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Contents

Evaluation of a Trans-Gesco TG 88 clambunk skidder working in northwestern British Columbia

Abstract

During the fall of 1999, the Forest Engineering Research Institute of Canada (FERIC) performed a short-term study on a Trans-Gesco TG 88 clambunk skidder working near Terrace in northwestern British Columbia. The study provided information about the skidder's productivity and cost. Production functions were derived to predict skidder performance over a range of operating conditions.

Keywords

Trans-Gesco TG 88 clambunk skidder, Skidding, Productivity, Costs, Soil disturbance, Northwestern British Columbia.

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Introduction

Forest management objectives and practices in western Canada are changing rapidly to place stronger emphasis on environmental protection, and new operational strategies aimed at minimizing soil disturbance are being developed, tested, and introduced. They include flexible harvest scheduling to take advantage of dry weather or frozen ground; using designated skid trails instead of unrestricted skidding; substituting low ground pressure skidders for conventional skidding equipment; and changing harvesting systems (e.g., substituting loader-forwarding for conventional skidding).[1] For successful implementation of new strategies and technologies, however, reliable information about their effectiveness and cost is necessary. To address this need, FERIC conducts an ongoing program in western Canada that monitors and reports on trials of alternative harvesting strategies aimed at minimizing soil disturbance.

One promising method suitable for harvesting sensitive sites is the clambunk system. Because of their track and wheel systems, clambunks can operate on weaker soils than conventional rubber-tired and track skidders. Clambunks travel over a portion of the skidding distance with only a partial payload due to their loading sequence. With proper planning and supervision, the partially loaded portion of the cycle can be matched to the weaker soils, thus reducing the ground impact. Clambunks do very little turning compared to conventional skidders, so they are not limited by the same slope constraints. Furthermore, the weight of the load bears down on the machines and improves their stability. Clambunks can be operated safely on slopes up to 60% (MacDonald 1999).

In 1999, Skeena Cellulose Inc., Terrace Operations (SCI), undertook a trial to investigate the feasibility of using a clambunk skidder to harvest a portion of a cutblock that was orginally laid out exclusively for cable yarding. SCI uses cable yarding systems

[1] Loader-forwarding is the use of hydraulic log loaders to extract stems from the falling site to the roadside or skid trail. Also referred to as excavator-forwarding, hoe-forwarding, hoe-chucking, or shovel logging.

extensively because of the generally steep and broken terrain in its operating area. However, portions of many of its cable cutblocks are potentially suitable for skidding with clambunk skidders. These sites represent opportunities to reduce overall harvesting costs by substituting lower-cost ground-based systems for cable systems. FERIC monitored the trial, which took place on a clearcut block in the Kiteen River watershed from August to October 1999. This report presents the results of the trial.

Objectives

The primary goal of this study was to assess the economic and operational feasibility of using a clambunk to skid timber over long distances in a steep, clearcut block. The following specific objectives were established to address this goal:

- Determine overall productivities and costs for the falling, bunching, skidding, processing and loading phases of the harvesting operation.
- Identify factors that influence productivity and cost of the skidding operation.
- Develop productivity and cost functions for the skidding phase.
- Identify operational factors affecting performance of the harvesting system, and recommend improvements where appropriate.
- Evaluate the clambunk performance as a component of a "hot logging" system.[2]
- Examine financial consequences of using the clambunk in a block designated initially for cable yarding.
- Determine the proportion of area disturbed by skidding and loader-forwarding activities.

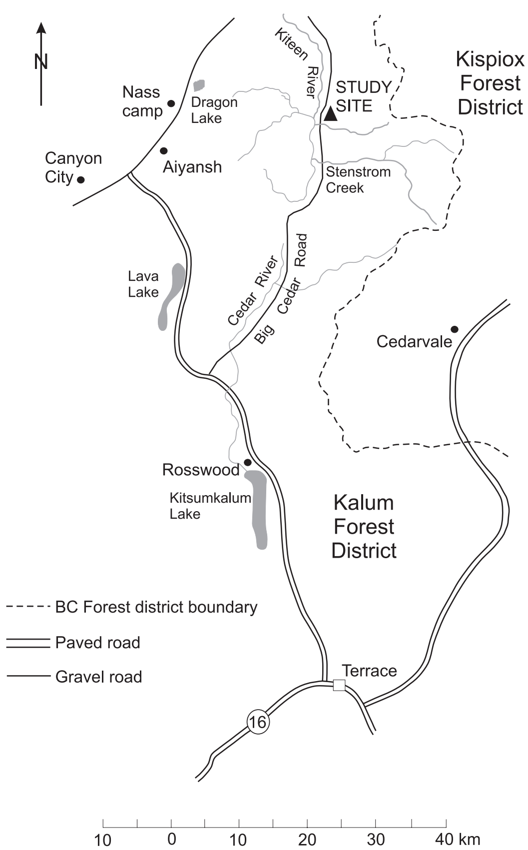

Figure 1. Location of study site.

Site and stand description

The study block monitored by FERIC was located in the Kalum Forest District (Figure 1). It is located in the Wet Submaritime subzone, Montane variant, of the CWH biogeoclimatic zone (CWHws2) in the Prince Rupert Forest Region (Banner et al. 1993). Table 1 summarizes site and stand information for the study block. Initially, cable yarding was prescribed exclusively for the study site. However, in an amendment to the prescription, a portion of the block area with moderate slopes was approved for

[2] A hot logging system is one where the harvesting operations occur simultaneously.

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extraction with a clambunk skidder. Long skidding distances and frequent slope breaks and steep pitches favoured the clambunk skidder over other ground-based options such as loader-forwarders or conventional skidders. The use of the clambunk eliminated a planned 1 170-m spur road and the need for backspar trails along the east and south boundaries of the block.

