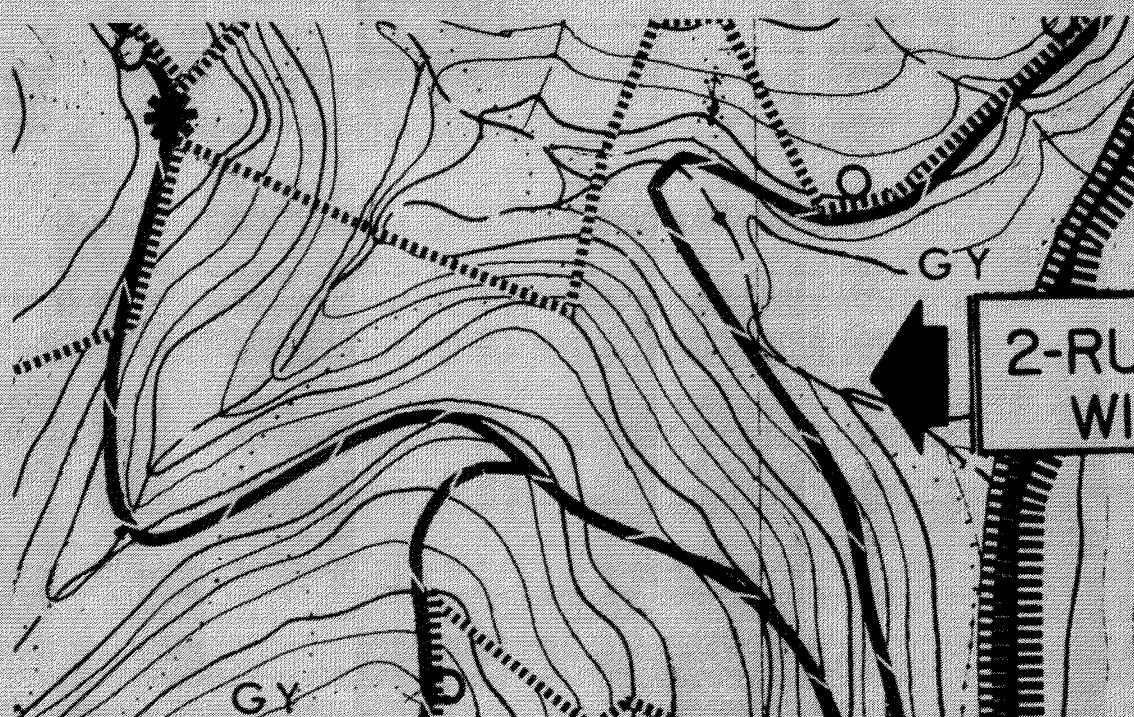
FERIC FOREST ENGINEERING RESEARCH INSTITUTE OF CANADA
INSTITUT CANADIEN DE RECHERCHES EN GÉNIE FORESTIER

COAST LOGGING: HIGHLEAD VERSUS LONG-REACH ALTERNATIVES

B.J. Sauder and M.M. Nagy
in co-operation with the United States Department of Agriculture
Pacific Northwest Forest and Range Experiment Station

Technical Report No. TR-19
December 1977



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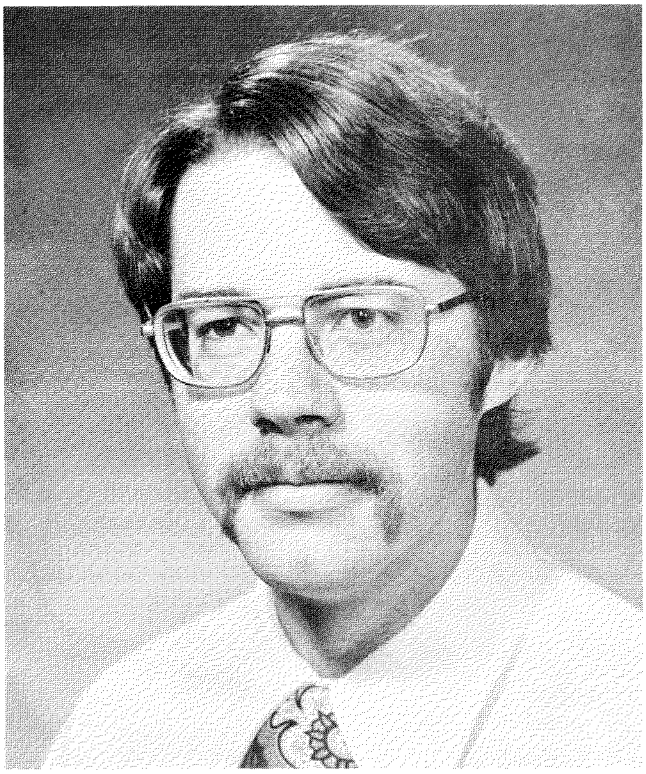

Brent J. Sauder received his B.S.F. from the University of British Columbia in 1974. In 1975 he joined FERIC in Vancouver after one year with private industry. He is a Registered Professional Forester and a member of the Canadian Institute of Forestry and he has been concerned with the problems affecting coastal B.C. logging.

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FOREWORD

This started as a study to see whether or not highlead could be profitably supplemented by balloon yarding, but it has now been expanded into a comparison of several other methods.

The authors wish to thank Mr. J.M. Grods and the Engineering Department of MacMillan Bloedel's Sarita Division for their co-operation in supplying maps and field data; Mr. A.G. Crimmons of Aerocrane Canada Limited for his technical advice; and Mr. E.J. Phillips of FERIC.

The authors would also like to acknowledge the help of Messrs. Hilton Lysons (Project Leader), Doyle Burke, Ron Mifflin and the research staff of the Pacific Northwest Forest and Range Experiment Station, Forest Engineering Laboratory, Seattle, Washington, for their engineering and technical assistance concerning the yarding crane running skyline (Washington 118) section of this report.

The draft report was reviewed by Mr. Frank Garrison, MacMillan Bloedel, Mr. E. Heidersdorf, FERIC, Montreal, and Mr. Hilton Lysons, Pacific Northwest Forest and Range Experiment Station. Their assistance is also gratefully acknowledged.

The use of trade names for the various machines in the report does not imply any recommendation or endorsement by FERIC. Equipment undergoes continual development and improvement, and readers should contact manufacturers directly for current specifications and full information.

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SUMMARY

This study is an initial evaluation of the effect of applying long-reach yarding systems to a representative logging area. The study is based on a map area of about 3,650 acres typical of many logging sites on the British Columbia coast. Four long-reach yarding systems and conventional highlead were evaluated.

The five systems compared are
1) Conventional highlead
2) Running skyline with fixed spar
3) Running skyline yarding crane
4) Balloon
5) Heavy-lift free-flying vehicle.

For the first four systems, productivity and cost data from representative operations were used as a guide. For the last one, a vehicle at the test model stage, no operational data was available.

The area was successively "logged" according to a realistic logging plan. In each case the layout was constructed to take full advantage of the logging system under study supplemented by appropriate auxiliary systems. For example, highlead in the study may include direct loading of right-of-way logs or short yarding by grapple yarder. Auxiliary yarding for the long-reach systems may include those systems already mentioned, plus auxiliary highlead applications. Productivity and cost predictions, assumed and calculated, were used to yield values for each of the five cost components considered in the study: road construction, falling, yarding, loading and hauling.

Costs derived are, of course, hypothetical, since the area was not physically logged; but they are logical in relation to the topography and current coastal logging experience.

Table S1 applies the calculated cost-per-cunit values derived in the study to the representative 3,650 acres. Using the assumption of 120 cunits per acre, these figures represent the total direct costs of accessing, falling, yarding, loading and hauling 438,000 cunits. Using the total direct cost of highlead as a standard, we found that the running skyline with yarding crane produced a saving of $1,686,300. It cost $1,436,640 more to operate the balloon system.

The costs for individual phases were affected differently by the different systems. In general, total road access cost decreased as yarding distance increased. As an extreme example, road construction costs for the heavy-lift, free-flying vehicle were only 28% of those for highlead.

Conversely, the assumptions used in calculating the falling cost led to falling costs that increased with increased yarding distances.

Yarding costs represented the highest cost component of the five systems under consideration. The average yarding costs for the four long-reach systems were higher than those for highlead.

The loading costs reflected the interaction of the yarding system with the loader; the long-reach systems had low average loading costs compared with those for highlead.

Hauling costs for the long-reach system were also lower than those for the highlead system because hauling was over shorter distances on roads of higher quality.

TABLE S1. TOTAL DIRECT LOGGING COSTS FOR FOUR LONG-REACH SYSTEMS AND HIGHLEAD.

System	Road Access $	Falling $	Yarding $	Loading $	Hauling $	Total $	Difference from Highlead $
Highlead	2,365,200	2,058,600	4,042,740	1,817,700	2,790,060	13,074,300	0
Running Skyline Fixed Spar	1,533,000	2,106,780	4,682,220	1,427,880	2,763,780	12,513,660	– 560,640
Running Skyline Yarding Crane	1,252,680	2,150,580	4,323,060	1,449,780	2,211,900	11,388,000	– 1,686,300
Balloon	1,278,960	2,251,320	6,600,660	1,624,980	2,755,020	14,510,940	1,436,640
Aerocrane	661,380	2,277,600	5,838,540	893,520	2,391,480	12,062,520	– 1,011,780

Based on 3,650 acres @ 120 cunits per acre
Total volume: 438,000 cunits

Table S2 shows total calculated average cost for the five components by system.

TABLE S2. CALCULATED AVERAGE TOTAL LOGGING COST.

System	Average Direct Total Cost $ per cunit
Highlead	29.85
Running skyline with fixed spar	28.57
Running skyline yarding crane	26.00
Balloon	33.13
Heavy-lift free-flying vehicle	27.54

Except for the balloon system, all long-reach yarding systems were lower than highlead in average direct cost.

The results of the study show the complex interaction of the yarding method and associated logging activities. Despite generally higher direct yarding costs for the long-reach system, the report indicates that this extra cost can be offset by reducing other cost components such as road construction, loading and hauling.

The report emphasizes that long-distance yarding systems are inherently more complex than highlead, requiring a higher standard of planning, supervision and mechanical servicing to maintain production levels. However, the highlead yarding system no longer warrants the automatic preference it has enjoyed in the past. The yarding cost advantage of highlead may be offset totally by the need for a costly network of roads and landings.

SOMMAIRE

Cette étude est une évaluation préliminaire des systèmes de débardage à longue portée dans une aire d'exploitation réprésentative. Il s'agit d'une superficie d'environ 3,650 acres délimitée sur une carte et typique de la région côtière de la Colombie Britannique. L'évaluation porte sur quatre systèmes de débardage à longue portée et sur le téléphérage conventionnel.

Les cinq systèmes mis en parallèle sont

1) Le téléphérage conventionnel.
2) Le câble-tracteur à mât de tête fixe.
3) Le câble-grue transversal.
4) Le ballon.
5) L'Aerocrane pour charges lourdes.

Pour les quatre premiers systèmes, des données de productivité et de coûts provenant d'opérations similaires furent utilisées. Quant au cinquième, un engin encore au stage expérimental, aucune donnée d'opération n'était disponible.

Le territoire fut successivement "exploité" suivant un plan réaliste. Dans chaque cas le plan fut préparé de façon à profiter pleinement du système d'exploitation à l'étude auquel furent ajoutés des systèmes auxiliaires appropriés. Par example, le téléphérage peut inclure le chargement direct des billots provenant de l'emprise ou un court débardage avec grappins. Le débardage auxiliaire pour les systèmes à longue portée peut inclure les systèmes déjà mentionnés, avec en plus des applications auxiliaires de téléphérage.

Des prévisions de productivité et de coût, hypothétiques et calculées, furent utilisées pour fournir des valeurs à chacun des cinq éléments de coût inclus dans l'étude: construction de chemin, abattage, débardage, chargement et transport.

Les coûts ainsi obtenus sont nécessairement hypothétiques, parce que l'exploitation n'a jamais pris place; mais ils sont néanmoins réalistes compte tenu de la topographie et de l'expérience des exploitants forestiers de cette région.

Dans le Tableau S-1 les valeurs calculées de coût par cunit sont appliquées au territoire de 3,650 acres. En supposant un volume de 120 cunits à l'acre, ces chiffres représentent la totalité des coûts directs pour l'accès, l'abattage, le débardage, le chargement et le transport de 438,000 cunits. Utilisant comme standard le coût direct total pour le téléphérage, on a trouvé que le câble-grue transversal a produit une économie de $1,686,300. Il en a coûté $1,436,640 de plus pour opérer avec le système par ballon.

Le coût de chaque élément a été influencé différemment par les divers systèmes. En général, le coût total du chemin d'accès a diminué à mesure que la distance de débardage augmentait. Comme cas extrême, les coûts de construction de chemin applicables au système Aerocrane n'étaient que 28% de ceux pour le téléphérage.

Par contre, les hypothèses posées pour calculer le coût d'abattage ont entraîné une augmentation de ce coût en fonction de l'accroissement de la distance de débardage.

TABLEAU S1. CÔUTS COMPLETS DIRECTS D'EXPLOITATION POUR QUATRE SYSTÈMES A LONGUE PORTÉE ET TÉLÉPHÉRAGE

Système	Route d'accès $	Abattage $	Débardage $	Chargement $	Transport $	Total $	Différence avec téléphérage $
Téléphérage	2,365,200	2,058,600	4,042,740	1,817,700	2,790,060	13,074,300	0
Câble-tracteur à mât de tête fixe	1,533,000	2,106,780	4,682,220	1,427,880	2,763,780	12,513,660	–560,640
Câble-grue transversal	1,252,680	2,150,580	4,323,060	1,449,780	2,211,900	11,388,000	–1,686,300
Ballon	1,278,960	2,251,320	6,600,660	1,624,980	2,755,020	14,510,940	1,436,640
Aerocrane	661,380	2,277,600	5,838,540	893,520	2,391,480	12,062,520	–1,011,780

Base: 3,650 acres à 120 cunits à l'acre. Volume Total: 438,000 cunits.

Les coûts de débardage ont constitué l'élément le plus coûteux pour les cinq systèmes considérés. Les coûts moyens de débardage pour les quatre systèmes à longue portée ont été plus élevés que ceux pour le téléphérage.

Les coûts de chargement ont révélé le rapport intime entre le débardage et le chargement: ainsi les systèmes à longue portée avaient des coûts moyens de chargement plus bas que ceux du téléphérage.

Les coûts de transport furent moindres pour les systèmes à longue portée que ceux pour le téléphérage parce que ce transport s'est effectué sur des distances plus courtes et sur des chemins de meilleure qualité.

Le Tableau S-2 montre le coût moyen total calculé pour les cinq éléments par système.

Sauf pour le système par ballon, le coût moyen direct a été moins élevé pour tous les systèmes à longue portée que pour le téléphérage.

TABLEAU S2. COÛT D'EXPLOITATION MOYEN TOTAL CALCULÉ

Système	Coût total direct moyen par cunit
Téléphérage	$29.85
Câble-tracteur à mât de tête fixe	28.57
Câble-grue transversal	26.00
Ballon	33.13
Aerocrane pour charges lourdes	27.54

Les résultats de cette étude font ressortir l'interdépendance complexe entre la méthode de débardage et les fonctions connexes d'exploitation. En dépit de coûts directs de débardage généralement plus élevés pour les systèmes à longue portée, le rapport indique que l'excédent de ce coût peut être compensé par la réduction des autres éléments de coût tels que la construction de chemin, le chargement et le transport.

Le rapport démontre que les systèmes de débardage à longue portée sont fondamentalement plus complexes que le téléphérage et requièrent une meilleure préparation, une plus grande surveillance et un entretien mécanique plus au point pour assurer un niveau de production acceptable. Cependant, il ne faut pas nécessairement donner la préférence au système de débardage par téléphérage comme cela s'est fait dans le passé. L'avantage du coût de débardage peut être complètement anéanti par la nécessité de construire des jetées et un réseau routier dispendieux.

INTRODUCTION

Yarding is the process of moving logs from the stump to the haul road. Processes such as road development, falling, loading and hauling complement yarding to make up the complete logging system. West coast loggers have traditionally favoured highlead yarding because of cheapness and simplicity, but highlead yarding is more limited in reach than several long-reach methods available. The advantage of cheap highlead yarding is at times offset by disadvantages, notably the need for densely-spaced roads. Road construction on mountainous terrain has become a major cost component in logging, and may also be a source of adverse environmental effects, which could be alleviated if fewer roads were built.

Attention must now be centered on the combined costs and effects of all parts of the logging system, rather than on yarding alone. Can long-reach alternatives overcome the problems of highlead, and if so, under what circumstances, and at what total logging cost?

This FERIC study was designed to provide preliminary answers to this question. The objectives of the study were

1. To prepare logging plans for each of several "stump-to-dump" logging systems covering the same representative coastal area;
2. To analyse and compare combined costs under each system;
3. To draw attention to any special features of the systems.

The results of this simulation are theoretical, but are based on coastal operating data and reasonable assumptions for the area. Projections apply specifically to the area chosen for the study, but could be extrapolated to fit other coastal areas. This initial analysis was done manually, but computerization would be a logical way to speed up similar simulations in future. A standard computer package designed along the lines followed in this study would help logging planners to develop the optimum combination of available systems. Both the Forestry Faculty at the University of British Columbia and the USDA Forest Engineering Laboratory, Seattle, are active in this field and FERIC will continue to monitor such studies.

STUDY METHOD

The map area used in our paper plan represents approximately 3,650 forested acres typical of many logging sites on the British Columbia coast (Figure 1). Topographic maps of this area at scale 400 feet to 1 inch* were provided by a co-operating coastal company, along with timber cruise data. Timber volume per acre is uniform, and for purposes of this study, was assumed to be constant at 120 cunits per acre. Sidehill slopes were uniformly steep and generally unstable, making road construction difficult and costly.

Representative machines chosen for each system are as follows:

Logging System	**Machine**
Highlead	Madill Model S Type 009 - 3 Drum Yarder
Running skyline with fixed spar	Madill 052
Running skyline yarding crane	Washington 118
Balloon	Washington 608A Balloon Yarder Raven 530K Balloon
Heavy-lift free-flying vehicle	Aerocrane; 16-ton sling load capacity

We laid out the map area five separate ways for each of the five successive systems (Table 1). In each case, the layout was intended to take full advantage of the main system, supplemented by auxiliary systems.

TABLE 1. PHYSICAL CAPABILITIES ASSUMED FOR REPRESENTATIVE MACHINES

	Physical Capabilities	
Machine	Maximum Yarding Distance	Minimum Deflection
Highlead	1,000 ft	6% mid-span
Madill 052	2,000 ft	8% mid-span
Washington 118	1,600 ft	8% mid-span
Balloon Yarder	4,500 ft	0 mid-span (Downhill yarding only)
Aerocrane	No defined maximum	(Downhill yarding only)

*A reduced-scale map illustrating the study area is located inside the back cover. It is a composite, showing a sample of each of the five systems analysed. Five 400-feet-to-one-inch work maps were prepared in the study, each entirely covered by one of the five systems.

The maps used were considered to be reasonably accurate, but still not of an order justifying detailed examination on an individual yarding road basis. Cost components were estimated for defined logging areas ranging up to 600 acres for each system. These area costs were then used to calculate the total component cost for the complete map area.

Because of the shape of the logging boundaries on the perimeter of the map, the total area logged varies for the five logging systems. Untimbered slides and previously logged areas within the study area were deleted for all systems.

Productivity and cost assumptions were made to produce values for the five components in logging cost: (a) road construction, (b) falling, (c) yarding, (d) loading, and (e) hauling, and these may be summed up as follows:

(a) Cost of road construction is based on three road standards and divided into subgrade and ballast costs. Subgrade costs were modified by the presence of rock and the side-slope angle. Ballasting costs were modified by the type of material available (shot rock or gravel), steepness of haul, and the presence of rock in the subgrade. Road standards, subgrade costs and ballasting costs are given in Appendix I.

(b) Falling productivity figures go down in direct proportion to the increase in distance from road access. For the purpose of this study, falling costs were grouped into areas less than 700 feet from road access and those over 700 feet from road access (Table 2).

