Assessment of Animal Skidding and Ground Machine Skidding Under Mountain Conditions

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ABSTRACT

The proportion of animal skidding in forest operations in Heilongjiang Forest Region has increased significantly in recent years. First, the development of animal skidding and machine skidding was demonstrated and analyzed. Then, two methods of ground skidding currently used in this region were evaluated both individually and comprehensively using the following criteria: operation efficiency or operation cost, degree of damage on soil and on residual stands, accident rate, and natural regeneration. Finally, according to the results of synthetic assessments, classification of operational conditions suitable to each skidding method were recommended quantitatively with considerations of multiple evaluation criteria.

Keywords: *Animal skidding, ground machine skidding, multiple criteria, assessment, classification of operation conditions.*

INTRODUCTION

Heilongjiang Province, with a 460,000 square km area and a population of 35 million, is located in the northeast part of China. Forest land, which is mainly dominated by three large forest areas: Yichun Forest Area (YC), Mudanjiang Forest Area (MDJ), and Daxinanling Forest Area (DXL), covers nearly 36% of total land area. More than 30% of total timber used in China since 1949 has come from Heilongjiang Province.

Forest harvesting in Heilongjiang Forest Region has been changed greatly. As shown in Table 1, timber volume harvested decreased gradually after 1970 while the harvesting area increased rapidly,

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Table 1. Yearly harvesting area and volume since 1951.

Year	Area ha	Volume m^3	Volume per ha m^3/ha
1951	51,715	3,589,766	69
1952	99,519	6,312,134	63
1953	139,749	8,494,393	61
1954	157,231	8,981,834	57
1955	81,936	4,862,339	59
1956	66,654	5,128,172	77
1957	83,307	9,423,450	113
1958	136,776	14,646,370	107
1959	123,100	13,223,070	107
1960	106,092	11,596,371	109
1961	64,034	7,596,371	119
1962	72,074	9,186,423	127
1963	92,056	12,198,774	133
1964	73,659	8,405,025	114
1965	117,499	10,476,164	89
1966	143,481	11,957,264	83
1967	128,761	12,043,031	94
1968	108,378	10,517,136	97
1969	130,514	11,623,822	89
1970	145,650	14,657,556	101
1971	153,942	14,478,452	94
1972	140,906	14,756,862	105
1973	149,077	14,558,978	98
1974	154,162	13,146,658	85
1975	157,537	13,835,151	88
1976	158,839	13,502,930	85
1977	165,206	14,036,841	85
1978	173,657	13,473,039	78
1979	170,353	13,956,080	82
1980	144,204	12,320,000	85
1981	147,465	11,854,000	80
1982	181,646	11,958,700	65
1983	169,230	11,707,000	69
1984	213,663	12,916,585	60
1985	270,940	11,901,837	44
1986	275,733	12,903,473	47
1987	324,427	12,469,903	38
1988	332,086	11,870,678	36
1989	350,759	11,720,367	33
1990	376,148	10,120,895	27
1991	346,247	9,010,925	26
1992	357,933	8,075,385	23

harvesting operations, such as operation site slope, forest stand volume per hectare, timber volume removed from site per hectare, timber volume per stem felled, and average skidding distance have adversely changed in recent years (Table 2). Now, selective cutting and thinning, representing up to 85% of total harvesting area, dominates in Heilongjiang Forest Region. Clear cutting, which was prevalent (highest about 90%) from 1950 to 1970 has gradually decreased.

Table 2. Changes of operation conditions.

	Yichun			Mudanjiang		
	1986	1990	1994	1986	1990	1994
Skidding Distance (km)	0.93	1.17	1.37	1.06	1.20	1.52
Average Slope (%)	19	21	24	22	23	27
Stand Volume per ha	151	148	134	104	98	93
Volume Removed per ha	78	55	39	32	20	18
Volume per Stem (m^3)	0.44	0.38	0.28	0.32	0.22	0.21

less consideration given to environmental factors. Most of the forest harvesting operations took place at sites with high stand density and even timber distribution, flat terrain, and high accessibility.

From 1965 to 1975, the proportion of both machine skidding and animal skidding fluctuated around 80% and 15%, respectively. Then, animal skidding increased steadily to 1994 while machine skidding declined after peaking between 1976 and 1979. Both values might reach 50% this year. The main causes for this development might be significantly adverse changes of operation conditions and harvesting policies with strong environmental constraints.

