AN ANALYSIS OF ROAD CHANGING ON SEVERAL CABLE LOGGING OPERATIONS

by

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Abstract

Road changing is the activity of moving operating lines on a cable yarding operation to permit access to logs in an unyarded portion of a logging unit. The time required to perform this activity varies widely and may consume a significant portion of the total yarding time.

With rising costs in the logging industry, the efficiency of cable logging systems is constantly under critical review. Additional research in the area of road changing has been suggested in several studies (Dykstra, 1974 and Peters, 1973).

Road changing information was gathered on several yarding operations in conjunction with detailed production studies of cable logging systems. On six of the operations the total time consumed by road changing was noted and recorded as a delay in the yarding process. On four operations, road changing was segmented into various activities, and factors hypothesized to influence road changing time were identified and measured.

On the four operations studied in detail, two crewmen timed the road changing operation as the activities involved occurred at widely separated locations on the logging unit. The continuous time study method used on the overall production study (Dykstra, 1975a) was also used during road changing.

The analysis of road changing involves a descriptive analysis of all the operations studied and a quantitative analysis of road changing on the four operations studied in detail. The descriptive analysis consists primarily of a comparative investigation of road changing time between the operations. The quantitative analysis consists of a regression analysis of the four operations examined in detail.

In the comparison of road changing times for the ten operations observed, road changing time varied widely. Even among similar systems a wide range was observed. This variability was most likely due to the differences in the road changing methods themselves, varying characteristics of the logging units and lengthy delays encountered during road changing. This could not be confirmed for six of the operations as road changing was not recorded in detail. However, among those operations observed in detail, this influence could be seen.

Following a breakdown of road changing into machine intensive activities, labor intensive activities and delays, a large percentage of road changing time is occupied by delays. Also, the greatest proportion of delay-free time involved labor intensive activities. This was expected on the operations where pre-layout of roads was not done. On the operation where roads were pre-layed, other activities requiring labor intensive action occurred. Some of the delays encountered may have been due to characteristics of the particular yarder being used.

A quantitative analysis was made of four operations. Road changing time, excluding delays and the time required to relocate the yarder was used as the dependent variable. Delay-free road changing time was found to be a function of the distance from the landing to the tailhold (SPAN) and groundslope. For two of the operations, identical machines and methods were used. A combined regression equation was formed based on the independent variable SPAN. Also, based on the scatter of observations for these systems, an equation using $SPAN^2$ as the independent variable was found to be a better predictor of delay-free road changing time than SPAN.

Acknowledgements

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AN ANALYSIS OF ROAD CHANGING ON SEVERAL CABLE LOGGING OPERATIONS

Introduction

Road changing is the activity of moving operating lines on a cable yarding operation to permit access to logs in an unyarded portion of a logging unit. The time required to perform this activity can vary widely and may consume a significant portion of the total yarding time on a logging unit.

Many publications have discussed rigging procedures which refer to the initial setup or overall layout of a particular system (Binkley, 1965, Gibbons, 1914 and Studier and Binkley, 1974). Road changing refers to the moving of lines only and may or may not involve relocation of the yarder and yarder setup. On the small, highly mobile yarders, rerigging may be done on every road change. In any case, the emphasis of this paper is not on rigging procedures.

With rising costs in the logging industry, the efficiency of cable logging systems in constantly under critical review. On several production studies made on yarding systems, the activity of road changing has been one area where additional research has been suggested (Dykstra, 1974 and Peters, 1973).

Published material dealing with road changing is sparse and there do not appear to have been any studies dealing solely with road changing on cable logging systems. An extensive report on logging, published in 1914 includes descriptions of several road changing techniques and estimates of the time required to complete this operation (Gibbons, 1914). However, this information is on early cable systems and would not be generally applicable to modern systems and techniques. In tests dealing with rigging procedures, road changing is mentioned in a very general sense. The importance of rigging and road changing to the total yarding operation is commonly pointed out (Studier and Binkley, 1974). A paper by Peters (1973) suggests a method of calculating road changing time based on external yarding distance using the following equation:

$$R = 40 + 0.05\ E$$

where

R = the time required to change skyline roads, in minutes

E = the external yarding distance in feet

This equation is suggested by Peters as an improvement over the present practice of ignoring the effects of external yarding distance. However, this equation was not developed through a detailed data analysis, but is based on a few field observations and communication with logging personnel.

In a detailed production study of logging systems on the Pansy Creek Basin of the Mt. Hood National Forest, average road changing time and the number of roads on the logging unit are used in addition to other variables in estimating total yarding time on a particular unit (Dykstra, 1975a and 1976). The actual road changing procedures are not presented and no attempt is made to analyze road changing in detail. In a follow-up report on this study, delays measured on the operations are analyzed. Road changing is again considered and several variables are suggested which may influence road changing time. These variables include external yarding distance, crew experience, rigging configuration, type of yarding equipment and the silvicultural prescriptions on the cutting unit (Dykstra, 1975b).

Objective of Study

The objective of this study is to critically analyze road changing on several cable logging systems to produce the following results:

1. A qualitative analysis of road changing on ten yarding operations studies in the Pacific Northwest.

2. A detailed analysis of four of these operations consisting of:

    a. a detailed description of the road changing process.

    b. a qualitative analysis of the individual activities within each road changing process.

    c. a quantitative analysis of road changing indicating those variables found to influence the duration of the process.

    d. suggestions for further research.

Scope

Road changing information was gathered on several yarding operations in conjunction with detailed production studies made on these systems. In 1973, on the Pansy Creek Basin of the Mt. Hood National Forest in Northwestern Oregon, several yarding operations were studied in an effort to obtain production rates and costs for these operations and to identify critical variables affecting production (Dykstra, 1975a). Road changes were treated as delays and the total time involved in road changing was measured. However, a detailed breakdown of the road changing process itself was not made. In 1974 the study on the Pansy Creek Basin was continued, and again the process of road changing was treated as an operating delay. In addition to this, the process itself was segmented into various activities, and additional factors pertaining to road changing were measured. On a study in Northern California on the Klamath Nation Forest in 1975, production rates were again measured along with a detailed breakdown of road changing.

This paper is limited to those operations examined in 1973, 1974 and 1975 on the projects mentioned above. Furthermore, the detailed analysis is limited to those operations on which road changing was closely monitored.

Road Changing as a Delay

It is debatable whether or not road changing can be classified as a delay. The activity of road changing is, in a sense, productive since it is an integral part of the road changing process. For the purpose of this paper, it will be useful to classify road changing as a productive delay. Other productive delays would include scheduled maintenance, refueling and lunch breaks. In general, productive delays are predictable and are initiated by the operator. Nonproductive delays include unscheduled maintenance, hangups during yarding, equipment breakdown and repairs and weather delays (Figure 1). These delays are unpredictable (although in some cases preventable), and their occurrence does not benefit the yarding operation. Those nonproductive delays which are preventable would be expected to decrease in frequency with an increase in crew experience and concern.

Delays occur between yarding cycles and within yarding cycles. A yarding cycle is defined as the sequence of productive activities beginning when the rigging leaves the landing on outhaul and ending when the turn of logs is unhooked at the landing (Figure 2).

Productive delays such as road changing generally occur between yarding cycles. Nonproductive delays may occur within or between yarding cycles depending on the nature of the delay.

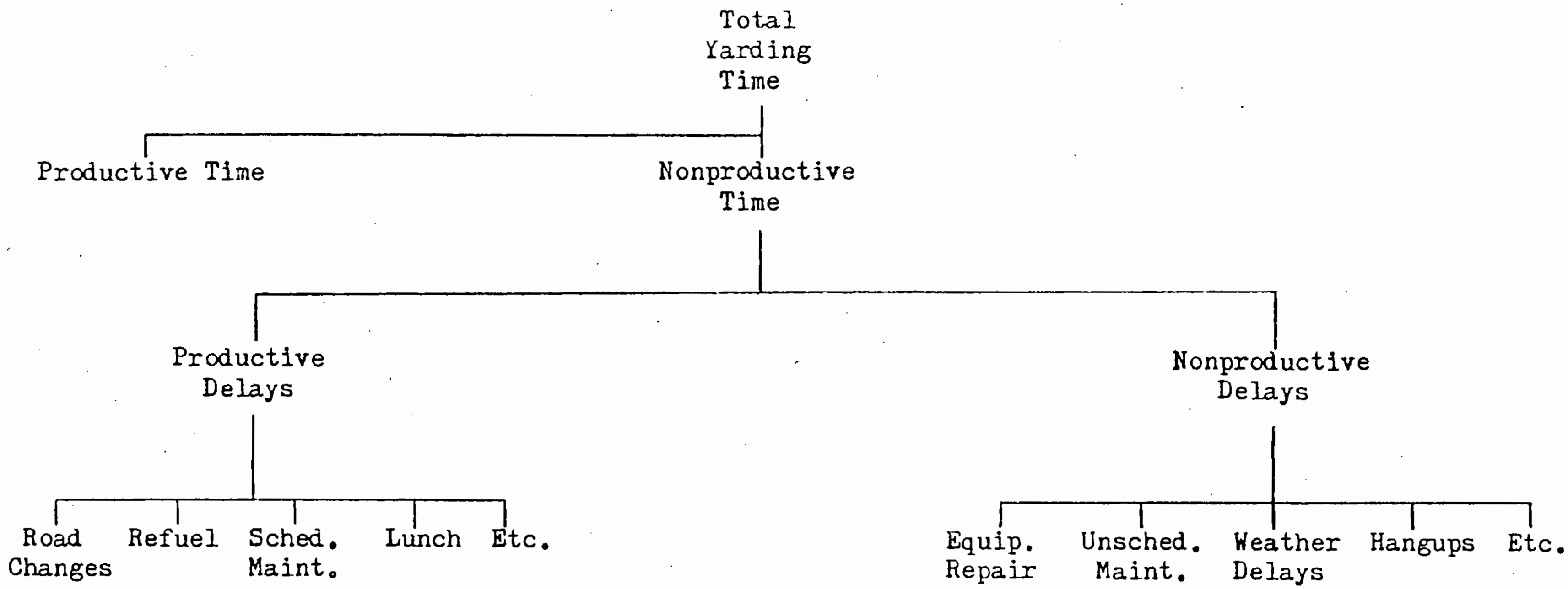


Figure 1. Total yarding time breakdown

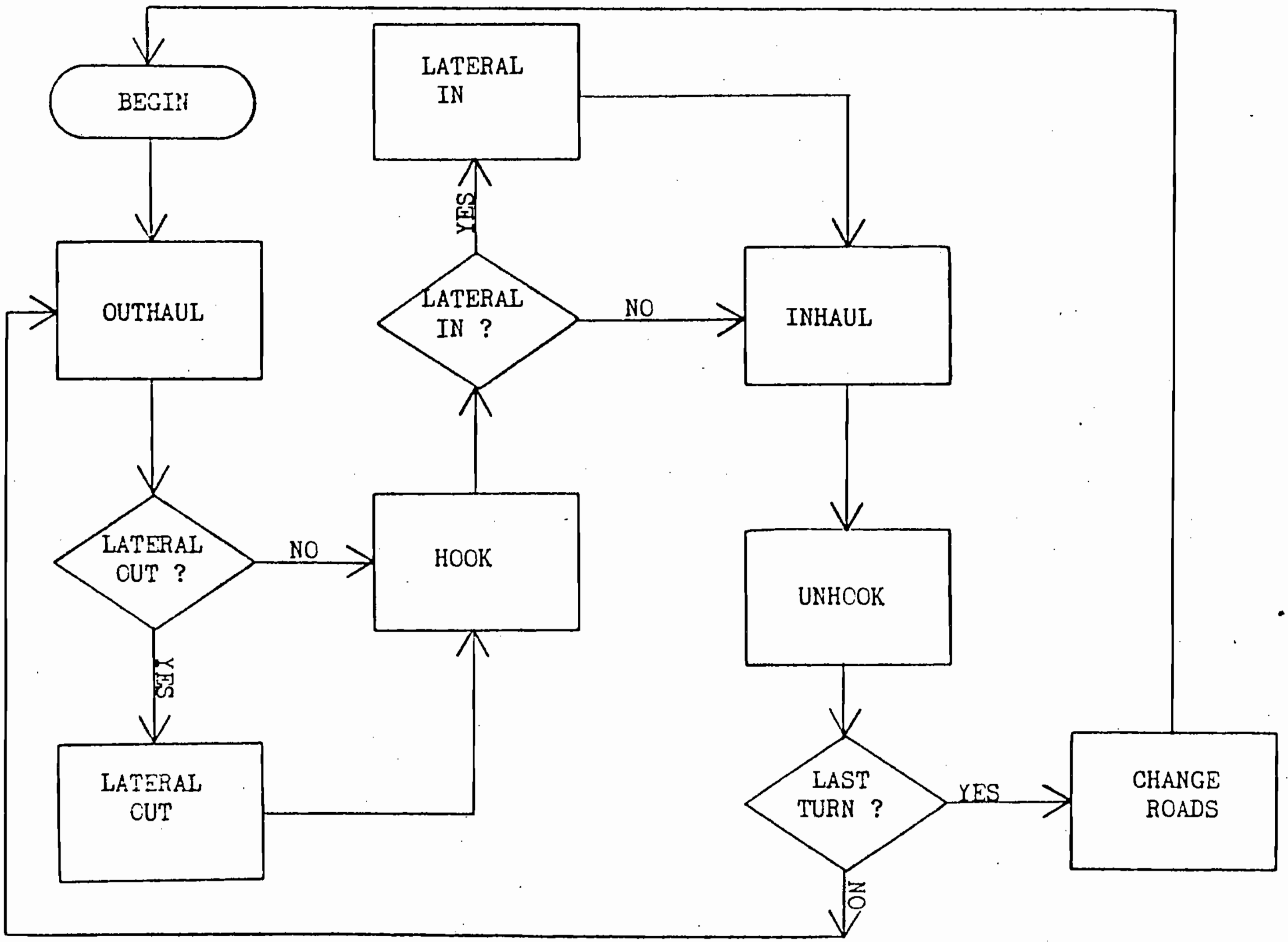


Figure 2. Typical yarding cycle

A flow chart of road changing is presented in Figure 3. Road changing methods vary widely depending upon the yarding system used, cutting unit characteristics, equipment and personal preferences. Portions of Figure 3 are therefore arbitrary, and the flow chart is intended only as a reference for discussion.

It should be evident from Figure 3 that the process of road changing involves two major decisions. In most cases the answer to the question at each decision point is dependent upon the characteristics of the setting and unit layout.

Two distinct situations are fairly common in cable yarding. In the first situation, one landing is used with several tailholds located in a more or less circular pattern around it (Figure 4).

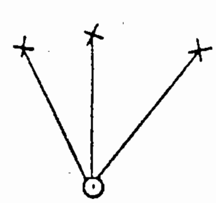


Figure 4. Single landing with multiple tailholds.

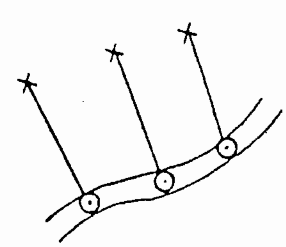


Figure 5. Parallel roads with multiple landings and tailholds.

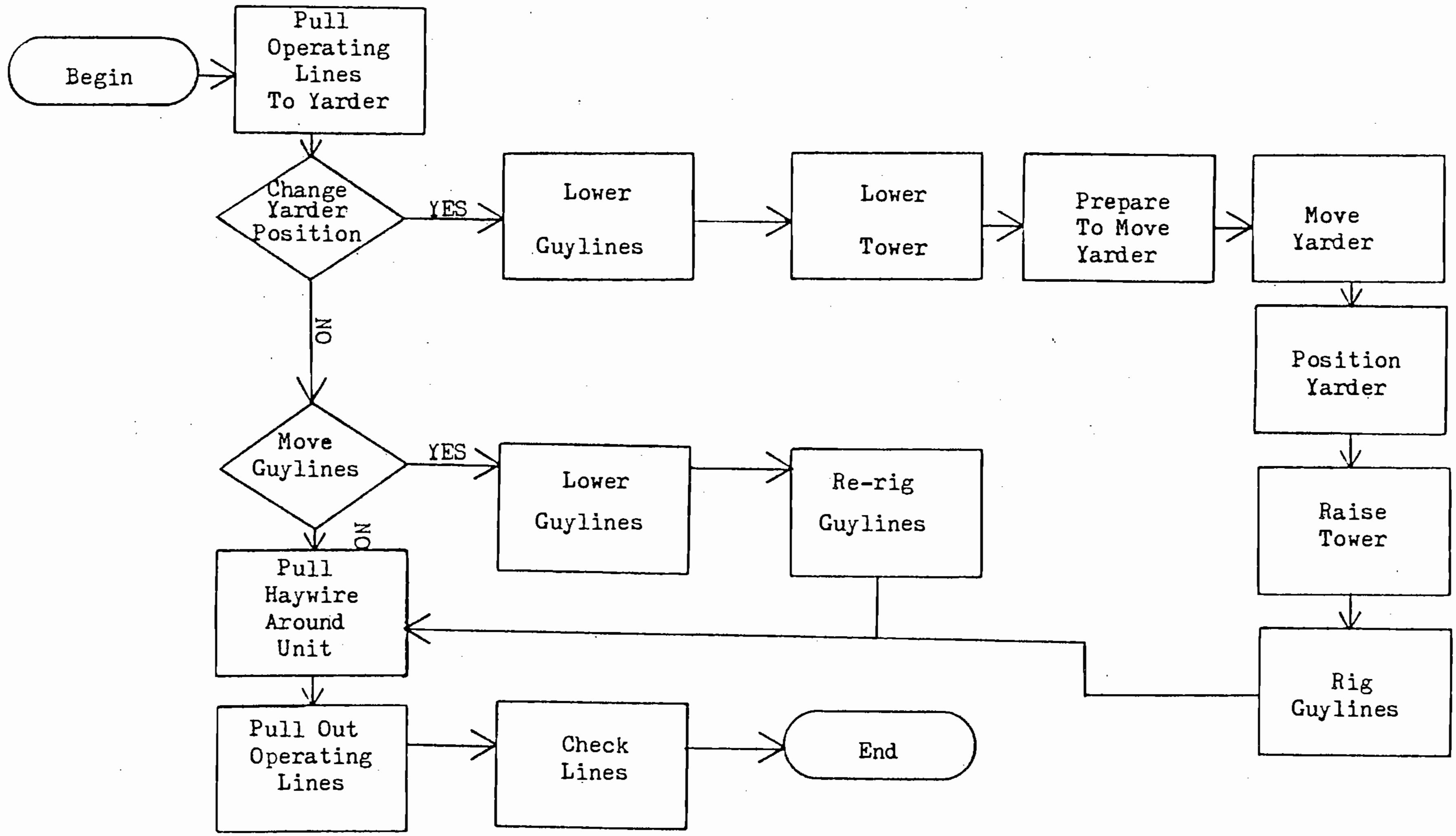


Figure 3. A general flowchart of road changing

In this situation, few yarder moves will be needed, and generally the moves made will be short distance moves to improve deflection. Guyline moves will be made whenever the guyline positions are inadequate for the present road or when they interfere with yarding.

