# Felling by a Five-Legged Walking-Machine

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## ABSTRACT

A 1/11 scale model of a walking machine with five legs was constructed, and its operation as a feller-buncher investigated. As slopes steepen, the machine when positioned straight up the slope becomes more efficient than when positioned parallel to the contour lines, because the downward operational range of the machine decreases with increased slopes. In the experiments, the ground pressure of the legs on the end opposite the boom was nearly zero when the boom holding felled trees was positioned at the side of the body and extended farthest from the body. However, further investigations (including such factors as ground disturbance, the operation of the machine, the degrees and the length of slope, and the fuel consumption) of felling operations are needed. Feller-bunching tends to be less efficient as tree density increases assuming that felling time per tree remains constant as tree diameter changes. To obtain greater productivity with the machine as a feller-buncher, it is essential to achieve faster walking-time and shorter felling-time per tree.

**Keywords:** *steep terrain, felling time, feller-buncher, walking machine.*

## INTRODUCTION

A walking machine with five legs, (track name: Menzi-Muck), having two front stabilizer legs with pads, two rear legs with wheels, and a hydraulic boom for working implements (and for moving the machine), is said to have a potential for forestry operations on steep slopes [1]. It propels itself by alternating three-point and four-point ground contact of the legs. It can keep its body level by hydraulically adjusting the length of the legs according to the slope, and can conduct forestry operations within reach of its boom. Although this machine may be classified as a hybrid of four legs and a boom, or two wheels and two legs and a boom, it is classified here as a five-legged walking machine. Such machines, capable of walking on steep slopes, will be needed in future forestry operations.

Although felling and bunching by the Menzi-Muck has been reported, and its stability on steep slopes has been determined already [1], we made a 1/11 scale model of the actual machine to experiment with its operational ranges under various conditions, and to investigate its performance on dangerous slopes as a feller-buncher. The boom of the model can be lifted and extended by two motors, and the cab can be rotated by a motor.

## OPERATIONAL RANGE

Experiments with the operational range of the boom on a solid slope, varing from flat to 30 degrees, on which the model could maintain its stability, were conducted.

The operational range of the boom does not vary much with different degrees of slope on slopes above the machine, whether the machine is positioned straight up the slope or parallel to its contour lines (Figures 1 and 2, and Table 1). However, the operational range of the machine on lower slopes decreases as slopes steepen [2]. This is because the operational range of the boom is a reflection of the height of the boom because the lower the boom, the more its reach extends. The boom can be set lower when the machine is positioned parallel to the contour lines than when it is positioned straight up the slope.

However, in an actual felling operation, the area in front of the machine is the net operational range, because the rear range of the machine has already been eliminated in moving. The operational range is all upward of the machine when it is positioned straight up the slope. On the contrary, half of the operational range is downward of the machine when it is positioned parallel to the contour lines. Therefore, the machine, when positioned straight up the slope, becomes more efficient than when it is positioned parallel to the contour lines. It also is reported that operations at right angles to the contour lines

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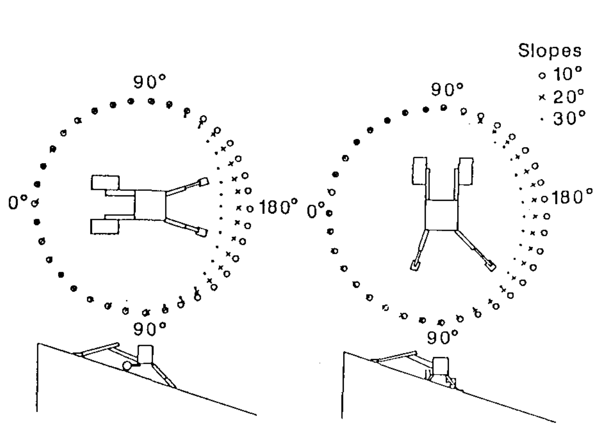



(a) Straight up the slope. (b) Parallel to the contour lines.

