Improving Roundwood Haulage Supply Chain through Optimising Volume Transported Under Ireland's Vehicle Legal Dimension and Weight Restrictions

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Abstract:
Wood transportation can cost up to 40% of the total supply chain costs, and this situation can be improved by optimising the volume of delivered load. In Ireland the loads transported are regulated by dimensions and gross vehicle weights (DGVW) of trucks and trailers. With a maximum of 42,000 kg for 5-axled trucks and 44,000 kg for 6-axled, hauliers in Ireland face the challenge of transporting enough material to optimise the revenue per load within the strict legal weight guidelines. The objective of this study was to create a method that optimises log transportation by maximising the volume transported without incurring overweight penalties. Information regarding weights, volumes, and moisture content (MC) was gathered from a total of 100 trucks loaded with pulpwood of Sitka spruce (Picea sitchensis). Volume and weight utilisation patterns were analysed based on stacked volume, truck volume, gross weights and tare weights measured from the weighbridge. The stack/solid volume conversion factor was estimated in order to understand the relation between the stack volume on the trucks and the actual solid wood volume. Different truck configurations and their Legal Maximum Payload (LMP) were grouped into five conditions in order to optimise the transported volume.
The weight of Sitka Spruce wood at different MC was calculated to analyse the variation of loadable volume on the trucks restricted by the LMP. Results showed that 100% of the trucks presented volume underutilisation, with an average of 34.6 m^3 (44%), equating to an average €917 lost revenue. In contrast, 65% of trucks were overloaded with an average excess weight of 1,788 kg; the remaining 35% of trucks were underweight with an average of 1,206 kg. The average stack/solid volume conversion factor was 0.68± 1.5%.
Volume optimisation showed that 51 trucks out of the 100 can be loaded up to 100% of their capacity, with wood at a maximum MC ranging from 18 % to 37%. On the other hand, the minimum optimal volume of the truck that could be loaded is 50 % with an average MC of 70%, represented by 43 trucks. Loading trucks under this volume could imply losses in revenue due to underutilisation of volume. This methodology, still in development, could be used by truck hauliers, enabling them to determine in forest the optimum volume and weight to be transported by knowing the % MC and the wood specie.

Keywords: log transportation, volume optimisation, payload weight, Ireland.

1 Introduction

In 2007, forests covered 10% of Ireland's land area, and this is projected to increase to 17% by 2030 (Department of the Environment, 2007). It is also forecasted that roundwood volume will increase from 3.79 million m^3 in 2011 to 6.41 million m^3 in 2028 (Phillips, 2011); increasing at the same time the logistics involved in the wood supply chain.

In the case of wood for energy purposes, biomass must be delivered to the energy plant or end user at the lowest cost possible. Several modes of transportation are used in the forestry sector and truck transportation constitutes an important part of the supply chain. Devlin *et al.* (2008) stated that road transportation is and will remain the most important mode of timber transport in Ireland, forming a substantial part of the industry's raw material cost and having a major influence on the sector's overall economic performance and competitiveness. Nevertheless, wood transportation can count for 20 to 40% of the overall supply chain costs (Andersson *et al.*, 2007).

All European countries impose haulage regulations related to the restriction on dimensions and weight of the trucks. The weight restriction is more complex due to the relation between number of axles and the distance between them and how this changes the maximum permissible weight. As an example, the code of practice for the transport of round timber, presented by the Irish Forest Industry Chain (2003) sets a maximum of 42,000 kg for trucks with 5 axles and 44,000 kg for trucks with 6 axles, and penalties are imposed to hauliers with trucks weighting over the legal limit. This highlights the challenge facing truck operators of placing enough material on a truck (and trailer) of fixed dimensions. According to Angus-Hankin *et al.* (1995) to carry less than the legal maximum weight is incurring opportunity costs.

There are many areas where the truck transportation of roundwood may be potentially improved; one of them is the maximisation of the delivered load up to the legal weight and dimension limits. The interactions between biomass Moisture Content (MC), dry matter, solid and bulk density and truck payloads constraints are complex but need to be evaluated in order to deliver the material cheaply and efficiently (Organisation for Economic Co-Operation and Development, 2004).

The objective of this study, based in Ireland, is to develop a method that optimises log transportation by maximising the volume and weight transported without incurring overweight penalties.

2 Material and methods

2.1 Utilisation of load volume and weight

This study was carried out in Medite Europe Ltd., one of the leading manufacturers of MDF (medium density fibreboard) in Europe, located in Clonmel, Co. Tipperary. In order to understand the pattern of utilisation of volume, two cameras were positioned on both sides of the weighbridge. Pictures were taken of every truck entering the weighbridge carrying logs (pulpwood). A total of 100 trucks loaded with Sitka Spruce (*Picea sitchensis*) were photographed over the weighbridge, images were then processed with Adobe Photoshop CS5 Extended ® software in order to calculate the Stack Volume. The truck's fixed volume was based on specifications of the different truck configurations.

