Asia Community Access Partnership

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Investigation of suitable dust suppressants for Low Volume Gravel Roads in the Terai region of Nepal

Phase 1 Final Report

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TRL Ltd

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TRL THE FUTURE OF TRANSPORT

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ASIA COMMUNITY ACCESS PARTNERSHIP (AsCAP)

Safe and sustainable transport for rural communities

AsCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Asia. The AsCAP partnership supports knowledge sharing between participating countries in order to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources. AsCAP is brought together with the Africa Community Access Partnership (AfCAP) under the Research for Community Access Partnership (ReCAP), managed by Cardno Emerging Markets (UK) Ltd.

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Acronyms, units and currencies

AsCAP	Asia Community Access Partnership
COPD	Chronic Obstructive Pulmonary Disease
DDC	District Development Council
DFID	Department for International Development
DoLIDAR	Department of Local Infrastructure Development and Agricultural Roads
DTL	District Team Leader
EIA	Environmental Impact Assessment
EPA	Environmental Protection Agency
FHWA	Federal Highways Authority (of the USA)
ICIMOD	International Centre for Integrated Mountain Development
LDO	Local Development Office
LFTT	Laboratory/Field Testing Technician
LIC	Low Income Country
ME	Gravel Roads/Materials Expert
PI	Plasticity Index
PM	Particulate Matter
PMU	Programme Management Unit
RAP	Rural Access Programme
RECAP	Research for Community Access Partnership
RMG	Road Maintenance Group
SIS	Social Impact Specialist
TR	Technical Referee
TL	Team Leader/LVR Specialist
ToR	Terms of Reference
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, UK)
USA	United States of America
WHO	World Health Organisation

cm	Centimetres
G_c	Grading coefficient
g/cc	Grams per cubic centimetre
kg	Kilograms
kph	Kilometres per hour
mg/m^3	Milligrams per metre cubed
m	Metre
mm	Millimetres
Rs	Rupees
µm	Microns
$\mu g/m^3$	Micrograms per metre cubed
%	Percentage

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1. Executive Summary

The project made a literature study of the recent history of dust on roads, identified a number of potential suppressants and procured appropriate equipment for measuring dust. This report summarises the equipment trials and proposes a methodology and research matrix for a future phase of the project, where the effectiveness of suppressants will be measured and the potential effects of dust on rural communities will be assessed.

The equipment was tested in high dust conditions, on two different roads in Kathmandu, for ease of implementation. One road was an intended sealed road constructed to specification, but only constructed to base course level, so that the dust could be measured on a gravel surface. This acted as a proxy for a gravel road constructed to specification; although the base course specification is different to the official wearing course specification, DoLIDAR invariably use the base course specification for gravel road wearing courses, so the example is realistic in terms of common practice in Nepal. The second road was a more typical DoLIDAR road which had not been constructed to specification and had little maintenance, with very high levels of dust. The equipment proved to be appropriate for providing measurement of road dust in this environment.

A stakeholder workshop was held in January 2018, where the results of the investigations so far were presented. Discussions at that workshop were focused on agreeing a methodology and way forward for the next phase of the project, where suppressants will be most probably trialled on a road in the Terai.

The main outcomes from the project can be summarised as:

- An extensive search of international companies offering dust measuring equipment resulted in the identification and procurement of the DustTrak equipment. This equipment has the capacity to:
    - be mounted on a vehicle to measure emissions directly behind the vehicle
    - be mounted on a tripod to measure the spatial distribution of dust
    - take gravimetric measurement of dust emissions
    - measure the various size components in the dust aerosol, from PM 1 up to PM 10, which is the range of dust that has the most potential to be harmful to health
- Trials proved the suitability of the equipment to measure dust, as well as the practical measures required to ensure its correct use.
- Visual evidence from rural roads and the sampling and materials testing on the equipment trial sections showed that the properties of the materials used for road building in Nepal contribute to dust emissions from unpaved roads through the presence of oversize material, which prevents effective compaction of smaller particles and makes it easier for vehicles to generate dust.
- The specifications and standards for rural road construction are not enforced in Nepal and essential parameters such as plasticity appear to be missing from some specifications.

- A review of the social impacts of dust from roads confirmed the potential harmful effects of road dust on health (of both road users and residents), agriculture, the environment and road safety.
- A workshop was held to discuss the initial findings from this phase of the project and to develop a methodology for a proposed subsequent phase of the project, which will trial the use of treatment to suppress dust emissions.
- The workshop provided useful guidance on measures that could be considered for a next phase of the research. These included:
  - Identification of additional social impacts (possible presence of endotoxins, impacts on road-drying of crops, roadside business and products)
  - Measurement of the composition of dust to identify harmful particles
  - Trials should be conducted in the Terai region and hills
  - The effect of alternative physical measures (e.g. hedges and fences)
  - Data on the impacts of dust on vehicle operating costs
  - Establishing acceptable/permitted levels of exposure to dust
  - Measurements of dust at different speeds
  - Dust to be included in police road accident reports
  - Measurement of dust emissions from other vehicle types
- Experience from the trials in Nepal has resulted in the development of a general recommended methodology for researching dust in other countries, but also highlighted the possible need to adjust these to meet local conditions.

2. Introduction

This project is being undertaken under the DFID-funded ReCAP programme with a focus on applied research and knowledge dissemination aimed at the promotion of safe and sustainable rural access in Africa and Asia. Nepal is one of the partner countries in the Asian component (AsCAP) of ReCAP. In discussions with the ReCAP Programme Management Unit (PMU), research related to the adverse impacts of dust from unpaved roads was identified as a priority need. Phase 1 of the research is being undertaken using individual frameworks, with two of the four consultants contracted through TRL Ltd.

People worldwide are becoming increasingly aware of the impacts of various forms of pollution on their daily lives, on their livelihoods and on the environment. In most countries an Environmental Impact Assessment (EIA) is now an essential requirement in road construction and rehabilitation projects. The project started in September 2016 and is due for completion in March 2018, following some delays in procuring the dust measuring equipment. There was also a long inception period as the project commenced during the monsoon season, when no dust is apparent on roads in Nepal.

The research is intended to focus on the Terai region of Nepal, which is the low-lying area across the south of the country, bordering with India. It was agreed that the dust measuring equipment would be tested close to Kathmandu on roads that would approximate conditions on the Terai. Dust starts to appear on roads in November and continues through to March or April throughout the dry season.

The main aim of the project is to test a variety of generic dust suppressants on gravel roads in Nepal, to see if a cost-effective solution can be found to this problem. The research will also attempt to define the potential health issues associated with dust and its potential to affect the livelihoods of communities along the road. There is concern about health effects of dust, which stem mainly from the smaller fractions; in terms of the equipment used this would be PM 4 and down, and to some extent PM 10 and down. In general PM 10 is the size at which dust starts to become visible (depending on environmental conditions) and this size of dust can have other detrimental effects on agriculture and road safety. The smaller sizes measured by the equipment, such as PM 4 and PM 2.5 are not visible and are associated more with respiratory diseases. The focus of the research in the next phase is expected to be on the health effects of dust for people using and living next to unpaved roads, which can be measured by the selected equipment.

Following initial investigations, it was agreed that the current phase of the project would mainly test the dust measuring equipment, especially with respect to the high levels of dust experienced on gravel roads in Nepal. If possible, a baseline would be established, but the main research with the use of suppressants would be carried out during the second phase.

3. Background

The request for this project came from DoLIDAR and local sources from within Nepal where road dust has been reported as being a problem [(1)] [(2)]. The first visit of the team in November 2016 established the motivation for the project and this was used to develop the direction for the rest of this research. The experience of the team confirms that dust is likely to be a problem for many people living alongside unpaved roads and this is likely to have serious social and economic effects. This research is also likely to have an impact beyond Nepal, with many other countries in Asia and Africa suffering from similar issues.

Measurement of the emissions and impacts of road dust have been carried out over the last 30 years. One review of much of this work was carried out for the World Bank in 2011[(3)], which confirmed the potential adverse health, road safety, agricultural and environmental impacts from road dust, including dust from gravel roads. Most of the studies have been conducted in high and middle-income countries (e.g. USA[(4)], Canada[(5)] , Australia,[(6)] New Zealand[(7)] and South Africa[(8)]). Some of these countries have large unpaved road networks and studies have resulted in various recommendations for measurement methods[(8)(9)(10)(11)], treatment,[(12)(13)(14)(15)] associated standards[(16)(17)] and impacts[(18)] as well as comprehensive guidelines[(19)] related to the reduction of dust emissions.

One of the most important outcomes in the report from the World Bank study was the conclusion on the lack of evidence available from developing countries and the limited progress that has seemingly been made to date in the form of additional evidence in relation to this situation, as is evident from the literature survey.

This conclusion is important because whilst the mechanisms governing the generation of traffic-generated dust from unpaved road dust in developed and less developed countries might be similar, the impacts are likely to be different. For example, in most of the countries mentioned above, many road users will be in modern vehicles, often with air conditioning. In many low-income countries, most of the road users are pedestrians (and in parts of Asia, on motorcycles) and a significant proportion of these will be children with a greater exposure to dust by all these road users. The volume of dust and hence the quantification of the problem will be directly related to the volume of motorised vehicles (cars, buses, trucks, etc.). Even where traffic is low, as it is on many roads in Nepal with the majority of rural roads having less than 50 vehicles per day, dust is still perceived to be a significant problem.

There are also other differences in the impacts which relate to the vehicles used and the journeys undertaken, as well as important differences related to the exposure to road dust by rural residents and differences in agricultural and environmental exposure and impacts. Vehicle speed has an important bearing on generation of dust. Many gravel roads in Nepal have tortuous alignments and rough surfaces, which limits speed. Despite this fact, dust levels are perceived to be high, so future research should consider this perception and investigate the role of road materials and construction standards on the generation of dust.

However, despite expressions of awareness and concern of the potential effects of traffic generated dust expressed by some senior government personnel in developing countries, virtually no studies appear to have been carried out to quantify the impacts of dust on local communities. Most of the available evidence in these countries is anecdotal and is not supported by quantitative data. Most developing countries also have large unpaved road networks, sometimes comprising over 90% of the total road network. Travellers and residents in these countries have greater exposure to traffic-generated dust than those in developed countries and the impacts will be greater.

Therefore, this project in Nepal has the potential of being the beginning of important research into the potential impacts of dust from a developing country perspective.

4. Equipment trials

The main focus of this phase of the research is to test the equipment that was procured and shipped to Nepal. Several trial runs were made during November 2017 on roads within the Kathmandu Valley.

4.1 Dusttrak DRX equipment use

The Dusttrak DRX machines were used to sample dust from two test sections. The purpose of these trials was to test the appropriateness of the equipment to measure high levels of dust. This was carried out near Kathmandu due to ease of operation, so two sites were selected within relatively easy reach of the DoLIDAR head office. The trials were carried out in November 2017, which is in the dry season when high levels of dust are prevalent. Roads were selected to approximate DoLIDAR roads that could exist on the Terai, which is the original location for this project.

It is recognised that the majority of DoLIDAR gravel roads are not constructed to specification due to various reasons, but mainly the lack of resources to find and process appropriate materials. However, in some internationally supported projects, gravel roads are being constructed to DoLIDAR specifications. With this in mind, two different sites were selected, one to represent a road constructed to specification and one to represent a typical DoLIDAR gravel road on the Terai.

The features of the sections were as follows:

- Site 1, Dhobikhola road: This section is located in central Kathmandu and was used as a proxy for a gravel road constructed to specification. It is in a highly populated area, but with few buildings directly fronting the road. To one side is Dhobi Khola, a tributary of the Bagmati river, and to the other a steep wooded slope. It was not possible to find a gravel road within Kathmandu valley that was constructed to specification, so a Department of Roads (DoR) paved road that was constructed to base course level was used. The base course had been in place for more than three weeks during the dry season and had been trafficked. Although there was still some moisture evident in areas that were not in direct sunlight, a reasonable amount of dust was being produced in areas that had fully dried out. It is recognised that base course specifications are not generally appropriate for use as wearing course due to differences in grading and plasticity, but DoLIDAR are generally using base course materials for wearing courses on gravel roads due to the availability of appropriate materials that require less processing to achieve the required standard. The base course on this road was constructed with material which is the nearest proxy to a road built to DoLIDAR specifications, although in practice, few DoLIDAR unpaved roads are built to this or the actual gravel road specification.

- Site 2, Power house road: This section is located to the south of the city, outside the ring road but within the Valley, and was used as a proxy for a typical DoLIDAR gravel road that would be found on the Terai. The area is a mix of agriculture and brick factories. The road runs parallel to the Bagmati river as it flows out of Kathmandu, approximately 200 m away. The site slopes from west to east, with the land to the west at road level, but the land to the east about 2 m below road level. Again, it was difficult to find a representative road within Kathmandu, but the road selected was single lane, reasonably straight and had been constructed several years before with little maintenance. This was deemed to be representative of the type of road experienced in Morang district by the materials specialist.

Three machines were used to measure dust. One was fixed to the vehicle on a rack that fits to the towing hook. This measures dust that is generated by the vehicle and is collected immediately behind the rear of the vehicle, as can be seen in Figure 1.

Figure 1 Dust equipment attached to vehicle

Two more static machines were placed on tripods at 1 m and 7 m respectively from the road edge. These are designed to measure dust that would affect pedestrian road users and people who live close to the road and were set at 1.7 m high, to represent an average height person. The static machines can be seen in Figure 2 and Figure 3.

Figure 2 Static machines

Figure 3 Static machine at 1 metre

4.2 Dust measurement results:

4.2.1 Data collection sheets.

Forms were developed to record the additional data required for every site. These were trialled on site and were found to be appropriate, although some small changes are necessary. A revised form can be found in Annex A.

4.2.2 Trials

Four different particle sizes were measured using the equipment, from PM 1 to PM 10, which represents the particle size of the dust in microns, as shown in Figure 4. A total of all sizes is shown as well. The 'X' axis on the graphs in Figure 5 and Figure 6 denotes progression in time, the mobile measurements were taken over a period of 15 - 20 minutes, and the static readings were taken over a period of one hour. The 'Y' axis shows the dust levels in mg/m^3 for all of the four sizes of dust, plus the total. It should be noted that each level is cumulative, so for example the 2.5 mg/m^3 also includes the 1 mg/m^3 readings, etc.

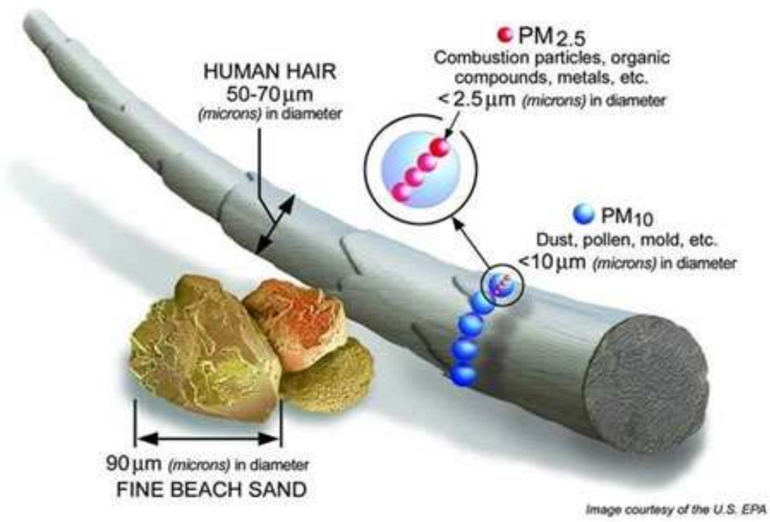

Figure 4: Dust particle size (image: U.S. EPA)

The first trials were carried out on Dhobikhola road, which was a base course for a paved road, constructed to specification. Figure 5 shows an overall view of the results for Dhobikhola road, with the maximum dust level reached of around 125 mg/m^3 in a dusty area. Figure 6 shows the results for the Power house road, with an overall higher concentration, with many results above 140 mg/m^3. The Y axis on the graphs shows the different sizes of Particle Matter (PM) and the volume measured in mg/m^3. Also, the concentration of dust is higher on the Power house road, with longer periods of high dust and more peaks. This reflects the situation experienced on site, with much more dust being visible on the Power house road than on the Dhobikhola road.

