Review of Timber Haulage and Forest Roads – Solutions for Cost-effective Transport and Strategic Benefits in Scotland

FINAL REPORT
CONTENTS

1. EXECUTIVE SUMMARY
   1.1. Introduction
   1.2. Forest Road Materials and Specification
   1.3. Forest Vehicle Specification
   1.4. Forest Road Network Management

2. FOREWORD FROM SCOTTISH ENTERPRISE
   2.1. Introduction
   2.2. Roots for Growth - Challenges in Timber Transport
   2.3. Addressing the Challenges - The Scottish Timber Transport Mapping Study
   2.4. Review of Timber Haulage and Forest Roads - Solutions for cost effective transport and strategic benefits in Scotland

3. INTRODUCTION
   3.1. Background
   3.2. The Geographical Focus and Overall Aim of this Project
   3.3. Impact of Timber Haulage on Communities and Public Roads in Galloway
   3.4. Forest Roads in Galloway

4. FOREST ROAD MATERIALS AND SPECIFICATIONS
   4.1. Current Road Construction and Materials
      4.1.1. Introduction
      4.1.2. Construction Over Peat
      4.1.3. Formation Method
      4.1.4. Construction Materials
      4.1.5. The impact of Weather on the Fabric of Forest Road
   4.2. Analysis of Current Road Materials and Structures
      4.2.1. Analysis of Current Road Materials
      4.2.2. Analysis of Current Road Performance
      4.2.3. Results of Analysis of Current Road Performance
   4.3. Alternative Designs for Road Pavements
      4.3.1. Conventional Pavements
      4.3.2. Aggregate
      4.3.3. Cross section
   4.4. Demonstration Project
      4.4.1. Overview
      4.4.2. Detailed Descriptions of Demonstration Sections
      4.4.3. Results of Demonstration
   4.5. Stabilisation Methods
   4.6. General Application of Principles to Other Parts of the Country
   4.7. Methods of testing Sub-grades and Aggregates
4.8. Design Recommendations
   4.8.1. Road Geometry Recommendations
   4.8.2. Road Pavement Recommendations

5. FOREST VEHICLE SPECIFICATIONS
   5.1. Application of Legislation to Forest Lorries
   5.2. Demonstration of Lorry Fuel Economy
   5.3. Demonstration of Impact of Diesel Type
   5.4. Comparison of Other Vehicle Costs
   5.5. Demonstration of Lorry Turning Movements
   5.6. Demonstration of Lorry performance on Gradients
   5.7. Comparison of Super Single and Twin Tyres
   5.8. Central Tyre Inflation
   5.9. Recommendations From the Haulage Companies
   5.10. The Future of Forest Vehicles
   5.11. Specialist Forest Road Vehicles
      5.11.1. Introduction
      5.11.2. The McCormick/McColm prototype
      5.11.3. Trial Objectives and Methods
      5.11.4. Trial Results
      5.11.5. Conclusions of the “physical” trial
      5.11.6. Estimating the cost of bespoke vehicles
      5.11.7. Introducing bespoke systems
      5.11.8. Areas for further research

6. ROAD NETWORK MANAGEMENT
   6.1. Introduction to Highway Development and Management – HDM4
      6.1.1. Background
      6.1.2. Life Cycle Analysis Concept
      6.1.3. Calibration and Adaptation of HD4 to local conditions
   6.2 Observations on Maintenance Strategies
   6.3 Saving in Vehicle Operating Costs
   6.4 Concluding Remarks

7. Appendix
1 EXECUTIVE SUMMARY

1.1 Introduction

The Review of Timber Haulage and Forest Roads, commissioned by Scottish Enterprise, involved representatives of the forest roads engineering, forestry and timber haulage sectors, supported by academics in engineering and logistics. The reasons for the review include:

- There are many environmental benefits associated with extending the use of forest roads to relieve pressure on rural public roads and local communities.
- At current timber prices, the forest industry cannot routinely afford high maintenance costs associated with many forest roads.
- The wood processing industries will be unable to access timber in many remote areas unless the cost of timber haulage and forest roads is reduced.
- The cost of timber haulage is heavily influenced by the performance and wear and tear on vehicles whilst negotiating unsurfaced forest roads.

This report was commissioned by Scottish Enterprise as part of its Strategy: Roots for Growth – Challenges in Timber Transport. A Project Team was formed with representatives from the forest industry supplemented by specialist advisors.

The Review of Timber Haulage and Forest Roads – Solutions for cost effective transport and strategic benefits in Scotland seeks to find solutions to the problems and challenges of timber haulage, particularly in relation to Galloway Forest District.

This is the first time that there has been such an extensive review of the issues facing timber haulage on forest roads. The conclusions and recommendations will influence future decisions on the specification and usage of forest roads, forest vehicles and public roads.

1.2 Forest Road Materials and Specification

Results from the investigation of forest road failures indicate that most failures are due to the surfacing aggregates being unable to withstand the higher intensities of lorry loading. The fact that there were few sub-grade failures would indicate that the overall road specification and construction were adequate.

The review concludes that Forest Enterprise forest road surfacing in Galloway was often defective in creating a deep pavement of poor quality (too soft) aggregate. As a result of this Review, Forest Enterprise have commissioned a geological survey and will henceforth refocus its quarrying operations on a restricted range of quarries where harder aggregates can be won. The higher cost of this aggregate will be offset by using less of it.

Forest Enterprise grading specifications are adequate and compared favourably with Swedish public road specifications (as demonstrated in the trials in Galloway). An important issue for road strength is to use aggregates at their optimum moisture content and then to properly drain the road. Dry roads are strong roads.
The Report also makes recommendations on road geometry. This is based on research from countries that have high-usage unsurfaced roads. Essentially, the Forest Enterprise forest road specified width (3.4m) is adequate for current usage, but strategic forest roads carrying in excess of 150 vehicles per day will need to be wider.

1.3 Forest Vehicle Specification

A detailed study has been made of the performance of different timber lorry configurations.

The main conclusion is that a major proportion of the wear and tear and other variable costs of timber haulage are associated with forest road travel, as compared to much longer distances on tarred public roads. These vehicles are designed for public roads.

Super single tyres are generally more damaging to forest roads than twin tyres, but the haulage industry is now almost entirely focussed on super singles. It also the case that in some circumstances super singles can actually be less damaging than twins (e.g. as regards trailers scouring unsurfaced roads at corners and bends). The overall conclusion is that wholesale conversion to twins is unlikely.

There was considerable work looking at alternative forest vehicle specifications that will reduce axle weights and road damage. The low impact vehicle tested was specifically built for forest road conditions with a view to delivery of timber to public roadside for onward dispatch to customers by conventional lorries. The cost of double handling is designed to be offset by use of red diesel and reduced roads (and possibly vehicle) maintenance costs. On the basis of this review, Forest Enterprise has issued a tender for haulage of 50,000 tonnes per year, with a view to introduction of low impact vehicles in Galloway. A number of low impact vehicle specifications are possible.

The logistics of timber haulage has also being examined, looking particularly at longer lorry movements and the use of red diesel within the forest. Legal advisors are still to finalise their conclusions.

1.4 Forest Road Network Management

It has been established that a road network management tool, such as HDM-4, is suitable for unsurfaced forest roads. The model has been widely used across the world, notably on the forest and public road networks of Sweden and Finland.

The model has been calibrated for a sample of forest roads but it is too early to select specific recommendations. Once the model has been fully calibrated, using the data from demonstrator sites, it will provide recommendations on maintenance regimes, restoning etc.
2 FOREWORD FROM SCOTTISH ENTERPRISE

2.1 Introduction

This report was commissioned by Scottish Enterprise as part of its Strategy: Roots for Growth – Challenges in Timber Transport. It is a demonstration project that complements The Scottish Timber Transport Mapping Study.

2.2 Roots for Growth - Challenges in Timber Transport

Roots for Growth, the Strategy for the Forest Industries was launched in November 2000. Scottish Enterprise facilitated the preparation of the Strategy, which was led by the Forest Industries. Roots for Growth identified three broad areas for action (a) Promoting innovation; (b) Market and Business Development; and (c) Infrastructure Development (including transport and logistics).

The challenges in timber transport were (i) access to the timber resource; (ii) lower levels of infrastructure investment when compared to other countries and regions; and (iii) community concerns about extraction.

2.3 Addressing the Challenges - The Scottish Timber Transport Mapping Study

An Industry Project Team was formed to look at the challenges in greater detail. Members included the United Kingdom Forest Products Association (UKFPA), the Ayrshire Joint Structure Plan Team and Forest Enterprise. There were three tasks:

- To collate available data on timber flows from resource to primary processor over a fifteen year time horizon.
- To highlight current areas where there are infrastructure impediments to the flow of timber and timber products.
- To make recommendations, in light of planned infrastructure upgrades and opportunities to overcome these barriers.

Consultants5 were appointed to take forward the Study, the outputs of which were a conventional report, The Scottish Timber Transport Mapping Study (an executive summary is accessible on http://www.forestryscotland.com/timber_transport/) with recommendations together with a Geographic Information System (GIS) Modelling Tool. The approach to the study was demand based. Some 57 destinations for Scottish timber (including past but not all current customers) were identified throughout Northern Britain together with some 1,700 exit points on the roads network for timber in Scotland.

The Study identified key barriers by road, rail and sea and made recommendations to overcome these barriers. Local road stress is a particular local challenge (for example in Dumfries and Galloway and Scottish Borders). Although the Study did not undertake a region by region examination of local roads issues the GIS modelling tool provides the platform for this work to be undertaken at a local level. By February of 2003 one such study (Ayrshire and Dumfries & Galloway) had been completed and

5 The Spaven McCrossan Partnership, Carl Bro IBI and Allan Massey
studies are underway in Scottish Borders and Grampian. By sea the key issue was quayside capacity and by rail the development of a network of forest and processor railheads, capacity upgrades and addressing network gaps caused by line closures in 1960s.

The Study's recommendations included:

- The development of a closer dialogue between timber suppliers and industrial processors.
- The development of identified rail and sea port capacity. This will entail working with industry, transport suppliers, local timber transport groups, the Scottish Executive, the Strategic Rail Authority and the Enterprise Networks to develop railheads at forest and the connection of processing plant, where appropriate, to the national rail network. It will also entail work to facilitate the development of new sea access points especially on the West Coast and North East Scotland.

In addition to taking forward the recommendations contained in the Study Scottish Enterprise and its partners are supporting a number of demonstration projects looking at innovative solutions to timber transport issues. These Projects will help to inform the implementation of the study's key recommendations.

2.4 Review of Timber Haulage and Forest Roads - Solutions for cost effective transport and strategic benefits in Scotland

The Review of Timber Haulage and Forest Roads - Solutions for cost effective transport and strategic benefits in Scotland aimed to find solutions to the issue of local road stress, identified in the Scottish Timber Transport Mapping Study. Forest roads are being subjected to heavier loads and an increased intensity of timber traffic. Roads, which have served well over many years, are being damaged by this increased intensity of traffic. Many rural public roads are experiencing the same problem and there is pressure to increase the use of internal forest roads where possible. In Ayrshire and Dumfries and Galloway the issues is particularly relevant given the proposed construction of a railhead at Barrhill, South Ayrshire.

In order to address the issues facing forest roads a Project Team was formed consisting of:

- David Killer, Head of Forestry Civil Engineering, Forest Enterprise (Chair).
- Rob Soutar, Forest District Manager, Galloway.
- Stan Corcoran, Forest Enterprise, Galloway.
- Wave Tyrrell, specialist Forest Civil Engineering Advisor.
- Andrew Dawson, University of Nottingham, Materials Specialist.
- JB Odoki, University of Birmingham.
- David Wightman, University of Birmingham.
- John Scott, JST Services Ltd (Haulage).

Some of which are addressed as part of the 10 year Strategic Plan unveiled by the Strategic Rail Authority in January 2002.
• Bill Tyre, Scottish Woodlands Ltd.
• Tore Hognas, Timber Logistics Manager, Forest Industries Development Council/Forest Industries Cluster.
• Steven Paxton, Scottish Enterprise Ayrshire/Forest Industries Cluster.
• Charles Stewart, Principle Solicitor, Scottish Enterprise

The Project remit was to:
• recommend road-surfacing specifications, using road stone from local sources;
• examine forest road geometry.
• consider a number of options for forest vehicle specification, including "bespoke systems", adapted rigs and central tyre inflation (CTI).
• clarify the position on the use of Red Diesel in internal haulage operations using short lengths of public road.
• use the HDM4 traffic modelling system to make recommendations on the management of the forest road network, surfacing characteristics for different intensities of use and also prescribe maintenance intervention periods.

The evaluation of the road surfacing specifications continued throughout the summer of 2002 and the evaluation of a specialist vehicle using low pressure tyres extended into the winter of 2002.

Steven Paxton
Scottish Enterprise Ayrshire/Forest Industries Cluster.
3. INTRODUCTION

3.1 Background

The high cost of timber haulage is the principle issue limiting the competitiveness of Scottish timber production in relation to imports. The main exporting countries in Scandinavia and the Baltic coast have much lower transport costs.

Forest roads are essential for the carriage of timber by lorry to the public roads, ports and railways. They are normally unsurfaced “gravel roads”, built and maintained by forest owners or forestry companies who carry the financial burden of their construction and maintenance. In recent years, maintenance costs have increased in response to damage arising from:
- Greater numbers of fully loaded axles.
- Reduced time for the roads to recover between loading.

The damage is related to an increasing intensity of use because:
- Gross vehicle weight for (most) articulated timber wagons has increased from 38 tonnes to 44 tonnes.
- Timber production from Scotland’s Forests is continuing to increase.
- Modern mechanised harvesting methods produce high volumes of cut timber to forest roadsides in a very short time.
- Scotland’s wood processing industries now need timber virtually every week of the year, so it is inevitable that forest roads remain in use when wet or thawing; conditions which predispose them to increased levels of damage.