Harvesting system and equipment

The 54-ha block was manually clear-felled before the yarding and skidding phases started. No delimbing or bucking was done at the stump, except for very large trees. The steeper portion of the block, consisting of about 33 ha, was harvested with a Madill 123 swing yarder. It was teamed with an MDI/Yutani MD320 loader used as a backspar, and a Link-Belt LS-4300 hydraulic log loader. The remaining area, about 21 ha, was harvested with a Trans-Gesco TG 88 clambunk (Figure 2). Two hydraulic log loaders assisted the clambunk. A John Deere 892D-LC loader used as a loader-forwarder moved stems over short distances and bunched them along the skid trails for subsequent skidding by the clambunk. The second Link-Belt LS-4300 log loader, assigned exclusively to the clambunk,

Table 1. Site and stand characteristics

Elevation (m)	
Range	500–650
Average	600
Slope (%)	
Range	20–45
Average	35
Terrain	Broken
Stand composition (% by net volume)	
Western hemlock	63
Amabilis fir	37
Stand parameters	
Net merchantable volume (m^3/ha)	586
Tree density (no./ha)	436
Avg volume (m^3/tree)	1.34
Avg diameter at breast height (cm)	46.6
Avg tree height (m)	36

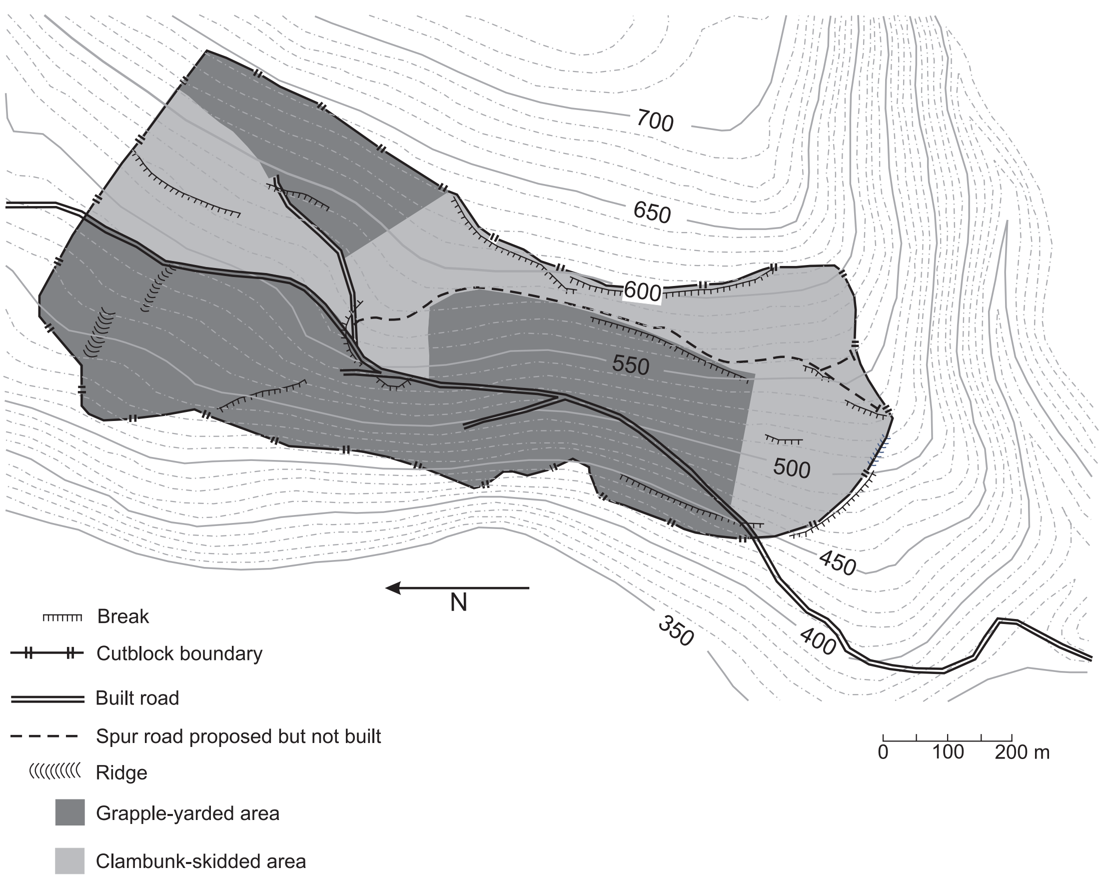


Figure 2. Layout of study block.

cleared the unloading area, spread the stems on the road for manual processing, sorted the logs, and loaded trucks.

The Trans-Gesco TG-88 is an 8-wheel-drive, rubber-tired, double-bogie clambunk designed to skid large loads of tree-length stems over long distances (Figure 3). It is 10.52 m long and 3.6 m wide, has a 5.66-m wheelbase and 0.86 m of ground clearance, and has an operating weight of approximately 29 320 kg with basic equipment. It is powered by a 246-kW diesel engine and driven by a hydrostatic transmission and four hydrostatic pumps that power each tandem wheel set. The hydraulic system for the loader, grapple, steering, front blade and clambunk grapple is powered by two load sensing pumps. The clambunk is fitted with a knuckle-boom loader with Trans-Gesco grapple and Rotobec rotator. The loader has a maximum reach of 7.6 m, and a lifting capacity of 2495 kg at a distance of 6.1 m. The hydraulically operated clambunk has a cross-sectional area of 3.53 m^2, a maximum opening of 4.19 m, and maximum load capacity of 31 750 kg.

The cutblock was originally laid out for cable yarding only and most of the road system was located on steep slopes. As a result, the clambunk could access ground skidding areas at only a few locations along the road, where the road cutbanks were low and gentle enough for the clambunk to climb. These locations effectively served as the landing areas for the clambunk. Logs were unloaded from the clambunk at these nodes and then sorted, processed, decked and loaded onto log trucks by the hydraulic log loader.

Figure 3. Fully loaded Trans-Gesco TG 88 travelling to the landing.

In the typical skidding cycle observed in this study, the clambunk travelled in reverse from the roadside to the furthest point of the skidding cycle. Travelling in reverse eliminated the need to turn the machine around at either end of its trip. The operator faced the rear of the machine, and looked over his shoulder when the machine travelled forward—the low travel speed made this workable.

The clambunk built its full payload in stages from several smaller piles. At the first loading site (the most distant point from the landing), the butt ends of the stems were lifted with the loading boom and dropped into the open clambunk grapple. When all stems within the reach of the boom had been loaded, the clambunk grapple was tightened to secure the load, the machine drove in the direction of the landing, and then stopped at the next loading site. This loading process was repeated until a full load had been accumulated. The clambunk then skidded the entire load the remaining distance to the roadside landing. The direction of all loaded travel was favourable (downhill). At the landing, five unloading modes were used:

- Dropping the load by opening the grapple and driving forward and out from under the load.
- Unload with the clambunk's own loading boom.
- Unload with the hydraulic log loader.
- Unload with both clambunk loading boom and hydraulic log loader.
- Unload initially by dropping the load and then with the clambunk's boom.

To minimize soil disturbance and facilitate the loading phase of the skidding operation, the John Deere loader-forwarder assisted the clambunk by retrieving stems from the areas located between the trails. The loader-forwarder bunched the stems in continuous windrows along the skid trails, forming a herringbone pattern (Figure 4). Occasionally, the loader-forwarder helped the clambunk to load large stems (Figure 5). The Link-Belt log loader worked on the landing (Figure 6) and frequently helped unload the clambunk. On the landing, the skidded stems were processed manually by a two-person team.