TABLE 2. FALLING COST ASSUMPTIONS

Fallers wage (including overhead and chainsaw)		$150 / day
Distance from road	**Production / shift cunits**	**$ / cunit**
0 – 700 ft	32	$4.69
Over 700 ft	26	$5.77

(c) Yarding costs represent the cost of yarding the total area and may include several auxiliary systems in addition to the main system under study. For example, highlead in this study may include direct loading of right-of-way logs or short yarding by grapple yarder. Auxiliary yarding for the long-reach systems may include those systems

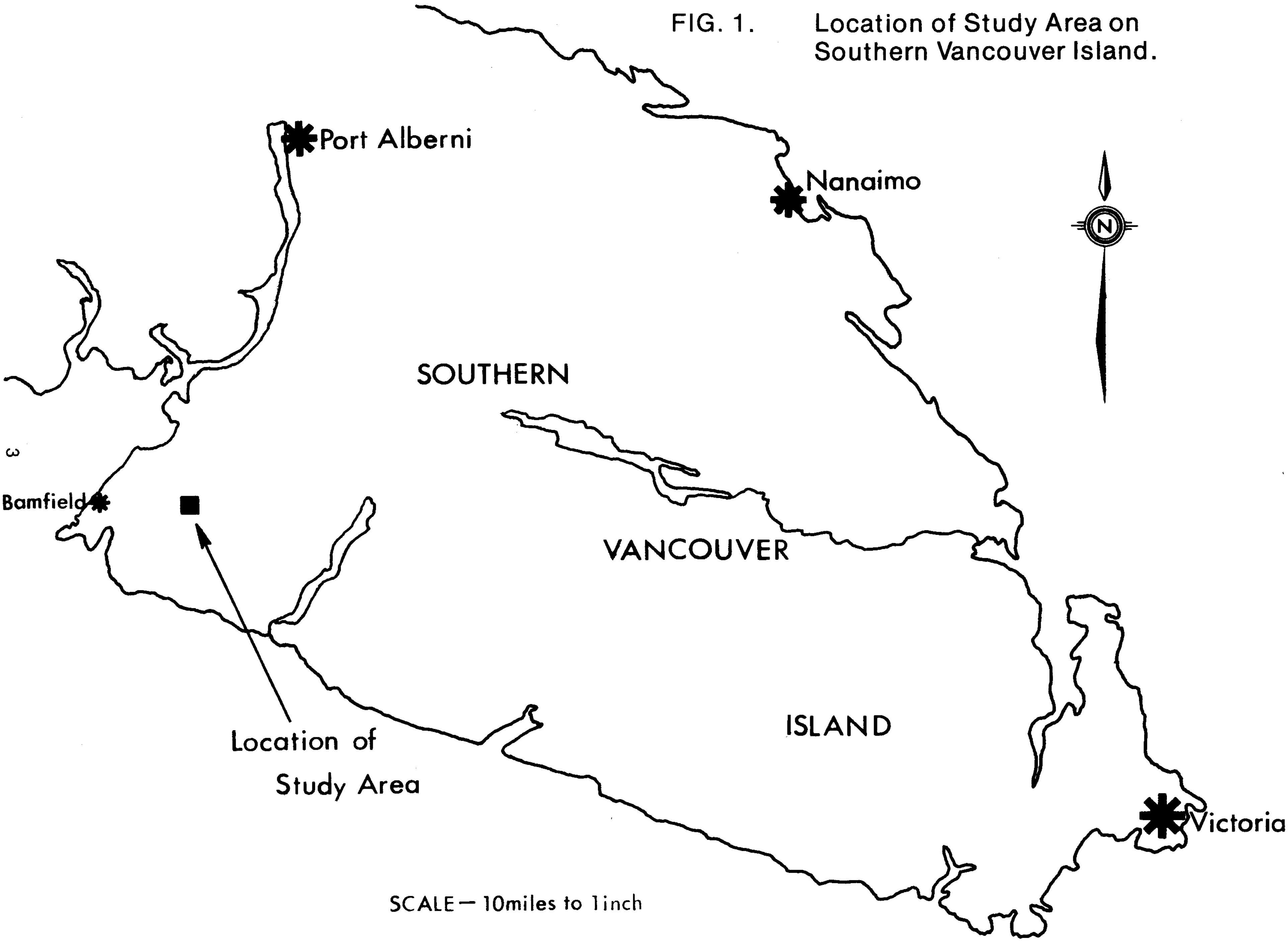
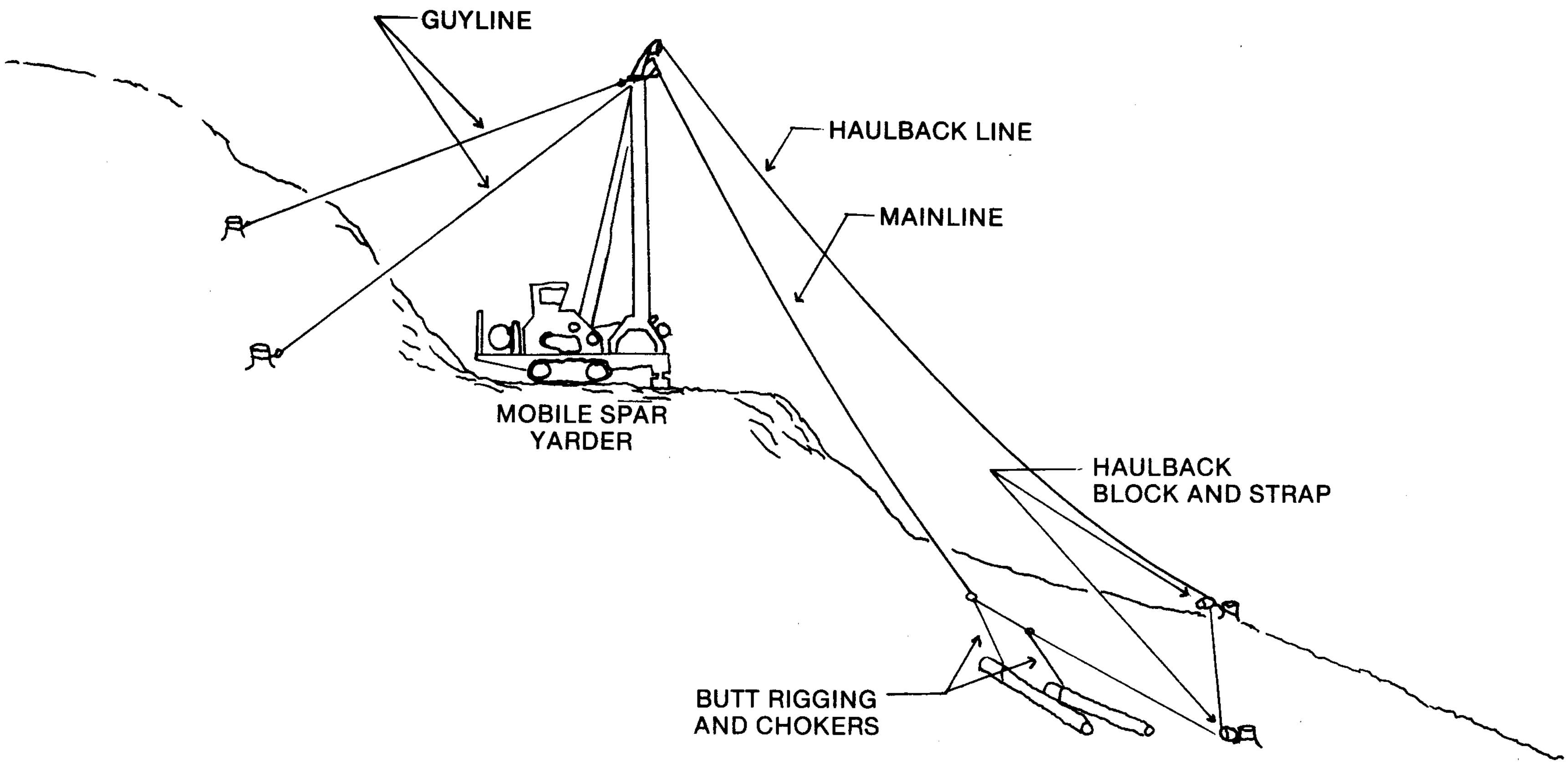


FIG. 1. Location of Study Area on Southern Vancouver Island.

FIG. 2. Highlead Yarding System.



already mentioned, plus auxiliary highlead applications where appropriate. Productivity is modified by landing quality, deflection and yarding distance. Landing quality or size was identified by the local area side slopes and the presence of rock (as determined from the map and from local knowledge of the area).

(d) Loading is affected directly by yarding productivity and landing size. Landing size controls the type of loader used, and the feasibility of sharing the loader among two or more logging sites. For example, on very steep terrain, a grapple loader must be present at all times to clear logs away from the yarder.

(e) Hauling costs reflect the length of the haul and delays at all points but particularly at landings. On small landings where there is no room to store logs, a truck must be present at all times. In this situation, the haul productivity is governed by the productivity of the yarding system.

Appendix IV gives the assumptions used to reflect these variables.

Cost elements other than those listed were left out for the sake of simplicity. For example, road maintenance costs might vary for the different systems, depending on the mileages and kinds of road. In the absence of concrete information, road maintenance was excluded.

SYSTEM 1: HIGHLEAD LOGGING

1.1 System 1 Operating Characteristics

The cable yarding system preferred on the British Columbia coast is the highlead system (Figure 3). Simplicity is the major advantage of this 2-line system, making it adaptable to a wide range of operating conditions.

A three-drum winch and a steel spar approximately 90 feet tall are mounted as a unit on either a tracked or a rubber-tired undercarriage.

A Madill Model "S" series mobile tower and winch is a typical highlead yarder. Machine specifications are given in Appendix II. The rigging configuration for highlead is shown in Figure 2. Logs are ground-skidded to the landing by the mainline, and the rigging and mainline are returned to the hooking site by the haulback.

Partial lifting of the logs to overcome hangups is done with the spar by tight-lining the cables. Since this lift effect is greatly diminished beyond the immediate vicinity of the spar, maximum highlead yarding distance is effectively limited to 1,000 feet with favourable deflection. These limitations dictate that the distance between haul roads must never exceed 2,000 feet and the distance between successive landings should be even less. The highlead system therefore requires more roads and landings than the other four systems.

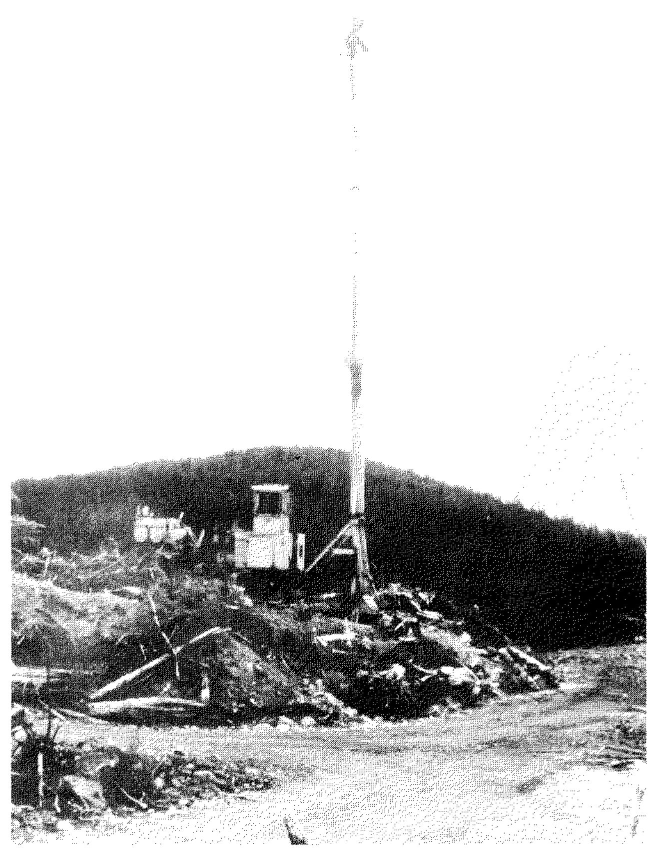


FIG. 3. Madill Highlead Yarder with 90-foot Spar.

The highlead landing must be a flat area with guyline stumps to set up the yarder and space to land the logs. Congested landings are a common feature of this system on steep ground, and may limit productivity. Landing density is affected by maximum yarding distance. Supportive equipment is limited to standard maintenance vehicles and a loader or skidder to keep the landing area clear. On steep ground with small landings, the loader is needed full time to hold the logs during unhooking.

1.2 System 1 Productivity and Cost

Yarder

The productivity of the highlead yarder was based on information from the local operator. Average productivity figures were modified by landing classification, deflection and yarding distance. Landing classification was good, fair or poor:

- Good - side slope less than 20 percent, no rock.
- Fair - 20 to 40 percent side slope, no rock.
- Poor - side slope over 40 percent or in rock.

Deflection was classified as good or fair by visual inspection of the yarding area on the contour map. Proper placement of landings resulted in at least fair deflection in all areas.

Optimal maximum yarding distance was assumed to be 700 feet, but actual yarding distance occasionally reached 1,000 feet. Settings were portioned into three yarding distance classifications — less than 300 feet, 300 to 700 feet, and over 700 feet from the landing.

A productivity matrix is given in Table 3 for the different combinations. Total operating cost was $923.52 per shift (Appendix III). Derived yarding costs per cunit are shown in Table 4.

Loader

In highlead, the productivity of the loader is largely governed by the yarder's productivity. The maximum loading capability of either a grapple or front-end type loader exceeds the productivity of a single yarder. A single loader can service two landings if they are reasonably close to one another. The type of loader and loading productivity were each determined by landing classification, ground side slope, and yarder productivity.

Landing classifications are the same as for yarding, with the addition of an "extreme" classification for landings with a side slope gradient over 60 percent. This classification reflects the need for a grappie loader to hold logs during unhooking.

By applying the operating cost estimate of $467.76 per shift for the rubber-tired front-end loader, and $577.20 per shift for the hydraulic grapple loader (Appendix III), a cost-per-cunit matrix was produced for loading (Table 5).

TABLE 3. HIGHLEAD PRODUCTIVITY MATRIX.*
(Cunits per 8-hour shift)

Landing Quality	Good		Fair		Poor	
Deflection	Good	Fair	Good	Fair	Good	Fair
<300 ft	105.0	94.5	100.0	90.0	90.0	81.0
300-700 ft	86.3	77.4	81.5	73.8	76.7	70.1
>700 ft	61.8	55.7	58.9	53.0	53.0	47.7

Volume/acre 120 cunits per acre Log Average 70 cubic feet

*Values represent productivity within the yarding distance classifications, and are not averages for the total setting.

TABLE 4. HIGHLEAD YARDING COST.*
($ per cunit)

Landing Quality	Good		Fair		Poor	
Deflection	Good	Fair	Good	Fair	Good	Fair
<300 ft	8.79	9.77	9.23	10.26	10.26	11.40
300-700 ft	10.70	11.93	11.33	12.51	12.04	13.17
>700 ft	14.94	16.58	15.68	17.42	17.42	19.36

*Values represent cost-per-cunit within the yarding distance classifications, and are not averages for the total setting.

TABLE 5. LOADING COST PER CUNIT MATRIX

Landing Quality	Good		Fair		Poor		Extreme side slope > 60%	
Deflection	Good	Fair	Good	Fair	Good	Fair	Good	Fair
Yarding Method								
Mobile Grapple	$3.66							
Highlead <300 ft	2.55	$2.84	$2.68	$2.98	$3.66	$4.07	$6.41	$7.05
Highlead 300-700 ft	3.11	3.46	3.29	3.63	4.30	4.70	7.53	8.23
Highlead >700 ft	4.34	4.81	4.58	5.09	6.22	6.91	10.89	12.10

1.3 System 1 Results of Paper Plan

Road Access

34.9 miles of road was necessary to access 3,652 acres for the highlead system. A tabulation of length of road by road standard is given in Table 6. Average cost of road construction per mile was calculated at $59,250.

Landing costs were included in the cost of road construction. One landing was assumed to be equal in cost to one station (100 feet) of adjacent road.

TABLE 6. LENGTH OF ROAD FOR THE THREE ROAD STANDARDS (HIGHLEAD).

Road Class	Length (miles)
3	7.8
4a	8.7
4b	18.4
	34.9

Total average cost for road access and landings (applying the costs in Appendix I) was $5.40 per cunit.

Falling

Of the total 3,652 acres, only 34 acres were over 700 feet from road access. Using the falling cost assumptions, we found the weighted average falling cost was $4.70 per cunit.

Yarding

Yarding of the logs was done in three ways. Right-of-way logs were removed 50 feet on either side of the road access by a hydraulic grapple loader producing 160 cunits per shift. Where applicable, grapple yarding within 400 feet of roads was applied at a production rate of 100 cunits per shift. The cost estimate for the grapple yarder is given in Appendix III. The remaining logs on the setting were highlead-yarded. Table 7 is a breakdown of yarding areas and cost per cunit by each method.

TABLE 7. YARDING AREA AND AVERAGE COST BY LOGGING METHODS.

	Acres Yarded	Cost $ / cunit (average)
Right-of-way	412	3.61
Grapple yard	813	7.34
Highlead	2,427	10.82
Total:	3,652	($9.23)

Yarding cost was estimated at $9.23 per cunit for the map area.

Loading

Average loading cost was calculated at $4.15 per cunit.

Hauling

The productivity and cost formula in Appendix IV, with a 1.8 hour-per-trip delay factor, worked out to an estimated hauling cost of $6.37 per cunit. The average hauling distance is 13.39 miles.

1.4 System 1 Summary of Costs

Table 8 summarizes the costs for the five activities calculated for the highlead system.

It would cost $29.85 per cunit to apply the highlead system over the entire study area.

TABLE 8. SYSTEM 1 – TOTAL LOGGING COST SUMMARY.

Road access and landing construction	$5.40/cunit
Falling	4.70/cunit
Yarding	9.23/cunit
Loading	4.15/cunit
Hauling	6.37/cunit
Total:	$29.85/cunit

SYSTEM 2: RUNNING SKYLINE WITH FIXED SPAR

2.1 System 2 Operating Characteristics

The 3-line running skyline system consists of a four-drum yarder and a slackpulling carriage which rides on the haulback. The slackpulling line and drum, plus the carriage, enable the system to control a drop line at the carriage for lateral yarding. This permits wider spacing of yarding roads. These combined features extend the feasible maximum yarding distance far beyond that for highleading. Both System 2 and System 3 fit this general description.

The rigging configuration for a running skyline is shown in Figure 4 (applying to System 2 and System 3). The carriage runs on the haulback, supported by one or more sheaves. The drop line is either stored on a drum in the carriage, or attached to the mainline as shown in Figure 5. The mainline and slackpulling drums are driven at the same speed and direction during inhaul and outhaul. To lower or raise the drop line, the drums are driven in opposite directions. The slackpulling line lowers the drop line, and the mainline raises it. Throughout the yarding cycle, the running lines are kept in the air. Correct line tensions are maintained between the three running lines by using nonregenerative brakes, regenerative brakes or hydraulic interlock (Mann 1976). The function of the interlock is to vary the speed of the haulback drum in relation to the mainline and slackpuller, in order to counteract the changes in drum diameter as cable is wound on or off, and to adjust the deflection to maintain constant tension.

The use of a drop line allows the yarding of logs not directly under the running lines. A yarding road will be wider using this system than that yarded by a highlead system. Lateral yarding and the ability to keep the running lines in the air allows preset chokers to be used in the system. (Preset chokers can be quickly attached to the drop line, reducing hookup time.)

The additional lift generated by the system extends the yarding range of the system to 2,000 feet or more. The controlling factor is adequate deflection. Five percent midspan deflection is considered to be the minimum, and eight percent or greater is preferred. Deflection can be improved by rigging backspars, or by locating tailholds up and across the valley bottoms.

Two types of running skyline systems are considered in this report — running skyline with a fixed spar (System 2) and running skyline yarding crane (System 3). The yarding pattern with the fixed spar is the same as for the highlead system, with a fan-shaped area for each yarding road being yarded to a central landing. The yarding crane is more mobile and uses fewer guylines. These yarders windrow, moving both tailhold and yarder on each road change, producing rectangular yarding areas.

The Madill 052 Tension Skidder (Figure 6) is representative of a running skyline yarder with a fixed spar. Specifications for this yarder and carriage are given in Appendix II.

Although fewer landings may be required than for highlead, the fixed-spar skyline yarder (Madill 052) still requires a flat area with adequate guyline stumps and space to land the logs. As in highlead, the productivity of the yarder is generally improved with larger landings and reduced when landings are too small.

Supportive equipment is limited to standard maintenance vehicles and a loader to keep the landing area clear. In some operations, a mobile back-spar mounted on a crawler tractor may be used.

FIG. 4. Running Skyline System.

