Impact of ground roughness on the productivity of CTL machines – a case study in Nova Scotia

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Introduction

Ground roughness is a difficult parameter to quantify because it represents a combination of surface features, including boulders (large and small), bedrock outcrops, steep pitches, and broken terrain (ledges, cliffs). Ground roughness can also be compounded by steep slopes (short or long) and even by soft areas that represent obstacles that must be worked around at the expense of productivity.

Pay-rate models that include ground roughness require some sort of roughness classification scale so that appropriate adjustments can be made. To date, the main classification system used has been the CPPA system (Mellgren 1980), for which ground roughness is one of three terrain parameters along with bearing capacity and slope (see Appendix 1). However, the three-digit CPPA system was derived from a Swedish one that associates roughness level closely with the absence or presence (five levels) of surface boulders, since this is the main terrain problem faced by machine operators in Sweden (Skogsarbeten, 1969).

In addition to necessitating extensive cruising efforts, this system becomes inadequate to describe the other macro and micro terrain features such as those mentioned earlier: bedrock outcrops, ledges, cliffs, and steep pitches. There are also some regions where roughness levels are significantly greater than the upper end of class 4, but are not adequately represented by the single final class (5). Finally, roughness often interacts with slope to affect normal machine work patterns, and attempting to describe these interactions with individual indices may fail to represent the true operating difficulty.

The Bowater Mersey Company (Liverpool, NS) operates in many areas of southwestern Nova Scotia that feature extreme ground roughness (Figure 1). The company recognizes that ground roughness negatively affects machine productivity and is looking for information that would help in establishing appropriate and equitable rate adjustments to compensate contractors that must work under such conditions.

Figure 1. A typical operating area with high ground roughness.

In 2004, FERIC and Bowater set out together to conduct both a long-term productivity monitoring program and short-term detailed timing studies to detect changes in harvester and forwarder productivity as a function of ground roughness. This report presents the results from the short-term study conducted by FERIC in November 2004. The long-term results based on block-level roughness assessments and overall machine productivity will be presented in a separate document to be produced by Mr. Breck Stuart, a student at the University of New Brunswick (Fredericton, NB).

Study approach

The study protocol was designed to capture the impact of moderate or high degrees of ground roughness on the individual production cycles of harvesters and forwarders. We favored this approach over the more traditional one wherein block parameters are assigned *a priori* and the productivity is then measured because of the difficulty in linking a roughness assessment to a given productivity level. For example, even within an extremely rough site, the harvester may sit on a fairly level “shelf” where its work functions can be executed normally. As well, ground roughness, especially at the higher end of the scale, varies considerably within a block.

The disadvantage of this approach is that it becomes difficult to extrapolate the results to other operations or conditions, because roughness is not measured using a pre-defined scale such as the CPPA roughness classification system. The compensating advantage, however, is that the approach lets us capture the magnitude of the change in productivity when machines operate in moderately rough to very rough conditions.

For the harvester, rough ground may lead to additional positioning time, delays in boom movements and product sorting, and possibly an increase in processing time. During the FERIC–Bowater studies, we recorded individual tree felling and processing cycles in three categories: unaffected by ground roughness, moderately affected, or strongly affected. The productivity under each of the three operating conditions was then compiled separately to permit a comparison.

For the forwarder, rough ground may increase loading times by making the boom extension and grabbing of the logs more difficult (Figure 2). As was the case with the harvester, loading time was categorized into three classes based on the degree of ground roughness. However, the biggest impact of rough ground on forwarding lies in the required changes in travel speed and in the distance traveled between the loading point and the landing. Speed is, of course, reduced while traveling over rough ground, around tight corners, and over steep pitches. We captured this impact by establishing speed-measurement sections along various parts of the forwarding trails. Under rough conditions, straight-line travel is much more difficult, and the forwarder operator must adjust the machine's course, thereby lengthening the actual distance traveled between the loading point and the landing. We measured this parameter by comparing the actual distance traveled within the forwarding trails with the straight-line distance between the beginning and end points.To account for this difference, we defined a *weave index* that equaled the ratio of actual travel distance to straight-line distance. The higher the weave index, the greater the discrepancy between the two values

Figure 2. Piled logs in rough ground.

Any other delays attributed to the rough ground for either class of machine were also measured and integrated into the results.

Results

We conducted the detailed time studies in the St. Margaret's Bay operating area, about 50 km northwest of Halifax, in early November 2004. The stand that was cut during the time study was located on a very rough hilltop (CPPA class 2.4(5).2) and consisted mainly of spruce and fir (90%), with a minor hardwood component (10%). The stand was well stocked (Figure 3), with a volume of more than 250 m^3/ha and a tree size averaging 0.17 m^3. The harvesting equipment was owned and operated by Mr. Andy Looke, owner of Looke Can Cut Ltd. (Barrs Corner, NS).