In the second situation (Figure 5), parallel yarding roads require yarder moves on each road change. In this situation, a highly mobile yarder is beneficial and can greatly reduce the time needed to rig-down, move, and re-rig a yarding system.

The decision involving guylines is a key decision. For yarder moves on machines equipped with vertical towers or using rigged trees with several guylines, the guylines will also be moved. On a leaning boom tower using few guylines, it may be possible to move the yarder and continue to use the same guyline anchors without rigging down and re-rigging the guylines. This decision depends on the physical characteristics of the setting and the knowledge of the rigging slinger or hooktender who should be aware of critical forces on the yarder tower.

Systems Descriptions

The following yarding operations were observed in 1973 and 1974 on the Pansy Creek Basin of the Mt. Hood National Forest. Road changing was not timed in detail on these operations. Complete descriptions are listed in the Appendix (pp. 82-84).

Yarder	System
West Coast Falcon	Highlead
West Coast Falcon	North Bend
Smith-Berger Marc I	Grabinski
Skagit BU-90	Shotgun
Washington 208	Balloon, inverted skyline
Washington 608	Balloon, haulback configuration

Beginning in 1974 on the Pansy Creek Basin and continuing in studies on the Klamath National Forest in Northern California, road changing was examined in detail on the following yarding operations. Complete descriptions are listed in the Appendix (pp. 81-86).

Yarder	System
Skagit GT-3	Running skyline
Washington 108	Running skyline[1]
Skagit BU-199	Tight skyline

[1]Two operations were studied in this yarder-system combination.

The Skagit GT-3 and the Washington 108 Skylok were used on three operations where road changing was studied in detail. Figure 6 is a diagram of the running skyline system used with both yarders and Figure 7 is a diagram of the general landing and unit configuration encountered during the study.

The Skagit BU-199 yarder was used in the configuration shown in Figure 8. The haulback line was used as the chord-slopes on the yarding roads were fairly flat (average chordslope = -10.3%), making gravity return of the carriage infeasible. Figure 9 is a general diagram of the landing and unit layout of the BU-199 operation.

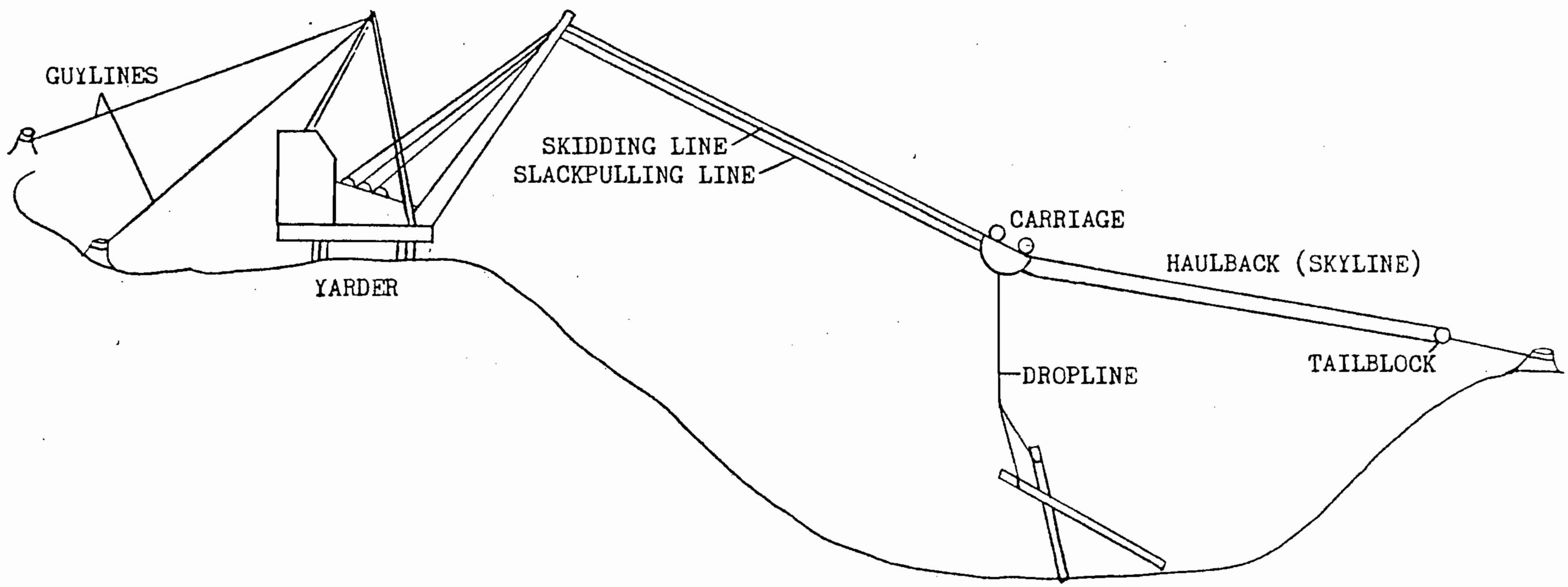


Figure 6. Running skyline with slack pulling carriage

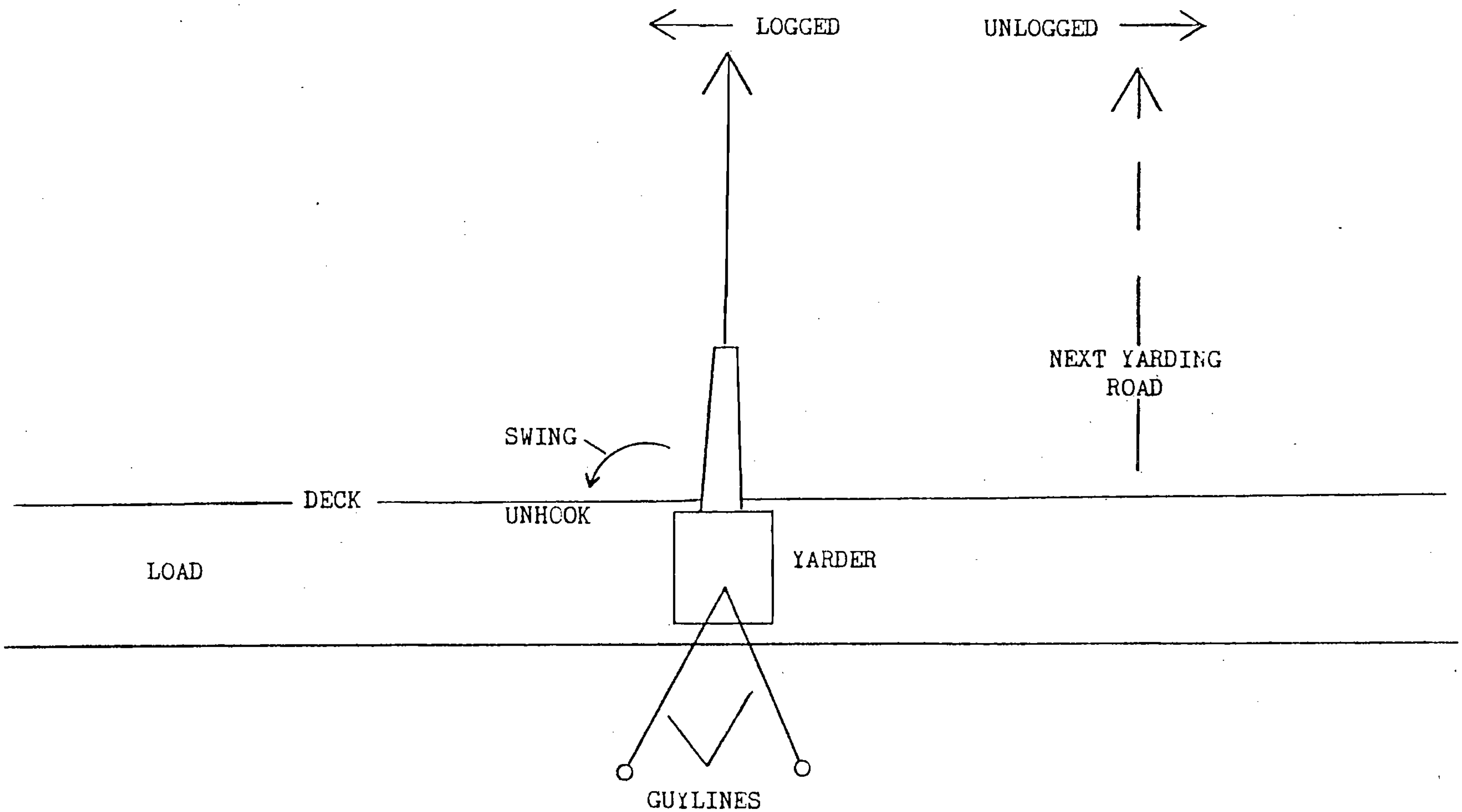


Figure 7. Running skyline road configuration used during study

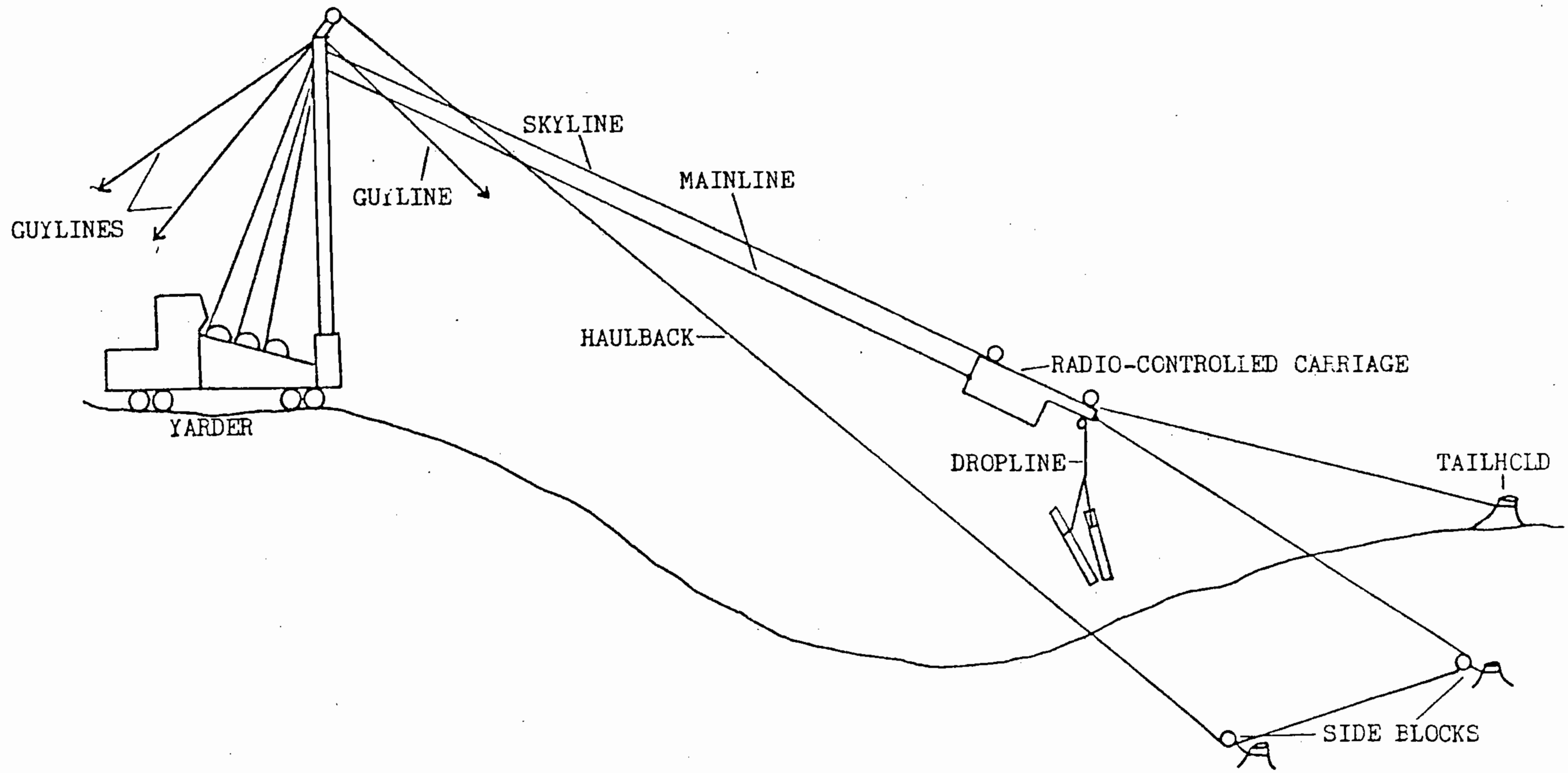


Figure 8. Long span skyline configuration

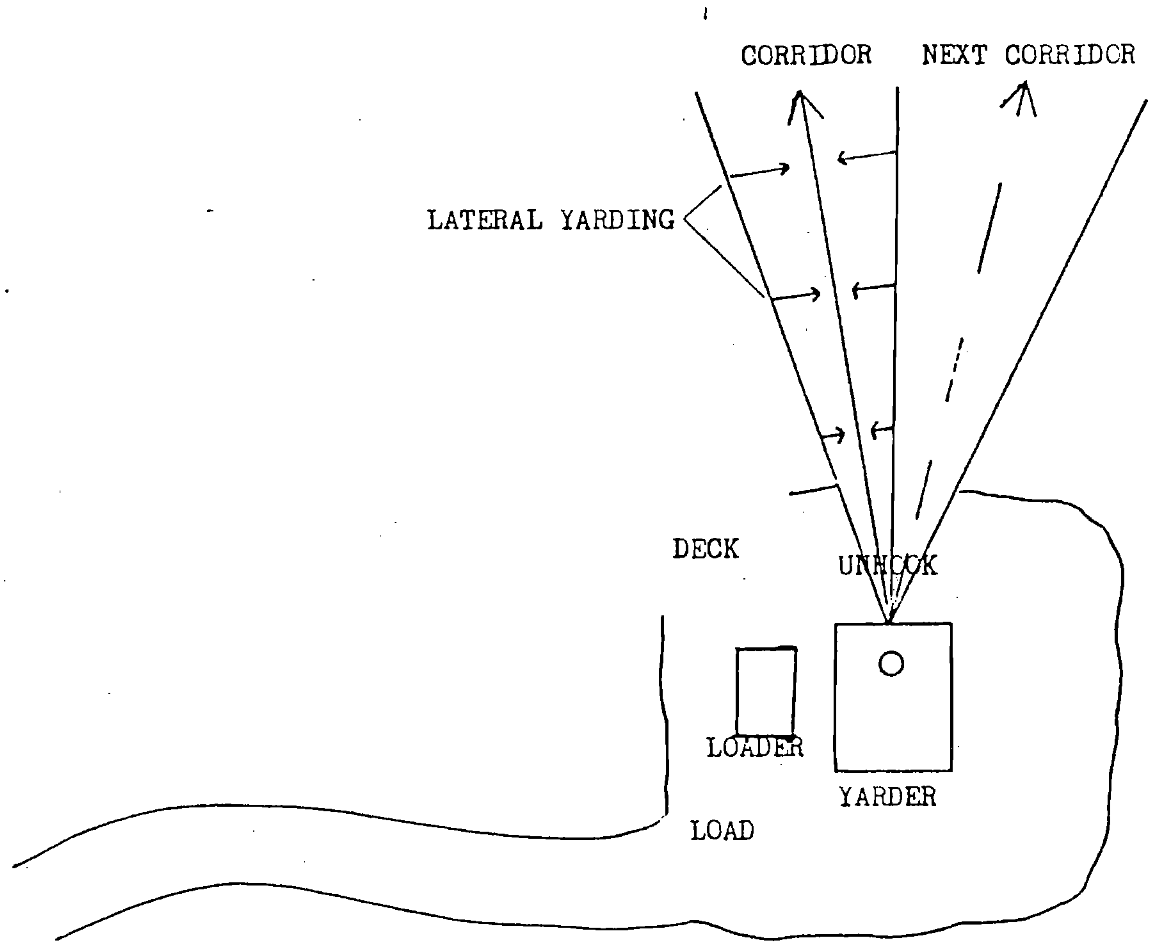


Figure 9. Long span skyline road configuration

The Study Units

The terrain in the study areas was generally steep and rugged. The only downhill yarding observed was in the case of the two balloon systems studied. This is important to the analysis, as downhill yarding could involve different methods of road changing due to the difficulties involved in laying haywire and holding tension on operating lines during road changes.