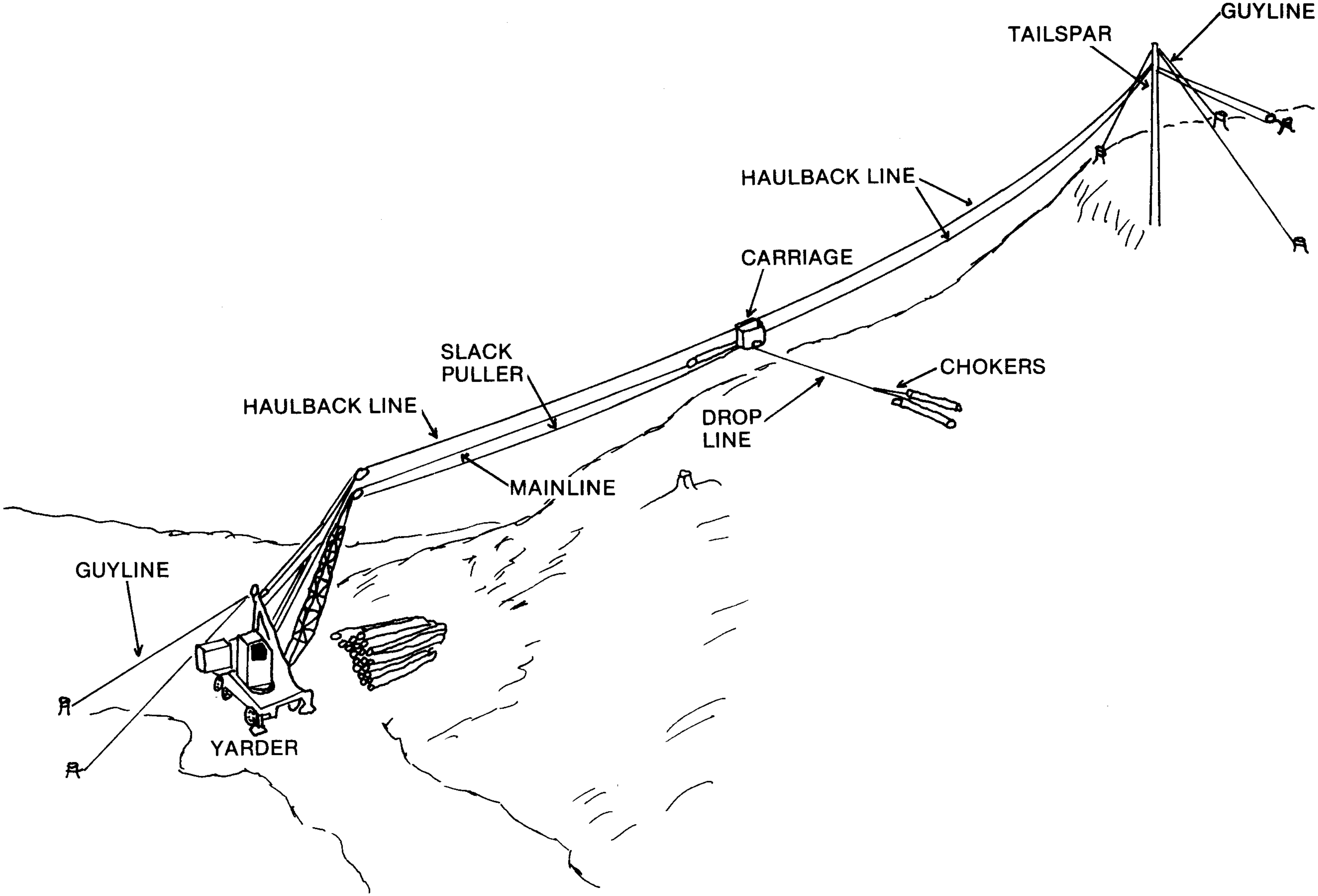
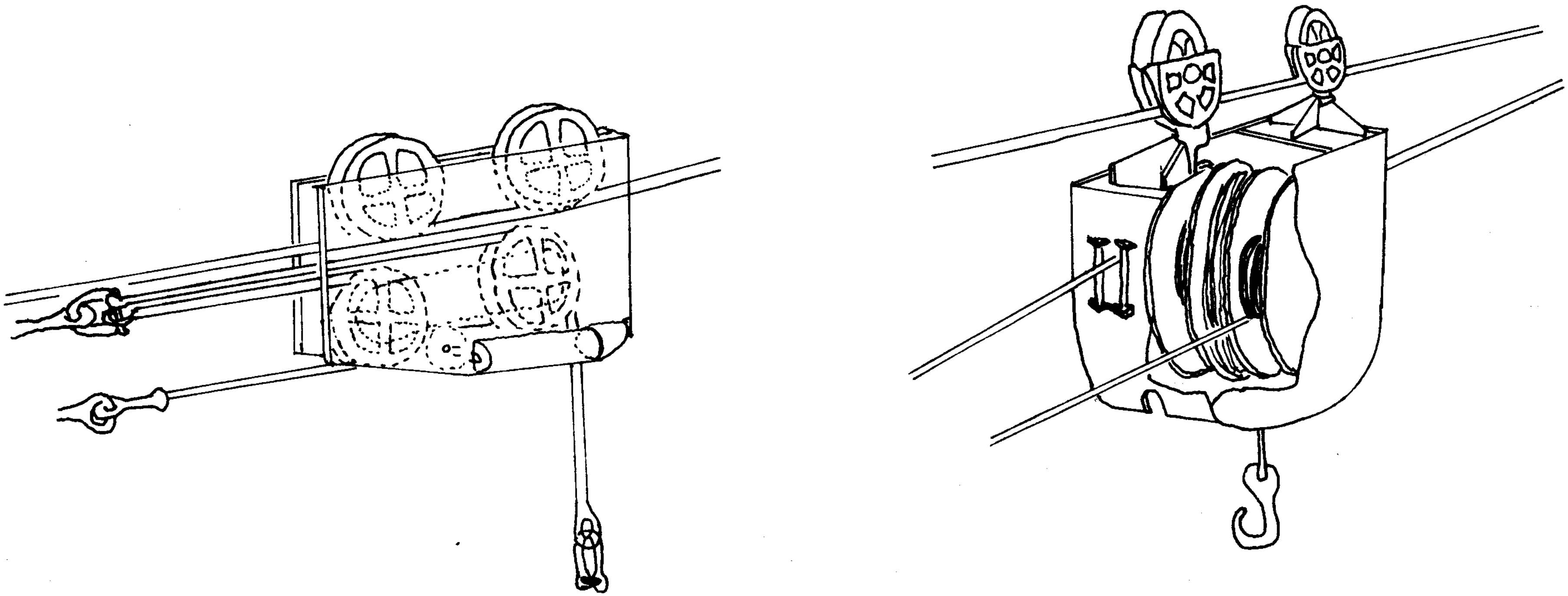


FIG. 5. Running Skyline Carriages.



(a) Dropline attached to mainline.

(b) Dropline stored inside of carriage.

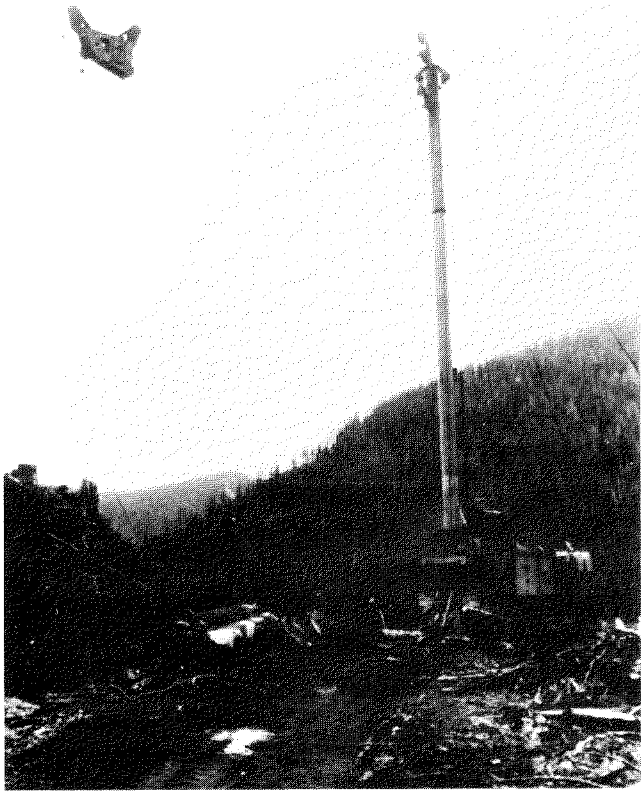


FIG. 6. Madill 052 Tension Skidder and Carriage.

2.2 System 2 Productivity and Cost

An average productivity of 90 cunits per shift is achieved by those logging with the Madill 052 Tension Skidder near the test area. Estimates are based on this figure. Shift operating costs for a Madill 052 Tension Skidder system are shown in Appendix III.

The Madill 052 was assumed to use a front-end loader for loading out its production. Operating costs for this combination are shown in Appendix III.

2.3 System 2 Results of Paper Plan

Road Access

For the Madill 052 Tension Skidder system to access 3,630 acres, 24.5 miles of road was necessary, compared with the 34.9 miles needed for highlead. Landing costs were included in the cost of road construction. As before, each landing was assumed to be equal in cost to one station (100 feet) of adjacent road.

Total average cost for road access and landings, applying the costs in Appendix I, was estimated at $3.50 per cunit. Average road cost was $53,695 per mile. Table 9 shows length of road by road standard.

TABLE 9. LENGTH OF ROAD FOR THREE ROAD STANDARDS (RUNNING SKYLINE WITH FIXED SPAR).

Road Class	Length (miles)
3	7.9
4a	5.7
4b	10.9
	24.5

Falling

Of the total 3,630 acres, 410 acres were over 700 feet from road access. Using the falling cost assumptions, we found that the total average falling cost was $4.81 per cunit. The slight increase over falling costs for the highlead system reflects added foot travel between roads which are further apart.

Yarding

Four methods were used to yard the logs. Right-of-way logs were cleared 50 feet on either side of the road by a hydraulic grapple loader producing 160 cunits per shift. Where applicable, a short-distance grapple yarder was employed at a production rate of 100 cunits per shift. Highlead logging was also used where applicable, using the productivity and cost values shown previously. The remaining area was yarded by the Tension Skidder system.

Table 10 is a breakdown of yarding areas and cost by yarding methods.

TABLE 10. YARDING AREAS AND AVERAGE COST BY LOGGING METHODS.

	Acres Yarded	Cost $/Cunit (average)
Right-of-way	287	3.61
Grapple yard	513	7.34
Highlead	1,653	10.63
Madill 052	1,177	13.98
	3,630	($10.69/cunit)

Total estimated average yarding cost for the area is $10.69 per cunit.

Loading

Total average loading cost was estimated at $3.26 per cunit. Table 11 shows loading rates per cunit for the yarding system.

TABLE 11. LOADING COSTS PER CUNIT FOR SYSTEM 2.

	Cunits	Loading Rate $/Cunit (Average)
Right-of-way	34,440	0 (Loading cost included in yarding cost)
Grapple yard	61,560	3.66
Highlead	198,360	3.69
Madill 052	141,240	3.29
	435,600	($3.26/cunit)

Hauling

Hauling cost was calculated using the productivity and cost formula in Appendix IV with a 1.8-hour delay factor for all yarding systems. This resulted in an estimated hauling cost of $6.31 per cunit. The average hauling distance was calculated at 13.13 miles (down slightly from the figure for highlead).

2.4 System 2 Summary of Costs

Table 12 gives the summary of costs for the five calculated activities for the Madill 052 Tension Yarder system.

TABLE 12. SYSTEM 2 – TOTAL LOGGING COST SUMMARY.

Road access		$ 3.50/cunit
Falling		4.81/cunit
Yarding		10.69/cunit
Loading		3.26/cunit
Hauling		6.31/cunit
	Total:	$28.57/cunit

It would cost $28.57 per cunit to apply the fixed-spar running skyline system (and auxiliary systems) to the study area. Falling and yarding are more costly than for highlead (System 1), but this is offset by reduced costs for roads and landings, loading and hauling.

SYSTEM 3: RUNNING SKYLINE WITH YARDING CRANE

3.1 System 3 Operating Characteristics

System 3 operates in many respects similarly to System 2. The main difference is that the crane yarder is often able to land logs directly on the road, and thus further reduce the cost of landing construction. This advantage can be applied whenever the road gradient is less than 12 percent. Natural roadside benches can also be used to advantage where they occur. In this case, logs can be windrowed to the roadside separating the loading activity from that of yarding.

The Washington 118 Mobile Yarder (Figures 7, 8) is typical of a yarding crane running skyline system. Specifications for this machine are given in Appendix III.

3.2 System 3 Productivity and Cost

Table 13 gives productivity estimates per shift for a Washington 118 yarding crane with yarding distance from 0 to 1,600 feet. These are based on a fixed time of 3.4 minutes for acceleration, deceleration, hookup, unhook and delays, and variable times for inhaul and outhaul. For each yarding road change approximately 150 feet apart, an allowance of 40 minutes was made. All productivity was based on 385 productive minutes per eight-hour shift. Estimated operating costs for a Washington 118 yarding crane are shown in Appendix III.

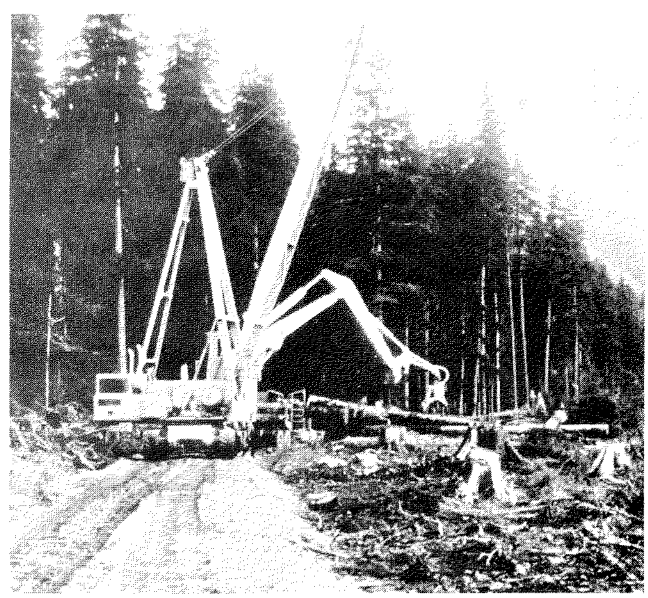


FIG. 7. Washington 118 Mobile Yarder working with Caterpillar 245 loader.

FIG. 8. Young YCC13 Carriage used on Washington 118 Mobile Yarder.

TABLE 13. ESTIMATED PRODUCTION FOR WASHINGTON 118 MOBILE YARDER.

Assumptions:

Slow-down & Speed-up time	0.5 min
Hookup time (preset chokers)	2.0 min
Unhook	0.5 min
Delays	0.4 min
Total fixed time/turn	3.4 min

Average line speed 749 ft/min
Average turn size 2.1 cunits (10,500 pounds)
Road change time 40 minutes; 150 feet apart
Productive machine time per shift 385 minutes

Yarding Distance (ft)	Turn Time (min)	No. of Turns per day	Volume per day (cunits)
200	3.93	98.0	205.8
400	4.47	86.1	180.8
600	5.00	77.0	161.7
800	5.54	69.5	146.0
1000	6.07	63.4	133.1
1200	6.60	58.3	122.4
1400	7.14	53.4	113.2
1600	7.67	50.2	105.4

3.3 System 3 Results of Paper Plan

Road Access

To access 3,562 acres for the crane system, 19.5 miles of road was necessary; there was no landing construction. A tabulation of length of road by road standard is given in Table 14.

TABLE 14. LENGTH OF ROAD FOR THE THREE ROAD STANDARDS (RUNNING SKYLINE YARDING CRANE).

Road Class	Length (miles)
3	6.6
4a	2.9
4b	10.0
	19.5

Total cost for road access, applying the costs in Appendix I, was estimated at $1,222,478 or $2.86 per cunit. Average road cost was $62,691 per mile.

Falling

Of the total 3,562 acres, 668 were over 700 feet from road access. Applying the falling cost assumptions, we found that the total average falling cost was $4.91 per cunit, slightly higher again than for the Madill 052.

Yarding

Yarding was done by only two methods. Right-of-way logs were cleared 50 feet on either side of the road access and loaded directly on trucks. This method accounted for 267 acres and cost $3.61 per cunit. The remaining 3,295 acres were windrowed by the Washington 118 at an estimated average cost of $10.38 per cunit.

Total estimated average yarding cost for the area is $9.87 per cunit.

Loading

Total average loading cost was estimated at $3.31 per cunit. A hydraulic heel-boom loader was assumed to be continuously employed with the yarder.

Hauling

Hauling costs, calculated using the productivity and cost formula in Appendix IV with a 1.2-hour delay factor, resulted in an estimated hauling cost of $5.05 per cunit. The average hauling distance was 12.4 miles, a further reduction from the hauling distance required for highlead.

3.4 System 3 Summary of Costs

Table 15 gives the summary of costs for the five activities calculated for the Washington 118 skyline system.

Direct cost to apply the yarding crane running skyline system on the area is estimated at $26.00 per cunit. Indicated costs are less than those for highlead (System 1) in all phases except falling.

TABLE 15. SYSTEM 3 – TOTAL LOGGING COST SUMMARY.

Road Access		$2.86/cunit
Falling		4.91/cunit
Yarding		9.87/cunit
Loading		3.31/cunit
Hauling		5.05/cunit
	Total:	$26.00/cunit

SYSTEM 4: BALLOON

4.1 System 4 Operating Characteristics

Sundberg in Sweden was the first to use balloons to aid a cable system in the yarding of logs. Since that initial test in 1956 many operations have used a balloon for logging (Garliki and Richenhaller).

FIG. 9. Raven 530K Balloon.

Up to this time, balloon systems have been combinations of cable systems with a stationary yarder and a helium balloon. The shape of the balloon has varied from the aerodynamic or barrage shape used in the initial trials, to the natural onion-shape balloon used today.

The major reason for the use of the balloon with the cable-logging system is to provide lift at increased yarding distance and reduce substantially access cost and environmental impact. Balloon systems overcome the constraints of topography and cable deflection to increase yarding distances beyond that of conventional systems into the 3,000 to 5,000-foot range.

The standard balloon used in logging is the 530,000 cubic foot natural-shaped balloon (Figure 9). Three of the four balloon operations in the United States use a Washington 608A Yarder (Figure 10). It is available on a special-order basis at a cost of approximately $500,000. This yarder has three drums (haulback, mainline and strawline), with planetary interlock between the haulback and mainline. Specifications for both the balloon and yarder are shown in Appendix II.

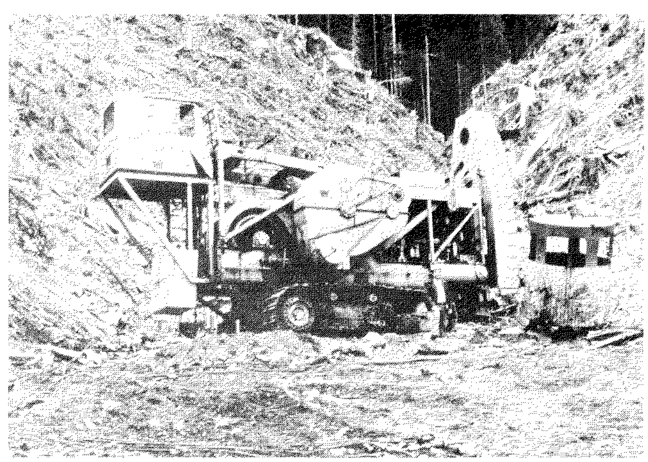


FIG. 10. Washington 608A Balloon Yarder. Note gondola at right.

A road system along valley bottoms will provide balloon landing points in most cases. The study area tends to have rounded ridges, however, where the timber is not accessible to the balloon from below. In these cases, ridge-top hauling roads are necessary for conventional highlead yarding. In other cases, deflection may be adequate for balloon yarding, but crew transport for felling and rigging is inadequate, even though the yarding crew can be transported using a gondola suspended under the balloon. Here, it may be necessary to build ridge-top roads of non-hauling standard for access purposes during and after harvesting.

The landing for a balloon can vary in size between a widening in the road to an area 200 feet square. Larger landings are convenient (as they are in most cable systems) because they give ample room for manoeuvering equipment. Major earth-moving is seldom required when landings are at the foot of the hill or in the valley bottoms, as are most landings.

