

Assess the Design of Lorries and Quarries for Aggregate Transport

MA1/S/6/01



Aggregates Strategic Research Programme

**Environmental impact of aggregate transport
by construction trucks**

**Project 6 – Assess the design of lorries and quarries for
aggregates transport**

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Executive Summary

The majority of aggregates extracted in the UK are transported from the quarry to the point of sale by construction trucks of either rigid chassis or articulated vehicle design. These vehicles have a unique set of requirements for haulage logistics as many of them must be capable of driving on unmade surfaces and constructed dirt roads not only within the quarry but more importantly at the goods destination. Such vehicles have to balance the on-road requirements of minimum energy consumption, low capital cost, low maintenance and low noise with the off road requirements of maintaining overall mobility whilst minimising their impact on the environment. This project investigates the environmental impacts of these vehicles and evaluates their design and use from an environmental perspective to establish whether changes to vehicle design or the layout of the quarries could lessen the impacts.

The project considered current practices used for aggregate transport by road including operational methods vehicle choice and logistics. A structured survey technique was used to gather data from quarries producing sand and gravel, limestone and igneous metamorphic rock, located throughout the UK.

The predominant findings were:

- 85% of road going aggregate transport trucks were required to travel on unsealed surfaces within the quarry.
- Trucks may be required to travel on unsealed surfaces at the point of delivery.
- 7% of the quarries surveyed had no means of cleaning debris from trucks before they left the quarry.
- All quarries covered loads when travelling on the highway.

The major environmental impacts were:

- Aggregate transport trucks generate a significant amount of noise especially when unladen.
- Aggregate transport trucks can contaminate the public highway, with quarry and/or delivery point acquired debris, both near to, and at some distance from the quarry depending on prevailing weather conditions.

To corroborate these findings using the general public's perspective, a small public survey was conducted using a face to face structured interview technique in three villages near to quarry operations. The results of this survey confirmed that noise from unladen trucks and debris deposited on the highway were the most significant impacts. To further investigate these issues an experiment was conducted to determine how the noise level from construction trucks compared to other road vehicles on the public highway. The results highlight the potential for empty trucks to generate significantly high impulse noise when travelling over uneven surfaces including potholes, manhole covers and drains. The predominant source of this noise is from the relative movement between the body and chassis. To control this movement the design of body damping systems should be investigated as a low cost solution.

The major source of material transfer into the environment was via the trucks tyres. Experimental results showed that halving the tyre's recommended inflation pressure had a significant effect on the material collected within the tyre tread on a sandy loam soil. However, the relationship between soil-tyre adhesion, axle load and the soil's initial bulk density remains unclear and requires a further detailed investigation. A chassis sheeting/enclosure system has been suggested as a low cost method of preventing material being transferred to the chassis which would otherwise fall off on the road.

Considering the design of construction trucks three areas were investigated namely; the tyre choice and use, the drive train and the body design along with the vehicles use within the quarry. Tyre choice is predominantly dictated by the aggregate's destination, which is often off-road and hence an off road biased tyre is chosen. Although in reality the majority of sites will not challenge the vehicles mobility, for those that might, the risk of getting a vehicle stuck was too great to justify the use of a more road biased tyre. However, the results from a tread cleaning experiment showed that inflation pressure could be used to reduce tread clogging. It is well reported in the literature that manipulating inflation pressure can improve the tractive capability of a tyre and maintaining the correct road inflation pressure can contribute to reduced fuel consumption. Central tyre inflation systems that are commercially available, allow inflation pressure to be controlled and monitored, however, further research is required to determine the optimum tyre pressure to be used for a given set of operating conditions.

Alternative methods of powering truck ancillary equipment, including load bed tipping, have been investigated to reduce the need to run the engine at high speed under low load when tipping the body. A kinetic energy recovery system has the potential to reduce the overall environmental impact of the transport operation by reducing fuel use and engine emissions, and this could be employed to power auxiliary systems, but would be far better utilised to assist with vehicle propulsion during the drive cycle.

Considering quarry design three options were highlighted that reduce the environmental impact of road going trucks:

1. Upgrade roads within quarries to enable low rolling resistance on-road tyres to be used on road going trucks without sacrificing mobility.
2. Adopt a demountable body system
3. Employ a flexible conveyor system from excavation face to quarry exit

Each option reduces the distance a truck must move within the quarry on un-sealed surfaces. The use of a demountable system would permit a clear segregation between on-road and off road vehicle use within the quarry, but the practical issues associated with the system such as reduced payload and container storage would prevent its widespread adoption where off road capability remains a requirement at the delivery point. The ultimate solution could be considered to be a flexible conveyor system, and low carbon goods transit thereafter. This could be achieved by an advance in conveyor design to allow it to follow the excavator's movements, and transfer the material to the edge of the quarry for onward movement by low carbon transport.

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1- Introduction

Aggregate transport following extraction has a unique set of requirements for haulage logistics as many of the vehicles must be capable of driving on unmade surfaces (where the bearing capacity is sufficient), constructed dirt roads and also on sealed highways at acceptable speeds.

Construction trucks in the form of rigid chassis vehicles with up to 4 driven axles are commonly used for transporting aggregates within, and external to, the quarry or source of the material. These trucks often have basic suspension and tyre systems that can promote very noisy operation when un-laden, high levels of soil material transfer onto roads, and airborne dust and debris from the tyres, vehicle structure and load area.

This project investigates the environmental sources of pollution specific to this transport application which emanate from the off-road aspect of the vehicles design and use. These are broadly categorised as noise, debris (soil/mineral material), dust (airborne debris) and fuel efficiency. The project does not investigate the specific application of low carbon drive train technologies such as hybrid electric drives, as this is currently being researched to a considerable depth by other research calls.

The project hypothesis is that the environmental impact of aggregate transport by lorry could be reduced by vehicle architecture optimisation and improved application strategies.

Advanced design features such as central tyre inflation systems (CTIS), Active load control and tyre tread cleaning were considered together with vehicle application to determine the most feasible methods for reduced environmental impact.

2 - Aim

The aim of the project was to evaluate the vehicle's design and use from an environmental perspective and establish whether changes to vehicle design or the layout of quarries would lessen the impacts.

3 - Project Objectives

The objectives of the study were:

- 1 – To describe current operational methods, including process flow, vehicle type, frequency of use and the predominant drivers and barriers to change.
- 2 – To describe and group the haulage vehicles in current use based on payload and off-road performance or application, and for each determine the current class leading design features and constraints, both real and perceived.
- 3 – To identify the primary mechanisms of environmental pollution from each vehicle segment and process specific to the problem and quantify the scale of each impact.
- 4 - To conceptualise and evaluate possible vehicle design features for reduced environmental impact.
- 5 - To evaluate the opportunity for reduced environmental impact from improved process design, quarry layout or vehicle application.

4 - Methodology

The project is divided into a number of key stages, in-line with the project objectives, these stages are:

- 4.1 – Industry survey, including vehicle segmentation and identification of sources of environmental pollution.
- 4.2 – Public survey to obtain a public perspective on the environmental issues surrounding aggregate transport by road.
- 4.3 – Noise literature review to determine the current issues surrounding road transport using heavy goods vehicles and aggregate transport specific data collection.
- 4.4 – Dust and debris literature review.
- 4.5 – Tyre investigation.

4.1 – Industry survey

To enable current practices and vehicle segmentation to be described it was necessary to gather data from a selection of quarries producing different aggregates across the UK. Relevant data were not available in the public domain, therefore, a questionnaire was produced, see Appendix A1, to enable these data to be gathered directly from quarries. The questionnaire was sent to transport managers at quarries that had agreed to help with the research. A list of quarries was drawn up (Adam, 2004) and initial contact was made by phone. A segmentation exercise was performed to categorise the aggregate quarries within the UK in terms of mineralogy, operator and location.

The quarries were initially divided into four groups based on aggregate type:

- Sand and Gravel
- Sandstone / Gritstone
- Igneous / Metamorphic
- Limestone, including agricultural lime

This list was further refined by only selecting one quarry from each operator and ensuring that, where geology allowed, the quarries selected were based in different areas of the UK. 100 quarries were initially contacted and this resulted in 50 that were prepared to help with the research by completing the questionnaire. The locations of these quarries are indicated in Figure 1

The key information requested in the questionnaire included:

- Number of years that the quarry had been operating
- Annual output
- Who owns the transport vehicles
- Types and payload of vehicles used
- Typical annual distances covered by each type of vehicle
- Whether the load was covered
- Whether vehicles used on the public roads also travelled off-road within the quarry
- Whether any form of vehicle cleaning system was installed and its effectiveness
- Views on environmental impact factors including: CO₂, exhaust smoke, noise and debris on the highway.

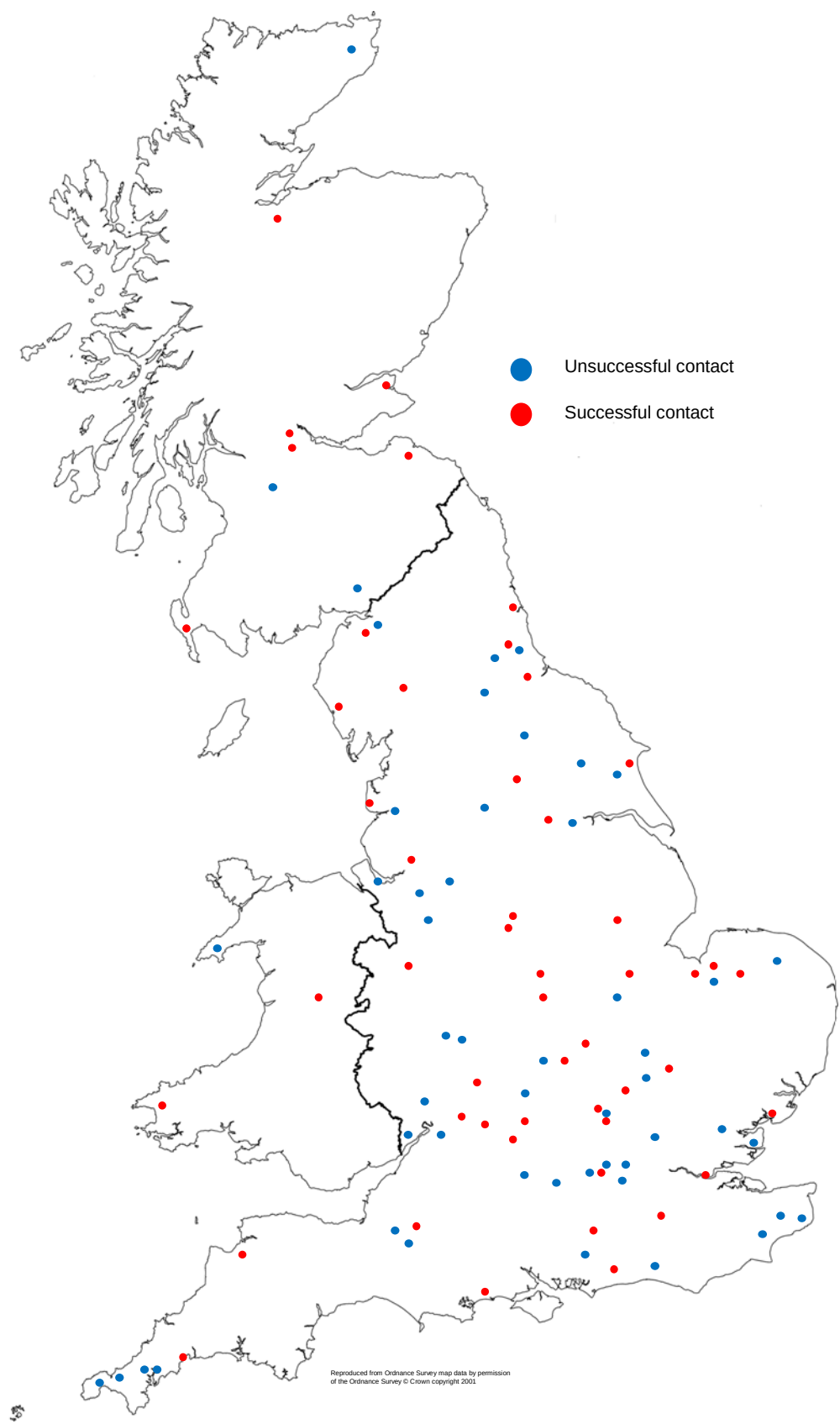


Figure1 Locations of the quarries contacted.

4.2 – Public survey

To gain an understanding of the public's perception concerning the environmental impacts of transporting aggregates by road a second questionnaire was produced see Appendix A2. In this questionnaire the questions concentrated on the perceived environmental impacts as follows:

- Exhaust emissions (Smoke, smell, CO₂ etc)
- Lorry engine noise
- Lorry structure noise (banging and rattling of empty bodies)
- Mud, dust and debris on the road
- Congestion
- Safety (are the roads less safe due to aggregate lorries)

This questionnaire was taken door to door in three villages near operating quarries to try and gauge the aspects that most concerned local people. The first village was near to three operating quarries whilst the remaining two villages were situated on the same main road serving a single larger quarry. Sand and Gravel quarries were chosen for these surveys as they generally tend to produce less in-quarry noise than hard rock quarries due to the lack of blasting and rock crushing. It was felt that the respondents would be more focused on the noise of the aggregate transport trucks if they were the predominant source of noise. Sand and gravel quarries also have the potential to cause greater contamination of the public highway due to the lighter and finer nature of the materials used in the access road construction and being driven-on within the quarry and transported on the highways. The door to door method was selected as it was felt that this would enable people that were actually affected by the day time operation of the quarry to be interviewed. If the questionnaire had been posted there would have been a greater possibility of the results being distorted by people who were not present during the day but resent having an operating quarry nearby. This method also enabled the interviewer to indicate to the interviewee the types of truck that the survey was focusing on.

Environmental pollution resulting from the transport of aggregates by road has been broken down into four areas:

- Noise due to powertrain and body/chassis
- Airborne dust emanating from the load being transported and/or collected on the chassis and body during loading and travelling in the quarry
- Debris – mud etc being deposited on the highway
- Exhaust emissions CO₂ and smoke

The above are dealt with to some extent in the two questionnaires, however, the data from these sources are subjective and it is desirable to also have objective data. To address this issue noise data were recorded near an operating quarry to support the subjective data gained from the questionnaires.

4.3 - Noise

The main issues relate to, what noise levels are generated by Quarry type vehicles in different operating conditions and what levels are acceptable from a public perspective? Also, can the sources of noise from the vehicles be broken down into component parts to allow potential reductions to be identified, linked to vehicle specification or method of use? To help answer some of these questions a literature review has been carried out together with a series of experiments to gather real data. These data are presented in the results and analysis section 5.3

4.4 - Dust and debris

A review of literature relating to this part of the project is presented in the results and analysis section 5.4

4.5 – Tyre investigation

To investigate the effects of tyre pressure on the ability of a tyre to collect and retain soil when driven on an unsealed surface an experiment was conducted in the Cranfield University Off Road Dynamics laboratory

using a 6 x 4 GMC tractor unit travelling on a sandy loam soil. Two tyre pressures, two axle loads and two soil bulk densities were used. A detailed methodology is presented in section 5.5.

5 - Results

5.1 - Industry Survey

A segmentation exercise was performed to categorise the aggregate quarries within the UK in terms of location, mineralogy and operating company. 100 quarries were initially identified as fulfilling the criteria set out earlier of which 50 agreed to help with the survey by completing a questionnaire. 46 questionnaires were emailed whilst 4 were posted to quarries that agreed to help. The reasons given for a negative response from the remaining 50 quarries included:

- Companies that had recently ceased trading
- Companies that had been taken over by an operator that had already been contacted
- Companies that were not prepared to help
- Companies that had changed operation i.e. from quarry to land fill site

Of the 50 people that offered to help 13 returned completed questionnaires as shown in Figure 2.

Quarry age

The mean age of the quarries that responded was 61 years. The newest quarry in the survey had been operating for only 2 years whilst the oldest has been operating for over 200 years. However, 85% of the quarries are in the range 20 to 80 years. These figures include extensions to the original quarry.

