EVALUATING FELLER BUNCHER PERFORMANCE IN INTERIOR BRITISH COLUMBIA

By

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ABSTRACT

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Keywords: Feller-buncher, Productivity, Utilization, Sustainability, FPTrak, Fuel Efficiency, Productive Machine Hours, Scheduled Machine Hours, Machine Performance, ArcGIS Pro, Geoprocessing, Productivity metrics, Time and motion study, Operator

This thesis examines the performance of harvesting equipment in British Columbia's forestry sector. The study examines two forest stands under CANFOR Ltd. in Prince George, British Columbia. It uses data from modern monitoring technology, FPTrak, to collect real-time data on two feller-bunchers, including their working and idle time. The primary goal is to collect data on the performance characteristics of these two feller-bunchers and determine whether there is variability in machine productivity under similar terrain conditions. The research also aims to identify factors that affect operational efficiency, reduce environmental consequences, and promote sustainability. It also seeks to analyze the productivity and utilization of the harvesting equipment and the amount they harvested. The study helps maximize efficiency, reduce environmental effects, and optimize harvesting machinery in the forestry industry. The results shed light on the variables impacting machine productivity, the effects of technology improvements, and the significance of sustainable forest management techniques. They also offer insightful information about the performance of feller-bunchers in British Columbia.

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INTRODUCTION

The forestry sector is crucial in addressing the worldwide need for timber and paper goods while upholding sustainable forest management principles (Lähtinen et al. 2017). At the core of this sector lie the essential components of harvesting machinery that substantially influence the wood supply network's overall effectiveness and ecological viability. Timber harvesting practices exhibit significant diversity across regions globally, reflecting the need to adapt technological approaches to each locality's intricate and geographically specific conditions (Lindroos et al. 2017).

Understanding the performance of harvesting machinery holds significant importance for multiple reasons. To begin with, implementing efficient harvesting operations plays a significant role in enhancing the economic sustainability of the forestry sector by reducing expenses related to timber extraction (Daigneault et al. 2019). Furthermore, maintaining biodiversity and ecosystem health necessitates minimizing the environmental impact of logging activities (Roser 2023). In addition, optimizing equipment performance plays a crucial role in promoting sustainable forest management, thereby guaranteeing the continued availability of timber resources in the long run (Lähtinen et al. 2017).

For operations to be efficient and productive, data collection regarding the functionality and output of equipment is essential. The FPDat system is one such system developed by FPInnovations. The purpose of FPDat is to gather and evaluate machine performance and productivity data (FPDat n.d.). It is a durable gadget that can survive the severe operating environments in mining, forestry, and the energy industry. After gathering and analyzing data on manufacturing activities, the computer notifies managers and operators about productivity, areas treated, and performance (FPDat n.d.). FPTrak is a web-based service that integrates data from FPDat and MultiDat units, allowing for remote monitoring of equipment production and performance (FPTrak n.d.). This secure solution provides immediate access to all FPDat and MultiDat data on a map and other information for tracking production progress and performance analysis (FPTrak n.d.).

The study investigates two forest stands under the SFL of CANFOR Ltd. located in Prince George (PG), British Columbia. Modern monitoring technologies mentioned above are used to gather data of two feller-bunchers, including the working and idle time of the machines in the blocks in real time. This thesis focuses on data collected from a 2021 Tigercat LX870D Levelling Feller-Buncher (FB23) and a 2022 Tigercat LX870D Levelling Feller-Buncher (FB25) owned by Lo-Bar Log Transport. This data is then used to find the productivity and utilization of these machines in two adjacent blocks, Block 1 and Block 2, situated in the Omineca Region in PG.

The primary objective of this study is to gather data about the performance metrics of these two feller-bunchers and to find if there is variation in machine productivity under similar terrain conditions. This is done by comprehensively analyzing the productivity and utilization of the mentioned harvesting machines and the volume they harvested and focusing on finding factors that affect operational efficiency, reduce environmental consequences, and promote sustainability.

LITERATURE REVIEW

British Columbia (BC), located in Canada, is widely recognized for its expansive and ecologically diverse forested areas, encompassing approximately 56 million hectares of land (MacKinnon 1971). Only about 22 million ha of this land witnessed timber harvest activities (Devisscher et al. 2021). The forestry sector in British Columbia (BC) generates the highest revenue in Canada. It is crucial in the provincial economy, substantially contributing to employment, trade, and sustainable resource management (Berryman 2012). Forest harvesting, an integral aspect of the forestry industry, involves carefully extracting timber resources from various forest areas. The importance of forest harvesting in British Columbia extends beyond just economic considerations. The forests in the province have a profound connection to the cultural heritage of Indigenous communities, as they have historically depended on these forests for sustenance, engagement in traditional activities, and spiritual significance (McIlveen & Bradshaw 2009). Moreover, this process is of utmost importance to fulfill the worldwide need for timber products, improve regional economies, and sustain the ecological balance of British Columbia's forests (Devisscher et al. 2021).

Harvesting is an essential component of sustainable forest and biomass management supply chains (Wang 2022). This book explained its applications, including timber and biomass feedstock production, wildlife habitat management, and wildfire risk reduction through fuel buildup reduction. The evolution of timber harvesting is visible over time, progressing from primitive manual tools to the modern deployment of automated machines (Wang 2022). These advances in timber harvesting have increased efficiency and productivity while decreasing labour-intensive tasks. Furthermore, the use of automated machines has increased worker safety by reducing the risks associated with manual labour in hazardous environments (Wang 2022). Implementing sustainable forest management practices constitutes a fundamental aspect of British Columbia's approach to timber harvesting (Campbell et al. 2009). The responsible extraction of timber resources has been facilitated by implementing stringent regulations and practices by the provincial government in collaboration with industry stakeholders (Campbell et al. 2009). Sustainable harvesting practices aim to balance the economic advantages of forestry and the necessity to preserve the long-term health and biodiversity of forest ecosystems (Campbell et al. 2009).