A bedding-down area near the logging site is required for initial inflation, routine maintenance, inspection, shelter, and for storage of the balloon. This area is in a clearcut where no trees will tangle with the balloon or lines. The area (approximately one acre in size) is generally surfaced with gravel or shot rock. Buried deadmen, stumps, or other anchors can be used as attaching points for the balloon handling lines. The balloon is anchored at the bedding-down area during storms.

A hold-down tractor (Figure 11) is necessary to transport the balloon between the bedding-down area and the logging site. For long-distance moves, the tractor can be transported on a low-bed truck. The tractor is equipped with a twin-spool winch to hold the balloon while each of the balloon's handling lines are being transferred. Supplementary helium is needed to supply the balloon throughout the operating season. Standard maintenance vehicles are also necessary, along with a front-end loader or skidder to keep the drop area clear at all times.

FIG. 11. Balloon hold-down Cat with double winch.

Three rigging configurations have been used for balloon logging. Balloon highlead (Figure 12) is simply an addition of the balloon to the standard highlead system. Inverted skyline (Figure 13) is a reversed version of the "shotgun" system. (This is a non-balloon skyline system for uphill yarding only, depending on gravity for the return of the empty rigging.) The balloon is used to return the carriage and tagline to the bush. The 'Yo-Yo' system (Figure 14) uses two single-drum yarders. This allows one yarder to be positioned at the top of the setting, (if accessible), reducing the length of the running lines. A fourth configuration concept is the running skyline (Figure 15). Computer simulation of this configuration — using a barrage balloon and five-drum yarder — shows that it is possible to induce extra lift at turn lift-off by using the natural drag of the balloon (Eggen, Jorgensen, 1977). These new configurations have the potential to improve efficiency and reduce cost.

For purposes of this study, only the first configuration was applied, because operating cost data were available.

4.2 System 4 Productivity and Cost

The productivity of the balloon system is based on an average cycle time of seven minutes (Peters, 1973), including road changes and an average turn volume of two cunits.

Seven productive operating hours are assumed for an eight-hour shift. The predicted shift productivity is shown by the following equation:

$$\frac{60 \text{ min/hour}}{7 \text{ min/turn}} \times 7 \text{ hr/shift} \times 2 \text{ cunits/turn}$$
$$= 120 \text{ cunits/ shift}$$

Estimated operating costs for a balloon operation are given in Appendix III and include a log loader.

4.3 System 4 Results of Paper Plan

Road Access

A total of 19.4 miles of road was necessary to access the 3,652 acres planned for the balloon

FIG. 12. Balloon, Highlead System.

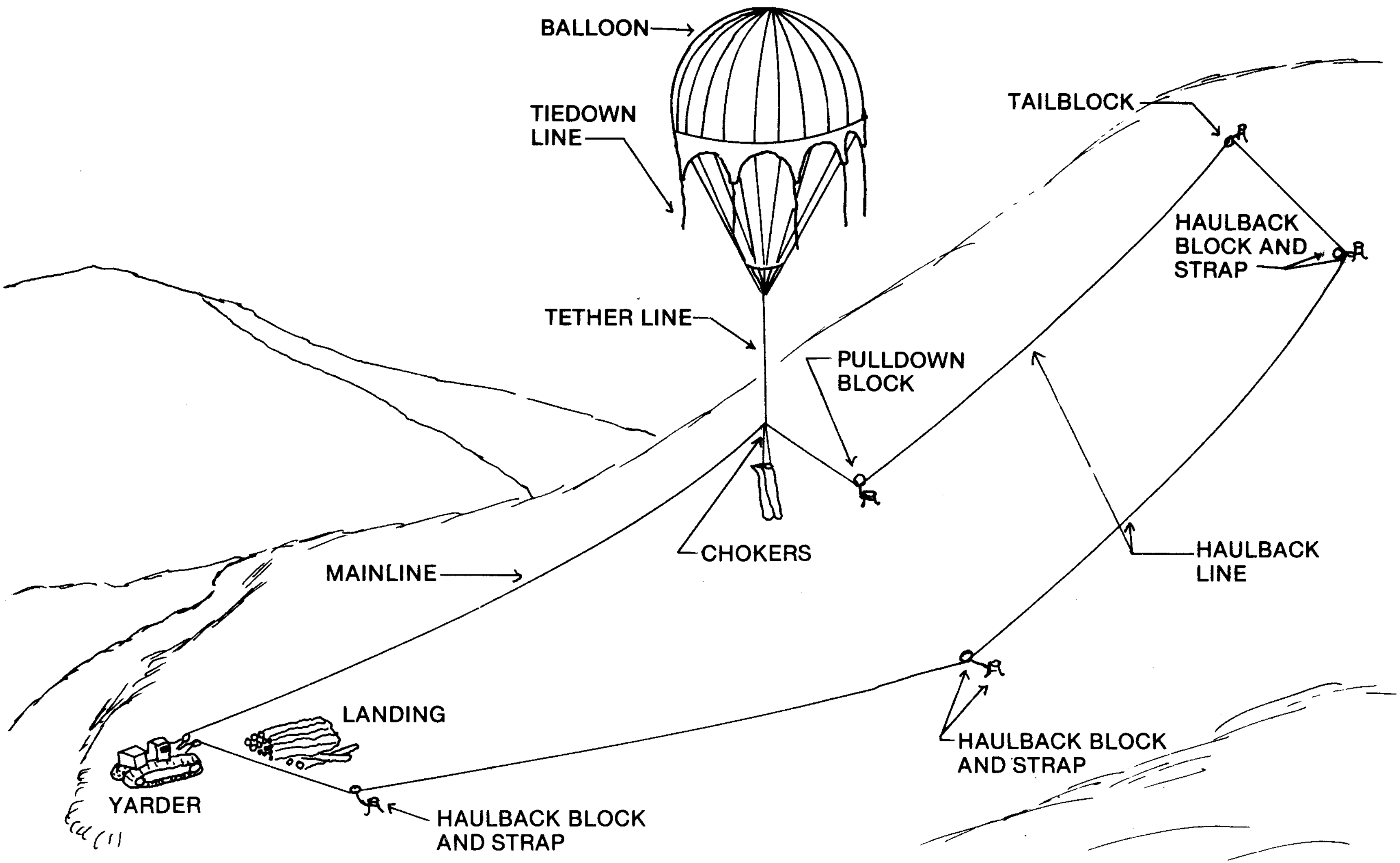


FIG. 13. Balloon, Inverted Skyline System.

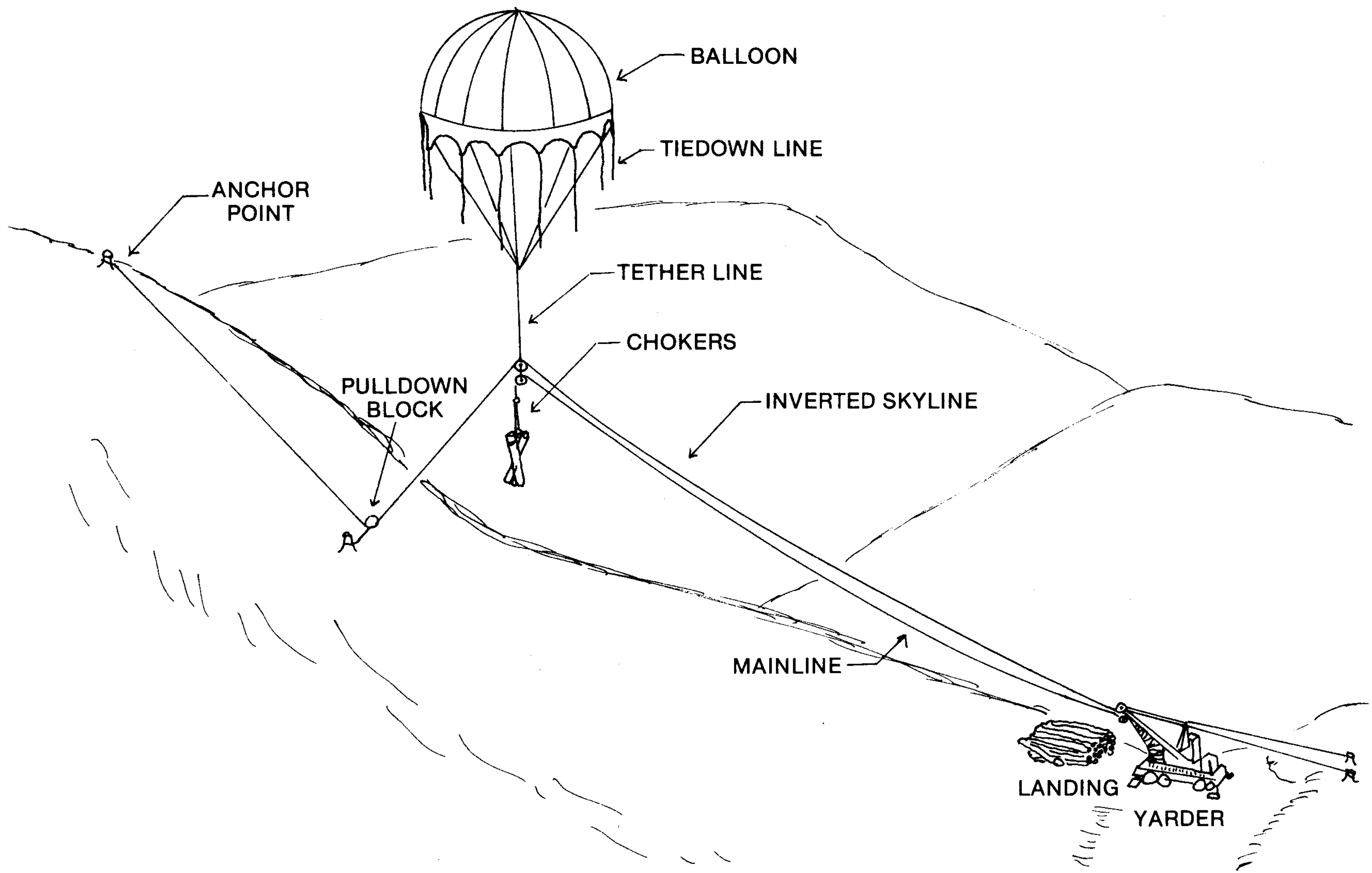


FIG. 14. Balloon, Yo-Yo System.

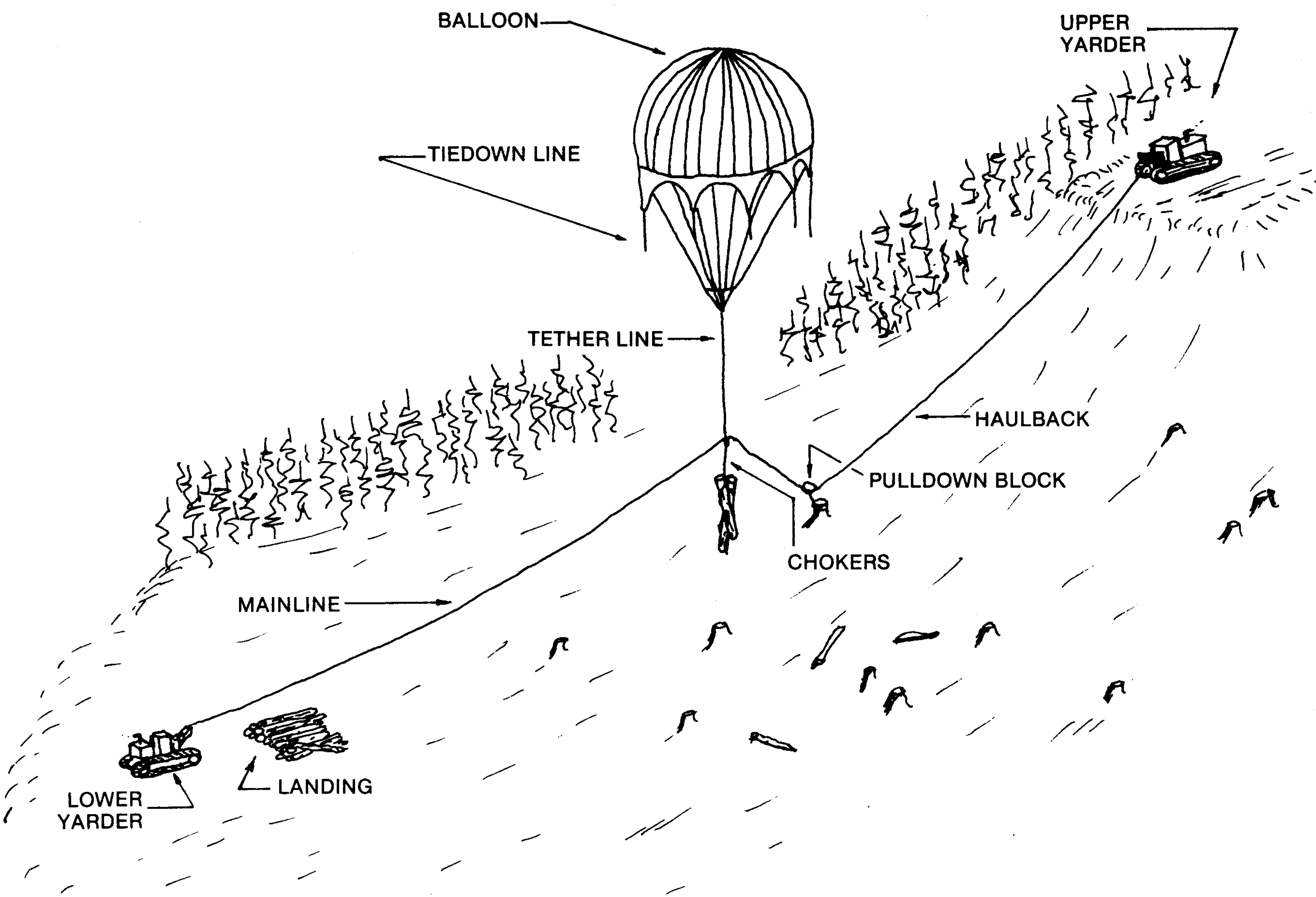
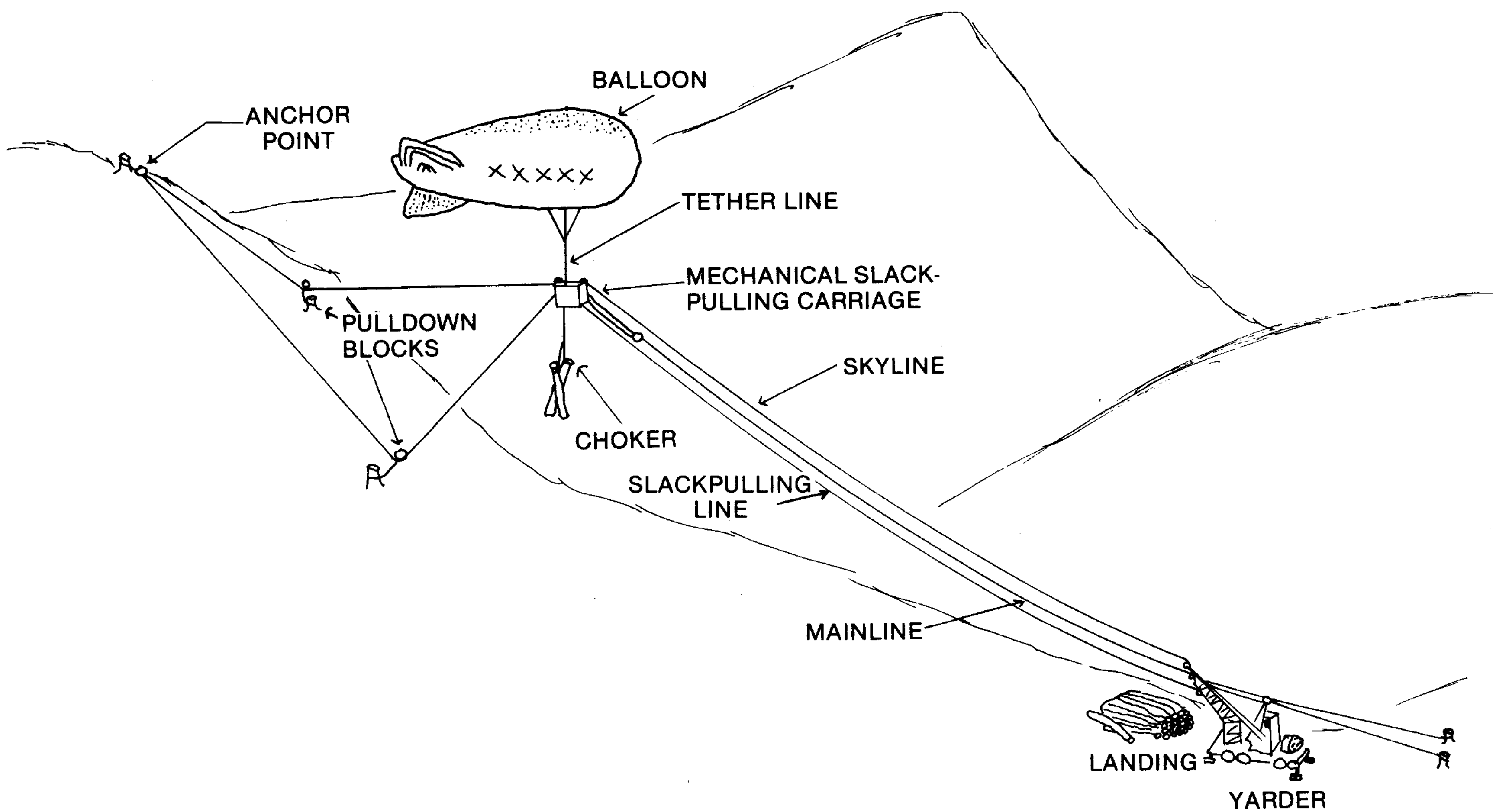


FIG. 15. Balloon, Running Skyline.



system. Ridge-top haul roads were found necessary as explained above. Cost of landings and bedding-down areas was included in road construction cost. Cost of road access is $2.92 per cunit. Average cost per mile is $57,231. Table 16 is a tabulation of length of road by road standard.

TABLE 16. LENGTH OF ROAD FOR THE THREE ROAD STANDARDS (BALLOON).

Road Class	Length (miles)
3	7.4
4a	2.2
4b	9.8
	19.4

Falling

Of the total 3,652 acres, 1,522 acres were over 700 feet from road access. Applying the falling rates, we found that the falling cost is $5.14 per cunit.

Yarding

Four methods of yarding were used: highlead spar; mobile grapple; direct loading right-of-way logs; and the balloon. The balloon yarded 1,504 acres. The remaining 2,148 acres were yarded conventionally. Yarding cost for the 3,652 acres is $15.07 per cunit.

Loading

Total loading cost was estimated to be $3.71 per cunit. A front-end loader was required continuously at the balloon landing to keep it clear.

Hauling

Hauling cost, calculated using the productivity and cost formula in Appendix IV with a 1.8-hour delay factor, resulted in an estimated hauling cost of $6.29 per cunit. The average hauling distance is 13.05 miles.

4.4 System 4 Summary of Costs

Table 17 gives the summary of direct costs for the five activities using the balloon system.

TABLE 17. SYSTEM 4 – TOTAL LOGGING COST SUMMARY.

Road access		$ 2.92/cunit
Falling		5.14/cunit
Yarding		15.07/cunit
Loading		3.71/cunit
Hauling		6.29/cunit
	Total:	$33.13/cunit

It would cost $33.13 per cunit to apply the balloon system on the study area. Cost of the yarding phase is significantly higher than for Systems 1, 2, and 3. In areas where ridge-top roads are unnecessary, the overall cost of the balloon system would be more competitive.