Despite the considerable costs, there is increasing pressure on the forest industry to extend the use of internal forest roads wherever possible so as:
- To reduce the physical impact of timber haulage on public roads by taking timber further through the forest, to avoid use of particularly weak sections or bridges.
- To reduce discomfort and inconvenience to the travelling public and rural communities.

3.2 The Geographical Focus and Overall Aim of this Project

The geographical focus of the project is Galloway where Forest Enterprise, in collaboration with private sector neighbours, has developed proposals for a strategic forest roads network and railhead. The purpose of the proposed strategic forest roads is to redirect timber traffic away from communities, and from the weaker public roads, through the forest to trunk roads and the railway. However, if this strategic forest roads network is to meet its maximum potential for public benefit, the use of forest roads (as expressed as tonnes x miles) may increase five-fold. The timber industry could not survive a proportional increase in the costs of maintaining its forest roads!

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3 Galloway Forest District extends to all parts of Dumfries &Galloway west of Castle Douglas, and includes all parts of South Ayrshire south of Girvan, and East Ayrshire, south of Dalmellington.
The overall aim of this project is to provide guidance, which leads to reduced maintenance costs on forest roads and encourages initiatives that reduce the impact of timber haulage on the public. The high cost of maintenance is the principle issue tackled in this project, with focus on three inter-related subjects.

- Forest road materials and specification
- Forest vehicle specification
- Management of traffic

3.3 Impact of Timber Haulage on Communities and Public Roads in Galloway

Within the most heavily afforested region of Scotland, the communities of Galloway have for many years had to bear the ever-increasing size and number of heavy lorries through their towns and villages. In the last 20 years the quantity of timber harvested in Galloway has increased six fold to over 600,000 tonnes per year and stone produced for forest roads has increased to nearly 400,000 tonnes per year. Timber haulage is also affecting the fabric of public roads and causing inconvenience and discomfort to the travelling public. Timber traffic is always on the agenda for the Councils and Community Councils and is the single most frequent reason for public correspondence with Galloway Forest District.

Many public roads serving forests in South West Scotland suffer from inadequate design and more recently a lack of maintenance. The problem of unsuitable public roads in Galloway has been recognised for more than 20 years. In the late 1980’s, Dumfries & Galloway Regional Council spent £1 million to £2 million annually on road and bridge improvements. This was done as part of the Dumfries & Galloway Roads Accord, with the Forestry Commission. For their part, the Forestry Commission built relief forest roads and invested in recreational facilities, including 3 Visitor Centres. This large-scale investment in public roads came to an end as European funding dried up in 1996. In all, the Dumfries & Galloway Roads Accord saw over £20 million invested in public roads used for forestry.

Representatives from the timber industry and Council officials now routinely meet in regionally organised Timber Transport Groups, under the umbrella of the Scottish Timber Transport Forum. These Groups follow on in the spirit of the Dumfries and Galloway Roads Accord and provide opportunities for discussion and problem resolution, as well as helping Council officials to prioritise their limited budgets for road maintenance. The main thrust of the Timber Transport Groups to date has been the preparation of agreed route plans for public roads that are now at the crucial stage of achieving industry wide approval.

Today, few public roads serving forests in South Scotland are fully adequate in design, strength or state of repair. Deflectograph measurements conducted by the Dumfries & Galloway Council last year highlighted the widespread weakness of public roads. There are a number of important single-track roads serving extensive forests that are weak and twisty, often traversing sections of peat. These roads fall well below current highway design standards and it would be unaffordable to bring them up to this standard. (Indeed, the Dumfries & Galloway Council budget for road maintenance has been reduced by a third over the last six years.) The use of unsurfaced public roads is an option to consider, especially since these are common in the rural areas of many other countries, notably in Scandinavia and North America. However, although a
lower standard of design could reliably serve the timber industry, the option of unsurfaced public roads is unlikely to be popular with the general public in Britain.

3.4 Forest roads in Galloway

Forest roads in Galloway are suffering from increasing use, with many becoming deeply rutted or impassable in winter. The worst problems appear when roads are used very intensively e.g. to load ships with timber. In such cases it is not uncommon to haul more than 40 lorry loads within 24 hours. This traffic intensity poses problems to both forest and rural public roads, (albeit that by normal criteria of highway design such usage is still very low). Forest road engineers have found it difficult to prepare roads to reliably take such traffic in wet weather. On public roads, Council engineers have sometimes tackled the problem by limiting traffic to a load every 3 to 4 hours to allow the roads to recover. This limits damage but it is generally unsatisfactory in that the volume of timber that may be hauled is well below what is necessary to match demand.

The underlying geology of the area is Greywacke and it is this rock that is mostly used in forest road construction. In wet saturated conditions, deep ruts occur as the pavement deforms and degrades into a thick soupy consistency. Materials in this state become impossible to repair or stabilise reliably. There is clearly a need to surface forest roads with materials stronger than the Greywacke roadstone. This is of greatest importance in relation to the arterial roads identified as strategic forest roads, including those to serve the proposed Barrhill railhead initiatives, where the emphasis must be on all weather roads 364 days of the year.

The proposed strategic Galloway forest roads network and railhead are designed to address public concerns and also to help the Councils’ stretched roads maintenance budgets to go further. There is also scope for “joint venture” initiatives between the Councils and woodland owners, to promote forest road bypasses of weak bridges and unsuitable public roads. In progressing such initiatives, the forest industry forest is saying “we want to help”, but nevertheless must also confirm that the survival of the industry depends on the public road network being fit for purpose.
4 FOREST ROAD MATERIALS AND SPECIFICATION

4.1 Current Road Construction and Materials

4.1.1 Introduction

The forests in SW Scotland are located over varying ground conditions ranging from soft deep peat to thinly covered hard granite. The south of Scotland lies mainly on greywacke rocks of Silurian and Ordovician age that have some very large granite intrusions and numerous smaller intrusions of metamorphosed shale. The strata generally consist of highly folded and occasionally metamorphosed greywackes, shale, siltstone and sandstones. The topography comprises flat areas over deep peat, hummocky areas in valleys derived from glacial moraines and rocky hillsides.

Two basic construction techniques are used for building forest roads that are referred to as overlay construction and formation. Usually, overlay construction is building on top over peat and formation construction is excavating through softer material to a hard base to take a thinner pavement construction. Commonly both these methods are employed in valley areas by excavating from one hillock to fill across to the next hummock.

4.1.2 Construction over peat

The first operation in overlay construction is to gather all brash from tree felling on to the line of the road to form a mat over which the material is placed. Rock is used mostly as an overlay material especially when there is water at or near the surface. When available, gravel may be used in preference to rock where it can be kept clear of water. Till is another material, but can only be used when conditions are dry because it becomes impossible to work when wet. In this type of construction, drains should not be dug close to the road because the peat underlying the road is displaced into the void created. Therefore drains should be dug at a distance of 1½ times the peat depth away from the road edge. Drains can be very effective in draining peat when installed well in advance, say 12 months.

The method of construction for crossing peat depends on its depth or the material below the peat. The generally accepted rule is that where the depth is less than two metres the peat be removed by either moving the peat to the side or using the replacement method. In the replacement method, done in small stages, an extra width of peat is excavated for both the road formation and an adjacent trench. The trench is dug in the underlying soil and the spoil cast to the side on top of the road formation. Then the peat from the next stage is placed into the trench and on top of it, supported by the embanked formation. The cycle is repeated. The formation of cast material is allowed to dry out to gain strength. The removal of peat overburden is not a good choice where the underlying soils are problematical such as blue clays. Under these conditions a peat and vegetation layer may act as a membrane preventing ingress of undesirable clay into the roadstone above.
4.1.3 Formation Method

The universally accepted and preferred method is to construct roads on a formation. In public road construction all unsuitable material including topsoil is removed until a load-bearing soil or rock is encountered. In low cost forest roads it is not possible to remove large quantities of unsuitable spoil where overlay construction is cheaper. Larger pavement deformations are acceptable in the forest environment. Constructing a formation on side slope is the preferred location for a forest road. This reduces cost as it gives the shortest movement distance for the excavated spoil, as it has only to be cast to the side with one machine rather than a number of machines to haul it a greater distance away. A side drain is constructed on the uphill side of the road to intercept groundwater and to dry the subgrade area where the road metal is to be placed. This drying process improves subgrade strength. Layers of stone according to subgrade strength are placed to carry traffic and disperse wheel loads down onto the road foundation.

4.1.4 Construction Materials

Greywacke is used in the construction of most forest roads in south Scotland. Very occasionally gravel, for example from Heathhall (near Dumfries), or till is used. The amount of stone laid on a road can vary from an average of 7 to 17 tonnes per linear metre. There are numerous quarries throughout the region, which gives the impression it is rich in this resource. This notwithstanding, poorer greywackes are called “rotten rock” locally. Some quarries are considered harder than others. The rocks in the better quarries appear to have had more metamorphism and have fewer bands of shale. The soft laminated shales and siltstones are interbedded with the harder sandstones. The stone produced from these quarries is a mixture of sandstones, siltstone and shales.

The quality of roadstone has improved gradually over the years as bigger excavators and greater drilling capacity for blasting has become available, allowing forest civil engineers to work harder stone. During the same period the impact on forest roads has increased in terms of amount of timber hauled, more intense use owing to mechanisation, (and arguably) larger vehicles and the introduction of super single tyres. Rock has been screened for more than 20 years starting with Simba grids to more modern vibrating screens. More recently, up to 10% of total stone production has been crushed with mobile plants. These improvements make a better-sized roadstone that can be compacted better. However, these advances have not really paid off because of the fundamental weakness of greywacke, owing to its susceptibility to weathering or degradation.

The study has begun to confirm the realisation that greywacke quarries do not provide a suitable surfacing stone. The quarried rock is hard enough when first quarried but it deteriorates in place. An examination of the surface of any forest road will reveal the flakiness of the material. Typically nearly half of the exposed stone will exhibit breakdown. Intrinsically, greywacke is not a sound and durable roadstone. The problem with greywacke quarries is that the soft thinly laminated shales and siltstones quickly degrade to form an excess proportion of fine material in the aggregate mix. This leaves the harder sandstones floating around in a pudding.
Black shale is the other notable rock type used and found in some of the dykes intruding into greywackes. The main sources are at Penninghame and Clatteringshaws where it is blasted and screened. The 50mm down material makes a superb smooth running surface that is dust free in summer. It is best used for recreational purposes on forest drives, car parks and footpaths. However, it does weather and deteriorates quickly under heavy traffic.

4.1.5 The Impact of the Weather on the Fabric of Forest Roads

Forest roads are susceptible to extreme weather conditions from November to March. This can attributed both to the climate and to the altitude of the forests. During these months, the forest roads rarely dry out and their surfaces readily disintegrate into mud when subjected to traffic by haulage vehicles. However, it is the cycles of frost followed by thaw that have the highest impact on the cost of maintenance of forest roads.

Frost is potentially responsible for three kinds of damage to pavements. Firstly, lengthy periods of sub-zero air temperatures cause a freezing front to progress downwards into the ground. As water in the pores of the aggregate freezes it makes the effective pore size smaller causing the suction to increase. Water is sucked to these pores yet, because it freezes upon arrival, the suction is not sated so water is continuously drawn upwards. If the pores are of a critical size then large suctions can develop yet the pores may be large enough to allow measurable amounts of water to flow from an adjacent supply (e.g. high water table or full drainage ditches). By this means ice-lensing may develop causing heave in the thawing aggregate, often over a frozen impermeable base. Once thawed loosened aggregate and an irregular pavement surface may result. For this mechanism to exist the pore size must be in a critical range, there must be a water supply to the aggregate and there must be enough continuous sub-zero weather. Where this is a problem better sub-pavement drainage and/or a coarser aggregate will usually provide a solution.

The second type of damage is caused during thaw of a pavement which is seasonally frozen. If the pavement has frozen over winter to a depth of, say, 1m then the spring weather will cause the surface to thaw first. At this point wet aggregate will lie over an impermeable frozen sub-stratum and traffic must be carried on this undrainable layer. This ‘Spring-thaw’ problem is a major problem in Canada, Sweden, Finland and parts of Russia and the USA. It has a considerable influence on aggregate selection, load limiting in Spring and maintenance strategies in these countries. The single thaw of continental areas is not found to any extent in Scotland but must be considered when seeking to draw on experience in those countries, as it may limit the applicability of their procedures and specification to Scotland.

Thirdly, some aggregate particles can be susceptible to freeze-thaw damage. Typically this occurs due to diurnal temperature cycling. This is a practical consideration for many of the poorest Scottish aggregates, though susceptible aggregates should not be placed in an unsealed pavement as they are usually mechanically weak and, hence, would damage unacceptably due to trafficking long before suffering significant freeze-thaw damage.
4.2 Analysis of Current Road Materials and Structure

4.2.1 Analysis of Current Road Materials

Materials sampled from the in-situ investigations of forest roads (demonstration sites – see section 4.5) were conveyed to the laboratory at the University of Nottingham and visually described. Then an initial testing programme comprising particle size analyses and plasticity assessments of fines was defined. The grading results are shown in Figure 1.

![Measured Gradings](image)

**Figure 1**  Measured Gradings of Aggregates used in Galloway Forest

All the plasticity assessments found that the material was non-plastic. However there was quite a wide range of Liquid Limit values, indicating that some of the fines were considerably more hydrophilic than others. Those specimens exhibiting greatest affinity to water were from Kirroughtree and Bennan with material from Pennington, Glentrool South and Ae showing an intermediate response. The aggregates collected from other locations or layers showed a much lower affinity to water.

The grading curves, Fig. 1, show that most of the materials are high in fines. In many conventional aggregate specifications a maximum proportion of the mix of 10% is allowed to be smaller than 75µm. However three of the gradings have proportions greater than in the 12-20% range. This has a number of deleterious effects:

- There is a greater likelihood of there being sufficient clayey fines to provide a soft and weak covering to the surfaces of particles which would otherwise have been clean and rough, generating a weaker material overall.
- There will be many more inter-particle contacts, but each will carry less load. However, mechanical interaction between particles is highly non-linear, with a stiffer response being observed at higher contacts stresses (a consequence predicted by Hertz contact theory).
The finer particles are often less frictional due to their lower roughness. Again, this promotes a weaker response.