Technological advancements have significantly transformed forest harvesting practices in British Columbia. These play a significant role in enhancing efficiency and promoting sustainability within the industry, encompassing the utilization of satellite imagery for mapping and planning purposes and integrating state-of-the-art machinery for timber extraction (Lindroos et al. 2017). These technological advancements contribute to the reduction of the environmental impact caused by harvesting operations while simultaneously optimizing the utilization of harvested timber resources (Wang 2022). Moreover, incorporating GPS technology into forest harvesting operations facilitates accurate navigation and monitoring, thereby mitigating the potential harm inflicted upon neighbouring ecosystems by the machines (Tai 2020). Furthermore, the utilization of automated machinery not only enhances efficiency but also ensures the safety of workers by reducing their vulnerability to dangerous situations (Chung et al. 2019).

The use of advanced machines in forest operations has increased in recent decades as forestry technology has advanced (Bilici 2021). The selection of appropriate machinery is of utmost importance due to its high operating costs, a task primarily accomplished through the utilization of productivity analysis (Bilici 2021). Productivity analysis enables forestry professionals to assess the efficacy and efficiency of various machinery options, facilitating informed decision-making processes (Bilici et al. 2019, Bilici 2021). By examining various factors, including machine availability, working hours, fuel consumption, output capacity, and maintenance requirements, researchers can ascertain the optimal machines that will yield the highest return on investment for specific forest operations. Furthermore, this analysis guarantees that the selected machinery follows sustainable forestry practices and effectively mitigates environmental consequences (Bilici 2021).

FELLER-BUNCHER

A feller-buncher is a self-propelled machine equipped with a cutting head that can grasp multiple trees' stems simultaneously (FOEC n.d.). The primary purpose of the cutting head is to fall the trees efficiently, hold them, and neatly arrange them on the ground (FOEC n.d.). Notably, feller-bunchers do not possess processing capabilities beyond these essential tasks. The operator positions the machine in front of a tree, grapples it with the felling head, chops it from the stump, and then descends it horizontally onto a pile or bunch of trees on the ground, hence the name feller-buncher (Uusitalo & Pearson 2010). The two main types of feller-bunchers include:

Drive-to-tree feller-buncher: The felling head is directly mounted on the machine body in this configuration. Unlike other types that rely on a separate boom, the drive-to-tree feller-buncher can approach trees directly and efficiently cut them down (Uusitalo & Pearson 2010).

Swing-to-tree feller-buncher: These machines feature a tracked chassis like what can be found in tracked excavators. The critical component is a heavy-duty boom attached to the chassis. At this boom's end is a specialized felling and bunching head. This head effectively cuts down trees and gathers them into neat piles for further processing (Uusitalo & Pearson 2010).

While slower than their wheeled counterparts, tracked machines offer enhanced stability on steep slopes. Tracked feller bunchers excel in operating on wet and loose soils—conditions that would hinder rubber-tired machines (Uusitalo & Pearson 2010). Additionally, some feller bunchers feature self-levelling cabs, allowing them to work effectively on varying slopes (Uusitalo & Pearson 2010). The levelling feller-buncher utilized in the study features Tigercat's exclusive ER® technology, which allows the machine operator to extend and retract the boom in a horizontal plane with a single joystick smoothly and quickly (LX870D 2023). However, the benefits go beyond reducing operator fatigue. Reduced energy consumption is crucial to ER technology (LX870D 2023). The ER system transfers energy between the main and stick boom functions, reducing the energy required to move the boom system. This reduces the demand for electricity, pump flow, and system cooling. As a result, production increases, but fuel consumption per unit output drops (LX870D 2023).

FACTORS AFFECTING MACHINE PRODUCTIVITY

Various factors can influence the productivity of a feller-buncher. These include the characteristics of the forest stand (such as tree size, density, and harvesting intensity), the terrain conditions (including slopes and roughness), the layout of skid trails, the choice of landing locations, and the skill and performance of the operator. While the harvesting system's fundamental techniques and machine categories have not undergone substantial changes, there have been undeniable advancements in the operators' proficiency, technical innovations in forest machinery, and modifications in the working conditions (Nurminen et al. 2006). Machine rates are commonly denoted in terms of productive machine hours (PMH) or scheduled machine hours (SMH) (Rolston 1972). The scheduled time refers to the designated period during which equipment is allocated for productive tasks. Productive time refers to the specific portion of allocated time in which a machine executes its designated operational tasks (Rolston 1972). The sum of productive and nonproductive time is equivalent to the scheduled operating time. The utilization rate of a machine refers to the ratio between the productive time and the scheduled time (Rolston 1972). Productivity can be defined as the product of the number of trees felled per cycle and the productive machine hour the forest machine achieves. (Miyajima et al. 2021).

Operator performance plays a significant role in determining the availability of machines and the productivity of timber harvest in commercial forestry (Pagnussat et al. 2021). The competence of equipment operators is a crucial factor in determining the performance of any harvesting equipment. Proficient operators play a crucial role in ensuring machinery's secure and effective utilization and mitigating adverse impacts on the surrounding environment (Pagnussat et al. 2021). Continuous training programs and strict adherence to industry best practices are necessary to fully optimize harvesting equipment's capabilities while upholding the principles of environmental stewardship (Pagnussat et al. 2021). The wide range of environmental conditions encountered during forestry operations substantially impacts equipment performance (Smidt 2023). The efficient operation of harvesting machinery can be hindered by undulating terrain, fluctuating weather conditions, the size of the trees, the strength of the soil, the slope of the land, and seasonal fluctuations (Smidt 2023). The interaction between the machine and site conditions influences equipment performance. However, logging planning can regulate performance by implementing strategies such as landing spacing and bunch size management (Smidt 2023).