Study methods

During the trial, FERIC and SCI representatives observed the harvesting operations and collected time and production information for the skidding phase. The field study involved collecting shift-level data, detail-timing the skidding operation, and gathering information on numbers of extracted stems and skidding cycles.

The shift-level data were collected daily and were complemented with the contractor's monthly work reports which documented shift times for all components of the harvesting operation. Net volumes of produced logs were obtained from the monthly weigh-scale records provided by SCI. Productivities were calculated for each harvesting phase based on net harvest volumes and total scheduled machine hours (SMH) for each phase.

Skidding cycles were detail-timed at frequent intervals throughout the study period. Each timed skidding cycle was subdivided into five timing elements: travelling unloaded; loading and moving to load; travelling fully loaded; unloading; and in-cycle delays (see Appendix I for definitions of timing elements). Additional data recorded for each cycle were travelling distances unloaded and fully loaded, number of stems per cycle, average slope of the skid trail, mode of unloading, and reasons for observed delays.

The detailed-timing data were analyzed using multiple regression techniques to determine relationships between total cycle time and skidding distances, slope of the skidding trail, and number of stems per turn. A .05 significance level was used to test the relationship and the contribution each independent variable made to the model. The results of the regression analysis were then used to develop equations to predict delay-free cycle time and to derive production functions.

Production functions in this report were developed to predict hourly skidding productivity, unit skidding cost, and total unit cost for the Trans-Gesco harvesting system. Production functions for the skidding phase were derived by using an average payload per cycle, and adjusting predicted cycle times to reflect both in-cycle and shift-level delays encountered in the skidding phase. Costs for the loader-forwarding, skidding, processing and yarding phases were calculated using FERIC's standard costing methods (Appendix II). Labour costs were based on Industrial Wood and Allied Workers of Canada rates. Information on falling unit costs, road construction costs, productivity for the grapple yarding operation, and post-harvest rehabilitation costs was supplied by SCI.

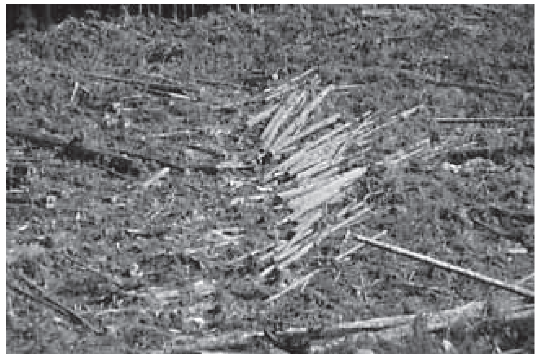


Figure 4. Stems bunched along skid trail by the John Deere loader-forwarder.

Figure 5. John Deere loader-forwarder assisting clambunk with loading large stems (photo courtesy of Woodima Forestry Services).

Figure 6. Link-Belt LS-4300 loader on the landing.

Following harvesting, a survey was conducted on a portion of the clambunk-skidded area to estimate the level of soil disturbance caused by clambunk and loader-forwarder trails.[3] Areas occupied by clambunk and loader-forwarder trails were determined by surveying all visible trails. For the purpose of FERIC's survey, skid trail segments were visually classified into one of three classes:

- First-class trails: Unbladed skid trails ending at the roadside landings and showing evidence of high levels of machine traffic, including extensive compaction, churning and/or exposure of mineral soil, and well-defined track ruts. From observations made during the detailed-timing phase, the typical first-class trail was estimated to have received from 15 to 25 passes by the clambunk. These trails correspond to "compacted areas" under the Forest Practices Code (FPC) (BCMOF 2000).
- Second-class trails: Unbladed skid trails characterized by extensive but discontinuous patches of exposed mineral soil and/or well-defined track impressions in crushed slash or litter layers. Second-class trails were usually less heavily travelled extensions of first-class trails, but still showed evidence of several machine passes. These trails were estimated to have received from 6 to 10 machine passes on average. Most of the second-class skid trails would meet the definition of "dispersed disturbance" under the FPC.
- Third-class trails: Lightly travelled trail segments characterized by occasional isolated patches of exposed mineral soil or other evidence of machine travel (e.g., track marks on the forest floor or slash). Third-class trails were estimated to have received from 1 to 3 machine passes. Most of these trails were used exclusively by the loader-forwarder. Except for isolated gouges or scrapes, third-class skid trails would not meet the definition of "dispersed disturbance".

For each trail segment, the dimensions (slope distance, width, and slope gradient) and traffic intensity were assessed and recorded. As an added check on the visual traffic intensity classification, the proportion of exposed mineral soil was estimated and recorded (to the nearest 5%) for each trail segment.

Table 2. Shift and productivity data for the clambunk

Description	Total
Available shifts (no.)	49
Productive shifts (no.)	25
Weekends and holidays (no.)	14
Mechanical downtime shifts (no.)	10
Total productive shift time (SMH)	247
Volume (m^3)	10 536
Stems (no.)	6 930
Truck loads (no.)	242
Average shift time (h)	9.9
Skidding cycles (no.)	353
Average load	
stems/cycle (no.)	19.6
m^3/cycle	29.8
Productivity	
m^3/SMH	42.7
m^3/shift	421
truck loads/10-h shift	9.8
Cost ($/SMH)	164.71
Unit skidding cost ($/$m^3$)	3.86

Results and discussion

Shift-level study

Skidding

The clambunk was scheduled to work one 12-h shift per day (except 9.5 h on Fridays), six days per week. During the monitoring period, 25 productive shifts were recorded. The shift lengths ranged from 6 to 13 h, and averaged 9.9 h.

Shift structure and productivities summarized in Table 2 are based on the contractor's monthly work reports. Overall, the skidding productivity was 42.7 m^3/SMH, at a cost of $3.86/$m^3$.

More detailed information on shift time structure, summarized in Table 3, was obtained

[3] All skidding activities on the study site were done using unbladed skid trails.

from shift-level data collected over 11 shifts. For this period, the clambunk's utilization and availability were 77% and 85%, respectively. Half of the delays were caused by mechanical problems related to hydraulic components.[4] No delays related to an interaction between skidding and yarding operations were observed.

Associated operations

Shift structure and productivities for loader-forwarding with the John Deere 892D-LC loader-forwarder, processing by the two-person bucking team, and loading with the Link-Belt LS-4300 loader are summarized in Table 4.