The finer grain structure means finer pores and capillarity. This means that water is more readily held in the pores, which decreases the material’s strength.

The gradings are also rather ‘flat’ (especially those of the Bennan and Kirroughtree aggregates), that is they do not follow a maximum packing curve. Other things being equal, a maximum packing curve would generate the highest density, the least deformable ‘skeleton’ of particles and the greatest resistance to damage by loading. However, when the curve is flat there are fewer than normal large particles which then ‘float’ in a matrix of finer particles with the disadvantages just mentioned.

4.2.2 Analysis of Current Road Performance

A comprehensive investigation of existing pavements was performed by Forest Civil Engineering in conjunction with the University of Nottingham. This was to assess in some detail, the types of distress and their probable causes. To achieve this, cross sectional trenches were dug across the pavements and measurements taken of the thicknesses of the various layers in the pavement. Samples of the materials forming the pavements were also taken and conveyed to the laboratory. Some of these are described in Section 4.3.2. Particular features which were sought were:

i. Evidence of subgrade intrusion (where a soft clay subgrade pushes its way upwards into the aggregate layers of the pavement due to an excessive kneading or pumping action caused by flexure of the pavement under repeated axle loading). This might indicate an unduly flexible pavement and/or a subgrade soil with high mobility.

ii. Evidence of subgrade depression due to a surface rut (which may have been infilled by maintenance intervention) pressing the subgrade surface down through the aggregate layer (Fig. 2a). This might indicate inadequate load spreading by the aggregate which could be a consequence of its low stiffness or of the thinness of the layer.

iii. Evidence of aggregate layer thinning due to shear within the aggregate layer (Fig. 2b). Usually this distress is characterised by localised heave either side of the ruts. This occurs where an aggregate has inadequate shear strength in the zone near the wheel. The highest shear is typically observed at a depth equal to 30-50% of the wheel-print width.

iv. Evidence of aggregate degradation in the form of localised excessive fines. If found in the aggregate beneath the wheel paths, but not elsewhere, this would indicate traffic induced damage. If found across the top of the pavement this might suggest environmental (especially freeze-thaw) damage.
4.2.3 Results of analysis of Current Road Performance

In fact, the chief distress (observed in 85% of the excavations) was distress type iii). There was also evidence that aggregate degradation (type iv) has an important role reducing strength and inhibiting drainage. However, it was not altogether clear whether this degradation was a consequence mostly of traffic, environmental effects or of damage (or inadequate control) during construction. It may be that significant fines generation was a consequence of damage during the crushing, handling, placing and compaction process.

It is very likely that the aggregates’ deterioration, for whatever reason, had a significant impact on the material strength hence explaining the observation that distress type iii) is by far the most frequent mode of failure. Thus, on the basis of the trenching operations it is concluded that poor aggregate quality is the primary cause of rutting distress in current Galloway forest roads. As has already been discussed, this poor quality is a consequence of their grading and shape. These features are controlled by the inherent quality of the aggregate and by the abrasion experienced in-situ. In the case of many of the aggregates used at present, this quality is intermediate and appears to be inadequate, in many circumstances, close to the trafficked surface of the pavement.

Visual observations of the aggregates show that they are often rather flaky and sub-angular or even sub-rounded at the edges. Generally, aggregates with blocky shape and angular asperities make better-performing aggregates whereas flaky aggregates with more rounded edges do not. There are probably several reasons why this is so, but the following are relevant here:

- More rounded edges are caused by the attrition of particle asperities under load, thus they are indicative of damage which causes irreversible (plastic) deformations within the aggregate.
- Smoother contact points generally have lower frictional properties and, thus, are the cause of weaker overall material strength.
- Flaky particles generally spread load well leading to moderate to high stiffness (as particles tend to stack flat side to flat side, like bricks) but develop poor horizontal interlock (along the “brick courses”) and, thus, experience higher than normal plastic deformation characteristics.
4.3 Alternative Designs for Road Pavements

4.3.1 Conventional Pavements

Conventional pavements usually comprise a minimum of three layers. At the bottom is the natural soil/rock subgrade on which the pavement is to be constructed (see Fig. 3).

Above this is an aggregate layer and above this a bound material (usually asphalt). The top layer provides a smooth running surface and a waterproofing layer. If it is thick then it will also have a structural ability, otherwise the structural capacity is provided by the aggregate layer(s).

![Typical Conventional Pavement](image)

Figure 3  Typical Conventional Pavement

In a forest environment a bound surfacing has seldom been used, mostly because of expense. However, such a construction could be considered for a spine road as it would almost certainly provide faster, more reliable and more fuel-efficient user journeys. Only a full cost-benefit study such as HDM4 would reveal its suitability for any particular scheme.

4.3.2 Aggregate

If a bound (asphalt) surface is not employed then an unsealed pavement (a “gravel road”) may be constructed. These pavements either require aggregate of high quality at the surface, or need to be stabilised in some manner. In outline the options are as follows:

- High quality aggregate throughout. The stone is resistant to environmental (rain/frost) attack and to tyre wear. It also has good load spreading ability such that a reasonable thickness will rapidly distribute traffic loading to a level which can be tolerated by the subgrade. Furthermore it has good internal resistance to shear, prevent rutting from forming within its thickness.
- High quality stone at the surface, but somewhat poorer quality at depth. This may save some money without compromising the structural ability of the overall pavement. It is important that the highest layer can still take the direct tyre and environmental loading. Deeper in the pavement, some load spreading by the top layer may allow a less structurally competent material to function adequately.
- A very dense mix in which all the particles lock together even though the stone quality may not be quite of the highest. Such a mixture will have little voids and an almost sealed surface. This tight surface will help to keep water out of the
pavement. The density of the mixture helps to give all particles good support from surrounding stones so that particle fracture and inter-particle attrition is limited. The grading may be defined by Fuller's theory which states:

\[ p_d = 100 \times \left( \frac{d}{D} \right)^n \]

where \( p_d \) is the percent of the mixture passing sieve sized \( d \), \( D \) is the maximum particle size and \( n \) is a power defining the grading shape (see Figure 4)

\[ \text{Sieve Size (mm)} \]

\[ \% \text{ Passing} \]

\[ 0.01 \quad 0.1 \quad 1 \quad 10 \quad 100 \]

\[ 0.7 \quad 0.3 \quad 0.4 \quad 0.55 \quad 1 \quad 0.25 \]

\[ \text{Fuller's n value} \]

\[ \text{Fuller Curves for 50mm maximum size aggregate} \]

- Treatment by some binder such as cement. This provides tensile capacity which hinders all interparticle movements including shear and tension cracking. Available binders are cement, lime, ash pozzolans and slag pozzolans.

- Treatment by a material modifier. Lime reacts with most clay minerals by cation exchange and other processes. The result is that the plasticity of a poor quality aggregate will be significantly reduced or completely removed. The clay component ceases to behave as a clay and the water retention drops and the strength increases. This benefit will not be felt by 'clean' aggregates. An alternative, polymeric, binder might be mechanically suitable in such cases, although it might be uneconomic.

Figure 4 Theoretical Maximum Grading Curves
The Swedish specification (Figure 5) seems to utilise the idea of a dense ‘Fuller’ grading for the base with a smaller maximum size of material, also to a Fuller grading, placed at the surface of the pavement to exclude rain water.

Observationally, on site and in the laboratory, it appears that the shale and greywacke facies have relatively weak particle strengths (although numerical data for this is not yet available). This will, undoubtedly, contribute to rutting as stones break and degrade by attrition against other stones. Probably, little can be done to address this limitation in a direct manner. However, some treatment methods may offer some help for some materials. In other cases a Fuller grading would tend to maximise the support available between particles, thus limiting their exposure to breakage stresses. The Swedish approach may be using this technique.

Improved conventional aggregate may be achievable by screening out the softer less durable rocks if they are contained in the small sizes. Then the finer fraction would be discarded to leave the coarse fraction to be crushed to produce a sound roadstone. Sometimes it appears that the stronger sandstone facies within the greywacke deposits might thus be separated. A trial would be required to assess the practicalities, economics and engineering properties of the final product.

Granite has been blasted and used on road lines, but it has not been quarried for roadstone. It is very hard to drill and difficult to blast. Blasting tends to produce blocky sized material with very poor fragmentation. It is not easy to correct the poor fragmentation by the typical methods of varying hole spacing or explosive type. Deeper holes might help. The other potential problem with granite is its

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preponderance to weather into small sand sized particles that would be harmful to salmon fish beds, if allowed to enter watercourses.

The whinstone at Ballochbeatties is the only known source of quality roadstone in the Forestry Commission forests in south Scotland. This may well be the best option if the increased haulage construction costs are more than offset by the benefits derived from good durability. This could support the construction of internal link roads through the forest.

4.3.3 Cross Section

As water is a key problem for unsurfaced pavements, and as much of the study area has very high rainfall levels, shedding water efficiently from the pavement structure becomes a priority. In general, purpose-built drainage provision is seldom provided. It is desirable that proper concern is given to removing water from the immediate vicinity of the pavement, so consideration should be given to

- setting a good crossfall on the pavement surface. This could be a single cross fall (although these are not liked by the haulage drivers and they may cause slightly higher loads to be thrown to the 'low' wheel track) or a cambered-type construction with a wheel-track either side of the apex.
- setting a good crossfall on the subgrade surface just prior to placing the first aggregate lift. The aim is to prevent water entering the subgrade from the aggregate, but rather shedding it laterally so that it exits the pavement at formation level.
- providing a very coarse lowest aggregate layer to act as an 'underdrain' so as to allow any water within the pavement to drain out in the place and manner desirable.
- providing drainage ditches and coarse aggregate-filled trenches (grips) both to carry draining water (whether from pavement run-off or from the structure) away from the pavement. Grips also intercept surface and near surface water flows in the ground adjacent to the pavement, preventing it from entering the pavement structure and, thereby, weakening the pavement. These are most important on sidelong ground where land water drainage would, otherwise, be routed into the pavement structure.

4.4 Demonstration Project

4.4.1 Overview

There has been a renewed technical interest in forest road building since the inception of Forestry Civil Engineering in 1998. There were two visits to Sweden in 2000 where gravel or unbound roads account for 20% of the National road network and 90% of the larger private road network. One of the findings of these visits was the greater use of crushed and screened materials in Sweden. The size or grading specifications for roadstone was considerably finer than is the practice in the Forestry Commission,
although they are similar to those adopted worldwide by other public highway agencies. One outcome was that we should trial the Swedish specification\(^5\).

Also in the background, it was found to be increasingly difficult to reliably repair roads that had rutted heavily and failed during the winter. One such case was at Knockycoid on a road that would be vital to the proposed railhead at Barrhill. This prompted the investigation into pavement failures.

The trial was set up to evaluate performance of varying surfacing specifications. Also, a dual carriageway section was built to compare the damage caused between super single tyres and the twin tyre configuration fitted to lorries. Traffic counters were installed to monitor traffic on the dual section. Details of the sections are given in Table 1 and the commentary which follows.

<table>
<thead>
<tr>
<th>Section</th>
<th>Length (m)</th>
<th>Material</th>
<th>Gradient</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>64</td>
<td>75mm Down from Craignell quarry</td>
<td>4% &amp; 1%</td>
<td>Control Section of current best practice.</td>
</tr>
<tr>
<td>2</td>
<td>34</td>
<td>Swedish Grading Specification from Craignell quarry</td>
<td>3%</td>
<td>FC Greywacke stone source.</td>
</tr>
<tr>
<td>3</td>
<td>34</td>
<td>Commercial Swedish Specification</td>
<td>4%</td>
<td>A more durable outside source.</td>
</tr>
<tr>
<td>4</td>
<td>34</td>
<td>Craignell quarry Free Draining Specification</td>
<td>8%</td>
<td>To see if a more open and permeable grading would be better suited to wet conditions.</td>
</tr>
<tr>
<td>5</td>
<td>34</td>
<td>Type 1 granite sub-base from Dalbeattie (Tarmac)</td>
<td>5%</td>
<td>Standard Highways specification.</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>Swedish Specification from FC Risk quarry</td>
<td>7%</td>
<td>Dual Section of poorer material to compare damage between super singles and twin tyres.</td>
</tr>
</tbody>
</table>

Table 1 Demonstration Project Sections

4.4.2 Detailed Descriptions of Demonstration Sections

**Section 1**
This section starts at the gate barrier and is longer than the other section because part of it is near level and thus might pothole. It is surfaced with 75mm crusher run from a Forestry Commission quarry at Craignell near Clatteringshaws. It represents the best of current practice and can be taken as a control against which to compare other specifications.

Section 2
This section was constructed from material from Craignell quarry that was screened and blended to meet the combined Swedish grading envelopes (Table 2 and Fig. 5). The material has not been tested to see if it complies with other criteria specified by the Swedish National road Authority. Thus the section is of local greywacke material simply meeting the grading requirement.

Section 3
This section is the same as section 2 except that the material has been sourced from a commercial quarry. Thus this section meets the grading specification and it is assumed British standards for strength. Thus the difference between rock types of different particle strength may be compared.

<table>
<thead>
<tr>
<th>Sieve (mm)</th>
<th>Wearing Course</th>
<th>Base Course</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max %</td>
<td>Min %</td>
</tr>
<tr>
<td>0.075</td>
<td>16</td>
<td>10</td>
</tr>
<tr>
<td>0.25</td>
<td>23</td>
<td>13</td>
</tr>
<tr>
<td>1.0</td>
<td>34</td>
<td>20</td>
</tr>
<tr>
<td>4.0</td>
<td>57</td>
<td>35</td>
</tr>
<tr>
<td>8.0</td>
<td>77</td>
<td>55</td>
</tr>
<tr>
<td>16.0</td>
<td>99</td>
<td>85</td>
</tr>
<tr>
<td>22.4</td>
<td></td>
<td>98</td>
</tr>
<tr>
<td>31.5</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Swedish (SNRA) roadstone grading specifications used on sections 2 and 3 of the demonstration

Section 4
One finding that emerged from the investigation was the high amount of fine material in the pavements. Heavy rutting may be a consequence of this. This section with material from Craignell has a more open grading and possibly more suited to the wetter climate in south Scotland. Thus a comparison will be made between another grading of the same material.