Figure 3. Harvesters at work on a rough hillside.

Harvesting

The harvester we studied was a six-wheeled Timberjack 1270 equipped with a Timberjack 762 head (Figure 4).

Figure 4. The Timberjack 1270 harvester.

FERIC conducted productivity studies of one harvester run by an experienced operator. The time study results are given in Table 1.

Table 1. Harvester time study results

	Roughness class		
	Low (CPPA 1-2)	**Moderate (CPPA 3-4)**	**High (CPPA 5+)**
Proportion of study time (%)	77	13	10
Trees harvested	497	61	36
Stem size (m^3/tree)	0.170	0.186	0.157
Productivity (trees/PMH)	93	71	59
Productivity (m^3/PMH)	15.8	13.2	9.3
Adjusted m^3/PMH @ 0.17 m^3/tree[a]	15.8	12.5	9.9
Impact of ground roughness (% reduction compared with "low roughness")	—	–21	–38

[a] Since tree size was not exactly the same under the three sets of conditions, we adjusted the productivity to a standard tree size using FERIC's *Interface 2003* software based on the productivity function for single-grip harvesters in eastern Canada.

The results show that the harvesting productivity was significantly lower when ground roughness interfered with normal processing cycles. In the worst case, the harvester operator could only fell the trees but not process them because of the machine's precarious position. Instead, he had to reposition the machine and grab the trees a second time before processing was possible. The high roughness thus caused major productivity reductions (on the order of 38%) compared with operating on favorable ground. This result probably represents the *maximum* impact of ground roughness on harvester productivity at the high end of the roughness classification (i.e., 5+ in the CPPA classification system).

We modified these results using the productivity function for single-grip harvesters in eastern Canada in FERIC's *Interface 2003* software, which relates machine productivity to tree size, and have presented the results in Figure 5. Again, these curves probably represent the *worst-case* scenarios in terrain with moderate to high roughness.

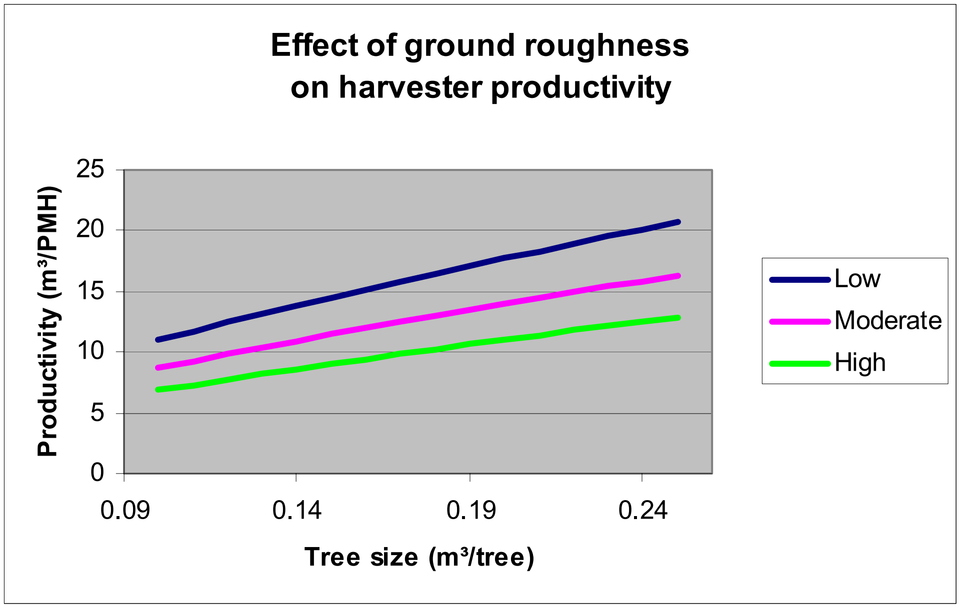

Figure 5. Harvester productivity adjustment (maximum) as a function of tree size and ground roughness (Note: Low – CPPA 1-2; Moderate CPPA 3-4; High – CPPA 5+).

Forwarding

The forwarders we studied were a Timberjack 1110 and a Timberjack 1010B, both eight-wheeled machines. Normally, loads consisted of bottom stacks of 8-ft pulpwood and studwood, with a second tier of 12- to 16-ft logs stacked on top (Figure 6).

Figure 6. A Timberjack 1110 forwarder carrying a typical load.