MATERIALS AND METHODS

The experiment involves the use of two levelling feller-bunchers, FB23 and FB25, in realistic logging circumstances, with a focus on two adjacent blocks of the SFL holder CANFOR Ltd., which are Block 1 and Block 2 in the Omineca Region in Prince George, BC. Advanced monitoring technologies were used to collect data from the equipment. The collected data includes time and motion analysis, which will be used to determine productivity. Sites with similar conditions were selected to determine if there will be differences in machine performance when under similar stand conditions. To fully understand the equipment's performance, factors affecting equipment performance, key metrics such as fuel efficiency, productivity, environmental impact, and overall system effectiveness will be meticulously studied from various articles online. The search was done using key searches in Google Scholar, J-STOR, and Lakehead OMNI.

The machines studied are a 2021 Tigercat LX870D Levelling Feller-Buncher and a 2022 Tigercat LX870D Levelling Feller-Buncher. Both the feller-bunchers are named FB23 and FB25, respectively, for identification purposes within the company. There is not much difference between the 2021 and 2022 models. The LX870D is a robust, tracked, swing-to-tree compact feller-buncher designed explicitly for challenging tasks such as thinning and final felling in steep terrain. The specifications of the feller-buncher are given in Figure 1.

Source: LX870D 2023

Figure 1. Shows the specifications and image of the Tigercat LX870D levelling feller-buncher.

Blocks 1 and 2 are adjacent blocks with slopes >35%, high soil compaction hazard, and a total area of 92.4 ha and 29.4 ha, respectively. However, the total area to harvest was reduced to 86.2 ha for Block 1 and 27.1 ha for Block 2 due to the presence of MFZs and winter harvest areas that have not been harvested yet. The volume and size data for each block are given in Table 1.

Table 1. The volume and size data of Blocks 1 and 2.

Volume and Size data	Block 1	Block 2
Total area (ha)	92.9	29.4
Total harvest area (ha)	86.2	27.1
Total harvested (ha)	86.2	25.7
Total volume harvested (m3)	20,939	5,898
Gross merchantable (m3)	26,693	8,561
Net merchantable (m3)	19,528	6,220
Net Merch (m3/ha)	261.0	256.0
Basal Area/ha (m2/ha)	38.3	41.9
Stems/ha	318.9	523.8
Average DBH (cm)	39.1	31.9
Net merch vol/tree (m3)	0.8	0.5

Table 2 gives a detailed summary of a harvest plan that consists of four separate units, all set to be summer harvest. The harvest methods assigned to each unit are "Steep Slope Conventional" or "Winch Assist," which correspond to the specific methods used to negotiate rugged terrain. The table also describes each unit's harvest technique, which differs for locations with slopes between ">35%-49%", >50-%-60% and "Machine Free Zones."

Table 3 is a comprehensive harvest plan created especially for Block 2, showing five different units with different important seasons, including summer and winter operations. All the units in Block 2 have opted to harvest using the "Winch-Assist" method, which involves using specialized equipment to traverse and retrieve timber from rugged terrain efficiently. According to its unique harvest strategy, each unit is carefully classified based on a range of factors, including slopes ">50%-60%", ">35%-49%", areas with a designated "Site Disturbance 5%", and zones designated as "Machine Free Zone" to guarantee the least amount of disturbance and environmental impact.

Both the tables show the area coverage in hectares (ha) and the volume of timber to be harvested in cubic meters (m^3) for each unit. This provides a quantitative overview of the harvesting activities planned for Blocks 1 and 2.

Table 2. Harvest Plan for Block 1

Harvest Unit	Critical Season	Harvest Method	Harvest Strategy	Area (ha)	Volume (m3)
1	Summer	Steep Slope Conventional	>35%-49%	28.4	7414
2	Summer	Winch Assist	>50%-60%	56.7	14803
3	Summer	Steep Slope Conventional	Machine Free Zone	0.4	104
4	Summer	Winch Assist	Machine Free Zone	0.7	183

Table 3. Harvest Plan for Block 2

Harvest Unit	Critical Season	Harvest Method	Harvest Strategy	Area (ha)	Volume (m3)
1	Summer	Winch-Assist	>50%-60%	19.3	5759
2	Summer	Winch-Assist	>35%-49%	5.3	1582
3	Winter	Winch-Assist	Site Disturbance 5%	1.3	388
4	Summer	Winch-Assist	Machine Free Zone	1.1	328
5	Winter	Winch-Assist	Machine Free Zone	0.1	25

The shape of the blocks was traced into ArcGIS Pro using the Create Feature Tool in Geoprocessing, which can be found under the Analysis tab. The tracks from the machines were found from the map drop-down on the FPTrak website by selecting the machines. Then, this was exported as a shapefile and put into ArcGIS Pro to find how long the machine stayed in the blocks. All tracks outside the blocks were deleted by selecting the polygon and then using the Clip tool to clip every track outside the block boundary. It defined its coordinate system using the Define Projection Tool under Geoprocessing in the Analysis Tab. These methods were repeated for each block and each machine. The information from the attribute table of the tracks was then used to find the time the machines spent in each block.

Table 4. The total time that the machines spent on each block.