Section 5
This section is surfaced with material meeting the standard MoT Type 1 specification using granite from Dalbeattie quarry. One option for improvement is to quarry granite from sources within the forest. Thus this section was evaluated with this in mind. The granite found in Galloway is extremely hard making it difficult to drill and fragmentation is poor when blasted. It is not an easy rock to quarry for roadstone aggregates.

Section 6
There is some evidence that lorries with super single tyres impart more damage onto roads than twin tyre configurations. The higher tyre pressures required would support this view. It is a controversial topic (and part of the work described in Chapter 5 of this report) and so a dual section was built. Vehicles with super singles are directed onto
the right hand lane going uphill while twin tyres vehicles are directed on to the other side. Light vehicles keep left as they would on a public highway so these should be distributed evenly. Traffic counters were placed to count both the types of vehicle and the numbers of each type. This section was surfaced with material from the Forestry Commission quarry at Risk in Kirroughtree forest that was screened and blended to meet the combined SNRA grading envelopes. This material is weak and should have failed relatively easily to aid the comparison.

4.4.3 Results of Demonstration

The conclusions were:

- Surface layers with harder stone aggregates resist rutting better than softer rock.
- The amount of rutting is dependent on moisture content and amount of traffic.
- The surface layer does not act as a fixed structural entity with the larger aggregate sizes locked firmly together. It was seen that ruts formed during wetter winter conditions and then healed in drier summer conditions. The surface profile is moving in a plastic fashion and is not being worn into the rutted shape.
- Vehicles with super single tyres were at least twice as damaging as those with twin tyres in trial section 6.

4.5 Stabilisation Methods

Stabilisation, as described briefly in Section 4.3.2 of this report, is an option in which a cementitious or pozzolanic binder is added to a soil or aggregate to increase the strength and/or stiffness and/or to reduce the propensity for rutting so as to provide greater load-carrying capacity. Cement stabilisation involves the mixing of Portland cement with aggregate to provide a very weak concrete-type material (typically having a cube compressive strength in the 2-5 MPa range). Higher strengths are undesirable because of the high cement content (and commensurate cost) required. Furthermore, high strength leads to a tensile load carrying capacity. This, in its turn, would lead to well-defined slabs being developed with wide but infrequent cracks at which weather-induced damage would become concentrated.

Stabilisation can also be provided by hydraulic binders which may act in a pozzolanic manner. Such binding requires a pozzolan and an activator (usually small percentages of lime). In the presence of clay, lime also has another beneficial effect (see Section 4.3.2 above), modifying the clay into a less moisture-sensitive and easier draining material. The non-plastic determinations made on the aggregates tested makes it somewhat doubtful that there will be sufficient clay for lime-stabilisation to function well on the Galloway greywacke aggregate fines.

Stabilisation can be applied to both the subgrade and to granular base. Where the problem appears to be the subgrade, and the soil is clayey, then the lime-amelioration mechanisms of clay soils, previously mentioned, could lead to a stronger sub-grade and hence, to a better performing pavement.

Most stabilisation methods are temperature sensitive. Cement is the most forgiving, working at temperatures approaching 0°C. However, most of the pozzolanic reactions
require higher temperatures (in excess of 10°C, desirably near 20°C). Thus lime or similar treatment will be a summer activity. All the stabilising techniques looked at give rise to highly alkalinic conditions, so care needs to be taken to ensure that the neighbouring ecology is not deleteriously affected (e.g. by changing ground pH affecting forest growth or by leaching into streams affecting fish and other fluvial fauna).

4.6 General Application of Principles to Other Parts of the Country

Much of the work described in the preceding sections has been specific to the situation of the Galloway forest. There are two major features here which may not be similar in other Scottish forests:

- High rainfall. Being on the western side of the country, Galloway picks up high rainfall (greater than 2m per year in parts). In dryer forests excess water may not be so problematic and drainage may be somewhat less important, although it is unlikely to be unimportant.
- Geology. The Ordovician & Silurian deposits, largely greywackes, are ubiquitous in the Southern Uplands but are not found widely in other Scottish forests (although there may be similar aggregates in forest areas of Central Wales and parts of Northern Ireland). Thus the particular strategies to make the most of these materials, and to limit their deleterious features, as discussed in this chapter, may not be immediately applicable elsewhere.

However, the general approach adopted here and the remedial strategies will be applicable elsewhere. Even in forests where trafficking-induced damage has not yet been seen to any great extent, the findings of this project are likely to have benefit in providing guidance on how to build pavements which are both reliable and economic. This is especially true in the face of a possible doubling in annual timber tonnage to be extracted from Scottish forests, in the near future. In particular the following transferable principles are highlighted.

- Pavement failures under trafficking can be due to a wide variety of reasons. Trenching across the pavement can quickly identify the cause so that construction and maintenance energies are not mis-directed.
- Careful attention to the gradings of aggregates can deliver significant performance benefits. Each forest should consider its available aggregate sources and determine, by means similar to those discussed here, whether the gradings employed are those of production least-resistance or whether a small amount of additional effort in grading proportion would provide a disproportionate in-pavement performance and reduced maintenance requirements.
- It is probable that most poorer quality aggregates can be used in pavement construction, but it may be necessary to use them selectively within the pavement structure.
- More widespread use of land drainage grips should be considered where excessive water is found to be an issue.
- Aggregate treatment techniques are available and should be considered, by laboratory and site trialling, where sufficient economy can be demonstrated.
4.7 Methods of Testing Sub-grades and Aggregates

Given that the prevalent failure mode of forest pavements is by rutting, it is important that the strength (rather than the stiffness) of both the aggregate and the subgrade is known. As rutting is a repeated loading effect, this should, fundamentally, be assessed by a repetitive loading method. Such methods do exist but are, typically, expensive and time consuming at laboratory scale. The repeated load tri-axial test is being used in this study, but will never be a routine tool (see below).

On site a relatively simple repetitive method is available in the form of a loaded lorry repeatedly rolling forward and backwards over a test construction section. This is a simply technique which should be employed more frequently. For testing aggregate the material should be placed at a location where the subgrade is relatively strong so that it is the aggregate which is assessed, as intended, and not the subgrade. Where the subgrade is to be assessed then a known quality aggregate should be placed at a tapering thickness on a carefully selected level subgrade. This will ensure that the amount of load-spreading provided by the aggregate will progressively decrease as the aggregate thins, hence allowing the quality of the subgrade support to be assessed on the basis of the point at which significant rutting commences.

However, in-situ methods of this sort are at the mercy of the weather and excessively dry conditions may give a false sense of security (and very wet periods may give unnecessarily pessimistic results).

Simpler in-situ testing is performable by the Dynamic Cone Penetrometer (DCP) which is a portable manually operated device in which a small cone is progressively thrust into the pavement construction by a repeatedly dropped mass. This can make a broad assessment of both aggregate and subgrade quality. As it is cheap to buy and simple to operate it may be employed at one site over a range of weather conditions and the sensitivity to environmental condition may then be easily assessed. However it’s relative lightness means that large stones in the aggregate will prevent any penetration, or will lead to artificially slow penetration, thereby giving a false indication of quality or even preventing assessments from taking place. For these reasons laboratory testing is usually an important element in subgrade and aggregate assessments.

At laboratory scale, the conventional methods for testing aggregates are grading size distributions, plasticity testing and particle strength measures. In this study all three were attempted but the abnormal size distributions (compared to those used in conventional pavements upon which standard testing procedures have been developed) prevented particle crushing tests from being performed according to the British Standard. When non-standard gradings are employed, as in many of the forest road pavements, then it is arguable whether routine testing is as informative as it should be.

In particular, particle strength is not of absolute interest, but rather the user is interested in the ease of particle breakage in the actual mix being employed. Thus, for example, an aggregate which is predominantly comprised of smaller than conventional particles will probably function adequately even though it contains weaker than normal
particles. This is because the smaller particle size means more particles and, hence, more particle contacts. As the loading applied to the aggregate (by compaction or trafficking) is at the same level as for the coarser aggregate, then each contact is stressed to a lower level. Hence particle abrasion and breakage can be expected to be smaller for the same strength material — or the same with a weaker material.

To study this effect, particle breakage and abrasion should be assessed on the whole grading. This can be achieved in the gyratory compaction equipment (Fig. 7) in which the whole grading (less any oversize particles) is compacted by applying a heavy, static, vertical stress on a specimen whilst the top of the specimen is displaced such that its centre describes a small circular track compared with the centre of the base of the specimen (like the action of stirring with a spoon - the spoon doesn't rotate on its own axis but it tracks a circular path). By applying several hundred gyrations, the aggregate particles are repeatedly sheared against one another while they are pressed into close contact. This has the effect of rapidly causing damage in weaker aggregates which is observed by grading the post-compaction specimen and comparing that grading with the pre-test version. While this is not a standard test it has been used by a number of researchers and is based upon a Finnish working practice.

Figure 7  Gyratory Compaction Test

The mechanical strength can, in part, be assessed at the same time by measuring the torque required to gyrate the specimen. However, the preferred technique is the repeated load tri-axial test that can be used to assess the rate of build up of permanent strain under the application of repeated loading. The test allows the stress level to be changed (a help when deciding at which level the material can be used in the pavement without causing a problem), the whole sample grading to be tested, and the moisture to be varied (helping the user to know the importance of drainage). Unfortunately the test is not cheap to perform and is unlikely to become a routine tool in the near future (though a draft CEN standard is currently in preparation). Several studies have shown, therefore, that the strength under repeated loading is, at a practical level, best assessed in-situ as described above.
With regard to treatment methods, the assessment of their capability relies on repeating the tests described above, before and after treatment.

### 4.8 Road Design Recommendations

#### 4.8.1 Road Geometry Recommendations

Virtually all forest roads in UK are unsealed (i.e. not surfaced with bitumen macadam, concrete etc.), their prime purpose being to provide safe access into the forest for normal road lorries. They are low cost, low speed, single carriageway roads designed to be used all year round except in adverse weather conditions.

Most forest roads in UK have been constructed to the design shown in Table 3 except that, until recently, roads were built to a width of 3.2m and not the 3.4m currently specified. The current specification for forest roads in the public sector is as follows:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design speed</td>
<td>25 km/h.</td>
</tr>
<tr>
<td>Design Loading</td>
<td>Full C&amp;U (currently 44 tonnes)</td>
</tr>
<tr>
<td>Road Width</td>
<td>3.4 m (+/- 200mm) - widened on inside of bends to suit radius.</td>
</tr>
<tr>
<td>Felled width</td>
<td>25 m recommended.</td>
</tr>
<tr>
<td>Max gradient</td>
<td>10% with small lengths (&lt;200m) up to 12.5% allowable with caution.</td>
</tr>
<tr>
<td>Min gradient</td>
<td>2% recommended.</td>
</tr>
<tr>
<td>Facilities</td>
<td>Passing places, turning places, harvesting facilities supplied as required.</td>
</tr>
<tr>
<td>Road construction depth</td>
<td>Chosen by relation to CBR of sub-grade.</td>
</tr>
<tr>
<td>Construction</td>
<td>Normally waterbound. Material as available.</td>
</tr>
<tr>
<td>Surfacing</td>
<td>As required. Good quality material. Normally waterbound, occasionally bituminous. Depends to some extent on classification.</td>
</tr>
<tr>
<td>Cross slope (camber or crossfall)</td>
<td>4.5% recommended minimum. Above 8% only to be used with care.</td>
</tr>
<tr>
<td>Geotextiles</td>
<td>Used occasionally for particular reason</td>
</tr>
<tr>
<td>Culverts</td>
<td>Minimum size 300mm although 450mm preferred. Spacing as required.</td>
</tr>
<tr>
<td>Road classification</td>
<td>Class A Main road</td>
</tr>
<tr>
<td></td>
<td>Class B Spur road</td>
</tr>
<tr>
<td></td>
<td>Class C Other road</td>
</tr>
<tr>
<td></td>
<td>(Class C not normally used for harvesting).</td>
</tr>
</tbody>
</table>

### Table 3 Forest Enterprise Road Specification

This design is adequate for roads with up to 50 vehicles per day (vpd) with a design speed of 25kph. It is possible to improve forest road specifications to allow speeds of up to 50kph. Road widths, junction layouts and visibility at bends all have to be
improved but it must also be realised that this creates new problems of increased dust, visitor safety and the potential for more serious accidents. Driving at higher speeds on unbound roads needs different skills, for example the stopping distance on an unbound surface at 50kph is 60m compared to 45m on a surfaced road (ARRB manual Table 4.4).

It is only as daily vehicle movements increase beyond 50 vpd that we need to consider alternative designs. Table 4 below is derived from experience in a number of countries including Australia (ARRB manual).

<table>
<thead>
<tr>
<th>Road Usage (vpd)</th>
<th>No. of Lanes</th>
<th>Carriageway Width</th>
<th>Structural Shoulders</th>
<th>Total Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50</td>
<td>1</td>
<td>3.4m</td>
<td>no</td>
<td>3.4m</td>
</tr>
<tr>
<td>50-150</td>
<td>1</td>
<td>3.4m</td>
<td>2x1.2m</td>
<td>5.8m</td>
</tr>
<tr>
<td>150-500</td>
<td>2</td>
<td>6.0m</td>
<td>2x1.2m</td>
<td>8.4m</td>
</tr>
</tbody>
</table>

**Table 4 Road Width Options for Different Road Usage**

The recommended width and gradients for horizontal bends are summarised in Table 5 below.