To study the pattern of utilization of weight; the tare weight and the gross vehicle weight (GVW) was recorded from the weighbridge and compared to the legal maximum weight established in the Ireland Road Traffic Construction and use of Vehicles Regulations (Minister for Transport Turism and Sport, 2003).

2.2 Stack / solid volume conversion factor

The most commonly used unit for the measurement of wood biomass is the cubic metre solid volume (m^3), and in Ireland, this usually includes bark (expressed as over bark volume, OB) (Forest Service, 1999). The stack volume determined by image processing does not accurately represent the amount of solid wood per m^3 since the logs are stacked with air spaces between them (Kofman, 2010). For this reason, a stack/solid volume conversion factor needs to be calculated in order to estimate the actual solid wood volume present in the trucks.

According to Kent *et al.* (2011) since density describes the relationship of weight to solid volume, and stack density is the relationship between stack weight and stack volume. Therefore, the stack density /solid density relationship equates to the stack volume /solid volume relationship.

The factor was determined as follows:

$$F = Dso/Dst \qquad (1)$$

Where F is the Stack/Solid factor, Dso = solid density (kg/m^3) and Dst = stack density (kg/m^3). The solid volume was determined following the Standard Procedures for the Measurement of Round Timber for Sale Purposes in Ireland (Forest Service, 1999).

2.3 Optimisation of load volume constrained by weight

Three types of trucks were identified in this study according to their volume capacity (Table 1):

Table 1: Truck classification based on volume capacity

Truck type	Truck configuration	Volume capacity [m^3]	Solid volume capacity [m^3]
T1	Articulated/ 3 bays capacity	67.6	45.97
T2	Articulated /4 bays capacity	78.2	53.18
T3	Rigid + Trailer/ 4 bays capacity	90.3	61.4

Wood basic density (ratio of the mass on a dry basis and the solid volume on a green basis) of Sitka Spruce was used in order to estimate the amount of wood to be loaded on the trucks. In Ireland Sitka Spruce density varies depending on the provenance, showing a difference of up to 10% (Treacy *et al.*, 2000). This variation was also found in Tobin and Nieuwenhuis (2007). A more recent study by Kent et al. (2011) estimated that the mean basic density of Sitka Spruce in Ireland varies from 453 kg/m^3 to 442 kg/m^3 with a mean of 447 kg/m^3. This is the value used in this analysis.

Since the density of wood is usually sufficiently accurate to permit proper utilization of wood products where weight is important, the density of wood including the water at a given MC was calculated in this study (Forest Products Laboratory, 2010).

$$\rho = 1{,}000 * Gm * (1 + MC/100) \qquad (\text{kg/m}^3) \qquad (2)$$

Where ρ is density of wood as a function of Moisture Content (MC), *Gm* is the specific gravity of the wood and MC is the moisture content (wet basis) of the wood. Moisture content wet basis was adopted from the European Technical Specifications as the standard method for expressing MC of solid biofuels (Coford, 2005).

After calculating the wood density (kg/m^3) at different MC using Kent et al. (2011) average basic density value of 447kg/m^3 the amount of wood to fill the two truck type's volumes was estimated (Table 2).

Table 2: Amount of wood with moisture content to be loaded in the trucks types

MC	Density [kg /m^3]	Payload T1 [kg]	Payload T2 [kg]	Payload T3 [kg]
0	447	20,548	23,770	27,448
30	581	26,712	30,901	35,682
40	626	28,767	33,278	38,427
50	671	30,822	35,655	41,171
60	715	32,876	38,031	43,916
70	760	34,931	40,408	46,661

To identify if the amount of wood loaded in the trucks was under the legal weight limit the average Legal Maximum Payload was calculated. This maximum payload is the product of:

$$\text{LMP} = \text{L}_{GVW} - \bar{x}\ \text{T}_w \qquad (\text{kg}) \qquad (3)$$

Where LMP is the Legal Maximum Payload, L_{GVW} is the legal gross vehicle weight, and T_w is the average truck tare weight. Based on this LMP and other truck configuration characteristics 5 Conditions were created (Table 3):

Table 3: Conditions based on truck configuration, maximum legal weight and maximum legal load

Condition	Truck configuration	Truck type	Maximum GVW [kg]	LMP [kg]
C 1	Rigid + Trailer no crane Rigid + Trailer with crane	T2	44,000	24,504 ± 5%
C 2	Truck articulated no crane	T1, T2	44,000	28,275 ± 4%
C 3	Truck articulated with crane	T1	44,000	25,856 ± 3%
C 4	Truck articulated no crane	T1,T2	42,000	27,484 ± 3%
C 5	Truck articulated with crane	T1	42,000	24,815 ± 1%

3 Results

3.1 Utilisation of load volume and weight

The stack volume measured from the 100 trucks through image processing showed to be under the maximum truck volume capacity with an average volume underutilisation of 34.6 m^3 (44%); truck volume type 3 (rigid + trailer) presented the highest volumes of underutilisation with 48.31 m3 (54%). In Ireland, at an average price of pulpwood in Ireland of €26.5 per m^3 implies an €917 of lost revenue per trip. In contrast, 65% of the 100 trucks were overloaded with an average of 1,788 kg. The remaining 35% trucks were under the legal maximum weight by an average of 1,206 kg.