Average skidding distance, representing the accessibility to scattered forest, and average slope at sites rose because trees available to be harvested were sparsely distributed on difficult terrain sites. The decrease of stand volume per hectare, timber volume removed per hectare, and timber volume per stem felled shows that the quality of forest in Heilongjiang Forest Region is getting poorer. Results of investigations and feedback information from harvesting practices also show that heavy skidding machines, such as J-50, J-80, and CAT518 have more difficulty than animals to fit operational conditions both today and in the near future. So, under these circumstances, animal skidding expanded again and replaced some machine skidding.

Environmental considerations play an important role in the decrease of ground skidding. Policy makers, administrators, and operators pay more attention than before to other important multiple functions of the forest except timber supply. The Act of Forest of China and the Regulations for Forest Harvesting and Regeneration of China noted clearly the multiple uses.

DEVELOPMENT OF GROUND MACHINE SKIDDING AND ANIMAL SKIDDING

Ground machine skidding in Heilongjiang Forest Region, including crawler, skidder and winch skidding, started in 1950, due to the introduction of tractor T-12 and C-80 from the former Soviet Union. Animal skidding was a traditional measure to transport timber off-road. Development of these two skidding methods from 1951 to 1994 is shown in Table 2.

As shown in Table 3, ground machine skidding increased rapidly but animal skidding decreased sharply from 1955 to 1965. This is introduced because the ground skidding machines showed higher operation efficiency and were more suitable to social demands and operating conditions, which included cutting method and harvesting policy, than the traditional ways. High timber demand for construction in China at that time, on the other hand, stimulated the development of skidding machines. Several type of tractors were continually introduced from the Soviet Union, and three new type of tractors, J-50, DFH-54, and DFH-75, were domestically manufactured during that period to meet the high demand of skidding machines for "busy" forest harvesting and wood production. The best criterion for evaluating forest harvesting within this ten year period was operation efficiency, with

Table 3. Development of proportion of ground machine skidding and animal skidding.

Year	Machine	Animal
1951	4.1	93.1
1952	3.8	95.2
1953	4.4	94.9
1954	6.8	89.9
1955	11.7	86.9
1956	25.2	81.4
1957	31.6	67.5
1958	27.4	59.8
1959	27.5	62.1
1960	25.0	68.8
1961	23.2	60.5
1962	29.8	55.6
1963	28.3	51.7
1964	64.1	32.1
1965	84.8	11.2
1966	83.4	10.8
1967	71.6	19.8
1968	79.7	16.4
1969	87.5	12.2
1970	90.2	8.7
1971	86.0	9.9
1972	79.7	12.9
1973	88.5	15.4
1974	92.0	12.7
1975	93.3	4.6
1976	96.3	2.1
1977	95.4	3.3
1978	96.7	2.2
1979	96.1	3.5
1980	94.1	5.0
1981	90.2	7.9
1982	89.7	8.3
1983	88.8	9.4
1984	88.3	9.3
1985	87.6	10.2
1986	84.0	12.5
1987	81.2	16.7
1988	79.3	17.9
1989	78.1	19.2
1990	77.6	21.5
1991	76.6	25.3
1992	75.8	28.3
1993	66.8	36.7
1994	56.1	41.9

ASSESSMENT OF GROUND MACHINE SKIDDING AND ANIMAL SKIDDING

Investigations were carried out in three major forest areas, covering animal, crawler, and rubber-tired skidding. Winch skidding was not included since it represented less than 1% of all skidding operations.

Effects of Ground Skidding on Soil Properties

Experiments for studying the effects of ground skidding on soil properties were conducted in Dailing Forest Enterprise, Yichun Forest Area. Three blocks with a mixed forest of conifer and broadleaf based on Dark-Brown soil, located at 128°37'46" E and 47°21'26" N, were selected as experimental plots. Other climate and terrain data are shown in Table 4.

Changes of Soil Physical Properties Caused by Ground Skidding

Soil samples for physical property tests were obtained at skidding roads (trails), operation sites, and reference forests very close to the sites along an S-shaped line by using a soil circle-cylinder. Sample numbers for each block were greater than thirty. Results of the laboratory analysis are shown in Table 5.