Completed questionnaires

As can be seen from the data presented in Figure 2 no completed questionnaires were received from quarries that produce sandstone or gritstone. This was a disappointing result. However, as sandstone is a sedimentary rock, made up of mostly sand sized grains of minerals and rock, it may be assumed that the environmental impact (contamination arising from dust or debris) of transporting this material could be similar to, or less than that of transporting sand and gravel.

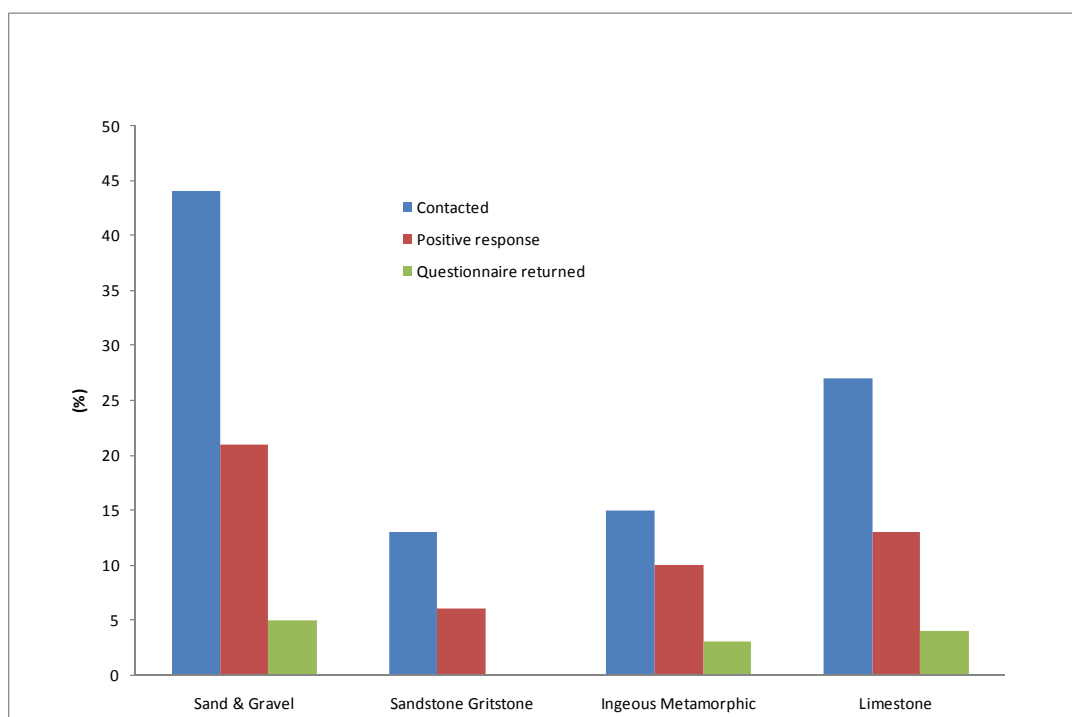


Figure 2 Comparison of quarries contacted, with questionnaires sent and questionnaires returned

Annual output

The quarries that responded to the questionnaire were segmented based on annual output. These data are presented in Figure 3

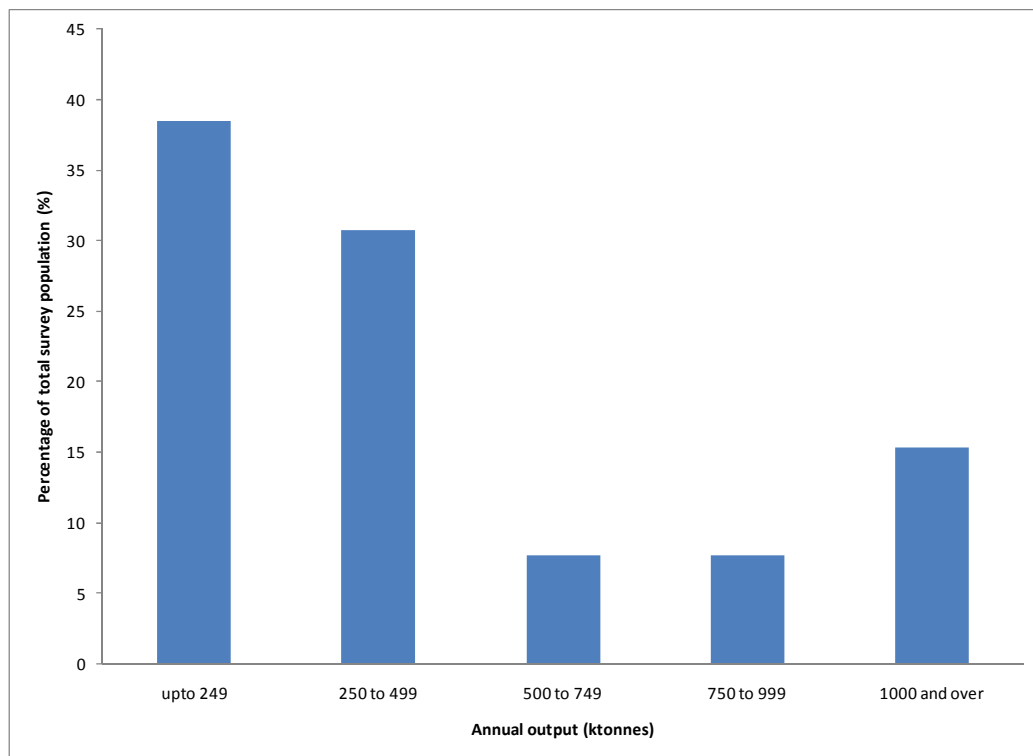


Figure 3 Surveyed quarries segmented by annual output

As can be seen in Figure 3 the highest proportion (38%) of questionnaires were returned by quarries with outputs of less than 250 kt per annum and 68% of the respondents had annual outputs of less than 500 kt. This may be due to data being more readily available for smaller operations where the numbers of quarries involved, per operator, are most likely lower.

5.1.1 - Vehicle segmentation and feature description

Transport routes

The vehicle transport routes are shown graphically in Figure 4. Survey data indicates that material transport mechanisms used within the quarry are dependant on the material being quarried (See Figure 5) but is predominantly carried out using a mixture of conveyors and articulated dump trucks. The dump trucks have capacities ranging from 20 to 90 tonnes.

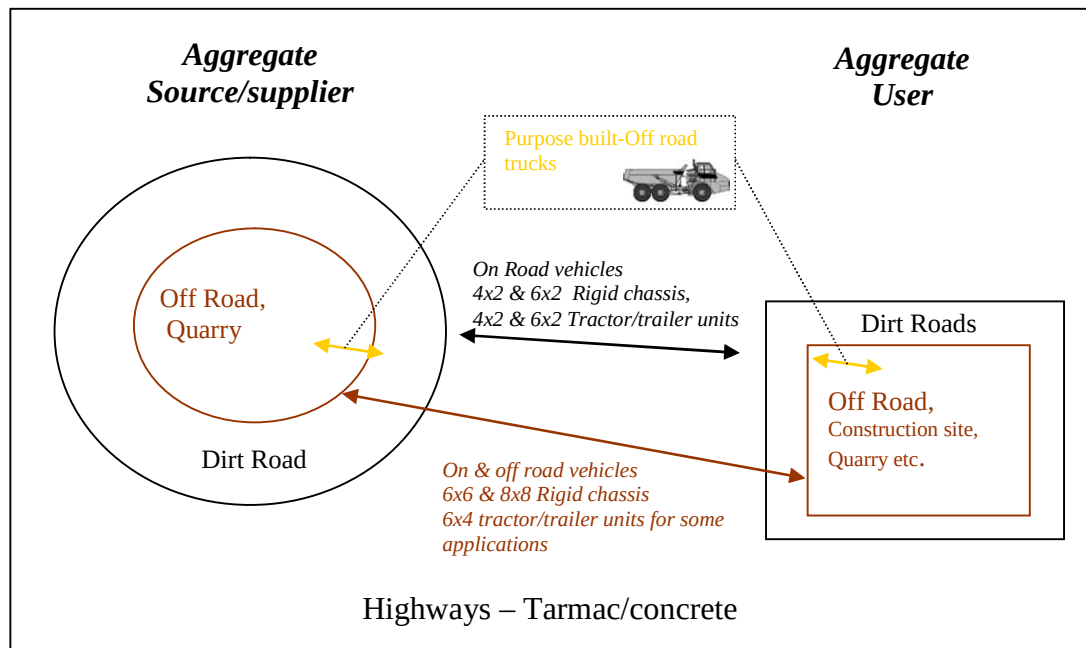


Figure 4 Transport routes within and outside the quarry

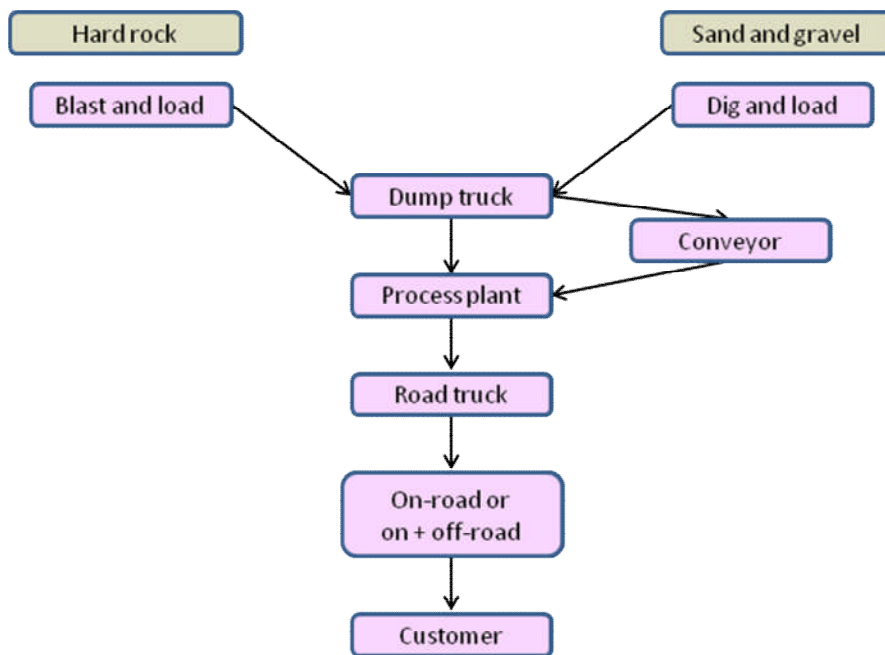


Figure 5 Actual transport routes for hard rock and sand & gravel as surveyed

On highway transport

On highway transport of aggregates is carried out using a mixture of rigid and articulated trucks. The ratio of rigid to articulated trucks, at the quarries surveyed, is shown in Figure 6. All of the quarries surveyed owned their within quarry transport, however, only 69% owned their road transport fleet. The remaining 31% used hauliers to transport their products.

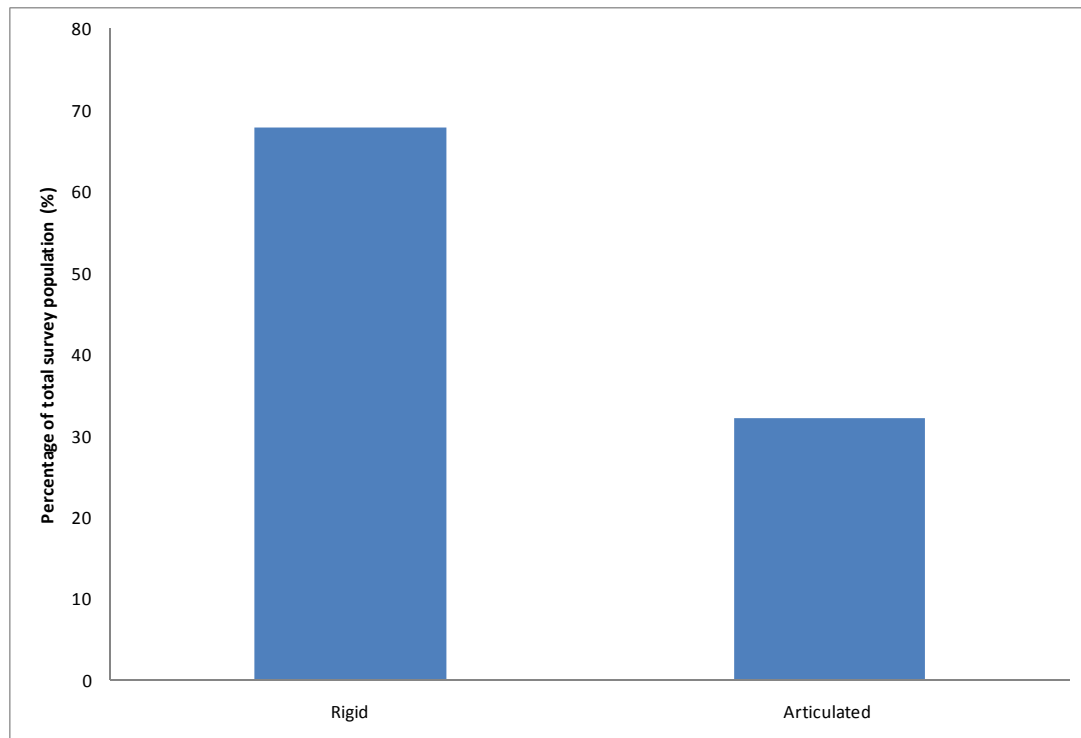


Figure 6 Comparison of the percentage of rigid and articulated trucks, used for road transport of aggregates, at surveyed quarries. Figures include trucks supplied by hauliers.

As shown in Figure 6, 68% of the aggregates transported by road, by the quarries surveyed, are transported by rigid tipper trucks with capacities of 7 to 20 tonnes, depending on capacity these vehicles are usually 4x2, 6x4 or 8x4 (see section 6). The remaining 32% of material is transported using articulated trucks with capacities of 20 to 30 tonnes.

Rigid trucks covered between 20000 and 80000 km with a mean annual distance of 47000 km and articulated trucks covered between 46000 and 100000 km with a mean annual distance of 68000 km.

5.1.2 – Environmental impacts

The environmental impacts were divided into three sub categories: vehicle cleaning, load covering and vehicle emissions. The sub categories are discussed in detail below.

Vehicle cleaning

85% of the on-road trucks were also required to travel off-road on unsealed surfaces within the quarry. These unsealed surfaces were generally made from the material being quarried i.e. sand and/or crushed rock. The potential for a vehicle to collect debris when operating within the quarry is dependent on the type of material being quarried, the material used to construct the within-quarry roadways and the prevailing weather conditions. Quarries were asked what types of wheel and or chassis cleaning systems were installed to reduce the risk of debris, picked up by the truck whilst in the quarry, being deposited on the public highway. A summary of the responses is presented in Figure 7.

