Estimation of the Serviceability of Forest Access Roads

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ABSTRACT

The purpose of this study was to ascribe attributes to forest access roads, to allow for estimation of their serviceability on the basis of their current condition. The approach estimates the quantity of timber that may be hauled through without critically damaging the flexible pavements. Seventy-two roads were classified on the basis of their surface conditions, subgrade material, and surface deflection as the strength parameter, for 40 and 60 t Gross Vehicle Weight. Using non-parametric statistical techniques, it was found that the surface quality of pavements was largely dependent on drainage conditions (coefficient of determination r^2 = 0.841, and that a strong relationship (r^2 = 0.90) also existed between drainage and the number of potholes. Pavements with peat subgrades were found to exhibit significantly higher critical deflections (5.6 mm) than pavements with mineral subgrades (1 mm), coupled with their inherent variability, it is arguable that visual classification may not be suitable for such pavements. On the basis of these results, the serviceability of individual roads, in Equivalent Standard Axle Loads (ESAL) was estimated. Potential pavement damage by a standard 6 axle timber haulage truck, of 40 t Gross Vehicle Weight, with a payload of 27 t, was evaluated to be triple that due to a standard axle (8.16 t). Increasing the payload by about 10%, increased the ESAL required to transport a unit volume of timber, hence potential pavement damage, by 20%. Consequently, a significant reduction in the serviceability of forest access roads may be incurred by small overload margins that are usually ignored.

Keywords: *Forest access roads, pavement classification, deflection, ESAL, bearing capacity.*

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INTRODUCTION

The forestry sector in Ireland is a major industry with over 2.4 million cubic metres of timber harvested annually. Eight percent of the land area is currently under afforestation, and this is expected to increase to 17% by the year 2035 [19]. The majority of commercial forests are located in remote areas on predominantly peat soils [26], which are accessed by peat based Flexible Pavements [8] that were designed for light traffic at low volumes. These roads exhibit extraordinary weakness with rapid deterioration when traversed by logging vehicles and other machinery peculiar to forestry operations. This imposes expensive repair and maintenance, and makes transportation a costly factor in the overall timber production process.

In an attempt to minimise the damage and wear to the forest access roads, hence reducing the cost of entire logging operations, several potentially beneficial investigations have been undertaken. These include; the establishment of safe axle load limits as the basis for designing an envirogentle trailer [25], establishment of optimal haulage vehicle combination [6], and the adaptation of trucks to impart lower ground contact pressures [27]. However, economic reasons require the maximisation of payload, and forest access roads are often expected to cater to heavier traffic resulting in accelerated pavement distress.

Pavement distress represents the undesirable manifestation of defects on the pavement surface that affect the road's structural capacity, appearance and hence, serviceability. Most pavements fail because of the accumulated distress from traffic and environmental factors. Deformation of pavement foundations result from the imposed load caused by traffic, and the weakening of the elastic properties of the pavement materials which increases its deflection [17]. Where a pavement has been stressed beyond its load bearing capacity, it may deform differentially, with longitudinal rutting and fatigue cracking [7], hence, classification methods based on the visual pavement surface condition have been developed 12,141. The design criteria for flexible pavements are based on the maximum permissible strain in the pavement [14] which may be quantified by measuring transient deflection [4, 8], hence, the development of deflection-repetition-performance charts [2] for assessment of these pavements. From the foregoing, it is apparent that measurement of deflection and the rating of corresponding surface condition offers a method of classifying the structural integrity of flexible pavements.

Structural damage to road pavements is mainly attributed to the axle loads imposed by heavy trucks [12], and the relationship between axle loads and their potential to cause damage to pavement structures can be expressed in Equivalent Standard Axle Load (*ESAL*), as in Equation 1 [1]:

$$ESAL = \left[\frac{L}{L_s}\right]^n \qquad (1)$$

where:

n = Index indicating the potential of load to cause damage.
L = Actual axle load, t.
Ls = Arbitrary standard axle load of 8.16 t, which is considered to have a damaging effect of unity [1].

The total potential damage due to a vehicle in ESAL's may be estimated by summing the loading factors for individual axles during a transportation cycle [29], which includes a pass of an empty vehicle and a pass of a laden vehicle. The relative damaging effect of an axle is considered to be approximately proportional to the fourth power of the load [1, 30]. However, this has been found to be an under-estimate for flexible pavements on weak subgrades such as peat [3,23], where damage has been found to be proportional to the sixth power and higher.