The results show that changes of soil physical properties depend greatly on the degree of disturbance. The more the disturbance, the greater are the changes that occur. All criteria of soil physical properties listed in this part are adversely proportional to skidding passes, except soil bulk density. Soil disturbance caused by ground machine skidding is stronger than that by animal skidding, since the difference of each criterion between skidding trail and reference forest caused by machine skidding is significantly larger than by animal skidding. Of course, not all data obtained show the same conclusion due to heterogeneity of soil distribution.

Changes of Soil Chemical Properties Caused by Ground Skidding

Soil samples used for chemical property tests were obtained at the same time as sampling for physical property tests. Groups of samples would be ready for laboratory testing after a series of processing steps, including classifying, mixing, air-drying, and grinding. Results of laboratory analysis

Table 4. Climate and terrain.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation (mm)	5.2	4.4	10	28.8	56	83	177	193	106	52	8.7	7.9
Temperature (°C)	-24	-19	-8	3.9	11	17	22	19	12	3.5	6.5	-19
Moisture (%)	75	71	64	55	58	71	79	82	77	73	71	76

	Block-1	Block-2	Block-3
Average Slope	30%	28%	28%
Conifer:Broadleaf	50%:30%	60%:40%	60%:40%
Timber Removed (m^3)	492	546	508
Area (ha)	11.8	14	12.9
Skidding Type	Animal	Crawler	Skidder

Table 5. Changes of soil physical properties caused by machine skidding and animal skidding. (Depth:0-20cm)

	Machine			Animal		
	trail	site	control	trail	site	control
Bulk Density(g/cm^3)	1.01	0.67	0.59	0.85	0.60	0.57
Capillary Porosity (%)	53.7	60.3	61.8	60.4	62.7	63.1
Noncapillary Porosity(%)	10.5	13.0	18.0	7.61	13.5	18.6
Total Porosity (%)	64.2	73.3	79.0	68.0	76.2	81.7
Capillary Capacity (%)	53.8	91.7	98.8	69.8	102	116
Field Capacity (%)	48.7	81.5	89.6	64.0	79.8	89
Saturated Capacity (%)	68.5	111	133	78.6	120	136
Water Conductivity (mm)	8.60	9.81	12.9	9.01	12.1	13.3

(Table 6) show that chemical properties of soil at the skidding trail also differ significantly from that of site soil and reference soil. It is explicit that many more nutrient elements in the skidding trail soil had been lost due to more heavy disturbance, and that more water-soil run-off had occurred along the trail. According to the results, disturbance by machine skidding is slightly more severe than animal skidding in spite of the heterogeneity of soil distribution.

Analysis of Skidding Operation Costs

Skidding operation costs consist of fixed costs and variable costs. Fixed costs include construction of skidding roads, construction of landing, maintenance and depreciation, fixing fees and management fees. Variable costs are composed of fuel, replacement of damaged equipment components, salary, margin, bonus, and small repair fees. Skidding costs vary from place to place and depend on conditions of terrain, trees removed and maintained, operation system, and organization. Data of fixed cost and variable cost for both animal skidding and tractor skidding are shown in Tables 7 and 8. The values used recommended by the Heilongjiang Forest Industry Bureau and are based on the following parameters of operating conditions: removed stem size 0.2 to 0.6 m^3; removed timber volume per hectare 20 to 60 m^3; and slope, 15% to 27%. Models using skidding distance as a variable for both animal and machine are derived from Tables 7 and 8 using a simple regression method:

$$CM=11.08 + 0.0017*X \qquad (1)$$
$$R^2=0.991 \quad F0=689$$

$$CA=3.3 + 3.86*EXP(0.00058*X) \qquad (2)$$
$$R^2=0.992 \quad F0=754$$

$$(500 < X < 2000)$$

where CM = machine skidding cost, Yuan/m^3;
CA = animal skidding cost, Yuan/m^3;
X = skidding distance, m.

Table 6. Changes of soil chemical properties caused by machine and animal skidding. (Depth: 0-20 cm).

