 12 | 50 |
| Truck | 17 | 2% | 35 | 10 | 45 |
| MGV | 65 | 7% | 40 | 15 | 50 |

**Table 4-2: Speed survey- Peak hour**

| Peak hour 5.00 pm - 6.00 pm | | | | | |
|---|---|---|---|---|---|
| **Vehicle Type** | **Number** | **Percentage** | **Speed (kmph)** | | |
| | | | **Normal** | **Work zone** | **Finished road** |
| Car | 416 | 29% | 25 | 10 | 45 |
| Three Wheel | 373 | 26% | 30 | 13 | 40 |
| Motor Bike | 458 | 32% | 40 | 25 | 55 |
| Bus | 57 | 4% | 22 | 8 | 40 |
| Truck | 43 | 3% | 22 | 7 | 35 |
| MGV | 85 | 6% | 25 | 10 | 40 |

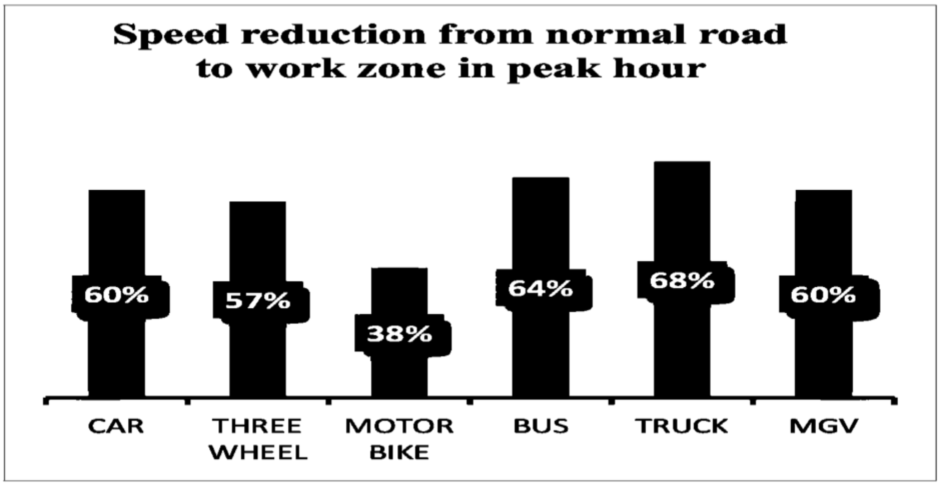



**Figure 4-1: Speed reduction from normal condition to work zone condition**

### 4.1.1 General Assumptions for Road User Cost Calculation

The following assumptions were made in the illustrative example.

- Effective work zone length = (150 + 100 + 150) = 400 m (Average queue length observed in traffic survey during peak time was 150 m)
- No queue was observed at off peak
- Morning peak:- 07:00h -10:00h, Off peak:- 05:00h – 07:00h & 10:00h – 16:00h, Evening Peak:- 16:00h – 19:00h & off peak:- 19:00h – 23:00h
- From 23:00h–05.00h, no traffic condition was assumed
- It was assumed that Saturdays have 75% of week day value and Sundays have 25% of week day value (6 week days per week)
- Only one work zone exist along the road at a day and the construction work equally interrupt the users along the entire construction period.

## 4.2 Estimation of Travel Delay Cost

The speeds in work zone and normal road segment are calculated from the speed survey and the work zone travel delays for different vehicle are estimated as mentioned in Delay time calculation. The travel delay cost is calculated by multiplying the delays by monetary of time for different vehicle types