Summary of productivities and costs

All phases of the Trans-Gesco system achieved similar productivities except for processing (Figure 7). Small differences in productivities resulted mainly from differing utilizations. Processing productivity per bucker of 24 m³/SMH was far below the skidding and loading productivities. Therefore, two buckers were employed to keep pace with

[4] The Trans-Gesco clambunk documented in this report had over 7000 hours and was in need of repair and hydraulic adjustment (per Scott Dorrett, Trans-Gesco Inc., personal communication, December 2000).

Table 3. Summary of shift-level time for the clambunk

Description	Total
Productive machine hours (PMH)	69.9
Mechanical delays (h)	
Hydraulic repairs	10.0
Other repairs	3.8
Total mechanical delays (MD) (h)	13.8
Non-mechanical delays (h)	
Interaction with other equipment	0.9
Refueling	2.5
Stuck on stumps and reloading	1.2
Discussion with supervisors	0.9
Other non-mechanical delays	1.0
Total non-mechanical delays (NMD) (h)	6.5
Total delays (MD+NMD) (h)	20.3
Scheduled machine hours (SMH)	90.2
Utilization PMH/SMH (%)	77
Availability (SMH-MD)/SMH) (%)	85

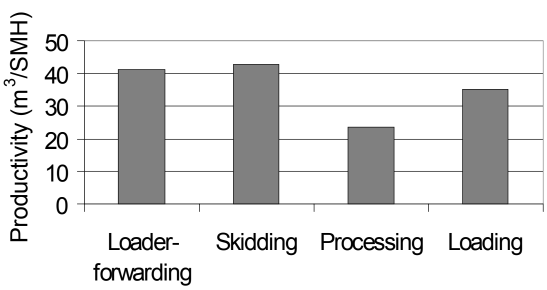


Figure 7. Clambunk system productivities by phase.

Table 4. Summary of shift-level time for loader-forwarding, processing and loading

Description	Loader-forwarding	Manual processing	Loading
Available shifts (no.)	36	89	47
Productive shifts (no.)	21	39	27
Holidays (no.)	10	24	12
Other-duty shifts (no.)	6	26	8
Total productive shift time (SMH) (h)	256	447	300
Haul truck loads (no.)	242	242	242
Average shift time (h)	12.2	11.5	11.1
Volume (m³)	10 536	10 536	10 536
Volume/truck load (m³)	44	44	44
Productivity			
m³/SMH	41.2	23.6	35.1
m³/shift	502	270	390
truck loads/11-h shift	10	6	9
unit cost ($/m³)	2.88	1.62	4.04

these operations. One bucker worked full-time, and the second spent about half of the daily shift working with the clambunk operation. The second bucker occasionally improved skid trails for the Trans-Gesco by reducing the heights of the stumps.

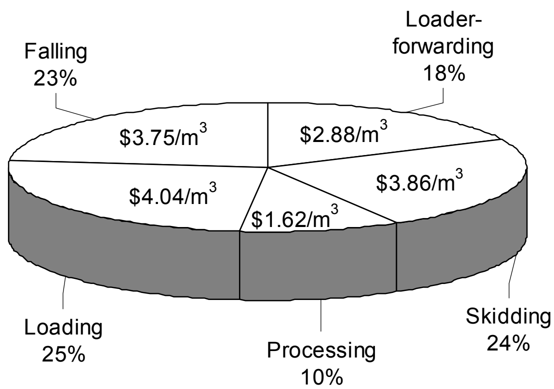


Figure 8. Distribution of harvesting costs for the clambunk system.

Table 5. Summary of detailed timing for the clambunk

Description	Total
Productive time (min)	4 192
Productive machine hours (PMH)	69.9
Total cycles (no.)	121
Stems (no.)	2 379
Estimated volume (m^3) [a]	3 616
Average cycle time (min)	34.6
Stems/cycle (no.)	
minimum	3
maximum	42
average	19.7
Average volume/cycle (m^3) [a]	29.9
Travel distance empty (m)	
minimum	35
maximum	550
average	236
Travel distance fully loaded (m)	
minimum	20
maximum	310
average	123
Productivity	
stems/PMH	34.0
m^3/PMH	51.7

[a] Using average piece size (from shift-level study) of 1.52 m^3.

Overall costs for falling, loader-forwarding, skidding, processing, and loading were estimated at \$16.15/m^3 (Figure 8).

Detailed-timing study: Trans-Gesco clambunk

Results of the detailed-timing study are summarized in Table 5. Using the average net piece volume of 1.52 m^3 from the shift-level study, 3 616 m^3 were skidded in 69.9 PMH, or 51.7 m^3/PMH. Figure 9 presents the distribution of cycle time for the clambunk. “Loading and moving to load” was the longest element of the skidding cycle, accounting for 13.3 min/cycle.

Timing results for the unloading phase are summarized in Table 6. The unloading times differed significantly for the five unloading methods. “Open clambunk and drive forward to drop the load” was the fastest unloading technique, but it left the stems somewhat tangled for subsequent processing. Unloading with the clambunk’s boom was the most time-consuming method.

Cycle time, productivity, and cost of skidding

Multiple regression analysis was performed on 101 detail-timed cycles. The analysis found a significant linear relationship between delay-free cycle time for the Trans-Gesco clambunk and the variables of travelling empty distance and number of stems per cycle (Equation 1, Appendix III). Travel fully loaded distance and unloading method were not significant variables.

Figure 10 presents predicted delay-free cycle time for the clambunk as a function of skidding distance and number of stems per cycle. Both variables have a strong impact on cycle time. For example, cycle time increases by 8 min as the number of stems per load increases from 20 to 40. For a skidding distance of 236 m (the average for this study), this represents a 25% increase in cycle time. The impact of the number of stems per load is even greater for shorter skidding distances.

Table 6. Summary of unloading time by unloading technique

Description	Observations (no.)	Average stems/load (no.)[a]	Average unloading time (min)
Open grapple and drive forward	12	19.2	0.30
Clambunk boom only	70	19.7	6.17
Hydraulic log loader only	14	20.6	3.80
Clambunk boom + hydraulic log loader	5	23.0	5.51
Open grapple and drive forward + clambunk boom	10	15.7	2.10

[a] No significant differences between means at $\alpha = .05$.

For a payload of 19.7 stems per cycle (also the average in this study), doubling skidding distance from 250 to 500 m results in a 50% increase in cycle time.

The shift-level and detailed-timing results were combined to estimate productivity during scheduled skidding time (Equation 2, Appendix III). This can be used to predict wood flow and schedule processing and hauling activities on a shift-level basis.