	Machine trail	Machine site	Machine control	Animal trail	Animal site	Animal control
pH	4.87	4.66	4.57	5.20	5.02	4.90
Organic Matter (%)	5.56	11.68	14.45	13.70	14.99	18.40
Total N (%)	0.292	0.653	0.754	0.476	0.772	0.790
Total P (%)	0.102	0.118	0.124	0.140	0.170	0.178
Total K (%)	0.358	0.350	0.340	0.404	0.389	0.384
Hydrolytic N (ppm)	364	686	751	669	1056	1254
Available P (ppm)	2.79	9.35	10.50	4.12	8.13	13.60
Available K (ppm)	154.5	229.7	258.0	324.0	397.1	430.2

Table 7. Fixed operation cost of machine skidding and animal skidding (Yuan/m^3).

	Construction of skid trail	Construction of landing	Maintenance and fixing	Management fees	Sum
Machine	1.2	1.5	4.3	1.0	8.0
Animal	0.5	1.2	0.6	1.0	3.3

Table 8. Variable operation cost of machine skidding and animal skidding (Yuan/m^3).

Skid distance(m)	500	600	700	800	900	1000	2000
Machine	4.0	4.1	4.2	4.4	4.6	4.9	6.5
Animal	5.4	5.5	5.7	6.0	6.4	6.9	12.5

From Equation (1) and Equation (2), animal skidding is more economical than machine skidding if the skidding distance X ranges 0<X<1769 m, otherwise machine skidding would be better. Results of field investigations show that rubber-tired skidders, under operation cost criterion, work slightly better than crawlers but not as good as animals in selective cutting and thinning operations.

Analysis of Accident Rate

According to the data from the Heilongjiang Forest Industry Bureau, the accident rates of both animal skidding and machine skidding since 1986 are shown in Table 9. The direct cost of accidents is 0.11 Yuan per cubic m, for animal skidding and 0.16 Yuan per cubic m for machine skidding if only considering insurance and subsidy fees. However, direct costs would be higher if they were not hidden in wood production and social costs.

Accident analysis showed that more than 80% of accidents are caused by improper operations on steep terrain, i.e., not correctly following operation instructions and regulations. A high percentage of accidents (nearly 70%) occurred due to operating at

Table 9. Accident rate (no./million cubic meters).

	Death	Seriously-Injured	Total	Mark
Machine	2.14	2.85	4.99	operators
Animal	18.71	35.69	54.40	most animals

more sharply in the last ten years. Conditions of over-slope limitation. Maximum slope limitation for animal skidding and machine skidding was stated in the Operation Safety Rules of Skidding of the Heilongjiang Forestry Industry Bureau as follows: seventeen degrees for both animal and machine skidding under normal skidding conditions and twenty degrees for machine skidding with the help of a winch during the winter period.

Analysis of Direct Damage of Skidding to Residual Stands and Young Seedlings

Field surveys of the direct damage of skidding operations on residual stands and young seedlings was carried out in three major forest areas before snowfall in 1994 (Table 10). There are at least thirty small squares, each 10 m by 10 m, in each of the samples used. The distribution of small squares follows the lines that cross the test site. All data, which might not be highly accurate, are from these small squares, where timber volume removed ranges from 22 to 38 m^3/ha. It is evident that the direct damage rate of machine skidding is much higher than animal skidding due to the machine's big size, high power, and low flexibility.

Analysis of Soil Erosion from Skidding Site

The quantity of water and soil run-off at the operation site caused by skidding depends on site area, slope, cutting method, operation time, period after cutting, operation system, soil, and skidding passes. It is difficult to integrate all factors for evaluating the amount of soil run-off from site to site. Therefore, the field surveys concentrate on skidding trails. Results of surveys using maximum run-off of soil from skidding trails of three major forest areas are shown in Table 11. Here, in order to comprehensively evaluate soil run-off along skidding trails, and considering other important influencing factors mentioned above, the coefficient of soil run-off from skidding trails is defined as follows:

$$RF = \Sigma\ (Li * Wi * Di * 10^6)/(S * I * Ai * Q * T * CF * TF) \quad (3)$$

where RF = soil run-off coefficient;
Li = length of skidding trail i;
Wi, Di = width and depth of skidding trail i;
S = area of converging water around skidding roads;
I = average slope of the site;
Q = timber volume per hectare removed from the site;
T = period after cutting and skidding;
P = yearly precipitation;
CF = coefficient of cutting method;
TF = coefficient of operation time.

In terms of Equation (3) and data from field investigations, the maximum RF for the three major forest areas is shown in Table 11. Under soil and water run-off criteria, animal skidding has obvious advantages over machine skidding.