Because of several terrain-related breakdowns experienced by the two machines during FERIC's study, it was not possible to measure a large number of forwarder trips. Table 2 presents the observed productivity of the forwarders while extracting wood from two parts of the block (one very rough and another with better loading conditions). However, this latter section had more hardwood products and thus required more sorts.

Table 2. Forwarder time study results

	Conditions during the study	
	Steep, rough hill top; softwood only	**Moderately rough, flat; softwood 65%, hardwood 35%**
Study duration (PMH)	4.6	2.0
Total volume extracted (m^3)	42.8	21.2
Average forwarding distance (m)	680-780	620
Average payload / trip (m^3)	10.7	10.6
Ratio: actual distance/straight-line distance	1.65	1.21
Gross productivity (m^3/PMH)	9.3	10.6

The productivity of the forwarders was roughly the same in the two block sections,. In both cases, the distance exceeded 600 m, so that a large part of the cycle was spent traveling empty or loaded. In the stand with a larger component of hardwoods, loading conditions were more favorable from the perspective of ground roughness and thus, productivity should have been higher. However, the higher proportion of hardwoods complicated the sorting of the various products during both the loading and unloading phases.

The actual distance traveled by the forwarder was higher in the rougher section (a ratio of 1.65 versus 1.21) because significant detours around hills and obstacles were necessary.

We used the detailed time study results, including travel-speed measurements, to build a model for predicting forwarding productivity as a function of distance and ground roughness. The model input parameters are presented for the three levels of ground roughness in Table 3, and the model results are displayed graphically in Figure 7. The mathematical model is given in Appendix 2.

Table 3. Forwarding productivity model inputs

	Roughness		
	Low (CPPA 1-2)	**Moderate (CPPA 2-3)**	**High (CPPA 5+)**
Payload/trip (m^3)[a]	11	11	11
Distance (m)[b]	400	480	660
Speed empty (m/min)	65	45	40
Speed loaded (m/min)	60	40	30
Loading time (min/m^3)	1.94	2.08	2.34
Unloading time (min/m^3)	0.92	0.92	0.92
Rough ground delays (% of PMH)	0	3.2	6.5
Operational delays (% of PMH)	3.0	5.0	8.0
Predicted productivity (m^3/PMH)	14.5	10.9	7.7
Productivity loss from ground roughness (% reduction compared with "low roughness")	—	–25	–47

[a] Payload was consistent in all conditions, although speeds decreased as roughness increased.

[b] Values equal the distance traveled in terrain with low ground roughness multiplied by the distance ratio in Table 2.

In the simulation described in Table 3, the travel distances for the moderately rough and very rough conditions are based on the distances under good conditions, but corrected for the increased ratio of actual travel distance to straight-line distance that was observed on the site (Table 2). This ratio is not fixed, and can vary from block to block as a function of the actual terrain conditions, configuration of extraction trails, and other restrictions such as the presence of buffers or roads and the desired landing locations. It is provided here as an indication of the order of magnitude by which actual travel distance can vary as a function of ground roughness.

We found that forwarder travel speeds were related to ground roughness, but also to the number of passes over a given section of trail. For example, the first time that a trail is used, the slash is not compacted and speeds are low, even with good ground conditions. Conversely, once a trail section has been used repeatedly, the travel speed can increase even if the ground has moderate surface roughness, and this is especially true if the presence of abundant slash cushions the ride for the operators.