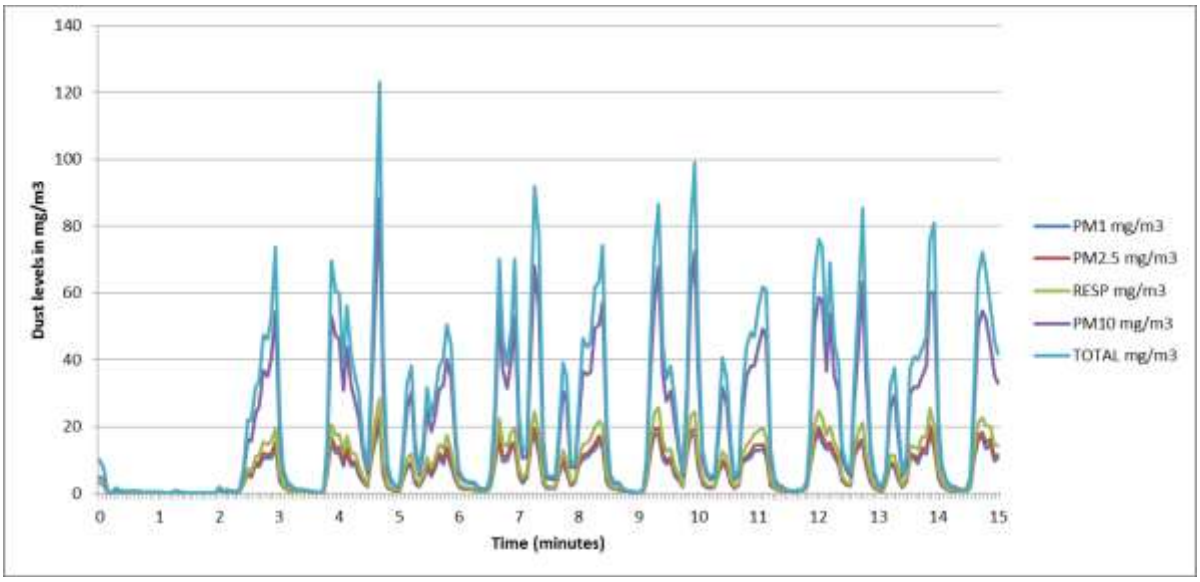

Figure 5 Trial runs on the Dhobikhola road

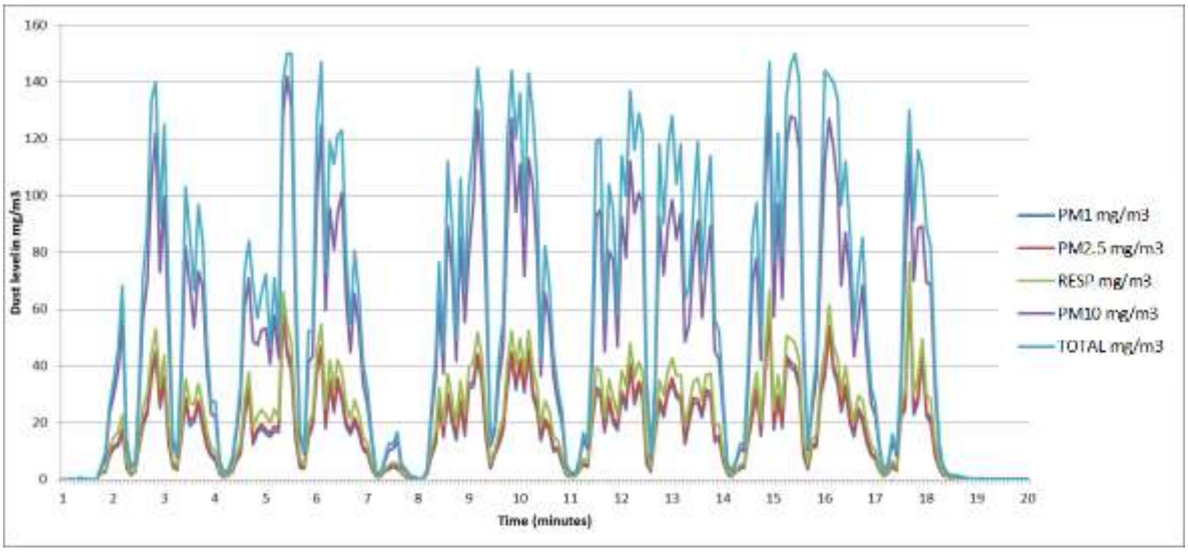

Figure 6 Trial runs on the Power house road

PM 10 is the highest component of the dust because the equipment measures each level of fraction as including all of the smaller fractions below it, for example PM 10 is PM 10 ‘and below’. The smaller, more harmful, components are consistently high and well above recognised safety levels, peaking at approximately 25 mg/m^3 and 65 mg/m^3 on the roads respectively. (It was noted that many pedestrians, including schoolchildren, use masks when using this road).

The World Health Organisation (WHO) standard limit[1] for PM 10 is 20 µg/m^3 (0.02 mg/ m^3) as an annual mean, or 50 µg/m^3 (0.05 mg/m^3) as a 24 hr mean, as shown in Table 1. This is essentially the average readings over one year or a 24 hr period. The total peak level experienced on the Power house road at the rear of the vehicle is about 150 mg/m^3 and consists mainly of PM 10 and lower amounts of the smaller components. This is therefore many times higher than the WHO 24 hr mean guideline, although depending on wind conditions, a significant proportion will re-settle on the road. The peaks are clearly high points and not averages, but this does signify that levels are likely to be higher on average than international guidelines. It is clear that the measurements taken from the static equipment is more relevant to the WHO figures.

Similarly, the total levels of PM 2.5 and smaller components on the Power house road also peaked at high levels of up to 65 mg/m^3, which is also significantly higher than the WHO mean 24 hr guidelines. This is also not an average value. It is also higher when other vehicles are passing but it does indicate that there could be some adverse effect on people's health long term.

Table 1 WHO guidelines for PM2.5 and PM10

WHO Guideline values
PM 2.5
- **10 µg/m^3 annual mean**
- **25 µg/m^3 24-hour mean**

PM 10
- **20 µg/m^3 annual mean**
- **50 µg/m^3 24-hour mean**

The nature of the road network meant that it was difficult to find long stretches of road with reasonably homogenous conditions. (This is unlikely to be as problematic in the Terai or in countries with flatter terrain). Therefore, the test sections were relatively short so the vehicle made several 'runs' or passes on each section, with the equipment continually recording. This explains the dips in the graph, which represents where the vehicle stopped and turned around. This also means that the vehicle passed over the same road several times, in both directions. In theory this should produce an approximate 'mirror image' of the dust graph, as can be seen in Figure 7. This mirror image would not be exact due to the vehicle acceleration, the influence of other vehicles on the road, unscheduled stops and starts and the fact that the vehicle does not run along exactly the same path in each direction. However, the graphs do show a pattern that reflects this.

[1] http://www.who.int/mediacentre/factsheets/fs313/en/

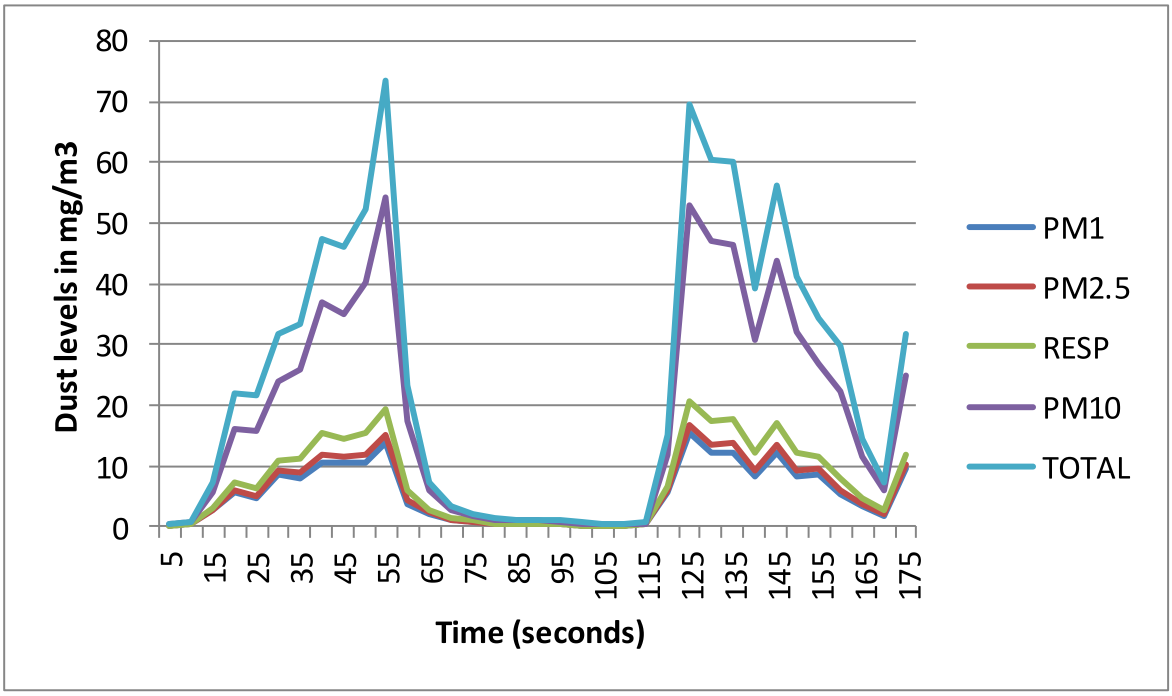

Figure 7 Detailed view of Dhobikhola road dust collection

The dips in the graph with low levels of dust coincided with the turning times of the vehicle, but also with areas that were in shade, that had different (less dusty) surfaces as seen on the Power house road where patching had been carried out using broken bricks, or where the vehicle was delayed by other traffic and travelled slowly or came to a halt in the middle of a run. All of these anomalies need to be recorded carefully on site so that the troughs in the graph can be accounted for. A video was taken using DashCams within the vehicle, which will assist greatly in this process.

The before and after pictures in Figure 8 and Figure 9 respectively show the amount of dust that was present on the dust enclosure (the plastic case that encloses the equipment) after only 5 runs (approximately 20 minutes of dust collection). This confirms that the equipment can operate in very high dust situations, which was the main purpose of the current trials.

Figure 8 Clean enclosure

Figure 9 Enclosure after 5 runs

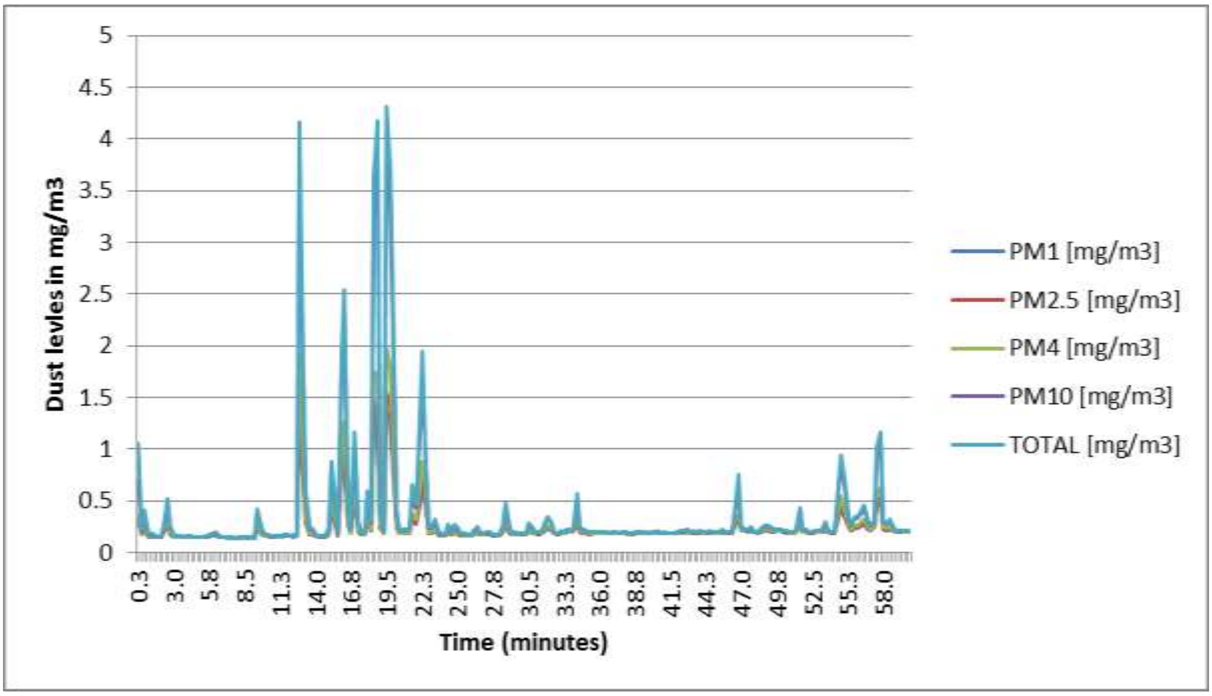

Figure 10 Static at 1 metre from the Power house road

Figure 10 shows the results for the measurements taken on the tripod situated 1 m from the edge of the Power house road and Figure 11 at 7 m from the road.

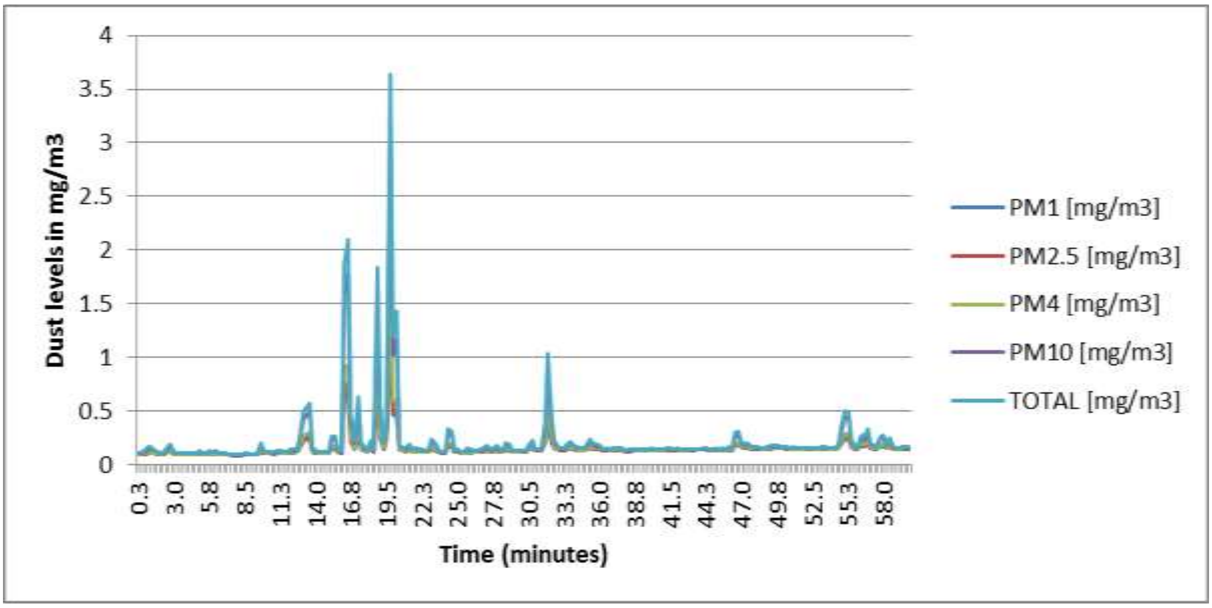

Figure 11 Static at 7 metres from the Power house road

As expected both results from the static machines situated at right angles from the Power house road clearly show levels of dust much less than that measured directly behind the vehicle. These values are not insignificant given that the duration of collection was just 1 hour and that the wind direction was taking the dust cloud in a direction away from the static measurements. In the full-scale trials, the static equipment would normally be in place for longer periods.

Traffic counts were also undertaken on all roads that were trialled in order to have an estimate of the volume of traffic that may be needed to generate dust and for use in the choice of suppressants. On the Power house road, the traffic speed was approximately 45 km/hr and included light trucks, cars, motorcycles and a minority of heavy trucks, buses and microbuses.

Unfortunately, there was not enough time with the vehicle to make enough runs to establish a reliable baseline. However, the results are consistent enough to confirm that the equipment records dust appropriately and can cope with the high levels of dust experienced in the dry season in Nepal.

4.3 Video camera recording

The video camera was set up in the DoLIDAR vehicle used for the dust collection. This allows a direct correlation of the dust collection runs with the video. The video has two cameras, one forward-facing that records the road ahead through the front windscreen, and one rear-facing that records the dust that has been generated through the rear windscreen. Both pictures can be viewed simultaneously using the software that comes with the video, as shown in Figure 12. The dust in the rear-view camera can clearly be seen in this picture.

