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Technical report:

A summary of results of recent projects

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Summary

The following paper is a technical report, including summaries of results of a recently published paper from Pierre Ackerman's research team. The summary includes a brief introduction, methods section and a discussion or conclusion section. However, the summary mostly focusses on the results.

This technical report provides a summary on the work of Pierre Ackerman, Chad Martin, Julia Brewer, and Simon Ackerman studying the effect of slope on *Eucalyptus* pulpwood harvesting productivity and cost. The study compared purpose-built and excavator-based machines to see how they'd perform across varying slopes and determine which machine is more productive and cost effective.

Effect of slope on productivity and cost of *Eucalyptus* pulpwood harvesting using purpose-built and excavator-based machines

Pierre Ackerman, Chad Martin, Julia Brewer, Simon Ackerman

1 Introduction

This study sets out to see if the slope can affect mechanized cut-to-length harvester operations' productivity and harvesting cost. To test this assumption, two different harvesters were applied to the study: an excavator-based machine (EBM) (Volvo EC210BF) and a purpose-built machine (PBM) (TimberPro TL725B). Both harvesters were equipped with a Maskiner SP 591 LX harvester head.

2 Methodology

The study was completed in the Melmoth area of KwaZulu-Natal. Study site details are described below (Table 1) and the study was carried out in late July 2015. The trees were harvested for pulp and paper purposes. The logs produced were 4.8m in length to a minimum under bark diameter of 8cm. The two machines applied differ in weight, fuel consumption, and engine power. The PBM is 2,000kg heavier than the EBM. It also has a higher fuel consumption at 35.0 l PMH^{-1} as appose to the EBM's 23.0 l PMH^{-1}. The PBM also has a 280kW engine while the EBM has a 155kW engine. However, arguably the greatest difference between the two machines is the PBM's higher ground clearance, larger and more aggressive tracks, and levelling ability, which allows for greater slope stability than the EBM. A single operator with 10 years' experience on both the EBM and PBM was applied to both machines to exclude the influence of the operator in the study.

Table 1: Site and stand characteristics based on cruise and experimental data

Attribute	Description
Species	*Eucalyptus grandis x camaldulensis*
Stand age at felling (y)	8
Stocking ($Stems.ha^{-1}$)	1667
Mean slope, (%)(Range)	23 (5 – 55)
Mean DBHOB, (cm). (Range)	15.89 (9 – 27.2)
Mean height, (m). (Range)	19.6 (15.1 - 24.2)
Mean merchantable tree volume, m^3. (Range)	0.154 (0.034 – 0.477)

The trial layout consisted of two continuous 12m wide harvesting corridor, five rows wide across a spectrum of slopes available in the stand for each machine. Each machine was allocated a corridor. Each corridor consisted of 500 trees with slopes ranging from level to 45%. Extreme slopes >55% were excluded from the study corridors, as it would have been outside the safe operating range of the EBM. Both up- and down- slope harvesting was included to make sure all the possible variables were included in the trial. Each harvested tree's volume in each corridor was determined individually to 5cm thin end. Time studies were done using a Trimble Geo-XM handheld computer. Slope at the point of harvesting was calculated from a LiDAR derived slope map (Figure 1).

In terms of analysis, the study used a 2 x 2 factorial design, comparing harvester type (EBM v PBM) with slope (%) and tree volume (m^3. tree^{-1}) as continuous variables for the purpose of the study. Two generalised linear models were created for both machines types. The first model was used to identify the main effects of both variables (tree volume and slope) on the productivity of the machines. The second model was used to test for covariance, hence an interaction effect, between slope and tree volume. Cost calculations were done using the COST Costing model (Ackerman et al. 2014) with field derived inputs and information provided by the contractor.

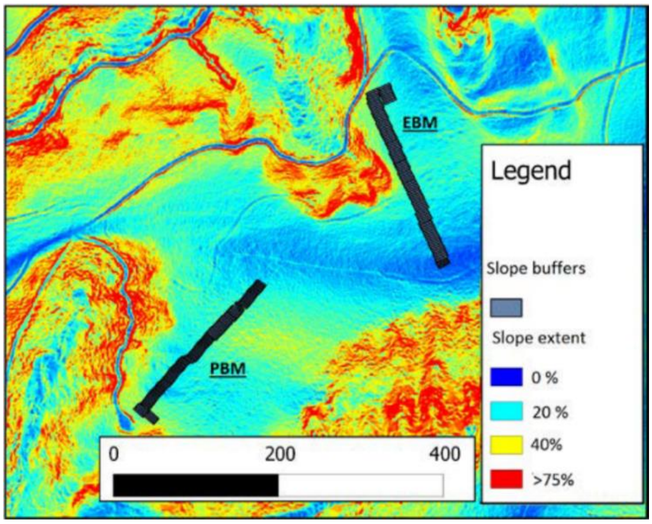

Figure 1: LiDAR derived slope map showing machine harvesting corridors over a gradient of slope

3 Results and discussion

Although there was a significant difference between the tree sizes the machines were exposed to, (EBM = 0.161m^3 and PBM = 0.147 m^3), they were within one standard deviation of each other and hence deemed sufficiently similar for the study. In addition, the PBM worked on an average slope of 26.08% and the EBM on 23.97%, which were not significantly different.