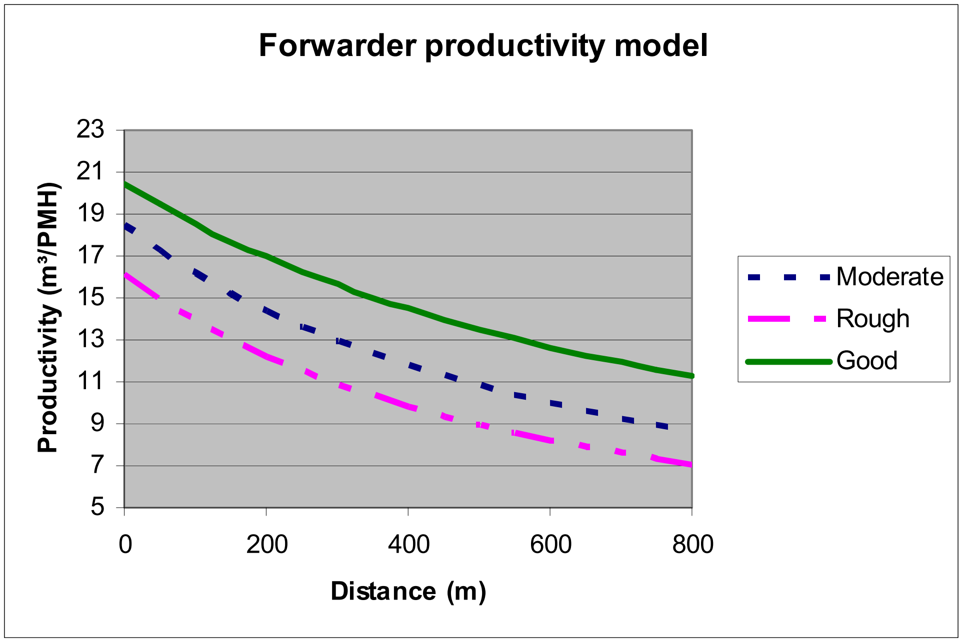

Figure 7. Forwarding productivity predicted by the productivity model described in Appendix 2 (Note: good – CPPA 1-2; moderate – CPPA 3-4; rough – CPPA 5+).

The predicted productivities illustrated in Figure 7 are specific to the data collected during the study and for the eight-wheeled forwarders we observed. Other machine types, operators, and block layouts are likely to produce different results. However, the *relative differences* between the curves should be similar (for eight-wheeled machines) among sites, and probably represent the *maximum* productivity spread between favorable and very rough conditions. Remember that any specific block is likely to contain a combination of the different roughness classes, and thus, overall productivity will reflect the proportions of the site categorized in each roughness class.

It is important to note that when comparing productivities between good and rough ground, one should extend the nominal forwarding distance to account for the ratio of actual travel distance to straight-line travel distance. For example, the productivity in good ground at 400 m must be compared with that at a much longer distance in rough ground (e.g., 660 m), since forwarders must travel further in rough terrain to navigate around obstacles.

Discussion

Assigning an exact ground roughness category to a harvest block is difficult because roughness is determined by a combination of several terrain features, and because roughness levels vary considerably within a block, especially under very rough conditions. Obtaining an average roughness for a block may thus not enable proper rate adjustments, depending on the relative proportion of each roughness category within the block and on the spatial distribution of each type of terrain.

The distance ratio we obtained (which can be estimated during the pre-harvest cruise or perhaps using an onboard GPS system) can be used to predict the additional travel distance that the forwarders must cover to go around obstacles during their work. Some post-harvest inspections of the blocks could also be used to confirm or correct the preliminary evaluations. Our ongoing long-term study should reveal whether an adequate relationship can be established between the pre-harvest cruise information (CPPA roughness assessment, distance ratio, or both) and the actual productivity measured during harvesting.

The results presented in this report are mainly intended to complement the long-term data collection process that is currently underway. Nevertheless, we feel that the detailed study reported herein is most appropriate as a description of the *maximum* spread in productivity differences for cut-to-length equipment operating under favorable versus very rough conditions.

Another element which has not been considered in the study but that should probably be considered in any future rate-adjustment model is the additional wear and tear imposed on equipment working under rough conditions. As was observed during this short-term study, the increased strain on the machines caused by rough terrain leads to structural failures, resulting in reduced operating hours and additional repair expenses. One can easily anticipate accelerated wear to the power train and driveline components, although this phenomenon is very difficult to quantify.

Acknowledgments

The author thanks the contractor, Andy Looke of Looke Can Cut Ltd., and FERIC technician Marianne Denis for their help and cooperation during this study.

References

Mellgren, P.G. 1980. Terrain classification for Canadian forestry. Canadian Pulp and Paper Association, Woodlands Section, Montreal, QC. 13 p.

Skogsarbeten. 1969. Terrain classification for Swedish forestry. Logging Research Foundation, Stockholm, Sweden. Report No. 9. 21 p.

Appendix 1 - CPPA ground roughness classification system

Roughness class	Height of obstacles (cm)	Number per 100 m²
1	10-30	0-4
2	10-30 30-50	> 4 1-4
3	10-30 30-50 50-70	> 4 5-40 50-70
4	10-30 30-50 50-70 70-90	> 4 5-40 1-4 1-4
5	All combinations more severe than 4	

Appendix 2. - Forwarder productivity model

The forwarder model takes the following form:

$$\mathbf{P = V / [((D_e/S_e) + (D_l/S_l) + (V * (L + U))) / ((60 * (1+ Del_{rg}+ Del_{op}))]}$$

where:

P:	productivity (m^3/PMH)
V:	payload volume (m^3)
D_e:	distance empty (m)
S_e:	speed empty (m/min)
D_l:	distance loaded (m)
S_l:	speed loaded (m/min)
L:	loading time (min/m^3)
U:	unloading time (min/m^3)
Del_{rg}:	rough ground delays (% of total, expressed as a decimal)
Del_{op}:	normal operational delays (% of total, expressed as a decimal)