The aim of this study was to estimate the serviceability of some typical forest access roads in Ireland, by applying the Kennedy and Lister [16] visual classification system and extrapolating the pavement deflection-performance chart. Extrapolation was necessary because this chart does not deal with the large pavement deflections associated with weak subgrades such as peat. The capability of the access roads to allow for extraction of the projected timber volumes was then evaluated.

METHODOLOGY

Description of the Experimental Site

For the purpose of this study, 72 forest access roads in the Cork region (South-West Ireland) were selected. The dispersed forestry in the area is serviced by a large number of roads, and thus lends itself to the study. Both qualitative and quantitative measurements were used to classify the experimental pavements.

The surfacing material used in the construction of pavements in the area conformed to Department Of Environment (DOE) specifications [9] and was generally a limestone mix of crushed rock with a bituminous sealant of 5-10 mm in thickness. It was found that 68% of pavements had been resurfaced, 10% of these within the last four years. Vegetation was visible in 49% of pavements, ranging from low level weeds to high grass and shrubs, and was prolific in 28% of the resurfaced roads. There was no evidence of potholes on 70% of experimental pavements while on 22%, open potholes made driving difficult. On the remaining 8%, potholes had been repaired.

Good drainage conditions (mean drainage ditch depth of 0.7 m) were recorded on 35% of pavements, a further 40% of pavements had satisfactory drainage conditions (mean drainage ditch depth of 0.5 m) and the remaining 25% of pavements had poor drainage conditions with an average drainage ditch depth of 0.2 m. The average rainfall measured in the region during the experimental period (July 1997) was 48 mm [21].

Qualitative and Quantitative measurements

The relationships between the qualitative data were assessed using the non-parametric statistical technique; Spearmans' Ranking Correlation for matched pairs [20] with a one tailed significance test at a = 0.05. The system described by Kennedy [14] was used to quantify the damage characteristics of rut depth and magnitude of cracking at the poorest point on each pavement. The inherent subgrade was defined as 'Strong' when it was mineral soil, and Weak' where peat was present in the subgrade. Pavement strength was evaluated by measuring the transient deflection using a Benkleman Beam [14], under controlled axle load conditions in accordance with the procedure described by Kennedy et *al.* [15]. The parameters of the test vehicles are outlined in Table 1.

It was assumed that the rate of deterioration of the experimental pavements was independent of their load history, since it was recorded that they had only been exposed to light traffic of up to 1 tonne. A mean deflection value for each visual category (Sound, Critical and Failed) was calculated on the basis of the depth of rutting and the extent of cracking [14]. Pavement serviceability was then determined for each test location, by evaluating the future road performance, in volume of traffic or cumulative standard axles that the road could sus-

Table 1. Parameters of test vehicles.

Characteristic	Tractor & Trailer†	Truck††
Rear axle load	**68kN** (6880 kg)	**70kN** (7150 kg)
Dual rear wheel load	39 kN (3 900 kg)	**35kN** (3500 kg)
Minimum gap between walls of twin rear wheels	25 mm	**30mm**
Tyre pressure	590 kPa (85 psi)	590 kPa (85 psi)

† *Ford County tractor and 2 axle trailer*
†† *Leyland Freighter 2613 Truck*

tain before failing from the mean pavement deflection, by fitting the data to extrapolated Kennedy and Lister [16] curves at 75% probability. The mathematical expression of the relationship is given in Equation 2.

$$x = \left[\frac{1.05}{Y}\right]^{3.13} \qquad (2)$$

where:

x = number of cumulative standard axles to failure, in millions, and
y = measured deflection in mm.

The distributions of the Tare Weight and the Gross Vehicle Weight (GVW) by axle, for a three-axle truck and a three-axle trailer that are traditionally used in timber transportation in Ireland are presented in Table 2. The tare weights for individual axles were obtained from vehicle manufacturer specifications [18, 30]. In the absence of actual axle weight measurements specific to timber haulage vehicles, measured individual axle loads from a study carried out for trucks of equivalent payload and configuration on a motorway in Ireland were adopted [24].

For the purpose of this study the weight of timber that can be transported is the GVW less the tare weight for each load category in Table 2. A factor of unity for the conversion of volumes of timber to their equivalent weights was adopted for the forest region studied [28].