**Table 4-3: Travel delay cost calculation**

| | Vehicle type | Duration (months) | road length (km) | Length of WZ (m) | Effective Length (m) | Normal Speed (kmph) | WZ Speed (kmph) | Travel Time - Nor. (mins /veh) | Travel Time - WZ (mins /veh) | Additional Time (mins /veh) | peak - day (Rs/ day) | Off peak day (Rs/ day) | peak - Evening(Rs/ day) | Off peak - Eve. (Rs/ day) | Cost (Rs/day) | Cost (Rs/ month) | cost for entire duration (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Car | 18 | 2.5 | 100 | 400 | 25 | 10 | 0.96 | 2.40 | 1.44 | 20577 | | 18600 | | | | |
| | 3Wheel | 18 | 2.5 | 100 | 400 | 30 | 13 | 0.80 | 1.85 | 1.05 | 7356 | | 6263 | | | | |
| | Mo. byk | 18 | 2.5 | 100 | 400 | 40 | 25 | 0.60 | 0.96 | 0.36 | 2490 | | 2242 | | | | |
| | Bus | 18 | 2.5 | 100 | 400 | 22 | 8 | 1.09 | 3.00 | 1.91 | 1012 | | 947 | | | | |
| | LGV | 18 | 2.5 | 100 | 400 | 22 | 7 | 1.09 | 3.43 | 2.34 | 19350 | | 19350 | | | | |
| | MGV | 18 | 2.5 | 100 | 400 | 25 | 10 | 0.96 | 2.40 | 1.44 | 10037 | | 10037 | | | | |
| | | | | | | | | | | | | | | | | | |
| P | 3Wheel | 18 | 2.5 | 100 | 100 | 35 | 20 | 0.17 | 0.30 | 0.13 | | 1189 | | 252 | | | |
| E | Mo. byk | 18 | 2.5 | 100 | 100 | 50 | 30 | 0.12 | 0.20 | 0.08 | | 789 | | 144 | | | |
| A | Bus | 18 | 2.5 | 100 | 100 | 37 | 12 | 0.16 | 0.50 | 0.34 | | 117 | | 46 | | | |
| K | LGV | 18 | 2.5 | 100 | 100 | 35 | 10 | 0.17 | 0.60 | 0.43 | | 3740 | | 1870 | | | |
| | MGV | 18 | 2.5 | 100 | 100 | 40 | 15 | 0.15 | 0.40 | 0.25 | | 3553 | | 1777 | | | |
| | | | | | | | Additional Total VOT Cost | | | | 60821 | 11740 | 57439 | 4629 | 134630 | 3231109 | **58159960** |

### 4.2.1 Estimation of Additional Vehicle Operating Cost

The speeds in work zone and normal road segment are calculated from the speed survey and the road roughness (IRI measurement) is measured by miniROMDAS equipment mounted on a Land Rover Defender and it is concluded that the road roughness in work zones is IRI = 6 and road roughness in normal segments is IRI = 3. The vehicle operating cost for different speed and different vehicles are adjusted to 2016 monetary values as described above in **Determination of VOC** section.

**Table 4-4: Additional VOC of work zone**

| | Vehicle type | No | Normal Speed (kmph) | WZ Speed (kmph) | Duration (months ) | road length (km) | Length of WZ (m) | Effective Length (m) | VOC - IRI 3. (Rs/km) | VOC - WZ (IRI 6) (Rs/km) | Additional VOC (Rs/km) | VOC (Rs/day) | Cost (Rs/ month) | cost for entire duration (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Car | 416 | 25 | 10 | 18 | 2.5 | 100 | 400 | 29.15 | 40.96 | 11.81 | 11791.10 | 282986 | 5093757 |
| P | 3Wheel | 373 | 30 | 13 | 18 | 2.5 | 100 | 400 | 19.27 | 26.5 | 7.23 | 6472.30 | 155335 | 2796032 |
| E | Mo. bike | 458 | 40 | 25 | 18 | 2.5 | 100 | 400 | 7.91 | 9.03 | 1.12 | 1231.10 | 29546 | 531837 |
| A | Bus | 57 | 22 | 8 | 18 | 2.5 | 100 | 400 | 55.5 | 98.94 | 43.44 | 5942.59 | 142622 | 2567200 |
| K | Truck | 43 | 22 | 7 | 18 | 2.5 | 100 | 400 | 53.2 | 91.4 | 38.20 | 3942.24 | 94614 | 1703048 |
| | MGV | 85 | 25 | 10 | 18 | 2.5 | 100 | 400 | 39.44 | 71.29 | 31.85 | 6497.40 | 155938 | 2806877 |
| | | | | | | | | | | | | | | |
| O | Car | 180 | 40 | 15 | 18 | 2.5 | 100 | 100 | 27.03 | 35.41 | 8.38 | 1810.08 | 43442 | 781955 |
| F | 3Wheel | 283 | 35 | 20 | 18 | 2.5 | 100 | 100 | 18.52 | 22.38 | 3.86 | 1310.86 | 31461 | 566290 |
| F | Mo. Bike | 326 | 50 | 30 | 18 | 2.5 | 100 | 100 | 7.88 | 8.81 | 0.93 | 363.82 | 8732 | 157169 |
| P | Bus | 32 | 37 | 12 | 18 | 2.5 | 100 | 100 | 43.5 | 89.34 | 45.84 | 1760.26 | 42246 | 760431 |
| E | Truck | 17 | 35 | 10 | 18 | 2.5 | 100 | 100 | 42.09 | 91.4 | 49.31 | 1005.92 | 24142 | 434559 |
| A<br>K | MGV | 65 | 40 | 15 | 18 | 2.5 | 100 | 100 | 32.47 | 55.26 | 22.79 | 1777.62 | 42663 | 767932 |
| | | | | | | | | | | | Total Additional VOC | | = | **18967084** |