	Block 1		Block 2	
Machine	From	To	From	To
FB23	6-Jul-2023	31-Aug-2023	22-Aug-2023	31-Aug-2023
FB25	5-Jul-2023	30-Aug-2023	17-Aug-2023	31-Aug-2023

As a part of finding the productivity and utilization metrics, the machines' Productive Machine Hours (PMH) were found by adding all the durations for which the status showed "WORKING." As the SMH was not set for the machines, the engine on was the SMH and was found by adding the duration of working to the duration when the recorder was "ON" and the motion was "OFF." The raw data for this calculation is provided in the Appendix. The machine utilization of the machines for each block was then found by dividing the PMH by the SMH and its formula (Uusitalo & Pearson 2010),

$$\text{Utilization (\%)} = \frac{PMH}{SMH}\ x\ 100$$

To find if the volume harvested impacts machine productivity, the volumes harvested between each machine in each block and the same machine between the different blocks are compared. This is done by estimating the total volume harvested by each machine. The volume harvested by each machine in each block is estimated by creating a polygon around the machines' tracks using the create feature tool. The area of the polygon is then found by right-clicking on the layer and selecting the attribute table. Select Add Field on the top left of the attribute table. The field name was changed to "Area," and the data type was changed to "Double." Then, hit save. Then go back to the attribute table, right-click the Area field, and select the Calculate Field option. In this set, the calculating Field is the polygon's area, which determines the units it needs to display (in ha). These methods are then repeated for each machine and each block.

The calculated area is then divided by the total harvested area of the blocks and then multiplied by 100 to find how much percentage of the block was harvested by the machines. This percentage is then multiplied by the total volume harvested from the blocks to get the volume harvested by each machine. The productivity of each machine was then found by using the equation as follows (Uusitalo & Pearson 2010),

$$P = \frac{Volume\ Harvested}{PMH}$$

The volume harvested is in m3, PMH is in hours, and productivity calculated is in m3/PMH.

RESULTS

A comparison of the FB23's performance characteristics between the two blocks is provided in Table 5. With 74 nonproductive hours, 151 scheduled machine hours (SMH), and 76 recorded productive machine hours (PMH), Block 1 had a 51% utilization percentage. Block 2, however, showed a PMH of 36, 8 Nonproductive Hours, an SMH of 44, and a higher Utilization Percentage of 82%. These data show the differences in productivity and utilization between the two blocks using the FB23. A table of raw data which is used to find the PMH and SMH is provided in the Appendices for each machine in each block.

Table 5. The Machine utilization (%) for FB23 in Block 1 and Block 2.

FB23		
	Block 1	Block 2
PMH	76	36
Nonproductive (hrs)	74	8
SMH	151	44
Utilization (%)	51%	82%

Table 6 compares the performance characteristics of the FB25 for two different blocks. In Block 1, Productive Machine Hours (PMH) were recorded at 138, Nonproductive Hours totalled 12, and Scheduled Machine Hours (SMH) were scheduled at 150, resulting in a 92% utilization rate. Block 2 had a PMH of 29, just 2 Nonproductive Hours, an SMH of 31, and a 94% utilization rate. These figures highlight the differences in productivity and utilization between the two blocks employing the

FB25. Block 2 stands out for its increased efficiency, particularly with a significant decrease in nonproductive hours.

Table 6. Machine utilization (%) for FB25 in Block 1 and Block 2.

FB25		
	Block 1	Block 2
PMH	138	29
Nonproductive (hrs)	12	2
SMH	150	31
Utilization (%)	92%	94%

The pie chart in Figure 2 depicts the utilization of FB23 in the two blocks. In Block 1, machine utilization accounts for 51% of the time, whereas nonproductive time accounts for 49%. This illustration highlights the significant amount of time the machine in Block 1 is nonproductive tasks.

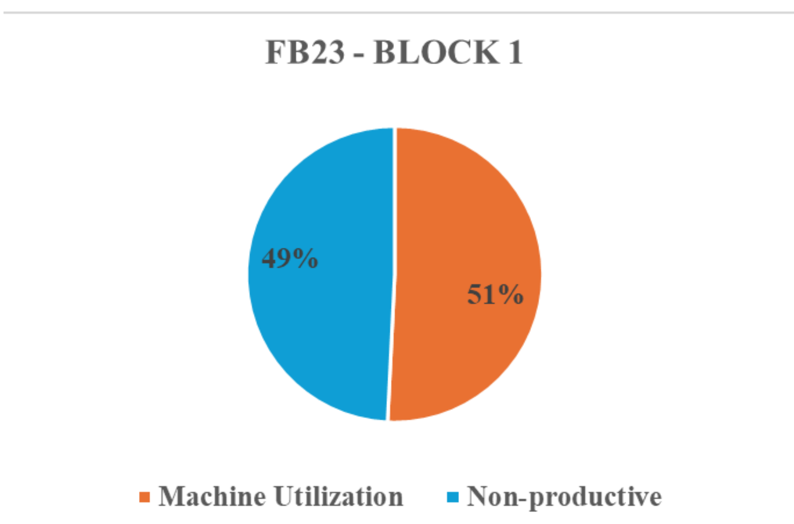

Figure 2. Displays the pie chart with the 49% utilization and 51% nonproductive percentage of time spent by FB23 in Block 1.

Figure 3 shows the machine usage and idle time for "FB23 - BLOCK 2." Visually, it shows that 82% of the chart is occupied by machine usage, represented by the orange hue, representing the machine's productive time. On the other hand, nonproductive time takes up 18% of the blue-coloured chart, suggesting that the machine spends less than quarter amount of time being nonproductive.