<table>
<thead>
<tr>
<th>Outside Radius</th>
<th>Minimum Widths For Maximum Angle of Deflection (°)</th>
<th>Transition Straight Length</th>
<th>Maximum desirable gradient on outside radius</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Running surface width</td>
<td>m</td>
<td>m</td>
</tr>
<tr>
<td>15</td>
<td>45</td>
<td>90</td>
<td>180</td>
</tr>
<tr>
<td>90</td>
<td>3.4</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>60</td>
<td>3.4</td>
<td>3.8</td>
<td>4.0</td>
</tr>
<tr>
<td>45</td>
<td>3.4</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>30*</td>
<td>3.4</td>
<td>4.4</td>
<td>5.0</td>
</tr>
<tr>
<td>25</td>
<td>4.6</td>
<td>5.1</td>
<td>5.3</td>
</tr>
<tr>
<td>20</td>
<td>4.9</td>
<td>5.6</td>
<td>5.9</td>
</tr>
<tr>
<td>15</td>
<td>6.3</td>
<td>7.0</td>
<td>40</td>
</tr>
<tr>
<td>10***</td>
<td>10.0</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

* Preferred minimum radius
** Figures based on experience
*** Absolute minimum hairpin

**Table 5 Horizontal bend recommended widths and gradients**

* Structural shoulders allow vehicles to pass with care, are constructed to full depth specification, and have a different cross-fall.
4.8.2 Road Pavement Recommendations

The results show that the dominant failure mode was in the top surface and this indicates shows that there is usually no value, in these cases, in adding more general fill to a failing road. The emphasis should be on placing a more durable and designed aggregate to the top surface. The extra cost of providing a better processed stone surface will be partly met by limiting the general fill to the optimum design thickness.

The Demonstration Project described in Section 4.4 also provided a number of useful conclusions:

- The aggregates in each of the Sections performed very well, including the finer material graded to the Swedish specification and the crushed granite.
- Although the Swedish specification material performed better than expected, even under wet conditions, the extra cost of production is not warranted on the grounds of improved performance. There is also the environmental concern of sedimentation from finer materials.
- The granite section performed very well but again the extra cost in winning and processing is not justified when similar results can be achieved from other local igneous materials.
- The fact that all materials performed well is an indication that most well-graded and durable aggregates are suitable if carefully placed and compacted around their optimum moisture content. More work needs to be done on site measurements of moisture content and density.
- The success of the trial sections can also be attributed to the good control of surface water. Achieving the design camber and crossfall with an unhindered drainage path into the ditch is vital.
5 FOREST VEHICLE SPECIFICATIONS

5.1 Application of Legislation to Forest Lorries

In terms of forest roads maintenance costs, the extended use of forest roads will be far more costly than in the present situation (where lorries tend to travel the minimum distance through the forest to the nearest public road). However, there is some potential to offset this higher cost by dedicating some lorries to work almost entirely within the forest area (e.g. delivering timber to a railhead in the forest). In this scenario, significant savings could be possible if the higher rates of duty on diesel and vehicle tax could be avoided under the exemptions that apply in agriculture.

The Scottish Enterprise legal department and solicitors have researched the law relating to the use of red diesel, including information contained in Customs & Excise Notice 75 which sets out the circumstances in which red diesel can be used.

In order to use red diesel vehicles must satisfy two different but related sets of criteria:
1. the vehicles must fall within the definition of an “Exempt Vehicle” as described in the Vehicle Excise and Registration Act 1994 (“the 1994 Act”); and
2. the vehicles must fall within the definition of an "Excepted Vehicle" as described in the Hydrocarbon Oil Duties Act 1979 (“the 1979 Act”).

There are several categories of Exempt Vehicle in the 1994 Act and several categories of Excepted Vehicle under the 1979 Act and some of these overlap.

In particular and of particular interest to us is a category headed “Vehicles Used between Different Parts of Land”. This appears both in the 1994 and the 1979 Act and is the same in both. Thus a vehicle is an Exempt Vehicle under the 1994 Act and an Excepted Vehicle under the 1979 Act if:

a) it is used only for purposes relating to agriculture, horticulture or forestry;
b) it is used on public roads only in passing between different areas of land occupied by the same person, and
c) the distance it travels on public roads in passing between any such two areas does not exceed 1.5 kilometres.

In the 1994 Act the definition of "Public Road" is contained in Section 62(1) which in turn refers to the Road Scotland Act 1984 ("the 1984 Act"). Section 151 of the 1984 Act defines a public road as "a road which a Roads Authority have a duty to maintain". Clearly the Roads Authority do not have any obligation to maintain forest roads and our legal advisers are of the view that they are not public roads as defined in the 1984 Act.

In the 1979 Act "Public Road" means a road which is repairable at the public expense. It is our contention that the cost of maintaining forest roads is met from income derived from the sale of timber and not directly from the public purse. If that is correct our legal advisers again feel that forest roads are not public roads as defined in the 1979 Act.

We have on more than one occasion written to HM Customs & Excise which among other things deals with tax on fuel and have been advised that if vehicles qualify as
Excepted Vehicles as described above they can use red diesel so long as they are licensed with DVLA under a “restricted use” licence.

The information we have at the moment is that vehicles which qualify as “Exempt Vehicles” under the 1994 Act are entitled to a restricted or limited use licence and that is something we are currently pursuing with DVLA. We are also seeking clarification whether it is the landowner or operator who has to register for this exemption.

Enquiries have also been undertaken into the Construction and Use Regulations that govern the construction, weight and use of motor vehicles on roads. Confusingly the definition of "road" for the purposes of these Regulations is different from the definition of "public road" used in the 1979 Act, but will almost certainly include all public roads. All vehicles using public roads even for short distances must comply with these Regulations and this will have an impact on the style/design of vehicles that the forest industry can use to haul timber.

5.2 Demonstration of Lorry Fuel Economy

Lorries use more fuel per mile on forest roads than they do on tarmac roads, but no hard figures were available to quantify this comparison until this trial.

Volvo Truck, Barrhead was commissioned to calibrate the on-board computers installed in two test vehicles. Tyre inflation pressures were checked so all vehicles involved were of equal standing. One test vehicle was driven along a pre-set route, which started near Ayr on the Ayr bypass and concluded, at Minishant on the A77 trunk road (“A” class), a distance of 5.5 miles. Once at Minishant, the information collated by the computer was downloaded and recorded. The trial then progressed to Linnfern on the A714 south of Straiton, where the computer was zeroed prior to commencement of the second part of the trial. The vehicle was then taken 5.5 miles through the forest where it was loaded to its maximum gross weight and the trials continued in reverse order following the same procedure as above. The findings of these trials are shown in Table 6.

| "A" Class Road | | | |
|----------------|------------------|------------------|
| Ayr bypass to Minishant (EMPTY) | Minishant to Ayr bypass (LOADED) |
| Distance | 5.5 Miles | Distance | 5.5 Miles |
| Fuel | 0.8 Gallons | Fuel | 1.1 Gallons |
| Average speed | 34 MPH | Average speed | 32 MPH |
| Time taken | 10 Min 45 Sec | Time taken | 12 Min 26 Sec |
| Fuel consumption | 6.88 MPG | Fuel consumption | 5.00 MPG |
| | | | |
| Forest Road | | | |
| Linnfern gate to Changue (EMPTY) | Changue to Linnfern Gate (LOADED) |
| Distance | 5.5 Miles | Distance | 5.5 Miles |
| Fuel | 1.4 Gallons | Fuel | 2.3 Gallons |
| Average speed | 15 MPH | Average speed | 10 MPH |
| Time taken | 22 Min | Time taken | 33 Min 38 Sec |
| Fuel consumption | 3.92 MPG | Fuel consumption | 2.39 MPG |

Table 6. Comparison of fuel consumption on “A” class road and Forest road
Table 6 demonstrates a substantial difference between the costs of travelling in a forest environment to one of an ‘A’ class road. It must be noted too that even on “A” class roads, timber vehicles have higher fuel consumption than typical road vehicles of the same weight. One reason is aerodynamics, since most typical road vehicles have smooth surfaces by virtue of containers or curtains, and most have air management kits fitted. This allows these vehicles to move through the air with the least amount of resistance, thus ensuring a higher fuel economy. This is not practical for timber carriage, because the overall dimensions of the trailer change every time the vehicle is loaded, and indeed 50% of the time the vehicle is empty. In this situation, the air management kit works against fuel efficiency. Beyond this, lorries with timber trailers might have as many as five solid walls of timber and ten protruding bolsters for air to negotiate before reaching the back of the vehicle.

5.3 Demonstration of impact of Diesel Type

Another factor is the fuel used to operate the p.t.o (power take off) and pump which are fitted to most timber haulage vehicles to power a crane to load and unload the timber. The use of rebated heavy oil (red diesel) for this operation would see a significant saving in fuel costs and reduce haulage costs. The law currently forbids haulage companies to use or even carry red diesel on British trucks (on the public highway), though this has been practised by French hauliers for a number of years. The French use a device that is fitted to the switch for the p.t.o. and when the p.t.o. is engaged it automatically switches from using derv (white diesel) to using red diesel. This allows the loading process to be achieved at minimum cost. Table 7 demonstrates the potential saving of £0.06 per tonne on loading and a total of £0.37 per tonne, that would have arisen in the trial, if red diesel could have been used in the forest.

<table>
<thead>
<tr>
<th>Activity in Forest</th>
<th>Litres of diesel used (actual)</th>
<th>Cost of red diesel (if used)</th>
<th>Cost of white diesel (actual)</th>
<th>Potential saving through use of red diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive from Linnfern gate to Changue unloaded</td>
<td>6.36</td>
<td>£1.05</td>
<td>£3.94</td>
<td>£2.89</td>
</tr>
<tr>
<td>Load vehicle</td>
<td>3.63</td>
<td>£0.60</td>
<td>£2.19</td>
<td>£1.59</td>
</tr>
<tr>
<td>Drive from Changue to Linnfern Gate loaded (25t)</td>
<td>10.44</td>
<td>£1.72</td>
<td>£6.47</td>
<td>£4.75</td>
</tr>
<tr>
<td>Total</td>
<td>20.43</td>
<td>£3.37</td>
<td>£12.60</td>
<td>£9.23</td>
</tr>
</tbody>
</table>

Table 7 Demonstration of Potential Saving on Use of Red Diesel in the Forest

5.4 Comparison of Other Vehicle Costs

Fuel is only one of the costs that run considerably higher with timber haulage vehicles than with general haulage vehicles. Standing costs (Table 8) are greater for timber haulage in comparison to general haulage. Insurance is close to four times the price of general haulage insurance, owing to:
- A higher frequency of claims from the timber sector.
- The value of the equipment is double that of general haulage.

One Insurance Broker approached during this study said companies would not insure any new timber haulage companies without a 100% loading on the policy, i.e. a company with no track record could now face an insurance cost of £12,000 per truck per annum!

<table>
<thead>
<tr>
<th>Typical Road Haulage</th>
<th>Timber Haulage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Figures based on 44 Tonne G.V.W. Articulated Vehicle with Costs as at December 2001</strong></td>
<td></td>
</tr>
<tr>
<td>Annual Mileage</td>
<td>70,000 miles</td>
</tr>
<tr>
<td>Life of Tractor in years</td>
<td>7 years</td>
</tr>
<tr>
<td>Life of Tractor in miles</td>
<td>490,000</td>
</tr>
<tr>
<td>Life of Trailer</td>
<td>12 years</td>
</tr>
<tr>
<td>Replacement Cost of Tractor</td>
<td>£48,940</td>
</tr>
<tr>
<td>Replacement Cost of Trailer</td>
<td>£20,948</td>
</tr>
<tr>
<td>Fuel Consumption (tarmac road)</td>
<td>9.8 MPG</td>
</tr>
<tr>
<td>Fuel Price per litre</td>
<td>£0.62</td>
</tr>
<tr>
<td>Tyre Life in miles for Tractor</td>
<td>58,000 miles</td>
</tr>
<tr>
<td>Tyre Life in miles for Trailer</td>
<td>49,000 miles</td>
</tr>
<tr>
<td>V.E.D</td>
<td>£1200</td>
</tr>
<tr>
<td>Insurance</td>
<td>£2,297</td>
</tr>
<tr>
<td>Depreciation of Tractor</td>
<td>£6,169</td>
</tr>
<tr>
<td>Depreciation of Trailer</td>
<td>£1,746</td>
</tr>
<tr>
<td>Total Standing Costs</td>
<td>£11,412</td>
</tr>
<tr>
<td>Fuel</td>
<td>£20,106</td>
</tr>
<tr>
<td>Tyres (for both tractor and trailer)</td>
<td>£2,591</td>
</tr>
<tr>
<td>Maintenance (for both t &amp; t)</td>
<td>£7,345</td>
</tr>
<tr>
<td>Total Running Costs</td>
<td>£30,042</td>
</tr>
<tr>
<td>Employment Costs</td>
<td>£19,674</td>
</tr>
<tr>
<td>Overheads</td>
<td>£12,248</td>
</tr>
<tr>
<td>Total Costs Overall</td>
<td>£73,376</td>
</tr>
</tbody>
</table>

Table 8 Demonstration of Costs of Timber Haulage Vehicles Compared to Typical Road Haulage Vehicles

The cost of tyres is more than double the average in general haulage, owing to the lack of traction on forest roads, and steep camber on each side of the road. These cause increased wear to the inside tyres of twin wheels, and excessive wearing to the shoulders of super singles. Timber haulage vehicles also suffer from a large proportion of tyres being punctured or destroyed due to stones. This is partly caused by sharp stones slicing the side walls of tyres, which can lead to:
- immediate ‘blow out’ of tyres.
- delayed ‘blow out’ two or three weeks later, owing to corrosion of their steel banding (chords) following ingress of moisture.
Even when stones only penetrate the running surface of the tyres, this requires major repair. Unfortunately, tyre manufacturer will seldom repair such tyres due to excessive damage to chords.

Other maintenance costs are also higher for timber haulage vehicles. This is not surprising, given that the vehicles are designed for tarmac roads, not for the forest environment. This causes excessive strain on all components. This is recognised by the Department of Transport who require, as part of a condition of obtaining an Operators’ Licence, that the service inspections are conducted at four weekly intervals rather than the usual six weekly intervals. In most cases timber haulage vehicles have to be replaced after three years owing to excessive maintenance costs and the down time, as opposed to 7 years in general haulage. With trailers, the expected life is five years against a twelve-year expectation in general haulage. Thus depreciation is a major influence on higher standing costs. This is combined with a higher initial cost of each item equates to hefty costs by comparison.