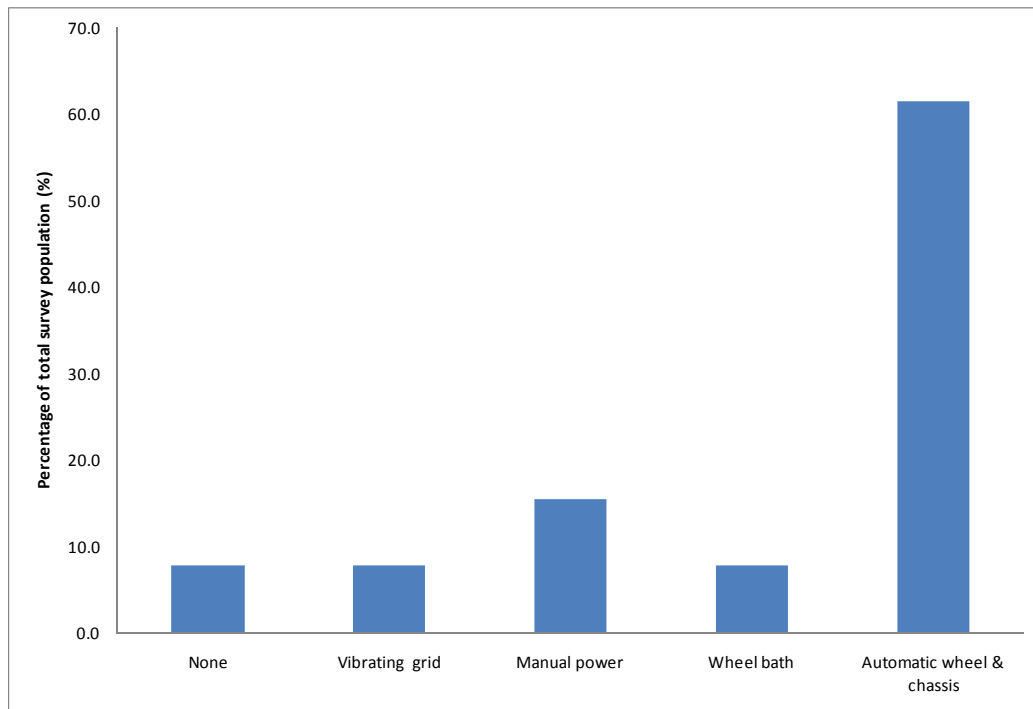


Figure 7 Vehicle cleaning systems used by surveyed quarries

As can be seen in Figure 7 cleaning systems ranged from none to fully automatic drive through wheel and chassis wash machines.

No cleaning system. Some quarries relied on having a long > 0.5 km access road where most of the tyre bourn debris was shed before the trucks reached the public highway. Whilst this method of cleaning tyres allows tyre borne debris to be deposited on roads owned by the quarry, it does not address the issue of mud and debris that is sprayed and/or splashed, by wheel rotation, onto the wheel arches and chassis whilst the vehicle is being driven within the quarry Figure 8. When the truck is driven on a wet carriageway the spray from the tyres can wash this debris off the wheel arches and chassis leaving it deposited on the public highway. This debris, an example of which is presented in Figure 9, can be deposited some distance from the original source. The image in Figure 9 was taken, after heavy rain, approximately 200 m from the entrance to a quarry that does not have a wheel or chassis cleaning system.



Figure 8 tyre and chassis contamination resulting from driving on unsurfaced roads within a quarry



Figure 9 Contamination of a public road ~200 m from the entrance to a quarry that has a ~ 0.8 km access road. Vehicles were not being cleaned at the time the photo was taken.

Vibrating grid cleaning devices consist of a grid suspended above a collection area or shallow tank as shown in Figure 10. The grid is usually made up of a series of fixed lateral bars spaced so that as a vehicle's tyres pass over them the tyres are distorted causing the treads to open and close as the wheel rotates. This action forces material from the tyre treads, the material then falls into the collection tray or tank below the grids (it should be noted that the bars themselves do not vibrate, they cause the wheels and axles of the vehicle, passing over them, to vibrate).



Figure 10 A vibrating grid type tyre cleaner (Econoclean Systems Ltd.)

Manual Power wash systems were employed at a number of the quarries surveyed. In some cases this was the only cleaning system available and was used when deemed necessary. In the remainder of the quarries this system was used to augment the main cleaning system when conditions deteriorated to a point where the main system was insufficient on its own.

Wheel bath cleaning systems usually consist of a large tank or pit containing water which the vehicles drive through. They rely on the agitation of the water caused by the moving wheels to wash the tyres and treads. These systems do not generally clean the chassis or wheel arches.

Automatic wheel and chassis wash systems can be self contained and portable or fixed built-in devices. An example of a permanent installation is shown in Figure 11.



Figure 11 Automatic drive through wheel and chassis wash system

These systems generally comprise of a metal grid suspended above a tank or collection pit and a series of high pressure water jets. High pressure upward and outward pointing water jets are positioned in the central area of the grid to wash the inside of the chassis and wheels and jets outside, facing inwards to wash the outside of the chassis and wheels. There may also be a set of higher level jets to wash the lower portions of the body sides. The water used in these devices is cleaned and recycled thus minimising waste and reducing the environmental impact. These machines usually start automatically when a vehicle enters the wash area and the vehicle then drives steadily through the wash zone. Quarries that had wheel and chassis washes installed rated their performance as excellent. These automated wash systems can cost in excess of £50k.

There are a number of different designs of mud flaps becoming available that are designed to reduce wheel generated spray when the vehicles are travelling on wet roads. This is generally achieved by producing an uneven surface, typically covered with rods, cones, corrugations, flutes etc., on the surface of the mud flap that faces the wheel. Whilst no vehicles observed during this study appeared to be fitted with these devices if they were used on trucks that ventured off road in wet conditions these mud flaps would have the capability to hold a significant amount of fine material that may be splashed/sprayed on to them. This material, if not washed off before leaving the quarry could be deposited on the public highway some distance from the source.

Amelioration of highway contamination 62% of the quarries surveyed had either their own, or access to, a road sweeper to clean the public highway when contamination was an issue and these quarries reported that the use of the sweeper resolved any issues related to highway contamination.

Load covering

All of the quarries surveyed covered the load when travelling on the public highway. These covers were usually semi automatic and either longitudinal or lateral as shown in Figure 12.



Figure 12 Longitudinal (a) and lateral (b) load covers used on aggregate trucks

Vehicle emissions

Questionnaire respondents were asked to give importance ratings to four environmental impacts related to the road transport of aggregates:

- CO₂ emissions
- Exhaust smoke
- Noise
- Debris on the road

The ratings that could be given ranged from -2 for least important, 0 for no opinion to 2 for most important. The results of this section are presented in Figure 13. It can be seen that from the transport managers view debris on the public highway scores the highest mark closely followed by exhaust smoke and noise. CO₂ emissions had the lowest score. When a number of respondents were asked why they rated CO₂ emissions as the least important factor the response was that these are set by the manufacturers and are, therefore, out of their control. However as CO₂ emissions are directly related to fuel consumption, burning 1 litre of diesel produces ~2.2 kg CO₂, a fuel efficient vehicle will produce less CO₂ than a less fuel efficient model.

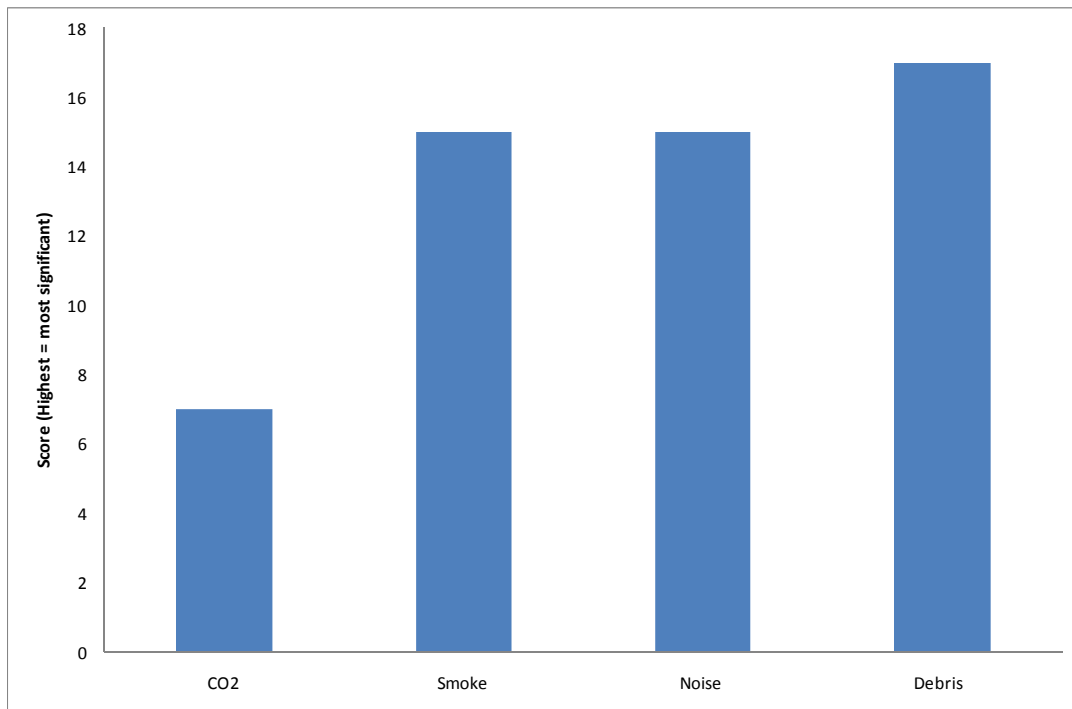


Figure 13 Environmental impact factor rating scores

5.1.3 – Alternative vehicle bodies

Respondents were asked to comment on the perceived advantages and disadvantages of using removable bodies on rigid trucks, also known as hook loaders or demountable rack offload and pickup system (DROPS) as shown in Figure 14



Figure 14 Hook loader and DROPS type truck bodies

The DROPS or hook loader system could potentially negate the requirement for the on-highway trucks to travel on unmade roads within the quarry and spend time weighing loads. It is envisaged that the quarry would have a clean area of hard standing where the demountable bodies could be dropped off and collected. Dedicated within-quarry vehicles would then transport the bodies around the quarry, on the unsurfaced

internal roads/tracks, to the loading point then return the, loaded, bodies via the weighbridge to the clean drop-off and pick-up area. By cutting down the amount of time that on-road trucks spend in the quarry, driving to the loading point waiting to be loaded and waiting whilst being loaded and weighing both empty and full, it would be possible to reduce the number of on-road trucks whilst retaining the same delivery rate, or alternatively more material could be delivered in a given time using the same number of trucks as currently used. The increase in material transfer rate would depend on the reduction in load capacity caused by the additional weight of the body loading attachment. It would be expected that the normal/general practise would be for bodies to be tipped/emptied at the customer's site in much the same way as is currently practiced using tipper trucks. However, it would be possible in certain circumstances to offload the body and leave it at the customer's site for collection at a later date. Although this practice would require the quarry to have spare bodies available. The results of this part of the survey are presented in Table 1.

Table 1 Advantages and disadvantages of removable truck bodies (respondent's views)

Advantages	Disadvantages
Cleaner, better public image	Additional cost of purchasing hardware
Possible to load outside normal hours	Heavier body and loading mechanism would reduce payload increasing the number of trips
Better utilisation of transport fleet	Number of units required
	Return journeys to collect empty bodies
	Not practical for one off deliveries
	Potential damage to bodies left on customers sites
	Responsibility for other peoples bodies and damage to them
	Not economic for small/part loads
	Not economic
	Time consuming
	Storage room at quarry

As can be seen in Table 1 the perceived disadvantages of using demountable bodies outweigh the perceived advantages in the eyes of the user.

Advantages Of the respondents that completed the questionnaire only two believed there were any potential advantages to using demountable bodies, although these two respondents also listed a number of potential disadvantages. The cleaner better public image was related to the removal of the need for road going trucks to travel off road within the quarry, therefore, it would be expected that the local roads around the quarry would suffer less contamination from quarry debris. Using demountable bodies would enable the quarry to load and weigh the bodies outside normal operating hours, which could be very useful in smoothing out uneven customer demand. One respondent did highlight better use of transport fleet as an advantage, however, this customer also ran a plant hire business and already used demountable bodies on the fleet for transporting bulk material, waste etc. Whilst this system would enable road-going trucks to be kept off unmade surfaces within the quarry they may still need to travel on unsealed surfaces at the point of delivery.

Disadvantages All of the respondents, that answered this question, listed a number of disadvantages. One of the main concerns was the significant up front capital cost of new bodies and lifting mechanisms and whilst trucks could be converted this would probably only be cost effective on relatively new vehicles. Therefore, quarries running older vehicles would have to purchase new vehicles as well as the demountable body system. It would also be necessary to purchase vehicles for moving/transporting the demountable bodies within the quarry and the cost associated with laying a sufficiently large area of hard standing to store both empty and full bodies. This hard standing would also need to be kept clean to gain the full benefit of using the demountable body system.

A number of respondents highlighted a potential negative environmental impact that arises from the extra weight of the loading system which could be up to 3000 kg (Palift T25). Any increase in vehicle unladen weight reduces the amount of payload that the vehicle can carry and increases its environmental impact. This could lead to more trips to the customer, and hence more road miles, to deliver a given amount of

aggregate. This could also impact negatively on the price of the aggregate as delivery cost makes up a significant portion of the total cost.

It was envisaged that the bodies would normally be tipped/emptied, at the customer's site, and returned with the truck to the same quarry. However, a number of respondents appear to have approached the idea with the view that the bodies would be dropped off at the delivery site to be collected at a later date. This led to a number of perceived disadvantages including: not practical for one off deliveries, trips with an unloaded truck to collect empty bodies, the number of extra bodies required to cover for those left on site, risk of damage to bodies left on the customer's site and damage to bodies belonging to other parties that ended up at their quarry. This last issue would only arise if bodies were regularly swapped between companies i.e. a truck delivers a load to a customer, leaves their body behind and takes back an empty body belonging to another company.

5.2 – Public survey

A public survey was carried out in three villages. One village was near to a group of three quarries the remaining two villages were on a main road that was used by a nearby quarry. Of the two villages on the main road one had a traditionally surfaced road and the other had recently undergone a road quietening scheme where the road surface had been replaced with a quieter material and the storm drains had been removed from the carriageway and relocated in the kerbing. In each of the villages residents who lived in property close to the road were asked to rate the significance, in their view, of different emissions from lorries used to transport aggregates. The residents were asked to rate the effect that: exhaust emissions (smoke CO₂), engine noise, banging and rattling from truck bodies, mud dust and debris deposited on the road, road congestion, and effect on road safety had on their local environment. The questions (Appendix 2) were in the form of statements related to each of these environmental effects and the residents were asked to give one of the following responses: Strongly disagree, disagree, no opinion, agree or strongly agree. These responses were then scored such that strongly disagree = 0% and strongly agree = 100%. The results of this questionnaire are presented in Figure 15. Village 1 is near three operating quarries and has a 30 mph speed limit, village 2 and 3 are on the same 'A' road serving a single large quarry. Village 2 has a normal road surface and a 40 mph speed limit and village 3 has a 30 mph speed limit, a new quieter road surface and repositioned storm drains (drains in the kerbing rather than in the road surface).

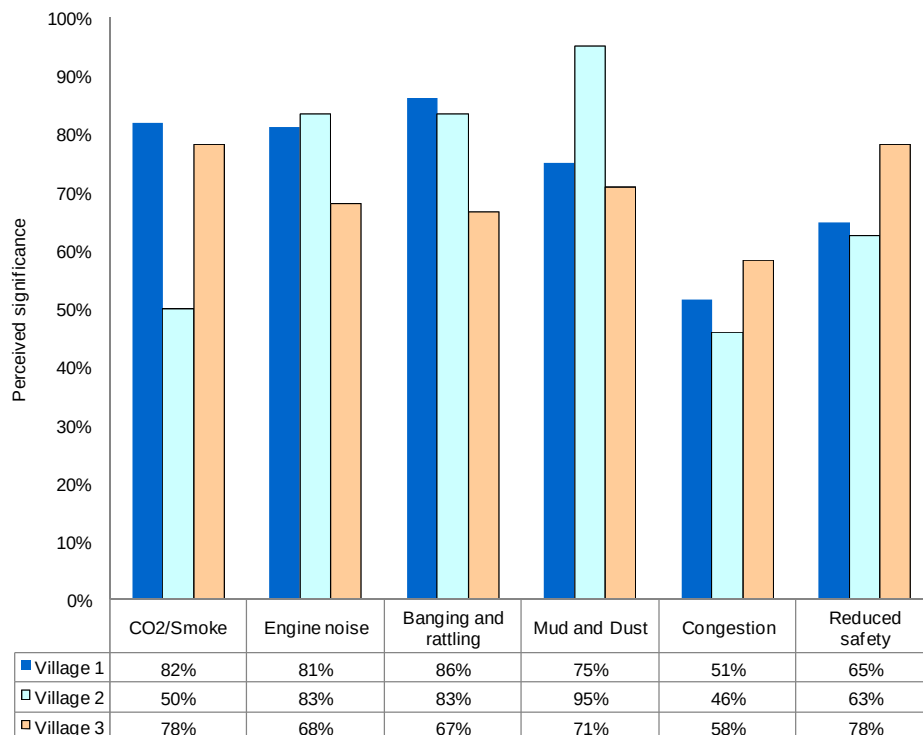


Figure 15 Public Survey results for perceived significance of emissions from quarry vehicles.