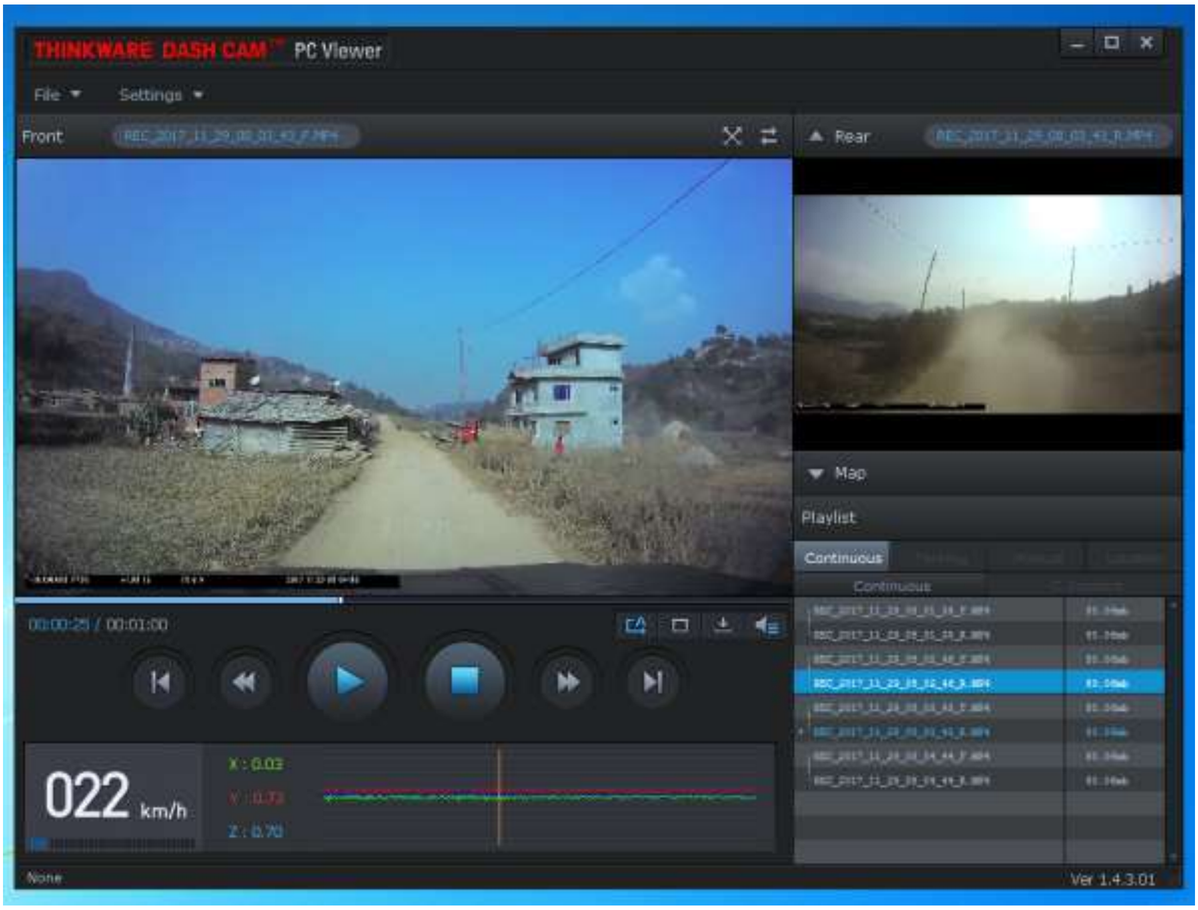

Figure 12 Dashcam view front and rear

It is also possible to show a map instead of the rear camera, which is generated by the GPS within the camera. This can be seen in Figure 13.

Figure 13 Dashcam view with map

In addition to the video pictures, the equipment also records the speed and GPS location, as well as the X, Y, Z movement of the equipment, as can be seen above.

The video is also useful for recording the wind direction, which can usually be seen by the movement of the dust in the rear video. Also, any disruptions or issues encountered should be visible on the video, for example in Figure 14, where two passing trucks held up the data collection. This is useful to identify any anomalies in the data.

Figure 14 Dashcam view with obstruction in road

Similarly, in Figure 15 a local resident is damping down the road surface using a hose pipe, which would show as a dip in the graph where less dust is collected. This type of anomaly can be identified directly from the videos.

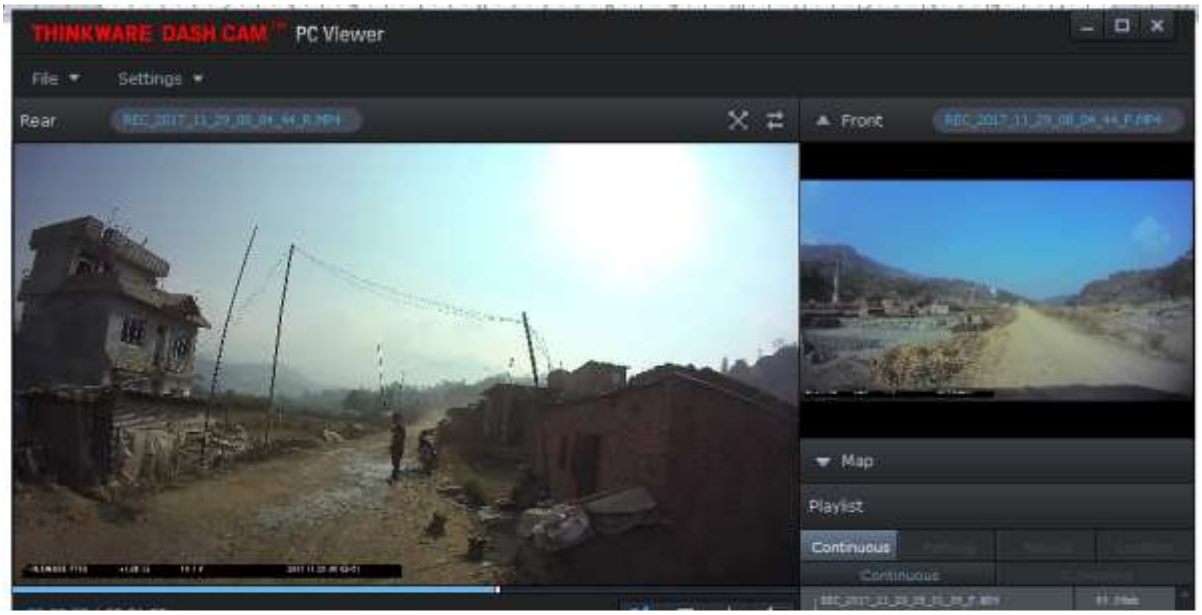

Figure 15 Dashcam view with damping of road surface

4.4 Roughness data collection

Roughness data in terms of International Roughness Index (IRI) was collected using a smartphone with the 'RoadLab' app installed. Site 1 at Dhobikhola is shown in Figure 16 & Figure 17. The blue line in Figure 16 is the GPS track of the road, superimposed on an image from Google Earth. Although this is only accurate to between 3 and 10 m horizontally it is close enough to be able to identify the road. Most satellite imagery is taken in the morning, so in this case the shadows of the trees partially obscure the road.

Figure 16 GPS track of Dhobikhola road

Figure 17 shows the roughness from the RoadLab software, which is indicated in lines of approximately 100 m. In this case the roughness is shown as yellow, which indicates a fair condition road.

Figure 17 Roughness summary of Dhobikhola road

Roughness is summarised from the RoadLab software as:

- Excellent (Dark Green): IRI < 2
- Good (Light Green): 2 < IRI < 4
- Fair (Yellow): 4 < IRI < 6
- Poor (Red): IRI > 6

It should be noted that this app is more relevant for paved roads, and use in other research (R Workman, 2017, ReCAP High-Tech Solutions project) has indicated that it is not able to provide an absolute measurement of IRI for gravel and unpaved roads. It does however enable the researcher to make comparisons between roads where the app has been used consistently.

Site 2 at the Power house road, Dakshinkali is shown in Figure 18 to Figure 20. Figure 19 shows the road alignment in blue, which is the GPS track recorded from the phone. Figure 18 shows the major bumps measured by RoadLab as red triangles (Dhobikhola road had no significant bumps), indicating that the road is in poor condition. Figure 20 confirms this with the condition on the Power house road shown as red lines, which indicates a poor condition road.

Figure 18 Bumps on Power house road

Figure 19 GPS track of Power house road

Figure 20 Roughness on Power house road

4.5 Issues encountered:

Some issues were experienced in the operation of the dust measuring equipment, they are summarised below:

- Limited availability of a vehicle suitable for attaching the equipment restricted the amount of fieldwork that could be undertaken. DoLIDAR have limited access to appropriate vehicles for dust collection. Most of the vehicles that are available, as for this project, are assigned to government officers, who require them to carry out their duties, which can clearly limit their use by visiting consultants. Availability was further exacerbated when the vehicle required essential servicing and repair, and on the final day allocated for fieldwork, when a snap public holiday was declared. These events are clearly outside the control of the consultants and sometimes of the host organisation too, but this arrangement can, as in this project, impact on planned activities and limit the ability of the consultants to comply with the assigned tasks.
- It should be noted that it is necessary to have a vehicle equipped with a tow-bar and to have an SUV type vehicle because of the rough roads, the need to transport equipment (Figure 21) and the requirement for a rear facing camera to monitor dust levels. Pick-ups are not appropriate. DoLIDAR used a vehicle borrowed from the DFID supported RAP project, which was the only appropriate vehicle available. When this vehicle was unavailable an alternative was also borrowed from RAP, but this was not equipped with the camera so videos were not taken for some trial runs. This all meant that vehicle availability was extremely limited and this restricted the time available on site. With time required to travel to and from site and the shorter winter working day in Nepal, dust measurements were sometimes restricted to as little as 3 hours per day. In future, the provision of a dedicated vehicle should be considered to ensure a vehicle is available for field trials.

Figure 21 Loading of vehicle

- The ToR called for at least one counterpart engineer to be assigned to the project. Although various DoLIDAR staff were included in the initial training, a regular counterpart engineer was not formally assigned, which made implementation and continuity of the project challenging. Assistance on some days was provided by the team of the local Materials Laboratory assigned to the project. Whilst this support was appreciated, the lack of available government staff with enough time to commit fully to the project needs to be considered with respect to the sustainability for future phases of this Project. In the next phase a counterpart engineer should be assigned to work with the team for the full time that trials are taking place, plus any other time in-country. The counterpart should also be the main contact person with the team and should be available to liaise with the team throughout the project, in and out of country.

- The staff assisting with the equipment tests were not researchers, and had to be instructed in the importance of preparing the equipment and data collection properly. It is felt that further instruction in how to conduct research is needed in order for staff to fully appreciate the importance of collecting data accurately and recording all parameters carefully. Also, their input was intermittent as stated previously, which further limits their experience.

- During the on-site trials and training the team experimented with using filters to collect gravimetric samples of dust. The amount of dust deposited on the filter paper is relatively small even in conditions of heavy dust emissions. The amount deposited depends on the concentration of dust particles and the distance over which dust is collected. A number of passes over the trial section was required to collect a sufficient quantity of dust that can be measured with a degree of accuracy. This involved the vehicle stopping and turning at the end of every run because of limitations on the length of road that could be used. Ideally and in terms of a methodology for use on roads elsewhere, it is likely that one pass on a longer section of road will be the preferred option and will be feasible. A sensitive balance is required for weighing the filters, but weighing of the samples is best undertaken in a stable and closed environment. Influences such as wind or even slight movement when weighing in a vehicle can affect the results. Figure 22 Shows the filters from the on-vehicle machine on the left, and the static machines in the middle (1 m from the road edge) and on the right (7 m from the road edge). The difference in dust collection is clear, with the on-vehicle machine collecting significantly more dust.

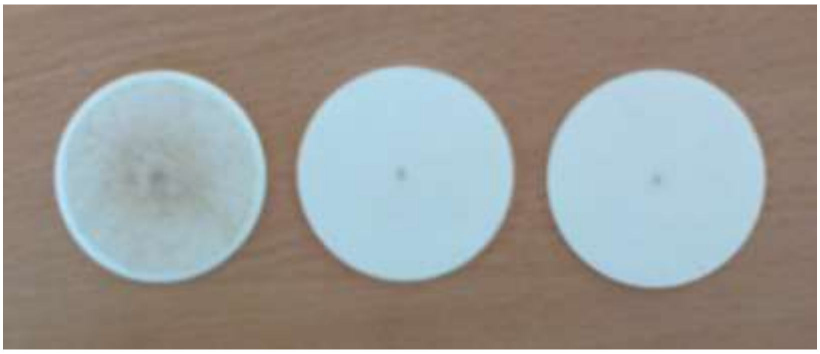

Figure 22 Dust filters for the three machines showing (from left to right) dust collected from the vehicle, at one metre and 7 metres from the road

- Even when following the manufacturer's instruction, incorrect replacement of filters can occur and this led to the machines showing almost exactly the same volumes of dust for all fractions of the aerosol, which was clearly not possible. The error was corrected on consultation with the manufacturers and was quickly resolved. This is a minor limitation of the equipment but an important lesson learned for its future use. The support provided by the manufacturers in the USA was very prompt and helpful; even given the time difference of 12 hours, a response was normally received in less than a day.

- As with any equipment of this type, understanding how it works and familiarity with its operation and careful storage are important. Calibration of the equipment is also required to be carried out by the manufacturers once per year. The nearest agents who can calibrate the machines are in Singapore and Beijing. Both are accessible from Kathmandu, Singapore directly and Beijing with one change, but given the issues with importing the equipment it will be more appropriate to bring a calibration engineer to Nepal to service and calibrate the machines, and train DoLIDAR in how to do this at the same time. It is recommended that this is built into the next phase. In the longer term there is clearly an issue with maintaining and calibrating the equipment, but in terms of the next phase this should be manageable.
- On the Power House road the wind increased towards the late afternoon on both days and was reasonably strong, estimated at between 15 and 20 kph each day. It was noticed that even a mild wind can significantly affect where the dust settles and is an important factor to consider during dust collection. In this case the wind was blowing from South East towards North West, and so was blowing the dust away from the static machines. It seemed to make little difference to the machine that was fixed to the vehicle as the dust is thrown up directly into the collector and there is not enough space for a wind of this magnitude to affect this action. It is difficult to control or shield for wind, so the wind effects will have to be measured and taken account of during analysis.

Despite these problems, it has been possible to assess the equipment and develop a methodology for its future use despite the constraints described above.

4.6 Areas for consideration in future trials:

- **Fixing to vehicle.** The rack that fits onto the tow-bar was found to be an ideal arrangement for mounting the equipment on the vehicle. It could be fixed to the vehicle with little effort and was robust enough to carry the equipment easily. However, fixing of the equipment to the rack was rather makeshift and this would need to be improved for further trials.

  The dust enclosure was strapped on by using ratchet straps (Figure 23), and although it was very secure it was a somewhat temporary solution. It is recommended that the rack is customised so that the enclosure can be screwed onto the rack using the tripod screw in the base of the enclosure. This would allow the enclosure to be fitted more easily and robustly to the vehicle and ease operation.

Figure 23 Enclosure fixed to vehicle rack

- **Operation of the equipment, start and stop.** Under the present set up, the equipment has to be started before the enclosure is closed and secured to the vehicle. This means that the precise start of the run cannot be timed accurately and matched to the videos and collated with other data. Ideally the equipment should be started and stopped by remote control and linked to GPS coordinates. This would allow an accurate recording of the specific runs to be made, which could be recorded on a map. At present the runs are timed and the results estimated from the graph that is produced. It should be possible to customise the management of the equipment to make it easier to operate, linking it to GPS and switching it on and off remotely, without any changes to the internal operation of the equipment itself.
- **Trial site selection.** The trial sites will need to be selected carefully. In order to test suppressants properly, it will be necessary to construct sections to DoLIDAR gravel road specifications, which would limit adverse impacts of their effectiveness such as from oversize materials. It is estimated that four suppressants should be trialled during the next phase of the project. Based on the field trials during the current project, it is recommended that the trials consist of:
    - Sections at least 300 m long
    - At least two control sections within the trial area that have no treatment
    - Sections that are in direct sunlight, and one or two sections that have some shade, for comparison purposes
    - One or two sections that run through villages, or populated areas
    - Sections should be fairly straight, but some horizontal curvature is allowable
    - Sections should be well constructed so that average speeds of up to 50 kph are possible
    - The start and end of the site should have a lead in and lead out section where the vehicle reach the desired speed before it starts to collect samples of dust
- **GPS location.** GPS location is provided by the video camera fitted in the vehicle. However, this is only accurate horizontally to between 3 m and 10 m. If it is necessary to use an additional GPS device for the dust measuring equipment, then a more accurate GPS machine should be used, ideally to within 1 m horizontal resolution.
- **Video equipment.** The video equipment provides a link to the GPS and roughness equipment and provides a visual image of the volume of dust.
- **Speed and distance for trials.** Based on the trials during the current phase, it is recommended that three speeds are used for dust measurement trials in Nepal. The three speeds are 20 kph, 30 kph and 50 kph where possible. These speeds represent a slow speed through a settlement, a road in very poor condition and the average speed for heavier vehicles on a gravel road in a fair condition, respectively. Previous research has shown that dust emissions are related to speed and higher speeds might be achievable on other unpaved road networks.
- **Vehicle type and shape.** Previous TRL research from Kenya suggests that the type and shape of the vehicle, particularly the shape of the undercarriage of the vehicle,

also has a bearing on the amount of dust produced. This is a potential area of investigation during the next phase which could lead to the development of vehicle aerodynamics to reduce dust. Large multiple-axled vehicles tend to produce the most dust.