Employment costs are also higher because drivers have to be highly skilled and dedicated to do this job. For example, drivers of timber haulage vehicles often have to grade and sort timber at forest roadside. They also have to make risk assessments in highly variable conditions and endure extreme weather and its affects on forest road condition. The greater demand on wages is also fuelled by comparisons with the harvesting sector where machine operators are paid considerably higher wages than most lorry drivers. This can lead to difficulties in retaining the best drivers.

Overhead costs are 33% more than in general haulage owing to the higher amount of administration involved. For example, in the general haulage sector a lorry may uplift a load in Aberdeen for delivery in London. This involves two telephone calls and the truck is employed for at least a day and a half. However, within timber haulage each vehicle on average does three loads per shift and for each load that requires three times the amount of phone calls and also results in three times the paperwork.

In summary, we estimate that two thirds of the cost of running conventional timber lorries is associated with work inside the forest, even though the roads distances on tarmac roads are much greater.

5.5 Demonstration of Lorry Turning Movements

Much of the damage to forest roads caused by timber lorries occurs at bends, where the verge and drains are often compromised and the road surface scoured and sheared by “tyre scrub”. In this study the impact of different lorry configurations was investigated as a means to identify which are least and most damaging.

Trials were done using different configurations of vehicles illustrated by Diagram’s A-D in appendix and summarised in Table 9.
Diagram A

Six-axle articulated combination with double-drive tractor, pulling a three-axle trailer on super single tyres.

Diagram B

Eight-wheeler rigid and drag trailer. The vehicle was fitted with super single tyres on both steer axles, twin wheels on both rear drive axles. The trailer was a three-axle configuration with mini wide super singles.

Diagram C

Six-wheeler rigid and a pull drag trailer. The vehicle was fitted with super single tyres on the steering axle and twin wheels on the drive axles. The trailer was a three-axle configuration with small twin wheels.

Diagram D

Six-axle articulated combination with single drive tractor unit and lift axle. The trailer was three-axle configuration with twin wheels.

Table 9 Configurations of Vehicles Used in Demonstration of Lorry Turning Movements (with reference to Diagrams A-D in the Appendix)

The detailed results of the trials are illustrated by Diagram’s E-H in appendix and summarised in Table 10.

<table>
<thead>
<tr>
<th>In order of best (tightest) turning circle</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diagram E Six-wheeler rigid and a drag trailer (Diagram C)</td>
<td>The lorry had a lot of tail-swing, which meant that the trailer followed well in the track of the lorry. However, the trailer went outside the straight line starting point of the vehicle before cutting in and making the turn. On a narrow road this could mean the trailer going in the ditch just after the driver makes the turn. It was also noted that the twin wheels on the drawbar trailer had more resistance to turning therefore caused more disruption to road material than single tyres.</td>
</tr>
<tr>
<td>Diagram F Eight-wheeler rigid and drag trailer. (Diagram B)</td>
<td>This did not make as tight a turn as the six-wheeler owing to the fact it has two steering axles. Its trailer did follow the path of the vehicle very well, and on the whole this vehicle was a lot kinder to the road surface than the six-wheeler and trailer. This is due to there being two axles front and back of the lorry and the fact that the drawbar trailer has mini super singles, which are easier to turn round corners.</td>
</tr>
<tr>
<td>Diagram G Six-axle articulated combination with single drive tractor pulling tri-axle trailer with twin wheels. (Diagram D)</td>
<td>This unit has a pusher lift axle, which is slight shorter than a double drive tractor unit and the tri-axle trailer with twin wheels has a high resistance to turning which makes it slower to cut in. During the manoeuvre the tyres on the trailer caused extensive disruption to the road surface i.e. tyre scrub.</td>
</tr>
<tr>
<td>Diagram H Six-axle articulated combination with double drive tractor, pulling a tri-axle trailer on super single tyres. (Diagram A)</td>
<td>The double drive tractor is slight longer which makes its turning radius bigger, road surface damage was less on this than the other articulated combination because super single tyres on the trailer are easier turned than twins.</td>
</tr>
</tbody>
</table>

Table 10 Summary of Results in Demonstration of Lorry Turning Movements (with reference to Diagrams A-H in Appendix)
5.6 Demonstration of Lorry Performance on Gradients

A trial was undertaken using a forest road gradient of approximately 1 in 8; the forest road surface was slightly loose but reasonably representative. Each vehicle (see Table 9) was then driven from a “standing start” to the same point on the hill. The results are summarised in Table 11.

<table>
<thead>
<tr>
<th>In reverse order of disruption caused to road surface</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Six-wheeler rigid and a drag trailer (Diagram C)</td>
<td>No problem with minimal disruption to road surface.</td>
</tr>
<tr>
<td>Eight-wheeler rigid and drag trailer. (Diagram B)</td>
<td>This was the best in the “pick off” (gaining early traction), largely owing to the fact that the vehicle carries most of the weight in relation to the trailer. Again minimal disruption to road surface.</td>
</tr>
<tr>
<td>Six-axle articulated combination with double drive tractor, pulling a tri-axle trailer on super single tyres. (Diagram A)</td>
<td>This had no problem “picking away” (gaining traction) on the hill. Compared to the drag trailer combinations there was more (albeit slight) disturbance to the road surface.</td>
</tr>
<tr>
<td>Six-axle articulated combination with single drive tractor pulling tri axle trailer with twin wheels. (Diagram D)</td>
<td>The drive axle wheels spun before the vehicle moved, casting off the looser top material before getting down to harder material and a better grip. Once in motion, there was no further problem.</td>
</tr>
</tbody>
</table>

Table 11 Summary of Results in Demonstration of Lorry Performance on Gradients (with reference to Diagrams A-D in the Appendix)

A further test was carried out on similar gradient, where the vehicles ran up the hill without a stop. The results of this were satisfactory for all vehicles as they climbed the hill without any difficulty, although the drive axle on the single drive vehicle (Diagram D) was spinning slightly. If these tests had been done on a “live” harvesting site, the vehicle with the single drive would have been unable to get sufficient traction in the additional mud or dust that would be expected.

5.7 Comparison of Super Single and Twin Tyres

There is considerable debate concerning the additional damage done to forest roads done by super single tyres as compared to the (now much rarer) twin tyres. Table 12 presents a summary of comparison demonstrating the issue is far from simple.
### Good Points

- Wheel combinations are lighter.
- Less drag on corners, which makes it less likely that the drawing vehicle will lose traction on corners with excess gradients.
- Better fuel consumption due to less drag.
- Lower purchase price compared with twin wheels.
- Allows trailer to be built with a wider chassis, which helps stability.
- Air suspension is not successful in the forest environment unless super single wheels are used, this is largely due to the chassis width. (The narrower the chassis becomes the more roll is produced, which also produces sideways forces exerted on the suspension.)
- The width of chassis means timber bolsters are supported further out; this gives longer life and less chance of cracking also helping to keep uprights straight.

### Bad points

- More damage to forest roads because wheel is working on the edge of the road.
- If punctured you must stop as opposed to a twin wheel, where you can still drive, carefully, to the nearest workshop/main road to get a repair done.
- If damage by sharp stones on forest roads occurs, the cost of replacing a super single is far greater than replacing one single wheel of a twin.

### Super Singles

- Kinder to forest roads as regards tracking.
- If one wheel gets punctured, generally the vehicle can still carry on the journey to the nearest tyre repair facility.
- If a tyre sustains damage due to sharp stones it is cheaper to replace than a super single.

### Twin Tyres

- Much heavier than equivalent super single combination.
- Does more damage to forest road surfaces on cornering, due to extra tyre scrub.
- Not as stable owing to narrow chassis design
- Trailer suspension more prone to faults owing to extra strain on corners, produced by roll due to a narrower chassis.
- Less efficient on fuel due to extra drag factor with more wheels.
- More expensive trailer build.
- Twin wheels tend to wear tyres unevenly (In forestry work the inside tyre wears away 30% quicker than the outside, owing largely to road camber).

### Table 12 Summary of Comparison between Super Single and Twin Tyres

<table>
<thead>
<tr>
<th></th>
<th>Good Points</th>
<th>Bad points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Super Singles</strong></td>
<td>• Wheel combinations are lighter.</td>
<td>• More damage to forest roads because wheel is working on the edge of the road.</td>
</tr>
<tr>
<td></td>
<td>• Less drag on corners, which makes it less likely that the drawing vehicle will lose traction on corners with excess gradients.</td>
<td>• If punctured you must stop as opposed to a twin wheel, where you can still drive, carefully, to the nearest workshop/main road to get a repair done.</td>
</tr>
<tr>
<td></td>
<td>• Better fuel consumption due to less drag.</td>
<td>• If damage by sharp stones on forest roads occurs, the cost of replacing a super single is far greater than replacing one single wheel of a twin.</td>
</tr>
<tr>
<td></td>
<td>• Lower purchase price compared with twin wheels.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Allows trailer to be built with a wider chassis, which helps stability.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Air suspension is not successful in the forest environment unless super single wheels are used, this is largely due to the chassis width. (The narrower the chassis becomes the more roll is produced, which also produces sideways forces exerted on the suspension.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• The width of chassis means timber bolsters are supported further out; this gives longer life and less chance of cracking also helping to keep uprights straight.</td>
<td></td>
</tr>
<tr>
<td><strong>Twin Tyres</strong></td>
<td>• Kinder to forest roads as regards tracking.</td>
<td>• Much heavier than equivalent super single combination.</td>
</tr>
<tr>
<td></td>
<td>• If one wheel gets punctured, generally the vehicle can still carry on the journey to the nearest tyre repair facility.</td>
<td>• Does more damage to forest road surfaces on cornering, due to extra tyre scrub.</td>
</tr>
<tr>
<td></td>
<td>• If a tyre sustains damage due to sharp stones it is cheaper to replace than a super single.</td>
<td>• Not as stable owing to narrow chassis design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Trailer suspension more prone to faults owing to extra strain on corners, produced by roll due to a narrower chassis.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Less efficient on fuel due to extra drag factor with more wheels.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• More expensive trailer build.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Twin wheels tend to wear tyres unevenly (In forestry work the inside tyre wears away 30% quicker than the outside, owing largely to road camber).</td>
</tr>
</tbody>
</table>

### 5.8 Central Tyre Inflation

Central tyre inflation systems make it possible for drivers to quickly and accurately reduce or increase tyre pressure. They are designed to keep tyres inflated to the correct pressure and to optimise fuel consumption. They also offer a practical possibility that tyre pressure could be reduced in the forest to reduce damage to the forest roads. However, heavy goods vehicles are designed to run with tyres at full
pressure; anything less than the correct pressure leads to feathering of the side walls of tyres and could result in casing failure within 2-3 miles if too soft. In addition, the central tyre inflation systems on offer in the UK are both expensive and susceptible to damage in the forest environment.

5.9 Recommendations from the Haulage Companies

The overall conclusion of the review of vehicle specifications is that a range of configuration options are available for use on forest roads. Timber hauliers and forest managers can use the arguments listed in the tables above to reach conclusions pertinent to their local conditions.

During the trials an area of quarry floor was marked out to simulate the dimensions of a turning area. Following failure to correctly manoeuvre any of the four vehicles in the trial, it was concluded that the specification was too tight. The marked area was then altered until all vehicles were able to complete the manoeuvre safely. A new specification has been derived to allow a longer lead-in. Turning area should always be made on the right-hand side of the road going in, this gives the driver good visibility when making manoeuvres, especially in the dark, or times of poor visibility.

The haulage companies also offered advice on dealing with or managing the damage caused by frost.
- Avoid travel on a recovering road until it has had time to naturally settle after ‘swelling’.
- Cut trees back a considerable distance from both sides of the road thus allowing daylight and ventilation by the wind. This enables the forest road to thaw and dry quicker.
- Time harvesting operation’s so that the sites that combine the higher altitude, alongside the furthest distance travelled on forest roads, are harvested during the summer months.

The haulage companies also called for forest engineers to further consider the impact of road camber on vehicles. Road camber on forest roads is very important to enable surface water to drain off. However, it was noted in the vehicle trials that on highly cambered roads, the trailers did not bounce vertically on their suspension but tended to bounce sideways. This lead to an oscillating motion and infers serious strains and damage to the air suspension system, which is not designed to take such imposed loads. Such sideways oscillation will also have an impact of the forest road pavement.

5.10 The Future of Forest Vehicles

Scandinavian countries have timber haulage vehicles with a maximum gross weight of 60 tonnes, bringing considerable efficiency in unit cost. Although such vehicles could arguably operate within Scottish Forests, they would not be allowed on any public road. This would not be a practical proposition, and it is concluded that vehicle combinations are likely to stay at 44 tonne gross in Scottish Forests. This maximum weight is only permitted if the vehicle has six axles and the trailer axles are suspended by air.
Super single tyres are, in particular circumstances, bad for the forest roads and there are occasional calls for a return to twin tyres as standard. However, the cost is not affordable by the forest industry. One factor in this equation is that trailer manufacturers now use only standard width chassis to run on super-single tyres, and a return to twins would involve specialist build.

All new vehicles and trailers are now built with lift axles, that cannot be lifted if their suspension has excess load. In the forest environment, hauliers find it important to be able to lift a trailer axle to give added traction to the drawing vehicle. This causes additional damage to forest roads.

The specification for generic haulage vehicles will definitely become more environmentally friendly by means of the introduction of Euro three and Euro four engines. Suspensions will become more road friendly in respect of public highways, though this may mean they may become less suited to forest roads e.g. in respect of ground clearance.

5.11 Specialised Forest Road Vehicles

5.11.1. Introduction

During the review it was concluded that in Galloway, the repair of ruts and associated carriageway failures cost the grower an average of £1.00 for every tonne of timber hauled. It was also concluded that perhaps two thirds of the costs for conventional articulated timber lorries arises from haulage on forest roads, even though the distance travelled on tarmac roads is far higher.