Whilst the public survey was relatively limited in its scope due to the size of the villages that were in suitable locations (19 respondents from village 1, 7 from village 2 and 9 from village 3), the results (Figure 15) show some interesting points.

CO₂/smoke emissions appear to be more of a concern to residents of villages 1 & 3 than to residents of village 2. Whilst there is no obvious explanation for this result, the interviewer commented that village 2 appeared to fall into a lower socioeconomic group than villages 1 & 3, this may have been an influencing factor.

Engine noise appears to be more of an issue for residents of villages 1 & 2 (30 and 40 mph speed limits) than to the residents of village 3. This is most likely due to the noise reducing measures that have been installed in village 3. Whilst the question specifically mentions engine noise this was to differentiate it from the noise of the body banging and rattling. It is unlikely that the respondents would have, or have been able to, differentiated engine noise from that of the transmission and tyres. Therefore, a reduction in tyre noise due to the improved road surface could be one of the reasons for the lower perceived significance attached engine noise in village 3.

Banging and rattling of the body and chassis had the highest significance in village 1 and equal second highest (with engine noise) in village 2 whilst in village 3 it rated just below engine noise at fifth highest with only congestion rating lower or less significant. This is most likely due to the new road surface that is not only made of a noise reducing material but being recently laid and having the storm drains let into the kerb is much smoother than the previous surface. A number of residents in village 3 commented that prior to the new road surface improvements the house would shake when lorries went past and post resurfacing this no longer happens. This is of particular interest as the previously referenced research does not specifically identify the noise associated with truck bodies banging and rattling to be an issue and yet the public consider it to be important. The interviewer noted that older trucks seem to make more body and chassis noise than newer models.

Mud and dust on the highway was seen as the main problem by residents in village 2, however, the residents of village 3 (on the same road and closer to the quarry) rated this as the third most important issue. This may have been due to the higher speed limit and rougher road surface in village 2 causing more chassis bourn debris to be dislodged and/or higher wheel speeds causing more spray, in wet conditions, which may wash more debris from the wheel arches than in the previous village with a lower speed limit. The residents of village 1 rated this issue as the fourth most important. This may be due to the quarries near village 1 having a more efficient wheel washing system. Although one resident in village 1 did comment that sand from the quarry trucks regularly blocked the surface water drain outside his property causing water from the highway to flow onto his property.

Congestion was rated as the least important factor in all villages.

Reduced safety was rated as the fifth most important factor in villages 1 & 2 and the residents of village 3 rated this as the equal most important issue alongside CO₂/smoke emissions. This may be due to the success of the road improvements in village 3. If residents in village 3 no longer have issues with noise and debris on the road then perhaps issues that residents in villages 1 & 2 find less important become more important to the residents of village 3.

5.3 - Noise

Work by the European Commission (2008) that looked at noise reduction in urban areas from traffic and driver management provides information on the significance of lorry noise emissions within the complete transport system. Figure 16 shows average maximum noise values (L_{max}) for different vehicles operating at different speeds.

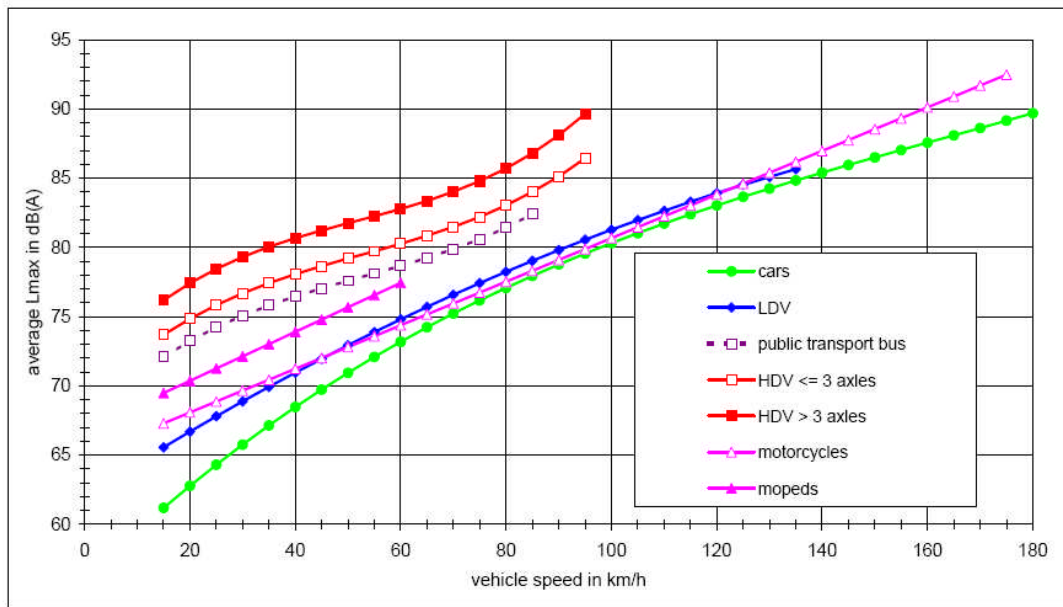


Figure 16 Average Lmax values for different vehicle categories and free flowing traffic. LDV light duty vehicle (van), HDV heavy duty vehicle (large truck). After Annecke et. al. 2008 .

It can be seen that there are clear differences in noise levels depending on vehicle type. At 60 km/h for instance the Lmax level from a truck with more than three axles is 83 dB(A), from a truck with up to three axles is 80 dB(A) and for passenger cars it is 73 dB(A). Although at first inspection these figures could be construed to not show large differences this is not the case, as a truck with up to three axles makes as much noise as 5 cars and a truck with more than three axles as much as 10 cars. The report states however that in reality the total effect of heavy vehicles is not as important as these figures suggest as in the general case on most roads heavy vehicles only contribute a small proportion of the total traffic. The report does identify that the peaks in traffic noise from trucks are high enough to cause annoyance or disturbance to people living close to the road area.

In the quarry situation, particularly at exit gates nearly all the vehicles will be HGV, with a high potential for noise generation. The importance of the proportion of truck density within the total traffic flow is confirmed by the results of a modelling study reported within the European Commission (Annecke, et. al. 2008) report that looked at the potential reduction in road noise resulting from restricting HGV use on a stretch of road (A4 Portway) in the Bristol area. Figure 17 shows the map of the area and resulting effect on traffic noise. The report states that there is a significant reduction and that this is because the pre-restriction traffic had 11% HGVs . The specific details of this case are not important to this discussion apart from underlining the potential for high noise generation near Quarry exits or on main routes used by quarries, from HGV traffic.

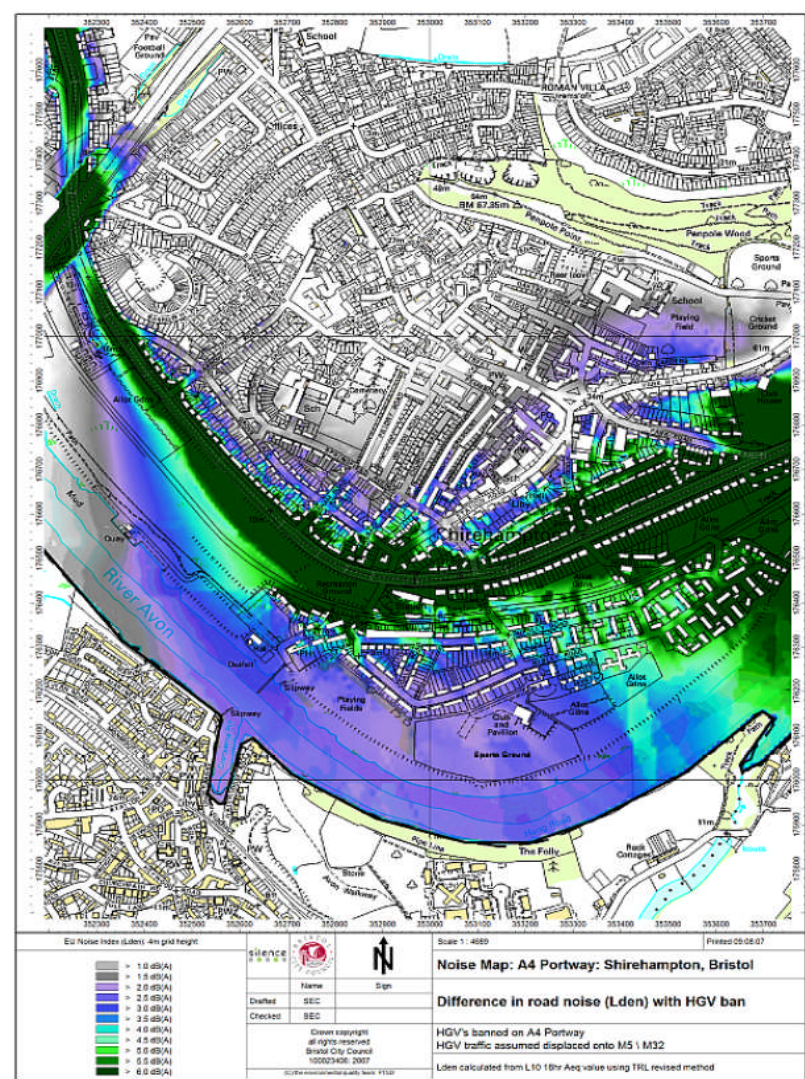


Figure 17 Potential reduction in road noise from HGV ban on A4 Portway. After Annecke et. al. 2008.

Figure 15 showed noise data for vehicles operating in dry conditions. The European Commission report (Annecke, et. al.2008) also checked the effect of wet roads on truck noise see Figure 18 and concluded that although the noise spectra were different the actual levels were not significantly altered.

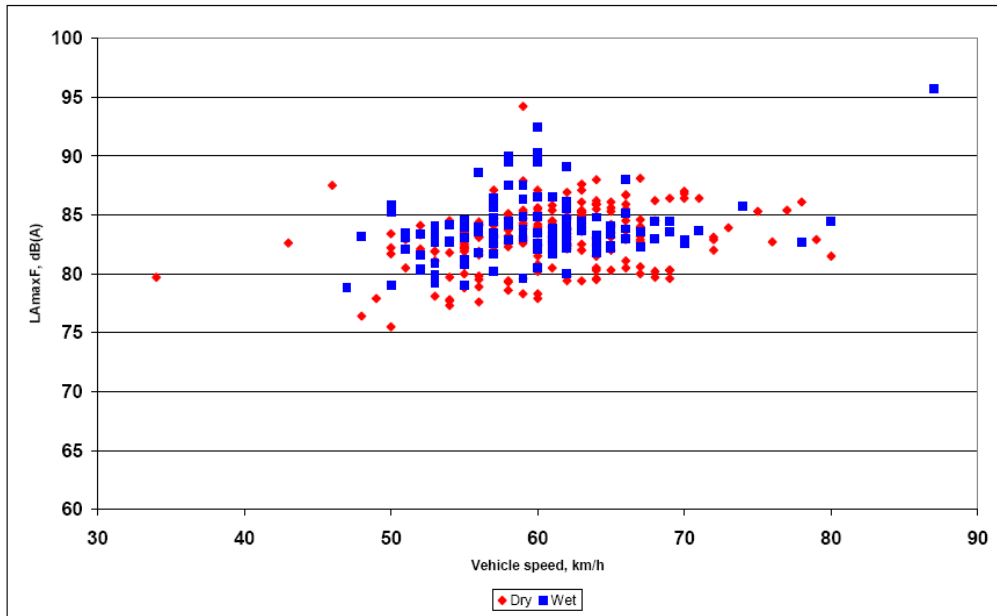


Figure 18 Articulated Trucks L_{max} levels on dry and wet road surface. After Annecke et. al. 2008.

Bentsden (1999) reports on work carried out by the Nordic Road Directorate relating the noise levels from traffic to the percentage of the public who became annoyed as a result, see Figure 19.

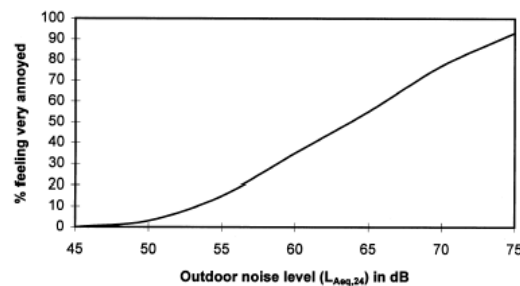


Figure 19 Relationship between outdoor noise level and annoyance factor to the public, After Bendtsen (1999).

A significant body of work has been done investigating the different sources of noise from HGVs. Generally, the approach taken is to divide the noise sources between that generated by the tyre ground interface and that generated by the rest of the truck. The latter component consists mainly of engine noise, but includes all other sources such as transmissions, wind noise braking systems etc.

Of particular interest is the work of Doisy et al. (2008) who empirically updated the parameters used in noise prediction modelling for transport vehicles and provided an informative breakdown of vehicle noise sources. The work included parameter definition for both light vehicles and also, relevant to this discussion, heavy goods vehicles. The noise sources were divided into a power unit component and a rolling noise component. The first depends on speed, acceleration and incline, the second on speed and road surface. Figure 20 shows total noise output for a heavy goods vehicle running at constant speed on different road surfaces and also shows the contribution made by the power unit component and the rolling component. R1, R2, and R3 correspond to rolling components for different surface types.

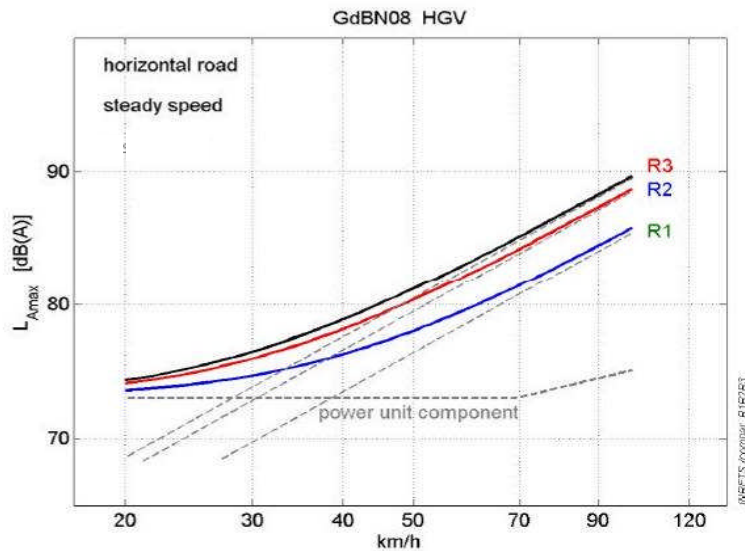


Figure 20 Relationship between total noise level for HGVs on level road and different steady state speed conditions. After Doisy et al.

R1 corresponds to a low noise category, R2 to an intermediate category and R3 to a noisy category of road surface. The solid lines correspond to the total noise output from the power unit and the rolling components. These are indicative trends for a general case of heavy goods vehicle. It should be noted that the noisiest road surface category R3 was still a made up surface and would be relatively smooth if compared to a rutted unmade track.

Figure 20 and 21 show that the significant factors to reduce truck total noise are 1) Truck speed 2) road surface conditions and, 3) acceleration, this being particularly significant at low speeds. Figure 20 also indicates that the rolling component becomes increasingly important as speed increases. The above section on Noise Level Generation and Acceptable Thresholds indicated that Quarry Trucks have the potential to produce noise emissions that are significantly high particularly near main transit routes such as quarry exit gates etc where truck density is high. The noise reduction factors are particularly important in this situation.