- **Roughness and IRI of gravel roads.** The roughness of the road has a bearing on the speed achievable and therefore on the volume of dust produced by different vehicles. If roads are in good condition and have been constructed to specification they should produce less dust. However, this will encourage higher speeds, which conversely increases dust. This relationship should be explored during any future phases. During the current trials the roughness/IRI was measured with a smartphone, using the World Bank RoadLab app. Although this is known to be less accurate for poor condition unpaved roads, it does provide an approximation of roughness and a reasonable basis for comparison of roughness of different roads. For a gravel road constructed to specification it is expected that the RoadLab app could be appropriate for providing an approximate IRI, but that it would probably not be appropriate to derive external correlations with dust. This can be linked to other data collected by the GPS track that is produced as part of the app.

- **Equipment performance.** The equipment was shown to perform well, even with high levels of dust. As expected, the dust measured showed significantly higher levels on the vehicle, than at the static locations next to the road. This indicates that there is some research to be carried out in determining who is affected most, and whether motorcyclists, cyclists and pedestrians and at more direct risk than people who live just a few metres away from the road. This would include schoolchildren who walk to school on the road itself.

- **Dust impacts.** Previous research has shown the adverse impacts of dust on health, the environment, agriculture and the potential impacts on road safety and on vehicle operating costs in developed countries (Ref: Greening, 2011). However, there is little evidence from developing countries where people generally have greater exposure to dust. The equipment described in this report can be used to measure the volumes of dust produced from vehicles, the exposure to dust by all road users and the impact of suppressants. It may, however, be more difficult to quantify how road dust affects health directly. Also, most health impacts from inhaled sources only manifest themselves some years later. In addition, the effects of dust are additional to the impacts from other sources of contamination that are collected within the measured PM levels and these can also cause health problems. Emissions from vehicles, cooking stoves using biomass fuels and crop burning are a few examples. This makes it very difficult to collect data that links health problems directly to road dust, although proxy evidence such as attendance at clinics in different locations has been suggested. Therefore, the social surveys may uncover some intrinsic health issues that could be linked to excessive road dust as well as the other adverse impacts.

5. Nepal in an international context

One of the main objectives in this project was to develop a methodology for the next phase of the research. In the context of developing a general methodology for use on rural roads elsewhere, Nepal is rather atypical in a number of ways. Whilst as in other countries, specifications exist for gravel wearing courses many, if not most, D0LIDAR gravel roads, especially in rural areas, are rarely constructed to specification. Many roads are constructed with as-dug material, often sourced from rivers. Large amounts of oversize material are evident and do not appear to be removed during construction as is the practice in most other developing countries (Figure 24 and Figure 25).

Another factor is that, whilst the general condition of unpaved roads in many countries tends to worsen in the dry season even with maintenance, and short sections with poor materials can become particularly poor, it is relatively unusual for the condition on long stretches of road to limit traffic to the very low speeds achievable on many rural roads in Nepal. This is understandable in the very mountainous region in the north of the country but traffic speeds in many of the areas at lower altitudes is restricted by poor road conditions.

Figure 24 Road with oversize on Terai

The result of the presence of oversize material is that roads display high levels of roughness which limits the speed of vehicles and has an adverse impact on vehicle operating costs. This also has an impact on maintenance because grading in the presence of large amounts of oversize is difficult and in general, in Nepal, gravel roads receive little maintenance. In contrast to roads in Africa, for example, grading is not regularly carried out and roads lose their shape within a few years of construction. This causes rutting, potholing and other defects that restrict the maximum achievable speed to around 30-40pkh.

Figure 25 Power house road showing oversize

Furthermore, oversize material results in under-compaction of the surrounding matrix of finer materials, which leads to rapid deterioration of the surface and the production of excessive amounts of dust in addition to the defects already mentioned.

Anecdotal evidence has been provided that roads with very high levels of fine dust are prevalent in the hills of Nepal, specifically between Hile and Basantapur in the East. Roads with a layer of many inches of dust are reported with just footsteps generating dust clouds.

6. Design and specifications for gravel roads

It is recognised that the terrain in parts of Nepal makes road construction extremely difficult and that the Nepalese government has made great strides in improving access to remote communities in the hills and mountain regions in recent years. Nevertheless, roads that are not built to specification inevitably deteriorate more rapidly and have higher levels of traffic–generated dust. Some of the highest levels of fine dust occur on roads in these hilly regions with potentially serious impact on the long-term health of road users and residents living close by, as well as affecting visibility and road safety on steep and winding sections of road. High levels of roughness also have an impact on transport costs and consequently on economic development.

In the Terai region, the terrain is more conducive to more conventional road design and there seems little justification for roads not being built to the prescribed standards and specifications in this region.

Most countries specify a maximum size for the material used in the construction of gravel wearing courses. The best way of ensuring this is by crushing and screening material at source so that the material dumped on the road already complies with the specified grading and maximum size. Where this is not possible for various reasons, usually the cost, then removal of oversize by hand during construction is employed. Whilst this method does not entirely remove oversize material, it does result in the removal of most of the larger sized aggregate, which has the greatest impact on compaction, maintenance and subsequent road performance, including dust emissions.

6.1 Specifications for gravel wearing courses in Nepal

The requirement in Nepal for material used in gravel wearing courses in terms of its grading is set out in the 'Standard Specifications for Road and Bridge Works' as shown in Table 2.

Table 2 Specifications for gravel wearing course

Sieve Size (mm)	Percentage Passing by Weight	
	Class 1	Class 2
37.5	-	100
25.0	100	85-100
20.0	95-100	85-100
14.0	80-100	65-100
10.0	65-100	55-100
4.75	45-85	35-92
2.00	30-68	23-77
1.00	25-56	18-62
0.425	18-44	14-50
0.075	12-32	10-40

This implies a maximum particle size of 37.5mm even for the lower classification. Other factors such as Plasticity Product or Shrinkage Product are also usually specified in many countries. These parameters help ensure that the material has sufficient binding properties. It has not been possible to fully establish from DoLIDAR, the circumstances which apply to these two grading specifications. However, it is almost irrelevant anyway because they are clearly rarely applied in the selection of the materials used for road construction. Considerable research has been undertaken on the properties of gravel road materials in relation to their performance, and this work has resulted in the diagram shown in Figure 26, which in general terms predicts the likely performance of roads constructed from the properties of construction material.

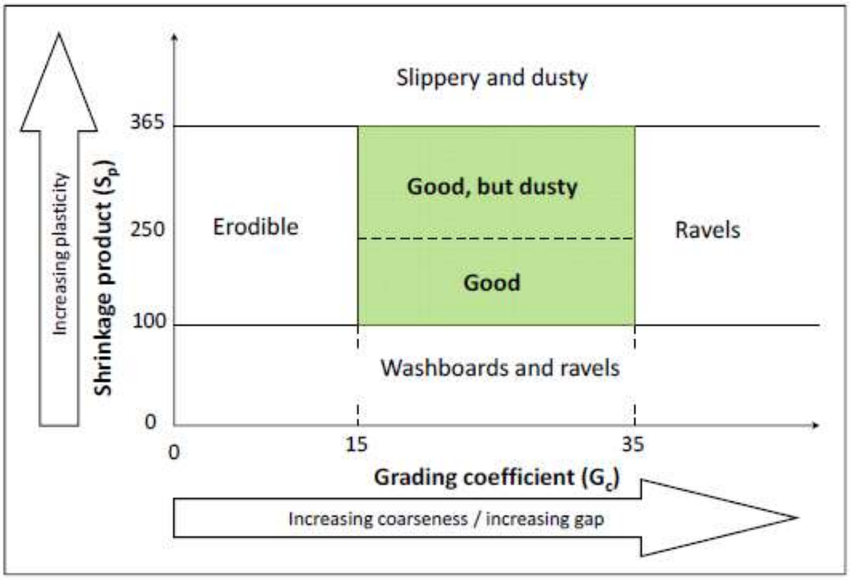

Figure 26 Material performance predictor chart (adapted from Paige-Green and D Jones)

Availability and haulage costs often limit the ability to use ideal material but the diagram shows the likely consequences of using locally available material that is outside specifications. It also gives an indication of the potential activities for improving material through crushing and blending, and in the context of oversize material, this is reflected in the value of the grading coefficient. The shrinkage product is the value obtained from the bar linear shrinkage test multiplied by the percentage of material passing the 0.425 sieve. This shrinkage test is used in preference to the standard tests for determining the Plasticity Index (PI) because of the variations in the test methods used, which can give different results for the PI. It is not normally carried out by materials testing laboratories in Nepal but it is related to PI which is routinely done in the country. In this case, the vertical scale in the diagram can be substituted by the Plasticity Product and retaining the same limits by using (0.5 x PI x % Passing 0.425mm sieve) for the vertical scale. This value (0.5 x PI) can also be used in the procedure for calculating a sufficiently close approximate value for the Shrinkage Product when determining the appropriate suppressant for dust reduction treatment.

The Grading Coefficient (G_c) is defined by the following equation:

G_c = {(%passing 25mm - %passing 2.36mm) x %passing 4.75mm}/100

(Note that for for coarse materials, the grading analysis should be normalised for 100% passing the 37.5mm sieve when calculating the Grading Coefficient)

The DoLIDAR roads both in Kathmandu and those visited in the Morang district of the Terai region confirmed the general experience of large amounts of oversize material and high level of roughness. Although there is a policy under the Rural Access programme (RAP) to increase the use of crushed gravel, its main role is maintenance rather than construction so unless there is a major policy change by DoLIDAR to ensure compliance with the specifications, the use of as-dug materials with oversize is likely to continue.

The presence of oversize material also has implications for the use of dust suppressants. The cheaper initial cost options for dust control involve the use of spray-on treatments which act on the finer fraction of the wearing course materials mainly by increasing the absorption of moisture. The presence of large amounts of oversize hard aggregate is likely to significantly reduce the impact of such treatments. Mix-in treatment such as bitumen emulsion, which is available in Nepal is also likely to be affected by oversize and will include limitations on achieving the required level of compaction after mixing. (Oversize material also restricts the benefits of grader maintenance, although the use of graders for maintenance appears to be rare on unpaved roads in Nepal).

It should also be noted that the high performance of gravel roads in parts of southern Africa reported at a ReCAP conference in Caledon was attributed to a reduction in the maximum particle size.

7. Criteria for designing trials

7.1 Location

Suggestions and the reasoning for the location of trials were set out in Progress Report No 2 and these are largely unchanged in that the Terai region remains the favoured location, although options for consideration other than Morang district alone are also likely to be considered. This is mainly because it is clear that the RAP cannot fund trials. However, other donors are funding construction projects in the Terai where the flatter terrain is also more typical of the majority of roads in many other countries and treatment options are likely to be more effective on these roads, if they are built to specification.

Given the changes that are taking place in respect of decentralisation and DoLIDAR's future role, it is currently unclear how a budget line has or will be established in time to cater for the construction cost of any trials in Phase 2. However, when the results of this phase are available there should be enough information in the report to make a detailed budget submission for inclusion in the new Nepali financial year, which is due to start in June 2018. A budget line in the partner organisation is essential to undertake research on Nepal roads and to ensure sustainable long-term research capacity It will also enable completion of an MSc research project on the impacts of road dust being undertaken by one of DoLIDAR's engineers and to finance the construction of the trials if partnerships with other programmes that can fund the construction costs do not materialise.

The location should be determined by the following factors:

- Available funding for an appropriate road
- Sections that are relatively flat and straight, although this is not an absolute requirement (Although it is recognised that dust is a problem on some of the very

steep and winding roads, their inclusion in Nepal might perhaps not be appropriate at this developmental stage of the research, which should initially concentrate on the development of sound and effective practice. Also, as the achievable speeds on these roads will be lower and so a range of speeds may be difficult to achieve)

- Reasonable accessibility for ease of transporting materials and access of the project team to supervise and monitor the trials
- There is also the potential for site demonstration visits, so if the site is within reasonable access to Kathmandu that would be beneficial (by plane or road)

The most appropriate location is still most likely to be on the Terai, so this requirement of the ToR can be adhered to.

It is proposed that one test road is identified during the next phase of the project. This road should have similar materials throughout and should be constructed to specification. It should be long enough to accommodate a number of test sections, each of which will be at least 300 metres long, including control sections. This will allow before and after measurement of dust to be carried out. If appropriate suppressants are identified for spray-on application, it may be worth also trialling a road that was constructed with local gravel and was not built to specification, which would be representative of the majority of DoLIDAR roads.

Two potential roads that are being constructed to specification have been identified, they are:

1. Chitwan: Khurkhure -Samithar Road 11.5 km (at present a gravel surface, but proposed to be blacktopped at some time in the future)
2. Sindhuli: Pipalbanjang - Haiutar Netrakali Road 29.0 km (gravel surface)

Both of these roads are currently under construction with the Earthquake Emergency Assistance Project (EEAP), and are in the inner Terai, rather than the main Terai. There should however be sufficient sections that are reasonably straight with surrounding areas where dust can be measured off the road. There may also be a possibility to partner with the Strengthening National Rural Transport Programme (SNRTP), which is a DoLIDAR project that is rehabilitating rural roads in many Terai districts http://snrtp.gov.np/. It is understood that SNRTP also has a budget for research. It is recommended that DoLIDAR explores the possibility of linking with SNRTP to identify a suitable road and coordinates to construct appropriate trial sections in further phases of this research.

There are also likely to be some gravel roads constructed in Nuwakot in the near future, and although this is in the hills, the roads are potentially in the flat areas of the valley.

The location of the trial sections was further investigated and discussed at the stakeholder workshop and will be presented in the final report. However, the final decision on the sites would have to be taken during the inception period of the next phase of the project.

7.2 Road materials

The properties of the road material are a factor in the choice of suppressant and although samples were taken from the roads used in the pilot study, these will not have a significant bearing on the trial sites where the materials are likely to be significantly different. However, sampling and testing of materials have been included in the current phase to get some idea of the properties of local materials and the availability and quality of laboratories for testing locally. Samples were taken from the three roads selected for initial testing and were in reasonable travelling distance from DoLIDAR.

The results of these tests are summarised in Table 3.

The results for the Grading Coefficient are lower than one might expect from the visual evidence of oversize. Recording of the amount of oversize material present in the bulk sample needs to be specified for material testing in Phase 2 so that it is possible, if necessary, to apply a correction factor for coarse materials to the value of the Grading Coefficient and will influence the procedure for treatment selection.

Table 3 Summary of material test results

Road Section	Grading Coefficient	Plasticity	Maximum Dry Density (g/cc)
Dashinkali-Pharping Powerhouse Road	16.4	Non-Plastic	2.003
Airport East Gate – Kadaghari Road	18.7	Non-plastic	2.278
Dhobikhola corridor Setopul (Left Bank) – Anamnagar	27.7	Non-plastic	2.240

The position of all these materials in terms of predicted performance is dominated by the fact that the material is non-plastic. However, this would suggest that either the material was non-plastic or slightly plastic when laid and has lost fines through dust to the extent that it has become non-plastic. Some plasticity is required on gravel roads to bind the fine material and a complete lack of plastic fines does inevitably lead to ravelling and rapid deterioration of ride quality and overall performance. In terms of Shrinkage Product, a value of around 240 is sometimes quoted as ideal for gravel wearing courses. It should be noted that most suppressants need plasticity in the host material to be effective, which would imply that blending to increase the PI might be necessary before treatment.

8. Suppressants

The recommended procedure for selecting treatment options is the one contained in the USA Federal Highways document 'Unpaved Road Dust Control and Stabilization Treatment Selection Guide' Publication No FHWA-FLA-14-002 published in January 2014. (Jones D, 2014). The document has been developed through extensive research carried out in the USA. It is important that practitioners who intend to use chemical treatment for dust control familiarise themselves with this document. The procedure seems rather complicated but providing the input data has been collected, the guide provides a logical process stepwise to determine the options for suppressants that are likely to be most effective. Choices can then be made based on costs, availability and objectives (i.e. dust control or stabilisation).