The 1973 studies were on clearcut units as was the balloon haulback system studied in 1974. All of the other operations were observed on partial cut units. The species present on the Pansy Creek Basin units were primarily Douglas-fir, (Pseudotsuga menziesii), western hemlock (Tsuga heterophylla), noble fir (Abies procera), western red cedar (Thuja plicata), western larch (Larix occidentalis) and western white pine (Pinus monticola). The timber was 150 to 200 years old and contained 40 to 85 Mbf per acre (Scribner log scale, gross volume) (Dykstra, 1975a). On the Klamath National Forest in Northern California, the primary species present were ponderosa pine (Pinus ponderosa), sugar pine (Pinus lambertiana), white fir (Abies concolor), Douglas-fir, and incense cedar (Libocedrus decurrens). Logged volume ranged from 18 to 24 Mbf (gross) per acre.

Study Procedures and Measurements

Field measurements of road changing were carried out as a supplement to time studies on yarder production.

Basic procedure

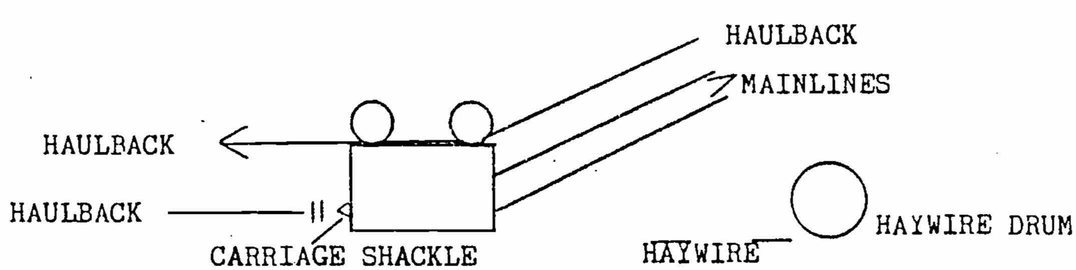
Two crewmen timed the road changing operation. One crewman stayed with the rigging crew and the other crewman remained at the landing. Timing was carried out for road changing using the continuous time study method used on the overall production study (Dykstra, 1975a). In this method of timing, watches are started synchronously in the morning and the watches run continuously throughout the day. Only the beginning time of each activity is recorded and elapsed time is obtained by subtraction. The system of continuous timing using two time study crew members is essential as the activities in road changing take place at widely separated points on the logging unit, primarily at the landing and the tailhold. The timing could be accomplished by a single man only if the tailhold and the corridor can easily be observed from the landing.

Element breakdown and coding

In this study, road changing was analyzed as a productive activity consisting of both productive and nonproductive elements. In order to do this, road changing time itself was segregated into basic elements. Elements that contributed directly to the completion of the road changing activity were termed productive activities and were coded for recording on the field data sheets shown in Figures 11 and 12. Interruptions in the road changing process were classified as delays.

Productive elements were initially isolated and coded based on the observation of road changes on the Skagit GT-3 running skyline operation. In later observations of road changing on other operations or under unusual conditions these same elements were used, but notes were made describing any variation from the basic element explained in the following discussion. The diagrams are schematic representations of the configuration of a slack pulling carriage using two mainlines.

Code	Element
1	UNHOOK HAULBACK FROM CARRIAGE Begins when the crewman (usually the chaser) approaches the carriage and ends when the haulback is completely free of the carriage. (Figure 10)



|| : Unhook activity

| : Hook activity

Figure 10. Unhook haulback from carriage

Code	Activity Description *
1	Unhook HB from carriage
2	Hook HW to HB
3	Outhaul HW (spool HB)
4	Inhaul HW
5	Handpull HW
6	Unhook HW from HB
7	Hook HB to carriage
8	Move guylines
9	Swing yarder
10	Prepare to move yarder (or re-rig)
11	Move yarder
12	Slack skyline
13	Tighten skyline
14	Move tailblock
20	Delay
30	End road change

* HB = Haulback
HW = Haywire

Figure 11. Codes for road change data sheets

TIME			
Begin	End	Activity	Comments

Date -	Unit -
System -	Road No. -
Crew size -	
Distance moved (ft.) -	Yarder -
	Tailhold -
Tailblocks	Wt. (lbs.) -
	Make -
	Size (in.) -
Straps	Diam. (in.) -
	Lgth. (ft.) -
Tailhold	Type -
	Ht. (ft.) -
	Prep. -
	Diam. (in.) -
DIAGRAM	

Figure 12. Road changing data form

Code	Element
2	HOOK HAYWIRE TO HAULBACK

Begins when the crewman grasps the haywire and ends when the haulback and haywire are connected. (Figure 13)

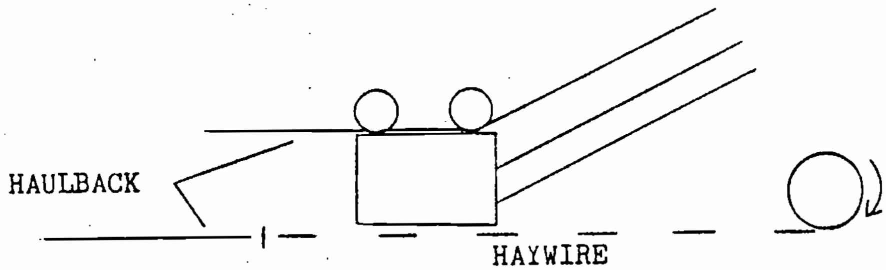


Figure 13. Hook haywire to haulback

These elements (1 and 2) were often recorded simultaneously as the operation generally was very quick, and a sharp distinction between the elements was not apparent. This was particularly true on the running skyline system. In steep uphill yarding using a running skyline, the haulback is often taut when the carriage is lowered to the landing due to the weight of the haulback downhill from the yarder. Due to this tension and the danger of letting the haulback slide down the steep slope, the haywire is often hooked to the haulback first. The haywire can then be used to pull slack in the haulback to permit unhooking of the haulback from the carriage.

Code	Element
3	OUTHAUL HAYWIRE

Begins when the haulback drum begins to turn and ends when the haulback eye is at the landing. (Figure 14)

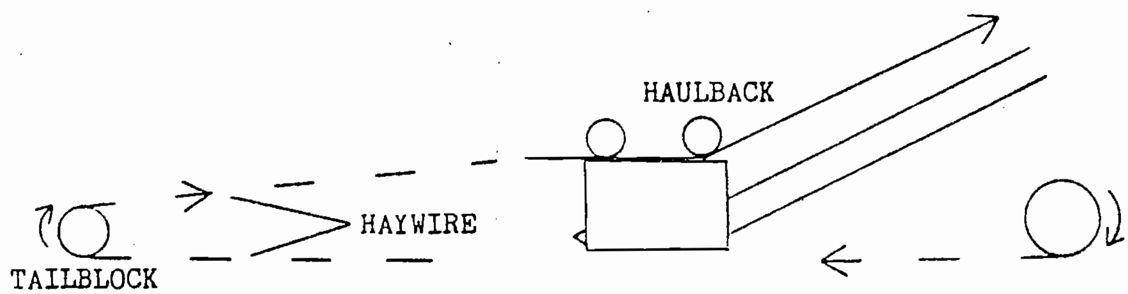


Figure 14. Outhaul haywire

Code	Element
4	INHAUL HAYWIRE
	Occurs whenever haywire is spooled on the haywire drum. If any lines are attached to the haywire they are noted. This activity begins when the haywire drum begins spooling and ends whenever the spooling is interrupted by a delay or by another element.
5	HANDPULL HAYWIRE
	Begins when any crew member begins pulling haywire by hand on the logging unit and ends whenever the pulling is interrupted.
6	UNHOOK HAYWIRE FROM HAULBACK
	Begins when the crew member approaches the connected lines and ends when the lines are no longer connected. (Figure 15)

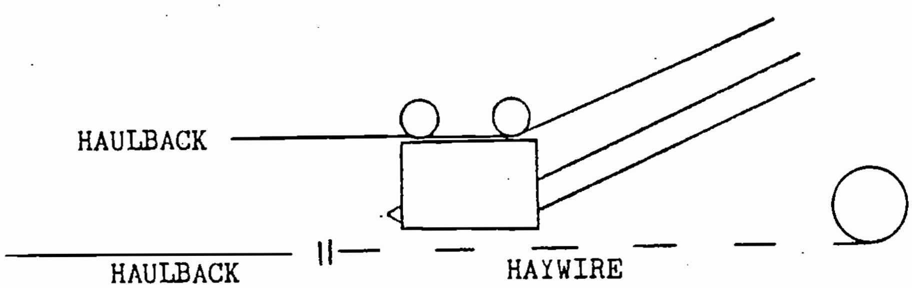


Figure 15. Unhook haywire from haulback

Code	Element
7	HOOK HAULBACK TO CARRIAGE Begins when the crew member moves the haulback eye to the carriage shackle and ends when the haulback is attached to the carriage. (Figure 16)

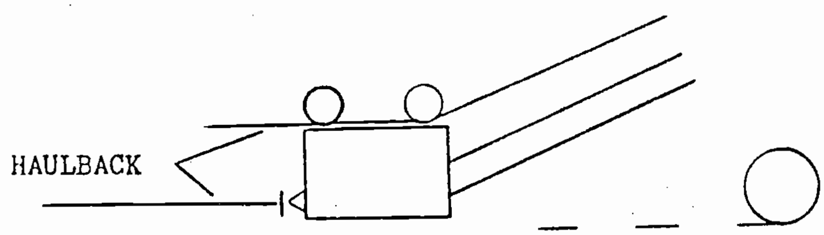


Figure 16. Hook haulback to carriage

Activities 6 and 7 also often occur together. Again, as in activities 1 and 2, the haywire is used to pull slack in the haulback and hold it until a connection between the haulback and the carriage can be made. Then the haywire is slackened, putting tension back onto the haulback, permitting the haywire to be unhooked.

Code	Element
8	MOVE GUYLINES
	Begins when crew members engage in an activity related to the moving of guylines. This may involve slackening the guylines or pulling haywire out to the guyline anchors. This activity occurs when the yarder is moved or when the guyline locations for a previous road are inadequate for the new road.
9	SWING YARDER
	In the case of the leaning boom tower, this begins when the yarder starts to turn away from the yarding road. This generally occurs in conjunction with a guyline change.
10	PREPARE TO MOVE YARDER OR RE-RIG
	This can be a number of activities related to moving the yarder and exact descriptions are noted in the comments column of the data sheets. Typical activities are: 1) raise or lower rams (outriggers) 2) raise or lower tower, and 3) load rigging on yarder.
11	MOVE YARDER
	Begins when the yarder is moving toward the new landing and ends when it stops at the new landing location.
12	SLACK SKYLINE
	This is generally the first activity on a road change and begins when the skyline drum begins spooling out and ends when the spooling out is interrupted. In the case of a running skyline system, this refers to the haulback drum.

Code	Element
13	TIGHTEN SKYLINE Generally the last element of a road change, this occurs when the system is rigged for yarding and the lines are tightened to check the configuration of the lines on the new road. At this point any problems with the new road due to inadequate deflection, lines rubbing on residual timber, etc. are corrected.
14	MOVE TAILBLOCK This activity was seldom recorded as a controlling activity as the tailblock was normally pre-rigged on the operations studied or the move occurred when other activities were controlling, such as yarder moves or guyline changes.
20	DELAY Begins when any of the coded elements are interrupted by nonproductive activities not related to road changes and ends when the productive road changing activities resume.
30	END ROAD CHANGE Recorded as the ending time of the last road changing activity observed before normal yarding activities begin on the new road.

The elements were segregated in this manner for several reasons: 1) the elements were easily distinguished for time study purposes, and 2) each element is conceptually influenced by a distinct set of variables. A specific set of variables were selected to be measured for road changing based on the hypothesized relationships listed below. For all of these elements, crew experience is assumed to be an important factor along with the number of crew members involved in the activity.

Hypothesized influencing variables

Element	Hypothesized influencing variables
1 - Unhook haulback from carriage	- Line size - Type of linkage between carriage and haulback
2 - Hook haywire to haulback	- Line size - Type of linkage between haywire and haulback
3 - Outhaul haywire	- Line speed of haulback - Distance to tailhold
4 - Inhaul haywire	- Line speed of haywire - Distance to tailhold
5 - Handpull haywire	- Distance haywire is pulled - Groundslope - Brush conditions - Soil conditions - Line size
6 - Unhook haywire from haulback	- Line size - Type of linkage
7 - Hook haulback to carriage	- Line size - Type of linkage
8 - Move guylines	- Guyline size - Distance to guyline anchors - Number of guylines - Groundslope - Brush - Soil conditions - Line size
9 - Swing yarder	- Distance to be swung - Speed of swing

Element	Hypothesized influencing variables
10 - Prepare to move yarder or re-rig	- Yarder type
11 - Move yarder	- Yarder speed - Distance to next landing - Grade - Width of logging road - Curve size and number - Yarder dimensions
12 - Slacken lines	- Drum speeds - Deflection
13 - Tighten lines	- Drum speeds - Deflection
14 - Move tailblock	- Distance - Block size - Strap size - Groundslope - Brush and soil conditions

As this was a first attempt at analyzing road changing in detail, both the beginning and ending times of an element were recorded. This was done in order to monitor all activities taking place. For example, haywire could be pulled while guylines were being slackened (Figure 17).

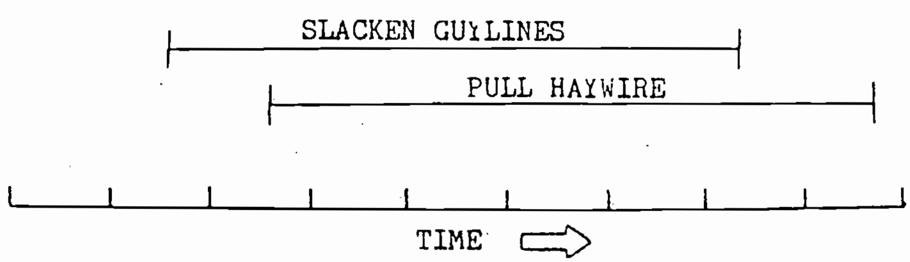


Figure 17. Example of simultaneous activities

In the data analysis only one activity was considered the controlling activity; that is, the one most critical to the completion of road changing.

Road Changing Procedures

Running skyline

The following is a list of road changing procedures observed on the Skagit GT-3 running skyline operating with a slack pulling carriage. Figures 18 through 27 illustrate the steps involved. The same procedures were used on the Washington 108 running skyline operations with the exception of Step #7 (Figure 23). For this step the procedures shown in Steps 7a through 7d were substituted (Figures 24 and 25). The alteration in procedure was most likely due to the steep terrain encountered in the Washington 108 operations making Step #7 very difficult, as it requires pulling the haywire uphill. The road profiles on the Washington 108 operations were in some cases concave, requiring some uphill pulling of haywire, but the adverse slopes were fairly short. If longer uphill pulls were encountered, it is likely that coils of haywire would have been shipped back on the rigging and strung downhill from the new tailblock.

A possible alternate method not used on the operations observed would be to lay both sections of haywire simultaneously by anchoring the free haywire end to the yarder and pulling the bight of the haywire to the tailhold and placing it in the block. This could have several advantages as only one crewman would be required to walk to the tailhold, uphill pulling of haywire to the yarder would be avoided and the danger of having wraps in the operating lines following road changing would be reduced.

Figure 28 is an illustration of the procedure used in changing roads when deflection blocks are used. Haywire is hung through the tailblock and deflection blocks when the tree is rigged. Road changing then proceeds normally.