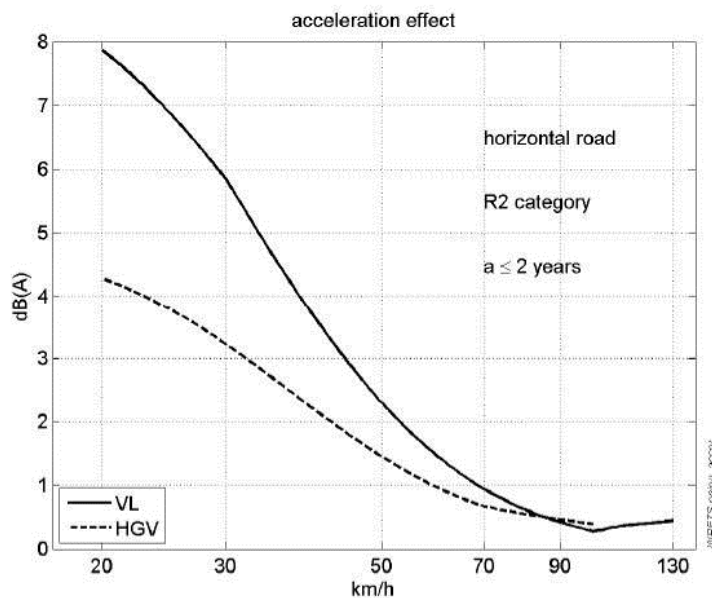


Figure 21 Noise level differences between an accelerating traffic flow and a traffic flow at a steady speed on R2 road surface. After Doisy et al. 2008

Sandburg (2001) confirmed that the rolling component noise (linked to tyre/surface interaction) becomes increasingly dominant as speed increases and also states that tyre type has an influence on noise levels at higher speeds. The range for Trucks can be as high as 10dB(A) if a large number (100) of tyre types are tested, but will be limited to a range of 3 - 4 dB(A) if the tyre sample size is restricted to 10 tyre types. This implies that Quarry operators may achieve noise reductions by selecting quieter tyres dependent upon the current tyre type in use.

Sandburg (2001) also highlighted that although it is generally accepted that the noise emissions from trucks are higher than those from cars, the rolling component per wheel is no higher. The main factor is the increased number of tyres on the vehicle.

The discussion so far has gathered data from available sources and although appropriate, has been based around HGVs that are not specific to quarry use. Data specific to quarries was gathered to confirm the validity of the above. Figure 22 shows relative noise level emissions for HGVs at an entrance to a quarry. The road surface was tarmac and the vehicles were running at low speeds. The data is presented to illustrate the relative dB(A) variation from the decelerating value and shows that vehicle acceleration is a significant factor on noise emission levels, this result agrees with the findings of Doisy et al (2008).

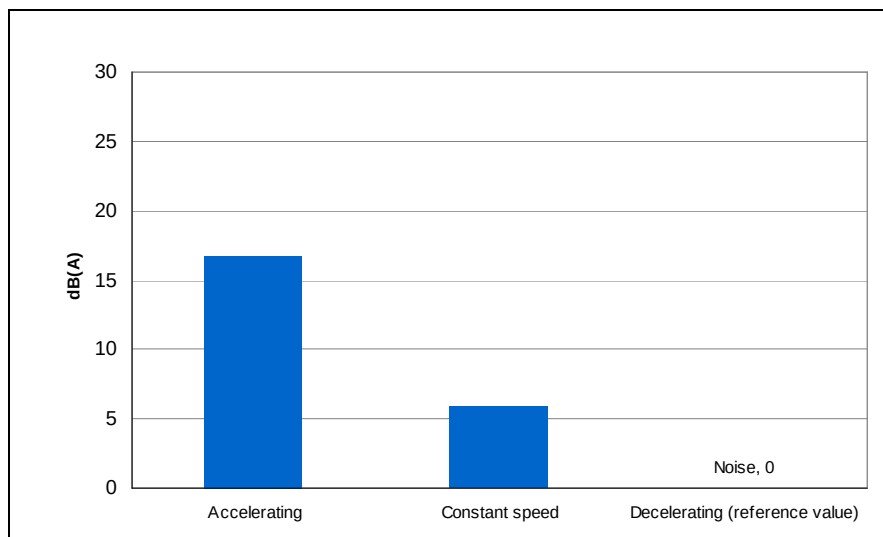


Figure 22 Relative noise level emissions for HGVs on Tarmac road at low speeds at quarry entrance.

A roadside survey was conducted near to a quarry entrance point to assess the measured noise levels for different vehicles with particular reference to the effect of road incline. Data were also gathered at different distances from a running but stationary vehicle to provide a method of correcting for distance. Figure 23 shows the results of using this correction in conjunction with the results of the roadside survey to plot noise level emissions for HGVs and cars running at constant speed on a tarmac road with a slight incline. As would be expected the HGVs showed higher values than for the cars, and both vehicle groups had higher emissions when running uphill than downhill. It should be noted that the survey was conducted on a smooth road surface without prominent bumps or raised drain covers. The magnitude of noise emissions corresponds with those from the European Commission (Annecke et.al. 2008).

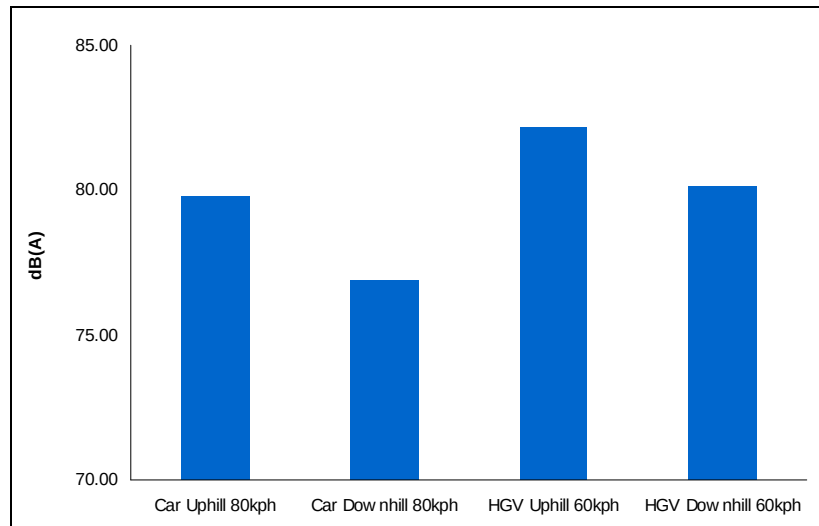


Figure 23 Noise level emissions for HGVs and cars running at constant speed on tarmac road with slight incline

A further roadside survey was carried out to attempt to give some indication of the noise emission values of different vehicle types when running over road undulations. Noise level readings were taken as vehicles crossed over a train crossing, shown in Figure 24, that was on a route to a quarry that used various lorry types.



Figure 24 Train crossing near to quarry exit.

As this was a public road a wide selection of vehicles passed during the four hour monitoring period. The results are shown in Figure 25, with the different types of vehicle groups shown with loading condition (empty or full) indicated. Figure 26 shows a typical eight wheel tipper and Figure 27 an empty trailer. In some cases empty vehicles emitted a banging/rattling noise as they passed over the train crossing and this is also identified in the data.

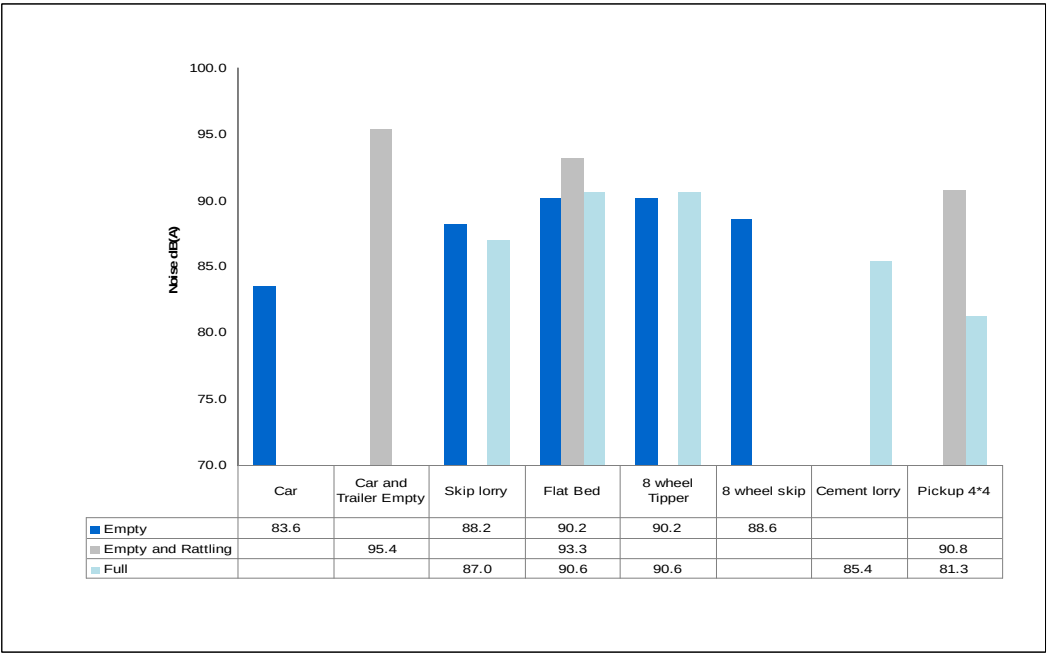


Figure 25 Noise level emissions for different vehicle types running at slow speed over train crossing.



Figure 26 Eight wheel tipper after passing train crossing.



Figure 27 Empty trailer.

This was a short study and therefore should be viewed as providing indications rather than definitive information. However, the results do show that generally cars have lower noise emissions than other vehicles when running slowly over road undulations and that eight wheel tippers and flat bed vehicles have the highest emissions if banging and rattling does not occur. If banging and rattling is present the resulting noise levels are particularly high as is shown for the cases of, car with empty trailer, flat bed and pickup vehicles.

5.4 - Dust

Although there have been a reasonable number of publications on dust pollution arising from quarries, the majority of the work concerns dust pollution resulting from the whole quarry operation and not specifically from the transport part of the business. There is little available work on dust pollution specific to truck movement within and around the quarries. Blades et al (2006) looked at transport specific dust pollution in three different quarries by monitoring dust deposition rates along transport routes and using chemical analysis to identify the proportion coming from the quarries concerned. Blades states that there is no universal size definition for dust, although it is usually understood to consist of organic and inorganic particles with a diameter in the size range 1-75 μm with particles less than 1 μm in diameter tending to behave like gases and particles above 75 μm having a very short airborne residence time. The research used both short and long term sampling techniques. Two of the quarries were transporting crushed limestone aggregates, and the third was transporting sand and gravel. The possible means of dust transport were described as emissions from aggregate lorries and then possible further distribution by re-suspension by other vehicles, pedestrians and the action of the wind. Most rock dust was considered to consist of fairly large particles, which cannot travel far before dropping out of the atmosphere due to gravity. The possible damage effects related to dust deposition on buildings were considered to be soiling and chemical attack. Results from the study showed the majority of dust close to roads was linked to quarry transport for the crushed limestone aggregates cases. No significant effects were found linked to the sand and gravel transport quarry. In all three cases the quarries had wheel washing facilities, but the whole vehicle was not cleaned on quarry exit.

Docx et al (2007) reported on work carried out in the limestone quarry environment looking into the distance that dust is carried from an on-site road. Different measuring techniques were investigated and results showed the maximum distance travelled to be 29m.

Organaniscak, J. et al. (2004) carried out work looking at dust generated by Trucks working within the mining sector. Although the aim of the report was to analyse the type and quantity of dust generated by haulage trucks within the quarry environment on unmade roads it still contains relevant information. Airborne dust sampling of visible and invisible particulates was conducted at multiple sampling locations away from an unpaved haulage road at a limestone quarry/plot and at a coal mine to measure the size characteristics, concentrations and dispersive behaviour of the dust cloud generated from truck traffic. Results show that at least 80% of the airborne dust generated by haul trucks was larger than 10 μm . Airborne respirable (region of 4 μm diameter), thoracic (region of 10 μm diameter) and total dust concentrations all decreased and approached background concentrations at a distance of 30.5 m (100 feet) from the road. This aligns well with the equivalent distance quoted by Docx et al of 29 m.

Organaniscak also states that prolonged exposure to airborne respirable coal dust and/or silica dust has been found to be responsible for the prevalence of occupational lung disease in mine workers. This is obviously in extreme cases of long term exposure although various other publications cite potential health issues relating to aggregate dust. Obviously, to minimise short or long term health issues and potential liabilities, dust generation must be well contained both outside as well as within the working quarry environment.

Best practice would be to have full vehicle washing on quarry exit and fully covered loads during transport.

5.5 - Tyre investigation

The industry survey highlighted that debris is a significant factor, and although this can be controlled at the quarry exit through the use of tyre washing plant, not all quarries have effective machines installed and in most cases there are no cleaning facilities at the goods final destination e.g. at building sites or road works.

To determine whether a change in tyre inflation pressure could influence the magnitude of soil adhesion to the tyre an experiment was conducted to measure the effect of two tyre pressures, at two vertical loads on a sandy loam soil of two bulk densities. Due to the difficulties associated with the control of field conditions, an experimental program was conducted within the controlled off road environment of the Cranfield University Off Road Dynamics Facility. The experimental layout is shown in Figure 28 below.



Figure 28 - 6x4 Tractor Unit used for the soil adhesion experiment within the Cranfield University Soil Dynamics Laboratory

The aim of the experiment was to investigate the effect of tyre inflation pressure, on rear tyre tread clogging of a twin axle heavy goods vehicle.

Method

The vehicle used was a GMC Volvo tractor unit which was adjusted to the treatment load on the rear axles using steel weights attached to the rear load frame above the back axle. The tyre was a Goodyear G362 285/75R24.5. The soil lane shown in Figure 28 was filled with a sandy loam soil prepared to each bulk density using a soil processing machine. The soil moisture content was maintained at 15% (dry basis). For each treatment the vehicle was reversed into the soil lane for one vehicle length, then driven forwards. This cycle was repeated such that only the rear tyres travel over the same piece of ground 5 times in each direction (10 passes). 0.3 mm of water was then added to the soil to simulate a light rainfall event. The vehicle was then reversed into the soil lane for one vehicle length, driven forwards, and the cycle repeated such that only the rear tyres travel over the same piece of ground 5 times in each direction (10 passes). Video footage was taken of the tyre during this time to record the progression of tread clogging. After the 20 cycles had been completed each of the tyre were photographed and within a square quadrat of 100 x100 mm all of the soil on the tyre was removed. A measurement was taken of the maximum volume of soil capable of being held in the tread void on each tyre for comparison purposes.

The tests were carried out according to the schedule listed in Table 2 below.

Table 2 - Treatment list

Treatment	Tyre pressure 6.90 Bar (100 psi)	Tyre pressure 3.45 Bar (50 psi)
1	High soil bulk density – laden	High soil bulk density – laden
2	Low soil bulk density – laden	Low soil bulk density – laden
3	High soil bulk density – un-laden	High soil bulk density – un-laden
4	Low soil bulk density – un-laden	Low soil bulk density – un-laden

Notes: Laden = 1810 kg/tyre, un-laden = 850 kg/tyre, high bulk density = 1750 kg/m³, low bulk density = 1300 kg/m³, Soil classification: Sandy Loam, 15% moisture content (dry basis).

Preliminary Results

The soil surface after 10 passes of the tyre at 6.90 Bar inflation pressure is shown in Figure 29.



Figure 29 – Soil surface after 10 passes.

A typical image of the soil adhesion to the tyre is shown in the Figure 30 below.



Figure 30 – Typical tyre condition after 10 passes.

The overall means with respect to inflation pressure are shown in Figure 31 below. The total possible capacity of the tread void in the same area is shown for comparison.