**Figure 1.** Operational range of the boom

were more efficient, particularly on the steeper slopes [1].

Furthermore, operations parallel to the slope are not stable, especially when holding logs on the downward slope. Although the model is not an exact replica of the actual machine regarding the centroid, the movement of the total centroid created by felled trees held on the boom is small when the boom is positioned to the front or rear ends. In experiments on level land, where a weight of 200 g, is equivalent to 330 kg of logs or 6% of the total machine weight loaded onto the end of the boom, the amount of movement becomes smaller as the boom comes closer to the body. However, ground pressure of the legs on the end opposite the boom becomes nearly zero when the boom holding felled trees is positioned at the side of the body and is extended farthest from the body.

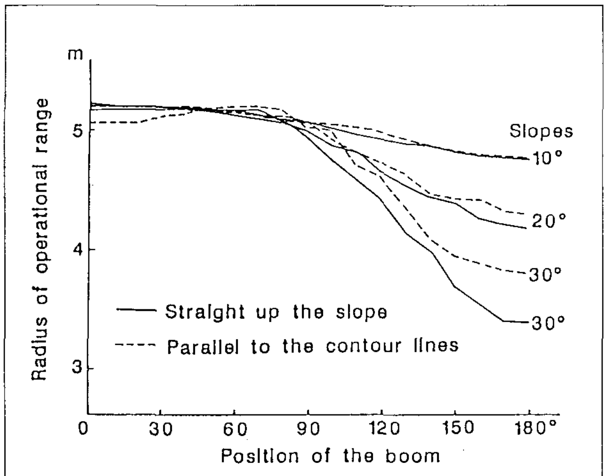



**Figure 2.** Radius of the operational range.

**Table 1.** Operational range of the boom ($m^2$).

| Slope | 0° | 10° | 20° | 30° |
|---|---|---|---|---|
| Straight up the slope | 59.82 | 50.46 | 46.47 | 42.24 |
| Parellel to the contour line | 59.82 | 53.68 | 48.54 | 43.62 |

Note: Converted into the actual size of the machine.

To investigate felling operations, including such factors as ground disturbance, the operation of the machine, the fuel consumption, and the size of felled trees, the degrees and the length of slope are needed. The length of slope affects the moving time to the next cut strip. Two examples of cutting patterns on a steep slope are shown in Figure 3. On a long slope, the total moving distance and the number of movements become shorter when the machine is positioned straight up the slope than when it is positioned parallel to the contour lines. On the contrary, on a short and wide slope, the total moving distance of the machine when positioned straight up the slope becomes longer than when it is positioned parallel to the contour lines.

## PERFORMANCE OF FELLING OPERATIONS

Felling time per tree of a feller-buncher can be summed up as follows:

t =hr/tree=positioning of the felling head and holding the tree + shearing + lifting the tree and swinging it + placing it in a bunch of other trees on the ground.

If t does not depend on the size of trees, and if the total felling time relates to the number of trees felled, the total felling time per hectare is:

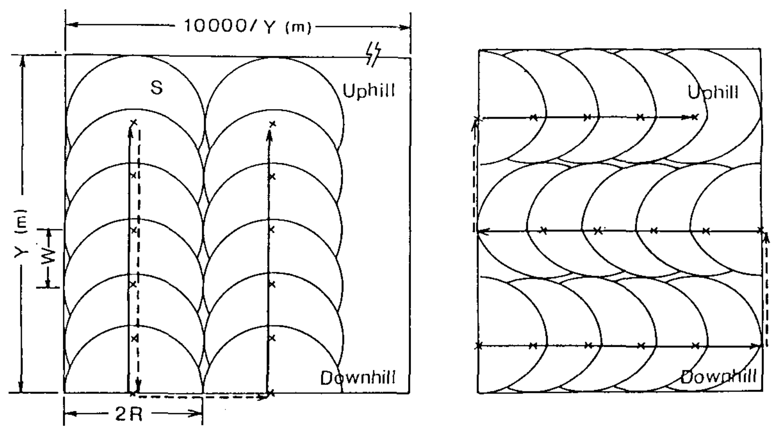
$$t \bullet n \text{ (hr/ha)} \tag{1}$$

where; n is the number of trees felled per hectare

The actual t is reported to be 0.66 min/tree [1].