Step #	Activity
1	Lower carriage to landing
2	Unhook haulback from carriage
3	Hook haywire to haulback
4	Inhaul haulback (outhaul haywire)
5	Unhook haywire from haulback
6	Inhaul haywire (may bring in blocks, etc.)
7	Handpull haywire around unit and back to landing
8	Hook haywire to haulback
9	Inhaul haywire (outhaul haulback)
10	Unhook haulback from haywire
11	Hook haulback to carriage
12	Tighten lines

End road change

7a	Pull haywire to new anchor point
7b	Unhook this section of haywire at the landing
7c	Pull second section of haywire to the new anchor-point
7d	Hook the two sections of haywire together at the new anchor-point

Continue with Step #8

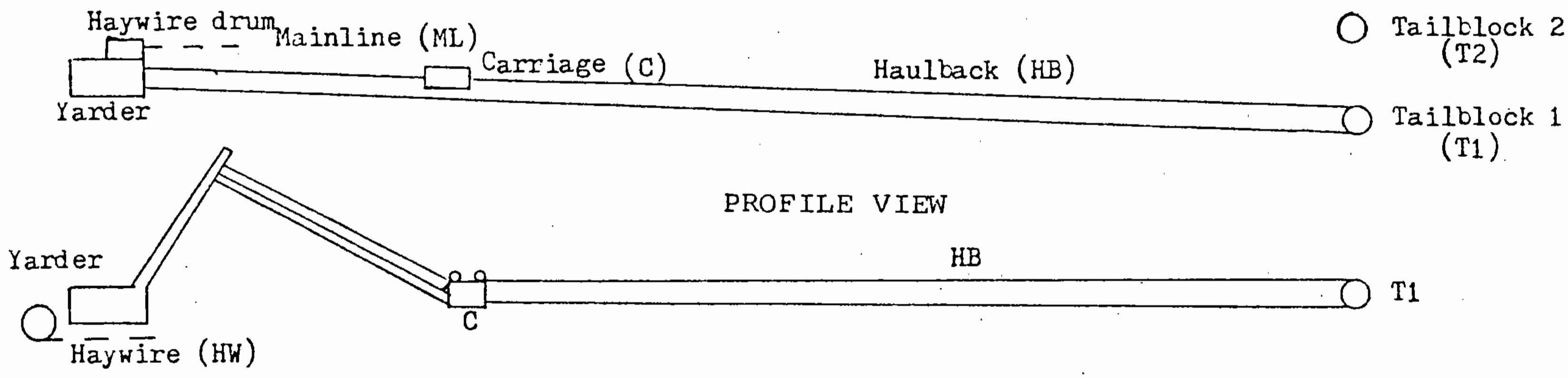


Figure 18. Step #1, running skyline: lower carriage to landing

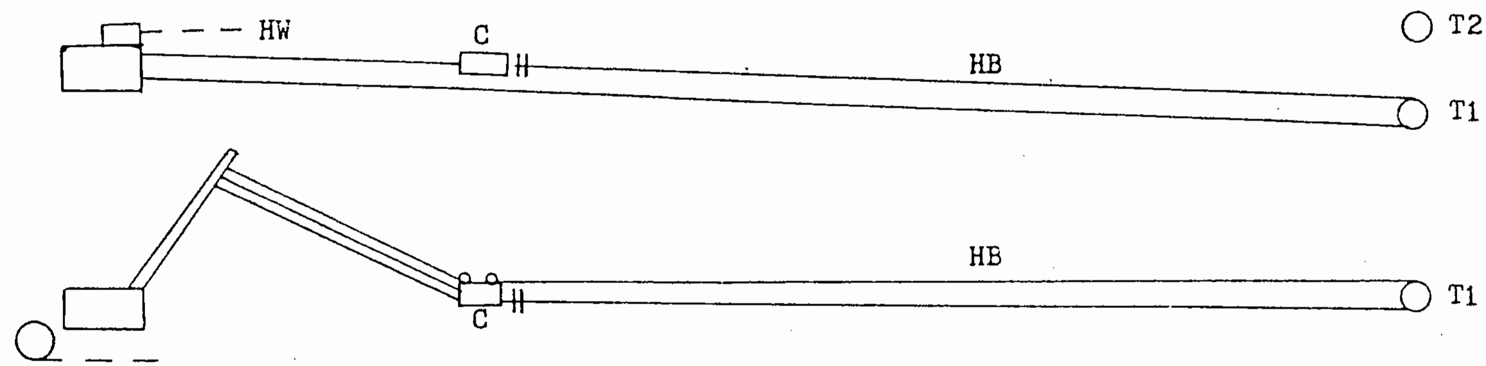


Figure 19. Step #2, running skyline: unhook haulback from carriage

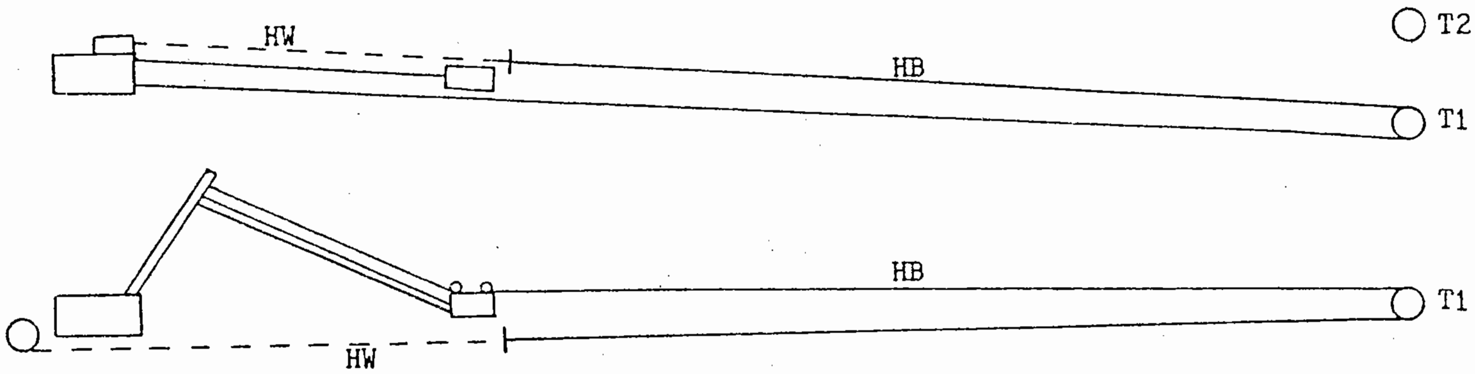


Figure 20. Step #3, running skyline: hook haywire to haulback

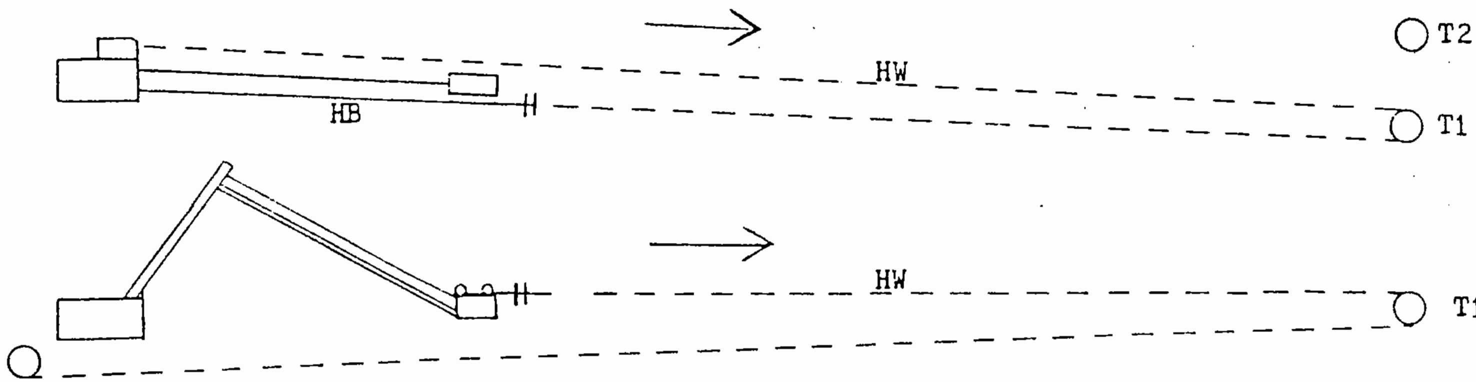


Figure 21. Steps #4 and #5, running skyline: inhaul haulback, unhook haywire from haulback

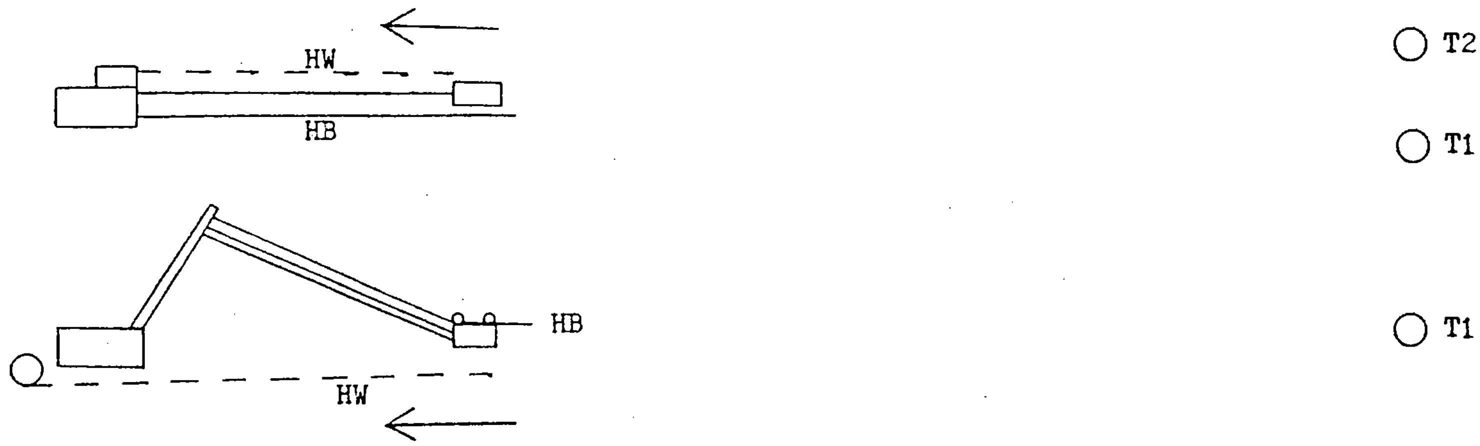


Figure 22. Step #6, running skyline: inhaul haywire

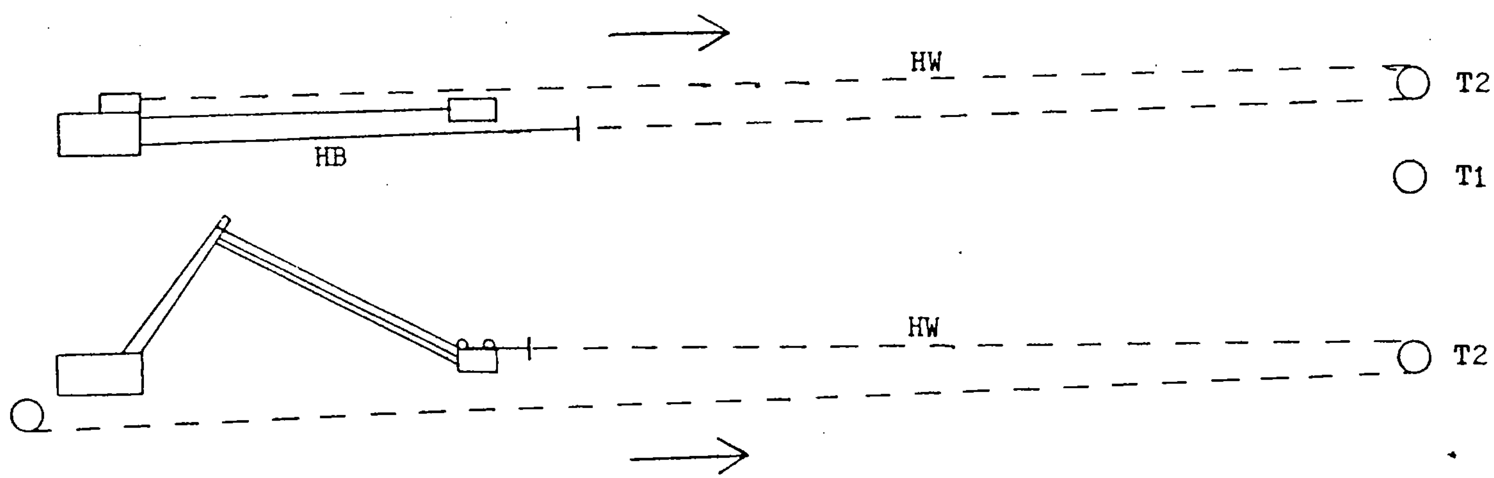


Figure 23. Steps #7 and #8, running skyline: handpull haywire around unit, hook haywire to haulback

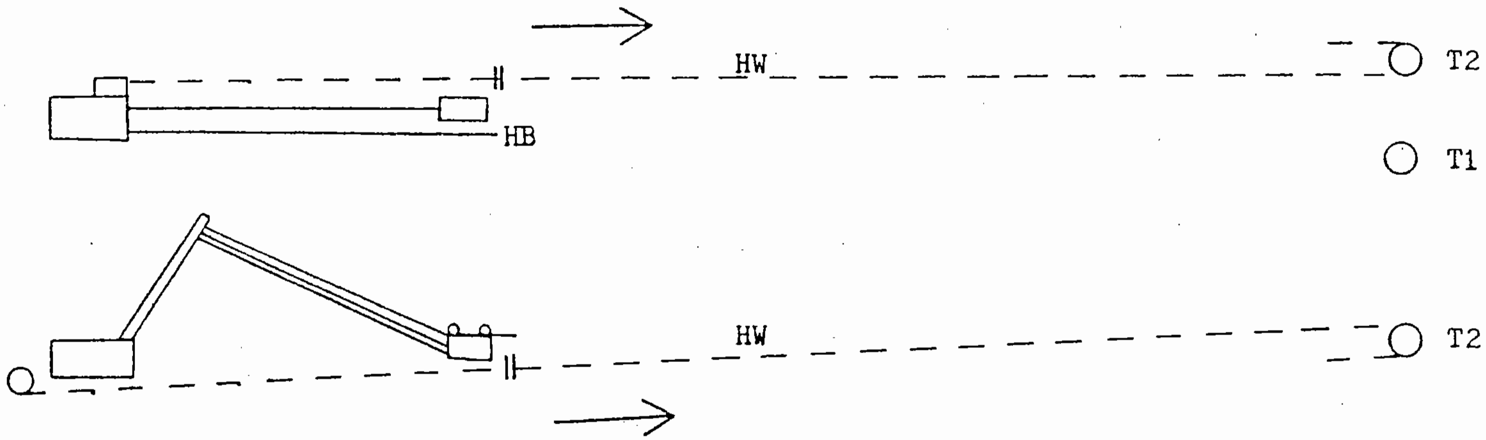


Figure 24. Steps #7a and #7b, running skyline: pull haywire to new anchor-point, unhook haywire section at landings

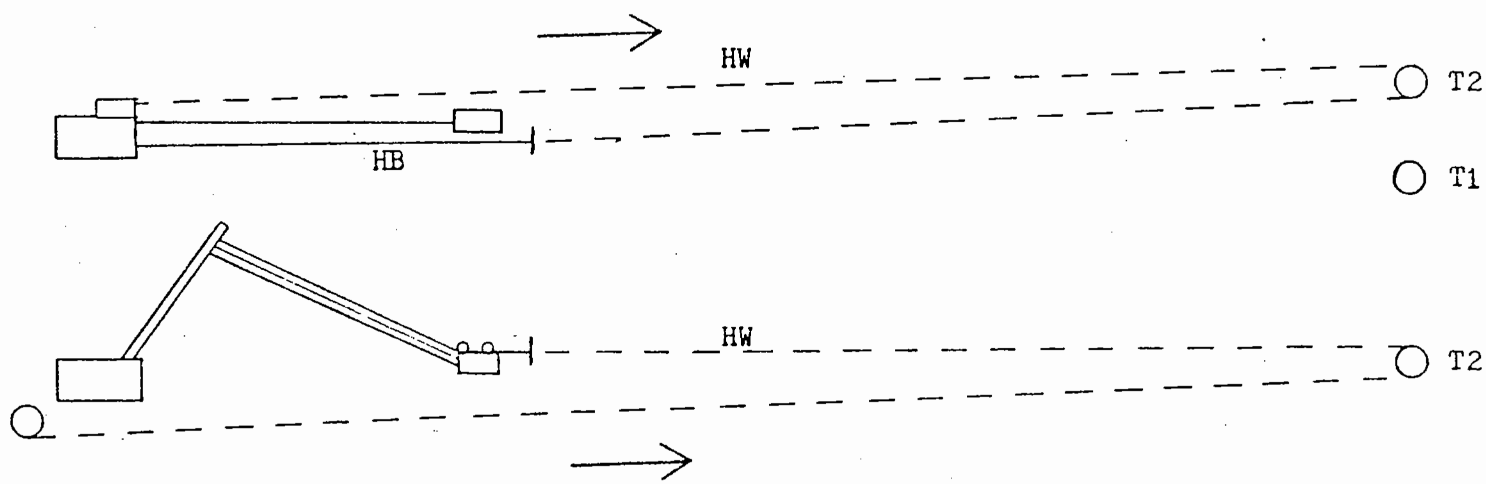


Figure 25. Steps #7c, #7d and #8, running skyline: pull second section of haywire to anchor-point, hook haywire sections together, hook haywire to haulback