3.2 Stack/solid volume conversion factor

The Sitka spruce pulpwood stack/solid volume conversion factor presented an average of 0.68 and a standard deviation of 0.05599. The margin of error associated with the overall factor was 0.01097 (1.5 %) meaning that the stack/solid volume conversion factor could vary between 0.66 and 0.69. An overall factor of 0.68 means that 1m^3 of stacked volume in the trucks equals to 0.68 m^3 of solid wood volume.

3.3 Optimization of load volume constrained by weight

Figure 1 shows the relation between weight and MC at a constant stack volume (37m^3). In this study, the maximum amount of wood to be carried on the trucks is reached at different MC for each of the five conditions.

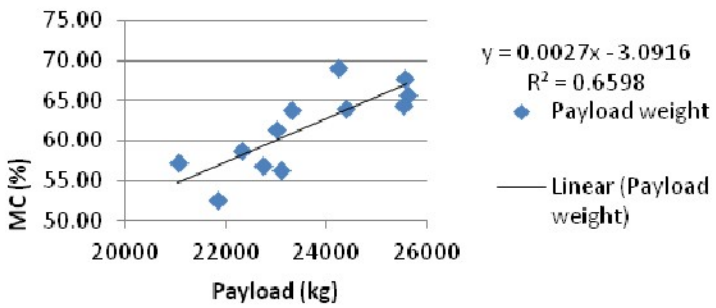

Figure 1: Relation between MC and Payload at a constant volume.

Table 4 shows an example of the optimisation process in one of the conditions (Condition 3), this type of truck can be loaded to 100% of its capacity with wood at 25% of MC, but the MC is lower to the one usually found in the field in Ireland. The next optimal scenarios would be to load the truck at 90% and 80% of its capacity with wood at 39% and 57% MC respectively. Loading this type of truck at less than 65% of its volume capacity will mean an underutilisation of volume since weight is not a constraint at this volume. Table 4 also shows that the minimum effective volume for the truck to be loaded is 70% with wood at a maximum of 79% MC. To load this type of truck at a lesser volume translates in revenues losses.

Table 4: Optimization of wood volume as a function of MC for Condition 3

MC	LMP (kg)	100%	90%	80%	70%
		45.97 m^3 vol.	41.37 m^3 vol.	36.77 m^3 vol.	32.18 m^3 vol.
25	25,856	25,685	23,115	20,545	17981
39	25, 856	28,561	25,704	22,846	19994
57	25, 856	32,260	29,033	25,805	22584
79	25, 856	36,780	33,101	29,421	25748

Table 5 shows the percentage of the truck volumes to be filled for the five conditions at different MC. Of the 100 trucks represented in the five conditions 51 trucks can be loaded up to 100% of their capacity with wood at a maximum MC ranging from 18 % to 37%. On the other hand, the minimum optimal volume of the truck to be loaded is 50 % (trucks in Condition1), represented in this case by 43 trucks. Loading trucks under this volume could imply losses in revenue due to underutilisation of volume.

Table 5: Different volume capacities to be filled at maximum MC for each Condition

Condition	100% truck Vol.	95% truck Vol.	90% truck Vol.	80% truck Vol.	75% truck Vol.	70% truck Vol.	65% truck Vol.	60% truck Vol.	50% truck Vol.
Maximum wood MC (%) at which the trucks can be loaded									
C1-T3	-	-	-	11	19	27	35	48	77
C2-T1	37	44	52	72	-	-	-	-	-
C2-T2	18	25	32	48	58	70	-	-	-
C3-T1	25	32	39	57	67	76	-	-	-
C4-T1	33	40	48	70	-	-	-	-	-
C4-T2	-	21	28	44	54	65	77	-	-
C5-T1	20	27	34	50	61	72	-	-	-

Comparison of the real load weights at different MC and their stacked volume from the 12 sampled trucks with the calculation of the optimal volume shows a variability of 14% from the estimated optimal weights at different MC and the actual weights obtained from the weighbridge.

4 Discussion

The aim of this study was to develop a methodology where the maximum truck volume can be loaded and transported under its maximum legal weight. The results show potential in achieving this optimisation. Nevertheless further studies should be carried related to the variability of basic density of Sitka spruce in Ireland, stack/solid volume conversion factors for other species and LMP for broader truck configurations.

A desired scenario for this study consists of truck hauliers being able to determine the moisture content (moisture meters) when loading the trucks. Weights of wood for specific species at different moisture content could be tabulated helping the hauler to determine the percentage (or side bar heights) of their trucks to be loaded; thus providing confidence to the hauliers that their load is under the maximum legal weight restrictions and to avoid penalties for breaching overweight restrictions.

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