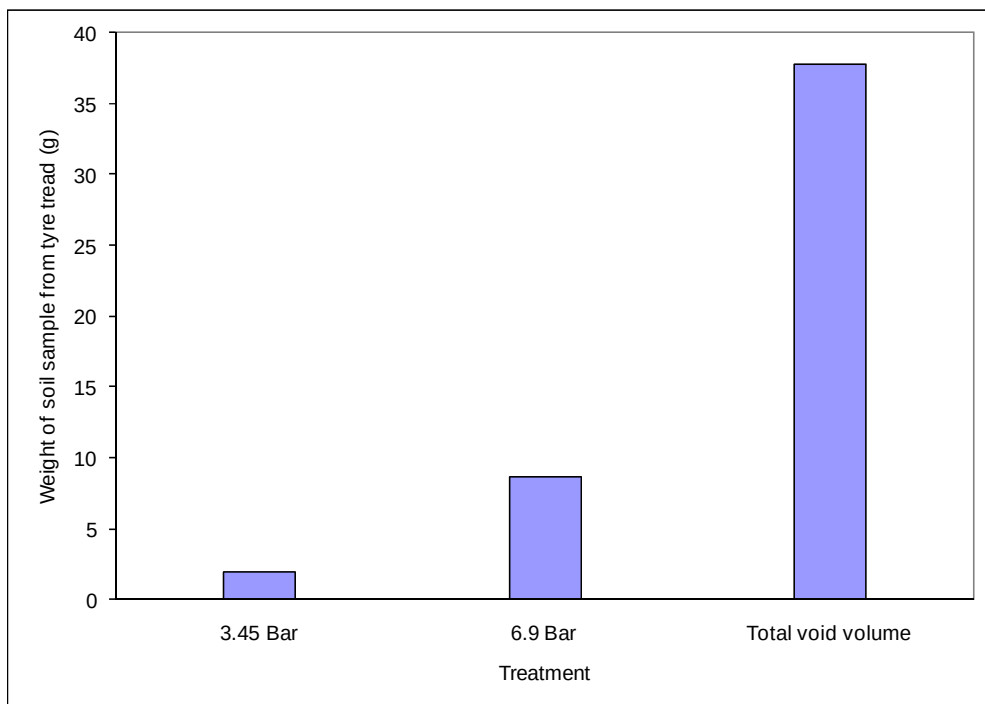


Figure 31 – Effect of tyre inflation pressure on tread cleaning

The results show that the maximum possible amount of soil within 10,000 mm² of tread was 37.8 g, and that at the highest (on-road) inflation pressure which corresponds to the rated pressure of the tyre at full load, a mean of 8.66 g was adhered after 20 passes. This indicates that this soil type (high sand content) does not adhere well to the tyre, predominantly due to its lack of cohesion. This is supported by the results from the quarry survey which showed that the tyres were covered in a film of soil (see Figure 8), rather than being completely full of soil.

However when the tyre pressure was reduced to half the original value a mean of only 1.95 g had adhered to the tyre and this was significantly different at the 95% confidence interval to the high pressure. Therefore indicating that tyre pressure can affect the amount of tread clogging even in this sandy soil.

Figure 32 shows, the combined data. As can be seen from the results 4 treatments, namely 6.9 bar low bulk density and 3.45 bar high soil bulk density, had no soil adhered to the treads. Therefore there is an interrelated effect between tyre load and inflation pressure. At high load there is a more significant difference between pressures, with the lower inflation pressure always showing less soil clogging, however decreasing the load at high pressure reduces the amount of soil clogging and at low pressure it increases the amount of soil clogging. It is, therefore, clear that these relationships warrant further research, the combination of soil cohesion, adhesion and interface pressure would need to be investigated to fully understand how soil adheres to the tyre.

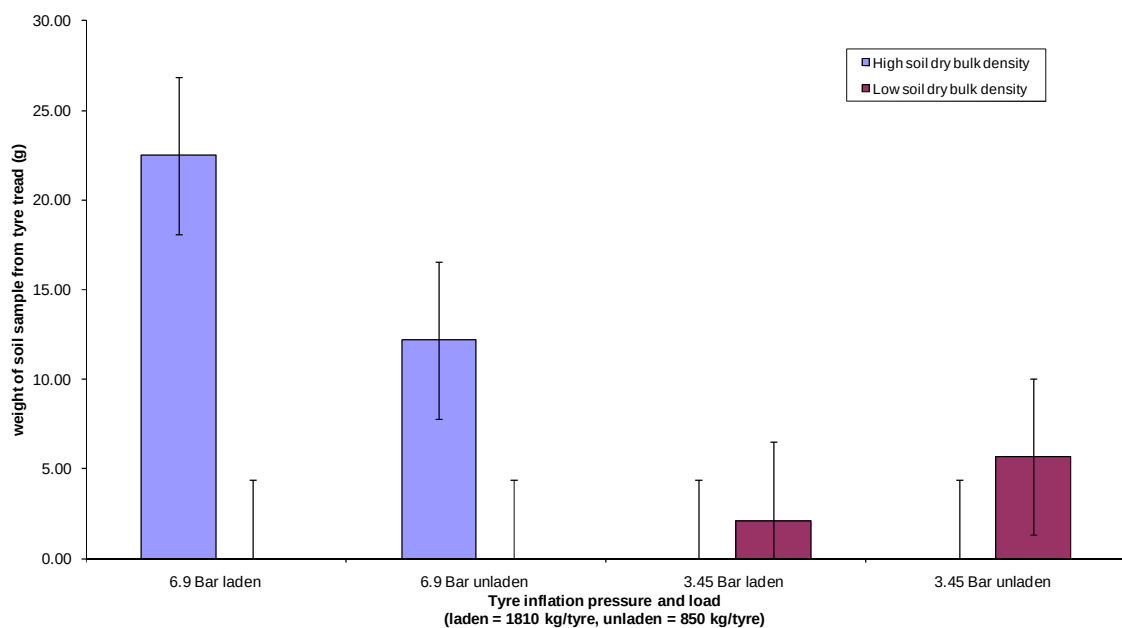


Figure 32 – Soil adhesion results (error bars indicate s.e.d. at 95% confidence interval)

It must be noted that this experiment was conducted at low values of wheel slip ratio (<10%). In field conditions, operating the tyre at road pressures, especially when negotiating a grade, will increase the wheel slip ratio. The effect of wheel slip ratio would need a further detailed study to cover the variables required. It is also worthy of note that the soil used represents a sand quarry condition and not necessarily the soil condition at the delivery point, which would often be of higher clay content and hence have more cohesion and adhesion. Unfortunately also often without wheel washes.

5.6 – Results summary

The key findings from the quarries surveyed are:

Current practices

- The transport fleet is made up of rigid tipper trucks (68%) with capacities from 7 to 20 tonne and articulated tipper trucks (32%) with capacities of 20 to 30 tonnes.
- 85% of road going aggregate transport trucks were required to travel on unsealed surfaces within the quarry.
- Trucks may be required to travel on unsealed surfaces at the point of delivery.
- Whilst many quarries had a system for cleaning debris from truck wheels and chassis before they were driven on the public highway, some quarries did not have any cleaning system.
- Vehicle cleaning systems employed by quarries included: vibrating grid, manual power wash, wheel bath and fully automatic chassis and wheel wash machines.
- 62% of quarries surveyed had their own, or access to, a road sweeper that enabled them to quickly and effectively deal with any contamination of the public highway.
- All quarries covered loads when travelling on the highway.

Views of transport managers

- The deposition of debris on the public highway was rated as the most important environmental issue concerning the transport of aggregates.
- Vehicle CO₂ emissions were rated as the least important environmental issue concerning the transport of aggregates.
- The perceived disadvantages outweigh the advantages of moving to demountable truck bodies.

Public perceptions

The key findings from the public survey are:

- The banging and rattling of the bodies on empty trucks is the most annoying issue, for residents living on transport routes, relating to aggregate transport trucks. However, in a village where steps had been taken to reduce noise by installing a quieter road surface and removing drain covers from the highway and placing them in the kerbs this issue moved from 1st to 5th most important issue.
- Engine noise was also rated as highly important to residents in two of the three villages surveyed, however, it was rated as less important in the village where a low noise road surface had been installed.
- The importance attached to the problem of debris on the road, deposited by trucks, varied between the three villages surveyed. This may be due to better management of truck cleaning at one of the quarries and different speed limits in the villages.
- Congestion and concerns over road safety rated relatively low in two of the three villages surveyed. However, these issues were rated as relatively high in the village that had the quieter road surface. Residents in this village may now be less concerned with the noise issue and are focusing their thoughts on previously low concern issues.

Noise

The main factors arising from both the literature survey and experimental work relating to aggregate transport lorry noise are:-

- Quarry trucks have the potential to produce noise emissions that are significantly high particularly near main transit routes such as quarry exit gates etc where truck density is high.
- Significant factors to reduce truck total noise at main exit points (low speed, high truck density) are
 - Truck speed (driver training)
 - Road surface conditions
 - Acceleration levels, this being particularly significant at low speeds (driver training)
- Noise reductions at higher speeds may be achieved by selecting quieter tyres.
- Public perception is that noise levels from these trucks is a significant problem. Also that the 'Banging and Rattling' component of the noise is more important than the engine noise.
- If trucks are in a condition that results in 'Banging and Rattling' then noise levels over road undulations are very high compared to other vehicles.

Dust

The main issues relating to aggregate transport truck dust emissions are:

- Quarry Trucks have the potential to produce dust emissions that could be harmful to the local environment. This can be in the form of visual deposits that may have corrosive effects on buildings etc, or in the form of invisible particles.
- The dust emissions could potentially have short or long term health issues for staff or members of the public.
- The majority of dust particles produced are larger than 10 μm .
- The majority of dust emissions are unlikely to be carried more than 30 m either side of the truck route.
- Practical measures to reduce dust emissions include:?
- Full Vehicle washing before quarry exit
- Adequate aggregate cover systems
- Truck design to minimise dust catchment storage and ejection points.

The key findings from the tyre investigation are:

- Tyre inflation pressure does have an effect on tread filling.
- There was also found to be an interrelated effect with vertical load and soil bulk density.

6 - Vehicle design appraisal.

The industry survey has shown that there is a considerable spread of features on existing construction trucks, depending to a large extent on the age and brand of the trucks used by the operator.

For the purpose of this appraisal the vehicle is divided into four key areas, namely drive-train, tyres, chassis (including suspension), and body as shown in Figure 33 below.

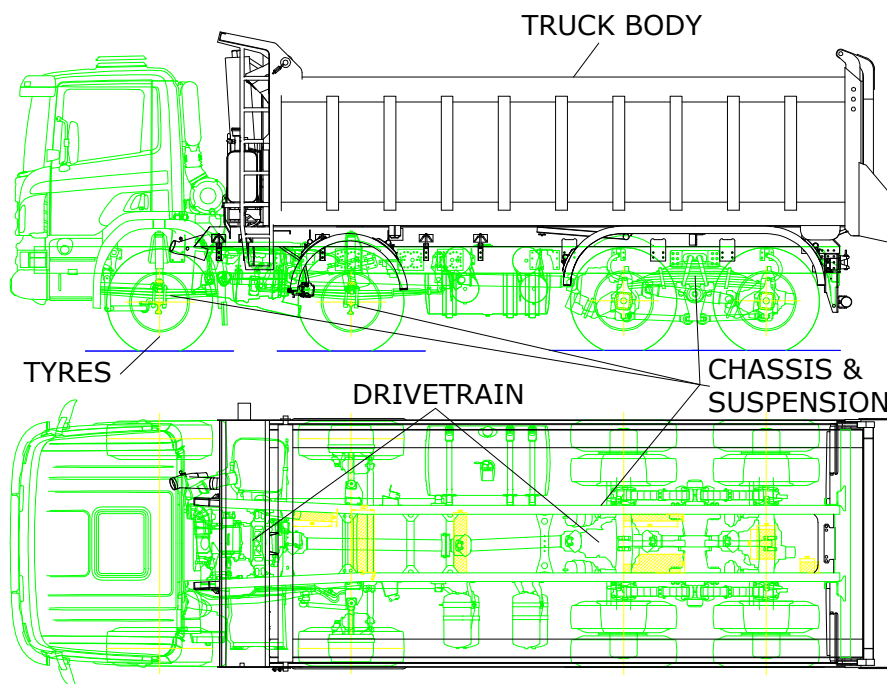


Figure 33 – 8x4 construction truck layout (cad courtesy of Scania)

6.1- Drive train.

The drive train can be divided into engine, transmission and driven axles. Its impact upon the environment with respect to this project is the emissions and noise emanating from the engine and drive-line.

Considering emissions these are mostly in the form of gas and particulate matter from the engines combustion process, with CO₂ being particularly significant. Older vehicles will have engines that are subject to less stringent emissions regulations than their modern counterparts which have to conform to the emissions levels set by the EU, currently "Euro5". Therefore this is almost entirely controlled at the EU level with all new vehicles having the same emissions requirement before they can be sold. It therefore follows that quarries that operate new fleets of vehicles will have better emissions than those that do not, and therefore represents best practice where economically viable, however it is also worthy of note that the fleet emissions as a whole will improve over time as the older vehicles are replaced.

The driveline is relatively similar across all construction trucks' comprising of a transmission, drive shafts and axles. The emissions will be in the form of an extremely small gaseous exchange to the atmosphere from the oil filled casings due to the temperature variation caused by the gears.

Considering the noise created by the engine and drive train, this exists at a similar level for all of the trucks surveyed, the noise limits being set by legislation, however this is almost entirely based on a drive-by measurement on a neutral throttle. When the engine is being accelerated, the noise level will increase and hence all IC engines will emit greater noise when moving off from standstill and changing speed. Therefore the most effective way to limit the noise of existing vehicles at the quarry would be through driver training.

Ultimately the IC engine and most probably the transmission will be replaced with electric drives, and this will change the noise characteristics of the vehicle drive line completely. If these are adopted in their current form, the noise problem changes from one which has too much noise, to one that has too little noise and hence techniques for warning other road users of the presence of a quiet vehicle are currently being researched. It is generally thought that the widespread adoption of electric vehicles is at least 10 years from the market (Baker et. al. 2009).

6.2 - Tyres

The tyres contribute to all areas of pollution considered in this study. They emit noise when the vehicle is travelling at road speeds, their interaction with the ground promotes dust, they transport aggregates and they contribute to the fuel efficiency of the vehicle. Most of the trucks in use require an off road biased tyre design, not necessarily because of the traction requirements within the quarry, but because the trucks delivery point is often off road and unknown until the driver makes the first visit. Such a building site (A421 Bedfordshire Road Building 2009) is shown in Figure 34, and comprises of a low friction, wet surface on a significant grade.



Figure 34 – Typical construction truck road used by 8x4 construction truck's to deliver aggregate.

This requirement for off-road biased tyres often results in a blocky tread pattern because the underlying physical principles of the interaction have yet to be researched fully. A blocky tread can tend to pick up soil material in soft conditions and exhibit higher noise levels when driving on the road, however they can often be cleaned more effectively than a heavily siped road tyre.

At present there is no clear standard for the description of the noise level a tyre will produce, that is available to the purchaser. As a result the purchase decision is most commonly based on cost and how aggressive the tread appears to the buyer. It would be considerably more acceptable to have a standard assessment procedure for tyres that would describe their tractive performance, noise level and rolling resistance. If the results of such a test were made available this would considerably enhance the purchase decision.

At present most tyre manufactures are working in the area of rolling resistance reduction. This work is primarily aimed at increasing the fuel efficiency of the whole vehicle and is often seen as a differentiating feature ensuring its continuous attention. Considering that the rolling resistance of a truck tyre can contribute up to a third of the energy required by the vehicle, gains in this area would have a large impact on CO₂ emissions.

6.3 - Chassis and suspension systems

The chassis and suspension will have an impact on the noise emitted from the vehicle and the debris movement.

The majority of the rigid construction vehicles in use have traditional mechanical suspensions comprising of leaf springs or elastomeric suspensions. These basic suspension systems tend to offer a poor compromise across the load range expected of a construction truck. The variation in load carried by the rear axle will be in the region of 14028 kg (Volvo FE 6x4, Insulated alloy body). When laden, lateral weight transfer can be large and when un-laden the suspension is often too stiff, over damped and creates little attenuation of the vertical road inputs which then get transmitted through the vehicle and body. These excitations can produce a very high level of noise as the body rattles against the chassis. New vehicles are available with air suspension, which although more expensive is considered to have better on-road performance and will attenuate the vibrations better at low axle loads thereby reducing the noise.