SYSTEM 5: HEAVY-LIFT FREE-FLYING VEHICLES

5.1 System 5 Concept

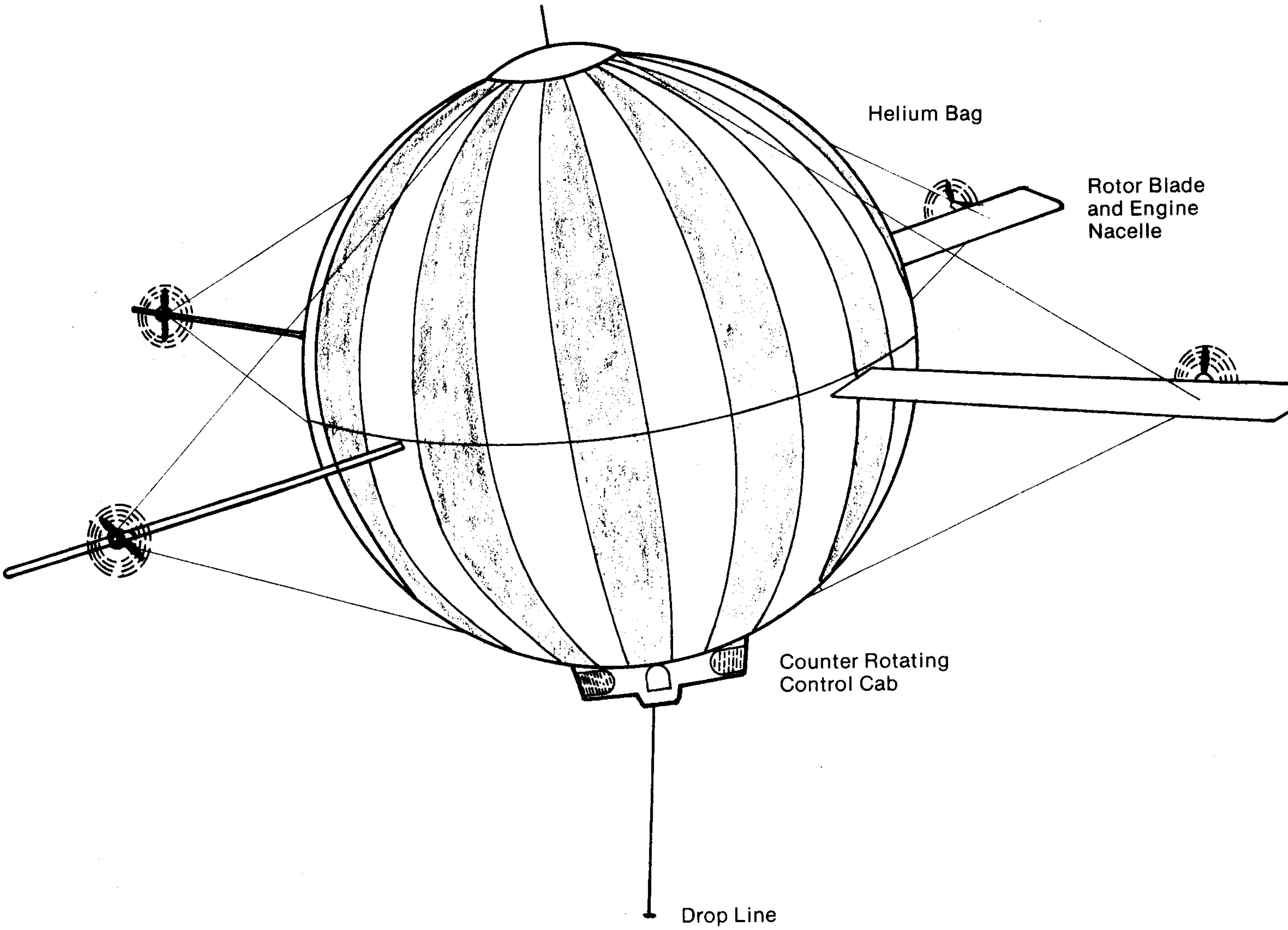
Giordano (1971) estimated that 15 percent of British Columbia's high-grade timber inventories was in scattered stands of timber considered to be inaccessible by traditional harvesting systems because of the high development costs involved. Even if high costs were tolerable, many of these areas are physically inaccessible at any cost, or would suffer massive erosion if subjected to normal road development. For these reasons, a free-flying vehicle would attract interest if it could transport logs efficiently from the stump to existing roads or to salt water.

Initially this study was planned to include helicopter logging. Earlier logging experiments proved they could lift logs directly off the ground with very little soil disturbance. This application is useful for harvesting scattered stands of timber without secondary road construction. These are features which readily meet forest management, silvicultural and aesthetic objectives.

However, helicopters have definite physical limitations when used for logging. One of these is weather. Winds in excess of 30 miles per hour — or downdrafts — may stop yarding. Visibility should be further than 2,000 feet, and both elevation and temperature will have a critical effect on the lifting capacity of the helicopter. It may well be that weather is a free-flying vehicle's greatest handicap in logging. The normal costs per cunit are critical enough when the machine can operate full time but become prohibitive when flying time is restricted by weather.

Another severe limitation on helicopters applied to date is their low production relative to costs. High owning and operating costs make helicopter logging difficult to justify except where conven-

FIG. 16. Artist's Conception of the Aerocrane.



tional development costs would be extremely high. O'Lone (1971) reported yarding costs of $60 per MFBM (approximately $33 per cunit) from initial trials in the Plumas National Forest with an S64-E helicopter. The cost of conventional yarding in the same area was estimated at $7.45 per MFBM (approximately $4.09 per cunit). Putting it another way, $52.55 per MFBM ($28.88 per cunit) could have been spent on roads and the roads would have been available for future use. High costs for the helicopter were generally attributed to the inherent complexity of the machine, the necessity for a highly-trained crew, and the quantity of fuel needed. This high cost has limited the potential use of the helicopter to harvesting very high-value timber stands.

It was also found that the helicopter has a low overload tolerance; overloading resulted in aborting the turn, substantially increasing cycle time and risk of accident.

Stevens and Clarke (1974) outlined some safety considerations for helicopter-logging operators. They noted such factors as static charges in the tagline; the gyration of the load at lift-off; the need for twin engines in case of engine failure; the load release system; rotor clearance; cable snap-back; pilot fatigue; and keeping personnel clear of the helicopter and its flight path.

After reviewing the performance of helicopter logging operations, we decided against including helicopter logging as a possible system in this study. Instead, we included a theoretical analysis of a new heavy-lift free-flying machine called an Aerocrane (Figure 16) which may profitably combine the advantages of the balloon and helicopter systems. The Piasecki Aircraft Corporation Helistat, also in the initial development phase, is an attempt to achieve similar results. Figure 17 is a photograph of a scale model in early testing stages.

The Aerospace Corporation (acting for the United States Department of Agriculture Forest Service) published a report in 1973 offering considerable potential for such a heavy-lift device in the logging operation, although they did not actually promote the Aerocrane as being the optimal design.

The second evaluation, *A comparative analysis of conventional logging in difficult areas,* published by All American Engineering Company, found that a profit could be generated by using a 50-ton Aerocrane in an area where conventional logging would result in a loss. Care was taken in this report to emphasize that the Aerocrane system had not yet been proven under actual field conditions for forest harvesting.

Although the Aerocrane must be regarded as only a concept not yet tested at any logging site, we have included a projection, based on assumed performance and cost characteristics, for comparison with other systems. If a machine and system can be developed to conform with the projections, the results would be encouraging.

The Aerocrane concept was developed in 1972 from All American Engineering Company investigations into expanding vertical lift capabilities beyond those of the helicopter, up to 50-100 tons of sling load. The logging machine postulated for this study would have a lesser sling capacity of 16 tons.

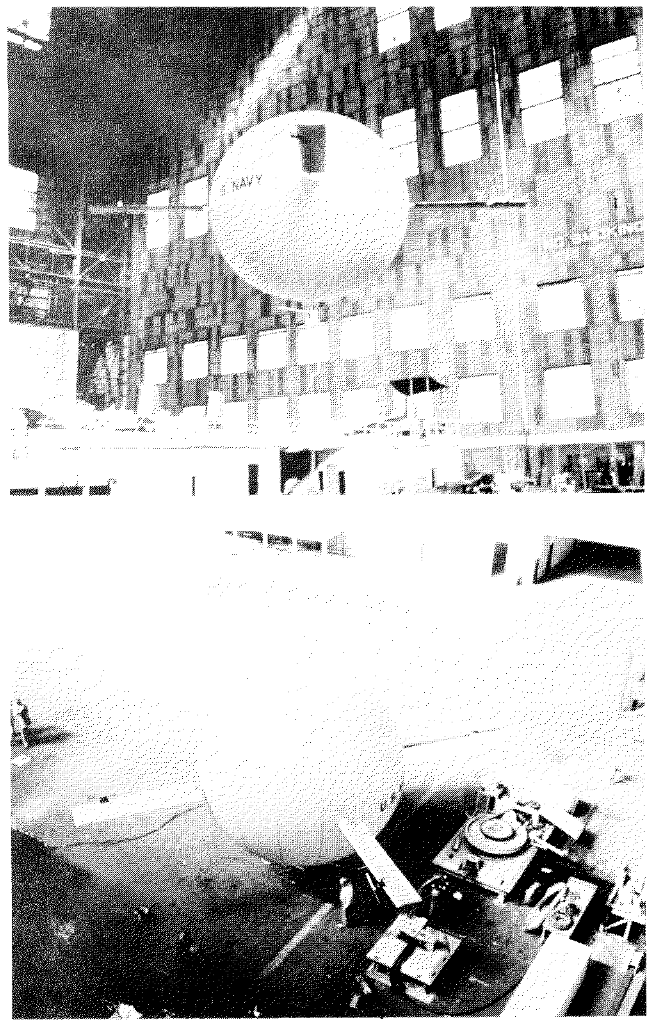
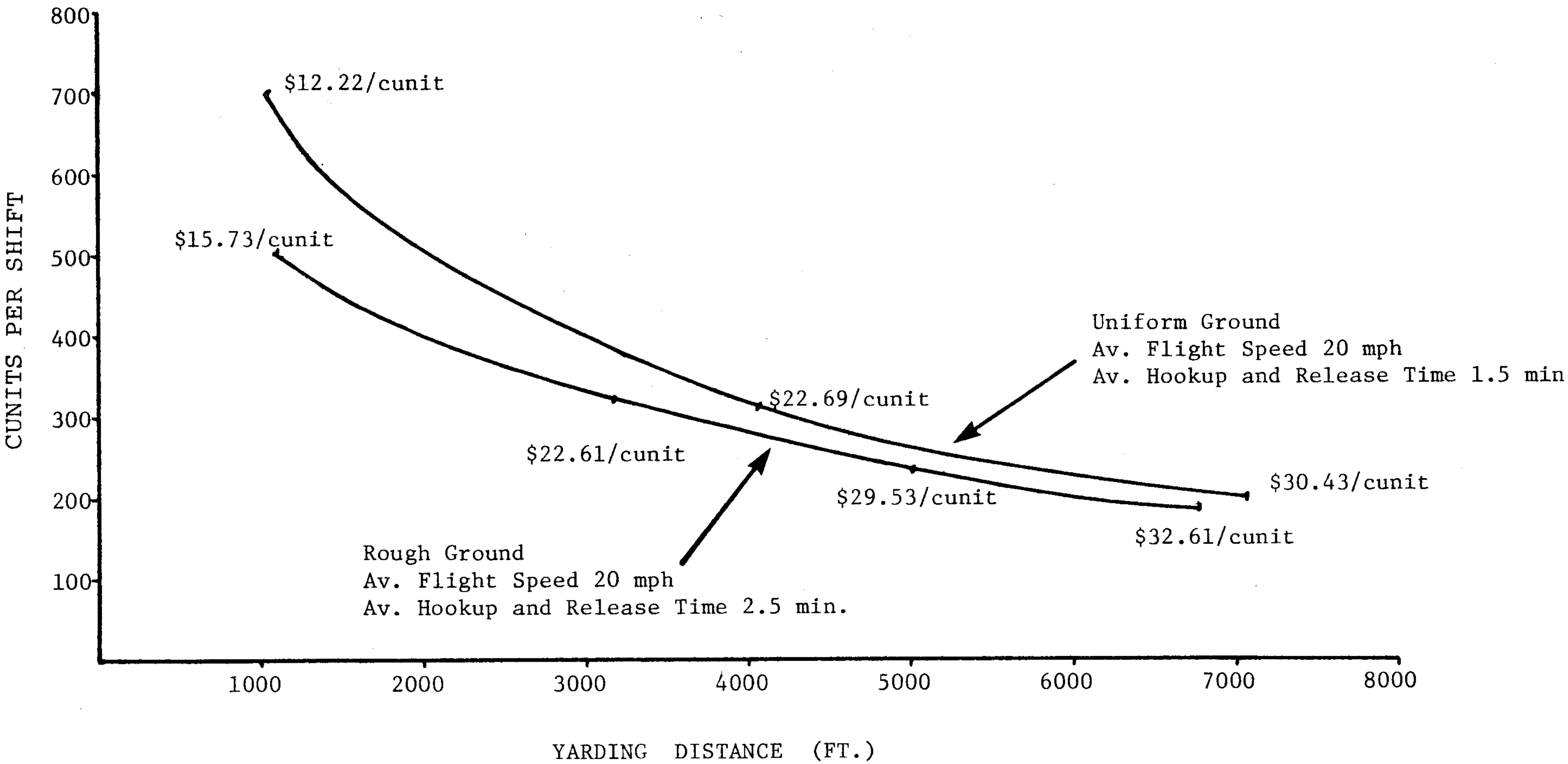


FIG. 17. Scale Model of Aerocrane undergoing tests in 1977.

5.2 System 5 Specifications

Projected Aerocrane specifications (Appendix II) describe a helium-filled central sphere acting as a support structure for a large rotor system. An engine would be located on each rotor blade toward the outer wing tip. Static lift would be

FIG. 18. AEROCRANE PRODUCTIVITY AND COST PER CUNIT; UNIFORM AND ROUGH GROUND.



generated by the helium, and dynamic lift by the movement of the wings through the air in rotation of the total vehicle. The static lift produced by the helium would represent 100 percent of the vehicle's structure weight, plus approximately 40 percent of the designed payload capacity. Rotation speeds would be on the order of 10 revolutions per minute. The control cab would be suspended below the centre body and would counter-rotate to preserve directional orientation of the pilot.

An Aerocrane would achieve horizontal motion in the same manner as a helicopter — by varying the attack angle of the rotor blades. The average horizontal speed of the Aerocrane is estimated at approximately 20 miles per hour (for the purposes of this study).

5.3 System 5 Operation

Our projections so far show that the operation should be the same as for the helicopter. Turns would be made up of whole trees or logs approaching the design payload of the vehicle. Preset chokers would be attached to a tagline suspended from the vehicle, and the turns would then be flown to the landing areas. The chokers can then be returned to the bush by the Aerocrane or by a small support helicopter. Several bush crews would be required to work in different locations throughout the logging area so that the vehicle would have a continuous supply of preset turns. Similarly, several landings and landing crews would operate simultaneously to accommodate peak log deliveries by one Aerocrane over short distances. Table 18 illustrates the variations in woods and landing crew sizes which might be required for various operating ranges. Crew size could be more balanced than indicated since there would be opportunities to combine short and long flights at any one time.

There would undoubtedly be special operational safety considerations for the Aerocrane as there are for the helicopter. There may still be the problems of static charge in the tagline; gyration of the load at lift-off; rotor clearance on steep sidehills; cable snap-back and pilot fatigue.

Certain physical problems need further investigation; one of these is spotting the hook accurately and allowing the hooker time to get into the clear, especially on rough terrain.

5.4 System 5 Ground Facilities

It is evident that longer yarding distances and the isolated nature of the harvested stands of timber would make some crew transport planning necessary. It might be possible to transport the bush crews and fallers in a personnel "pod" carried by the heavy-lift vehicle. Ridge-top access roads may be necessary to meet requirements for emergencies and for stand management after harvesting. Landings would have to be adequate to handle the expected production of the system, and they would normally be at a lower elevation than the logging site, to take advantage of gravity.

TABLE 18. GROUND CREW REQUIREMENT FOR AEROCRANE SYSTEM.

Yarding Distance (feet)	Landing Crews No. of crews-men/crew	Woods Crews No. of crews-men/crew	Total Ground Personnel
Good Terrain			
700 – 1,400	4 x 3	3 x 3	21
1,400 – 2,200	3 x 3	3 x 3	18
2,200 – 2,400	3 x 3	2 x 3	15
2,400 – 5,700	2 x 3	2 x 3	12
5,700 – 6,100	2 x 3	1 x 3	9
6,100 – 8,000	1 x 3	1 x 2	5
Rough Terrain			
700 – 1,500	3 x 3	3 x 3	18
1,500 – 4,800	2 x 3	2 x 3	12
4,000 – 5,300	2 x 3	1 x 3	9
5,300 – 8,000	1 x 3	1 x 3	6

5.5 System 5 Ground Support

Support equipment would have to include a helium supply and fuel supply trailers, service vehicles, parts storage and shop buildings. Front-end loaders of sufficient capacity and number to handle the produced volume would be needed to keep the drop area clear. These machines would also sort, pile and help in bucking the logs. A small light-duty helicopter might also be used for crew transport, return of chokers and other administrative needs.

To repair and maintain the Aerocrane, there would have to be adequate mooring in close proximity to the logging area, with the capability to hold the vehicle down during adverse weather conditions. There would be a portable maintenance shop in the mooring area with spare parts storage and a place for refueling the vehicle. Engine servicing would be accomplished by tipping the vehicle, bringing one wing and engine at a time to the ground.

5.6 System 5 Productivity and Cost

As the Aerocrane concept is only at the scale-model level of development, all costs and production predictions are approximations based on published studies of helicopter logging.

An average payload of 16 tons (maximum about 23 tons for some loads) is projected for the Aerocrane considered in this report. At 60 pounds per cubic foot, loads would average 5.3 cunits, allowing tree-length handling of smaller timber and normal log-lengths for larger pieces.

Figure 18 shows estimated productivity and cost per cunit, for uniform or rough ground and for yarding distances between 700 and 8,000 feet. The decreased productivity on rough ground reflects the increased difficulty of assembling turns, and the time needed for the hooker to get clear before lift-off. Average hookup and release times are 1.5 minutes on uniform ground and 2.5 minutes on rough. Average flight time is 20 miles per hour. Productive time, after allowances for refueling and choker return, is estimated at 360 minutes per 8-hour shift.

Shift costs for all elements of the Aerocrane system are developed in Appendix III.

5.7 System 5 Results of Paper Plan

Road Access

To access the 43 landings for the heavy-lift free-flying vehicle, 8.3 miles of road was necessary. Landings were costed at $2,550 each. In addition to the main access roads, a low-standard 4-wheel drive quality ridge-top access road (costing $181.50 per 100 feet, and 15,000 feet in length) was considered necessary.

Construction costs are shown in Table 19.

Table 20 is a tabulation of road lengths for the three road standards.

The area accessed is 3,400 acres, or 408,000 cunits, working out to a development cost of $1.51 per cunit. The low development cost reflects the use of segments of the existing road network as landing locations, and the over-flying of areas previously harvested. Average cost per mile for haul road construction was $56,428.

TABLE 19. ROAD COST FOR HEAVY-LIFT VEHICLE.

Haul Road Construction	$468,357
Ridge Access Road Construction	27,225
Aerocrane Landings	109,650
Conventional Landings	14,031
Total:	$619,263

Falling

Of the total 3,400 acres, 1,606 acres were over 700 feet from road access. Applying the falling cost assumptions, we found the average falling cost was $5.20 per cunit.

TABLE 20. LENGTH OF ROAD FOR THE THREE ROAD STANDARDS (HEAVY-LIFT VEHICLE).

Road Class	Length (miles)
3	5.1
4a	0.7
4b	2.5
	8.3

Yarding

Of the total 3,400-acre area, 1,160 acres were logged conventionally. Yarding distance in this 1,160-acre area was limited to 700 feet, and methods employed were highlead spar, grapple yarder and direct loading of right-of-way logs. The remaining 2,240 acres was logged by Aerocrane.

Table 21 is the summary of acres yarded and average costs per cunit.

TABLE 21. SUMMARY OF AREA YARDED AND AVERAGE COST PER CUNIT.

	Acres Yarded	Cost $/Cunit Average
Conventional Yarding	1,160	8.89
Aerocrane	2,240	15.63
	3,400	($13.33)

Average yarding cost was $13.33 per cunit for the map area.

Loading

Table 22 is a summary of the loading costs.

TABLE 22. LOADED VOLUMES AND AVERAGE COST PER CUNIT.

	Volume (cunits)	Cost $/Cunit (average)
Loading for conventional logging	139,200	2.95
Loading for Aerocrane logging	268,800	1.57
	408,000	($2.04)

The loading cost for the conventional yarding was estimated in the same manner as for the highlead analysis. The loading cost for timber yarded by the Aerocrane is based on a shift cost of $393.36 for a front-end loader and operator, and a capacity to load 250 cunits per shift. High availability of logs on the landings would permit economics of scale in the loading phase.

Hauling

Table 23 summarizes the factors and resulting cost of hauling the harvested timber from the landings to the log dump, using the productivity and cost formula in Appendix IV.

TABLE 23. HAULING DATA FOR HEAVY-LIFT VEHICLE.

