SESSION 4
Reference Paper
(Tabled)

SKIDDERS AND TRACTORS ON STEEP COUNTRY - A PLANNING OPTION

(A Literature Review)

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INTRODUCTION

The use of skidders or tractors on steep country has commonly been critised. This is mainly because of the problems of machine and operator safety, and erosion of soil and water values.

As an alternative system for logging hill country though, skidder and tractor operations have some attractive features. The equipment required is simpler, lower cost and more versatile. Personnel required in all aspects of the operation do not need to be as highly skilled. As well, a suitable tracking system, if created, can improve forest access for many other in-forest operations from silvicultural work to fire fighting and wood recovery.

It is no wonder then that over the past decade considerable development work has been carried out world-wide in an effort to overcome the problems of using skidding equipment on steep slopes. Better equipment has become available, improved operating techniques have been developed, and much more is now known about the possibilities and limitations of such operations.

This paper reviews the literature available in LIRA's library on the topic, and attempts to identify some of the more important factors to consider for this planning option.

EQUIPMENT OPTIONS AND HISTORY

The range of skidding machinery available has developed over the past years to now include the crawler-tractor-dozer, the wheeled fixed-frame type agricultural tractor, the articulated rubber-tyred log skidder, and the tracked log skidder. The sizes currently available in each of these options is shown in Table 1.

Of this range only the rubber-tyred and tracked skidders are purpose built or designed for logging, and the crawler tractor is the only machine designed for dozing or tracking work. The tracked skidder is the newest development and to date is not available in a full range of sizes or in a wide range of brands.

The various machine types have different operational limitations, performance abilities and system planning needs, that need to be understood for effective application on hill country.

Machine type	Up to 75 h.p.	75 h.p. to 150 h.p.	Over 150 h.p.
Crawler tractor	wide range	wide range	wide range
Wheeled agric. tractors	wide range	wide range	limited range
Artic.Rubber-tyred skidders	very limited range	wide range	wide range
Tracked Skidders	none available	very limited range	very limited range

Table 1 : Range of Machinery Available by Type and Size

The historical trends in using such machinery on steep country as covered in the literature shows the following :

In 1971 an international symposium on forest operations in mountainous regions (Ref.1) summarised the trends up to 1970. It found that skidding systems using medium-sized machines were proving feasible and justified, versus cable systems on steeper country. Also that the four-wheel drive articulated rubber-tyred skidder was out-performing the crawler tractors on steep country and that the non-articulated wheeled agricultural type tractor had very limited ability on slopes

Emphasis thus went on to the application of aritulated rubber-tyred skidders and medium-sized crawler tractors on steep country, and by 1975 much was known about their respective abilities and limitations. Wellburn in considering alternatives for steep country logging in Canada (Ref.2) indicated that generally, tracking was required for these machines once slopes exceeded 30%.

A new machine type that could work on untracked slopes to 50% then arrived on the scene. It was the tracked skidder with examples being the American FMC 200, the Canadian Bombardier B15, and the Russian Belarus TD (Ref.3). The application of these machines in steep country has continued to develop since their introductions.

More recently though, since 1979/80, for very steep slope logging (70%-80% slopes) and where tracking is required for skidding extraction, both Australia and Canada have used small sized crawler tractors (Refs. 4 and 5) in an effort to minimise ground disturbance.

Such then are the equipment options developed to date, but what are their capabilities.

FACTORS AFFECTING SKIDDING PRODUCTIVITY AND COSTS

Before summarising the literature on the operational limitations and systems of application for skidding on steep slopes, it is pertinent to touch briefly on just what are the important factors affecting productivity and costs.

A number of reports give good coverage of the factors affecting productivity and only specific ones are noted here.

In one of the earlier reports Parker (Ref.22) illustrates the productivity differences between the crawler tractor and the rubber-tyred skidder, as shown in the figure below (provided the terrain permits operation). This is due to the different speed and pull capabilities of the two machine types.