It is assumed that the machine works straight up the slope, and that the operational range is upward of the machine. After felling a strip, the machine moves to the bottom of the slope in order to start the next cut strip. The operational area of the boom per setting of the machine can be considered to be a segmented circular band including the half circle of the first cut in a felling strip (Fig. 3(a)). The radius of the segmented circular band, R (m), is the maximum radius on flat ground from Figure 1 (a), and is constant regardless of the degrees of slope. Letting W (m) be the moving distance per setting (Figure 3 (a)), and assuming $W \neq 0.8R$, then the operational area of the boom, S ($m^2$), nearly equals the area of a half circle with radius R, that is,

$$S = \pi R^2/2 \quad (2)$$



(a) Straight up the slope. (b) Parallel to the contour lines.

**Figure 3.** Cutting patterns on a slope.

It follows that the total moving distance is:

$$\{2(Y-R)+2R\} \bullet 10000/2RY = 10000/R \quad (3)$$

where Y is the length of slope, and that the number of movements per hectare is nearly

$$(Y/W \bullet 10000/2RY = 10000/2RW) \quad (4)$$

Then the total moving-time per hectare, $T_m$ (hr/ha), is:

$$T_m = 10000/Rv + T_s \bullet 10000/2RW, \quad (5)$$

where v is the speed of the machine (m/h), and $T_s$ is the machine positioning time. If the moving time does not vary with tree density, the total felling-time per hectare, T (hr/ha), including decking is as follows:

$$T = t \bullet n + T_m \quad (6)$$

The productivity can be determined by V/T ($m^3$/hr), where V is the harvested volume of trees per hectare ($m^3$/ha).

The maximum moving speed of the actual machine is said to be 1.2 km/h on level land [1]. Here, let v be from 120 to 300 m/h in the forest, and $T_s$ be 0.1 minute [1]. Then the moving time per setting ranges from 0.8 to 1.85 minutes, or the total moving-time per hectare ranges from 8.2 to 19.7 hours.

In order to compare the potential productivity of this machine with that of chainsaw operators on equivalent steep slopes, the following simulation is made.

The felling-time by chainsaw operations is:

$$t_0 \text{ (hr./tree)} = 0.159\ D^2/3600 + L/v_m \quad (7)$$

where, D = D.B.H. of the felled tree

$v_m$ = moving speed of chainsaw operator (m/h)

L = mean distance to nearest felled tree (m)

when $L = {}^{1/2}\sqrt{\rho}$ [3]

Here, we include the time of plan actions, shrub-clearing, and other delays in the moving speed, since these times and moving speed often vary a wide range with the operational conditions. The average moving speed is assumed here to 2 m/min [4].

For the case of a Japanese standard broad-leaved stand [6], the total felling-time per hectare and the productivity of the feller-buncher are compared with those of chainsaw operations in Table 2. The total cutting-time per hectare by chainsaw operations decreases as the tree density increases, because the average D.B.H. becomes smaller, but the total moving-time per hectare increases. Therefore, the total felling-time per hectare by chainsaw operations does not vary with tree density. But productivity decreases as the tree density increases (Figure 4), because the volume of trees per hectare decreases. Feller-bunchers tend to be less efficient as tree density increases [1,5], and as moving speeds become slower (Figure 4).