## 4.2.2 Estimation of Additional Emission Cost

The speeds in work zone and normal road segment are calculated from the speed survey and additional emission cost is calculated as described above in the report.

**Table 4-5: Additional emission cost**

| | Vehicle type | No | Normal Speed (kmph) | WZ Speed (kmph) | Duration (months ) | road length (km) | Length of WZ (m) | Effective Length (m) | Emission cost(Rs per 1000 km/veh) | Additional emission cost in WZ (Rs/day) | Cost (Rs/ month) | cost for entire duration (Rs) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Car | 416 | 25 | 10 | 18 | 2.5 | 100 | 400 | 5230.80 | 10445 | 250677 | 4512180 |
| P | 3Wheel | 373 | 30 | 13 | 18 | 2.5 | 100 | 400 | 2284.80 | 4091 | 98177 | 1767185 |
| E | M.Byk | 458 | 40 | 25 | 18 | 2.5 | 100 | 400 | 962.60 | 2116 | 50788 | 914190 |
| A | Bus | 57 | 22 | 8 | 18 | 2.5 | 100 | 400 | 11023.30 | 3016 | 72383 | 1302901 |
| K | Truck | 43 | 22 | 7 | 18 | 2.5 | 100 | 400 | 11023.30 | 2275 | 54605 | 982890 |
| | MGV | 85 | 25 | 10 | 18 | 2.5 | 100 | 400 | 5666.00 | 2312 | 55481 | 998666 |
| | | | | | | | | | | | | |
| O | Car | 180 | 40 | 15 | 18 | 2.5 | 100 | 100 | 5230.80 | 2260 | 54233 | 976193 |
| F | 3Wheel | 283 | 35 | 20 | 18 | 2.5 | 100 | 100 | 2284.80 | 1552 | 37244 | 670393 |
| F | M.Byk | 326 | 50 | 30 | 18 | 2.5 | 100 | 100 | 962.60 | 753 | 18075 | 325356 |
| P | Bus | 32 | 37 | 12 | 18 | 2.5 | 100 | 100 | 11023.30 | 847 | 20318 | 365727 |
| E | Truck | 17 | 35 | 10 | 18 | 2.5 | 100 | 100 | 11023.30 | 450 | 10794 | 194292 |
| A<br>K | MGV | 65 | 40 | 15 | 18 | 2.5 | 100 | 100 | 5666.00 | 884 | 21214 | 381843 |
| | | | | | | | | | | | **Total Additional Emission Cost in WZ** | **13391817** |

# 5 WORK PLAN FOR THE REMAINING TASKS

### 5.1.1 Monitoring and Evaluation

The activities outlined in the project and the current status is summarized as follows.