Analysis of Natural Regeneration at Operation Sites

Skidding is one of the disturbances that is affected by natural regeneration at operation sites, espe-

Table 10. Ratio of direct damage to residual stands and young seedlings (%).

Forest	Machine		Animal		
Area	mean	var.	mean	var.	Samples
Mudanjiang (MDJ)	38	6.7	13	4.3	15
Yichun (YC)	34	8.3	16	6.6	15
Daxinanling (DXL)	28	9.4	16	8.2	16

Table 11. Maximum water and soil run-off from skidding trail (m^3/m).

Forest	Machine		Animal		Volume	RF		
Area	mean	var.	mean	var.	m^3/ha	mach.	ani.	Samples
MDJ	0.26	0.07	0.07	0.02	25	0.164	0.03	12
YC	0.18	0.11	0.08	0.03	22	0.119	0.01	15
DXL	0.15	0.09	0.03	0.01	18	0.107	0.01	16

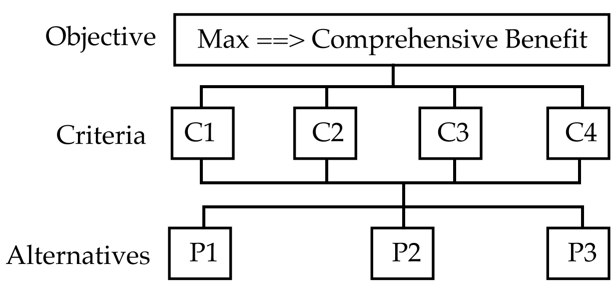
cially at skidding roads and off-road sites close to trails. Sites disturbed only slightly by machines (except heavily damaged main skidding roads) have a better regeneration. For example, results of a field survey in Yichun Forest Area showed that one year after cutting there were 18.5 seedlings per m^2 for slightly touched sites, 9.8 seedlings for untouched sites, and 1.1 seedlings for heavily damaged main skidding roads. Most of the animal skidding took place on frozen soil. Therefore, animal skidding had no significant disturbance of topsoil due to snow cover and the high resistance of the frozen topsoil.

Results of field surveys for the three major forest areas (Table 12) show that two or three years after operation, natural regeneration at machine skidding sites is better than at animal skidding sites. It is, however, difficult to predict the further development of that now.

COMPREHENSIVELY EVALUATING ANIMAL SKIDDING AND GROUND MACHINE SKIDDING USING AHP

In order to comprehensively evaluate animal skidding and ground machine skidding, a structure model with two hierarchies is presented as follows: using AHP (Analytic Hierarchy Process):

C1 = operation cost;
C2 = accident rate;
C3 = damage to residual stands and seedlings;
C4 = damage to soil;
P1 = animal skidding;
P2 = crawler skidding;
P3 = skidder skidding.



In terms of practical operations in the three major forest areas, the typical classification of operation conditions is suggested here as an example:

1) timber volume removed from site: 20 to 60 m^3/ha;
2) average skidding distance: less than 1700 m;
3) average slope: less than 28%;
4) average timber volume per stem: less than 0.5 m^3;
5) cutting method: selective cutting;
6) operation period: soil frozen period.

The results of the AHP show that animal skidding is the best choice among the three alternatives under multi-evaluation criteria such as cost, accident rate, damage to residual stands and seedlings, and damage to soil.

CONCLUSIONS

Animal skidding is significantly superior to heavy machine skidding in selective cutting or thinning operations under evaluation criteria such as operation cost, damage to residual stands and seedlings, and disturbance to soil, but slightly inferior to machine skidding only considering accident rate and regeneration. The results of a comprehensive assessment under evaluation criteria (operation cost, accident rate, damage on residual stands and seedlings, and disturbance to soil) showed that animal skidding is a first preference among skidding alternatives in the moderate and steep terrain conditions that are popular in Heilongjiang Forest Region. The wheeled skidder had advantages over other ground skidding methods in longer distance skidding.

Table 12. Natural regeneration at sites machine skidding and animal skidding (number/ha).

Forest	Machine		Animal			
Area	mean	var.	mean	var.	Selection	Samples
MDJ	4300	108	3668	89	40%–60%	15
YC	3900	179	3732	112	40%–60%	15
DXL	3760	168	3302	97	30%–60%	16

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