**Table 2.** Calculated felling-time per hectare and productivity by feller-buncher and chainsaw perations.

| **Tree density (trees/ha)** | **500** | **1,000** | **1,500** | **2,000** | **2,500** | **3,000** | **3,500** |
|---|---|---|---|---|---|---|---|
| Assumed average D.B.H. (cm) | 35 | 21 | 15 | 12 | 9 | 7.5 | 6.5 |
| Volume in trees ($m^3$/ha) | 254 | 186 | 152 | 134 | 120 | 111 | 105 |
| Mean distance to nearest tree (m) | 2.24 | 1.58 | 1.29 | 1.12 | 1.00 | 0.91 | 0.85 |
| [Feller-buncher] | | | | | | | |
| Total felling-time (hr/ha) | | | | | | | |
| Moving speed = 120 m/h | 25.2 | 30.7 | 36.2 | 41.7 | 47.2 | 52.6 | 58.2 |
| Moving speed = 200 m/h | 17.6 | 23.1 | 28.6 | 34.1 | 39.5 | 45.0 | 50.5 |
| Moving speed = 300 m/h | 13.8 | 19.3 | 24.7 | 30.2 | 35.7 | 41.2 | 46.7 |
| Productivity ($m^3$/hr) | | | | | | | |
| Moving speed = 120 m/h | 10.1 | 6.0 | 4.2 | 3.2 | 2.5 | 2.1 | 1.8 |
| Moving speed = 200 m/h | 14.4 | 8.0 | 5.3 | 3.9 | 3.0 | 2.4 | 2.1 |
| Moving speed = 300 m/h | 18.4 | 9.6 | 6.2 | 4.4 | 3.3 | 2.7 | 2.2 |
| [Chainsaw (average moving speed = 2m/min)] | | | | | | | |
| Cutting time (hr/ha) | 17.1 | 14.3 | 13.0 | 12.3 | 11.9 | 11.0 | 10.9 |
| Moving time (hr/ha) | 9.3 | 13.2 | 16.1 | 18.7 | 20.8 | 22.8 | 24.8 |
| Total (hr/ha) | 26.4 | 27.5 | 29.1 | 31.0 | 32.7 | 33.8 | 35.7 |
| Productivity ($m^3$/hr) | 9.6 | 6.8 | 5.2 | 4.3 | 3.7 | 3.3 | 2.9 |

## CONCLUSION

The feller-buncher may be suitable for clear-cutting where trees are not small. However, we must consider that a chainsaw operation is difficult work, especially on steep slopes, and often is accompanied by hang-ups of felled trees among residual ones.

To obtain greater productivity, with the machine as a feller-buncher, it is necessary to increase tree size or extend the reach of the boom [1], but it is most essential to achieve faster walking time and shorter felling time per tree.

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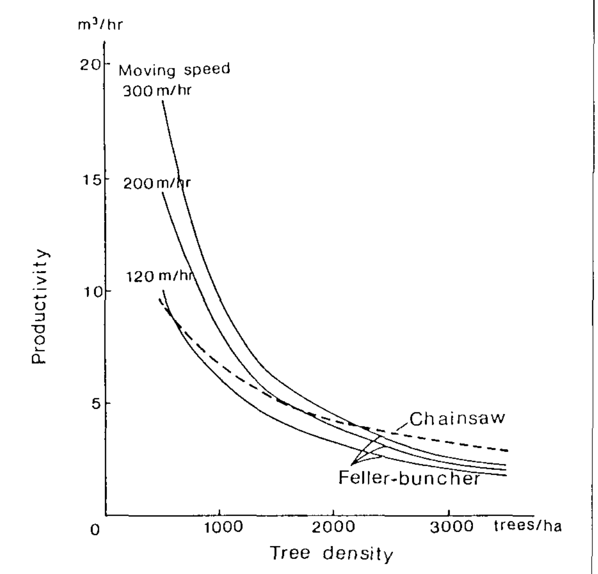


**Figure 4.** Comparison of productivity between feller-buncher and chainsaw operations.

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*The titles in parentheses are tentative translation from the original Japanese titles by the authors of this paper.*