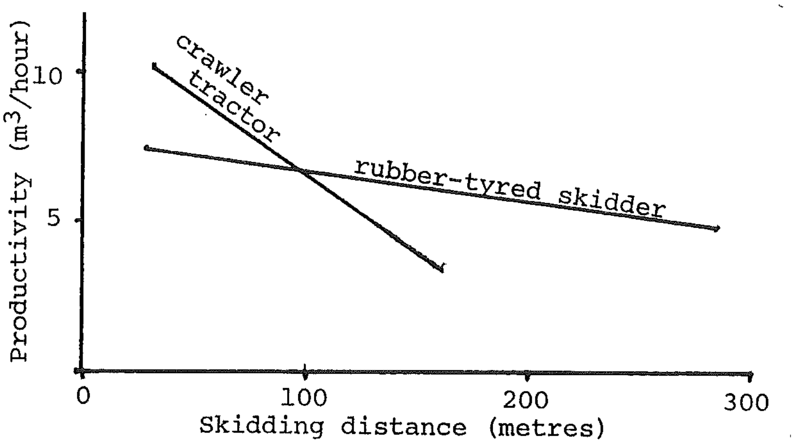

Figure 1. Difference between crawler tractor and rubber-tyred skidder.

Following on from this, Silversides (Ref.6, 1967) notes the factors having greatest effect on productivity as including :

Tree size,
Load size,
Distance travelled.

The typical relationship for a particular machine in a particular forest he illustrates as follows :

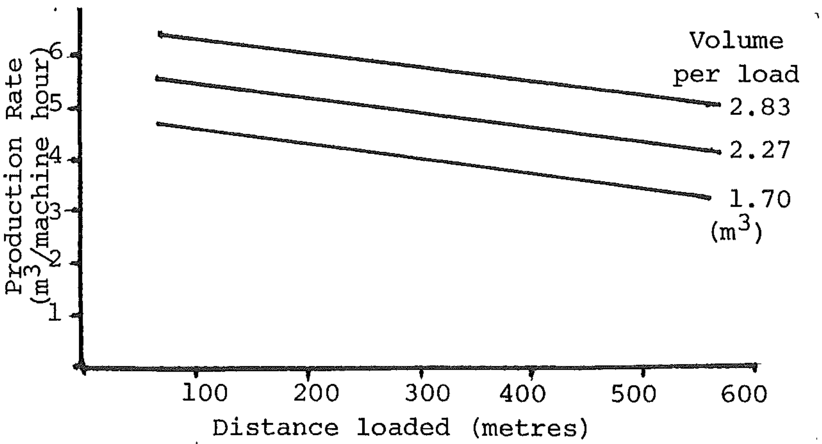

Figure 2. Effect of volume per load and distance loaded on productivity.

McIntosh and Johnson (Ref.7, 1974) extended this by noting that the major factors affecting productivity between different forest types were :

Average tree size and log size,
Stand and terrain characteristics,

and between operations within a forest type were :

Degree of difficulty of logging the area,
Skidder operators skill and motivaton.

Koger (Ref.8, 1976) touched on costs as well as productivity and from a detailed study of different sized skidders under a variety of conditions, found the following :

1. *An increase in horsepower increased production but does not necessarily reduce logging costs. Minimum costs occur for each skidder when it is fully utilised.*

2. *When volume per cycle is low (small logs, insufficient chokers, etc) in relation to the skidder, potential smaller skidders have lower costs per unit volume production.*

3. *When skidding short distances and small volumes per cycle, load positioning (skidding butt first versus top first) does not significantly reduce logging costs.*

4. *Logging costs can be reduced by locating skid roads that are as straight as terrain and stand characteristics permit. Crooked skid roads with frequent sharp turns increase logging costs.*

Finally, a report that provides a good all round summary of the factors affecting productivity and costs is by Sampson and Donnelly (Ref.9, 1977). They summarise that productivity is affected by :

- *the machine (pulling power, speed capability, tractive characteristic)*
- *the forest (piece size, stocking, residual stand requirement)*
- *the terrain (slopes, skid distance, surface characteristics)*
- *the operator (skill, motivation).*

They report that the main opportunities available to increase productivity lie with maximising volume skidded per turn and minimising delay time. They also confirm findings from other studies that 30%-40% of production variation can result from operator differences.

Notably slope, although a factor affecting productivity, is not the major factor, provided the machine can operate. What then are the operational limitations for skidding machinery on steep slopes?