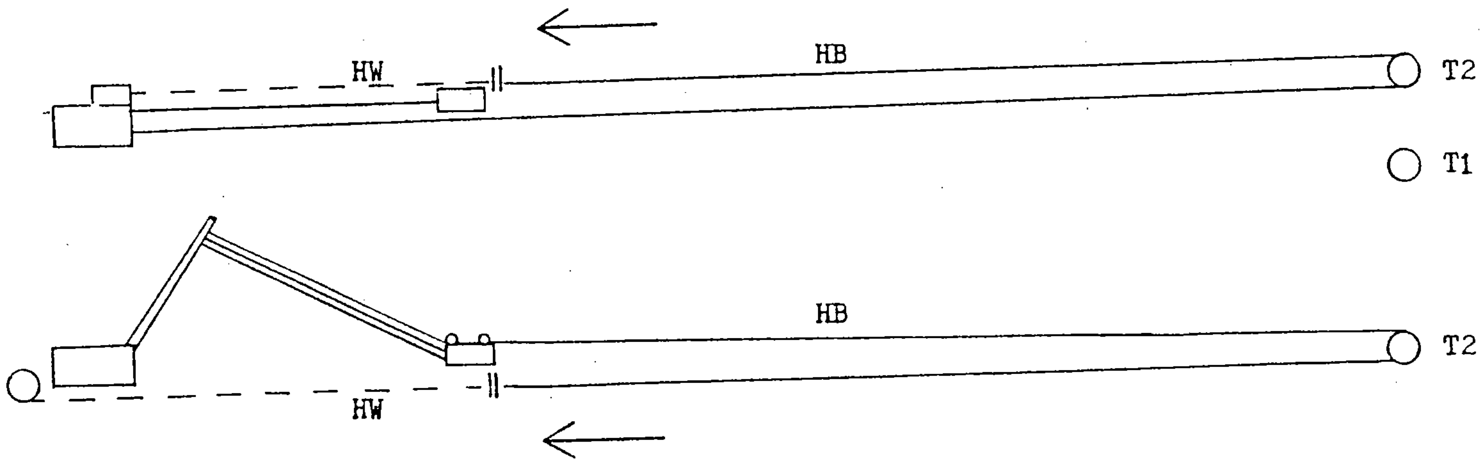


Figure 26. Steps #9 and #10, running skyline: inhaul haywire, unhook haulback from haywire

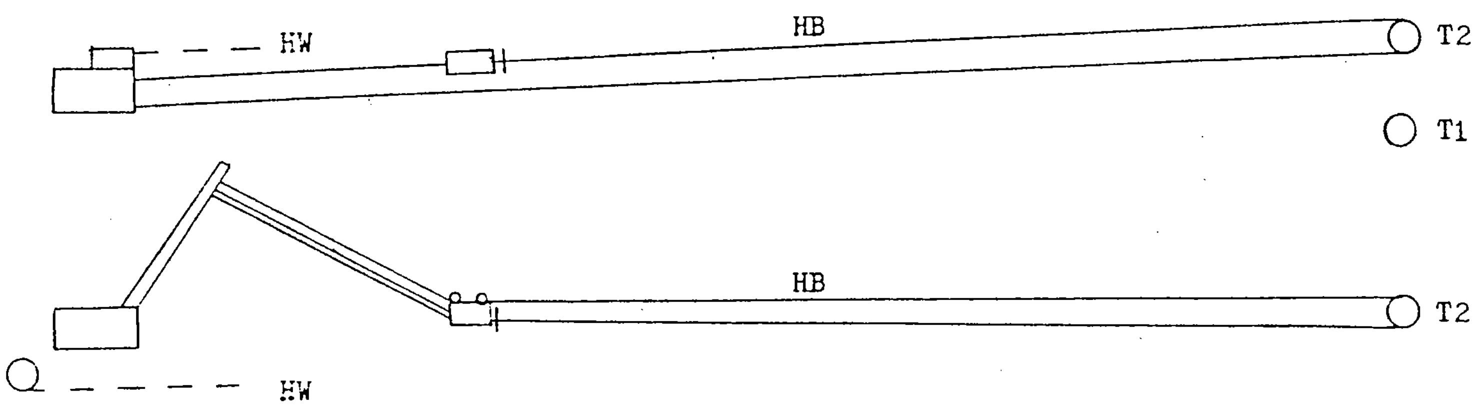


Figure 27. Steps #11 and #12, running skyline: hook haulback to carriage, tighten lines

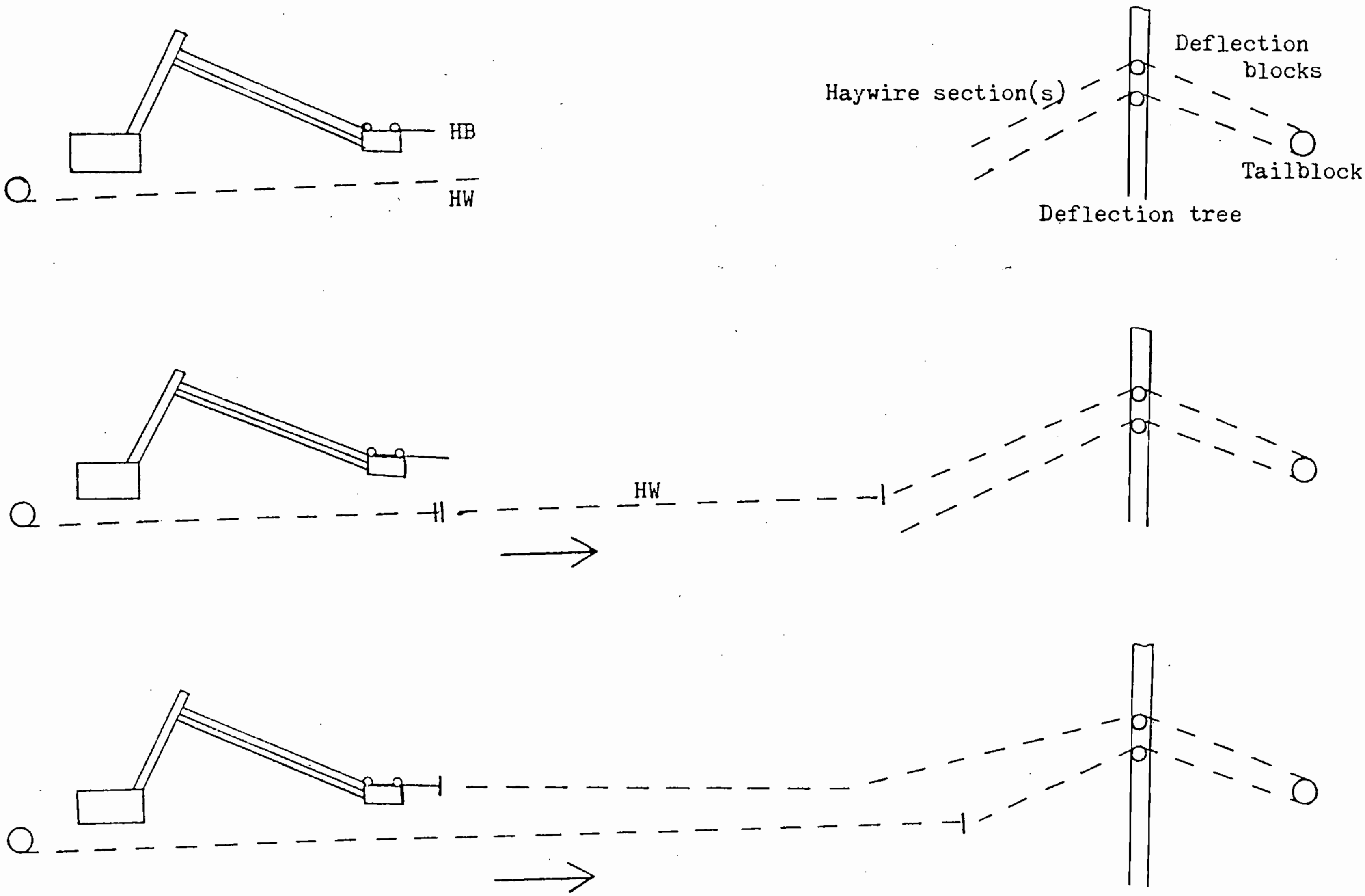


Figure 28. Procedure change for use of deflection on running skyline

Tight skyline

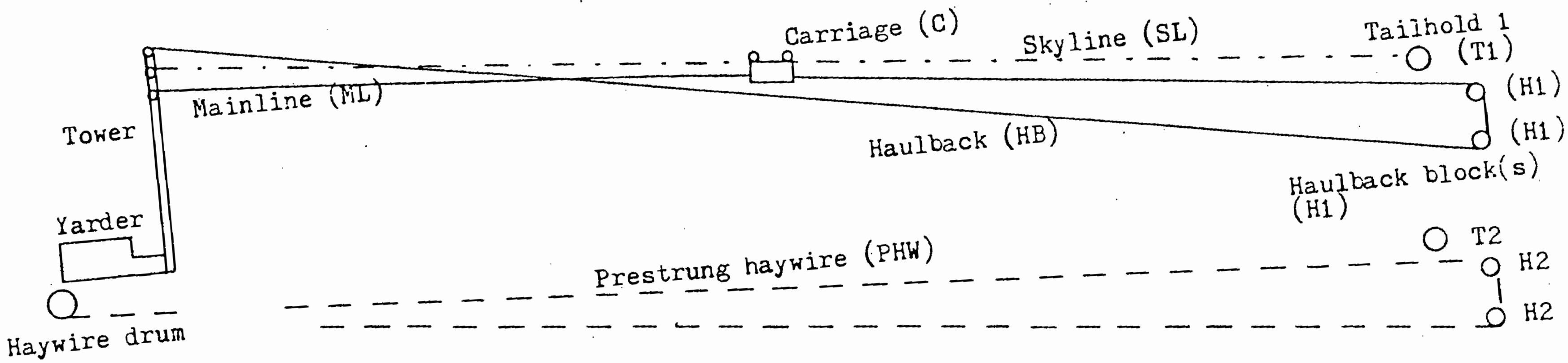
The following steps were followed during road changing on the Skagit BU-199 tight skyline operation with a radio-controlled carriage. These steps are illustrated in Figures 29 through 39.

This is a road changing procedure used in a partially cut unit. Road changing in a clearcut unit most likely would follow a different procedure.

Step #	Activity
1	Lower carriage and shut off engine
2	Unhook haulback from carriage
3	Hook haywire to haulback
4	Inhaul haulback (outhaul haywire)
5	Unhook haywire from haulback
6	Inhaul haywire (with blocks)
7	Lower carriage
8	Remove skyline from carriage
9	Hook haulback to pre-strung haywire and pre-strung haywire end to haywire drum
10	Inhaul haywire (outhaul haulback)
11	Hook skyline to haulback
12	Inhaul haulback (outhaul skyline and haywire)
13	Hook skyline to tailhold

Step #	Activity
14	Unhook haulback from skyline
15	Inhaul haywire (outhaul haulback)
16	Unhook haywire from haulback
17	Hook haulback to carriage
18	Thread skyline through carriage sheaves
19	Tighten skyline

End of road change



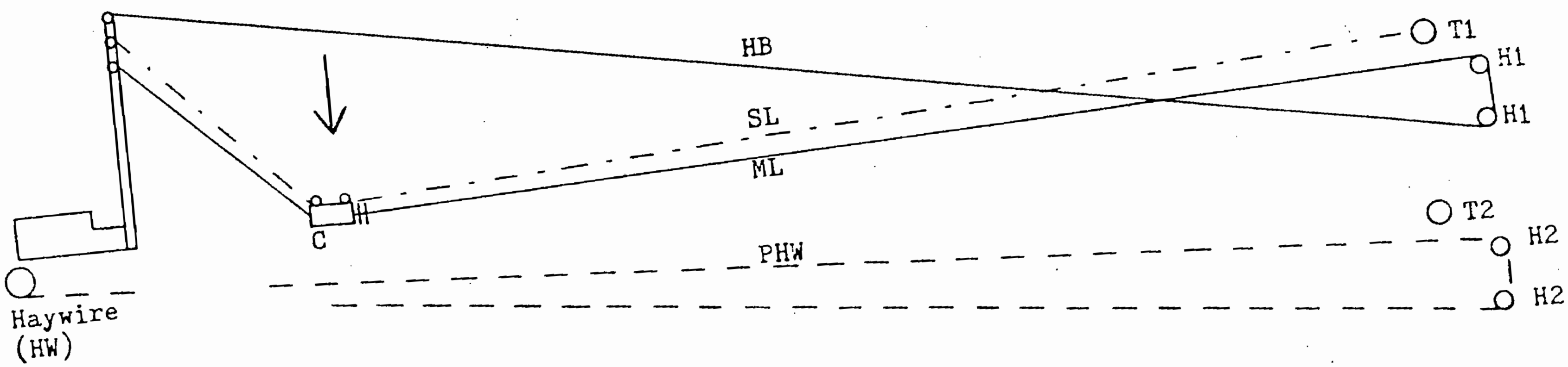


Figure 29. Steps #1 and #2, tight skyline: lower carriage and shut off engine, unhook haulback from carriage

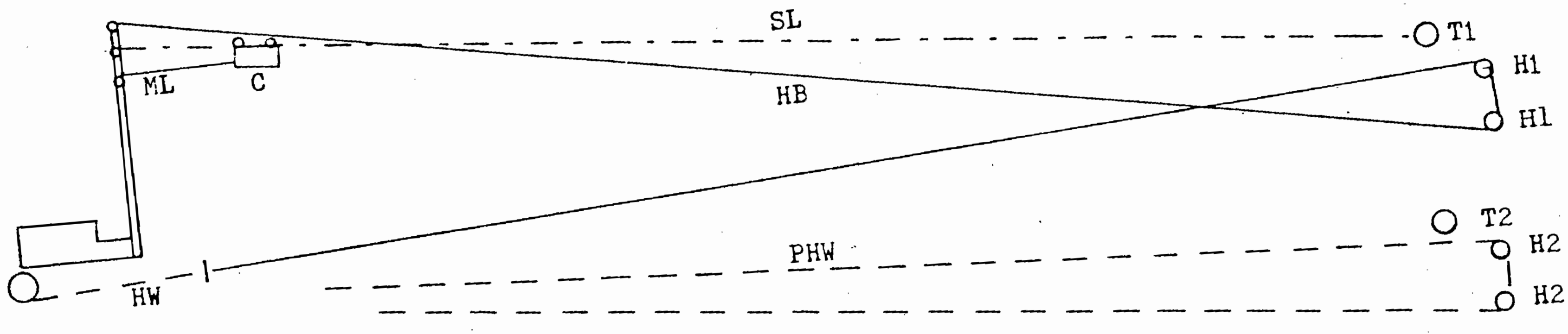


Figure 30. Step #3, tight skyline, hook haywire to haulback

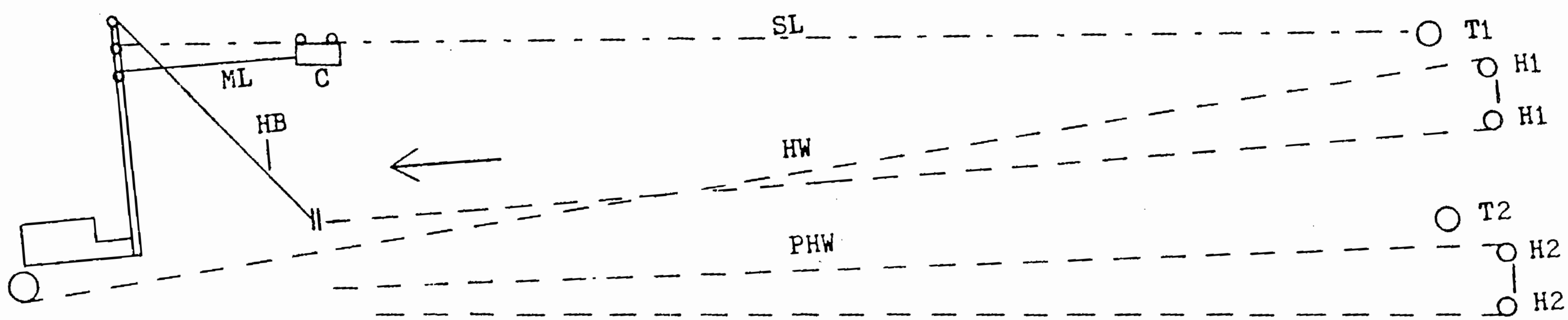


Figure 31. Steps #4 and #5, tight skyline, inhaul haulback, unhook haywire from haulback