The overall approach is shown in the diagram in Figure 27, which also indicates the relevant chapters of the FHWA report.

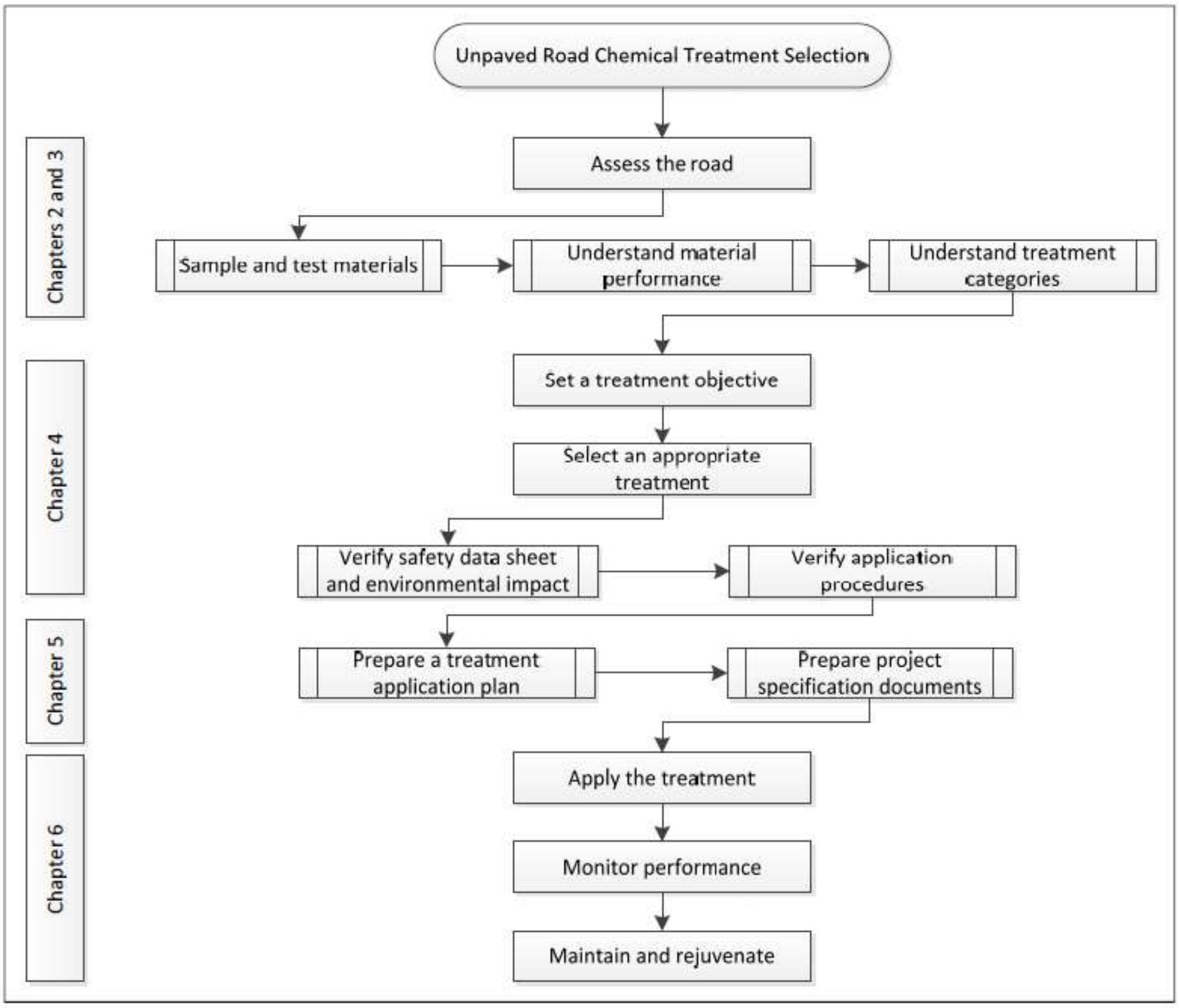

Figure 27 Approach to selecting unpaved road chemical treatments (reproduced from FHWA Report)

The whole procedure leading to treatment choice is quite detailed but can easily be done if the data required is available and the steps given in the Guideline are followed. (Note: The author of the FHWA report has informed the consultants that a revised and simplified procedure is due to be published shortly, and should this occur before the workshop, it will be presented there, but it should in any case be available before final design and treatment selection is required for the trials)

The technical data needed to use the selection procedure is as follows:

- Material Properties
    - % Passing 25mm sieve
    - % Passing 4.75mm sieve
    - % Passing 2.36mm sieve
    - % Passing the 0.425mm sieve
    - % passing the 0.075mmsieve

    - Plasticity Index or Bar Shrinkage (PI used as <3, 3 to 5, 6 to 15, >15)
- Objective of treatment
    - Short-term dust control
    - Long-term fines preservation
    - Long-term fines preservation/stabilisation
    - Long-term stabilisation
- Classified traffic data (vehicles per day) (Used as <100, 100 to 250, >250) (%trucks)
- Climate Factor (Dry, Damp to Dry, Wet) as defined in the report
- Indication of steepness and curvature and its impact on maintenance
- The above values and indictors then enable a process of assessment of the various suppressants to be made in the colour charts provided in the FWHA report.
- An example of the procedure is given in the FWHA report.

The choice of suppressant will depend on the values of the inputs described above, together with other external factors including cost and availability. Tables in the FHWA report give comprehensive details of the origin, attributes, form of supply, application rates and frequency of application, potential environmental impacts and limitations on use of each treatment.

The consequences on performance when unpaved roads are constructed with materials outside specifications is discussed in Chapter 6 and shown in terms of Shrinkage Product and Grading Coefficient in Figure 26 of this report. Figure 28 shows the potential changes (good - green, and fair - hatched) that, depending on material properties, can be achieved by the addition of appropriate chemical treatments. So the aim for the designer of road using dust suppressants would be to achieve a surface that falls within the green area shown in the diagrams.

Until the roads and road sections have been selected for the trials, it is not possible to decide definitively which treatments will be appropriate. However, and as an example, the material testing results given in Table 3 already indicate the absence of plasticity and this will limit the effectiveness and choice of some suppressants. Initial blending with clay to increase plasticity or treatment with bentonite are possible options in these circumstances. At this stage it is possible only to consider, in principle, what trials might be feasible for the next phase in Nepal but may become clearer after discussions with DoLIDAR on the precise locations for trial sections.

Possible suggested options for discussion include:

1. At least two sections of road (each of minimum length 300m), one using a spray-on and the other a mix-in treatment using a chloride of sodium, calcium or magnesium in solution or solid (pellet or flake) form.
2. Apart from water, which is effective for only a few hours, these spray-on options are likely to be the cheapest. The spray-on options need to be applied twice a year after the wet season(s).

3. If the road is an existing rural road using as-dug gravel and unprocessed gravel, then one section should be constructed using crushed material that is within specification.
4. On a road constructed with in-spec materials, a mix-in treatment using bitumen emulsion. (the type of emulsion will depend on the material)
5. The inclusion of a section with a low cost seal should also be considered in terms of determining the relative performance of various options treatments and life-cycle costs.
6. If there are other chemical treatments available in Nepal, which can be procured (e.g. lignosulphonate) then these should also be considered for inclusion in the trials.

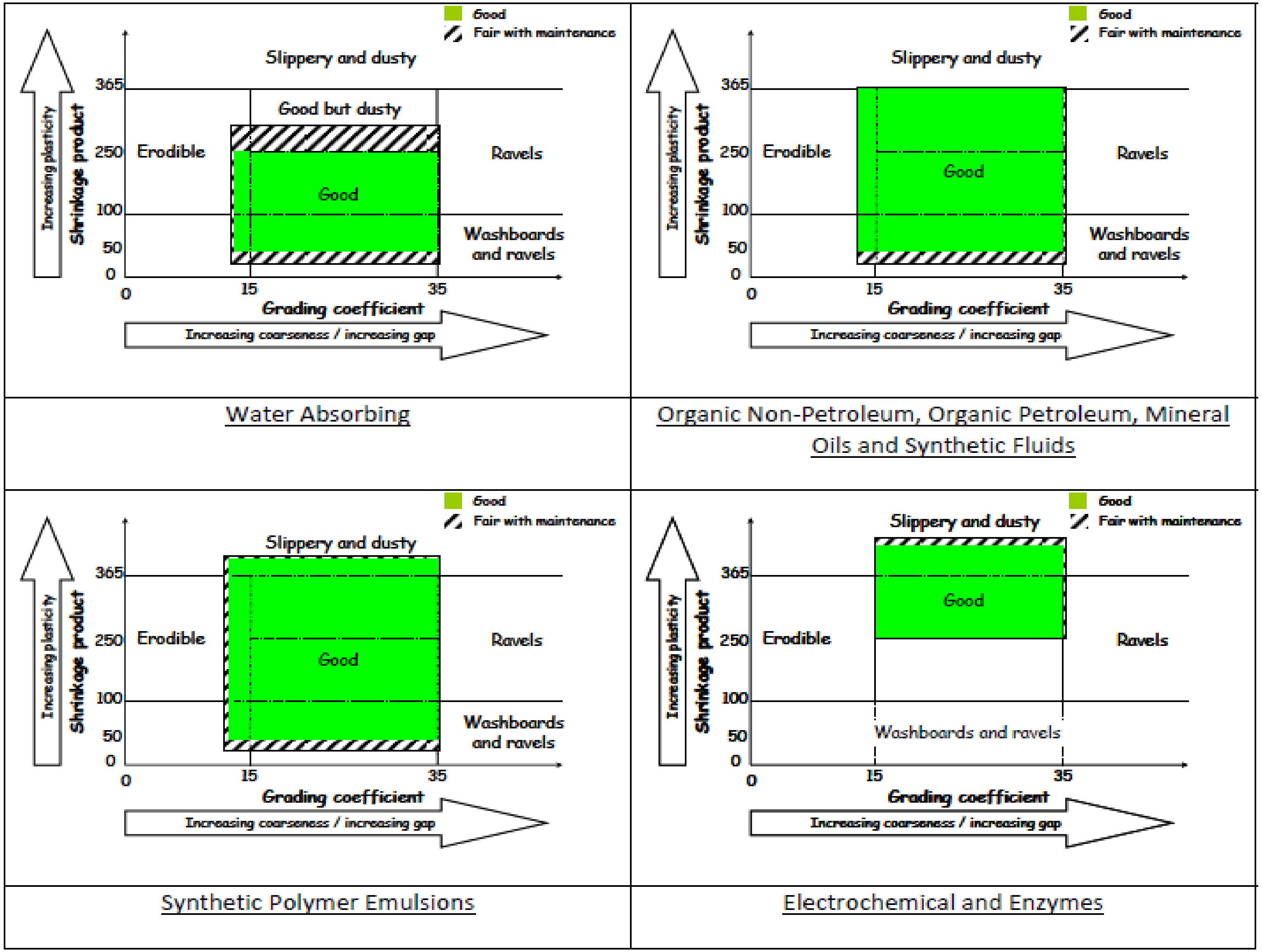

Figure 28 Expected performance of unpaved roads after chemical treatment

As a guide only, typical application rates, effectiveness and approximate costs for a sample of treatments are provided in Table 4. A more detailed technical and cost analysis will be required when the location(s) for the trials have been agreed.

Table 4 Typical application rates of sample of treatments (approximate costs in NRs)

Product	**Form**	**Approx. Cost per tonne**	**Application Rate (Depends on concentration)**	**Supplier**
Water, with and without surfactant	Liquid		Spray on. Higher rates for sandy materials. Effective for 0.5 to 12 hours	Local
Sodium chloride	Powder	Rs 2,900	Spray-on. Usually mixed with Ca Cl_2 and $MgCl_2$ Rate varies	dir.indiamart.com
Calcium chloride	Powder	Rs 5,500	Spray-on/mix-in Liquid: 0.9 to 1.6l/m^2 Flake: 0.4 to 1.1kg/m^2 Pellet: 0.4 to 0.7 kg/m^2 1 to 2 applications per season	dir.indiamart.com
Magnesium chloride	Powder ?	Rs 5,000	Spray-on or mix-in 1.4 to 2.3 l/m^2 1 to 2 applications per season	dir.indiamart.com
Lignosulphonate	Powder	Rs 35(/kg)	Spray-on or mix-in 1 to 2 applications per season	dir.indiamart.com made in China.com
Bentonite	Solid	Rs 2,000	Mix-in only Typically 3% Target PI after treatment 6 to 10. Slippery when wet One-off treatment	dir.indiamart.com
Asphalt/bitumen	Emulsion	Costs to be confirmed	Mix-in Available in Nepal	

Note: It will only be possible to determine accurate costs per km when the roads have been identified and the materials are known.

9. Social surveys

Team discussions were held to discuss this aspect of the research aimed at assessing the social impact of dust and outline recommendations on the required approach were agreed for the next phase of the project. The aim will be firstly to identify the negative impacts of dust that already exist, with an assessment of the type and severity of impact. Then the potential improvements in livelihoods and health through reduction in the impact of dust can be estimated. It is expected that the main reduction in impact will be through the use of dust suppressants, but there may be additional measures that can be implemented as a result of the project, such as natural shields (hedges).

The intention will be to develop questionnaires for semi-structured interviews to gather information on experiences, perceptions and quantitative estimates in selected households, farms, businesses, road workers (e.g. maintenance groups), education and medical facilities along unpaved roads / surfacing trial sections, and a control area less affected by road induced dust. Checklists will be developed and Focus Group Discussions will be held with local government representatives, police, health workers, commerce organisations, transport groups and roadside communities to gather their experiences and perceptions of the impact road induced dust has in different areas, including the trial sections. Secondary data will be gathered to support the triangulation of findings and to provide improved quantitative estimates of impacts.

The survey will be repeated three times to identify changes relating to the trial sections; first to gather baseline data before the application of treatments, one follow-up during the surfacing trials and one at the end of, or in the next, dry season after trial completion. Limited interviews will also be carried out in areas less affected by road induced dust for comparison. The focus group discussion participants should have a sufficiently broad experience to capture differences on a number of roads and on communities living near and far from roads.

It is proposed that a Nepali social research manager be engaged and field level social researchers be employed to develop, test and implement the research on social and economic impacts, working under the direction and leadership of the Social Impact Specialist.

Interviews and discussions will focus on the following issues:

- Mitigation measures used by road users and roadside residents to protect themselves against dust, including use of facemasks, damping down road surfaces, using fencing / plants as a dust shield and speed control bumps.
- Data from local hospitals, health centres, health workers on illnesses possibly linked to air pollution in general, investigate possible correlation of patient's dust exposure sites and unpaved roads. Disaggregate statistics by gender, ethnicity and age groups. Perhaps sampling of road surface or dust collected for toxins including lead, endotoxins and correlation of these with reported illnesses. Maybe also test roadside land and water courses for lead and other dust-related contaminants.
- Impact on domestic work burden, especially of women and girls (frequency of dusting / sweeping, washing clothes, hair and food items, dust mitigation activities)

- Impact on community / public meetings, gatherings (social or official) – time lost due to dust from passing vehicles.
- Impact on agricultural and business productivity, including cleaning agricultural produce, equipment efficiency and deterioration rates including e.g. vehicles, computers, water pumps, solar panels, animal mortality (chicken farms close to the road).
- Impact on education, road accidents.

10. Way forward for the next phase

10.1 Methodology for Nepal

This methodology has been revised following the stakeholder workshop held in Kathmandu on 26th January 2018.

10.1.1 General Methodology

A general methodology for research into the reduction of dust by using suppressants can be summarised in the following steps:

- Develop and design the research project appropriate to local conditions and needs
- Procure dust measuring equipment
- Select road(s) for trials
- Collect baseline data (dust, social surveys) plus traffic, climate and terrain data
- Sample and test road materials
- Decide on strategy (dust control/stabilisation)
- Familiarise with procedure required to select best options for treatment (e.g. based on FHWA Report on road dust control, 2014)
- Use test data and procedure to select and trial products most likely to be a cost-effective treatment for suppressing dust
- Design trials
- Procure suppressant
- Select contractor (if not in-house)
- Contractor training (spray and mix-in methods as appropriate)
- Construct and supervise trials (maybe using more than one application rate for comparative purposes)
- Design monitoring programme
- Collect road performance data, measure dust emissions and conduct social surveys.