Since the payload volumes skidded by the clambunk in each cycle were consistent and reasonably close to the study's average volume of 30 m^3/cycle, the predicted productivity was developed as a function of the average stem volumes. Four classes were arbitrarily chosen for the average stem volumes: 0.75, 1.00, 1.50, and 2.00 m^3. For a payload of 30 m^3/cycle, the chosen volumes corresponded to 40, 30, 20, and 15 stems/cycle.

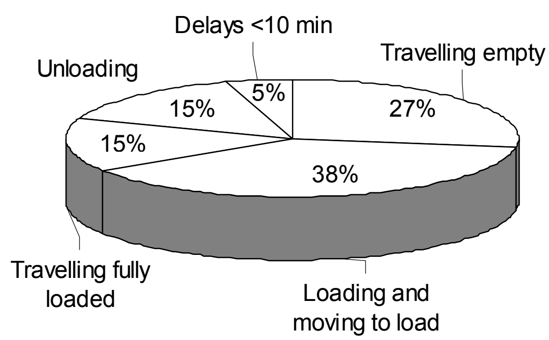


Figure 9. Distribution of cycle time for the Trans-Gesco clambunk.

Figure 11 shows predicted skidding productivity for the clambunk as a function of skidding distance and payload size (number of stems per cycle or, interchangeably, average stem volume). Because of the relatively low travel speed of the clambunk and high proportion of time for loading and unloading phases, the productivity is very sensitive to skidding distances and average stem volumes. For example, doubling skidding distance

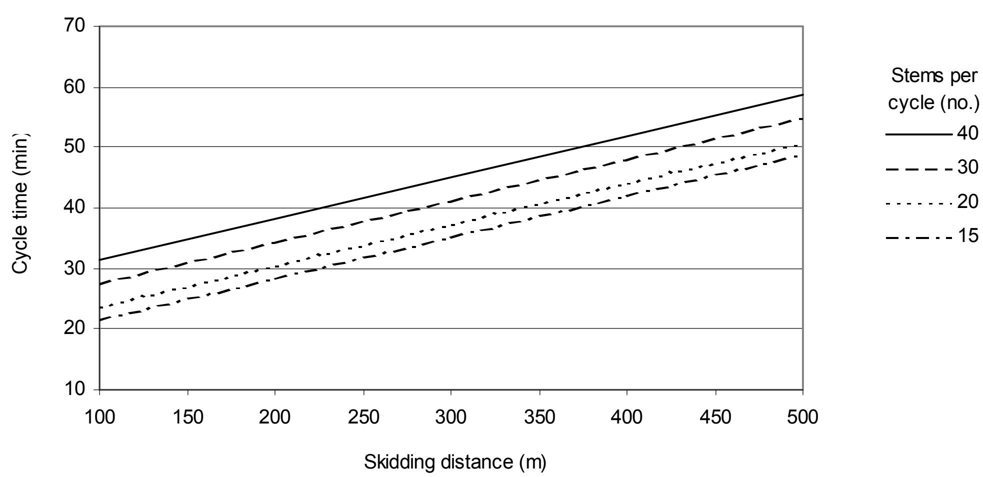
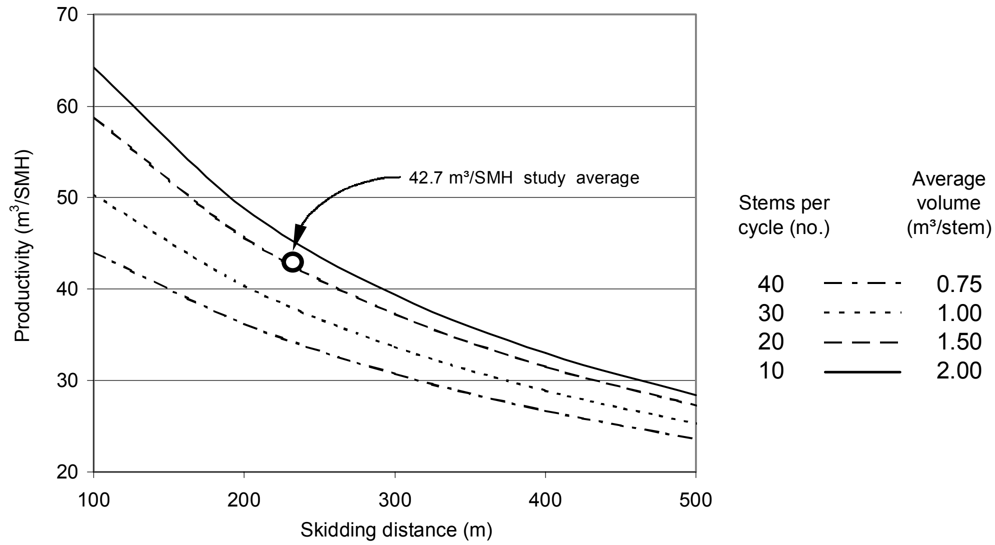


Figure 10. Predicted delay-free cycle time as a function of skidding distance and number of stems per cycle.

Figure 11. Predicted skidding productivity as a function of skidding distance and number of stems per cycle.



from 200 to 400 m results, depending on the average stem volume, in a 25–32% reduction of the skidding productivity. For all skidding distances, productivity increases as the average stem volume increases. This effect is especially apparent for short skidding distances.

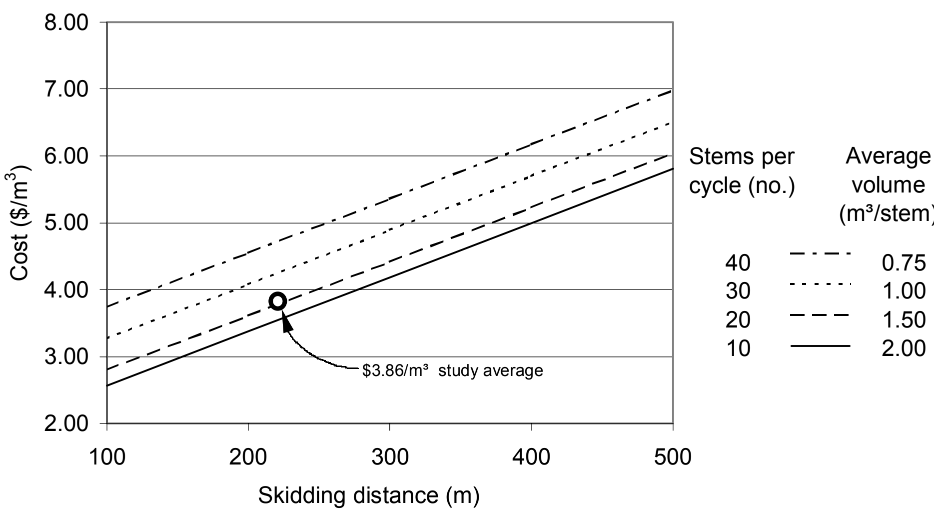
For the values recorded in this study, Equation 2, Appendix III predicts a skidding productivity of 41.7 m³/SMH. This agrees well with the average skidding productivity of 42.7 m³/SMH from the shift-level study (Table 2).