OPERATIONAL LIMITATIONS FOR SKIDDING MACHINERY ON STEEP SLOPES

The major concern for any machinery on sloping ground is that of stability. Different machine types can operate to different limits of slope, and to operate beyond this limit a tracking system can be used. Also of importance is traction and like with stability, different machine types have different tractive capabilities for pulling loads. The literature shows the following :

A 1967 report by Park, Gibson and Phillips (Ref.10) finds that only a few of the early rubber-tyred articulated skidders on the market then, could operate on slopes of 40-45%. One of the major reasons for this was arch and fairlead design.

By 1971 however an international symposium (Ref.1) put the climbing limits for rubber-tyred skidders at 58-72% slope, depending on soil, and the climbing limits for crawler tractors at 87-100% slope, also depending on soil conditions.

A detailed analysis of the articulated rubber-tyred skidder side slope stability by Gibson and Biller was published in 1974 (Ref.11). This indicated that the unloaded stationary skidder would tip at a 55% slope if aligned across the slope, however, more importantly it could tip at 47% slope if fully articulated while aligned across the slope. From this work important guidelines resulted on the operating technique for articulated skidding machinery on slopes. These minimise the danger of over-turning due to shifting the machine centre of gravity outwards by articulation.

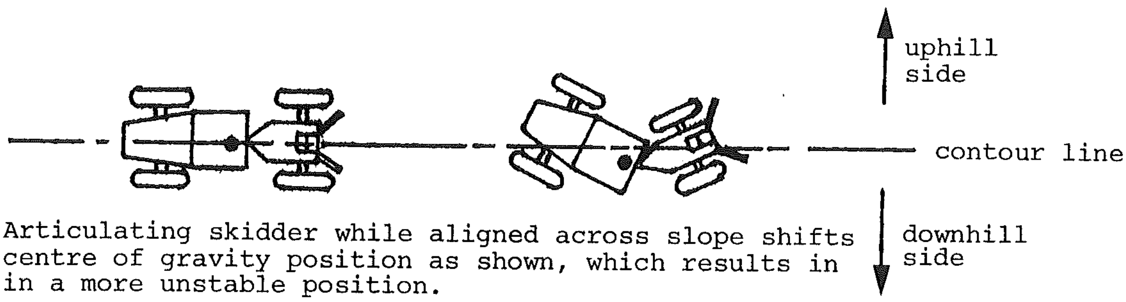

Figure 3. Articulated rubber-tyred skidder side slope stability

Wellburn in 1975 (Ref.2) in considering alternative methods for steep slope logging, notes that wheeled skidders can operate without skid roads on slopes (with firm ground) to 30%, but are restricted to downhill skidding. He reports that early trials with a tracked skidder puts its limitations at 40% plus. Also he notes that crawler tractors can operate on slopes over 30% (depending on soil and moisture content) provided skid roads are bulldozed.

Traction is obviously one of the limiting features of rubber-tyred skidders and Anderson quantified this in 1976 (Ref.12) by advising that if uphill skidding with rubber-tyred skidders is necessary then gradients should be restricted to less than 12-14%.

In a 1975 N.Z. study (Ref.23) of skidder logging on hill country gravels, an uphill track gradient of up to 35% became impassible by the unloaded skidder in wet weather due to loss of traction.

By 1976 the stability and traction capabilities of the various skidding machines were obviously beginning to be well known, and FERIC (Forest Engineering Research Institute of Canada) published an excellent Handbook (Ref.13) for planning skidding operations on steep country, without skid roads. It indicates the limits as shown in figure 4.

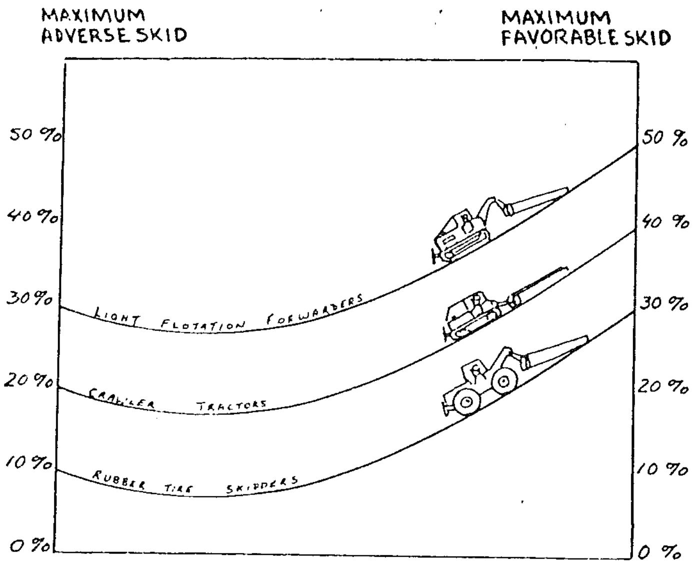

Figure 4.