| **Activity** | **Current Status** |
|---|---|
| Conduct surveys at road upgrading project sites to measure traffic volume, composition, travel speed, road condition (roughness, distresses) and traffic management methods. Evaluation of roadway and traffic conditions at work zones | Surveys in progress<br><br>A report to be submitted with a summary of the findings by end of August 2017 |
| Estimate the fuel consumption, vehicular depreciation and emission levels based on the traffic composition, speed, and road conditions using methodologies available in literature (HDM4 software will be used, other methodologies will also be explored).<br><br>Carry out surveys to estimate fuel consumption levels for different roadway conditions (measured in terms of road roughness only) for selected vehicle types. | Calibration work relating to HDM4 model in progress.<br><br>A detailed methodology will be included in final report including the assumptions made, references for data sources.<br><br>The survey routes and the procedure followed to estimate fuel consumptions will be submitted in Progress report - 2 |
| Develop methodology to estimate the economic cost of poor roadway conditions in work zones of road rehabilitation projects. | Background information and preliminary methodology is elaborated in the progress report-1. A detailed methodology will be included in final report including the assumptions made, references for data sources. |

**Table 5-1: Work plan**

| Task Description | Timeline |
|---|---|
| Roughness surveys will be conducted in selected work-zones using the miniROMDAS vehicle mounted equipment. | End of 31st August 2017 |
| Data collection on Emissions in work-zones | End of September 2017 |
| Analysis of emission and roughness data using HDM-4 | Ending on 2nd week of November 2017 |
| Submission of Project report | End of December 2017 |

# 6 APPENDIX I

## 6.1 Travel Delay Cost

#### 6.1.1.1 Introduction

Delay in travel is a major indication of inconvenience created due to work zones. The major component of the Work zone related user cost (WZRUC) is also delay cost. Travel delay cost is calculated by multiplying the additional delay to passenger vehicle and freight consignees caused by the work zone (hr) by the value of time (Rs/hr).

#### 6.1.1.2 Delay Time Calculation

The additional delay caused by the work zones is calculated according to the speed changes from the normal road section to work zones. There are 5 kinds of delay estimations described in (2), such as Speed change delay, stopping delay, reduced speed delay, Queue delay and Detour delay. A full detailed speed survey is required to estimate the delays more accurately. Except detour delay, other delays are taken in to effect by considering an effective work zone segment (effective work zone segment = Average queue length approaching the work zone + length of work zone +average queue length leaving the work zone). For example, if a vehicle is travelling in normal segment of the road at 40 km/h and travelling in a work zone at 15 km/h, the delay time is calculated by subscribing the expected additional time the vehicle takes to cross the effective work zone segment at 15 km/h compared to the time to cross the segment at 40 km/h.

*Delay time = Time taken to travel in the effective work zone – Time taken to travel in the normal road*

Assumptions made for the calculation of Delay time

- Effective work zone length = (150 + **100** + 150) = 400 m (Average queue length observed in peak time was 150 m & length of work zone is 100 m)
- Queue formation is only during the peak times
- 2300h to 0500h, it was assumed to have no contribution
- Saturdays, 75% and Sundays, 25% traffic was assumed

- Work zone interruption is of same severity to all the road users
- One work zone per road

#### 6.1.1.3 Monetary Value of Time

The monetary value of travel time is defined in Federal Highway Administration, as it is based on the concept that time spent traveling otherwise would have been spent productively, whether for remunerative work or recreation. Travel time saving is one of the major targets in a road rehabilitation or new road costruction. The system used in Sri Lanka to estimate the saving in travel time while upgrading a road is based on a survey/ estimation done in 2000 by the Department of National Planning. This research updates the monetary values according to the DNP guideline to 2016 values. The monetary value of time is calculated in two categories, Passenger Vehicle and Freight consignees.

*Passengers*

The additional time spent on a work zone affects the economy in terms of value of time (VOT). It is the most significant loss in a work zone comparatively. The VOT depends on the trip purpose and passenger income according to Department of National planning. VOT is a combined calculation of hourly income, trip purpose, and Quantum of travel time saved.

Hourly income is calculated as follows, as mentioned in Sri Lankan road user charges study (RUCS).

Hourly income = $\frac{Monthly\ income * 12}{2000\ (hours\ per\ year)}$

RUCS assumed that public and private transport user groups could be linked to particular income category for the Income computation the following assumptions were made in this study for the income level of the people. RUCS study was done in 1992 and 1999. Assumptions made for this study are in the 2016 column.