Central tyre inflation systems can be fitted to the chassis for the manipulation of tyre pressure when off road. These systems can be used to improve the tractive capability of the vehicle and may have the potential to reduce the amount of soil collected on the tyres (see section 5.4 tyre experiment).

The chassis can also be responsible for an amount of debris movement. This is due to its design consisting of a pair of C section rails, mounted to which are all the trucks sub-systems. The tyres interaction with the ground surface will inevitably throw up soil onto the chassis' many ledges which can hold and trap the material. Where under-body truck washes are not used this material will ride on the truck until it experiences a vertical input to the tyres, for example when it traverses a pothole, which can dislodge the material onto the road. 7 % of quarries surveyed had no wheel or chassis washing systems, and hence in this environment, the chassis has the potential to carry a significant amount of material from the quarry onto the public highway, due to the current design. One simple solution would be to cover the chassis components with a sheeting system to prevent the storage and transportation of soil material. This would be significantly more attractive to smaller quarries where the cost of installing a full washing facility would be prohibitive.

6.4 - Truck Body

Traditionally truck bodies were supplied by specialist body builders; however OEM vehicle manufacturers such as Volvo and Scania now supply complete vehicles. The body of the vehicle is therefore available in many configurations and can be customised to suit the customer's requirements. The most common body is a tipping body with front or mid mounted tipping gear as shown in Figure 35.



Figure 35 – Tipper body with lateral sheeting system unloading aggregate.

The rear of the body is closed with a tailgate and the top is often covered with a longitudinal or lateral sheet system.

The body influences the noise emissions, debris and dust emitted from the vehicle. The noise is produced by the cavities within the buck and the body's displacement relative to the chassis. This noise source is excited by the suspension system described above and can be in the region of 90 dB(A).

The cover systems vary considerably but two designs predominate. These can be broadly categorised as longitudinal, which are often employed on un-insulated basic bodies see Figure 36, and lateral sheeting systems, which are often used on insulated bodies as shown in Figure 37.



Figure 36 – Longitudinal sheet system



Figure 37 – Lateral sheet system fitted to an insulated tipper body.

The effectiveness of these two designs varies considerably, depending upon the material load. The lateral sheeting system will seal the load space much better than the longitudinal. Figure 38 shows a truck body with longitudinal sheet in place, but it clearly shows that the sheet does not fully cover the load. Vortices along the sides of the body can then blow the material out of the body.



Figure 38 – Longitudinal sheet covering aggregate on an 8x4 construction truck.

In summary the vehicles with the lowest environmental impact using existing technology will be a modern vehicle with Euro5 emissions engine, air suspension on all axles, road biased low rolling resistance tyres with a central tyre inflation system, fitted with a light alloy body with a lateral sheeting system.

7 - Conceptual design

The survey and experimental results have indicated that some aspects of truck design could be improved to lessen their environmental impact. This section considers these issues from a design perspective to assess their feasibility.

Tyre

Although the tread clogging experiment would need to be significantly expanded to give a clear indication of the effectiveness of changing pressure, the results do show that there is an effect of pressure with respect to tread clogging on the sandy loam soil type investigated. Reducing the inflation pressure of the tyres can also be used to improve the traction capability of the tyre on difficult surfaces and hence there would be a benefit in changing tyre inflation pressure depending upon the driving environment.

Clearly, the driver could change the air pressure of his vehicles tyres using a simple air-line and tyre inflator connected to the vehicles compressed air system, however this would be an onerous task and can be very time consuming on a larger truck considering that there could be 12 tyres to adjust on an 8x8 construction truck, even if each one only takes a few minutes the lost time would soon accumulate throughout the course of a day or week.

Therefore some form automation would be the only feasible solution and such systems are termed Central Tyre Inflation Systems (CTIS). Such systems are regularly used on off road vehicles such as agricultural tractors, trailers and also military vehicles. There are also systems available for trucks which are most common on forestry or logging vehicles and are available as aftermarket fitment or OEM supplied on new vehicles.

There are two conceptual embodiments available, depending on how the air is carried to the tyre. Many systems such as the one shown in Figure 39 have an external air line on the outside of the wheel, with a rotary coupling in the centre of the wheel. These are the cheapest embodiment, but are obtrusive and vulnerable to damage, as they may protrude slightly outside the main body width.

An alternative design uses a rotary coupling on the inside of the wheel and hence avoids this problem. The most advanced design uses a through axle air line such as that used on the Hummer H1 vehicle. This is only available from the OEM because of the cost associated with the supply of custom axles.

The control systems of most CTIS systems are manual allowing the driver to adjust between the pressures he desires, some systems feature an automatic inflation when the vehicle reaches a set speed. This is an important safety feature because operating the vehicle at high road speeds on under inflated tyres creates a significant safety risk.

This approach works well, but good driver training is essential, because each time the tyres are inflated, energy is consumed. Therefore the inflation cycle needs to be kept to a minimum and the tyres should only be reduced by the minimum change in inflation pressure required.

This minimum inflation pressure depends upon the environment and vehicle speed. Therefore conceptually an automatic system would be better suited to the task. It could be designed to adjust the tyre pressure depending on the traction requirement of the vehicle and the environmental impact both in terms of rut creation and material transport. This could be based on a suite of sensors to measure the parameters (laser sensing systems exist for tread measurement and sinkage measurement, and wheel speed and vehicle speed systems can be used to assess the local wheel-slip ratio).

However this would be an expensive system to fit for this application, and therefore a camera and image processor with associated algorithms could be a cheaper alternative; however its accuracy and therefore effectiveness would need to be quantified in a robust manner.

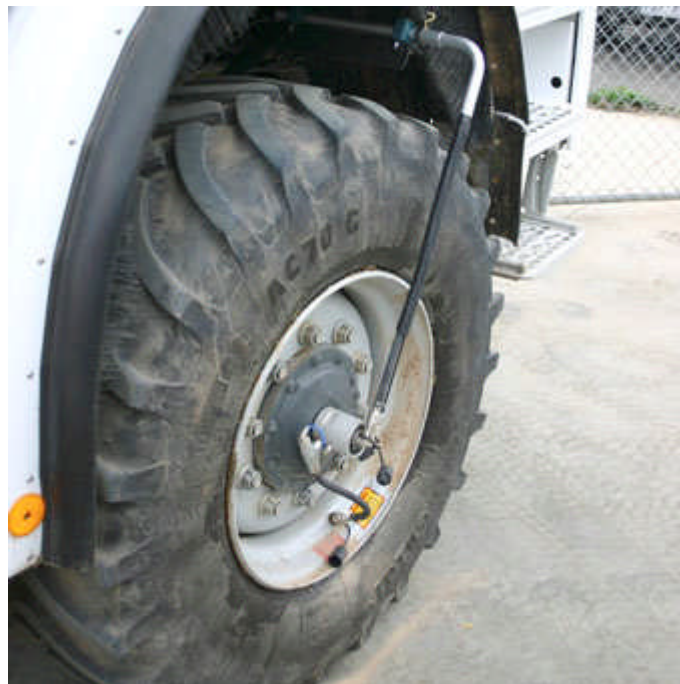


*Fig 39 - PTG Central tyre inflation system, external umbilical
(www.ptg.info)*

Truck drive train

Construction trucks are required to operate auxiliary equipment to raise the tipping body for the purpose of unloading the cargo. During this operation the engine will be lightly loaded and consequently not running at its maximum efficiency. To discharge the load the truck body is tipped, to an angle of up to 52° , using a hydraulic system comprising a linear actuator and an engine driven pump. To maximise the speed of the tipping operation the truck driver will often run the engine at high idle (full throttle, light load). It might appear that an alternative power source that did not require the truck engine to be running at full throttle would reduce fuel consumption and emissions. The truck engine will generally need to be running during the unloading operation as the truck will have to be inched forward to allow the load to discharge. The energy required to tip a 24 t load (20 t load + 4t body), to an angle of 52° is approximately 0.67 MJ. The tipping operation can typically take 25 s resulting in a power requirement of ~26 kW. There are a number of potential

alternative energy storage systems that could be used to tip the truck body, these include: electrical, hydraulic, pneumatic and mechanical or any combination of more than one of these systems. An all electric system could use an electric motor to power the hydraulic pump, however, to produce 26 kW, if running at the normal vehicle system voltage of 24 V, would require a current of >1000 A and a battery pack that would weigh in excess of 1000 kg. This would reduce the load carrying capacity of the vehicle by a similar amount. If the batteries were to be recharged using the vehicle's engine-driven alternator this would reduce overall efficiency rather than increase it. An alternative may be to use a hydraulic accumulator to store the energy required for tipping. The standard hydraulic pump and accumulator could form part of a Kinetic Energy Recovery System (KERS) by arranging for the pump to charge the accumulator when the vehicle is decelerating thus recovering kinetic energy from the vehicle via the transmission system. This system could store sufficient energy to tip the load, however, the hydraulic energy could be used for little else on the vehicle. A pneumatic energy recovery and storage system could harvest kinetic energy, that is normally converted into heat, by the brakes when the vehicle decelerates, via a larger than standard compressor. The compressor could be either engine or transmission mounted and used to charge high pressure receivers mounted within the truck chassis. The stored energy could be used to drive the hydraulic tipping pump and also be used in the braking system reducing the requirement for an engine mounted compressor that runs continuously. An alternative to a hydraulic or pneumatic system could be a flywheel based mechanical energy recovery and storage system similar to the systems currently being developed and tested by Flybrid systems. The high speed flywheel can be charged mechanically directly from the transmission during deceleration events and the stored energy could be used to power the hydraulic pump used for tipping the load bed and/or if the unit was connected to a generator it could be used to power other ancillaries. Whilst the flywheel system can be charged at a very high rate, making it ideal for recovering energy from braking events the self discharge of ~2% per minute does not lend itself to longer term energy storage, therefore a combination of flywheel and batteries may be more appropriate.

Body design and Control

The public survey results highlighted the issue of truck noise when driving over irregular surfaces such as pot holes and speed bumps, which is especially significant when the truck is unladen. A significant proportion of this noise comes from the body vibrating against the chassis, and therefore a system to isolate or dampen this movement could be of benefit.

The body must be pivoted at the rear of the chassis and have some attachment to the lifting mechanism at the front end. When driving, the body is supported on several brackets along the length of the chassis.

If we assume that the truck body cannot change significantly to allow retro-fitment to existing trucks, two conceptual designs could be considered. One is to mount damper bushes to the mounting brackets on the body. The purpose of these would be to attenuate the frequency and amplitude of the body movement relative to the chassis, but also to maintain contact between the two components. These would be tuned to suit the unladen mass of the body, and when laden the dampers would compress to allow full support of the load. A second option would be to support the body on the lifting gear and add damping to the hydraulic system using a hydraulic accumulator. This could potentially stop all contact related body noise. However, current vehicle chassis are not designed to drive at any speed with a raised body and further chassis limitations may exist. Therefore a detailed analysis of the operating states of the vehicle and chassis would need to be conducted to determine the feasibility of this design.

Flexible conveyor system

The requirement for road going construction trucks to drive off-road within the quarry or the use of off-road dump trucks could be reduced if conveyor systems were used to transport the aggregates, sand and gravel, within the quarry. At present conveyor usage from the point of extraction is restricted within the constraints of current conveyor designs. This results in dump trucks being used to ferry material from the excavator to the conveyor.

Conceptually the optimum conveyor design would follow the excavator, loose no material during loading or transit, be energy efficient in use and be of low initial cost. These are clearly not mutually compatible so compromise trade off's would be required. However from a conceptual perspective the conveyor head could be designed to follow the excavator within grade limits via an electric drive carriage. The conveyor could then be designed to allow an increase or decrease in belt length using a lost motion mechanism mounted on the slack side of the belt. Implementation of such a design would require different planning of the quarry

excavation operation to minimise conveyor movement, and keep the grades to an acceptable level. The implementation of such a system can be seen in Figure 40 where the requirement for dump truck to ferry material from the excavator to the main conveyor in a sand and gravel quarry is bypassed or eliminated.

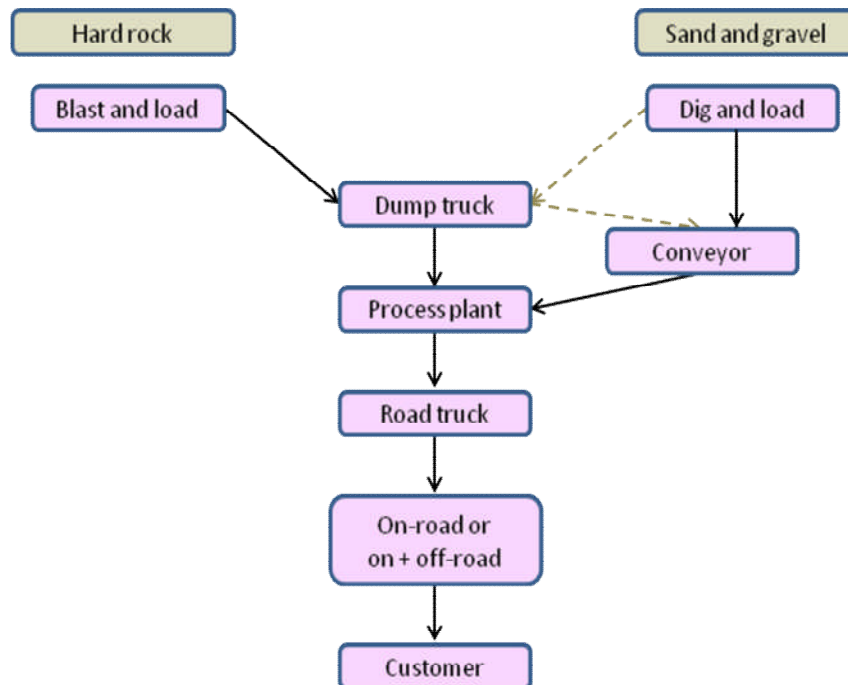


Figure 40 Solid line denotes direct excavator to conveyor material path eliminating the need for a dump truck (broken line)

8 – Discussion

The results have shown that there are significant environmental impacts from the use of construction trucks which will be discussed under the following headings, covering vehicle design and then quarry design:

Road contamination

Debris deposited on the public highway by trucks was rated as highly important by both quarry operators and the public. This debris is not only unsightly but can cause safety issues for motorists due to a reduction in the coefficient of friction between vehicle tyres and the road surface, especially when the surface is wet. Some of the debris will ultimately be washed into storm drains reducing their effectiveness and increasing the maintenance cost to local authorities.

The open tyre tread design used on quarry transport vehicles to increase their mobility off-road, both within the quarry and at the delivery site, enables them to carry more debris onto the public highway than a more road biased tread design that would have a more limited off-road capability.

Cleaning all trucks before they leave the quarry or preventing on-road trucks going off-road in the quarry will reduce the transfer of quarry materials onto the public highway near the quarry but will not overcome the issues caused by the trucks having to travel off-road at the delivery point. As trucks are required to travel on a variety of off-road surfaces at their delivery destination this becomes the predominant driver for vehicle and tyre selection by the fleet manager. Because off-road capable vehicles are required regardless of quarry design, improvements to vehicle design should be considered. A recognised benefit of changing tyre pressure is to improve traction in difficult conditions, such as on building sites with unmade roads. Therefore a system employed on the truck to change tyre pressure could allow more road biased tyres to be used, which are then deflated to increase their tractive capability when required. The results from the tread study showed that halving the inflation pressure of the tyre could significantly reduce the amount of soil adhered to the tyre. Therefore, CTIS may also have the potential to allow at least partial cleaning of the tyres at the delivery site, although this will require further investigation to fully define its effectiveness.