Skidding Machine Limitations

NOTE: Left and right hand side of the graph represents traction under the best conditions but gradeability may be reduced with soil and weather conditions.

Kochenderfer in 1977 (Ref.14) also confirmed that a 30% slope was the limit for safe wheeled-skidder operation over land (no tracking). He also notes that wheeled skidders are not as suited to winching logs uphill as an equivalent weight crawler tractor, presumably because of traction differences.

Better information on the capabilities of tracked skidders starts to appear in 1977 with one report (Ref.3) noting that one model (Bombardier B15) would handle grades up to 60% adverse and 40% side slope.

Following this in 1978 Powell concludes (Ref.15) from a FERIC study that the FMC 200 tracked skidder could operate effectively on untracked slopes to 50% while still meeting production and environmental requirements.

About the same time a comparison of the tracked skidder and rubber-tyred skidder capabilities was put out by the U.S.D.A. (Ref.16) and this is indicated in the following figure.

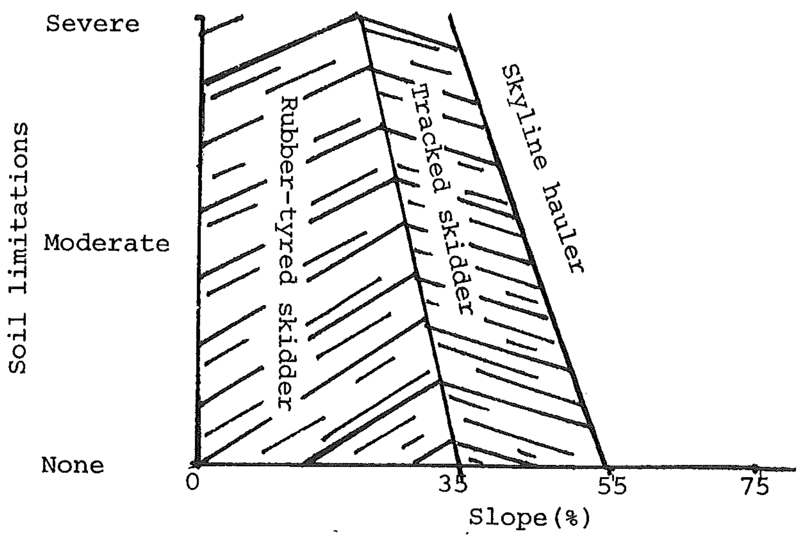

Figure 5.
Machine Limitations

A good summary of the above slope limitations of various skidding machines is thus given by the above figure 4, from the FERIC handbook (Ref.13).

Once tracking or skid trail systems are introduced, steeper slopes can of course be worked, although the trail grade limitations will be as covered in the proceeding section. Formed trail systems on steep slopes however cost extra money, dictate the operating pattern and can result in significant environmental damage if not carefully controlled.

TRACKING PATTERNS AND CONTROLLING ENVIRONMENTAL DAMAGE

As skidding distance is one of the major factors affecting productivity, initial methods of logging very steep slopes with tracking patterns concentrated on minimising the skidding distance.

The literature indicates that prior to 1970 skidding roads were commonly formed diagonally across the slopes within gradients on which the machines could safely operate. The overall pattern was to radiate tracks out from the landings, and slopes up to 80% were logged in this manner (Ref.1).

Robinson (Ref.17) of New Zealand notes that skid tracks for 130 hp rubber-tyred skidders were generally kept within grades of 7% to 17%, or in dry weather up to 50%, provided traction on the intermixed gravel and sand soils was adequate. He states that skidding distances were preferably kept within 400 metres maximum. Similarly Bills (Ref.18) of Australia describes tracks for a 100 hp skidder with a consistent grade between 21% and 29% used on slopes of 30% to 70%.