One of the aims of the review was to identify whether the unit cost of timber haulage and roads maintenance could be reduced by introduction of “bespoke” systems. These systems might involve specialist vehicles that are both robust and less damaging to forest roads, delivering timber to skeletal trailers parked in landings near public roads. It was conjectured that the use of red diesel within the forest, and the potential for cheap haulage by “tarmac only” vehicles might offset the additional costs of double handling. The “tarmac only” lorries could have markedly lower running and repair costs. The use of skeletal trailers also promises to reduce lorry journeys (by 15-20%) on public roads because their payload does not include a heavy crane. Normal articulated lorries with fitted cranes carry 25 tonnes of timber payload as against 29 tonnes for skeletal trailers.

5.11.2 The McCormick/McColm prototype

In January 2002, Messrs Chic McColm and Brian McCormick approached Forest Enterprise to request that we consider testing the prototype timber trailer they had independently designed, and which was then at an advanced stage of construction. The Review of Timber Haulage and Forest Roads was nearing completion at that time, and was extended to permit testing to take place (amongst other reasons). Until this point in the review, physical trials had involved only conventional timber lorries, and consideration of more specialised vehicles had been in theory only. The trial of the
prototype was largely funded by Scottish Enterprise as an addition to the main review, and Forest Enterprise provided timber haulage contracts for the trial and also to allow initial trouble-shooting before the first trial began in July 2002. In an extension to the initial trial, to test the combination in winter conditions, Forest Enterprise also provided financial assistance. Howie Forest Products and John Miller Transport supported the trial with organisational and physical assistance during (and before) the trials.

In the trial, the prototype trailer was linked to a military specificati on lorry. The trailer has a unique configuration of axles and wheels designed to reduce ground pressure overall and spread much of the weight into the middle of the road, where the road is strongest. This configuration evenly rolls the road surface, and reduces the rutting commonly seen when “super single” articulated lorry trailers are used for timber haulage. The trailer has a system of double articulation, which is designed to ensure that the trailer follows the tug and that there is reduced corner damage to roads from “scrubbing”. Scrubbing occurs when multi–axle trailers are pulled round corners and wheels are dragged transversely across the road causing scraping of the surface layer. The double articulation initially made reversing impossible, but this problem was solved during the winter trial.

5.11.3 Trial Objectives and Methods

The objectives were:

- To assess the practicalities of operating a system of timber haulage using a specialist vehicle to move timber from work sites to roadside landings.
- To assess the performance of the prototype vehicle on forest roads in respect of both damage to roads and to its efficiency in timber haulage (with reference to payload and turn around time).
- To determine the time taken on the individual elements of the system, with a view to estimating overall costs and determining where savings could (or should) be made.
- To determine an optimum landing size and shape to suit the prototype and similar vehicles
- To make recommendations for further developments based on the evidence collected

In order to accommodate sufficient skeletal trailers for effective changeovers, landing bays were constructed at the end of two key forest roads and within 500 metres of tarmac public roads. These trailers were removed, unloaded and returned on a regular basis to avoid bottlenecks (as far as possible). In the summer trial, John Miller Transport provided five trailers working with a single tug which was designed to shuttle continuously delivering six loads per day to the sawmill. Howie Forest Products changed their working pattern to allow offloading of these trailers at the sawmill. In the winter trials, John Scott Transport provided trailers for deliveries of pulpwood and chipwood to customers in Ayrshire.

The prototype vehicle was used to move timber from harvesting sites to the trailers in the landings. Times were measured for each element of the movement of timber from work site to either Howie sawmill or Caledonian Pulpmill using the prototype vehicle.
This was repeated for conventional lorries fitted with loaders delivering timber to the same locations.

D&G Council agreed to weigh the prototype vehicle, a standard lorry with skeletal trailer, and a multidrive tractor and trailer unit to permit comparison of axle weights. These readings were to provide an indication of the ground pressure being exerted by each vehicle, in conjunction with an understanding of the footprint area of their tyres.

5.11.4 Trial Results

The results of the time trials are shown below in table 13. In essence, the double handling associated with use of the prototype increased the overall time required by 24% for typical haulage distances.

<table>
<thead>
<tr>
<th>Product</th>
<th>Short Roundwood (SRW)</th>
<th>Sawlogs/bars</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>To Landing 1</td>
<td>To Landing 2</td>
</tr>
<tr>
<td>PROTOTYPE VEHICLE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel from landing to work site</td>
<td>6.0</td>
<td>13.1</td>
</tr>
<tr>
<td>Load prototype vehicle</td>
<td>26.1</td>
<td>25.0</td>
</tr>
<tr>
<td>Secure load</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Travel loaded</td>
<td>9.6</td>
<td>29.0</td>
</tr>
<tr>
<td>Release load</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>Load skeletal trailer from prototype vehicle</td>
<td>24.0</td>
<td>28.6</td>
</tr>
<tr>
<td>Travel time of turning</td>
<td>4.1</td>
<td>2.4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>79.1</td>
<td>107.4</td>
</tr>
</tbody>
</table>

| TARMAC ROAD HAULAGE ONLY               |                       |              |
|                                        | From Landing 1        | From Landing 2|
| Trailer change                         | 8.5                   | 9.0          |
| Secure load                            | 5.0                   | 6.6          |
| Travelling time to mill                | 91.0                  | 92.6         |
| Turnaround time in mill                | 28.0                  | 23.0         |
| Travel unladen                         | 73.0                  | 80.0         |
| TOTAL                                  | 205.5                 | 211.2        |

| FITTED CRANE LORRY HAULAGE             |                       |              |
|                                        | Whole distance        | Whole distance|
| Load vehicle                           | 31.0                  | 30.3         |
| Secure load                            | 5.0                   | 5.0          |
| Travel loaded                          | 97.0                  | 99.0         |
| Turnaround time in mill                | 34.0                  | 27.0         |
| Travel time returning                  | 70.0                  | 86.0         |
| TOTAL                                  | 237.0                 | 247.3        |

Table 13 Result of time trials comparing prototype (in forest) plus tarmac haulage to conventional haulage with conventional fitted crane system

The results of the weighbridge studies (Table 14 below) confirm that when loaded, the prototype trailer exerts much less ground pressure per wheel than a skeletal lorry trailer (less than 70%), and about the same as the multi drive trailer (which has a far smaller payload). When unladen, the ground pressure per tyre was least for multi-drive trailer and roughly similar for the prototype and skeletal trailers. The main
feature of the prototype trailer was, of course, that much of the burden is spread into the middle of the road. The “military tug” lorry has very high ground pressure per wheel (140% of the conventional lorry tug) and the multi-drive tractor, when laden, is comparable to the conventional lorry tug.

<table>
<thead>
<tr>
<th>Prototype trailer with &quot;military tug&quot;</th>
<th>TUG</th>
<th>TRAILER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axle 1</td>
<td>Axle 2</td>
<td>Axle 3</td>
</tr>
<tr>
<td>laden weight (Kg)</td>
<td>9400</td>
<td>6290</td>
</tr>
<tr>
<td>empty weight (Kg)</td>
<td>6570</td>
<td>4270</td>
</tr>
<tr>
<td>wheels</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>laden ground pressure Kg/wheel</td>
<td>4700</td>
<td>3145</td>
</tr>
<tr>
<td>empty ground pressure Kg/wheel</td>
<td>3285</td>
<td>2135</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Skeletal trailer with &quot;conventional tug&quot;</th>
<th>TUG</th>
<th>TRAILER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axle 1</td>
<td>Axle 2</td>
<td>Axle 3</td>
</tr>
<tr>
<td>laden weight (Kg)</td>
<td>6220</td>
<td>8860</td>
</tr>
<tr>
<td>empty weight (Kg)</td>
<td>5280</td>
<td>3550</td>
</tr>
<tr>
<td>wheels</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>laden ground pressure Kg/wheel</td>
<td>3110</td>
<td>2215</td>
</tr>
<tr>
<td>empty ground pressure Kg/wheel</td>
<td>2640</td>
<td>888</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simple trailer with &quot;Multidrive tractor&quot;</th>
<th>TUG</th>
<th>TRAILER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axle 1</td>
<td>Axle 2</td>
<td>Axle 3</td>
</tr>
<tr>
<td>laden weight (Kg)</td>
<td>3790</td>
<td>6860</td>
</tr>
<tr>
<td>empty weight (Kg)</td>
<td>3920</td>
<td>5710</td>
</tr>
<tr>
<td>wheels</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>laden ground pressure Kg/wheel</td>
<td>1895</td>
<td>3430</td>
</tr>
<tr>
<td>empty ground pressure Kg/wheel</td>
<td>1960</td>
<td>2855</td>
</tr>
</tbody>
</table>

Table 14 Axle loading of different configurations of tugs and trailers

The damage inflicted on roads is only crudely assessed by ground pressure per wheel, as this parameter takes no account of the size of the footprint (which is relating to tyre size and pressure). The prototype trailer has larger wheels than the skeletal trailer and a lower tyre pressure (75 versus 120 psi). The prototype trailer thus appears to be even more road friendly than the figures for ground pressure per wheel suggest. These considerations also apply to the tug vehicle, but are unlikely to change the relative rankings of the vehicles and the poor assessment of the “military tug”.
The visual assessment of the road surfaces confirmed the prototype trailer and tug to be generally less damaging than conventional lorries, and indeed had a beneficial effect on the running surface. The benefits were especially marked where forwarders had rutted the forest road and where the road had been potholed and/or patched before the trial. There were no adverse comments from any observer on the effect of the prototype on the roads. Access for small vehicles i.e. vans and cars was maintained without any requirement for additional rolling.

5.11.5 Conclusions of the physical trials

The results from the trial demonstrated that haulage from timber production sites in Galloway Forest District to customers can be effective using a system where a purpose built lorry and trailer moves timber to skeletal trailers parked in landings for onward dispatch by standard road going tugs. The system if affordable would reduce the number of timber lorry journeys on public roads by increasing the payload of each journey. There benefits in being able to demonstrate to the public that by using skeletal trailers every effort is being made to reduce the number and frequency of lorry journeys through rural communities. Some hauliers already operate a loading system, which achieves part of this objective.

It is clear that the prototype trailer will successfully reduce damage to forest roads, but the “military tug” is more damaging. A more conventional lorry tug or tractor would be preferred.

5.11.6 Estimating the cost of a “bespoke haulage” system using the prototype system as an example.

The following calculations (in table 15 below) are based on the information supplied by two of the largest timber haulage firms in the south west of Scotland (from table 8 above). It may be appropriate to inflate the tarmac only haulage rate (of £1.048 per mile) given the poor standard of the “B” and “C” class roads routinely used by timber lorries, albeit for a small proportion of their journeys. However, it is clear that tarmac road haulage is considerably easier on men and machinery than timber haulage on forest roads, and machines last much longer, than in systems which incorporates both forest road driving and timber loading. The average distances used in these calculations are from the two landing areas already trialled in the prototype haulage system. The apparent financial competitiveness of the prototype trailer relies in great part to the use of red diesel within the forest.
### Table 15 Indicative costs of a trial “bespoke” system compared to conventional haulage

<table>
<thead>
<tr>
<th>Product</th>
<th>Sawlogs /bars</th>
<th>Pulpwood</th>
<th>Chipwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>A “bespoke” system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance of round trip to mill in miles</td>
<td>105</td>
<td>83.5</td>
<td>91.0</td>
</tr>
<tr>
<td>Projected cost of trip @ 104.8 p per mile ++</td>
<td>£110.04</td>
<td>£87.51</td>
<td>£95.37</td>
</tr>
<tr>
<td>Price per tonne for a 28 tonne load</td>
<td>£3.93</td>
<td>£3.12</td>
<td>£3.41</td>
</tr>
<tr>
<td>Prototype vehicle cost estimated from £350 per shift</td>
<td>£2.00</td>
<td>£2.00</td>
<td>£2.00</td>
</tr>
<tr>
<td>Total</td>
<td>£5.93</td>
<td>£5.12</td>
<td>£5.41</td>
</tr>
<tr>
<td>Conventional haulage system</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Projected Cost @ 187.3 p per mile costing from Table 8 of report and 25 tonne load ++</td>
<td>£7.86</td>
<td>£6.26</td>
<td>£6.82</td>
</tr>
<tr>
<td>Current Rate</td>
<td>Commercial in confidence</td>
<td>£6.30</td>
<td>£6.30</td>
</tr>
</tbody>
</table>

*** Calculated from HFP contract, subject to commercial confidentiality, but the figure can hopefully be divulged for this report.

++ Figures taken directly from table 8 above

Table 15 above appears to indicate that there is scope within timber haulage in Galloway for the cost-effective introduction of a “bespoke” haulage system employing a specialist vehicle within the forest. This is true even if a 40% increase in the factor of £1.04 per mile is used to calculate tarmac haulage costs. It is remarkable that these trials indicate that savings in timber haulage costs are likely without the need to take account of potential savings in road damage.

It is also remarkable that these strong indications of savings were forthcoming from a trial that identified a number of areas of improvement for the particular vehicle combination involved. Loading and unloading time for the prototype lorry constituted over 50% of the time in one full cycle of timber movement in a round trip of nearly 11 miles on forest roads. There is scope to reduce this total time considerably with technical improvements. The most direct change could be in the loader type and size and a specialist in loaders estimated a saving of 40% of the loading time. The implications of this on the cost of prototype haulage is considerable and could reduce costs by as much as £0.50 per tonne (all other things being equal!). Other possibilities for reducing costs may be considered such as having forwarders load of low ground pressure trailers if these could be hitched and unhitched quickly to the tug vehicle.