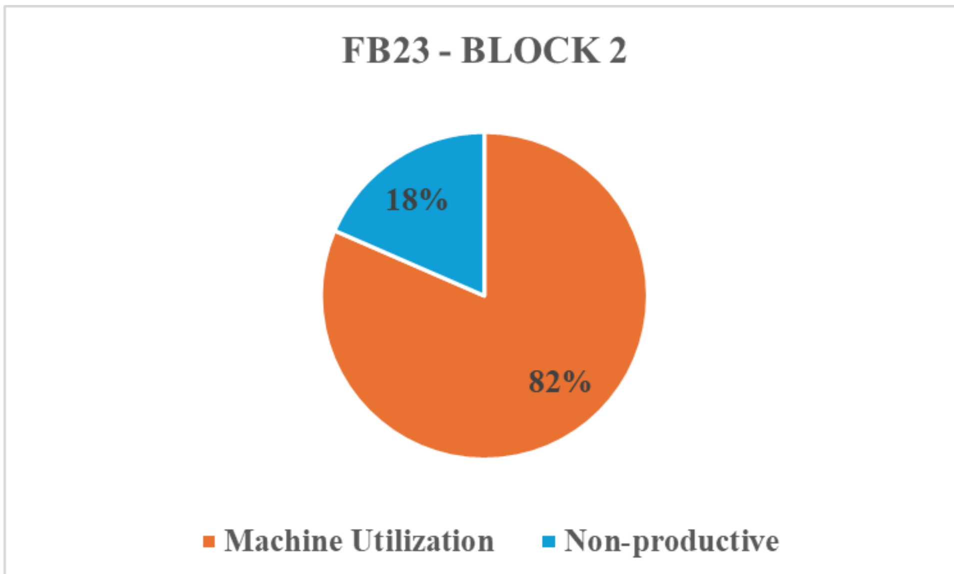

Figure 3. The pie chart shows the 82% utilization and 18% nonproductive percentage of time spent by FB23 in Block 2.

As per Figure 4, FB25 in Block 1 has 92% of the time devoted to machine utilization (shown by the green section), and 8% is spent on nonproductive activities (shown by the blue section).

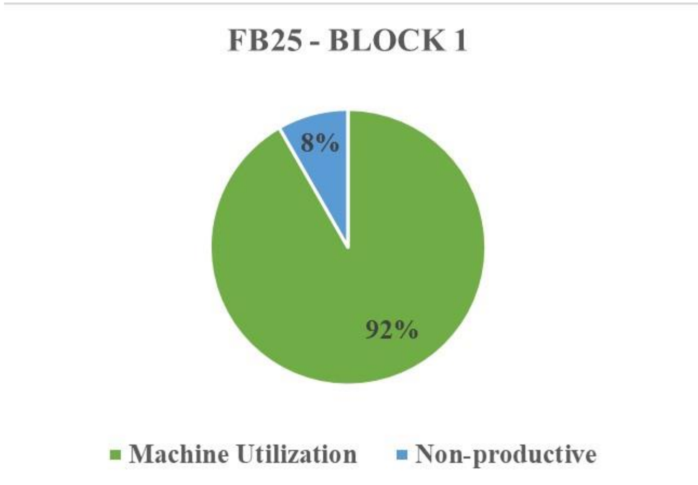

Figure 4. Displays the pie chart with the 92% utilization and 8% nonproductive percentage of time spent by FB25 in Block 1.

The graph illustrating FB25 in Block 2, as per Figure 5, clearly depicts machine use and nonproductive time. The green section, which represents machine usage, takes up 94% of the chart and represents the period when the machine is productive and efficient in executing its intended activities. In contrast, the blue section, representing nonproductive time, accounts for 6% of the chart and signifies downtime or periods when the machine is not operating or contributing to productivity. This graphic breakdown shows that the machine is used most of the time in FB25's Block 2.

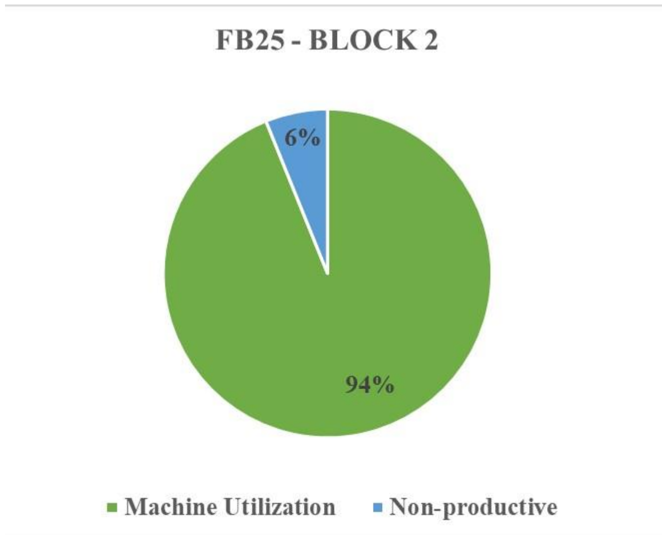

Figure 5. The pie chart shows the 94% utilization and 6% nonproductive percentage of time spent by FB25 in Block 2.

Figures 6 to 9 show the calculated areas of the polygons around the tracks where the machines have been in the blocks from ArcGIS Pro. The calculated values are 27.24 ha for FB23 in Block 1, 7.36 ha for FB23 in Block 2, 42.8 ha for FB25 in Block 1, and 7.12 ha for FB25 in Block 2. This shows that FB25 covered more area in Block 1 and FB23 covered the most in Block 2.

Figure 6. Shows the outline for Block 1 with the calculated polygon area (ha) around the tracks of FB23.

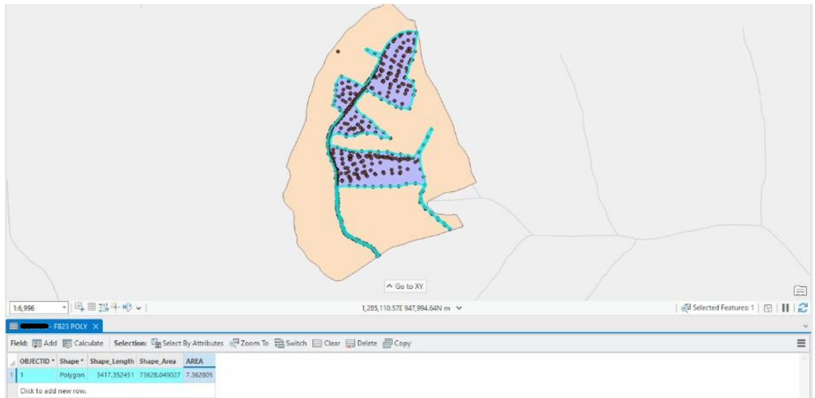

Figure 7. Shows the outline for Block 2 along with the calculated polygon area (ha) around the tracks of FB23.