This methodology is broadly appropriate for any country, including Nepal. However, the following points are relevant to Nepal and should be taken into account when developing a methodology specific for Nepal, or areas in Nepal.

10.1.2 Timing

It is recommended that the trial sections are constructed towards the end of the monsoon in September or October. It should then be possible to undertake some trials by the end of November / December when the road surface should have dried sufficiently to produce dust. Additional trials should be carried out in January/February and March/April to determine the time of highest dust in Nepal. From May onwards the monsoon rains are likely to start, plus on the Terai there is often mass burning of stubble from late April, which could interfere with the results by adding additional particulate matter into the air. The timing of the chemical application in relation to the road trial section construction is important to consider, as well as the measurement of any residual suppressant if rejuvenation is being trialled.

10.1.3 Road identification

It is assumed that the trial roads will be located on the Terai, as this was the intended focus of this pilot project. However, there were suggestions in the stakeholder workshop that research could be carried out on hill roads as well, as there can also be significant dust even at slow speeds.

In terms of constructing the trials, it was agreed that the gravel roads to be trialled have to be constructed to specification. Specifications are available, but are not often adhered to rigidly. It may be more efficient for DoLIDAR to request an existing project to construct the trials, at least up to base course level. Some possibilities for this are included in the workshop proceedings (Annex C).

The basic methodology for determining the effectiveness of dust suppressants on rural roads in the Terai will be to establish field trials on a gravel road that has been constructed to specification. The road will be divided into several sections, which will include control sections that have received no treatment, and test sections that have received treatment of the selected suppressants. All sections should be constructed to the same standard and laid at the same time, so far as is possible, and given the same time to dry out before they are tested.

If any of the recommended suppressants are 'spray-on' and can be applied to the surface of the road without any mixing in, it would also be desirable to carry out trials on a 'typical' rural road that has not been constructed to specification, but has been constructed using locally sourced 'as-dug' gravel, as this constitutes the majority of rural roads in Nepal. Typically, these types of road produce higher volumes of dust as the particles are not bound so tightly. Also, if the material is less strong it will have a tendency to break down more easily, thus producing more dust. The 'mixed-in' dust suppressants are unlikely to be relevant to this type of road as they require well graded material and appropriate compaction.

10.1.4 Section identification and design

The methodology for trials design will be to identify sections of 300 m minimum length and design the trial sections, based on the materials to be used for construction and other environmental and local factors. Steps would be to:

- Undertake traffic count surveys on the trial road/sections.
- Note other relevant site features (e.g. gradient, curvature, prevalent wind direction)
- Specify and agree the necessary materials tests to allow identification of the suppressant
- Collect bulk samples of road material accordingly
- Arrange for testing of road material and analyse material test results

Carry out baseline monitoring using static equipment on tripods (alongside the road) and vehicle-mounted equipment (includes downloading information from equipment and weighing filters for gravimetric data). Analyse and report results of the baseline survey.

10.1.5 Vehicle and speed settings

Based on feedback from the stakeholder workshop, the researchers should determine an appropriate vehicle to use for mobile dust measurement. It was suggested in the workshop that a light truck or small bus would represent a typical vehicle. Some investigation should be undertaken to determine an appropriate vehicle, but there may be logistical issues with attaching the equipment to a bus or small truck. It is possible that two or three different types of vehicle could also be trialled as a comparison, to determine the different levels of dust they may produce.

Some suggestions were also made as to an appropriate speed at which to measure dust. Group work at the workshop suggested that the speeds of 20 kph and 30 kph would be appropriate for gravel roads. Feedback also suggests that even though higher speeds could be achieved on newly constructed roads, it is unlikely that they will remain in good enough condition to allow higher speeds for very long, so the slower speeds would be more appropriate. Speed would also vary between the hills and the Terai. It is recommended that some further investigation be carried out to determine an appropriate testing speed/s.

It should be note that newly constructed RAP roads have achieved average speeds of 25 kph in hilly areas. This is however an exception and most hill roads would average lower than this.

10.1.6 Select treatment options

Once the site/s are agreed, it will be necessary to check the properties of the construction materials in detail. Adequate materials for construction should be processed and stockpiled ready for use to ensure that the materials are as homogeneous as possible, by random sampling of the stockpiles. The materials to be used for construction should be determined and samples taken for testing.

The testing should involve the following standard tests:

- Sieve analysis
- Modified Proctor test
- California Bearing ratio (CBR)
- Atterberg Limit (Plastic limit, Liquid limit, Linear shrinkage)

Select treatment options based on the results of material tests and other site data, as mentioned in 10.1.3. The research team, in association with DoLIDAR, can determine an appropriate dust suppressant for that site and calculate cost and quantities of treatment products required. DoLIDAR should then prepare a detailed contract for applying selected treatment(s) and procure a contractor, with the support of the research team. The team should also liaise with DoLIDAR to provide for supervisory expertise to advise the contractor in how to apply the suppressant on site. For chemicals that are diluted in water it is essential to ensure that the tanker spreads the diluted chemical evenly over the exact surface area.

10.1.7 Construction of trial sections

Construct trial sections using identified suppressants, making sure that all stages of construction are in line with existing specifications and standards. The necessary steps are:

- Supervise contractors closely during application of suppressants.
- Check traffic levels again following construction.
- Monitor sections in line with established guidelines for research monitoring.
- Repeat application of suppressants where specified over time.
- Analyse data and compare with the baseline and control sections (ensuring no run-over of chemicals during construction or by traffic during normal use), then report the results.

It may also be desirable to trial physical barriers to dust, such as road side hedges, to see what effect they can have in limiting the spread of dust from the road.

10.1.8 Dust measurement equipment

The dust will be measured using the DustTrak DRX equipment currently in Nepal with DoLIDAR. This measures four different fractions of dust, PM 10, PM 4, PM 2.5 and PM 1. The different fractions have different effects on health, so this will provide important information on the impacts of dust, including on people's health and livelihoods.

The equipment will need to be calibrated before any dust measurement is undertaken. Possibilities for this have been included in section 4.5 above, as well as in the recommendations in section 10.3. On-site training should be carried out to demonstrate the operation of the equipment to DoLIDAR staff.

Equipment trials were carried out using one machine fixed to the back of a vehicle, and two static machines at 1 m and 7 m from the road edge respectively. Feedback from the workshop also suggested that dust could be measured actually on the edge of the road (shoulder), as many people use this part of the road to walk on or to wait for buses. If this recommendation is accepted the equipment will need protection from passing vehicles, although this may affect the speed of vehicles passing the machine and therefore affect the results, so this should be carefully considered if it is to be implemented.

This methodology allows measurement of dust directly on the road itself as it is generated, alongside the road where perhaps pedestrians or traders would be located, and at the extent of the road reserve where it is legal to construct houses and other structures (when enforced, the road reserve for rural roads is generally 20 m, at a distance of 10 m each side from the centre-line of the road). It is proposed to retain this setup for the next phase so that the three different scenarios for dust can be recorded.

During the trials the equipment was set up at a height of 1.7m to simulate an average person. This was discussed in the workshop and it was recommended that dust be measured at three different heights, for the average man, woman and child, 1.7m, 1.5m and 1.0m respectively. Approximately 15 cm should be deducted from these heights to match the normal nose/mouth level.

10.1.9 Testing the chemical composition of dust

As suggested in the workshop, it would be valuable to test the mineralogy of the dust to determine what harmful minerals may be present. Specifically tests should also be carried out to look for toxins and endotoxins, which can cause long term health damage.

10.1.10 Social and health effects

Monitoring of health and livelihoods effects will be carried out as per the social methodology in section 9. The focus will be on assessing potential negative health effects by conducting interviews and meetings at the local level. Other aspects such as the effect on livelihoods, agriculture, environment and road safety will also be explored through an established system of questionnaires, interviews and meetings. This will provide a baseline against which any improvements as a result of dust suppression can be measured.

The intention will be to gather information on experiences, perceptions and quantitative estimates in selected communities along the trial sections, and a control area less affected by road dust. Survey activities will include:

- Checklists for Focus Group Discussions with local groups to gather their experiences and perceptions of the impact of road dust. Secondary data will be gathered to provide qualitative information.
- The survey will be repeated three times:
  - Baseline before construction
  - At completion of trials
  - In the following dry season after completion
- Limited interviews will also be carried out in areas less affected by road induced dust for comparison.

It is proposed that a Nepali social research manager be engaged and field level social researchers be employed to develop, test and implement the research on social and economic impacts, working under the direction and leadership of a Social Impact Specialist.

A useful suggestion that came out of the workshop was that communities affected by dust should be consulted to help develop the final design of the social research.

10.1.11 Define acceptable limits of dust

One of the key issues is to define an acceptable level of exposure to dust that is generated from gravel roads. This should involve consultation with a wide range of people, but will need to be based on the results of the dust trials and linked to international best practice, established guidelines and exposure limits.

10.1.12 Further recommendations

It is possible that this research will uncover some related areas that need to be revised as a result of the outcomes. This could include making recommendations for revising the existing specifications for gravel road wearing courses, for example.

Another possible recommendation could be that the Traffic Police include the possibility of recording 'dust' as a reason for collisions, as suggested at the workshop. This would allow a picture to be built up over time of the effect dust has on road safety. How dust influences driver behaviour could also be an interesting area of research.

The research team should bear in mind the possibility of further recommendations when analysing the results of the project.

10.1.13 Resources required

When the site/s have been identified an estimate of the resources required for the trials can be made.

10.2 Research Matrix

The draft research matrix can be seen in Annex B. This was used as the basis for discussions at the workshop. It will be revised following comments and feedback on this report and will be included in the Final Report.

10.3 Recommendations for next phase

The following recommendations are made for the next phase of the project:

- Types of research. A number of potential areas of research were identified. They have been proposed to extend our understanding of the nature of dust, how it is generated and how it can be mitigated, as well as the potential effect it can have on people's health and livelihoods. This can be summarised as:
    - The reduction in dust that may be achieved by using generic dust suppressants on a properly constructed gravel road
    - The potential effect on people's health, to be estimated for different types of road user (vehicles, motorcyclists, pedestrians, etc.) and people who live alongside the road
    - The potential effect on livelihoods, including damage to crops, increase in time taken for cleaning, reduction in prices for crops grown in dusty areas, etc.
    - The amount of dust generated by different types and size of vehicles and any potential improved aerodynamics that could be applied to vehicles to reduce dust emissions.
    - The volume of dust generated at different speeds, and possibly on different types of road alignment, i.e. on the Terai and in the hills of Nepal.
    - The composition of dust in terms of mineralogy and chemical composition, and the inclusion of harmful particles.
    - The type of dust generated by different road materials, and how the volume of dust is related to construction specifications and quality of construction, i.e. if the road is compacted properly, does it reduce dust?
    - The reduction in dust between areas in direct sunlight and shade. Monitoring of moisture content will be necessary.
    - The time of highest dust in Nepal (assumed to be between November and April)

  Not all of these areas will specifically contribute towards the use of dust suppressants, but they will increase understanding of road dust and the effect it has on rural communities. In this respect it is recommended that as many of the above subjects as possible be included in the next phase of this research.

Other potential areas of research regarding road dust are road safety, vehicle operating costs (transport costs) and the environment. In addition, it would be possible to try and capture dust on steel trays, as per the TRL Kenya dust study. This would allow the analysis of the chemical composition and mineralogy of the dust more easily, thus determining whether there are particles that are harmful to health. It would also provide an indication of the volume of dust deposited at a specific point close to the road.

- Dedicated vehicles should be allocated for the suppressant trials. It may not be possible to rely on DoLIDAR alone to supply vehicles, especially in light of the changes in government and the different role that DoLIDAR is likely to adopt. In addition to a vehicle that can be used to support equipment to measure dust directly on the road, it is desirable to make comparisons of the amount of dust produced from different types of vehicles. This is likely to involve hiring such vehicles for short periods. It is estimated that up to four different vehicles would need to be hired for a period of one week to carry out these trials.
- An allowance should be made to calibrate and maintain the dust measuring equipment, as this is due on an annual basis. The best option could be to bring a calibration expert from the TSI base in Singapore, who could then train DoLIDAR in how to calibrate the equipment in the future. This would be the most sustainable solution in the long term.
- DoLIDAR should include in their budget an allowance for constructing and monitoring the trial sections. It may be possible to secure funding through an existing project as suggested at the workshop, but it is essential that DoLIDAR prepares financially for this in advance, so that the necessary resources are available when they are needed.
- DoLIDAR must assign a counterpart engineer specifically to this project. This engineer should be senior enough to act as a liaison officer with the consultant's team and to independently arrange field visits, workshops and site trials. It is recommended that the counterpart also receives some instruction in research and how to manage trial sections, data collection, data analysis, reporting etc. as this is a skill that is lacking in DoLIDAR staff to date.
- The existing equipment provided under Phase1 in Nepal consists of three DustTrak DRX machines, a 'Thinkware' video camera (forward and rear facing), a weighing scale, a carrying rack and various fixing straps and USB storage drives will all be required for the next phase. The equipment is in good condition. At present the equipment is stored in one corner of the DoLIDAR meeting room, due to a lack of space. This is not ideal as the meeting room is continually used. It is recommended that DoLIDAR find a more secure and safe place to store the equipment. Following the workshop there was a suggestion that RAP could be able to store the equipment for DoLIDAR, so this should be pursued.
- In the next phase, it is recommended that the training in the use of the Dusttrak DRX be repeated and consolidated into a guideline, so that issues such as the incorrect replacement of filters can be avoided. The online videos are a very good source of

information/training, but a guideline should also provide a useful checklist of how to operate the equipment.

- It is recommended that the principles of this research be considered for other countries in Asia and Africa, where it could have a significant impact on people's lives. Whilst the general methodology adopted in other countries is expected to be similar to the sequence shown in section 10.1.1, it is clear that some parameters in the research (e.g. speed at which measurements are taken, suppressant type, etc.) will need to be tailored to reflect local road conditions and traffic.

The proceedings of the workshop can be seen in Annex C.

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Annex A: Dust measuring data sheet

Dust Measuring Data Sheet

Name of Researcher: Date:

Vehicle: Video taken? Y/N by Vehicle /Phone/Camera

Site description (road type, surface, sun/shadow, etc.):

Road location:

GPS coordinates:

Section to be surveyed

Length: Start: GPS:

End: GPS:

Machine on Vehicle: DRX No. Serial No.