Figure 12 shows unit skidding cost for the Trans-Gesco clambunk as a function of skidding distance and payload size (number of stems per cycle or, interchangeably, average stem volume). For all payload size classes, the unit skidding cost increases at a rate of $0.81/m³ for each 100-m increase in skidding distance. The predicted unit skidding cost of $3.95/m³ for the values recorded in this study is very close to the average cost of $3.86/m³ calculated for the shift-level study.

Skidding and cable yarding compared to cable yarding only

The use of the clambunk system to harvest a portion of a cutblock that was initially designed for cable yarding results in changes to the equipment complement, redistribution of the harvest volume between extraction modes, time to complete harvesting operations, and length of required haul roads. Some of these changes have the potential to reduce overall harvesting costs (e.g., reduction in

Figure 12. Predicted unit skidding cost as a function of skidding distance and number of stems per cycle.



road construction), while others have the potential to increase costs. To evaluate the financial consequences of these changes, an analysis was performed for two harvesting systems: a cable-yarding-only system (as originally planned); and a clambunk-and-yarder system (as observed in this trial). The following differences between the two options were assumed:

- The total block volume was distributed between two extraction systems.
- Using the Trans-Gesco clambunk eliminated a planned 1170-m spur road.
- An additional loader was required to align and bunch stems to improve the efficiency of the skidding operation.
- Skidding productivity exceeded cable-yarding productivity, resulting in reduced loader time and landing operation costs.
- Some skid trails in the portion of the block extracted with the clambunk had to be rehabilitated.
- There were no substantial differences in falling and processing costs between the two systems.

In the financial analysis, productivities and costs of the skidding system were based on the shift-level study results. Information on road construction costs, yarding productivities, and post-harvest rehabilitation cost was supplied by SCI. The results of the analysis are summarized in Appendix IV.

The use of the clambunk system resulted in a new volume distribution between both systems and in a substantial saving of $70,000 on road construction. Skidding of 10 536 m³ reduced the cable-yarded volume from 30 037 to 19 501 m³. Because the skidding productivity was much greater than yarding productivity, the total extraction time was reduced from 1 306 to 1 095 SMH. With the yarder and backspar costs of $343/SMH, reduced yarding time resulted in a 38% yarding cost reduction, from $470,602 to $290,598. In the clambunk-and-yarder system, the total hours worked by the two Link-Belt loaders was only 1 148 SMH, which was less than 1 306 SMH in the yarder-only system. It resulted in a cost reduction of $22,398. The new cost subcategories emerging with the introduction of the Trans-Gesco system included skidding cost of $40,683, bunching cost of $30,350, and skid trail rehabilitation cost of $3,320.

The sums of the selected cost subcategories for the yarder-only and clambunk-and-yarder systems were $864,078 and $689,029, respectively, so using the Trans-Gesco clambunk resulted in a savings of $175,049 or $5.83/m³. Even if the spur road construction ($70,000) was considered as a site-specific cost, savings would be $105,049 or $3.50/m³.

Soil disturbance

After skidding was completed and before the skid trails were rehabilitated, a 9.33- ha clambunk-skidded area in the southern part of the block was surveyed to estimate skid trail occupancy and soil disturbance levels (Table 7). This sub-unit was considered representative of the entire ground-skidded area.

The clambunk and loader-forwarder developed a total of 3 906 m (horizontal distance) of unbladed skid trail to harvest this unit, for an average of 419 lineal m/ha. Of this total, 867 m were first-class (heavy use) trails, 1 841 m were second-class trails, and 1 198 m were third-class (light use) trails.

Skid trail widths varied from 3 to 10.7 m and averaged 4.8 m overall. Average skid trail width increased with traffic intensity, from 4 m for third-class trails to 4.7 m for second-class trails, and to 6.2 m for first-class trails. Most of the third-class trails were probably made and used only by the loader-forwarder, since the average width of these trails is narrower than the Trans-Gesco clambunk (4.5 m when equipped with 1.37-m-wide tracks, as in this study).

A total of 1.9 ha, or 20.4% of the harvested area, was occupied by all classes of skid trails. First-class trails accounted for 0.54 ha, second-class trails for 0.87 ha, and

Skid trail characteristics	Skid trail class 1st	2nd	3rd	All classes
Length (m)	867	1 841	1 198	3 906
Area (ha)	0.54	0.87	0.49	1.90
Width (m)				
minimum	4.4	3.3	3.0	3.0
maximum	10.7	6.2	5.8	10.7
mean [a]	6.2	4.7	4.0	4.8
Slope (%)				
minimum	5	5	(20)	(20)
maximum	50	47	47	50
mean [b]	28	29	26	28
Proportion of trail area with exposed mineral soil (%)				
minimum	30	5	0	0
maximum	100	100	60	100
mean [c]	91	39	14	42

Table 7. Summary of the skid trail survey

[a] Differences between means significant at $\alpha = .01$
[b] No significant differences between means at $\alpha = .05$
[c] Differences between means significant at $\alpha = .01$

third-class trails for 0.49 ha. All of the first-class trails were heavily disturbed due to repeated machine traffic. The surfaces of these skid trails consisted almost entirely of exposed mineral soil (average 91%), usually heavily churned and mixed with broken slash and woody debris, with deep continuous impressions created by the skidder's tracks and the dragging ends of large logs.[5]

Second-class trails represented a gradient of disturbance conditions. This ranged from extensive stretches of exposed and churned mineral soil suggesting numerous machine passes, to shallow track impressions in otherwise intact forest floor indicating only a few passes. A typical second-class trail consisted of well-defined track impressions in crushed slash and forest floor material, interspersed with discontinuous patches of exposed mineral soil. While it was obvious that second-class trails were used for skidding, overall these trails were much less heavily disturbed than first-class trails. Exposed mineral soil averaged only 39%, considerably less than that of first-class trails.

Most of the third-class trails were thought to have been created by the loader-forwarder as it aligned logs for the clambunk, and were not used for skidding. For the most part, these trails were identified by faint track impressions on slash or forest floor layers. Exposed mineral soil averaged 14% and occurred in small, isolated patches at points where the loader-forwarder changed direction of travel.