The total ESAL damage imposed on the pavement was calculated by summing individual axles during a transportation cycle. In the case of over-loaded vehicles, where the extent of damage for axle loads is greater than the standard axle load (8.16 t), a higher index (n=6) in Equation 1 was also evaluated [3, 23]. The required number of ESAL's to transport 1 m^3 of timber for each haulage strategy was evaluated from the ESAL for the respective transportation cycles, and the volume of timber that was transported.

Table 2: Axle load distribution for individual vehicle axles.

Axle	Load Distribution, t Tare	Legal Load	Over- Loaded		
		GVW			
	13t	**40 t†**	43t	**48t**	**60t**
Steering	4.49	6.37	6.85	7.60	9.48
Drive	1.735	5.48	5.89	6.57	8.14
Drive	1.735	7.38	7.93	8.85	10.97
Single	1.67	7.32	7.87	8.77	10.88
Tandem	1.67	7.60	8.17	9.12	11.29
Tandem	1.67	6.22	6.69	7.45	9.24

†*Maximum permitted Gross Vehicle Weight of 40 tonnes [10].*

RESULTS AND DISCUSSION

Using Spearmans' Ranking coefficient, a positive correlation was found to exist between all qualitative variables of surface dressing condition, number of potholes and drainage conditions. The coefficient of determination ($r^2 = 0.73$) between the condition of the surface dressing and the number of potholes, implies that the surface dressing condition accounts for 73% of the variability in the occurrence of potholes. The poor surface conditions in 84% of pavements were attributed to inadequate drainage. The relationship between drainage condition and the number of potholes ($r^2 = 0.90$) confirms that a lack of adequate drainage increased the possibility of potholes occurring.

Classification of the experimental pavements based on rut depth and extent of cracking is presented in Table 3. The Sound, Critical and Failed deflection values determined for pavements with mineral subgrades were observed to increase from 0.9 mm, to 1.0 mm and 2.7 mm, respectively. The critical point of deflection, 1.0 mm, for pavements with mineral subgrades compares favourably with the 0.9 mm critical point of deflection, at 75 % probability, determined by Kennedy and Lister [16]. Thus, visual classification can be said to provide an accurate representation of the strength of such pavements. On the basis of mean deflection for pavements with mineral subgrades, a total 48 % were deemed to have failed (Table 4), as the recorded deflection values were in excess of the failure condition of 2.7 mm.

Pavements with peat subgrades exhibited significantly higher deflections in all classes (Table 3), with only 23% of these in the Sound category. The mean deflection for the Critical category (5.6 mm) exceeded the mean for the Failed category (4.1 mm). The majority (77%) of peat based pavements were therefore considered to be in a critical state. The significantly higher deflections and their inherent variability for pavements with peat subgrades indicated that classification on the basis of visual characteristics may not be suitable for such pavements.

The projected relative pavement damage for individual axles in ESALs, evaluated using Equation 1 together with the axle loading conditions in Table 2, was used to determine whether the experimental pavements could facilitate the extraction of timber in the region without critically damaging the pavement surface. From Table 5 it can be seen that a pass of a 40 t GVW vehicle carrying a 27 t payload, will cause approximately 3 times the damage of a standard axle. A vehicle carrying a 47 t payload (GVW 60 t), using the fourth power model, will cause approximately 15 times the damage of one standard axle. If the sixth power model is adopted, the damage ratio increases by factor of 24. Thus, the impact of heavier vehicles, particularly on weak pavements, will have an adverse effect on road wear greatly accelerating the rate of pavement deterioration.

Inserting the measured deflection of y = 1.98 mm for peat based roads into Equation 2, it is evaluated that a total of 130 000 standard axles must pass be-

Table 3. Mean pavement deflection (mm ± Std. Error of mean) determined for each visual category.

Class	Pavements with mineral subgrades	Pavements with peat subgrades	All pavements
Sound	0.9 ± 0.5	1.7 ± 1.4	1.1 ± 0.8
Critical	1.0 ± 0.4	5.6 ± 3.4	3.5 ± 3.2
Failed	2.7 ± 0.9	4.1 ± 2.0	4.1 ± 1.6

Table 4. Classification of the experimental pavements based on rut depth and extent of cracking.