Machine Static: DRX No. Serial No. Location GPS:

Machine Static: DRX No. Serial No. Location GPS:

Runs

Run description (also include comments below on issues, disruptions, etc.):

Run 1:

Run 2:

Run 3:

Run 4:

(continue overleaf if necessary)

Annex B: Draft Research Matrix

Research Questions	Methodology	Statistical analysis
Are suppressants useful in reducing dust on gravel roads?		
• Which are the most useful?	Trial suppressants on a test section, as described in draft final report	Analysis of results from dust trials
• How often do suppressants have to be applied, how long do they last as spray-on or mix in solutions?	Check manufacturer's recommendations, guidelines and previous research in this area. Trial on site if possible.	Manufacturer's guidelines
• How cost effective are suppressants?	Compare the cost per unit, cost to apply and duration before subsequent application to determine cost effectiveness	Economic analysis
• How available are the proposed suppressants in Nepal?	Check suppliers of suppressants in Nepal	Availability in terms of delivery times, need to import, etc.
Which compositions of road materials are suited to which suppressants?		
• Is there a typical road material type in the country that causes problems with dust?	Source local knowledge, recent lab testing results, etc.	Analyse different information on road material composition
• Which suppressants are suitable for this and other types of road material and what conditions do they work best in?	Source manufacturer's information, previous dust reports, etc.	Analyse previous research results and literature
• What materials tests are necessary to be carried out on the materials to determine their suitability for the application of certain suppressants?	Check previous dust and suppressant reports, guidelines and manufacturer's information.	Analyse the properties of the road materials and link to how the suppressants work in order to match the suppressant to the material

Does road dust have an effect on people's health? • Is it possible to quantify health effects? • What type of health problems could be caused/exacerbated by road dust? • How long would it take to see adverse health effects from road dust? • What other sources of inhaled matter could affect/contaminate the results?	Likely that anecdotal evidence will prevail, together with data from local clinics and information gleaned from focus group discussions and other meetings Use focus groups and community meetings to determine possible health problems Source general medical information, previous research reports on dust and respiratory diseases and their causes Find possible sources from FGDs and community meetings	Collect data from local institutions and try to correlate it with anecdotal evidence collected in discussions and interviews Analysis of health problems in communities close to the road, compared to those who live away from the road or near a surfaced road Data might not be available locally as it is essentially long term but comparisons could be possible with incidence in developed countries Analyse dust composition to determine the constituents
Does dust have an effect on people's livelihoods, and if so, how? • Is agricultural production affected, if so how? • Do people get lower prices for dust-affected crops? • What is the effect on people's lives (especially women and girls) when dust levels are high?	Evidence to be extracted from previous research and group and community discussions Interviews with farmers and traders Focus group discussions with women's groups. Check evidence from WHO and research comparing health risks to women in developing countries	Analyse local agricultural data, if available, otherwise review group discussion feedback Analyse interview data against local price records, if available Analyse results of discussions and interviews, primarily with women but checked against male feedback
Who is affected by road dust most, and		

how? • Motorcyclists? • Pedestrians? • Drivers? • People living next to the road? • People living near the road?	Results of trials using vehicle mounted equipment and static equipment mounted next to the road	Analyse interviews with road users and anecdotal evidence, set against the evidence from the trials that will show where the highest concentration of dust is on the road and off it
Which speeds produce the most dust? • 20 kph • 30 kph • 50 kph • >50kph (in other countries)	To be determined using primarily vehicle mounted equipment that measures dust directly on the road	Analysis using the data collected from the Dusttrak machine, video and data sheets
What types of vehicle and vehicle aerodynamics produce the most dust? • Heavy, medium or light? • Tyre sizes? • High, medium or low clearance?	Trials using three or four different types of vehicle with different characteristics	Analysis using the data collected from the Dusttrak machine, video and data sheets
What effect does road dust have on road safety?	Possibly beyond the scope of the project, but trials could be designed to test this.	Check if traffic collision data is available and if dust is recorded as a factor
What effect does road dust have on vehicle operating costs?	There has been some initial research in this area, but again it may be beyond the scope of this project.	Check research reports from elsewhere and in-country anecdotal evidence
What effect can road dust have on the environment?	This is a wide area to research and could be beyond the scope of the project, but some immediate effects could be measured such as the siltation of rivers and effect on wildlife.	Some suggestion of possible pollution to water storage, Check literature

Annex C: Stakeholder Workshop Proceedings

Workshop Proceedings Report

Nepal Dust project: NEP2087A

Workshop Date: 26th January 2018

Workshop Venue: Summit hotel, Lalitpur

Workshop participants and Director General's introductory address

1 Workshop Proceedings

The schedule for the workshop can be seen in Appendix 1, and the list of participants in Appendix 2. The workshop was opened by Mr. Jeevan Guragain of DoLIDAR, and the moderator Mr. Bishnu B. Shah proposed a round of introductions and invited the DG of DoLIDAR, Mr Jeevan Kumar Shrestha, to chair the proceedings. Mr. Shrestha chaired the session and made an introductory address, and Mr. Les Sampson, Team Leader of ReCAP, also addressed the workshop.

The workshop had the main purpose to discuss recommendations for cost-effective solutions for controlling and minimising dust pollution from gravel roads in Nepal. The project also has an objective to scope a detailed methodology and research matrix for a next phase of the project, which will test the efficacy of dust suppressants.

At the workshop a proposed methodology and research matrix were presented, along with recommendations for a subsequent phase of the project to investigate, monitor and evaluate appropriate dust suppressants for Nepal. A key part of this will be to identify potential cost-effective dust suppressants that can be used for the trials in the next phase. This will be discussed and feedback will be taken on board for inclusion in the final report.

The potential for using a similar methodology in other countries was also discussed at the workshop, and is mentioned in Section 5. Although this was not the prime purpose of the workshop, it became clear that the conditions could vary greatly, so the methodology would need to be adjusted for the conditions in each country. For example in some countries in Africa it is possible to drive up to 100kph on good gravel roads, which is not possible in Nepal. Insights were gained into the relevance of dust suppression in different environments, with the potential for sharing of experiences and potential partnerships.

1.1 Introductory Presentation

Robin Workman, Team Leader (TL), presented an introduction to the project and the objectives of the workshop, the schedule and the methodology that would be used to produce the conclusions. The overall Goal and Objectives for the project were presented to the participants, as well as the objectives of the workshop, which were defined as:

- Agree a methodology for future research, with recommended suppressants for use in Nepal
- Consider the proposed research matrix, including what to research & how
- Define a way forward for a next phase

The TL then went on to present the background of the project, and also introduced Mr Tony Greening, TLS, to provide a more in-depth background of road dust.

1.2 Background to Road Dust

Mr. Greening provided an overview to the issue of road dust in general, and mentioned some of the previous research in this area, which is included in the literature review. He covered the following subjects:

- The reasons why road dust is a concern
- The potential impacts of road dust on health, agriculture, the environment, road safety, road condition and vehicle operating costs
- Road dust from gravel roads as a significant component of air pollution
- The harmful effects to health, and the persons at risk (particularly children), of particulates in road dust
- The differences between developed and less-developed countries in terms of dust
- The reasons why road users and residents in these countries face increased risk
- The influence of material properties on unpaved road performance
- Gravel roads built to specification produce less dust
- Road users in developing countries are particularly at risk
- Most research has been carried out in high-income countries (e.g. USA, Australia, New Zealand)
- The need for research in developing countries
- Cost impacts of dust from gravel roads

1.3 Progress of the project and methodology

The TL gave an overall review of the progress so far, including:

- Dust measuring equipment identification and procurement
- How the equipment works
- Training carried out in how to use the equipment
- Mobile measurement of dust
- Static measurement of dust
- Dash cam videos of dust
- IRI measurement by smartphone
- Gravimetric measurement of dust

He then introduced the subjects to be covered by the other members of the team:

- Suppressants – Tony Greening
- Materials – Bishwa Shahi
- Social and economic effects – Kirsteen Merrilees

1.4 Dust Suppressants: Overview of impacts and options for control

Tony Greening gave a presentation on the options for dust control. The topics included:

- An overview of the various generic products available for dust control and stabilisations
- The difference between dust control and stabilisation
- The decision-making process for practitioners on the choice control/stabilisation options
- Examples of products that can be used for dust control and stabilisation
- The precautions required when choosing proprietary products
- An explanation of why only generic treatments (i.e treatment with known origins and/or chemical properties) are considered for use in this project
- Outline of a procedure developed in the USA for treatment selection
- The properties of the road material and other data required in the selection process
- Factors that influence the final selection process of specific dust palliatives
- The various categories and properties of generic suppressants available
- Suggestions of possible treatments for use in Nepal

1.5 Materials

Bishwa Shahi gave a presentation on the tests of road materials used in the equipment trial sections and specifications for gravel roads in Nepal.
The presentation included the following topics:

- Material sampling of the gravel wearing courses on road sections used for the equipment trials
- Laboratory testing carried out according to the specified test methods used in Nepal
- Description of the test methods and equipment used
- Materials testing for gradation, plasticity and strength
- A summary of the test results (the materials on each of the roads were non-plastic)
- The influence of plasticity on road performance
- Rural roads constructed in Nepal contain large quantities of oversize material
- The inspection by members of the research team of roads in the Terai
- Photographs of roads in the Terai showing the extent of oversize material
- The effects of oversize material and non-plastic materials on the performance of gravel roads and on dust palliative treatments
- Discussion on the specifications for gravel roads in Nepal

Materials presentation

1.6 Social and economic effects of dust

Kirsteen Merrilees presented:

- The typical social and environmental effects that are associated with dusty environments including effects on health, agriculture, the economy, environment, safety, and social effects
- Outline of the proposed social impact research methods and the social research data to be collected
- Suggestions on dust measuring methodology that might better enable correlation between potential impacts and dust volumes / compositions, including taking into account different heights of men, women and children, measuring dust on the road where most people walk, and testing the dust collected for toxins and endotoxins.

1.7 General comments and questions from the participants

After each session a question and answer session was facilitated by the moderator. The following are the questions and comments that were aired during these sessions:

(Q=Question, C=Comment, A=Answer)

Q: Have there been any developments in the natural world to adapt to road dust, either in flora or fauna?

A: The team were not aware of any such developments, but it was an interesting question.

The experience from the Kathmandu valley is that high levels of dust pollution overwhelm the (human) body's ability to cope through its normal biological mechanisms to protect itself against dust, with something like 30% of Kathmandu residents now reporting occasional atypical asthma type conditions (as mentioned by Jun Hada of SDC). Perhaps over very long periods of time the body may adjust, but human evolution takes place over generations, rather than a few years. Behavioural adaptations include damping down road surfaces and the wearing of face masks. The use of face masks has become a common feature in recent times among regular pedestrians at least in urban areas and for motorbike drivers. The proposed social impact research includes investigation into the mitigation measures applied by roadside residents and roadside users.

Robin had a comment about a study on sheep and how their teeth wore down more quickly when grazing in dusty areas.

Workshop Plenary

Q: Are there other harmful aspects of dust, apart from road dust?

A: Road surfaces are likely to become contaminated over time from, for example, exhaust emissions, fluid leakages and spills. It is not clear to what extent or for what duration different contaminants may remain in the surface materials. Although fuel is now lead-free, there may be residual lead contamination on older roads. Roadside businesses and communities often throw waste fluids onto the road which may contain a wide range of pollutants. Roads with lower traffic volumes are often used for drying crops, and may therefore become contaminated with endotoxins. It is proposed that the dust study includes analysis of the composition of the road surface material and the traffic induced dust to determine the presence of different contaminants and the extent to which this may contribute to health and environmental impacts.

C: A wider turning circle reduces dust. This was a comment that wider turning circles allow for a smoother change in speed and could therefore reduce spikes in dust levels.

C: Different materials on the road will affect the types of suppressants used. This is a relevant comment and is included in the research into suppressants.

C: Speed to record dust in Nepal should not be more than 25 kph as this is generally the fastest speed that can be achieved on the majority of rural gravel roads. This is due to the larger size of the gravel used. Design speeds of DOLIDAR roads are 50kph on roads in the Terai (minimum 40kph) and 25kph on hill roads (minimum 20kph). These speeds are only likely to be achieved on newly constructed / rehabilitated roads and the actual safe speeds are likely to deteriorate fairly rapidly without a proper maintenance regime. The speeds used for testing should take these as a maximum value.

2 Group Work and feedback

Some participants left after lunch, but the remaining participants were split into three groups of approximately 7 – 8 people.

Group 1 was assigned to consider the use of suppressants.

Tasks: Appropriate suppressants for use in Nepal

- Is the research trials methodology appropriate?
- What suppressants could be appropriate for Nepal?
- Where/how should we consider using suppressants?

Group 2 was assigned to consider the social and economic effects of road dust.

Tasks: Social and economic effects of dust

- What health effects should we try to measure?
- What livelihood effects should we try to measure?
- Ideas to effectively research this subject?

Group 3 was assigned to consider other technical issues.

Tasks: Other problems associated with dust

- Who should we be focusing on?
- What factors should we consider for effective dust suppression?
- Do we consider safety, VOCs, environment? – prioritise these….

2.1 Summary of Group 1 conclusions

The presentation from Group 1 can be seen in detail in Annex 3.

Group 1 concluded that the Methodology was appropriate, with the following comments:

- Grading of gravel is different in Nepal, much gravel is taken from the river with no plasticity, or 'as dug' graded material. The specification used is 63mm down, as per base/sub-base. Ideally this needs a gravel wearing course on top, but this is rarely implemented. It is recognised that these specifications need to include plasticity in order to bind the gravel, which will affect the type of suppressant used.
- Trial sections should be in Terai and Hills. With high curvature of the road, dust is more. One site should be close to Kathmandu so that it can be demonstrated easily. It may be possible to get support from existing projects, such as World Bank funded SNRTP, ADB funded RCIP and DFID funded RAP.
- It was proposed that the wearing course should be funded and implemented by ReCAP/the project, as this is the part that will be researched. Up to base course can be managed by DoLIDAR.
- Results should be disseminated widely, given the international interest in this area.

Discussion:

- Maysam Abedin noted the request for funding of the wearing course for trial sections and said it could possibly be considered by ReCAP, but this would have to be discussed with DoLIDAR before the next phase is developed.
- Tony Greening noted that DoLIDAR will need to budget for the trial sections well in advance, so that the construction can proceed smoothly.
- The project manager of SNRTP (World Bank funded) offered to fund the trial construction, depending on the length of road to be tested.
- It was noted that Department of Roads (DoR) have a gravel road specification that can be used by DoLIDAR.

Group 1 Discussions

2.2 Summary of Group 2 conclusions

Health problems were presented:

- It will be necessary to find baseline data and compare this to post-construction (after suppressants have been applied). Collecting such data may not be easy, but the tools that could be used are questionnaires, discussions in schools, clinics and hospitals nearby the road and far from the road, for comparison.
- The project should consult with the communities to discover the best way to collect such data.

Livelihood problems were presented, some issues identified were:

- Cottage industries, how they are affected
- Agriculture, quality of crops may increase with suppressants, so price for crops will increase
- Businesses close to a gravel road may not be used so much, due to the dust
- Small industries may be affected

Discussion:

- Health problems can include skin conditions as well as cardio-pulmonary effects. Baseline data should capture common ailments found in the test section and control areas before and after the trials. There may be some changes especially in allergy type ailments, but other health effects will take much longer to become apparent. The research should include reviews of hospital and health clinic data and patterns. For livelihoods, the research should include how dust influences people’s preferences when choosing services along unpaved roads. It should also investigate what mitigation measures are being used or which might also help reduce the effects of dust other than the surface treatments (e.g. the use of hedges to limit the spread of dust).
- The social research team should consult with people affected by road dust before fully designing their research questionnaires, so they are based on a better understanding of the issues and perceptions of affected communities from the start.
- Existing mitigation measures – should we investigate the effectiveness of different types of mitigation measures used?

Group 2 Discussions

2.3 Summary of Group 3 conclusions

The presentation from Group 2 included the following:

- The principle focus was proposed as:
  - Pedestrians
  - People living next to the road
  - Motorcyclists
  - People living nearby the road
  - Drivers
- What speeds should be researched:
  - 30 kph
  - 20 kph
- What type of vehicles should be researched:
  - Primarily medium vehicles, such as buses (40 pax), light trucks or tractors, as these are the primary modes of transport on gravel roads
- The Road Safety issues to be researched would be primarily the visibility on the road. It was noted that the police do not record 'dust' or 'visibility' as a reason for accidents, it is simply put down to weather
- In terms of the environment there could be scope to research respiratory disease and its link to road dust
- Vehicle Operating Costs (VOCs) could be investigated to see if dust increases the cost
- In terms of the environment, important issues are pollution, washing of dust into water courses and its effect on aquatic life, mud flows, how flora and fauna are affected and general health

Discussion:

- Should we investigate lower speeds to determine at which speeds traffic induced dust stops posing a problem? Could this be used to establish speed limits through built up areas / near schools – or the design of speed control measures?
- A comment was also made that this phase of the project is also tasked with developing a methodology for use in other countries in Asia and Africa. The design speed and the actual speeds achieved on unpaved roads in many of these countries are often very much higher than in Nepal. Therefore, the methodology may need to be fine-tuned in terms of the average speeds prevailing locally. This may also be relevant for other variables.
- What is an acceptable level of dust? Reference can be made to WHO limits, but these are daily averages and not directly related to this research.

Group 3 Discussions

2.4 Summary of Plenary discussions, following group work

Following the group work the floor was then opened up to the plenary discussions, which were held over the various aspects of road dust in Nepal.

These discussions are summarised as:

- It would be useful to have the dust measuring equipment mounted on a light truck, as these are the most common vehicles on most roads.
- Stationary measurement is also important, as demonstrated. Dust could be measured at different heights to represent the different heights of women, men and children. Average heights in Nepal are 1.7m for men and 1.5m for women. However, the tests should be set at about 10-15cm lower to match average nose / mouth level. Tests should also be done at a lower level (<1.0m?) for children. It was also suggested that we do stationary tests actually on the edge of the road too – where people normally walk / stand while vehicles pass?
- Different speeds could be used in the research, depending on the location of trials (Hills or Terai) and road quality.
- Monitoring of dust could be carried out with different types of vehicles to test the differences.
- Trials will be the most effective way to test the effect of dust and suppressants, location will probably be linked to a project and the location will depend on that project.
- Dust is a factor in road safety, but should be specifically included as a reason for collisions when the collisions are recorded.
- Speed limits could be an effective solution for reducing dust, especially through inhabited areas.
- Hedges and physical barriers could be tested as a way to reduce the spread of dust from the road, as road dust tends to settle quite quickly.
- Acceptable limits for road dust will need to be determined as part of the research, which should involve all stakeholders.
- It will be better from resource management aspects to carry out trials on suitable roads already being constructed/ rehabilitated under existing projects and to work out what the project will cover.
- Specifications for materials can have an effect on dust, as shown in the presentations. These may need revising for Nepal as a result of the trials.