It was soon found however with increasing environmental awareness that such skid trail patterns were a major contributor to erosion. Kochenderfer (Ref.19) in 1970 notes that they remove the litter cover to expose soil, and the skidding machinery compacts the soils to reduce soakage. Water therefore tends to collect on the skid roads, which once running on the bared soils cause erosion. The steeper the water channel (skid trail) the faster the flow and erodibility. Also, some soil types are more erodible than others. He advises that a tracking system using one climbing road and several contour spur roads works well in reducing erosion. To control erosion the road and trail system mustbe properly planned well in advance of logging. His report (Ref.19) also goes into drainage requirements (e.g. suggesting 3% outsloping roads, road drainage dips at planned intervals, etc) and subsequent trail maintenance needs.

With skidding trails there is not only an erosion concern. Such operations also compact the soil and this affects growth rates. In 1970 Hatchell Rolston and Foil (Ref.20) reported significantly retarded growth rates of loblolly pine growing on skid trails and they estimated that the compacted and disturbed soil would take 20-40 years to recover.

In 1976 following considerable development work in interior British Columbia, FERIC published a handbook (Ref.13) that was aimed at *establishing good ground skidding and roading practices, to skid efficiently and minimise soil disturbance and erosion.*

The preferred method outlined was to use skidding machinery that did not require formed trails as far as practicable. Where trails were required they tabled guidelines on the pattern requirements which were dependent on moisture, soil and slope characteristics as shown in the following table:

TABLE 2 : Trail Patterns and Machine Types for Different Conditions of Soil Moisture and Slope.

Slope	Moisture and Soil	Machine type	Trail Pattern
Gentle (0-25%)	Dry-stable	All types	Random depending upon desirability of soil disturbance
	Variable	Skidders & Crawlers	Systematic taking advantage of dry or elevated areas
		Light Flotation Tracked Skidders	Random
	Wet-unstable	All types	Random on frozen ground
		Light Flotation Tracked Skidders	Systematic taking advantage of dry or elevated area
Moderately (26-49%)	Dry-stable	All types	Systematic taking advantage of most favourable soil and slopes
	Variable	All types	Systematic on frozen ground or during dry weather
	Wet-unstable	All types	Systematic on frozen ground
		Light Flotation Tracked Skidders	Systematic in dry weather

Cont/...

Slope	Moisture and Soil	Machine type	Trail Pattern
Steep (50-69%)	Dry-stable	All types	Systematic taking advantage of most favourable soil and slopes pre-located if necessary
	Variable	All types	Systematic with adequate snow cover
	Wet-unstable	None	No ground skidding permitted
Very Steep (70%+)			On site inspection required

Slope and skid trail definitions:

(a) Gentle slope - ground skidding areas where skid trails are not necessary and may be undesirable. Fully mechanised systems may be used on these slopes, provided Workers Compensaton Board regulations are followed.

(b) Moderate slope - ground skidding areas requiring some skid trail construction. These slopes must be considered the most critical because trails tend to be constructed on a hit and miss basis.

(c) Steep slope - ground skidding areas where skid trails must be side cut. Construction of these trails must be held to an absolute minimum.

(d) Random trail pattern - machines operate freely on the area and avoid soil disturbance by spreading the traffic over the whole area.

(e) Systematic trail pattern - planned trails.

Notably, on slopes over 50% they were very careful about the use of ground skidding trails.

Further work by Köchenderfer on tracking systems in eastern U.S.A. was reported in 1977 (Ref.14). He notes that for wheeled skidders, the skid trails need to be wider and straighter than those needed for crawler tractors. Also, wheeled skidders are not as suited to winching logs uphill as an equivalent weight crawler tractor with arch. For rubber-tyred skidders a closely spaced skid trail network (45 metres maximum spacing on slopes over 30%) results because of this, as well as the difficulty of pulling rope. As such, roads and landings accounted for 10.3% of a skidder logged area compared to 7.8% for a similar *jammer cable logged area. For comparison he also cites west coast U.S.A. figures for soil disturbance as :*

tractor logging - 9%
skyline logigng - 2%
helicopter logging - 1%.