This survey was not done to measure compliance with the FPC. However, the skid-trail classes as defined for this study correspond generally with FPC definitions of "compacted areas" and "dispersed disturbance" (BCMOF 2000). First- and second-class trails occupied 5.8% and 9.3%, respectively, of the harvested area. In the author's opinion, virtually all of the first-class trails and perhaps three-quarters of the second-class trails qualify as "compacted area" and "dispersed

[5] "Exposed mineral soil" was one of the criteria used in this study to differentiate between first-, second-, and third-class skid trails, and is not equivalent to "soil disturbance" as defined in the FPC.

disturbance", respectively, while lightly-travelled segments of second-class trails and all of the third-class trails would not count as soil disturbance. Thus, total soil disturbance using FPC definitions is probably about 12–13% of the Net Area to be Reforested (NAR), whereas the maximum disturbance level allowed for a site with a moderate to high soil sensitivity rating is 10%. Although the clambunk probably exceeded the allowable limit on this particular sub-unit, this survey suggests that it should be possible to satisfy soil disturbance objectives by carefully planning skidding patterns and subsequently rehabilitating the heavily-travelled skid trails after harvesting.[6]

Results of the soil disturbance survey suggest that with careful planning and commitment to rehabilitating heavily travelled skid trails, the clambunk can meet soil disturbance objectives in this type of application.

The use of easily recognized, designated skid trails facilitated identification and post-harvest rehabilitation of disturbed areas.

Conclusions

The study demonstrated that the Trans-Gesco TG 88 clambunk was capable of working efficiently in a clearcut block designed initially for cable yarding only. The clambunk met all basic expectations: it was able to negotiate steep terrain, build its full payloads from smaller piles, and skid these payloads over long distances without a dramatic loss in production.

The clambunk's cycle time was strongly correlated with skidding distances and number of stems per cycle. The clambunk's payloads averaged 20 stems and 30 m³ per cycle, based on the average volume of 1.5 m³ for this study. The average skidding productivity was 42.7 m³/SMH, and the skidding cost of $3.86/m³ constituted 24% of the total cost to put the logs on the truck (estimated at $16.15/m³). Repairs to components of the hydraulic system of the machine were the main source of all delays.

The clambunk was able to work as part of a hot logging system. Delays resulting from the interaction between the clambunk and other components of the harvesting system were rare and constituted a very low portion of the shift time.

The financial analysis showed that the introduction of the Trans-Gesco system to the study block resulted in considerable time and financial savings, up to $5.83/m³.

Implementation

During the observed harvesting operation, FERIC identified conditions for successful and efficient use of the Trans-Gesco clambunk:

- The Trans-Gesco clambunk can be employed in clearcut blocks with slopes up to 50%.
- Skidding with a clambunk is especially advantageous in blocks with high average stem volumes. Skidding productivity and cost strongly depend on average stem volumes.
- To build up large loads and to use its full payload capacity, the clambunk requires cutblocks with relatively long distances between roads and block boundaries.
- To achieve an efficient skidding operation in manually felled cutblocks, and to facilitate the loading phase of the skidding operation, felled trees should be retrieved from the areas in between the trails with a loader and bunched along the skid trails in continuous windrows. Windrowed timber should be oriented in a "herring-bone" arrangement. Stems should be located close to the skid trail, within the reach of the clambunk's boom, and with butts pointing toward the trail. The angle between the skid trail and stems should be in the range of 30–45°. Placing the stems parallel to the skid trail should be avoided.

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[6] The FPC allows soil disturbance limits to be temporarily exceeded if certain conditions are met and the disturbed area is appropriately rehabilitated after harvesting, as was done in this study (BCMOF 2000).

- To avoid unnecessary soil disturbance, a system of skid trails for the clambunk should be laid out. Skid trail sections should be as long as possible, oriented perpendicular to the contour lines, connected by gentle curves, and free of ground obstacles. The location of the skid trails has to be known to the loader operator bunching the stems for the skidding operation. Stumps on the skid trail and its vicinity should be kept low to avoid machine hang-ups. After several passes of the clambunk, the height of the stumps usually has to be reduced with a power saw.
- Retrieving and bunching stems along skid trails should start early enough to avoid delays resulting from loader and clambunk interaction. For cutblocks with limited access to the haul road and limited landing capacities, a hot logging system is recommended.
- Unloading the clambunk with a loader facilitates preliminary sorting of stems, keeps the landing area clean, and creates safer working conditions on the landing for the processing team.
- The loader-forwarder should be utilized whenever possible. In blocks harvested with clambunks, the loader-forwarder can be used to extract timber from the block area close to the road.
- The Trans-Gesco system can be combined with a cable yarding system and may result in considerable financial savings. With proper planning and layout of yarding roads, skid trails, and landings, no delays related to the interaction between the two extraction systems should occur. If two or more extraction systems are employed in the same block, landing and loading activities of these systems should be supported with one hydraulic log loader to increase its utilization and reduce costs.
- Employment of two or more extraction systems in the same block requires more elaborate site reconnaissance, planning and layout because the requirements of the systems on the shape of the cutblock, location of roads, falling and extraction directions, etc. may be in conflict with each other. Final decisions may be based on prioritization of extraction systems or on study results of several possible solutions.
- Strategic planning is necessary to determine the long-term capability of the company to support the Trans-Gesco system as a substitute for cable systems. It should identify suitable locations, timber volumes, and predicted finanical outcomes for potential employment of the clambunk. The planning span should not be shorter than one year but it would be advantageous if it was equal to the expected machine life.

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Appendix I

Cycle elements for detailed timing of skidding operation

Travel unloaded:	Begins when the clambunk starts moving away from the deck, and ends when the clambunk stops to load the first stem.
Loading and moving to load:	Begins after travel unloaded is completed, and ends when the last stem of the full cycle load is placed on the machine and the clambunk grapple is closed to secure the load.
Travel fully loaded:	Begins after loading and moving the load is completed, and ends when the clambunk opens the grapple for dropping the load or stops on the landing for unloading.
Unloading:	Begins after travel fully loaded is completed, and ends when the clambunk starts moving away from the deck.
Delay:	Begins when a productive function is interrupted, and ends when a productive function is recommenced. In-cycle delays include mechanical and non-mechanical delays of 10 min or less that occur sporadically in the skidding cycles.