System	Volume (cunits)	Delay Factor	Cost $/Cunit (average)
Conventional	139,200	1.8 hours	6.34
Aerocrane	268,800	1.2 hours	5.01
	408,000		($5.46)

The average hauling cost of $5.46 per cunit represents an average haul distance of 12.61 miles.

5.8 System 5 Summary of Costs

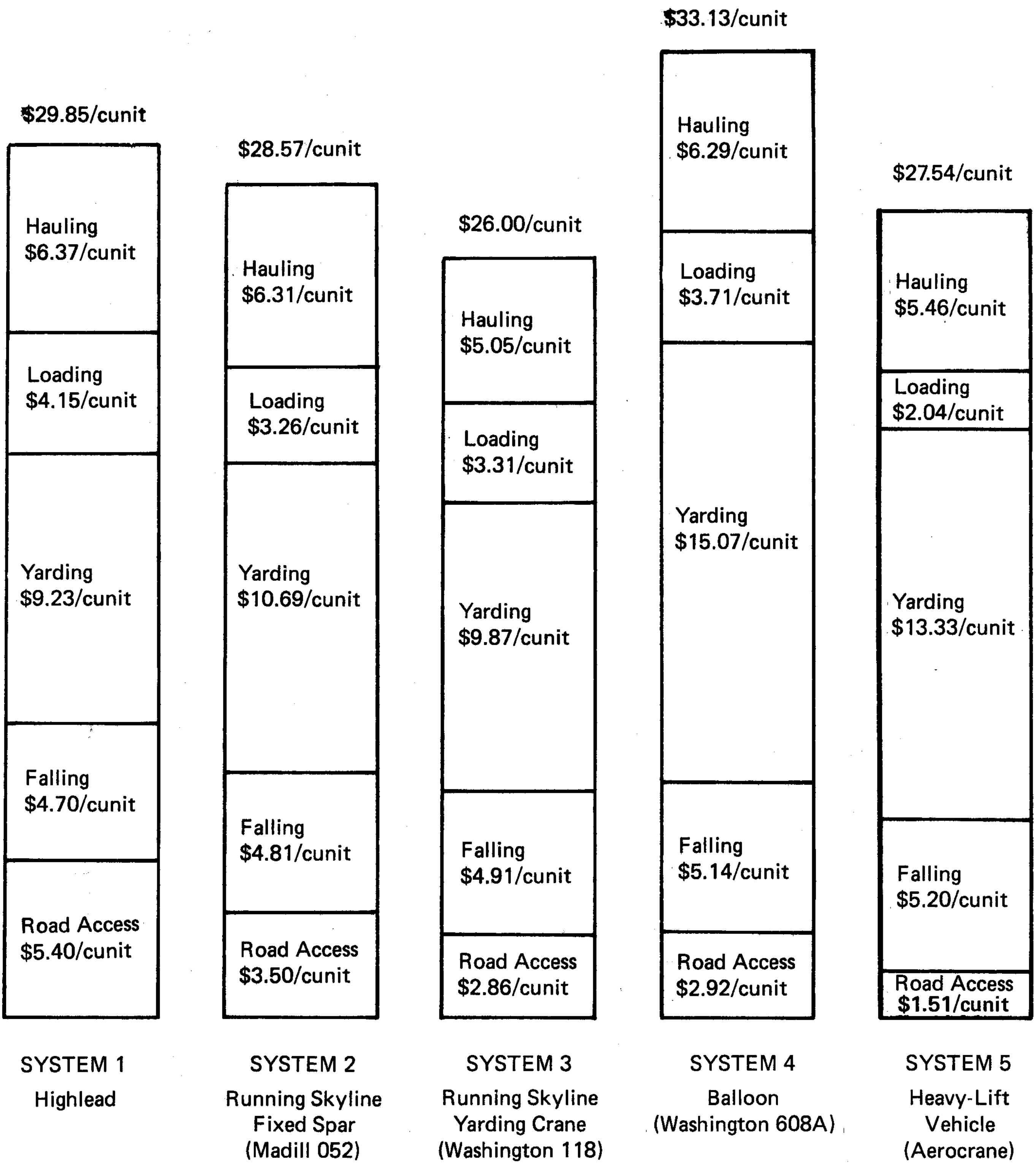
Table 24 gives the summary of costs for the five activities calculated for the heavy-lift free-flying vehicle.

TABLE 24. SYSTEM 5 – TOTAL LOGGING COST SUMMARY.

Road Access		$1.51/cunit
Falling		5.20/cunit
Yarding		13.33/cunit
Loading		2.04/cunit
Hauling		5.46/cunit
	Total:	$27.54/cunit

Based on these projections, it would cost $27.54 per cunit to apply the Aerocrane system on the study area.

FIG. 19. COST COMPARISON OF THE FIVE YARDING SYSTEMS.



Portion of study area logged by "Main" system									
68%		32%		93%		41%		66%	

DISCUSSION OF RESULTS

Figure 19 summarizes the per-cunit costs derived for each system. Per-cunit costs for road access (including landings), falling, yarding, loading, and hauling are shown side by side, together with their summations. Cost of yarding alone is cheapest with highlead (System 1), but total system cost is lower than highlead for every other system except the balloon (System 4).

Two features of this study must be remembered in comparing the results. First, while every effort was made to impart realism through the use of the best available productivity and cost information, plans may change in actual logging operations. Second, all results are specific for the study area chosen. On different areas, factors like the distance from valley bottom to ridge-top (or timber line) might alter the effectiveness of any one system profoundly. Computer programs capable of rapid simulation on any new area would be a powerful tool for preliminary choice of logging systems.

Road Access Costs

As expected, systems with longer yarding distance permit lower per-cunit costs for road access. Road costs are lowest with the Aerocrane (System 5), at $1.51 per cunit, and highest with highlead (System 1), at $5.40 per cunit.

Differences in road cost result from the mileages required, the density and kinds of landing areas needed, the proportions of the various classes of road needed, and the locations of roads in relation to terrain. The ways that these factors interact are reflected in Table 25, which shows the mileages by road class, the haul road costs, and the cost of landings and non-haul access roads for each system. In general, the four long-reach systems contrast with highlead (System 1) by permitting reduced road mileages, especially of Class 4(b). As an extreme example, the total access cost for the heavy-lift vehicle (Aerocrane) system is about one-quarter of that for highlead.

Special features of each system follow:

System 1 (Highlead, roads $5.40 per cunit)

By a wide margin, this system required more roads and landings, with higher per-cunit road access costs than any other system. The proportion of lower standard Class 4(a) and 4(b) roads was the highest, but contrary to normal expectations, these roads and associated landings would cost more per mile than Class 3 roads and landings since the latter tend to occur on lower slopes with moderate terrain.

System 2 (Running Skyline with Fixed Spar, roads $3.50 per cunit)

As with System 3, mid-slope roads on steep and unstable terrain were required for this system. Some flexibility in their location between landings reduced costs per mile of road, but this advantage was more than offset by the need for excavated landing sites on steep ground.

System 3 (Running Skyline Yarding Crane, roads $2.86 per cunit)

This system incurred the second lowest road cost per cunit, but cost per mile was the highest. This was because considerable Class 4(a) and 4(b) hauling road was required. These roads for the yarding crane must provide adequate deflection throughout their length, rather than merely at discrete landings, as in the use with fixed spar (System 2) or highlead (System 1). This means that the System 3 road must be located more rigidly, and cannot avoid local rock or slide areas. Despite the high road cost per mile the elimination of landings resulted in a low development cost per cunit for System 3.

System 4 (Balloon, roads $2.92 per cunit)

The presence of hidden timber on rounded ridge tops made it impossible to take full advantage of the road-saving features of the balloon system on the study area. If all slopes had been straight or concave up to the timber edge, auxiliary highlead operations on ridge-tops would have been unnecessary, and road costs would have compared more favourably with those of other systems.

System 5 (Aerocrane, roads $1.51 per cunit)

Since the Aerocrane is free-flying, almost all roads and landing points are of high standard, and located on relatively moderate terrain in valley bottoms. The lowest road access cost of all systems results. This cost includes some access roads for fallers and for auxiliary highlead yarding, but these are less extensive than for the other systems (indeed it might become necessary to build additional access roads after logging, for forest management and other purposes).

Of the five systems compared, the three which exhibit the least road cost would also create the least

TABLE 25. COMPARISON OF ACCESSING COSTS FOR THE FIVE YARDING SYSTEMS.

System	Miles of Road: Road Class 3	4a	4b	Total Miles	Average Cost/Mile ($)	Total Haul Road Cost ($)	Total Landing & Access Road Cost ($)	Total Development Cost ($)
1. Highlead	7.8	8.7	18.4	34.9	59,250	2,067,818	298,678	2,366,496
%	22	25	53	100				
2. Running Skyline (Fixed Spar)	7.9	5.7	10.9	24.5	53,695	1,315,528	207,482	1,523,010
%	32	23	45	100				
3. Running Skyline (Yarding Crane)	6.6	2.9	10.0	19.5	62,691	1,222,478	–	1,222,478
%	34	15	51	100				
4. Balloon	7.4	2.2	9.8	19.4	57,231	1,110,311	169,350	1,279,661
%	38	11	51	100				
5. Heavy-Lift Vehicle	5.1	0.7	2.5	8.3	56,428	468,357	150,906	619,263
%	62	8	30	100				

environmental disturbance. Not only are there fewer roads, but also run-off water can be dispersed, rather than concentrated in the fan-shaped yarding roads created when logs are dragged downhill to central spar locations.

Falling Costs

Under the falling cost assumptions made, cost increased with increased yarding distances. It must be noted, however, that in all the long-yarding systems the maximum distance from road access was approximately 1,800 feet. To realize this standard, the four-wheel drive access road was included in the heavy-lift free-flying vehicle plan. If such an access road is not provided, falling costs will be higher. Resulting per-cunit falling costs are shown for all systems in Figure 19.

Yarding Costs

The yarding costs represent a weighted average after combining all yarding methods used in each system. In each case, the area was planned to utilize the main yarding system to the fullest extent feasible, but to supplement this with grapple-yarding or highlead where the main system was judged inapplicable. The extent to which the main system could be applied is shown in Figure 19 (bottom line). Only 32 percent of the area could be yarded by the main system in System 2, while the main system could be applied over 93 percent of the area in System 3 (Running skyline with yarding crane). While the planning and engineering requirements of System 3 are strict, the need to integrate main and auxiliary yarding systems is minimized. This advantage would be of practical significance in day-to-day operating.

Yarding cost alone is lowest with right-of-way, grapple and highlead. The use of these methods as an auxiliary therefore reduces yarding costs, although it generally increases road access costs and total system costs. For example, yarding with the balloon costs $23.50 per cunit (based on Appendix III total less loading costs). The final yarding cost, $15.07 per cunit, for System 4 (Balloon) is a much-reduced weighted average resulting from utilizing right-of-way, grapple and highlead yarding over 59 percent of the area, while only 41 percent is balloon-yarded. Production estimates for the highlead and running skyline with fixed spar are based on the local operator's background data. The production data for the running skyline with yarding crane is based on limited field observations with a machine in operation.

The production figures for the balloon system were based on an operation carried out in 1973. Since then, the balloon system has undergone little change or development and has been generally described as needing improvement to reach full operating potential. With alterations to the system such as increased yarding speeds, automatic flight path control and better balloon shape, productivity should increase (Jorgensen, 1975). The cost effectiveness of any new design will require expensive operation testing.

The production and cost estimates for the heavy-lift free-flying vehicle are based on the best theoretical information available but may be considered open to further discussion. If a free-flying vehicle can be built to meet these cost and performance specifications it will be a valuable tool for the forest industry.

As yarding equipment becomes more expensive, the need for continuously high production will become critical. High-quality engineering, planning, close supervision and experienced crews are necessary. Crew acceptance of a long-reach yarding system will require some adjustments. Field personnel must be willing to work at longer distances. All of these factors have already been observed during helicopter operations where the logging system must be well planned and coordinated to minimize costly yarding delays.

The importance of engineering layout for the long-reach systems is obvious. Adequate deflection by proper landing, road and back-line placement is needed or the anticipated production and cost advantages will not be achieved.

Loading Costs

The loading cost reflects the interaction of the yarding system with the loader. Systems which cannot utilize the full productivity of the loaders result in an increase in loading cost. The front-end loader is more efficiently used in the running skyline with fixed spar. It can be shared with other landings in this operation. (With the balloon system, the loader must be available at all times to keep the landing clear.) The low loading cost for the heavy-lift free-flying vehicle shows the saving possible if a loader can be used to capacity and is not dependent upon the yarding system for wood supply.

The loading cost reduction realized when these systems were compared to highlead can be attributed, individually or in combination, to the following factors:

(a) better quality landings, with fewer small mid-slope landings, allowing sharing of loaders;
(b) greater use of front-end loaders;
(c) higher yarding system productivity and reduced waiting time for loaders.

Hauling Costs

Hauling costs, like loading costs, depend on the availability of a sufficient supply of logs to reduce delay. In the hauling cost calculations, different loading delay factors were assumed for different systems. For instance, in the operations of the running skyline system with yarding crane and the heavy-lift free-flying vehicle, where logs can be stock-piled for loading, the average terminal time was reduced from 1.8 hours to 1.2 hours per trip.

The further effect of higher hauling speeds on better quality roads was not considered in this report. It is probable that development plans including this factor would show that trucks can reduce costs by averaging more than 16 miles per hour on better quality roads. The long-reach yarding systems, particularly the Aerocrane system, would be favoured if this were confirmed.

CONCLUSIONS

A map area of approximately 3,650 acres, typical of British Columbia coastal logging conditions, was used to compare five logging systems, including the conventional highlead system as a standard for comparison. The map-planning approach used was theoretical, permitting absolute comparability of the terrain being "logged", and yielding results long before the results of practical applications of all the systems could have been obtained.

The results of the study indicate that:

1. The highlead yarding system should no longer be given the automatic preference it has enjoyed in the past. This is primarily because this system requires an extensive and costly network of roads and landings, the cost of which may offset cost advantages in yarding itself.
2. In comparing systems, the costs of road access, falling, yarding, loading, and hauling are inseparable, and interact in complex ways in determining the total direct cost of logs at the unloading point.
3. Depending on topographic conditions, several long-reach yarding systems, including two running skyline systems, the balloon, and a free-flying vehicle, show promise as alternatives to the highlead system. Despite higher capital investment per machine and consequently higher direct yarding cost, added complexity of planning, supervision, and mechanical service, and lack of universal applicability on any area, the benefits of added reach and reduced road cost justify serious consideration of these long-reach systems.
4. On the study area, the lowest per-cunit logging costs for all cost components combined was achieved with the running skyline yarding crane (System 3). This system was capable of reducing road costs, virtually eliminating costs for landing construction, and still maintaining reasonably low costs for yarding alone. Further, the machine was found to be operable over 93 percent of the total area, requiring supplementation by other yarding equipment on only 7 percent of the area.
5. The heavy-lift free-flying vehicle (Aerocrane, System 5) closely followed System 3 in the cost comparison. To maintain this favourable position, and to replace the helicopter on logging areas where road access is costly, it would be necessary that the machine finally developed could
   - be available for at least 1600 hours per year, despite marginal coastal weather conditions;
   - be owned and operated at no more than half the hourly cost of a large helicopter;
   - display safety, manoeuvrability, and performance characteristics at least equivalent to those of the helicopter for logging.
6. Long-distance yarding systems like the Aerocrane leave fewer roads behind after logging, for use in subsequent forest management. The implications of this fact were not made a part of this study.
7. Aside from apparent cost advantages, all of the long-reach systems would tend to provide better protection of watershed and soil values, by reducing road density and by reducing the impact of yarding on runoff patterns.

Logical and comprehensive assumptions were made to serve as a basis for comparisons between systems. The next step would be to reduce these into a computer program which could be applied to any new area as an aid to the decision maker.

This study shows that in the area evaluated several alternative logging systems could be considered. Although the study area is typical of coastal British Columbia, the choice of the correct system combination for a specific area requires a systematic analysis taking into account the interacting costs of all components.

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APPENDIX I

Specifications and Assumptions for Road Development

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Specifications and Assumptions for Road Development

ASSUMED ROAD CLASS SPECIFICATIONS

Road Class	Subgrade Width		Running Surface Width	
	feet	metres	feet	metres
3	24	7.2	18	5.4
4a	22	6.6	16	4.8
4b	20	6.0	16	4.8

TABLE OF SUBGRADE VOLUMES

Road Class 3.

Subgrade width: 24 ft (7.2 m)
Cut slope: 1.1

	Side Slope	Cut at C/L		Cu. Yd./*	Cu.m/*
	%	ft	m	10 ft	m
66% of Subgrade on Cut	40	1.6	.18	38	9.5
	45	1.8	.54	42	10.5
	50	2.0	.60	48	12.1
	55	2.2	.66	57	14.3
	60	2.4	.72	72	18.1
	65	2.6	.78	72	18.1
100% of Subgrade on Cut	70	8.4	2.5	75	18.8
	75	9.0	2.7	80	20.1
	80	9.6	2.9	85	21.3
Rock: Vertical Cut Slope	85	10.2	3.1	91	22.9
	90	10.8	3.2	96	24.1

*Excavated volumes differ from theoretical calculated values due to the assumed digging characteristics of the grade shovel.

Road Class 4a.

Subgrade width: 22 ft (6.6 m)
Cut slope: 1.1

	Side Slope	Cut at C/L		Cu. Yd./*	Cu.m/*
	%	ft	m	10 ft	m
66% of Subgrade on Cut	40	1.4	.42	28	7.0
	45	1.6	.48	32	8.0
	50	1.8	.54	39	9.8
	55	1.9	.57	51	12.8
	60	2.1	.63	66	16.6
	65	2.3	.69	66	16.6
100% of Subgrade on Cut	70	7.7	2.3	63	15.8
	75	8.2	2.5	67	16.8
	80	8.8	2.6	72	18.1
Rock: Vertical Cut Slope	85	9.3	2.8	76	19.1
	90	9.9	3.0	81	20.3

*Excavated volumes differ from theoretical calculated values due to the assumed digging characteristics of the grade shovel.

Road Class 4b.

Subgrade width: 20 ft (6.0 m)
Cut slope: 1.1

	Side Slope	Cut at C/L		Cu. Yd./*	Cu.m/*
	%	ft	m	10 ft	m
66% of Subgrade on Cut	40	1.3	.39	21	5.3
	45	1.5	.45	29	7.3
	50	1.6	.48	33	8.3
	55	1.8	.54	42	10.5
	60	2.0	.60	51	12.8
	65	2.1	.63	51	12.8
100% of Subgrade on Cut	70	7.0	2.1	52	13.1
	75	7.5	2.3	55	13.8
	80	8.0	2.4	59	14.8
Rock: Vertical Cut Slope	85	8.5	2.6	63	15.8
	90	9.0	2.7	67	16.8

*Excavated volumes differ from theoretical calculated values due to the assumed digging characteristics of the grade shovel.

EQUIPMENT COSTS AND PRODUCTION

Subgrade Construction

a) Cable Shovel: 1 3/4 cubic yard capacity.

Excavation:

Production (cubic yards per hour)
= (Maximum Production) x (Job Efficiency Factor) x (Swing & Depth Factor) x (Bucket Fill Factor)

Maximum Production: Earth & Hard Clay 250 cu. yd./hr. (191.1 m^3/hr.)

Job Efficiency Factor: 0.52

Swing & Depth Factor: 1.00

Bucket Fill Factor: Earth & Hard Clay 0.80

Production:
250 x 0.52 x 1.00 x 0.80 = 104 cu. yd./hr. (79.5 m^3/hr.)

Cost Formula:

Total Hours
= Grubbing & Logging Hours + Excavation Hours

$$= \frac{\text{Total Stationage}}{\text{0.6 sta./hour}} + \frac{\text{(cu. yd. / sta.) x Total Stationage}}{\text{104 cubic yards/hour}}$$

Machine Rate: $72 per hour (all found)

Cost = Total Hours x Machine Rate.

b) Bulldozer and Drill.

Equipment Rate — Tank Drill (all found): $70 per hour.

Average Production: 500 ft (150 m) of drill holes in 8 hrs: Drilled, Loaded and Blasted.

Hole Size: 2 inches

Explosives: Forcite 75% and Amex II: 1 lb /ft (1.5 kg/m)

Hole Density: 10 x 50 ft (15 m) Holes per Station (one station per 8-hour shift)

Explosives used per station per 8-hr shift: 450 lb (204 kg)

Explosives cost: $60 per 100 lb (45.3 kg) all found.