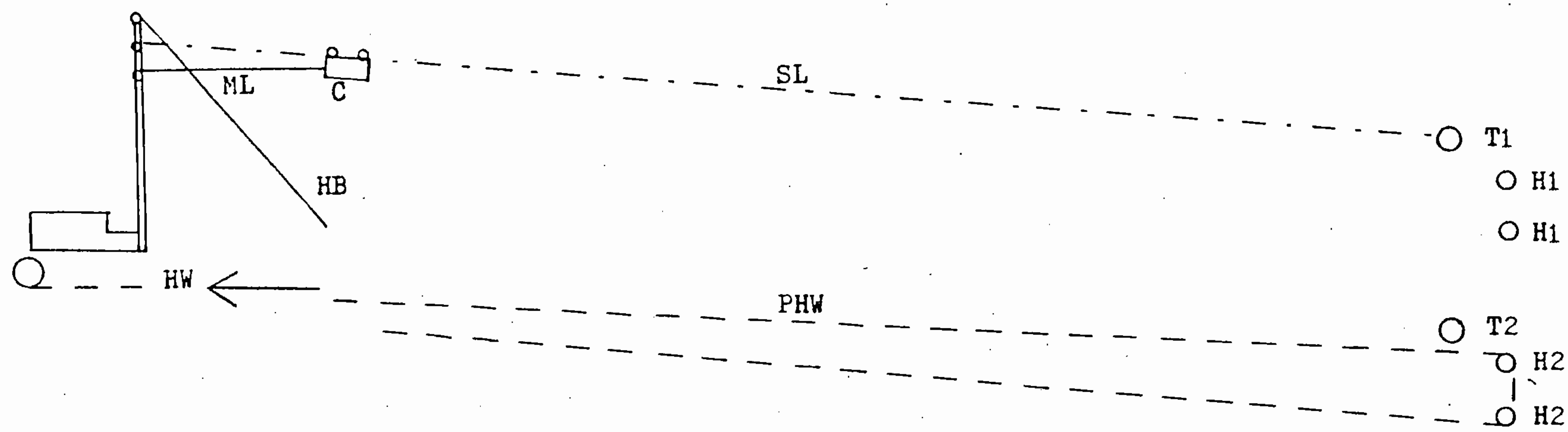


Figure 32. Step #6, tight skyline, inhaul haywire

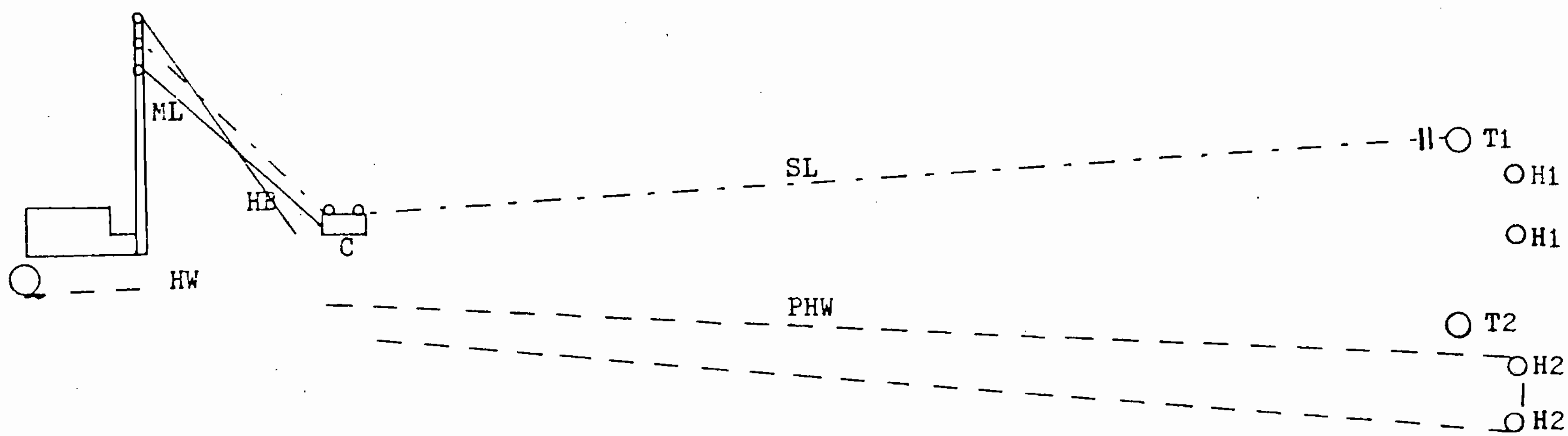


Figure 33. Step #7, tight skyline, lower carriage

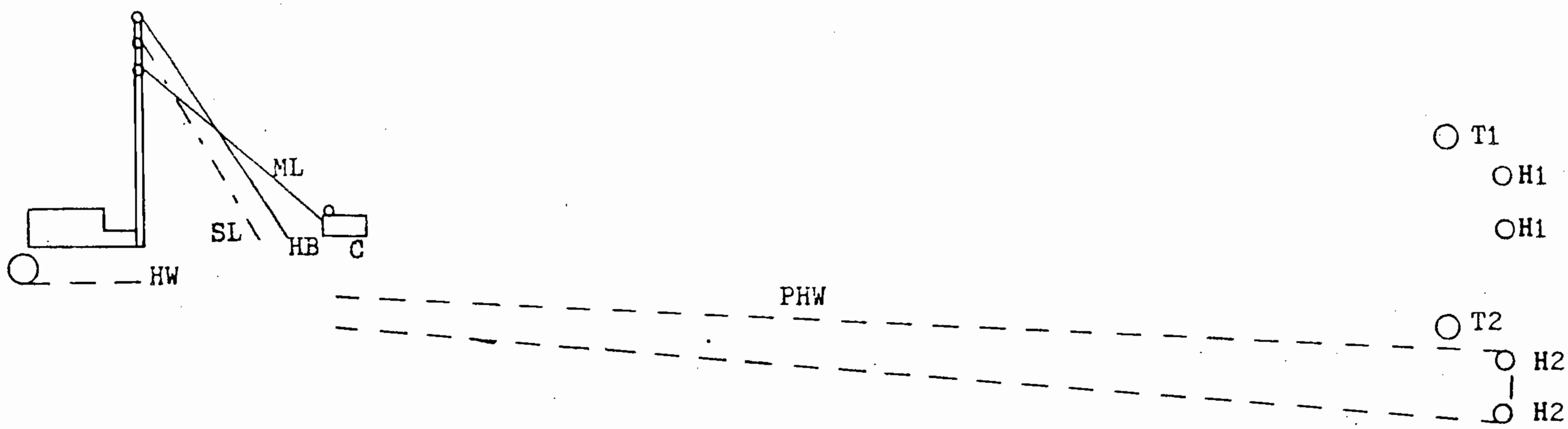


Figure 34. Step #8, tight skyline, remove skyline from carriage

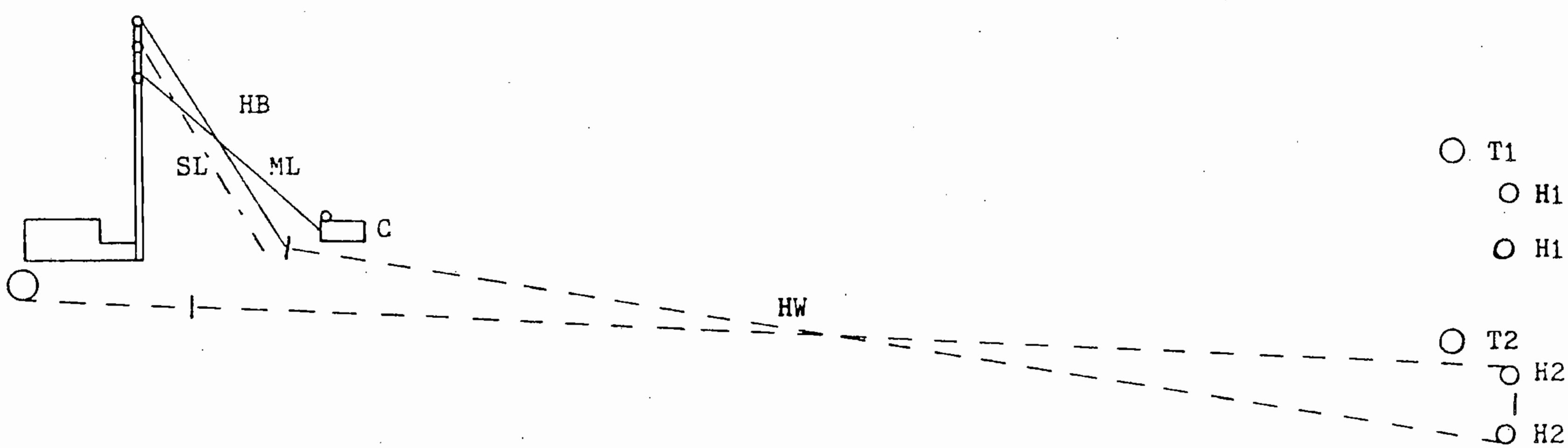


Figure 35. Step #9, tight skyline, hook pre-strung haywire ends to haulback and to haywire drum

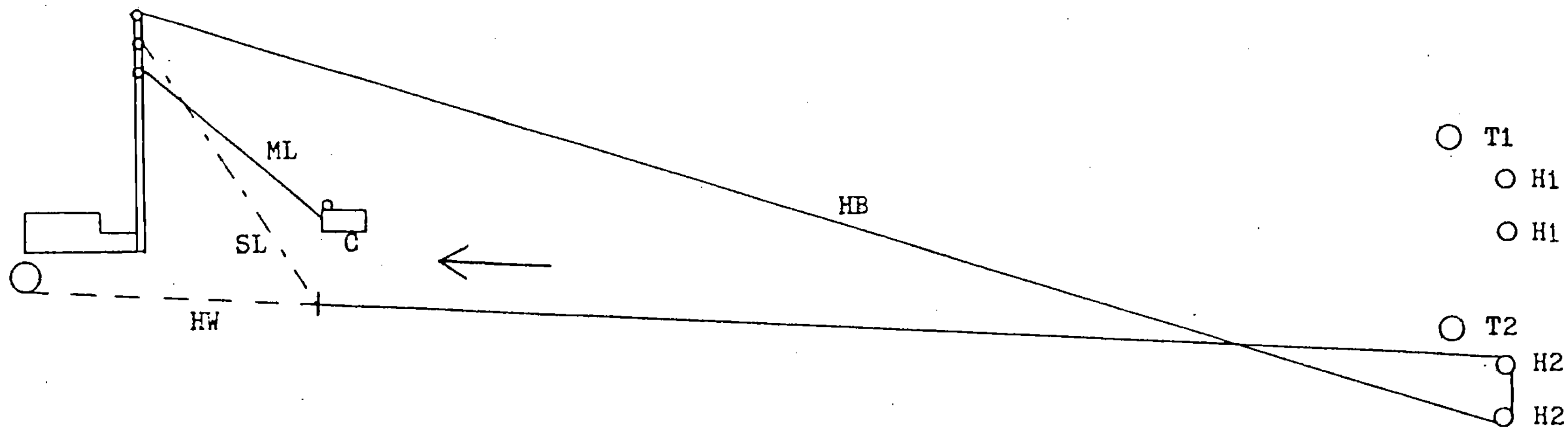


Figure 36. Steps #10 and #11, tight skyline, inhaul haywire, hook skyline to haulback

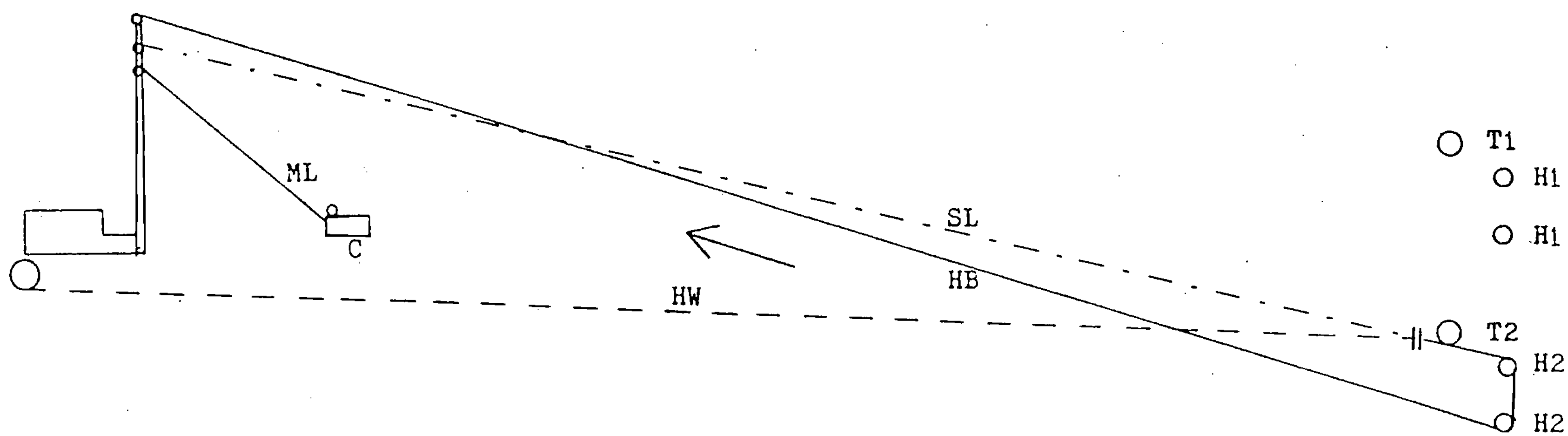


Figure 37. Steps #12, #13 and #14, tight skyline, inhaul haulback, hook skyline to tailhold, unhook haulback from skyline

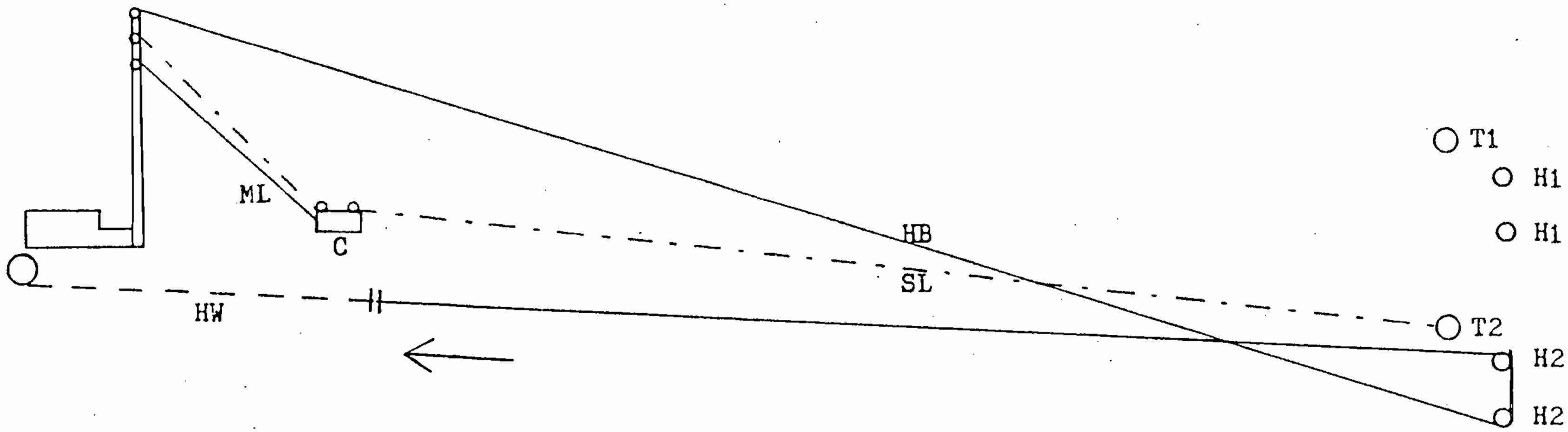


Figure 38. Steps #15 and #16, tight skyline, inhaul haywire, unhook haywire from haulback

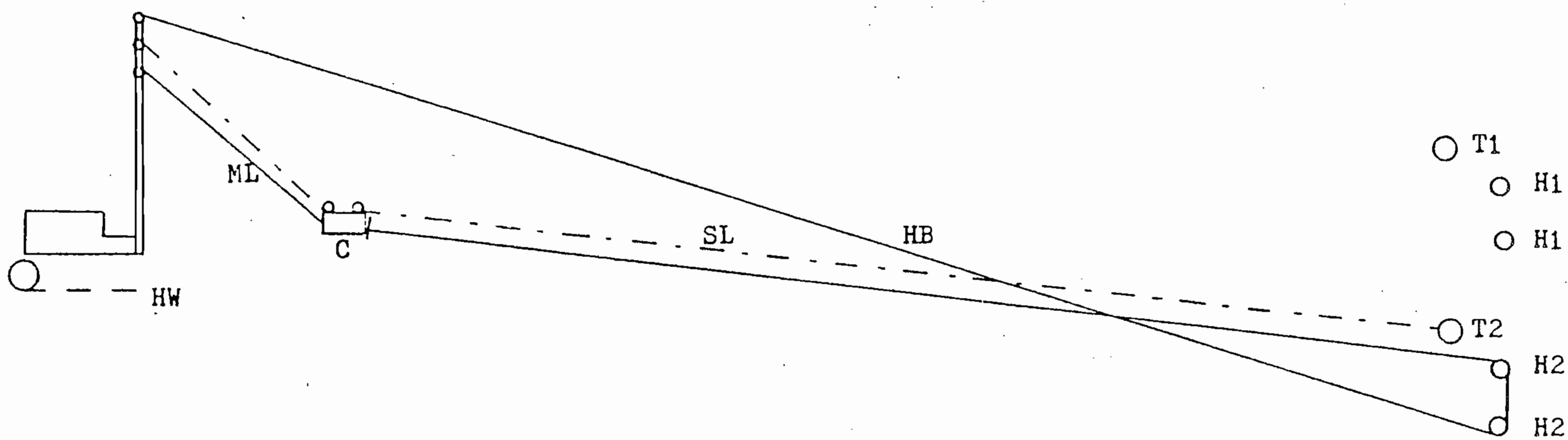


Figure 39. Steps #17 and #18, tight skyline, hook haulback to carriage, thread skyline through carriage sheaves

Descriptive Analysis

General analysis

Table 1 lists some of the characteristics of the yarding operations which are of interest in an analysis of road changing.