By 1979 rubber-tyred skidder operations on steep slopes in Nelson, New Zealand, had developed considerably with contour tracks (put in by a D6 sized crawler tractor) at 30 metre spacing being used (Ref.21). Down tracks following the ridges were used leading onto landings located either on the ridge or just off the ridge as in the sketch below :

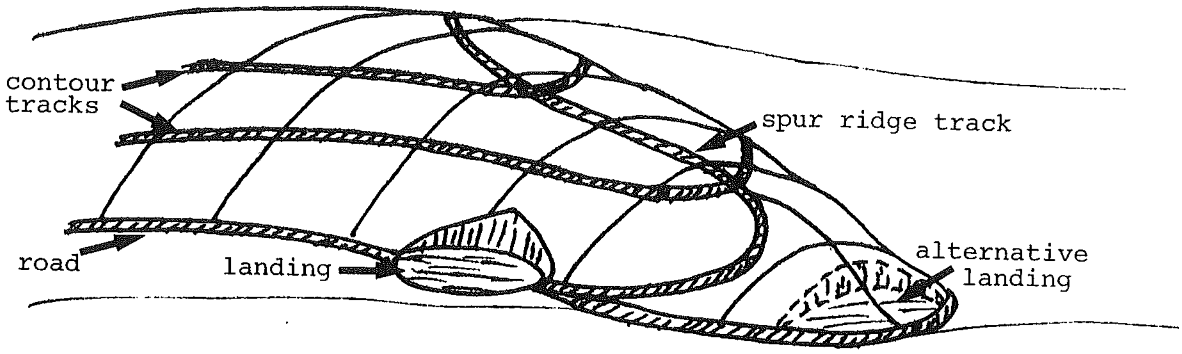

Figure 6. Tracking Patterns and Landing Placement

As such this trail system did not accumulate large water flows, and to control flow on the down-tracks cutoffs are put in at 40 metre spacing. The limit to maximum slopes on which this system is applied is determined by the ability of the skidder to climb back up the ridge track. Generally haul distrances planned were within a 400 metre maximum.

In 1979/80 developments in British Columbia took an interesting turn. They considered that road and trail related soil disturbance could be reduced in a system using very small crawler tractors instead of the medium sized rubber-tyred skidders or crawlers. McMorland reports (Ref.5) that on slopes up to 80% contour tracking at 30 metre spacing for small crawlers (70 hp) caused one-third less site disturbance than tracking with a large crawler for rubber-tyred skidders. Also the logging costs with these smaller crawlers were :

9% lower than with rubber-tyred skidder,
17% lower than with tracked bunk grapple skidder,
61% lower than with cable hauler.

The small crawlers were used on skid distances up to 330 metres.

A similar operation using small crawlers and contoured tracking on slopes to 70% was also reported in Australia by Lembke during 1979 (Ref.4). Both uphill and downhill logging were performed with skid distances uphill being restricted to 60-80 metres and downhill being extended to 250-300 metres. This report adds, however, that the economics are just not there when the going gets worse, as on steeper and rocky slopes.

The literature thus indicates that where tracking patterns are necessary to enable ground skidding to be carried out, then considerable attention needs to be paid to using a tracking system that minimises environmental disturbance. Important factors influencing the suitability of an area to tracking include :

- nature of topography, evenness of slope, angle of slope and slope length
- soil structure, ease of dozing, erodibility
- rainfall, moisture characteristics of region.

CONCLUSIONS

An increasing portion of New Zealand's logging is to be carried out on steep country or on slopes traditionally considered only suited to cable logging. Literature indicates that developments world-wide over the last ten years have resulted in skidding machinery and operating techniques that offer a possible alternative to cable systems for steep country logging. This alternative is economically competitive and involves equipment with greater versatility (than cable systems) which must be important to a relatively small industry like New Zealand's. Skid trail tracking systems have been developed that are suited to specific categories of steep country and which meet environmental requirements. With the fast growing forest crops predominant in New Zealand, the value of such an integral tracking system that allows improved forest access is increased.

Skidders and tractors on steep country (whether with or without formed tracking systems) must therefore be a planning option to be considered seriously in New Zealand. Currently some use is being made of this alternative, however, more extensive trials are required to establish the areas in which it is suited.

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