Figure 8. Displays the Block 1 outline with the calculated polygon area (ha) around the tracks of FB25.

Figure 9. Displays the Block 2 outline with the calculated polygon area (ha) around the tracks of FB25.

In Block 1, the harvesting operation covered 86.2 hectares, with FB23 harvesting 27.2 hectares for a 32% coverage rate. The total volume collected was 20,939 cubic meters from the whole block, with FB23 contributing 6,616.9 cubic meters. Block 1's productive machine hours (PMH) were 76 hours, resulting in a production rate of 86.6 cubic meters per PMH. In Block 2, the harvesting operation covered 25.7 hectares, with the machine covering 7.4 hectares, for a coverage rate of 29%. The total volume harvested in Block 2 was 5,898 cubic meters, of which the FB23 accounted for 1,689.1 cubic meters. Block 2 operated for 36 productive machine hours, yielding a productivity rate of 47.0 cubic metres per productive machine hour.

Table 7. The calculated productivity metrics for FB23 in Block 1 and Block 2.

FB23		
	Block 1	Block 2
Total area harvested (ha)	86.2	25.7
Area covered by machine (ha)	27.2	7.4
% coverage of machine	32%	29%
Total vol harvested (m3)	20,939	5,898
Vol harvested by FB23 (m3)	6616.9	1689.1
Productive Machine Hours (PMH)	76	36
Productivity (m3/PMH)	86.6	47.0

In Block 1, the harvesting operation covered 86.2 hectares, with the machine covering 42.8 hectares, representing a 50% coverage rate. The total volume harvested in Block 1 was 20,939 cubic meters, with FB25 contributing 10,396.6 cubic meters. Block 1 had 138 productive machine hours (PMH), resulting in a production rate of 75.4 cubic meters per PMH. Block 2 harvested 25.7 hectares, with the machine covering 7.1 hectares for a coverage percentage of 28%. The total volume harvested in Block 2 was

5,898 cubic meters, of which the FB25 contributed 1,634.0 cubic meters. Block 2 worked for 29 productive machine hours, yielding a productivity rate of 56.9 cubic metres per productive machine hour.

Table 8. Calculated productivity metrics for FB25 in Blocks 1 and 2.

FB25		
	Block 1	Block 2
Total area harvested (ha)	86.2	25.7
Area covered by machine (ha)	42.8	7.1
% coverage of machine	50%	28%
Total vol harvested (m3)	20,939	5,898
Vol harvested by FB23 (m3)	10396.6	1634.0
Productive Machine Hours (PMH)	138	29
Productivity (m3/PMH)	75.4	56.9

The productivity calculated for each machine in each block was 86.6 m3/PMH for Block 1, 47 m3/PMH for Block 2 for FB23, 75.4 m3/PMH for Block 1 and 56.9 m3/PMH for Block 2 for FB25.

DISCUSSION

Time studies are essential for analyzing the time connected with the operational elements of the feller-buncher (Miyajima et al. 2021). They allow for identifying time losses in operational elements and factors that may contribute positively or negatively to the operations. These studies also provide information on increasing efficiency and cutting expenses during felling operations (Miyajima et al. 2021). The results section provided insight into feller-bunchers' performance under similar terrain conditions. A study by Strandgard and Mitchell in 2010 indicates that site factors, including the terrain conditions and tree size, impact the productivity of feller bunchers. The parameters calculated and assessed give a detailed comparison of harvesting performance in Block 1 and Block 2 of the FB23 system, highlighting changes in area coverage, amount harvested, and productivity rates. The comparison is made such that there are no technical differences between machines as they have the same make and model with few variations between the years they were manufactured.

The average DBH and tree volume were higher for Block 1, with 39.1 cm average DBH and 0.8 m3/tree. Block 1 also had a higher net merchantable of 261 m3/ha, whereas Block 2 had a slightly lower net merchantable of 256 m3/ha. Nonetheless, Block 2 has a higher basal area and number of stems per hectare than Block 1. Block 1 had a basal area and stems per hectare of 38.3 m2/ha and 318.9 stems/ha, and Block 2 had 41.9 m2/ha and 523.8 stems/ha. Both blocks have the most harvesting in >50% to 60% slopes and the rest in slopes >35% to 49% and Machine Free Zones (MFZs). Block

1 had a larger average diameter at breast height (DBH) and tree volume than Block 2, resulting in a higher net merchantable volume per hectare (Miyajima et al., 2021). However, Block 2 exhibited a larger basal area and stem count per hectare, indicating denser vegetation (Miyajima et al., 2021). The two blocks had similar topography conditions, including slope grades and machine-free zones, underlining the importance of tree characteristics in harvesting performance.

While comparing the same machine performance in the two blocks, it was found that FB23 was most utilized in Block 2 with 82% machine utilization even though it covered a lower area coverage of 29% than Block 1, where it covered 32% and only has a machine utilization of 51%. Despite covering a lesser area in Block 2, the FB23 machine demonstrated greater utilization than Block 1 (Miyajima et al. 2021). This difference can be linked to Block 2's higher stem density and lower DBH, which may enable faster harvesting procedures (Miyajima et al. 2021). However, the productivity calculated for FB23 is higher for Block 1 than Block 2, with values of 86.6 m3/PMH and 47 m3/PMH, respectively. The higher productivity of FB23 in Block 1 could be linked to factors other than machine use, such as tree size and density, that significantly impact overall productivity.