Appendix II

Machine costs [a]

	Trans-Gesco TG 88 clambunk	Link-Belt LS-4300 loader	John Deere 892D-LC loader [b]	Madill 124 swing yarder with grapple [c]	MDI/Yutani MD320 loader
OWNERSHIP COSTS					
Total purchase price (P) $	742 000	450 000	310 000	1 315 000	100 000
Expected life (Y) y	10	6	6	12	10
Expected life (H) h	18 000	10 800	10 800	17 280	14 400
Scheduled hours per year (h)=(H/Y) h	1 800	1 800	1 800	1 440	1 440
Salvage value as % of P (s) %	20	30	30	30	30
Interest rate (Int) %	9.0	9.0	9.0	9.0	9.0
Insurance rate (Ins) %	3.0	3.0	3.0	3.0	3.0
Salvage value (S)=(s•P/100) $	148 400	135 000	93 000	394 500	30 000
Average investment (AVI)=((P+s)/2) $	445 200	292 500	201 500	854 750	65 000
Loss in resale value ((P-S)/H) $/h	32.98	29.17	20.09	53.27	4.86
Interest=((Int•AVI)/h) $/h	22.26	14.63	10.08	53.42	4.06
Insurance=((Ins•AVI)/h) $/h	7.42	4.88	3.36	17.81	1.35
Total ownership costs (OW) $/h	62.66	48.67	33.53	124.50	10.28
OPERATING COSTS					
Wire rope (wc) $	-	-	-	40 000	-
Wire rope life (wh) h	-	-	-	1 440	-
Rigging and radio (rc) $	-	-	-	12 500	-
Rigging and radio life (rh) hy	-	-	-	5 760	-
Fuel consumption (F) L/h	38	30	30	36	8
Fuel (fc) $/L	0.55	0.55	0.55	0.55	0.55
Lube & oil as % of fuel (fp) %	15	15	15	15	15
Annual tire consumption (t) no.	4	-	-	-	-
Tire replacement (tc) $	4 000	-	-	-	-
Track & undercarriage replacement (Tc) $	12 000	35 000	30 000	63 000	-
Track & undercarriage life (Th) h	9 000	8 000	8 000	8 000	-
Annual operating supplies (Oc) $	-	-	-	10 000	-
Annual repair & maintenance (Rp) $	59 400	60 000	44 800	116 000	5 000
Shift length (sl) h	10	11	12	11	11
Wages $/h					
Operator	22.92	23.24	23.24	25.58	-
Hooktender	-	-	-	24.87	-
Total wages (W) $/h	22.92	23.24	23.24	50.45	-
Wage benefit loading (WBL) %	38	38	38	38	-
Wire rope (wc/wh) $/h	-	-	-	-	-
Rigging and radio (rc/rh) $/h	-	-	-	2.17	-
Fuel (F•fc) $/h	20.90	16.50	16.50	19.80	4.40
Lube & oil ((fp/100)•(F•fc)) $/h	3.14	2.48	2.48	2.97	0.66
Tires (t•tc/h)	8.89	-	-	-	-
Track & undercarriage (Tc/Th) $/h	1.33	4.38	3.75	7.88	-
Operating supplies (Oc/h) $/h	-	-	-	6.94	-
Repair & maintenance (Rp/h) $/h	33.00	33.33	24.89	80.56	3.47
Wages & benefits (W•(1+WBL/100)) $/h	31.63	32.07	32.07	69.62	-
Overtime (0.5W(sl-8)(1+WBL/100)/sl) $/h	3.16	4.37	5.35	9.49	-
Total operating costs (OP) $/h	102.05	93.13	85.03	199.43	8.53
TOTAL OWNERSHIP AND OPERATING COSTS (OW+OP) $/h	164.71	141.79	118.56	323.93	18.81

[a] These costs are based on FERIC's standard costing method for determining machine ownership and operating costs. These costs do not include supervision, profit, or overhead, and are not the actual costs incurred by the contractor or company.

[b] The John Deere 892D-LC is not available any longer. Purchase prices used in the cost analysis is based on John Deere 330 LC.

[c] The Madill 123 is not available any longer. Purchase price used in the cost anaysis is based on Madill 124. An allowance of $15,000 was used for the grapple.

Appendix III

Results of regression analysis

Equation 1: $CT = 7.17 + 0.0682\ DE + 0.396\ ST$

n = 101 cycles R^2 = 80.7% $S.E.E.$ = 4.916

where:

CT	=	Delay-free cycle time (min)
DE	=	Travel empty distance (m)
ST	=	Stems in payload (no./cycle)
n	=	Number of cycles used in the regression analysis
R^2	=	Multiple coefficient of determination
S.E.E.	=	Standard error of estimate

This equation is applicable for the following ranges:

- DE: 35–550 m
- ST: 3–42 stems/cycle

Equation 2: $$Productivity = \frac{60(CV)(U)}{CT + DT}$$

where:

Productivity	=	Predicted productivity measured in m^3/SMH
CV	=	Average volume per skidding cycle (m^3)
U	=	Utilization (from Table 3)
CT	=	Cycle time from Equation 1 (min)
DT	=	"In-cycle" delay time/cycle from Figure 9 (min)

Appendix IV

Summary of harvesting costs for cable-yarding-only and clambunk-and-cable-yarding systems

Description	Cable yarding	Clambunk and cable yarding
Volume yarded (m^3)	30 037	19 501
Volume skidded (m^3)	-	10 536
Yarding productivity (m^3/SMH) [a]	23	23
Skidding productivity (m^3/SMH)	-	43
Yarding time (SMH)	1 306	848
Skidding time (SMH)	-	247
Total extraction time (SMH)	1 306	1 095
John Deere loader time (SMH)	-	256
Link-Belt loader time (SMH)	1 306 [b]	1 148 [c]
Yarder and backspar costs ($/SMH) [d]	342.74	342.74
Clambunk cost ($/SMH)	-	164.71
John Deere loader cost ($/SMH)	-	118.56
Link-Belt loader cost ($/SMH)	141.79	141.79
Falling unit cost ($/$m^3$)	3.75	3.75
Processing unit cost ($/$m^3$	1.62	1.62
Falling cost ($)	112 639	112 639
Yarding cost ($)	470 602	290 598
Skidding cost ($)	-	40 683
John Deere loader cost ($)	-	30 350
Link-Belt loader cost ($)	185 178	162 780 [e]
Processing cost	48 660	48 660
Road construction cost ($) [f]	70 000	-
Area rehabilitation cost	-	3 320
Total cost ($)	864 078	689 029
Cost ($/$m^3$)	28.77	22.94

[a] Yarding productivity information supplied by Skeena Cellulose.
[b] Working time for the loader was assumed to be equal to the yarding time.
[c] Sum of the employment time in yarded and skidded portions of the block (848 and 300 h, respectively).
[d] Hourly yarder cost calculated by FERIC.
[e] Sum of loader costs in yarded and skidded portions of the block.
[f] Road construction cost based on information supplied by Skeena Cellulose.