The relationship between productivity and tree volume for both machines used in this study had a strong correlation (Equation 1 and Equation 2). The functions below, Equation 1 and Equation 2, predict productivity using respective tree volume (m^3. $tree^{-1}$) for the EBM and the PBM respectively:

$$Y = 0.0072x^{1.0702} \quad (1)$$

Where:	Y	=	Productivity	(m^3PMH^{-1})
	X	=	Tree volume	(m^3)

$$Y = 0.0102x^{1.0676} \quad (2)$$

Where:	Y	=	Productivity	(m^3PMH^{-1})
	X	=	Tree volume	(m^3)

As expected, the PBM was significantly more productive (16.24 m^3 PMH^{-1} versus 13.00 m^3 PMH^{-1}) over the whole trial period. This variation could be accounted for by the relationship between productivity and tree volume for both machine types (Equations 1 and 2).

Results also indicate that the productivity of the EBM was negatively affected by an increase in slope; EBM's productivity decreased by 0.048 m^3 PMH^{-1} for every 1% increase in slope. The following equation describes the relationship is observed between productivity, volume and slope for the EBM.

$$Productivity = (57.386)Volume + (-0.048)Slope + (4.898) \quad (3)$$

With:	Productivity	in	(m^3PMH^{-1})
	Volume	in	(m^3)
	Slope	in	(%)

Unlike EBM, PBM is not significantly affected by changes in slope encountered in this study, but tree volume was found to significantly affect productivity. Tree volume was in fact the most significant variable in terms of predicting productivity rates for either machine. Increased slope increases unit harvesting costs for EBM and decreases productivity (Figure 2). Comparing the difference in mean harvesting costs of the two machines shows that at R122.61·m^{-3}, the PBM had a 30% higher mean harvesting cost than the EBM's mean of R92.81·m^{-3}. Therefore, any variation in PBM harvesting cost is primarily determined by its productivity, which in turn is determined by tree volume. The unit cost of harvesting with the EBM varied based on slope from approximately R86.49·m^{-3} in the flattest areas of the study to R99.27·m^{-3} in the steepest areas (Figure 2).

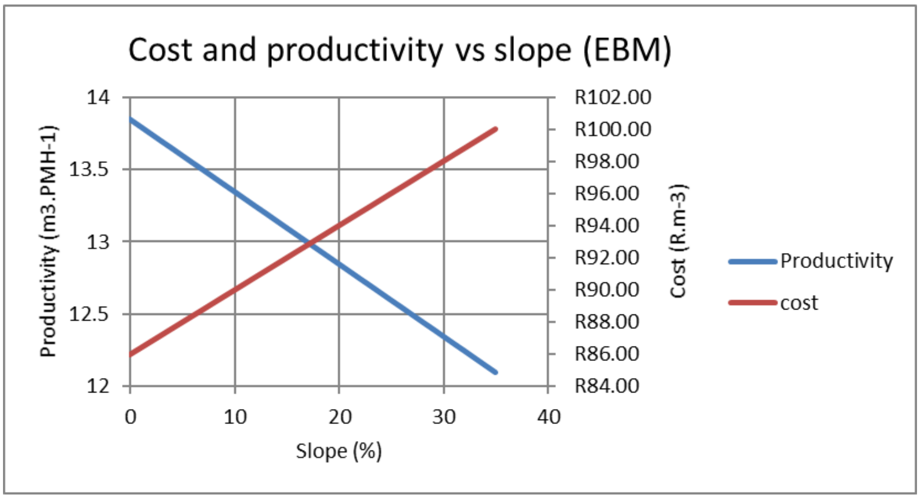

Figure 2: Cost (R m^{-3}) and productivity (m^3 PMH^{-1}) vs slope (%) for EBM

It is therefore more economical to use the EBM over the PBM, assuming the working conditions are within the EBM's safe operating range.

4 Conclusion

The PBM performed significantly better than the EBM in terms of productivity and consistency across the range of slopes studied. However, the PBM still does not stand out as being the most efficient option due to its operational costs being much higher than the equivalent EBM. In this study, even at the most extreme slopes, the unit costs of harvesting were always lower when using the EBM. This suggests that the productivity of the PBM needs to be higher in order for the two machines to be on a level footing from the outset. While the EBM is adequate for most situations found in the area, there are harvesting areas beyond the EBM's slope safety limits where alternative measures (PBM or chainsaw) must be employed. Therefore, despite the differences in costs and production rates, the situation will sometimes dictate the need for using specialised PBM's over EBM's. More research should be done to assess the relevance of the slope limits in place.

In conclusion, this study has shown that productivity and harvesting cost of the EBM is significantly influenced by the slope the machine is experiencing during harvesting. An increase in slope leads to a decrease in productivity. Slope, in terms of the slopes encountered in this study (0% - 40%), did not significantly influence the PBM. However the results of this study suggest that the EBM, which has a cost range of R86.49·m^{-3} to R99.27·m^{-3} depending on slope, is more cost efficient than the PBM (R122.61·m^{-3}) when harvesting in terrain that does not exceed the safety guidelines. This suggests that the EBM was more suitable in terms of economics across the conditions encountered in this study. However, data from this study suggests that the EBM will at some point become more expensive than the PBM as the slope increases beyond 35%.

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