**Table 6-1: Assumed income values for 2016**

| Road Users | In 1992 | In 1999 | In 2016 |
|---|---|---|---|
| Car/Jeep Passengers | Second half of 10$^{th}$ Decile (95-100 %) | 10$^{th}$ Decile | 8$^{th}$ ,9$^{th}$ & 10$^{th}$ Deciles |
| Motor cycle users | First half of 10$^{th}$ Decile | 8$^{th}$ Decile | 4$^{th}$ ,5$^{th}$ ,6$^{th}$ & 7$^{th}$ Deciles |
| Van users | Not considered | 9$^{th}$ Decile | Included with car passengers. |
| Three wheel users | Not considered | Not considered | 5$^{th}$ 6$^{th}$ 7$^{th}$ & 8$^{th}$ Deciles |
| Public transport (Bus) | First 9 deciles (0-90%) | 1$^{st}$ to 8$^{th}$ Decile | 1$^{st}$ to 7$^{th}$ Decile |
| Non-motorized transport | Not considered | 1$^{st}$ to 4$^{th}$ | Not considered |

Above assumptions were made under several bases such as;

- Car, SUV
    - At present, low budget cars are widely available
    - Loan and leasing facilities are widely available
    - Involvement of cars in taxi services (e.g. Uber, Pick Me)
    - Increased willingness of people to own a car
    - Dissatisfaction on public transport has created a norm to own a car
    - Convenience in using without delays as of in public transport
- Motorcycle
    - Low ownership cost
    - Handy in congested roads
    - Ability to find parking is higher compared to a car
    - Convenience in using without delays as of in public transport
- Three wheel
    - Ability to find parking easily
    - No need to own to use

    - Handy in congested roads
    - Fair is acceptable
    - High availability
    - Convenience in using without delays as of in public transport
- Public transport – Bus
    - In current Sri Lankan practice, the willingness to use public transport is very low
    - Takes more time to travel a short distance in peak hours
    - Although many people use the buses due to its low fare, generally they are not comfortable for the users.
    - Unreliable with departure and arrival times and duration of travel

*Trip purpose*

As the literature reveals trips undertaken in working time and hence referred to as work time trips, should be valued at the hourly income rate plus an allowance for employer's overhead. RUCS assumptions are as follows

Work time VOT = Hourly income rate x 1.2

Non Work time VOT = Hourly income rate x 0.2

## 6.2 Vehicle Operating Cost

A normal road handles tens of thousands of vehicles a day. The impact of the road condition affects all the vehicles that use the road. The irregularities of the road results in high fuel consumption, high wear and tear of internal components of vehicles such as engine, gearbox and suspension components, high lubricant wear, and many more. Hence identifying how the Vehicle Operating Cost varies with the road condition is a major area to save money in the long-term operation of the highways. A criterion to calculate the Vehicle Operating Cost accurately is a major perk in making decision regarding upgrading of existing highways and also in establishing new road traces and designs.

VOC is defined in Federal Highway Administration Manual as the running costs that vary with the degree of vehicle use, and are thus mileage dependent, and do not include fixed costs such as insurance, time – dependent financing and storage. Also, VOC is an aggregation of:

- VOC of speed change is the additional cost incurred due to decelerating and accelerating in a restricted flow situation such as a work zone.
- Additional VOC incurred by having to stop the vehicle and accelerate back up to running speeds, in areas such as work zones.
- Queue idling VOC is the additional cost associated with stop-and-go driving in the queue. The idling cost rate multiplied by the additional time spent in the queue is an approximation of actual VOC associated with stop-and-go conditions. When a queue exists, stopping delay and VOC replace the free-flow speed change delay and VOC.
- Detour VOC is the additional cost associated with the excess distance to be travelled by selecting a detour route under unrestricted or restricted conditions.

#### 6.2.1.1 Determination of Vehicle Operating Cost

Vehicle operating cost includes:

- Fuel consumption
- Tire consumption
- Lubricant consumption
- Depreciation cost
- Capital cost
- Maintenance labour cost

Determining VOC requires two sets of information

- The economic cost of input such as labour, fuel, spares, replacement cost etc.
- The relationship between consumption of inputs and speed, congestion, and roughness by the type of vehicle.