Cost per Station where rock is present:

Tank Drill:	8 hr @ $70 per hr	$560
Explosives:	450 lb (204 kg) @ $60 per 100 lb (45.3 kg)	270
Misc.:		100
		$930
Bulldozer:	D8 (all found) 8 hr @ $77 per hr	616
Total cost per station:		$1,546

BALLASTING MATERIAL

Rock Cost in Quarries

Production: 2,000 solid cu. yd. (1529 m^3) in 4 days = 2,600 loose cu. yd. (1988 m^3)

Air Track (all found): $60 per hour

Explosives (all found): $30 per 100 pounds (45.3 kg)

Bulldozer D7 (all found): $52 per hour

Air Track:	32 hours @ $60 per hour	$1,920
Explosives:	2000 pounds @ $30 per 100 pounds (45.3 kg)	600
D7:	6 hours @ $52 per hour	312
Misc.:		418
Total Cost for 2600 loose cu.yd. (1988 m^3)		$3,250

Cost per cu.yd. (.764 m^3) loose: $1.25

Gravel Cost in Pits

Production: 3,300 cu.yd.

Bulldozer D7 (all found): $52 per hour

D7: 16 hours stripping @ $52 per hour	$832
Misc.	168
Total Cost for 3,300 cu.yd. (2523 m^3) loose	$1,000

Cost per cu.yd. (.764 m^3) loose: $0.30

BALLASTING ON-SITE COST

Average Haul Distance: 0.4 miles (.64 km)

Number of Trucks: 3

Truck Size: 14 cu.yd. (10.7 m^3)

Truck Haul Rate: $2.70 per cu.yd. per hr or $.794 per cu.yd. ($3.53 per m^3 per hour or $1.04 per m^3)

Trips per 8-hour Shift: 27.2 (based on experience)

Volume Hauled per 8 hours: 3 x 14 x 27.2 = 1,143 cu.yd.

Hauling Cost per 8 hours: 1,143 cu.yd. @ $.794/cu.yd. (874 m^3 @ $1.04 per m^3)	$908
Loader 966 C: 8 hr @ $42 per hr (all found)	336
Bulldozer D7: (Spreading) 8 hr @ $51.5 per hr (all found)	412
Misc.: (include culvert cost)	378
Total Equipment Cost:	$2,034

Quarried Rock

1,143 cu.yd. @ $1.25 per cu.yd. (874 m^3 @ $1.64 per m^3)	$1,429
Equipment Cost:	2,034
	$3,463

Cost per cu.yd. (.746 m^3) rock spread: $3.03

Gravel

1,143 cu.yd. @ .30 per cu.yd. (874 m^3 @ .39 per m^3)	$ 343
Equipment Cost:	2,034
	$2,377

Cost per cu.yd. (.764 m^3) gravel spread: $2.08

Adjustments for Road Gradient: Quarried Rock.

Gradient (uphill haul)	Productivity Adjustment	cu.yd./ 8-hr	m^3/ 8-hr	$/cu.yd. spread	$/$m^3$ spread
up to 7%	+10%	1,257	961	2.755	3.60
8 - 14%	0%	1,142	874	3.030	3.96
15% and greater	–10%	1,029	787	3.365	4.40

BALLASTING COST: ROAD CLASS 3

Running Surface Width: 18 ft (5.4 m)

Surfacing Material: Quarried Rock, Gravel.

Yardage: Quarried Rock - 234 cu.yd. per station (5.9 m^3/m) over shovel subgrade
108 cu.yd. per station (2.7 m^3/m) over rock subgrade

Gravel: 260 cu.yd. per station (6.5 m^3/m) over shovel subgrade

Shovel Subgrade Ballasting Cost; Quarried Rock.

Gradient (uphill haul)	$ per station	$ per m
up to 7%	644.67	21.14
8 - 14%	709.02	23.36
15% and over	787.41	25.83

Shovel Subgrade Ballasting Cost; Gravel.

Gradient (uphill haul)	$ per station	$ per m
up to 7%	491.66	16.13
8 - 14%	540.80	17.74
15% and over	rock surfacing only	

Rock Subgrade Ballasting Cost; Quarried Rock.

Gradient (uphill haul)	$ per station	$ per m
up to 7%	297.54	9.76
8 - 14%	327.24	10.73
15% and over	363.42	11.92

BALLASTING COST: ROAD CLASS 4a

Running Surface Width: 16 ft (4.8 m)

Surfacing Material: Quarried Rock

Yardage: 210 cu.yd. per station (5.3 m^3/m) over shovel subgrade
70 cu.yd. per station (1.8 m^3/m) over rock subgrade

Shovel Subgrade Ballasting Cost.

Gradient (uphill haul)	$ per station	$ per m
up to 7%	578.55	18.98
8 - 14%	636.30	20.87
15% and greater	706.65	23.18

Rock Subgrade Ballasting Cost.

Gradient (uphill haul)	$ per station	$ per m
up to 7%	192.85	6.33
8 - 14%	212.10	6.96
15% and greater	235.55	7.73

BALLASTING COST: ROAD CLASS 4b

Running Surface Width: 16 ft (4.8 m)

Surfacing Material: Quarried Rock

Yardage: 135 cu.yd. per station (3.39 m^3/m) over shovel subgrade
60 cu.yd. per station (1.5 m^3/m) over rock subgrade

Shovel Subgrade Ballasting Cost.

Gradient (uphill haul)	$ per station	$ per m
up to 7%	371.93	12.20
8 - 14%	409.05	13.42
15% and greater	454.26	14.90

Rock Subgrade Ballasting Cost.

Gradient (uphill haul)	$ per station	$ per m
up to 7%	165.30	5.42
8 - 14%	181.80	5.96
15% and greater	201.90	6.62

APPENDIX II

Mechanical and Performance Specifications for Yarding Machines

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Mechanical and Performance Specifications for Yarding Machines

SYSTEM 1: HIGHLEAD

Madill Model "S" Series Tower
Type 009-3 Drum Yarder

Engine	Cat 9L5136
Rated engine power	535 hp (398 kw)
Undercarriage	Tracked or Rubber-tired carrier
Tower type	Steel tube
Tower height	90 feet (27 m)
Weight	Tracked: 141,800 lb (64,454 kg) Rubber: 121,625 lb (55,284 kg)
Drum capacities:	
Mainline	1,400 ft - 1 1/4 in. diameter (420 m - 3.1 cm diameter)
Haulback	3,400 ft - 7/8 in. diameter (1320 m - 2.2 cm diameter)
Strawline	3,700 ft - 7/16 in. diameter (1100 m - 1.1 cm diameter)
Guylines	6: 1 1/4 in. - 1 3/8 in. diameter (3.1 cm - 3.5 cm diameter)
Line Speeds:	
Mainline	860 ft (26 m) per minute. Mid-drum; no load.
Haulback	2,320 ft (696 m) per minute. Mid-drum; no load.
Line pull:	
Mainline	92,000 lb (409 kN) Mid-drum; stall
Haulback	34,000 lb (151 kN) Mid-drum; stall
Interlock	None

SYSTEM 2: RUNNING SKYLINE WITH FIXED SPAR

Madill 052 Tension Skidder

Engine	Cat 9L5136
Rated engine power	535 hp (398 kw)
Undercarriage	Tracked or Rubber-tired carrier
Tower type	Steel tube
Tower height	90 feet (27 m)
Weight	185,000 pounds (84,091 kg)
Drum capacities:	
Mainline	2,800 ft - 1 in. diameter (840 m - 2.5 cm diameter)
Slackpuller	2,800 ft - 1 in. diameter (840 m - 2.5 cm diameter)
Haulback	5,500 ft - 1 in. diameter (1650 m - 2.5 cm diameter)
Strawline	6,000 ft - 7/16 in. diameter (1800 m - 1.1 cm diameter)
Dropline	350 ft - 1 in. diameter (107 m - 2.5 cm diameter)
Guylines	8: 1 1/4 in. - 1 3/8 in. diameter (3.1 cm - 3.5 cm diameter)
Line Speeds:	
Mainline)) Slackpuller)	1,700 ft/min (510 m/min) 30,000 lb (133 kN) tension 1,700 ft (510 m) yarding distance
Haulback	2,200 ft/min (660 m/min) 20,000 lb (89 kN) tension 1,700 ft (510 m) yarding distance
Interlock	Non-regenerating slip clutch interlock

SYSTEM 3: RUNNING SKYLINE WITH YARDING CRANE

Washington 118

Engine	Detroit 8V-71
Rated engine power	318 hp (273 kw)
Undercarriage	Tracked or Rubber-tired carrier
Tower type	Steel box construction, "A" frame
Tower height	54 feet (16.2 m)
Weight	Tracked: 114,000 lb (51,818 kg) Rubber: 118,000 lb (53,636 kg)
Drum capacities:	
Mainline	1,620 ft - 7/8 in. diameter (486 m - 2.2 cm diameter)
Slackpuller	1,620 ft - 7/8 in. diameter (486 m - 2.2 cm diameter)
Haulback	3,300 ft - 7/8 in. diameter (940 m - 2.2 cm diameter)
Strawline	4,450 ft - 3/8 in. diameter (1,335 m - 1 cm diameter)
Guylines	2 or 3
Line Speeds:	
Mainline	1,440 ft (432 m) per minute. Full drum. No load.
Slackpuller	1,440 ft (432 m) per minute. Full drum. No load.
Haulback	1,440 ft (432 m) per minute. Full drum. No load.
Line Pull:	
Mainline	86,600 lb (385 kN) Empty drum, Stall
Slackpuller	43,300 lb (100 kN) Empty drum, Stall
Haulback	25,000 lb (111 kN) Empty drum, Stall
Interlock	Veri-lok hydraulically controlled interlock

SYSTEM 4: BALLOON SYSTEM

Washington 608A Aero Yarder

Engine	Detroit 12V-71N65
Rated engine power	700 hp (522 kw)
Undercarriage	Caterpillar D9
Weight	149,600 lb (68,000 kg)
Drum capacities:	
Mainline	5,100 ft - 1 in. diameter (1,530 m - 2.5 cm diameter)
Haulback	7,600 ft - 1 in. diameter (2,280 m - 2.5 cm diameter)
Strawline	9,700 ft - 7/16 in. diameter (2,910 m - 1.1 cm diameter)
Line Speeds:	
Mainline	1,591 ft/min (477 m/min) Full drum
Haulback	2,156 ft/min (647 m/min) Full drum
Line Pulls:	
Mainline	90,000 lb (400 kN) Empty drum
Haulback	46,000 lb (204 kN) Empty drum
Interlock	Hydraulic planetary

Raven Model 530K Logging Balloon

Volume	530,000 cubic feet (15,010 m^3)
Diameter	105 feet (31.5m)
Height	113 feet (34.4 m)
Approx. Balloon Weight	6,200 pounds (2,818 kg)
Net Usable Lift	25,000 pounds (11,364 kg) Sea level

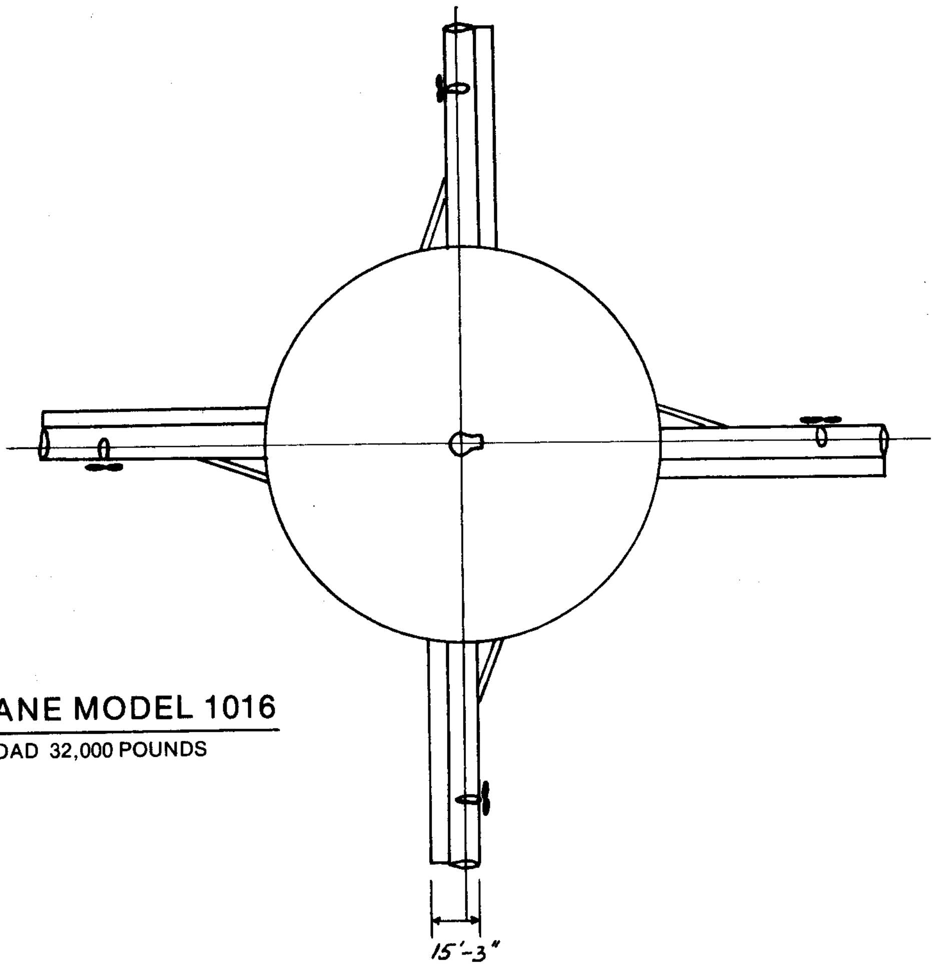
SYSTEM 5: HEAVY-LIFT FREE-FLYING VEHICLE

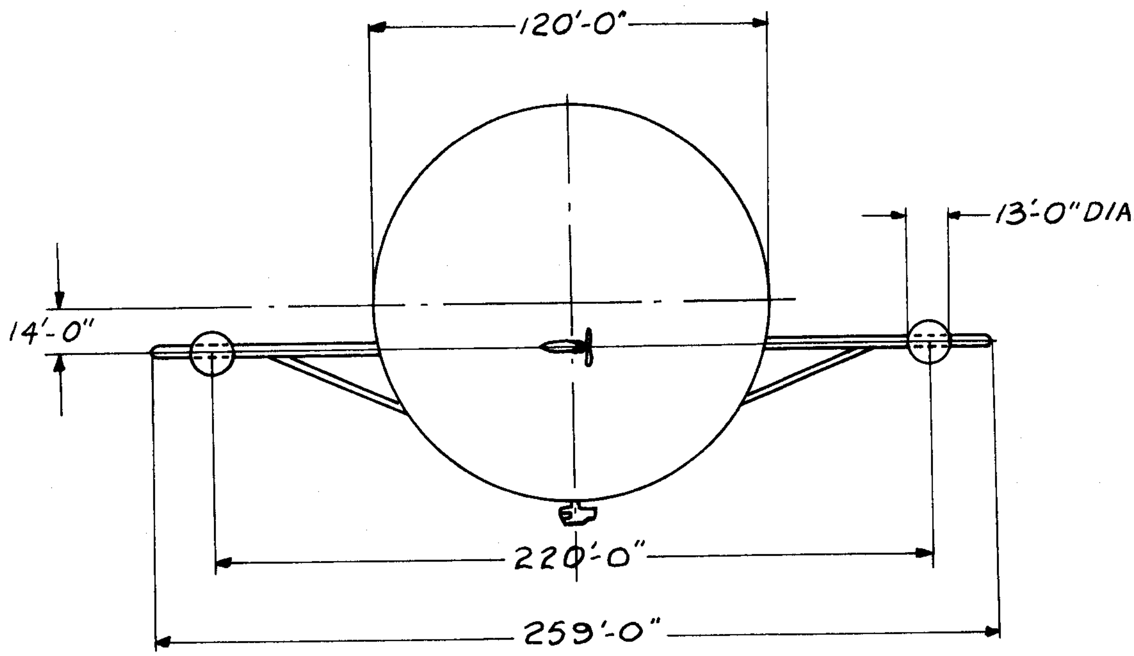
Aerocrane

Engine	Four PT6-A-27
Rated engine power	550 hp (410 kw) each engine
Rotation Speed	10 - 15 rpm
Average cruise speed	20 mph (32 km/hr)
Fuel consumption	144 gallons per hour (655 litre/hr)
Tip-to-tip diameter	259 feet (78m)
Balloon diameter	120 feet (36 m)
Sling Load	32,000 pounds (14,545 kg)

AEROCRANE MODEL 1016

SLING LOAD 32,000 POUNDS





APPENDIX III

Cost Assumptions for Yarding and Loading Equipment

APPENDIX III

Cost Assumptions for Yarding and Loading Equipment

MAIN SYSTEMS

SYSTEM 1: HIGHLEAD

Machine: Madill Model "S" Series Tower Type 009-3 Drum Yarder

Owning Cost:

Purchase Price	$180,000
Rigging	16,000
Delivery	8,000
Capital Cost	$204,000

Depreciation:

Depreciation Period - 8 years (1600 hours annual use)

Residual Price - Nil

$\frac{\text{Net Value}}{\text{Depreciation Period}}$ = $25,500/year **$15.94/hour**

Interest and Insurance:

Interest 10%
Insurance 2.5%
Factor: .048
Hourly Cost = **$9.80/hour**

Operating Supplies:

Wire Rope:

Mainline — 1450 ft of 1-1/8 in. dia. (435 m of 2.8 cm dia.) @ $1.60/ft ($5.25/m) = $2,320

Haulback — 3600 ft of 7/8 in. dia. (1080 m of 2.2 cm dia.) @ $1.25/ft ($4.10/m) = $4,500

Strawline — 3700 ft of 7/16 in dia. (1110 m of 1.1 cm dia.) @ $0.36/ft ($1.18/m) = $1,332

Total Cost = $8,152

Line Life — 2400 hours

Line Cost = $\frac{\$8,152}{2400 \text{ hr}}$ = $3.40/hour

Rigging — $5,000/3200 hours =		$1.56/hour
Fuel — 50 GPD (227 l) @ 55¢/gal (12¢/l)	$27.50	
Oil + lube (15% of Fuel)	4.13	
	$31.63	$3.95/hour
Total Operating Supplies Cost =		**$8.91/hour**

Repairs: $\frac{\$204,000 \times .09}{1000}$ **$18.36/hour**

Operating Labour:

Hook Tender	— 9 hr @ $9.07/hr	=	$81.63/day
Yarding Engineer	— 9 hr @ $8.23/hr	=	74.07
Rigging Slinger	— 8 hr @ $8.01/hr	=	64.08
Landing Man	— 8 hr @ $7.79/hr	=	62.32
2 Chokermen	—16 hr @ $7.34/hr	=	117.44
			$399.54/day
	25% Overhead		99.89
			$499.43/day
Total Operating Labour Cost			**$62.43/hour**

Summary:

Depreciation	$15.94/hour
Insurance and Interest	9.80
Operating Supplies	8.91
Repairs and Maintenance	18.36
Operating Labour	62.43
Total:	**$115.44/hour**

SYSTEM 2: RUNNING SKYLINE WITH FIXED SPAR

Machine: Madill 052 Tension Skidder

Owning Cost:

Purchase Price	$250,000
Rigging	25,000
Delivery	9,000
Capital Cost	$284,000

Depreciation:

Depreciation Period — 7 years (1600 hours annual use)

Residual Price — $25,000

$\frac{\text{Net Value}}{\text{Depreciation Period}}$ = $37,000/year; **$23.13/hour**

Interest and Insurance:

Interest	10%	
Insurance	3%	
Factor:	.05	
Hourly Cost	=	**$14.27/hour**

Operating Supplies:

Wire Rope:

Mainline —	2000 ft of 7/8 in. dia. (600 m of 2.2 cm dia.) @ $1.25/ft ($4.10/m)	=	$2,500
Haulback —	4400 ft of 7/8 in. dia. (1320 m of 2.2 cm dia.) @ $1.25/ft ($4.10/m)	=	5,500
Slackpuller —	2000 ft of 7/8 in. dia. (600 m of 2.2 cm dia.) @ $1.25/ft ($4.10 m)	=	2,500
Strawline —	4800 ft of 7/16 in. dia. (1440 m of 1.1 cm dia.) @ $0.36/ft ($1.18/m)	=	1,728
	Total Cost		$12,228