3 Conclusions

The following conclusions can be taken from the stakeholder's workshop:

- The proposed methodology and research matrix is largely appropriate, with some minor changes/additions as shown below.

The following aspects should be included in the research methodology:

- Testing at different heights, on and beside the road.
- Investigate the chemical composition of dust – look for toxins, endotoxins.
- Consult with communities affected by dust to help develop the final design of the social research
- Construction of trials will probably need external funding, but ReCAP will explore the possibility of providing resources for perhaps the wearing course
- Trial speeds – Carry out testing at speeds that represent local conditions

- Testing with other types of vehicles that are relevant for typical vehicles on gravel roads in Nepal
- Roads should be built to specification before they can be effectively tested in this research

Road Safety

- Dust should be a included as a factor in police road accident reports
- Dust can influence driver behaviour

Environment

- Pollution of rain and water sources and impacts on aquatic life should be investigated
- More frequent washing and wear on clothing is a possible social impact

Agriculture

- Impacts on vegetation (flora) and fauna (grazing)

Miscellaneous

- There is a requirement for a budget line in DoLIDAR for research into dust, in order to fund capital costs and staff related costs. Even though some project funding may be possible for the trial sections, DoLIDAR will still need a budget line for road dust research.
- The TL expressed some concern over storage of the dust measuring equipment. At present the only place DoLIDAR has available is their meeting room, where it is stored in the corner and could be vulnerable to damage or misuse. Kirsteen suggested that RAP may be able to store the equipment for DoLIDAR, as they have a dedicated and secure storage facility. If this is acceptable to DoLIDAR they should formally contact RAP to request this.

Nepal Dust - Stakeholder Workshop schedule
26 January, 2018
Moderator: Bishnu B Shah

Day 1	**Subject**	**Present / Facilitate**
8:30 - 9:30	Arrival, Breakfast and Registration	
Session 1 9:30 – 10:45	Opening by DoLIDAR Comments by ReCAP Self-Introduction by participants Introduction to project, background, definition of the problem Update on progress, results of equipment tests *Discussions*	DoLIDAR ReCAP Robin Workman / Tony Greening
Tea Break 10:45 – 11:15		
Session 2 11:15– 12:30	Overview of suppressants and materials *Discussions* Social and health impacts of dust *Discussions* Present workshop questions, arrange groups	Tony Greening / Bishwa Shahi Kirsteen Merrilees Bishnu Shah
Lunch 12:30 – 13:15		
Session 3 13:15– 14:30	Workshop Discuss core questions in groups: • Appropriate suppressants for use in Nepal • Social and economic effects of dust • Other problems associated with dust	Bishnu to facilitate
Session 4 14:30 – 15:30	Report back in Plenary Summary of outcomes Concluding Remarks Close	Bishnu to facilitate Robin Workman DoLIDAR
High Tea 15:30 – 16:00		

4 Workshop assessment by participants

The following results of the assessment questionnaire have been produced from the analysis:

Question 1: How much have you learned from this workshop?:

Course No.	Dust Workshop	**Q:** How much have you learned from this workshop? Nothing → A Lot					Score
		1	2	3	4	5	
1	Informative or not?						3.8

General comments under Question 1 included that the research of dust was a new subject for many people, although all were aware of dust problems. Most learned something from the workshop, although some found it hard to link this to their current work.

Question 2: What part of this workshop was the most useful?
Most participants responded that the introduction of dust suppressants and the social/economic effects was most useful. There was also a positive response to the group work.

Question 3: What part of this workshop was the least useful?
There were only three comments in this section, one though that the use of suppressants was least useful, whilst two thought the introduction was least useful.

Question 4: How do you rate this workshop:

Question No.	Dust Workshop	**Q:** How do you rate this workshop overall? Nothing → A Lot					Score
		1	2	3	4	5	
4.1	Useful/Not useful						4.2
Question No.	**Dust Workshop**	Nothing → A Lot					**Score**
		1	2	3	4	5	
4.2	Not Interesting/Very interesting						3.7
Question No.	**Dust Workshop**	Basic → ← Complicated					**Score**
		1	2	3	4	5	
4.3	Basic/Complicated						3.6

This question was designed to show how appropriate the workshop was for the participants and whether it has been pitched at an appropriate level.
4.1 In terms of how useful the workshop was the average score was 4.2 out of 5. This suggests that the participants could see the potential of the research subject.
4.2 In terms of how interesting the workshop was the score was 3.7 out of 5. This is a reasonable score, given that the subject of dust research is new to most of the participants.
4.3 The ideal score for this question is 2.5, which would show a balance between too basic and too complicated. The average score was 3.6, which suggests that the subject was slightly too complicated, although this is not surprising as it is a new subject for most participants.

Question 5: How do you rate the facilities of the workshop?

Questions 5.1 to 5.4 relate to the facilities at the workshop. The scores are evident, but it seems that most people were relatively happy with the venue and it would therefore be appropriate for future workshops.

Question No.	**Dust Workshop**	**Q:** How do you rate this workshop overall? Poor → Good					**Score**
		1	2	3	4	5	
5.1	Room facilities						3.9
Question No.	**Dust Workshop**	Poor → Good					**Score**
		1	2	3	4	5	
5.2	Food / refreshments						4.4
Question No.	**Dust Workshop**	Poor → Good					**Score**
		1	2	3	4	5	
5.3	Comfort of seating						3.8
Question No.	**Dust Workshop**	Poor → Good					**Score**
		1	2	3	4	5	
5.4	Convenience / location						4.2

Question 6: Further comments:

Further comments noted by the participants were as follows, these have been summarised in most cases:

- If the research programme could find a solution to dust it will be a great help to rural road users
- I hope this workshop will be fruitful for report preparation and hope our suggestions and recommendations will be included in final report
- To make this workshop most effective the number of participants and time should be increased
- Participate engineers from DoR also (DoR were invited) so that a lot of idea regarding the research topic may be fruitful also
- Research might have been carried out in other places and can be useful as it is, ensure we don't duplicate other research
- Please formulate research to follow specific topics, i.e. cost/availability in Nepal, replicability/scalability, affects to plant life and other organisms
- Related draft should be sent before
- I hope this will be made very soon and presentation of results shall be very fruitful for our department
- Practical application in earthen and gravel roads should be increased as a pilot programme
- Make such meeting again and again, associate to publication in DoLIDAR on a regular basis (assumed this refers to all ReCAP projects, not only Dust project)
- Exposure field visit may be useful
- Key note speaker who worked specifically on dust related research must have been contacted or at least video conferenced (presume this refers to Dave Jones)
- Need to further the research and institutional set-up for research (in DoLIDAR)

5 Workshop Participants

S. No.	Name	Designation	Organisation
1	Jeevan Kumar Shrestha	Director General	DoLIDAR
2	Madan Maleku	MD	NTDRC
3	Ram Hari Sharma	SDE	World Bank
4	Mahesh Chandra Neupane	SDE	DoLIDAR
5	Kamal Jaishi	SDE	DoLIDAR
6	Bidur Pokharel	Engineer	DoLIDAR
7	Roshan Pathak	Engineer	DoLIDAR
8	Dipendra Kumar Chaudhary	SDE	MoFALD
9	Bal Krishna Aryal	Engineer	DoLIDAR
10	Bir Bahadur Khanal	Engineer	DoLIDAR
11	Jeevan Guragain	SDE	DoLIDAR
12	Maysam Abedin	Regional Coordinator	ReCAP
13	Les Sampson	Team Leader	ReCAP
14	Robin Workman	Project Team Leader	ReCAP Dust project
15	Tony Greening	Consultant	ReCAP Dust project
16	Kirsteen Merrilees	Consultant	ReCAP Dust project
17	Bishwa Shahi	Consultant	ReCAP Dust project
18	Shyam Sunder Mishra	SDE	DTO Sindhuli
19	Sanjeev Shrestha	SDE	DTO Parsa
20	Ishwar Chandra Marahatti	DDG	DoLIDAR
21	Kumar Thapa	SDE	DoLIDAR
22	Michael Green	PM	RAP 3
23	Jun Hada	SPO	SDC
24	Umesh Ranjittar	SSP	Traffic Police

S. No.	Name	Designation	Organisation
25	Amit Shrestha	SDE	DoLIDAR
26	Bed Raj Regmi	Engineer	DoLIDAR
27	H K Mishra	SDE	DoLIDAR
28	Prem Dutt Bhatt	SDE	DoLIDAR
29	Bharat Prasad Aryal	SDE	DoLIDAR
30	Rupak Acharya	Engineer	DoLIDAR
31	Chandra Dev Bhatt	Engineer	DoLIDAR
32	Megh Raj Marasin	SDE	DoR
33	Uma Shankar Sah	SDE	DoLIDAR
34	Din Binod Khadka	Engineer	DoLIDAR
35	Mohan Raj Chapagain	SDE	DoLIDAR
36	Naresh Prahdan	SDE	ADB

Annex D: Contribution to ReCAP Log Frame

Service Providers should forecast the contributions the project will make to the ReCAP logframe over the period of the project.
Details of basis for calculation and recording are contained below. Number of columns should be adjusted to suit the length of project.

Intervention Logic	Indicator	Source of Verification	Baseline (Date)	Milestone 1 4 May 2017	Milestone 2 8 September 2017	Milestone 3 31 February 2018	End of Project Target (31/3/18)	Assumptions
Outcome: Sustained increase in evidence base for more cost effective and reliable low volume rural road and transport services, promoted and influencing policy and practice in Africa and Asia	1. SUSTAINABILITY: Partner Government and other financiers co-funding research with ReCAP. Contributions in kind (K) and Core Contributions (C)	Project reports and ReCAP PMU	October 2016	Vehicle provided for trials, but limited use	Vehicle provided for trials, but limited use	Limited access to vehicles supplied by DoLIDAR, restricted amount of data that could be collected		
	2. Concrete examples of change (applied or formally adopted), influenced by ReCAP research that will be allied to #km of road in focus countries.	Project reports and ReCAP PMU	N/A	N/A	N/A	N/A		
	3. Number of citations in academic articles of ReCAP peer reviewed articles and/or working papers, conference papers etc.	Project reports and ReCAP PMU	N/A	N/A	N/A	Planned for Mombasa conference in June 2018		

Intervention Logic	Indicator	Source of Verification	Baseline (Date)	Milestone 1 4 May 2017	Milestone 2 8 September 2017	Milestone 3 31 February 2018	End of Project Target (31/3/18)	Assumptions
Output 1: RESEARCH and UPTAKE: Generation, validation and updating of evidence for effective policies and practices to achieve safe, all-season, climate-resilient, equitable and affordable LVRR and transport services in African and Asian countries. (Low Volume Rural Roads : LVRR / TS – Transport Services)	1.1 LVRR: Number of peer reviewed papers generated from ReCAP supported or related LVRR research projects made available in open access format.	Project reports	N/A	N/A	N/A	Planned for Mombasa conference		
	1.2. TS: Number of peer reviewed papers generated from ReCAP supported or related LVRR research projects made available in open access format.	Project reports	N/A	N/A	N/A	N/A		
	1.3 Engineering Research: National policies, manuals, guidelines and/or research outputs that have been fully incorporated into Government/Ministerial requirements, specifications and recommended good practice as a result of ReCAP engineering research (including climate change adaptation and AfCAP and SEACAP	Not relevant for this study as only a preliminary investigation	N/A	N/A	N/A	N/A		

Intervention Logic	Indicator	Source of Verification	Baseline (Date)	Milestone 1 4 May 2017	Milestone 2 8 September 2017	Milestone 3 31 February 2018	End of Project Target (31/3/18)	Assumptions
	adaptations). To include introduction of new policies and modification to existing policies.							
	1.4 TRANSPORT SERVICES Research: National policies, regulations and/or practices for rural transport services modified or introduced as a result of ReCAP research (including road safety and gender and AFCAP and SEACAP research) To include introduction of new policies and modification to existing policies.	Not relevant for this study as only a preliminary investigation	N/A	N/A	N/A	N/A		
	1.6. LVRR and TS information generated for dissemination, and disseminated, that is not peer reviewed. Total to include research papers, final	Project reports and ReCAP PMU, ReCAP website	February 2017	Progress report 1	Progress report 2	Final report, including outcomes of stakeholder workshop		

Intervention Logic	Indicator	Source of Verification	Baseline (Date)	Milestone 1 4 May 2017	Milestone 2 8 September 2017	Milestone 3 31 February 2018	End of Project Target (31/3/18)	Assumptions
	research reports, workshop reports, manuals and guidelines.							
Output 2: CAPACITY BUILDING: The building of sustainable capacity to carry out research on low volume rural roads, and rural transport services in African and Asian countries.	2.1. African / Asian experts or institutions taking lead roles in ReCAP Research Projects.	More relevant in the follow-up of this project	February 2017	No counterpart engineer assigned	No counterpart engineer assigned	Local staff engagement minimal		
	2.3. Research projects with female researcher inputs at senior technical level.	ReCAP PMU	February 2017	No female researcher assigned to project, but one of consultant's team is female	No female researcher assigned to project, but one of consultant's team is female	No female researcher assigned to project, but one of consultant's team is female		
Output 3: KNOWLEDGE: Generated evidence base of LVRR and transport services knowledge is widely disseminated and easily accessible by policy makers and practitioners (including education and training institutions).	3.2. ReCAP generated knowledge presented and discussed at high level international development debates and conferences	Proceedings of conferences	February 2017	N/A	N/A	Potential to present at IRF conference in USA		
	3.3.ReCAP generated knowledge disseminated through significant workshops and dedicated training, virtually or physically, that is rated by participants as effective...	Project reports and ReCAP PMU and website	February 2017	N/A	N/A	Potential to present at IRF conference in USA		

Annex E: Risk Matrix

Table to be updated to reflect project risk.

Programme Risk Assessment and Mitigation Matrix			Very High	High	Medium	Low

Potential Risk	Risk Grading[2]		Description of risk	Proposed Management and mitigation actions
	Probability	Impact		
A. Programme Management Risks				
A1:Implementation delays due to hazards / risks at country level	M	M	Possibility of political disruption or earthquake.	Tale all necessary precautions against getting caught up in political demonstrations. National strikes are common and may disrupt. Travel can always be problematic for various reasons.
A2: Financial fraud	L	M	Assumed that there is always the risk of corruption and fraud, but little opportunity in this project due to the funding mechanism.	PM will be responsible for ensuring the sound financial management of the programme. This will be overseen by TRL support staff and TR. TRL have strong financial management and monitoring systems in place that will be relevant to the project. These measures will include: - Anti-bribery and anti-corruption undertakings in all supplier contracts - All staff aware how to detect and act on combat fraud and corruption issues - No suppliers used by TRL - Payments of expenses against original third party receipts only - Payments of fees against timesheets countersigned by the PM of the project - Payment of suppliers consistent with sub-contracts - Periodic independent audits of the Programme Funds
B. Risks associated with Research				
B1.Commitment	L	M	Lack of commitment from partner countries	PMU have already got firm commitments, project to follow this up and plan inputs in association with partner country

[2] **Probability** = the likelihood of this risk occurring despite the management and mitigation activities being in place. **Impact:** = the effect on the ability of the programme to achieve its objectives without major revision or review.

Programme Risk Assessment and Mitigation Matrix				Very High (red) High (orange) Medium (yellow) Low (green)
Potential Risk	Risk Grading[2]		Description of risk	Proposed Management and mitigation actions
	Probability	Impact		
B2.Counterpart resources	L	M	Partner country has to provide transport to site, may not be forthcoming	Plan ahead and gain firm commitments of resources
B3. Dust collection	M	M	May not be possible to establish baseline due to time of year	Already recognised by PMU. Visits will centre on appropriateness of proposed equipment and methodology to collect dust.
B4. More work than expected	M	M	Very little established work on road dust in developing countries, may have to rely on USA data which has limited applicability.	Literature review and equipment investigation took more time than expected. Provide overview of situation, make recommendations for next phase.
B5. Equipment availability and cost	M	M	Relevant equipment may be very expensive, cheap equipment may not be appropriate.	Make review and advise PMU on way forward. Equipment identified and estimate gained. PMU agreed to increase provisional sum accordingly.
B6. May be delays in importing equipment.	M	M	Customs and ordering delays	PMU/DoLIDAR to procure and manage import of equipment
B7. Function of dust measuring equipment	M	M	There is some concern that the equipment may struggle with the volume of dust as measured on the road from the vehicle, if quantities are very high	Follow instructions closely, regular cleaning and calibration of equipment. Check data regularly for anomalies that may indicate any malfunction from the equipment