HDM-4 with proper calibration for Sri Lanka could be used to accurately calculate the VOC values for different roughness, terrain and speeds.

## 6.3 Calculation of Emission Cost

Some assumptions were made to estimate the cost of emissions in a work zone.

- Effective work zone length = (Observed average queue length (for vehicle approach WZ) + work zone length + Observed average queue length (for vehicle release from WZ))
- Morning Peak (07.00 - 10.00), off-peak (05.00 - 07.00 & 10.00 – 16.00), Evening peak (16.00 – 19.00) & off-peak (19.00 – 23.00) (6 peak hours and 12 off peak hours)
- 23.00 to 05.00 were assumed to be of no traffic.
- Its assumed that Saturdays = 75% of week day value and Sunday = 25% of week day value (6 week days per week)
- From a study on vehicle emission, it was estimated that amount of CO emission rate is 3times more in 15kmph speed than 40 km/h speed for passenger cars.( As no studies done with the roughness and emission rate) it is assumed that work zone average speed is 15 km/h and normal road section speed is 40 km/h.
- Emission rate of Buses and Large good vehicles are same in both speeds.
- Only one work zone exists along the road at a day and equal interruption is caused to the users along the entire construction period.

Estimation of cost of emission per liter of fuel consumed was calculated by multiplying grams of emission per pollutant, by respective costs of damage.

**Table 6-2: Amount of pollutants per liter of fuel**

| Emission | Rs per MT | Small Car gm. Per ltr | Motorcycle gr. Per ltr | 3 Wheeler gm per ltr | Van/ Ute gm.per Ltr | Lrg Bus gm. per Ltr | Med Lorry gm.per Ltr | Lrg Lorry gm.per Ltr |
|---|---|---|---|---|---|---|---|---|
| CO | 8050 | 283 | 400 | 283 | 11 | 22 | 15 | 22 |
| CO2 | 4255 | 2,200 | 2,200 | 2,200 | 2,600 | 2,600 | 2,600 | 2,600 |
| Nox | 1874500 | 18 | 3.6 | 15 | 10 | 20 | 15 | 20 |
| HC | | 46 | 88 | 67 | 14 | 14 | 14 | 14 |
| CH4 | | 0.8 | 4.4 | 2.4 | 0.1 | 0.25 | 0.18 | 0.25 |
| NMVOC | | 41.6 | 160 | 100 | 5 | 8 | 6.5 | 8 |
| PM | 15157000 | 1 | 3.5 | 6 | 5 | 5 | 5 | 5 |
| Lead | | 0.4 | 0.4 | 0.4 | 0 | 0 | 0 | 0 |
| Sox | 7567000 | 0.25 | 0.25 | 0.25 | 13 | 13 | 13 | 13 |
| N20 | | 0.03 | 0.04 | 0.04 | 0.13 | 0.13 | 0.13 | 0.13 |
| Total Rs per Litre (2010) | | **62.43** | **36.38** | **56.81** | **46.95** | **65.78** | **56.35** | **65.78** |
| Total Rs per Litre(2016) | | **62.77** | **36.58** | **57.12** | **47.20** | **66.14** | **56.66** | **66.14** |

Estimation of cost of Emission per kilometer by vehicle type at 40 km/h was calculated by dividing the cost of emission per liter fuel (Rs/l) by fuel consumption rate (km/l) [(Rs/l) / (km/l) = (Rs/km)]. Fuel consumption rate was calculated from the HDM-4 model.

**Table 6-3: Emission costs of few vehicle types**

| Vehicle type | Fuel consumption at 40km/h (km/l) | Emission cost per liter of fuel (Rs/l) | Emission cost (Rs/1000km/veh) |
|---|---|---|---|
| Car | 12 | 62.77 | 5230.80 |
| Three wheel | 25 | 57.12 | 2284.80 |
| Motor bike | 38 | 36.58 | 962.60 |
| LGV/Bus | 6 | 66.14 | 11023.30 |
| MGV | 10 | 56.66 | 5666.00 |