Line Life — 2400 hours

Line Cost = $\frac{\$12{,}228}{2400\text{ hr}}$ = $5.09/hour

Rigging — $8,000/3200 hours = $2.50/hour

Fuel —

60 GPD (273 l) @ $0.55/gal ($0.12/l)	=	$33.00/day
Oil + Lube (15% of Fuel)	=	4.95
		$37.95/day
		$4.74/hour
Total Operating Supplies Cost	=	**$12.33/hour**

Repairs and Maintenance:

$\frac{\$284{,}000 \times .09}{1000}$ = **$25.56/hour**

Operating Labour

Hook and Rig	— 9 hr @ $9.35/hr	=	$ 84.15/day
Yarding Engineer	— 9 hr @ $8.51/hr	=	76.59
Rigging Slinger	— 8 hr @ $8.23/hr	=	65.84
Landing Man	— 8 hr @ $7.79/hr	=	62.32
4 Chokermen	—32 hr @ $7.34/hr	=	234.88
			$523.78/day
	25% Overhead	=	130.95
			$654.73/day
Total Operating and Labour Cost			**$81.84/hour**

Summary:

Depreciation	$23.13/hour
Interest and Insurance	14.27
Operating Supplies	12.33
Repairs and Maintenance	25.56
Operating Labour	81.84
Total:	**$157.13/hour**

SYSTEM 3: RUNNING SKYLINE WITH YARDING CRANE

Machine: Washington Model 118 Mobile Yarder

Owning Cost:

Purchase Price	$495,000
Delivery	7,000
Capital Cost	$502,000

Depreciation:

Depreciation Period - 8 years (1600 hours annual use)

Residual Price — $74,000

$\frac{\text{Net Value}}{\text{Depreciation Period}}$ = $53,500/year; **$33.44/hour**

Interest and Insurance:

Interest	10%	
Insurance	2.5%	
Factor:	.048	
Hourly Cost	=	**$24.10/hour**

Operating Supplies:

Wire Rope:

Mainline —	1600 ft of 7/8 in. dia. (480 m of 2.2 cm dia.) @ $1.25/ft ($4.10/m)	=	$2,000
Haulback —	3300 ft of 7/8 in. dia. (990 m of 2.2 cm dia.) @ $1.25/ft ($4.10/m)	=	4,125
Slackpuller —	1600 ft of 7/8 in. dia. (480 m of 2.2 cm dia.) @ $1.25/ft ($4.10/m)	=	2,000
Strawline —	4450 ft of 3/8 in. dia. (1335 m of .95 cm dia.) @ $0.30/ft ($1.18/m)	=	1,335
	Total Cost	=	$9,460

Line Life — 1200 hours

Line Cost = $\frac{\$9{,}460}{1200\text{ hr}}$ = $7.88/hour

Rigging – $5,000/3200 hours	=	$1.56/hour
Fuel –		
60 GPD (273 l) @ $0.55/gal ($0.12/l)		
	=	$33.00/day
Oil + Lube (15% of Fuel)	=	4.95
		$37.95/day
		$4.74/hour
Total Operating Supplies Cost	=	**$14.18/hour**

Repairs and Maintenance:

$$\frac{\$502{,}000 \times 0.09}{1000} = \mathbf{\$45.18/hour}$$

Operating Labour:

Hook Tender	– 9 hr @ $9.07/hr =	$81.63/day
Yarding Engineer	– 9 hr @ $9.07/hr =	81.63
Rigging Slinger	– 8 hr @ $8.01/hr =	64.08
Landing Man	– 8 hr @ $7.79/hr =	62.32
3 Chokermen	– 24 hr @ $7.34/hr =	176.16
		$465.82/day
	25% Overhead	116.46
		$582.28/day
Total Operating Labour Cost		**$72.78/hour**

Summary:

Depreciation	$33.44/hour
Interest and Insurance	24.10
Operating Supplies	14.18
Repairs and Maintenance	45.18
Operating Labour	72.78
Total:	**$189.68/hour**

SYSTEM 4: BALLOON (WITH LOADER)

Machine: Washington 608A Balloon Yarder
Raven 530K Balloon

Owning Cost:

Balloon.		
Raven Industries 530K Balloon	$ 175,000	
Federal Tax	21,000	
Delivery	5,000	
		$ 201,000
Helium 530,000 cu.ft. (15,619 m^3)	$ 34,185	
Provincial Tax	2,393	
		$ 36,578
Helium Trailer	$ 12,000	
Tax	840	
		$ 12,840
Hold-down Cat and Winch		$ 50,000
Yarder.		
608A Washington Iron Works on Used Base, complete	$ 500,000	
Federal Tax	60,000	
Delivery	10,000	
		$ 570,000
Cable.		
Mainline: 5500 ft x 1 in. dia. (1650 m x 2.5 cm dia.) @ $1.57/ft. ($5.23/m)	$ 8,635	
Haulback: 7000 ft x 1 in. dia. (2100 m x 2.5 cm dia.) @ $1.57/ft. ($5.23/m)	10,990	
Strawline: 7500 ft x 7/16 in. dia. (2250 m x 1.1 cm dia.) @ $0.36/ft ($1.20/m)	2,700	
		$ 22,325
Blocks.		
Four 18 in. (45 cm) x 2½ in. (6.26 cm) @ $570	$ 2,280	
Additional Blocks	1,720	
		$ 4,000
Butt Rigging and Carriage		$ 4,500
Chokers and tagline		$ 1,000
Loader.		
Cat 980 Grapple Loader c/w tires	$ 143,000	
Delivery	2,000	
		$ 145,000
Miscellaneous		5,000
	Capital Cost:	$1,052,243

Depreciation:

	Years Depre-ciated	Present Value	Residual Value	Annual Depre-ciation
Balloon	3	201,000	—	67,000
Helium	2.5	36,578	—	14,631
Trailer	7	12,840	1,926	1,559
Yarder	7	570,000	85,500	69,214
Loader	5	145,000	36,250	21,750
Hold-down Cat	7	50,000	5,000	6,429
Butt rigging & carriage	3.5	4,500	—	1,286
Cables	1.5	22,325	—	14,883
Hardware & Misc.	2	10,000	—	5,000
Tires	1.5	8,000	—	5,333
			Total:	$207,085
				$129.43/hour

Note: 1600 hours annual use.

Interest and Insurance:

	$/Day	$/Hour
Yarder: 10% INT + 2.5% INS = 12.5%	218.88	27.36
Balloon and Helium:		
10% INT + 13% INS = 23%	190.06	23.76
Loader: 10% INT + 2% INS = 12%	52.20	6.52
Hold-down Cat:		
10% INT + 1% INS = 11%	16.40	2.05
Helium Trailer:		
10% INT + 1% INS = 11%	4.20	0.53
Total:	$ 481.74	$ 60.22

Operating Supplies:

Fuel —		
Yarder: 200 GPD @ $0.55/gal (900 l @ $0.12/l)	110.00	13.75
Loader: 48 GPD @ $0.55/gal) (216 l @ $0.12/l)	26.40	3.30
Hold-down Cat: 22 GPD @ $0.55/gal (99 l @ $0.12/l)	12.10	1.51
Helium Trailer: 10 GPD @ $ 0.55/gal (45 l @ $0.12/l)	5.50	0.69
Total:	$ 154.00	$ 19.25
Oil and Lubricants —		
Yarder: 15% of Fuel Cost	16.50	2.06
Loader: 15% of Fuel Cost	3.96	0.50
Hold-down Cat: 20% of Fuel Cost	2.42	0.30
Helium Trailer: 15% of Fuel Cost	0.83	0.10
Total:	$ 23.71	$ 2.96
Total Operating Supplies Cost:	$ 177.71	$ 22.21

Repairs and Maintenance:

Yarder:

$$\frac{\text{Capital Cost} \times 0.09}{1{,}000} = \frac{\$570{,}000 \times 0.09}{1{,}000} = \$\ 51.30/\text{hour}$$

Balloon:

$$\frac{201{,}000 \times 0.02}{1{,}000} = \$\ 4.02/\text{hour}$$

Helium Trailer:

$$\frac{12{,}840 \times 0.04}{1{,}000} = \$\ 0.51/\text{hour}$$

Cat and Winch:*

$$\frac{120{,}000 \times 0.04}{1{,}000} = \$\ 4.80/\text{hour}$$

Loader:

$$\frac{145{,}000 \times 0.06}{1{,}000} = \$\ 8.70/\text{hour}$$

Miscellaneous: = $ 3.50/hour

Helium Loss:

$$\text{40\% loss per year of \$36,578 total cost} = \frac{14{,}631}{1600\ \text{hr}} = \$\ 9.14/\text{hour}$$

Total: **$ 81.97/hour**

*Repair and Maintenance based on new price.

Operating Labour:

	Hours	Rate	$/Day
Hook and Rig	9	9.35	84.15
Engineer	9	9.07	81.63
Rigging Slinger	8	8.23	65.84
Chokerman (3)	24	7.34	176.16
Chaser	8	7.44	59.52
Loader Operator	9	8.51	76.59
Utility Man	8	7.79	62.32
Total:			$606.21
Supervision			110.00
Total labour cost:			$716.21
25% Overhead			179.05
Total Cost:			$895.26
Total Cost per hour			**$111.91**

Summary:

	$/Hour	$/Day	$/Year
Depreciation	129.43	1,035.44	207,085
Interest and Insurance	60.22	481.74	96,354
Operating Supplies	22.21	177.71	35,537
Repairs and Maintenance	81.97	655.76	131,152
Operating Labour	111.91	895.26	179,056
Total:	**$405.74**	**$3,245.91**	**$649,184**

SYSTEM 5: HEAVY-LIFT FREE-FLYING VEHICLE

Machine: 16-Ton Sling Load Aerocrane

Owning Cost:

Purchase Price	
Balloon	$220,000
Helium	36,600
Airframe & Engines	760,000
Controls	300,000
Capital Cost	$1,316,600

Depreciation:

	Depreciation Period	Residual Value	Annual Depreciation
Balloon	3 years	0	$ 73,300
Helium	3 years	0	12,200
Airframe & Engines	7 years	89,400	95,800
Controls	10 years	15,000	28,500
			$209,800
Total Depreciation Cost (1600 hr/yr)			**$131.13/hour**

Interest and Insurance:

Interest	$168,522/year	
Insurance	78,995	
	$247,517/year	**$154.70/hour**

Operating Supplies:

Fuel – 154 gal/hr (700 l) @ $0.50/gal ($0.11/l) **$77.00/hour**

Repairs and Maintenance:

Balloon	$3,000/year	
Helium	14,200	
Airframe & Engines	110,000	
Controls	3,000	
	$130,200/year	
Total R and M Cost		**$81.37/hour**

Operating Labour:

4 pilots @ $37,500/year	=	$150,000/year
2 mechanics @ $12/hour		
2 apprentice mechanics @ $9/hour		
1 First Aid person @ $9.30/hour		
= $51.30/hour x 1600	=	82,080/year
Overtime for hourly rates		
= 450 hours/yr @ $25.65	=	11,550/year
1 Foreman	=	33,000/year
		$276,630/year
Total Operating Labour Cost		**$172.89/hour**

Support Equipment for Aerocrane System:

Investment:	Helium Trailer	$12,840
	Other	40,000
	Total:	$52,840

Depreciation	$7,800/yr	$4.88/hr
Interest and Insurance	7,500	4.69
Operating Supplies:		
Fuel and Lube	1,000	0.62
Misc. (chokers, wire rope etc.)	50,000	31.25
Repairs and Maintenance	2,000	1.25
Total:	**$68,300/yr**	**$42.69/hr**

Summary:

	Aerocrane ($/hour)	Support Equipment ($/hour)	Total ($/hour)
Depreciation	131.13	4.88	136.01
Interest & Insurance	154.70	4.69	159.39
Operating Supplies	77.00	31.87	108.87
Repairs & Maintenance	81.37	1.25	82.62
Operating Labour	172.89	–	172.89
Total:	**$617.09**	**$42.69**	**$659.78**

Aerocrane Landing Crew:

1 Front-end Loader	$58.47/hour (all found)	
1 Chokerman	9.00/hour	
1 Bucker	11.30/hour	
	$78.77/hour	$126,032/year
Overtime:		4,500/year
		$130,532/year
1 Crew sorts 250 cunits/shift		**$ 81.58/hour**

Woods Crews:

3-Man Crew		
1 Rigging Slinger	$10.00/hour	
2 Chokermen	18.00/hour	
	$28.00/hour	$44,800/year
Overtime:		6,300/year
Total Cost, 3-Man Crew		$51,100/year
		$31.94/hour
2-Man Crew		
1 Rigging Slinger	$10.00/hour	
1 Chokerman	9.00/hour	
	$19.00/hour	$30,400/year
Overtime:		4,275/year
Total Cost, 2-Man Crew		$34,675/year
		$21.67/hour

AUXILIARY EQUIPMENT

Machine: Mobile Grapple Yarder

Owning Cost:

Purchase Price (incl. rigging)	$250,000
Delivery	7,000
Capital Cost	$257,000

Depreciation:

Depreciation Period — 8 years (1600 hours annual use)

Residual Price — $37,000

$$\frac{\text{Net Value}}{\text{Depreciation Period}} = \$27{,}500/\text{year}; \qquad \mathbf{\$17.19/hour}$$

Interest and Insurance:

Interest	10%	
Insurance	2.5%	
Factor:	.048	
Hourly Cost	=	**$12.34/hour**

Operating Supplies:

Wire Rope — included in repair and maintenance.

Rigging — included in repair and maintenance.

Fuel —

60 GPD (273 l) @ $0.55/gal ($0.12/l)	=	$33.00/day
Oil + Lube (15% of Fuel)	=	4.95
		$37.95/day
Total Operating Supplies Cost	=	**$4.75/hour**

Repairs and Maintenance:

$$\frac{\$257{,}000 \times 0.09}{1000} = \mathbf{\$23.13/hour}$$

Operating Labour:

Hook Tender	— 9 hr @ $8.79/hr	=	$79.11/day
Chokerman	— 8 hr @ $7.34/hr	=	58.72
Yarding Engineer	— 9 hr @ $9.07/hr	=	81.63
			$219.46/day
	25% Overhead		54.87
			$274.33/day
Total Operating Labour Cost			**$34.29/hour**

Summary:

Depreciation	$17.19/hour
Interest and Insurance	12.34
Operating Supplies	4.75
Repairs and Maintenance	23.13
Operating Labour	34.29
Total:	**$91.70/hour**

SUPPORT EQUIPMENT

Machine: Rubber-tired Front-end Loader

Owning Cost:

Purchase Price	$143,000
Delivery	2,000
Capital Cost	$145,000

Depreciation:

Depreciation Period — 5 years (1600 hours annual use)

Residual Price — $36,250

$$\frac{\text{Net Value}}{\text{Depreciation Period}} = \$21{,}750/\text{year} \qquad \mathbf{\$13.59/hour}$$

Interest and Insurance:

Interest	10%	
Insurance	2%	
Factor	.045	
Hourly Cost =		**$6.53/hour**

Operating Supplies:

Tire Cost — $8,000

Tire Life — 2400 hours

$$\text{Tire Cost} = \frac{\$8{,}000}{2400\ \text{hr}} = \qquad \$3.33/\text{hour}$$

Fuel —

48 GPD (218 l) @ $0.55/gal ($0.12/l)	=	$26.40/day
Oil + Lube (15% of Fuel)	=	3.96
Other	=	10.00
		$40.36/day
Fuel Cost		$5.05/hour
Total Operating Supplies Cost	=	**$8.38/hour**

Repairs and Maintenance:

$$\frac{\$145{,}000 \times 0.06}{1000} = \mathbf{\$8.70/hour}$$

Operating Labour:

Loader Operator	— 9 hr @ $8.51/hr	=	$76.59/day
Second Loader	— 8 hr @ $7.44/hr	=	59.52
			$136.11/day
	25% Overhead		34.03
			$170.14/day
Total Operating Labour Cost			**$21.27/hour**

Summary:

Depreciation	$13.59/hour
Interest and Insurance	6.53
Operating Supplies	8.38
Repairs and Maintenance	8.70
Operating Labour	21.27
Total:	**$58.47/hour**

Machine: Hydraulic Log Loader

Owning Cost:

Purchase Price	$200,000
Delivery	7,000
Capital Cost	$207,000

Depreciation:

Depreciation Period – 6 years (1600 hours annual use)

Residual Price – $20,000

$\frac{\text{Net Value}}{\text{Depreciation Period}}$ = $31,167/year; **$19.48/hour**

Interest and Insurance:

Interest	10%	
Insurance	3%	
Factor	.05	
Hourly Cost	=	**$10.35/hour**

Operating Supplies:

Fuel –

40 GPD (182 l) @ $0.55/gal ($0.12/l)	=	$22.00/day
Oil + Lube (18% of Fuel)		3.96
Other		10.00
		$35.96/day
Total Operating Supplies Cost	=	**$4.49/hour**

Repairs and Maintenance:

$\frac{\$207{,}000 \times 0.08}{1000}$ = **$16.56/hour**

Operating Labour:

Loader Operator	– 9 hr @ $8.51/hr	=	$76.59/day
Second Loader	– 8 hr @ $7.44/hr	=	59.52
			$136.11/day
	25% Overhead		34.03
			$170.14/day
Total Operating Labour Cost			**$21.27/hour**

Summary:

Depreciation	$19.48/hour
Interest and Insurance	10.35
Operating Supplies	4.49
Repairs and Maintenance	16.56
Operating Labour	21.27
Total:	**$72.15/hour**

APPENDIX IV

Assumptions for Log Hauling

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Assumptions for Log Hauling

Logging Truck Cost (all found)	\$396/day (\$44/hr)
Average Load	24 cunits (68.01 m^3)
Average Speed	16 mph (25.8 km/hr)
Terminal time (average loading, unloading plus delay time)	1.8 hours if loaded from yarder
Terminal time	1.2 hours if loaded from pile

$$\frac{\text{Haul Distance (Miles)} \times 2}{\text{16 MPH}} + \text{Average Terminal Time} = \text{Trip Time (hr)}$$

$$\frac{\text{9 hours/day}}{\text{Trip Time}} = \text{Trips/day}$$

$$\text{Trips/Day} \times \text{24 cunits/Trip} = \text{Production/day}$$

$$\frac{\text{\$396/day}}{\text{Production/day}} = \text{\$/cunit cost}$$

Additional delay cost if landing over 60% side slope

$$\text{8 hours} - \frac{\text{Yarder Production/8 hour shift}}{\text{24 cunits (68.01 m}^3\text{)/load}} \times \text{1.2 hour delay}$$

$$= \text{Additional Delay (hours)}$$

$$\frac{\text{Additional Delay(Hours)} \times \text{\$44/hour truck cost}}{\text{Yarder Production/8-hour shift}}$$

$$= \text{Additional Delay Cost (\$/cunit)}$$

APPENDIX V

Conversion Factors of Basic Measures

English				Metric
inch	x	25.4	=	millimetre
foot	x	0.3048	=	metre
mile	x	1.6093	=	kilometre
pound	x	.4536	=	kilogram
cunit	x	2.8317	=	cubic metre
gallon	x	4.5461	=	litre
cubic feet	x	0.0283	=	cubic metre
acre	x	0.4047	=	hectare
cunits/acre	x	6.9970	=	cubic metres/hectare


48°50'00"
124°55'00"
ROSSEAU LAKE
Br 205
Br 207
Br 209
Br 326
Br 328
Br 209
1-HIGHLEAD
2-RUNNING SKYLINE
WITH FIXED SPAR
3-RUNNING SKYLINE
WITH YARDING CRANE
4-BALLOON
5-AEROCRANE
MAP OF STUDY AREA
*NOTE: THE STUDY EVALUATED EACH OF THE FIVE SYSTEMS AS THEY ARE LAID OUT OVER THE TOTAL MAP AREA. RATHER THAN SHOW ALL FIVE MAP LAYOUTS, HOWEVER, WE HAVE DIVIDED THE MAP TO ILLUSTRATE THE FIVE SYSTEMS.
LEGEND
Study Area Boundary
Proposed Setting Boundary
Boundary
Setting Symbol
Landing Symbol
Main Logging System:
1-Highlead HL
2-Running Skyline with Fixed Spar TS
3-Running Skyline with Yarding Crane YC
4-Balloon BAL
5-Aerocrane AC
Auxiliary System: Grapple Yarder GY
Scale
0 200 400 600 800 1000 Ft
0 150 300 m
Contour Interval 25 Feet (7.6 M)
Slide
Rock
Creek
DEFINED
UNDEFINED
Existing Road
Road Proposed for Study