For the ten observations shown in Table 2, average road changing time can be seen to vary widely from 12.8 minutes on the North Bend system to 106.9 minutes on the Washington 108 running skyline operation.

The average road changing times in Table 2 reflect road changing times on operations studies in 1973, 1974 and 1975. During this time 78 road changes were timed. At times the crews in 1973 and 1974 did not time some road changes. This analysis demonstrates the difficulty involved in obtaining a large sample of road changes within a system. On the four running skyline systems, more road changes were timed due to the high mobility of these yarders and the relatively short yarding distances observed.

The excessive duration of the maximum times recorded can be attributed to lengthy delays rather than excessively long productive operations. For example, on the longest maximum time recorded for the Washington 108 (Crew #1) of 238.7 minutes, over 40 percent was due to a delay involving improper spooling of the haulback. As the analysis becomes

TABLE 1. CHARACTERISTICS OF THE YARDING OPERATIONS, AVERAGE VALUES

SYSTEM	SPAN* (ft.)	CHORD-SLOPE (%)	GROUND-SLOPE (%)	SOIL*	BRUSH*	CREW SIZE	NO. OF ROADS	NO. OF LANDINGS	PRODUCTION (Mbf/hr)
Highlead	530 (162 m)	- 9.9	10.9	0.2	0.9	5	4	1	2.7
North Bend	440 (134 m)	-19.8	27.2	0.0	0.0	5	4	1	6.6
Grabinski	760 (232 m)	-34.4	29.7	0.0	0.0	5	7	10	6.5
Shotgun	1,310 (399 m)	-44.3	67.2	0.0	0.0	6	11	1	6.4
Balloon, inverted skyline	1,520 (463 m)	26.8	30.8	0.1	1.0	5	2	1	5.5
Balloon, haulback	1,590 (485 m)	33.6	57.4	0.3	1.2	7	6	2	5.5
GT-3 running skyline	500 (152 m)	-16.0	18.9	0.0	1.0	5	18	10	3.6
Washington 108, running skyline, Crew #1	475 (145 m)	-41.3	38.4	0.0	0.0	6	10	9	4.5
Washington 108, running skyline, Crew #2	381 (116 m)	-45.6	43.0	0.0	0.1	6	12	12	4.2
BU-199 skyline w/radio-controlled carriage	1,114 (340 m)	-10.3	47.4	0.0	0.1	6	4	2	9.6

* SPAN = the total horizontal distance between the headspar and the tailhold

TABLE 1. (continued) CHARACTERISTICS OF THE YARDING OPERATIONS, AVERAGE VALUES

* Subjective values were assigned to account for soil and brush conditions on the unit. (Dykstra, 1975a)

Soil:
1) firm, even footing - solid and dry soil
2) muddy, slippery, or loose gravel
3) rocky, gravel-strewn, or otherwise hazardous footing

Brush:
1) light or nonexistent - does not restrict movement
2) medium - causes some difficulty in moving
3) heavy - hampers movement considerably

TABLE 2. DESCRIPTIVE ANALYSIS

ROAD CHANGING TIME - MINUTES

YARDER	SYSTEM	MINIMUM TIME	MAXIMUM TIME	AVERAGE TIME
West Coast	Highlead	14.0	22.2	17.3
West Coast	North Bend	5.1	29.0	12.8
Berger Marc I	Grabinski	18.6	41.9	29.1
Skagit BU-90	Shotgun	10.5	107.4	46.1
Washington 208	Balloon, inverted skyline	74.4	74.8	74.6
Washington 608	Balloon, haulback	41.4	119.2	68.1
Skagit GT-3	Running skyline	15.6	91.9	44.0
Washington 108	Running skyline Crew #1	30.0	238.7	98.2
Washington 108	Running skyline Crew #2	74.5	189.0	106.9
Skagit BU-199	Tight skyline w/RCC-15	43.9	130.8	85.2

more detailed, the large influence of delays on road changing time will become more apparent.

Based on the information in Table 2, a comparison can be made between the four running skyline systems timed. The Grabinski system is a form of running skyline closely related in configuration to the other three running skylines (Appendix, Figure 47). Since the Grabinski system was used on a clearcut unit and the other three systems operated on partial cut units, it could be suggested that the reason for the lower average time required to change roads on the Grabinski system was due to the cutting prescription on the unit. This is probably true since the road changing method on a clearcut could be considerably different than methods used on a partial cut, but it is not possible to come to this conclusion based on the information in Table 2. In the method of timing used, yarder moves were included in total road changing time. Therefore, before comparing these systems it is necessary to remove the effect of yarder moves, since on the partial cuts yarder moves occurred on 55-100% of the road changes for a given system. On the Grabinski system, the yarder was not moved on any of the seven road changes timed.

As the three running skylines on partial cuts were timed in detail, the effect of yarder moves can be eliminated from total road changing time (Table 3). Yarder moves include rigging down the guylines, preparing the yarder for moving, moving the yarder and re-rigging the guylines.

Now it can be hypothesized that cutting perscription influences road changing time. Unfortunately this can neither be confirmed nor denied, based on the information in the more detailed analysis, as none of the operations examined in detail were in clearcuts. The reasons for lower expected average road changing time on clearcut units may include: 1) better visibility of ground conditions which aids in layout and reduces hangups, 2) residual timber does not have to be removed from the yarding corridor, and 3) operating lines can be pulled across the unit rather than restringing them from the landing. The effects of span and slope may prove to be more critical.

Road changing methods vary among systems, equipment and crews. This fact, coupled with changes in groundslope, span, soil and brush conditions and other logging unit characteristics, make an overall comparison of road changing between operations difficult, if not impossible, without very detailed information concerning road changes made. Thus, it is incorrect to assume that road changing on a Washington 108 running skyline is subjectively more difficult than road changing on any of the other operations. On the North Bend operation, three of the changes timed were actually corner block changes, and in only one timed sequence of activities the skyline was moved to a new corridor. In instances where this happens, the two operations, corner block changes and skyline location changes, should be treated separately as they vary widely in duration and procedure.

Detailed analysis of road changing

For the purpose of examining road changing in detail, it is useful to group the elements of road changing under four categories: 1) machine intensive activities, 2) labor intensive activities, 3) activities related to yarder moves, and 4) delays (Figure 40).

Machine intensive activities are those road changing activities carried out by yarder power. The following elements of road changing previously described (see Figure 11) fall into this category:

Code	Description
3	Outhaul haywire or spool haulback
4	Inhaul haywire
12	Slacken skyline
13	Tighten skyline

Labor intensive activities are those road changing activities carried out by yarding crew members. The following elements of road changing fall into this category:

Code	Description
1	Unhook haulback from carriage
2	Hook haywire to haulback

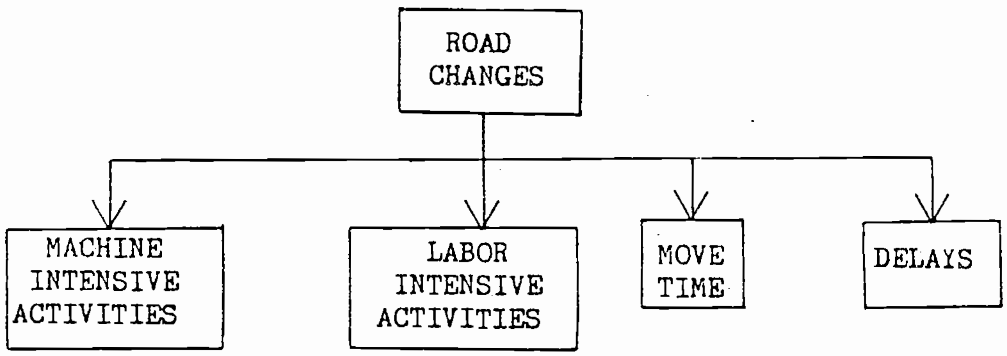


Figure 40. Road changing breakdown

Code	Description
5	Handpull haywire
6	Unhook haywire from haulback
7	Hook haulback to carriage
14	Move tailblock

Several activities are related only to yarder moves. These activities are segregated from other road changing activities for two reasons: 1) the activities do not occur on all road changes, but only on those where the landing is changed and 2) in general, the activities involved are not influenced by the independent variables most strongly influencing the other road changing activities.

On the average, delays may consume as much as 49% of total road changing time (Table 3). On three of the operations studies, delays consumed a fairly consistent average of 30-32% of road changing time. This factor may be important if this percentage is repeated in other operations. Future studies may confirm or deny this.

Since delays consume such a high percentage of road changing time, a short discussion concerning the nature of these delays is useful.

On the GT-3 running skyline operation, common delays included repairing or replacing haywire, clearing residual timber from the yarding corridor and rechanging roads if a stump was pulled or if deflection was inadequate. The most

TABLE 3. DETAILED DESCRIPTIVE ANALYSIS OF ROAD CHANGING ON FOUR YARDING OPERATIONS
(Time in minutes)

OPERATION	AVERAGE TOTAL TIME	AVERAGE TOTAL TIME LESS DELAYS	AVERAGE TOTAL TIME LESS DELAYS AND MOVE TIME	MOVE TIME AS % OF TOTAL TIME	DELAY TIME AS % OF TOTAL TIME	AVERAGE SPAN (feet)	NO. ROADS TIMED IN DETAIL
Skagit GT-3 running skyline	48.1	24.8	16.5	17	49	481 (147 m)	9
Washington 108 running skyline, Crew #1	102.1	69.7	36.1	33	32	475 (145 m)	10
Washington 108 running skyline, Crew #2	106.9	75.1	26.6	45	30	381 (116 m)	13
Skagit BU-199 w/RCC-15	85.2	59.7	59.7	0	30	1,114 (339 m)	4

common and frequent delay was that of straightening and respooling lines on the slack pulling carriage. Crew experience, particularly the experience of the hooktender or rigging slinger, would tend to reduce delays relating to the first two delays involving haywire problems and rechanging of roads. Clearing of residual timber may or may not relate to experience, but may be reduced if haywire is prestrung before road changing. The delay relating to the carriage was an equipment related delay, with the amount of time required to correct the situation dependent partially on crew experience.

The Washington 108 running skyline operations experienced similar delays to the GT-3 operation. Carriage problems were fewer, but a significant amount of time on the Washington 108 (Crew #1) was spent in spooling the haulback line. As mentioned earlier, rather than the 2,200' of 3/4" (671m of 19mm) haulback normally used on this yarder, these yarders were operating with approximately 2,200' of 7/8" (671m of 22mm) haulback. This resulted in spooling difficulties as the extra diameter of wire rope was accumulated on the haulback drum. On the Washington 108 (Crew #1) operations, haulback spooling delays occurred on eight of the ten road changes timed in detail, consuming an average of 41% of the total delay time on this operation. Also, the spooling difficulty caused normal spooling operations during road changing to be slower than normal. This delay was not encountered on the Washington 108 (Crew #2) operation. The most likely explanation is that the second machine was operating with less line (due to breakage and splicing). This cannot be confirmed as a measurement of the total line length on each yarder was not made.

On the BU-199 skyline operation, using a radio controlled carriage (Skagit RCC-15), common delays included freeing the pre-strung haywire from logs during road changing and checking lines for proper deflection and clearance from residual timber along the corridors which were partially pre-cut prior to road changing. Two other common delays were related to the large radio-controlled carriage. Due to the carriage size and the use of a diesel engine in the carriage, a flat area on the landing must be prepared so that the carriage may rest on it during road changing. This generally involves removing brush and logs from the area where the carriage is to be placed. This delay did not occur on the running skylines using slack pulling carriages as the skyline (haulback) is never completely removed from the carriage during road changing and the carriage can be supported by the mainlines. The second delay involved carriage maintenance on the engine, or in one case, the radio controls.

Another delay, common to all systems during road changing involved communications between members of the yarding crew. This delay consisted usually of instructions from the hooktender or rigging slinger to members of the crew and communications between the yarder operator and members of the landing crew.

Yarder moves also consumed a high percentage of total average road changing time in proportion to the number of landings encountered on the units (Table 4). No moves were timed in conjunction with road changes on the BU-199.

The bulk of the time involved in moving the yarder consisted of rigging down and re-rigging guylines. This activity should be influenced by groundslope, number of guylines, distance to guyline anchors and soil and brush conditions between the yarder and guyline anchors. On the GT-3 operation the guylines were pulled to the guyline anchors by hand, and on the Washington 108 operations guylines were rigged using haywire. The reason for this is the difference in the guyline configuration on these two yarders. On the GT-3 only a single line is pulled to each anchor while on the Washington 108 the guyline is doubled around a block and a tagline is used to connect to the guyline anchor requiring the use of haywire. The use of haywire in this operation and the guyline configuration differences may account for the greater move times experienced on the two Washington 108 yarders. Factors affecting guyline rig-up were not measured during this study so a more detailed analysis of guyline rigging cannot be made.

Yarder moves also include yarder positioning and this may account for the unexpected negative correlation between

TABLE 4. YARDER MOVES

OPERATION	TOTAL AVERAGE TIME PER MOVE (minutes)	AVERAGE TIME YARDER MOVE ONLY (minutes)	NUMBER OF MOVES	AVERAGE DISTANCE MOVED (feet)
GT-3	12.5	1.7	6	317(97m)
Washington 108, Crew #1	33.6	7.8	10	97(30m)
Washington 108, Crew #2	48.5	2.5	11	116(35m)

average distance moved and the average time required to move the yarder (Table 4).

Total road changing time minus delays, minus yarder move time (including guyline rig-up and rig-down) will be referred to as delay-free road changing time for this discussion. Delay-free road changing time is dependent on the completion of both labor intensive and machine intensive activities. Labor intensive activities consumed over 70% of delay-free time on three of the operations studies (Table 5). Machine intensive activities accounted for 24-29% of delay-free road changing time on these three operations.

On the Washington 108 (Crew #2) operation there is a noticeable rise in average machine intensive activity time, while the labor intensive time is comparable to the times on the other 108 yarder. This is most likely explained by the problem mentioned earlier of difficulties involved in spooling the haulback line on the yarder drum. Although this was recognized as a delay when possible, this spooling problem also resulted in longer productive activity times related to element #2 of road changing, outhaul haywire, spool haulback.

The average time for labor intensive activities on the BU-199 operation is more than twice the average on the other three operations. Since all roads were layed out before road changing took place, the higher labor intensive activity

TABLE 5. DELAY-FREE ROAD CHANGING TIME BREAKDOWN

(Time in minutes)

OPERATION	TOTAL DELAY-FREE TIME	AVERAGE TIME FOR LABOR INTENSIVE ACTIVITIES	% OF DELAY-FREE TIME	AVERAGE TIME FOR MACHINE INTENSIVE ACTIVITIES	% OF DELAY-FREE TIME
Skagit GT-3 running skyline	16.5	12.6	76	3.9	24
Washington 108 running skyline, Crew #1	36.1	20.0	55	16.1	45
Washington 108 running skyline, Crew #2	26.6	18.8	71	7.8	29
Skagit BU-199 w/RCC-15	59.7	42.8	72	16.9	28

time on this operation seems unusual. However, the removal and replacement of the skyline on the RCC-15 carriage consumed a large amount of labor intensive time. The higher average machine intensive activity time on the BU-199 is due to the greater number of machine intensive activities on this system and the longer distances involved.

Quantitative Analysis

On pages 28 and 29, those variables felt to influence each road changing activity were listed. Now it is possible to eliminate several of these variables from consideration and concentrate on those variables most critical to production. It is important to remember that road changing is an activity within the much larger operation of yarding, and it is useful to be able to predict road changing based on variables also used to make yarding production estimates and avoid special measurements related solely to road changing.

For the purposes of quantitative analysis, road changing time will be examined individually for each yarding operation studied in detail. This will remove any variables associated with the four yarder moving activities (move guylines (8), swing yarder (9), prepare to move yarder (10) and move yarder (11)). Also, any variable that remains constant in the system can be disregarded including line sizes, linkage types, line speeds and anything mechanically associated with an individual yarder. This leaves the following variables for consideration:

1. Distance from tailhold to landing
2. Distance line is pulled
3. Brush and soil conditions
4. Ground clearance

5. Distance and terrain over which tail-block is moved

6. Groundslope

Variables 1 and 2 can be combined as the distance line was pulled was always highly correlated with SPAN.

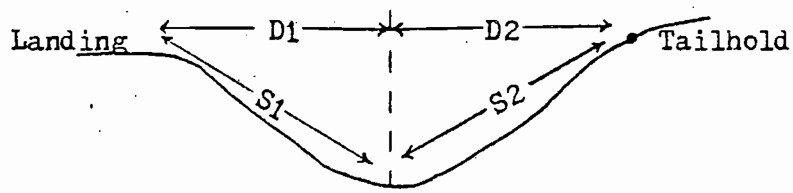
Brush and soil conditions were quantified as shown on Table 1 and these variables were recorded for the overall yarding production study but not for the road changing process individually. Due to the subjective nature of these variables, the low levels of brush and soil recorded (Table 1) and the similarity of brush and soil conditions on yarding roads within a system, these will not be considered as independent variables in the quantitative analysis.

Ground clearance influences the time required to lower and raise the skyline. The time required to do this is very short, consuming a very small portion (3 to 5%) of delay-free road changing time. Also, the method of accounting for the groundslope described below also accounts for ground clearance.