Truck noise

Truck noise, specifically the banging and rattling of empty bodies, is a major cause of irritation to residents living on or near to transport routes used by quarries. Field noise measurements indicated that it is not only empty trucks used for aggregate transport that cause the short duration high level impulse noise, that humans seem to find annoying. Flat bed trucks and small trailers can produce similar levels of noise pollution. However, if a quarry regularly uses a particular route with easily identifiable trucks it would be easy for the public to make the connection, with the most commonly seen trucks, and blame the quarry trucks for all of the noise. Installing a quiet road surface, with kerb mounted storm drains, in villages on transport routes appears to significantly reduce both tyre and body noise and reduces the impact these factors have on the local population. It was also noted that older trucks appear to make more body and chassis noise than newer models. This could be due to wear in the body to chassis mounting bushes, which would be more likely on older trucks, and allow the body to move relative to the chassis causing the increase in noise. If this is the case then simply overhauling the body mounting system may well significantly reduce the amount of impulse noise generated when the vehicles are travelling over uneven surfaces.

Possible improvements to truck design include the installation of body damping systems and the use of road biased low noise tyres. Further research is required concerning the design of these systems.

Exhaust emissions

Exhaust emissions were rated as low importance by transport managers as they were generally seen as out of their control and a function of truck design and, therefore, under the control of the truck manufacturer. The public in two of the three villages surveyed, rated exhaust emissions as high concern whilst the third village rated it as a relatively low concern. The public's perception could easily be swayed by the media and the current amount of coverage being given to CO₂ and its potential effects on the environment. As truck manufacturers are bound by regulations on emissions and presumably aim to minimise fuel consumption and, therefore, CO₂ emissions, the only recommendations that could be made relating to minimising CO₂

emissions from aggregate transport trucks would be to buy fuel efficient trucks, train drivers to drive efficiently and minimise fuel consumption by not running the engine when its output is not required.

Truck type

Articulated trucks are more efficient, when fully loaded, but less capable off-road than rigid bodied trucks with multiple driven axles. Articulated trucks are useful for large consignments where little or no off-road travel is required at the destination and for longer routes as indicated by their higher annual mileages. If it were practical to segment loads in articulated trucks they would be able to make multiple drops reducing the number of return trips to the quarry and saving time. Any load segmentation device would have to be light weight to avoid significantly reducing the load capacity of the vehicle and quick and easy to adjust at the quarry to enable the load compartment to be split up in different volume ratios. There may also be safety/stability issues when the first part of a load had been discharged if the remainder cannot be moved within the trailer.

Reducing emissions from transport

Diesel powered bulk tipper trucks are generally used for transporting aggregates in the UK. These vehicles contribute significantly to CO₂ emissions and account for ~ 35% of the total CO₂ emissions from the aggregate industry in the UK (BCG, 2009). Vehicle CO₂ emissions are directly related to the amount of fuel burnt (burning 1 litre of diesel produces ~2.2 kg CO₂), therefore, reducing fuel consumption also reduces CO₂ emissions. A typical delivery cycle would involve weighing the empty truck on the weighbridge, driving to the loading point in the quarry, loading, driving back to the weighbridge, weighing, driving to the destination, unloading and returning to the quarry. Often the truck engine will be running during the whole cycle even though the truck is not always in motion.

This cycle could be split into three components: loading, transporting and unloading. The loading operation is generally performed by a loading shovel, conveyor or some similar machine and often does not require the truck engine to be running, therefore, switching off the truck engine during loading, if the truck is not required to move, is one way of reducing fuel consumption and emissions.

Fuel consumption during the transport operation can be heavily influenced by driving techniques and driver behaviour as well as vehicle condition. It has been suggested that Safe and Fuel Efficient Driving (SAFED) training can reduce fuel consumption by up to 12% (BGC, 2009). Fuel consumption may also be reduced by using route optimisation software and by ensuring transport vehicles are regularly serviced and correctly maintained. Considering tyre pressure, a 20% under inflation can lead to a 3% increase in fuel consumption (Continental Automotive GmbH). CTIS can also help in this regard by maintaining the correct tyre inflation pressure all of the time.

A modern 20 t rigid truck can average 10 mpg which is the equivalent fuel energy consumption of 15 MJ per mile. A tipping requirement of 0.67 MJ would require approximately 2.1 MJ* of fuel energy, which is the equivalent of travelling ~ 0.14 miles or 224 m on the highway. Therefore, using a kinetic energy recovery system (KERS) that is designed specifically and solely for storing energy to raise the load bed, once in each round trip does not appear to be commercially feasible. However, a KERS system that recovers and stores energy that can be used to power the drive-train and truck-mounted systems such as braking, engine cooling fan, engine coolant pump, engine control and monitoring systems, lighting as well as raising the load bed may be feasible. There is already a move towards using electrically powered cooling fans and engine coolant pumps and it has been suggested (Baker et.al., 2009) that air compressors, air conditioning compressors and power assisted steering systems could also be electrically driven. All of these items were traditionally mechanically driven by the engine and ran continuously when the engine was running, regardless of whether their output was required or not.

* $0.67/0.32 = 2.1 \text{ MJ}$ (0.32 = typical combined efficiency of engine and hydraulic pump)

Quarry Design

Trucks used to transport aggregates on the highway tend to have a potentially greater (adverse) impact on the environment than similar trucks that are only used on the highway. This is due to the more aggressive tread patterns on the tyres used to give the trucks additional off road capability either in the quarry (on-road

trucks were required to travel off-road within the quarry in 85% of the quarries surveyed) or at the delivery point. These aggressive tread patterns have the potential to transport material from off-road locations (either at the quarry or the delivery site) onto the highway. These tyres also tend to produce more noise and may, depending on their construction, have a higher rolling resistance than a tyre with an on-road biased tread pattern. It is believed that the environmental impact of transporting aggregates by road could be reduced if the transport vehicles were fitted with low rolling resistance on-road tyres and all vehicles leaving a quarry were clean i.e. carrying no quarry acquired debris that would be likely to be deposited on the highway. Three options have been identified to achieve this:

1. Upgrade roads within quarries to enable vehicles to be fully mobile when fitted with on-road tyres and install full chassis and wheel cleaning systems at all quarries (only 60% of the quarries surveyed had these systems installed)
2. Adopt a demountable body system as discussed in chapter 5
3. Employ a flexible conveyor system from excavation face to quarry exit, in quarries where road going transport trucks are currently loaded at the quarry pit or face.

The National Aggregates Mineral Survey 2005 reports that 36.2% of primary aggregate sales were used as concreting aggregate. It is most likely that trucks used to deliver these aggregates would not be required to travel off-road at the delivery point and could, therefore, use on-road biased low rolling resistance tyres. The delivery sites for a portion of the remaining 63.8% of aggregates have the potential to require the delivery trucks to have a certain amount of off-road capability.

If the terrain that trucks were expected to cope with at the delivery point could be controlled and options 1, 2 or 3 above were adopted then aggregate transport trucks could be fitted with road biased tyres reducing their environmental impact to a similar level to that of other delivery truck of similar size and capacity.

Of the three options, option one is the easiest to adopt, with relatively simple modifications to existing trucks including best practice sheeting systems, low rolling resistance tyres, CTIS, and body damping. Option two, although conceptually beneficial, would be difficult to implement commercially, due to the disadvantages outlined in Section 5. For widespread adoption, a more holistic logistics operation would be required and the payload penalty would need to be reduced by using light weight materials within the lifting gear. Option three removes the trucks from the quarry altogether, but would require a new and novel conveyor system and even if adopted at the quarry, would be prohibitively expensive for the majority of delivery sites.

9 - Conclusions

The following conclusions can be drawn from the study, which highlight the issues involved with the environmental impact of construction trucks:

- Quarry operators rate debris on the highway as the most important environmental issue connected with aggregate transport. Not all quarries have cleaning systems to enable them to minimise the amount of debris that is carried out of the quarry and potentially deposited on the public highway. Of the quarries surveyed 62% had full wheel and chassis cleaning systems which were clearly the most effective of the systems surveyed.
- The public rate vehicle body noise as the most important environmental issue.
- Installing quiet road surfaces with kerb mounted storm drains can significantly reduce the impact that vehicle noise has on residents that live near to transport routes.
- New vehicles were observed to be considerably quieter than older vehicles which could be due to improved vehicle design but also poor maintenance on older trucks. It has been observed that a wide range of vehicle ages are used at different quarries.
- A significant proportion of the vehicle's noise on rough surfaces when unladen was observed to be from the body and chassis combination. Improved body mounting or control systems could be designed to reduce this noise.
- Quarry operators rate CO₂ as the lowest priority, primarily because they believe this is determined by the truck manufacturer.
- Whilst it would be possible, if prohibitively expensive, to modify quarries to eliminate the need for on-road vehicles to travel off-road within the quarry. It may be more appropriate to ensure that quarries that have the potential to cause highway contamination have internal roadways that enable trucks to be fitted with road biased tyres and to have wheel and chassis cleaning systems installed. This would help to reduce the potential for contaminating the highway with quarry-acquired debris and reduce road noise. However, this would not overcome the requirement for on-road vehicles to travel off-road at the delivery point.
- Lowering tyre pressure has been shown to have the potential to reduce the amount of debris that a tyre collects when driven over a deformable off-road surface. The use of a central tyre inflation system (CTIS) could aid tread cleaning and its use in combination with road biased low rolling resistance tyres should be investigated for the maintenance of off road performance and improved on road performance. The use of CTIS may be of greatest benefit when the vehicles are required to travel on unsealed surfaces at the point of delivery, where it is unlikely that wheel cleaning facilities will be available and the required level of mobility is unknown.
- A previous study has shown that safe and fuel efficient driving (SAFED) training can reduce fuel consumption by up to 12%. Fuel consumption may also be reduced by using route optimisation software and by ensuring transport vehicles are regularly serviced and correctly maintained with particular reference to tyre pressures.

- A kinetic energy recovery system, fitted to transport trucks, could have the potential to reduce the environmental impact of the transport operation only if the stored energy were to be used to power multiple systems and ancillary equipment such as cooling fans, coolant pump, power assisted steering system, body tipping system and drive train.

10 - Further research

This study has highlighted three main areas where truck design and use could be investigated further to fully quantify the future potential to reduce their environmental impact:

- Improved tyre design and use guidelines would be beneficial with respect to optimising the on-road and off road performance of the vehicles, in terms of rolling resistance reduction and tread cleaning and traction improvement. The experimental work conducted with respect to tread clogging should be extended to cover a wider range of surfaces and a full vehicle trial to definitively prove if changing tyre inflation pressure can be of benefit both in terms of fuel consumption and energy use as well as debris transfer onto the roads.
- The project has also highlighted noise as a major factor associated with construction trucks and simple systems such as body dampers should be investigated to determine if a simple retrofit system could be beneficial.
- A new flexible conveyor system that allowed the excavator, in sand and gravel quarries, to load directly onto the conveyor rather than using trucks for transport within the quarry could be more efficient and reduce the amount of dust, debris and pollution. The design of the conveyor would need considerable attention to ensure that the flexibility and reliability of the solution does not compromise the efficiency of the excavation operation.
- A survey of end user sites is required to enable a) the percentage of on-road trucks that are required to travel off-road at the delivery point to be determined, and b) the type of off-road conditions the trucks are expected to travel over. These data, together with minimum safe operating pressures for road tyres operating at low speed on deformable surfaces (from tyre manufacturers) and further tyre pressure effect on tread clogging and off-road performance studies for on-road tyres used at these minimum recommended pressures, could be used to determine whether an environmental benefit could be gained from fitting trucks with a combination of on-road biased tyres and CTIS.

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Appendix A1

Aggregate Transport Questionnaire

Company Name _____
Quarry Name _____
Address _____

Tel No. _____

Contact name _____
Position _____
Date _____
Confidentiality: All data will be treated as strictly confidential. Data will be pooled and no names of companies or individuals will be linked to specific data unless the permission of the company or individual has been obtained.

Questions

Please answer the following questions

1. Approximately how many years has the quarry been operating? _____ years

2. What types of aggregates are produced and/or transported? _____

3. What is your approximate annual aggregate output? _____ Tonnes
 _____ Tonnes

4. What is a typical aggregate pathway from ground to point of sale?

5. Do you use your own transport :

Within the quarry _____ (Yes/No)

Outside the quarry _____ (Yes/No)

6. What type of transport is used and what are their payloads (e.g. articulated lorry, rigid tipper lorry, other)? Please complete the following table:

No.	In quarry and/or on highway	Vehicle type	Number of vehicles	Payload (tonnes)
1				
2				
3				
4				

7. What are the typical annual mileages covered by the different types of vehicle listed in question 5?

1. _____

2. _____

3. _____

4. _____

8. Is the load covered, i.e. sheeted:

when transported on site? _____(Yes/NO)

when transported off site? _____(Yes/NO)

9. Do lorries that are used on the public roads also drive on unmade roads in the quarry?

_____ (Yes/No) If yes what type of surface do they drive on?

10. Do you have any system for cleaning lorry wheels, tyres, chassis before they are driven on public roads? _____ (Yes/No) If yes what type of system do you have installed? _____ What part of the vehicle does it clean? _____

How effective is it? _____

11. Have you ever had any comments/complaints from the public or government agencies regarding mud, dust or material on public roads? _____(Yes/No). If yes what action was taken?

12. If your company operates more than one quarry do all of the quarries have the same level of equipment and controls for reducing the environmental impact of transporting aggregate materials? _____(Yes/No). If no please explain why, (e.g. different geology, small operation with different constraints etc).

13. How do you rate the following impacts?

(- = less important, + = more important)

	-2	-1	0	1	2
CO ₂	☐	☐	☐	☐	☐
Exhaust smoke	☐	☐	☐	☐	☐
Noise	☐	☐	☐	☐	☐
Debris mud etc.	☐	☐	☐	☐	☐

14. What would you see as the main advantages and disadvantages of using a containerized system such as demountable rack offload and pickup system DROPS?

Advantages:

Disadvantages:

Comments:

Are there any comments that you would like to make regarding the environmental impact of transporting aggregates.

Many thanks for your help.

Appendix A2

Aggregate Transport Questionnaire

Please complete the following questions.

1. Please circle one of the following to indicate your point of view when answering the following questions:
 - a. Car driver
 - b. Lorry driver
 - c. Cyclist
 - d. Pedestrian
 - e. At home
 - f. Other – please state _____

Please indicate by putting a tick in the appropriate box your reaction to the following statements:

2. Exhaust emissions (smoke CO₂) from lorries used to transport aggregate is a major environmental problem

Strongly agree	Agree	No opinion	Disagree	Strongly disagree
☐	☐	☐	☐	☐

3. Noise from lorry engines is a major problem

Strongly agree	Agree	No opinion	Disagree	Strongly disagree
☐	☐	☐	☐	☐

4. Banging and rattling noise from aggregate transport lorries is a major problem

Strongly agree	Agree	No opinion	Disagree	Strongly disagree
☐	☐	☐	☐	☐

5. Mud, dust and debris left on the roads by aggregate transport lorries is a major environmental problem.

Strongly agree	Agree	No opinion	Disagree	Strongly disagree
☐	☐	☐	☐	☐

6. Congestion on the roads caused by aggregate transport lorries is a major problem

Strongly agree Agree No opinion Disagree Strongly disagree

☐☐☐☐☐

7. The roads are less safe because of aggregate transport lorries

Strongly agree Agree No opinion Disagree Strongly disagree

☐☐☐☐☐

8. Please circle one of the following to indicate your age group

- a. Under 20
- b. 20 – 35
- c. 36 – 50
- d. 51 – 65
- e. Over 65

9. Do you have any direct connection with the transport of aggregates e.g. work for a quarry or company that transports aggregates.

Comments

Please use this section to provide any extra information that you think may be useful regarding the use of lorries to transport aggregate.

Many thanks for completing this questionnaire.



DSPACE

<https://dspace.org/>

Assess the design of lorries and quarries for aggregates transport. Report to the Minerals Industry research Organisation

Brighton, James L.; Richards, Terence E.

2010-05-05T00:00:00Z

<http://dspace.lib.cranfield.ac.uk/handle/1826/8237>

Brighton JL, Richards TE. Assess the design of lorries and quarries for aggregates transport. Report to the Minerals Industry research Organisation. Environmental impact of aggregate transport by construction trucks. Project 6 – Assess the design of lorries and quarries for aggregates transport. Cranfield University. May 2010