5.11.7 Introducing “bespoke systems”

The following discussion relates very much to Galloway, where timber haulage often involves very long distances of forest road travel and shorter distances on tarmac roads than in many other forest areas. There is no presumption that “bespoke” systems will be appropriate in other conditions.
Haulage contracts are normally set by competitive practice and to date have almost exclusively involved the carriage of timber from deep in the forest to the customer. The haulage companies have invested in equipment to do the work, including various loaders, trailers and tugs. A new tender structure needs to be developed which permits hauliers to reposition their annual investment programme with confidence that their profit levels can be sustained.

Forest Enterprise now plan to tender a sizeable proportion of their haulage with a view to encouraging competing interests to introduce bespoke systems with specialist forest vehicles. On the flip side of this argument, there needs to be provision for hauliers to invest in lightweight “tarmac only” kit so that savings may be achieved outside the forest.

It is important that the forest roads used by specialist vehicles are not also used by conventional lorries, so we need to ensure the bespoke systems apply to all the products from given harvesting sites; sawlogs as well as short roundwood. Pulp mills and particleboard factories unload lorries, but sawmills seldom do. The wholesale introduction of bespoke systems can only happen if the sawmills have sufficient capacity to unload or if that capacity can be put in place.

Sawmills have historically been supplied by lorries that unload themselves. Many companies have a requirement for all logs to be uniformly orientated tip first onto the log deck, in order for them to be presented correctly for sawmilling. The trial has demonstrated that some degree of unloading is already possible and that the orientation issue can be overcome. It is anticipated that a steady flow of skeletal trailers could already be accepted, at our trial mill, but subject to limits on overall volume and periodicity. Wholesale conversion to deliveries by skeletal trailers would probably require additional investment, though the potential for utilisation of existing loaders at the sawmill is not yet fully explored.

Forest Enterprise is currently consulting with its customers and haulage operators with a view to arranging an opportunity for bespoke systems to be introduced on routes that involve long hauls over forest roads. The overall scale of this opportunity may total 50,000 tonnes per year in Galloway. The opportunity will only be realised if the net cost of haulage is improved upon in a tender.

The prototype trailer used during the trials, or its successors, will be acceptable, subject to the following caveats:

- a means of easily reversing in order to turn in standard lay-bys
- a change to the tug unit
- a change in tug unit configuration to assist reverse turning by allowing more overhang behind the rear drive wheels
- a larger capacity crane which would be faster and able to lift more with each grapple full
- an oil cooling system for the crane to ensure constant efficiency
- a covered loading cab for the safety and comfort of the operator.

The prototype has now been acquired by John Scott Transport Ltd, who wish to develop the concept further. At the time of writing there is a possibility that a related
Companies developing other forms of low impact vehicles will also be encouraged to compete for the opportunity. We know that there will be competition, and that others see advantages in introducing robust specialist vehicles for use in forests. Forest Enterprise will use mechanical and civil engineering specialists to help evaluate new technologies as they come forward.

5.11.8 Areas for Further Research

Trials of forwarder loading of prototype trailers and/or containerisation should also be conducted in an attempt to reduce costs further. Containerisation or bundling could be incorporated into the movement chain from standing timber, but no clear methodology exists yet that fits into the local conditions of Galloway. Although this concept was tried on a large scale for use in loading trains it is still felt that smaller scale bundles or “palletisation” could feature as a cost saving element of the timber movement system. Future developments such as rail transport may further highlight the need to focus on the possibility of containerisation.

As there is the likelihood that some railhead facility will be constructed near Barrhill there is scope for the specialist vehicles to be extended in length by the addition of further trailers to form a “road train”. This train would follow the road because of the method of articulation, use road friendly axle configurations and deliver a greater payload for every journey made which should reduce road and haulage costs.
6 ROAD NETWORK MANAGEMENT

6.1 Introduction to Highway Development and Management – HDM-4

6.1.1 Background
The Highway Design and Maintenance Standards Model (HDM-4) was dealt with in detail in the Interim Report, and only a summary of the methodology is given here. Given the increasing demands on the forest pavement network, it is becoming increasingly important to apply modern management techniques so that material can be maximized for the available funding. For the Galloway study area, the HDM-4 Highway Development and Maintenance tool has been applied. HDM-4 is a sophisticated transport model designed to evaluate different transportation options taking into account vehicle operating costs, road design and maintenance costs. The comprehensive approach allows the engineer to compare a wide range of options of vehicle type, road design and maintenance strategies. In the Scottish forestry context, the model is perhaps more complex than required, but vitally, it provides a standard and established methodology to evaluate and decide on optimum timber transport solutions.

6.1.2 Life Cycle Analysis Concept
The HDM-4 analytical framework is based on the concept of pavement life cycle analysis. This is applied to predict the following over the life cycle of a road pavement, which is typically 15 to 40 years:
- Road deterioration
- Road work effects
- Road user effects
- Socio - Economic and Environmental effects

6.1.3 Calibration and Adaptation of HDM-4 to local conditions
To obtain a working model for the Galloway area each of these affects must be modeled in a manner which is calibrated for the local situation. Road Deterioration and Works effects for unsealed roads depend on a number of factors including roughness, material loss, rutting, surface looseness and impassability. Each of these is modeled using previously established relationships which were calibrated on the basis of local experience using a simple classification approach for the inputs (as opposed to precise enumeration of values). Road User effects include vehicle operation costs, travel time costs and accident costs.

As it is not possible to model the operating costs of individual vehicles, we must resort to the use of representative vehicles. For this project they were assumed to range from a light van to a heavy timber vehicle and a road construction tipper truck. The data for these vehicles was derived from data previously presented in Table 13 and from typical values available to HDM-4. The tipper truck was assumed to contribute 10% of the traffic, the timber truck 20% with the remainder being the lighter vehicles. Zero growth rate was assumed as, for any pavement, the traffic only depends on the volume of timber being accessed.
<table>
<thead>
<tr>
<th></th>
<th>Typical Road Haulage</th>
<th>Timber Haulage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Figures based on 44 Tonne (gross) articulated vehicle with costs as at December 2001</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Mileage</td>
<td>70,000 miles</td>
<td>70,000 miles</td>
</tr>
<tr>
<td>Life of Tractor in years</td>
<td>7 years</td>
<td>3 years</td>
</tr>
<tr>
<td>Life of Tractor in miles</td>
<td>490,000 miles</td>
<td>210,000 miles</td>
</tr>
<tr>
<td>Life of Trailer</td>
<td>12 years</td>
<td>5 years</td>
</tr>
<tr>
<td>Replacement Cost of Tractor</td>
<td>£48,940</td>
<td>£60,670</td>
</tr>
<tr>
<td>Replacement Cost of Trailer</td>
<td>£20,948</td>
<td>£50,180</td>
</tr>
<tr>
<td>Fuel Consumption (tarmac road)</td>
<td>9.8 MPG</td>
<td>6.0 MPG</td>
</tr>
<tr>
<td>Fuel Price per liter</td>
<td>£0.62</td>
<td>£0.62</td>
</tr>
<tr>
<td>Tire Life in miles for Tractor</td>
<td>58,000 miles</td>
<td>25,000 miles</td>
</tr>
<tr>
<td>Tire Life in miles for Trailer</td>
<td>49,000 miles</td>
<td>20,000 miles</td>
</tr>
<tr>
<td>Vehicle Road Tax</td>
<td>£1200  1.72  2%</td>
<td>£1200  1.72  1%</td>
</tr>
<tr>
<td>Insurance</td>
<td>£2,297  3.27  3%</td>
<td>£8510  12.16  6%</td>
</tr>
<tr>
<td>Depreciation of Tractor</td>
<td>£6,169  8.81  8%</td>
<td>£14,255 20.36 11%</td>
</tr>
<tr>
<td>Depreciation of Trailer</td>
<td>£1,746  2.49  2%</td>
<td>£11,785 16.84 9%</td>
</tr>
<tr>
<td>Total Standing Costs</td>
<td>£11,412 16.29 15%</td>
<td>£35,750 51.08 27%</td>
</tr>
<tr>
<td>Fuel</td>
<td>£20,106 28.72 27%</td>
<td>£32,839 46.92 25%</td>
</tr>
<tr>
<td>Tires (for both tractor and trailer)</td>
<td>£2,591 3.70 4%</td>
<td>£5,580 7.97 4%</td>
</tr>
<tr>
<td>Maintenance (for both t &amp; t)</td>
<td>£7,345 10.49 10%</td>
<td>£10,720 15.31 8%</td>
</tr>
<tr>
<td>Total Running Costs</td>
<td>£30,042 42.91 41%</td>
<td>£49,139 70.20 37%</td>
</tr>
<tr>
<td>Employment Costs</td>
<td>£19,674 28.11 27%</td>
<td>£28,244 40.35 22%</td>
</tr>
<tr>
<td>Overheads</td>
<td>£12,248 17.49 17%</td>
<td>£18,000 25.71 13%</td>
</tr>
<tr>
<td><strong>Total Costs Overall</strong></td>
<td>£73,376 104.8 100%</td>
<td>£131,133 187.3 100%</td>
</tr>
</tbody>
</table>

**Table 13 Demonstration of Costs of Timber Haulage Vehicles Compared to Typical Road Haulage Vehicles**

Using this approach, nine road sections within the Carrick part of the Galloway Forest were analyzed using HDM4. Information was collected on section length, width, vertical and horizontal alignment. Pavement data were collected on road surfacing
material and subgrade material characteristics. Pavement condition data were obtained through visual survey these include roughness and surfacing material thickness. For the purpose of this trial application it was assumed that the 9 sections were in a more or less the same condition (of roughness 9 IRI and surfacing material thickness 75 mm).

Traffic level was defined in terms of annual average daily traffic (AADT) for the nine road sections. Road section A carries an AADT of 30 vehicles per day, Sections B, C, D, E and F carry AADT of 20 vehicles per day, Sections G, H and J each carries 10 vehicles per day.

The economic analysis parameters used include analysis period of 20 years, and a discount rate of 5%.

The following six road maintenance strategies were investigated:

- **Base Alternative:** Grading once a year, and spot repair (or patching) by replacing 20 percent of annual material loss when surfacing material thickness falls below 50 mm
- **Alternative 1:** Resurface/regravel every 10 years, grading once a year, and spot repair (or patching) by replacing 20 percent of annual material loss when surfacing material thickness falls below 50 mm
- **Alternative 2:** Resurface/regravel every 10 years, grading twice a year, and spot repair (or patching) by replacing 20 percent of annual material loss when surfacing material thickness falls below 50 mm
- **Alternative 3:** Resurface/regravel every 7 years, grading once a year, and spot repair (or patching) by replacing 20 percent of annual material loss when surfacing material thickness falls below 50 mm
- **Alternative 4:** Resurface/regravel every 7 years, grading twice a year, and spot repair (or patching) by replacing 20 percent of annual material loss when surfacing material thickness falls below 50 mm
- **Alternative 5:** Resurface/regravel every 14 years, grading once a year, and spot repair (or patching) by replacing 20 percent of annual material loss when surfacing material thickness falls below 50 mm

In general, road sections carrying high traffic level will experience a faster rate of roughness progression than those with low traffic levels. Road surfacing materials with a high percentage content of coarse or large size particles exhibit a faster rate of roughness progression when compared to road surfacing materials with a high percentage content of fine particles.

Material loss is affected by traffic volume, road geometry (in particular the vertical alignment), and material properties. Road surfacing materials with a high percentage content of coarse or large size particles exhibit a slower rate of material loss when compared to road surfacing materials with a higher percentage content of fine particles.
6.2 Observations on Maintenance Strategies

The results of economic analysis of the 6 maintenance strategies defined above show that the best strategy for each road section depends mainly on the traffic level and the road geometry. The maintenance strategy defined by Alternative 4 gives the lowest average roughness of 7.1 IRI over the analysis period for road section A. This compares with the average roughness of 7.5 IRI given by Alternative 2, which is most economical alternative for road section A. For all the other sections with 20 or 10 AADT, the economically best maintenance strategy is the base alternative defined as grading once a year, and spot repair (or patching) by replacing 20 percent of annual material loss when surfacing material thickness falls below 50 mm.

In general, for roads carrying about 25 AADT the economically best maintenance strategy is that which is defined in Alternative 2. For road sections with less than 25 AADT it would be better to apply the base alternative maintenance strategy. Further analysis showed that when the traffic on road section E, which has a steep gradient (RF = 81 m/km), is increased from 20 to 22 vehicles per day the best maintenance strategy changes from that defined by the base alternative to that defined by Alternative 2. This shows that the effect of road geometry on selecting the optimal maintenance strategy for a road section is significant.

It is also interesting to note that from the results of economic analysis of road section A Alternative 2 is better than Alternative 1, and the only difference between the two alternatives is in the frequency of grading. In Alternative 1 grading is applied once a year while in Alternative 2 grading is applied twice a year. Alternative 4 with a grading frequency of twice a year is the second best maintenance strategy for section A. This result shows that grading frequency is a key factor in determining the optimal maintenance strategy to be applied to a road section.

6.3 Savings in Vehicle Operating Costs

It is sensible to use the predicted absolute values of Vehicle Operating Costs (VOC) to compare the percentage change in vehicle operating costs for each pair of the maintenance strategies defined above. As an example, consider the analysis of road section A which showed that the economically best maintenance strategy is that which is defined by Alternative 2. A comparison of the VOC per km predicted under Alternative 2 with the VOC per km calculated under the base alternative, the percentage difference or savings in vehicle operating costs is about 4 % for Volvo FM12 truck. This method of comparison could be used to compute the percentage savings of vehicle operating cost per kilometer for different pairs of maintenance strategies. Alternative 4 gives the lowest average roughness and also the lowest average vehicle operating cost per vehicle kilometer. The percentage saving in VOC when compared to the prediction under base alternative is about 4.8% for Volvo FM12 timber truck.
6.4 Concluding Remarks

The trial application has demonstrated the capabilities and suitability of using HDM-4 to develop/derive solutions for cost-effective transport and strategic benefits in Scotland, but remain interim prior to a more detailed calibration.
7. Appendix (Lorry Configurations)

![Diagram A](image1.png)
VALUE £120,000

![Diagram B](image2.png)
VALUE £130,000

![Diagram C](image3.png)
VALUE £125,000