Similarly, FB25 had a higher machine utilization rate in Block 2, achieving 94%, than in Block 1, when it only managed 92%. Even with this increased use in Block 2, FB25 only covered 28% of that block instead of 50% in Block 1. There could be several reasons for this difference in the area covered, including the density of trees, the topography, and the operational effectiveness of each block. Despite harvesting a larger area in Block 1, FB25 had higher productivity than Block 2. The productivity of FB25 was measured at 75.4 m3/PMH in Block 1 but declined to 56.9 m3/PMH in Block 2. This disparity in productivity demonstrates the impact of site-specific circumstances on machine performance. The differences in tree characteristics could explain FB25's increased productivity in Block 1 while covering a larger area. This is because Block 1 has comparatively fewer trees with a higher average DBH or spacing, allowing for more efficient harvesting operations and higher volume output per machine hour.

The comparison of feller-bunchers within the same block yields valuable information about their operating efficiency and productivity dynamics. In Block 1, FB25 covered a more significant proportion of the harvested area (50%) than FB23 (32%), indicating higher utilization for FB25. Similarly, in Block 2, FB25 covered 28% of the total block area, somewhat less than FB23, which covered 29%. The volume harvested per Productive Machine Hour (PMH), a productivity statistic, the area covered, and the volume collected by each machine exhibit noteworthy connections. For 6616.9 m3 harvested in Block 1, FB23 achieved 76 PMH, whereas FB25 achieved 138 PMH for 10,396.6 m3 harvested. Similarly, in Block 2, FB23 harvested 1689.1 m3 in 36 PMH, and FB25 harvested 1634 m3 in 29 PMH. This shows that the volume harvested and PMH positively correlate, indicating that greater productivity results from improved utilization and efficiency.

However, there are slight variations in the productivity between FB23 and FB25 in the same block. Even though FB25 harvested more volume and covered a larger area in Block 1, FB23's productivity was better at 86.6 m3/PMH than FB25's 75.4 m3/PMH. This implies that FB23 generates a more significant harvested volume per productive machine hour, suggesting possible differences in operational methods or machine capabilities. However, FB25 may be more efficient regarding the area covered and volume harvested. Similarly, in Block 2, FB25's 56.9 m3/PMH was higher than FB23's 47 m3/PMH, although it covered less area and volume. This demonstrates the complexities of factors influencing productivity, such as operator skill and operating parameters.

The relationship between tree size and feller-buncher output has been a source of interest and disagreement in forestry research. Previous research has provided different viewpoints on this relationship, offering insight into the complexity involved. Ghaffariyan et al.'s 2012 study found a low correlation between tree size and feller-buncher productivity. However, Bilici et al.'s 2019 study contradicts this finding, suggesting a positive linear association between tree DBH and feller-buncher output. The differences between these findings could be attributed to various factors, including the methodology used, the specific conditions of the study sites, and technological developments in feller-buncher design and operation over time. It is important to note that while Ghaffariyan et al.'s study evaluated a more extensive range of variables influencing production, Bilici et al. concentrated on the relationship between tree size and productivity, providing a more detailed analysis.

Taking the volume of trees into account, as noted by Acuna and Kellogg in 2009, provides a complete understanding of the impact of tree size on operation productivity. Trees with bigger DBHs contribute more volume to the total timber harvest. As a result, feller-bunchers operating in regions with more big trees may be more productive due to the increased volume of wood extracted every felling cycle. Variations in tree size and volume between the two blocks can explain why feller-buncher production was higher in

Block 1 and lower in Block 2. Block 1, with its higher average DBH and net merchantable volume per hectare, is expected to provide more favourable conditions for effective harvesting operations. Block 2, on the other hand, may have presented obstacles to feller-buncher productivity due to denser vegetation and lower tree diameters.

Furthermore, the impact of terrain conditions, particularly slope, on production should not be underestimated. Hiesl's 2013 study found that slope substantially impacts machine stability, travel speed, and work step duration. Steep and steep terrain can limit machine maneuverability, raise the danger of accidents, and diminish operator performance, lowering output rates.

As per the study by Purfürst and Lindroos in 2011, the analysis of operator experience and efficiency of feller-buncher performance is critical for understanding the operating dynamics and productivity differences observed between various machines, such as the FB23 and FB25. In this study, the utilization data clearly shows a significant difference in performance between the two machines, primarily due to operator experience and efficiency. Operator expertise is critical in forestry harvesting operations, especially when crossing rugged terrain with slopes exceeding 50%. The operator's familiarity with the equipment, topographical features, and operational procedures substantially impacts their ability to move efficiently and sustain productivity.

In this study, the operator of FB25 is expected to have more expertise and proficiency in running the Tigercat LX870D self-levelling feller-buncher than the operator of FB23. The utilization metrics show a clear trend where FB25 consistently outperforms FB23 regarding machine utilization. This difference can be explained by the operator's skill at operating the feller-buncher under varying environments, including dense vegetation, uneven terrain, and steep slopes. The operator's experience will likely lead to faster decision-making, smoother operations, and improved machine performance, resulting in increased productivity. Moreover, the selection of equipment like the Tigercat LX870D self-levelling feller-buncher contributes to the observed variations in utilization. Combined with the operator's experience, this machine's advanced features and capabilities improve operating efficacy and efficiency, particularly under challenging conditions. For example, the self-levelling feature can significantly reduce the effects of uneven terrain, making harvesting operations more stable and precise while reducing soil compaction in high soil compaction areas, as in this study.

CONCLUSION

Understanding forestry harvesting equipment performance has been of greater interest these days. Considering this, the study's main objective was to assess the performance indicators of two feller-bunchers, FB23 and FB25, working in two nearby forest blocks in Prince George, British Columbia's Omineca Region. The study evaluated variables influencing operational efficiency, minimizing environmental effects, and promoting sustainability in timber harvesting operations. It used contemporary monitoring technology to gather data on machine productivity and utilization. The study's findings shed light on feller-bunchers' performance across different forest blocks. The results revealed differences in machine productivity and utilization between the two forest blocks, emphasizing the importance of site-specific conditions on machine performance. The study also compared the volume collected by each machine in different blocks, which provided helpful information on the relationship between the volume harvested and machine productivity.