Class	Feature		Proportion of pavements (%)		
	Average rutting, mm	Evidence of cracking	Mineral subgrades	Peat subgrades	All roads
Sound	6 ± 3	No	41	23	37
Critical	14 ± 3	Yes	11	77	39
Failed	17 ± 7	Yes	48	0	24

fore a deflection reading of 5.6 mm is obtained and the pavement fails. Therefore, 42 000 transportation cycles, equivalent to 1140 000 tonnes of timber could be hauled at a payload of 27 t. If the payload is increased to 47 t (GVW = 60 t), 5 000 transportation cycles, equivalent to the haulage of 250 000 tonnes of timber, can be sustained. Therefore, the accelerated pavement deterioration caused by a greatly overloaded vehicle results in a reduction in the number of round trips remaining to failure, and hence, a reduction of approximately 75% in the quantity of timber that may be hauled in an envirogentle system.

For pavements with critical deflections a small increase in the GVW of timber haulage vehicles can produce a significant reduction in the volume of timber that may be hauled, consequently, projected harvest volumes may exceed the maximum recommended volumes that can be hauled before pavement failure occurs. For example, using Equation 2, a deflection of 5.5 mm equates to 5657 ESALs and from Table 3, the critical point of deflection for a peat based pavement is 5.6 mm (ESAL = 5347). Therefore, the number of remaining ESAL to failure is 310. If the maximum permitted payload of 27 t for a 13 t tare weight vehicle is adopted (Final ESAL = 3.083, Table 5) then a total of 100 transportation cycles, or 2 700 tonnes of timber may be transported before failure. Increasing the payload to 35 t (Final ESAL = 7.133, Table 5) only 43 transportation cycles will be realised, and 56 % less timber (1505 tonnes) will be hauled before pavement failure. The average total weight of timber in a single forest compartment is approximately 400 tonnes, and a single pavement may be used in the extraction of timber for up to 25 compartments. Therefore, haulage of timber even from a single harvest over this road, may result in its failure.

Options that could be used to attenuate stresses and strains to increase the lifespan of paved and unpaved roads include: increased number of axles, and constantly reduced pressure and variable tyre pressure technologies. On unpaved roads reduced tyre pressure reduces rut damage [11]. Reduced tyre pressure results in reduced road and vehicle maintenance costs for pavements with thin asphalt surfacings and a weak subgrade [22]. Central Tyre Inflation (CTI) is used to manage variable tyre pressures while a vehicle is in motion. At low pressure a tyre spreads the load over a greater tyre print area thus, reducing the contact pressure and load impact, while providing better traction under poor trafficability conditions [5].

Table 5. Equivalent Standard Axle Loads (ESAL) for haulage conditions. Using a three-axle rigid truck and a three- axle trailer.

Axle	Tare ESAL			GVW ESAL		
	n=4 13t	n=4 40t	n=4 43t	n=4 60t	n=6 48t	n=6 60t
Steering	0.092	0.371	0.497	1.822	0.770†	2.459
Drive	0.002	0.203	0.271	0.990	0.422†	0.990†
Drive	0.002	0.669	0.892	3.266	1.634	5.903
Single	0.002	0.648	0.865	3.160	1.556	5.619
Tandem	0.002	0.752	1.005	3.665	1.949	7.015
Tandem	0.002	0.338	0.452	1.644	0.700†	2.108
Total	0.102	2.981	3.982	14.547	7.031	24.094
#Final ESAL		3.083	4.084	14.649	7.133	24.196
ESAL for unit volume of timber		0.114	0.136	0.312	0.204	0.515

† *n=4 Model adopted (see Equation 1) where the actual load is less than the standard load.*

‡ *Determined by summing ESAL individual axle values for each load category.*

Table 5 also shows that the number of ESALs required to transport a unit volume of timber increases significantly for an overloaded vehicle. For example, Transportation of 27 t of timber requires 0.114 ESAL per m^3, which increases to 0.136 ESAL per m^3 when a payload of 30 t is hauled (11% more wood), and 0.204 when 35 t of timber is hauled (30% increase in the payload). This increase per unit volume of timber, of approximately 20% and 80% respectively, is indicative of the acceleration of road deterioration caused by overloading.

CONCLUSIONS

Knowledge of the remaining life of forest access pavements permits the development of a timber haulage strategy which can indicate the volume of timber that can be transported without pavements reaching their failure condition.

Economic reasons necessitate the maximisation on the payload within the current load restrictions for road haulage. However, even the current restrictions seem to be inadequate for roads with peat subgrades. Therefore, the adoption of alternative options such as increased number of axles on haulage vehicles, constantly reduced pressures, and variable tyre pressure using CTI technology to minimise pavement wear and damage, may facilitate a rational approach to the problem of reducing pavement damage.

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