Although operator performance influenced machine utilization, according to the findings of this study, harvesting trees in more than 35% slopes with >31cm DBH is most efficient with the type of feller-buncher evaluated in this study. The study also emphasized the significance of operator experience and competence in improving machine efficiency under challenging terrains. Furthermore, adequate maintenance and upkeep of the feller-buncher equipment were discovered to be critical for peak performance in such settings.

Furthermore, the thesis analyzed the findings' significance for British Columbia's forestry sector, highlighting the possibility of optimizing harvesting machinery to improve operational efficiency, reduce environmental impact, and promote sustainable resource management. The study adds to the more extensive discussion about forest harvesting techniques, technological improvements, and the ecological and economic importance of British Columbia's forestry industry. The study also emphasized the value of time studies and data gathering in operational element analysis and improvement identification. Forestry experts can limit environmental impacts, increase operational efficiency, and save expenses by making informed judgments based on parameters, including equipment utilization, nonproductive hours, and productivity rates.

The study offers insightful information about the performance indicators used by feller-bunchers in forestry operations. It emphasizes the necessity of ongoing observation, data analysis, and optimization techniques to guarantee effective and sustainable forest management techniques. Future research could investigate novel technologies and delve further into certain elements influencing machine performance to improve operational outcomes in the forestry industry.

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APPENDICES

APPENDIX I – FB23 BLOCK 1 DATA 2023

RECORDER	ON
MOTION	(All)

Sum of DURSECONDS	Column Labels		
Row Labels	NO RESPONSE TO PROMPT	WORKING	Grand Total
6-Jul		362	362
12-Jul	132	52	184
13-Jul	9888	4039	13927
14-Jul	2105	4777	6882
15-Jul	31321	5695	37016
16-Jul	24825	13216	38041
17-Jul	2344	33957	36301
18-Jul	1772	9821	11593
19-Jul	586	1002	1588
20-Jul	348	928	1276
21-Jul	994	835	1829
22-Jul	1461	817	2278
23-Jul	1097	876	1973
24-Jul	25380	13214	38594
25-Jul	13088	9707	22795
26-Jul	628	1420	2048
27-Jul	31404	10789	42193
28-Jul	46	1048	1094
30-Jul	380	675	1055
2-Aug	9861	24137	33998
3-Aug	2409	20667	23076
4-Aug		317	317
14-Aug	11525	17320	28845
15-Aug	15896	27036	42932
16-Aug	2432	261	2693
17-Aug	20067	16259	36326
18-Aug	5510	22124	27634
21-Aug	21511	15956	37467
22-Aug	1923	4186	6109
23-Aug	267	157	424
24-Aug	4430	2472	6902
28-Aug	5247	5308	10555
29-Aug	443	246	689
30-Aug	16648	5422	22070
31-Aug	851	114	965
Grand Total	266819	275212	542031

APPENDIX II – FB23 BLOCK 2 DATA 2023

MOTION	(All)
RECORDER	ON

Sum of DURSECONDS	Column Labels		
Row Labels	**NO RESPONSE TO PROMPT**	**WORKING**	**Grand Total**
22-Aug	**2559**	**23081**	**25640**
23-Aug	**16816**	**24185**	**41001**
24-Aug		**807**	**807**
28-Aug	**1402**	**29717**	**31119**
29-Aug	**2679**	**31399**	**34078**
30-Aug	**372**	**5167**	**5539**
31-Aug	**5508**	**15100**	**20608**
Grand Total	**29336**	**129456**	**158792**

APPENDIX III – FB25 BLOCK 1 DATA 2023

RECORDER	ON
MOTION	(All)

Sum of DURSECONDS	Column Labels		
Row Labels	NO RESPONSE TO PROMPT	WORKING	Grand Total
5-Jul	1138	10386	11524
6-Jul	2016	36596	38612
7-Jul	1221	21117	22338
10-Jul	1115	7887	9002
11-Jul	157	5733	5890
12-Jul	286	11703	11989
13-Jul	214	1274	1488
14-Jul	977	16494	17471
17-Jul	2202	20707	22909
18-Jul	346	5595	5941
19-Jul		1967	1967
20-Jul	304	1650	1954
21-Jul	214	1226	1440
24-Jul	658	1438	2096
25-Jul	281	278	559
27-Jul		557	557
28-Jul	677	17215	17892
31-Jul	2169	14724	16893
1-Aug		3676	3676
2-Aug	1213	29355	30568
3-Aug	2322	33297	35619
10-Aug	3472	29709	33181
11-Aug	1737	15865	17602
14-Aug	2315	30729	33044
15-Aug	751	41130	41881
16-Aug	7818	35426	43244
17-Aug	880	36358	37238
18-Aug	1956	20669	22625
21-Aug	1330	28103	29433
22-Aug	5272	9143	14415
23-Aug	527	2637	3164
24-Aug	544	1413	1957
28-Aug	15	1086	1101
29-Aug	307	1160	1467
30-Aug	497	67	564
Grand Total	44931	496370	541301

APPENDIX IV – FB25 BLOCK 2 DATA 2023

RECORDER	ON
MOTION	(All)

Sum of DURSECONDS	**Column Labels**		
Row Labels	**NO RESPONSE TO PROMPT**	**WORKING**	**Grand Total**
4-Jul		**2467**	**2467**
5-Jul	**2**	**28**	**30**
17-Aug	**82**	**3419**	**3501**
21-Aug		**2818**	**2818**
22-Aug	**3250**	**22720**	**25970**
23-Aug	**2**	**21779**	**21781**
24-Aug		**7111**	**7111**
28-Aug	**485**	**29549**	**30034**
29-Aug	**1084**	**9877**	**10961**
30-Aug	**699**	**2546**	**3245**
31-Aug	**1139**	**1126**	**2265**
Grand Total	**6743**	**103440**	**110183**