For the road changing operations examined in this study, tailblocks were either rigged ahead of time or rigged while another acitivity such as yarder move was taking place. Thus, variables influencing this activity must be disregarded.

Groundslope is difficult to quantify for road changing in that the overall groundslope of the corridor must be accounted for as well as uphill and downhill slopes. It is important to consider groundslope as a high proportion of the labor intensive activity time is related to pulling lines on the unit. Groundslope was accounted for in the following manner and involved the use of several variables.

Given the following profile:



where D1 = total horizontal distance of downhill slope

D2 = total horizontal distance of uphill slope

S1 = total slope distance on the downhill portion

S2 = total slope distance on the uphill portion

SPAN = D1 + D2

As steepness or roughness increases, S1 increases in relation to D1 and S2 increases in relation to D2.

SLFR1 = S1/D1 = downhill slope fraction

SLFR2 = S2/D2 = uphill slope fraction

As downhill slope increases, SLFR1 increases and as uphill slope increases, SLFR2 increases. This, therefore, becomes an index of groundslope free of the influence of distance since SLFR would be approximately the secant of the slope angle.

The variable of groundslope would be difficult to apply as an independent variable in road changing if it was not for the method of pulling haywire on two of the running skyline operations (Figures 24 and 25). For the case where two sections of haywire are pulled to the tailhold, the present method of accounting for groundslope is adequate. However, in the case where haywire is pulled completely around the unit, the method of using a "slope fraction" to account for groundslope is inadequate. It is inadequate because haywire is pulled both uphill and downhill on the same slope. In the GT-3 operation where this occurred, the yarding profiles were relatively flat and for this reason the relationship of total slope distance to horizontal distance is used as a roughness coefficient in this case.

The quantitative analysis centers on consideration of the linear relationship between the variables believed to influence road changing and the time required to perform this operation. This technique is known as linear regression and can be useful in constructing a predictive equation for road changing which will approximate the relationship observed between variables (Draper and Smith, 1966).

For the purpose of this analysis the four operations will be treated separately. Some comparisons will be made between systems following the individual operation analysis. A hypothesis is formulated including all of the independent variables to be examined. The coefficients for the independent variables are then tested for significance using the t-test. Any coefficient not significant at the 20% level has been excluded from the final equation. The levels of significance are listed in parentheses immediately following the variable.

The coefficient of determination (R^2) is listed for each equation. This value is an expression of the percentage of variation in the dependent variable explained by the independent variable(s). Thus, if $R^2 = 0.70$, then 70% of the variation is explained.

In each case a second equation is included, based on the single independent variable of the horizontal distance from the headspar to the tailhold (SPAN). This is included for two reasons: 1) past estimates of road changing have centered on the use of this variable, and 2) it is easily measured.

Finally, these equations are for <u>delay-free</u> road changing time, that is, total road changing time minus move time, minus delay time. The number of observations (n) is listed for each operation.

Skagit GT-3, running skyline

Hypothesis: DFCT = f(distance to tailhold, groundslope)
(n = 9) were DFCT = delay-free road changing time

In the case of the GT-3 operation, groundslope was necessarily treated in a different manner than mentioned on page 65. This is due to the way haywire was pulled on this operation. Rather than pulling two sections of haywire downhill to the tailhold, the haywire was pulled around the tailblock and back uphill to the yarder. The groundslope was not steep, making this operation possible. The groundslope indicator in this case is more of a "roughness factor" and is equal to:

$$\frac{\text{SDIST}}{\text{SPAN}}$$

where SDIST = distance on the ground between the landing and the tailhold
and SPAN = total horizontal distance between the headspar (landing) and the tailhold

The equation based on the above hypotheses is:

$$\text{DFCT} = 8.1806 + 0.0172\ \text{SPAN}\ (.02) \qquad R^2 = 0.267$$

The roughness factor failed to enter the final equation, most likely due to the moderate slopes on the logging unit studied. Figure 41 is a plot of the regression line and the plotted field observations.

Washington 108, running skyline, Crew #1

Hypothesis: DFCT = f(D1, D2, S1, S2) n = 10

In this case only two observations of D2 and S2 were made, eliminating them from the final regression equation.

$$\text{DFCT} = 14.291 + 0.051817\ \text{D1}\ (.05) \qquad R^2 = 0.483$$

Since D1 is a distance measurement, and slope did not enter into the equation, an equation using SPAN should be as useful:

$$\text{DFCT} = 7.8815 + 0.062536\ \text{SPAN}\ (.02) \qquad R^2 = 0.520$$

A plot of the regression line and the field of observations are provided in Figure 42.

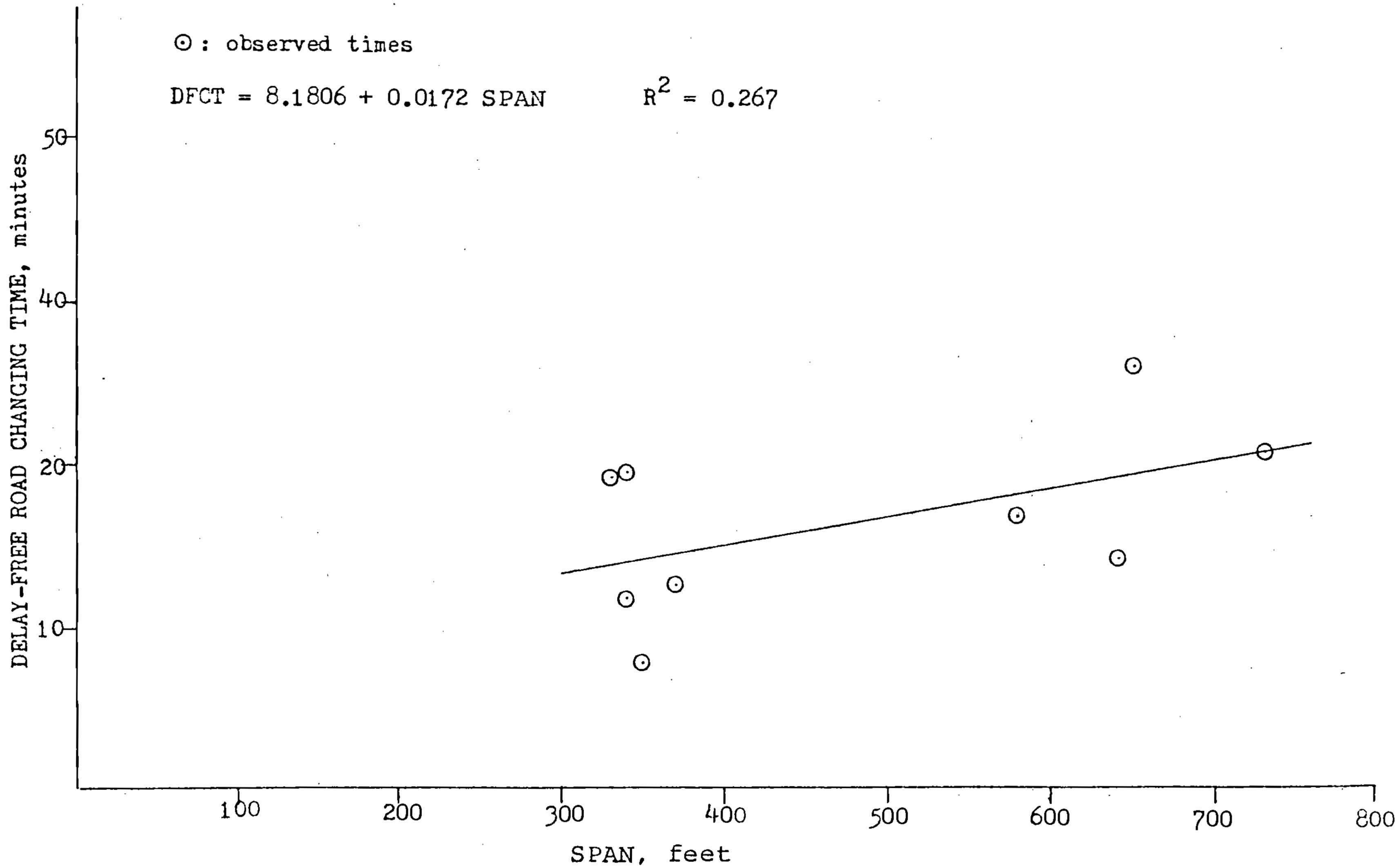


Figure 41. Delay-free road changing time vs SPAN, Skagit GT-3

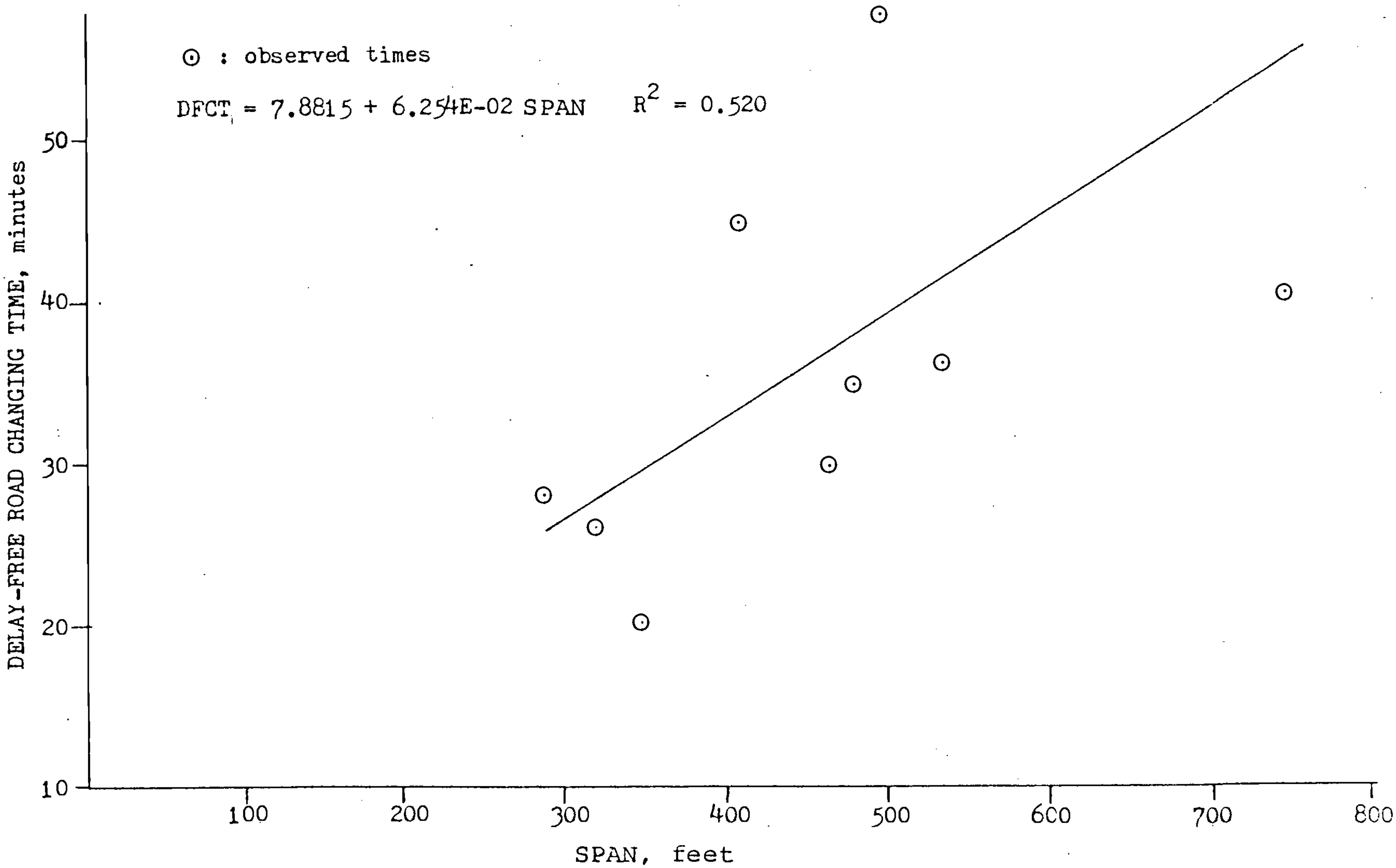


Figure 42. Delay-free road changing time vs SPAN, Washington 108, crew #1

Washington 108, running skyline, Crew #2

Hypothesis: DFCT = f(D1, D2, S1, S2) n = 12

$$\text{DFCT} = -76.616 + 0.040092\ \text{D1}\ (.05) + 80.667\ \text{S1}\ (.02) \qquad R^2 = 0.476$$

Hypothesis: DFCT = f(SPAN)

$$\text{DFCT} = 11.434 + 0.03989\ \text{SPAN}\ (.02) \qquad R^2 = 0.458$$

Figure 43 is a plot of delay-free road changing time as a function of SPAN for the Washington 108, Crew #2 operation.

Skagit BU-199, tight skyline w/radio-controlled carriage

For this system, haywire was pre-strung prior to road changing. For this reason it was not necessary to include a slope term in the regression. Also, no yarder moves were recorded for this operation.

Hypothesis: DFCT = f(SPAN)

$$\text{DFCT} = 92.6041 - 0.0235\ \text{SPAN}\ (\text{n.s.}) \qquad R^2 = 0.027$$

The nonsignificance of the regression coefficient and the low R^2 value can be accounted for in two ways: 1) the number of observations was small, and 2) the range of spans observed was very small with a difference of only 305 feet (93 meters) between the shortest and longest observations. More data is needed before a detailed quantitative analysis of this system can be made.

Combining data for similar systems

On two of the operations observed, identical road

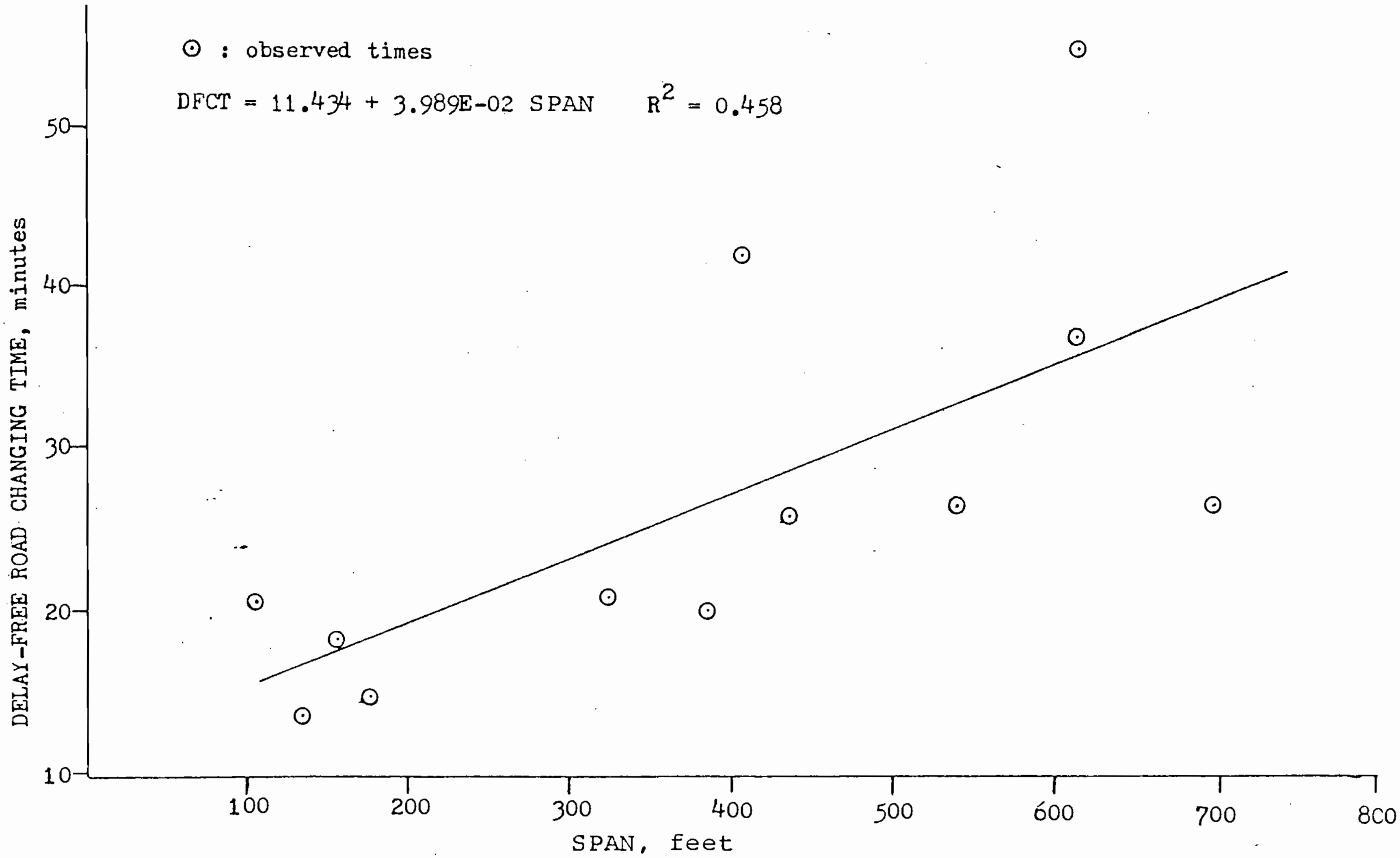


Figure 43. Delay-free road changing time vs SPAN, Washington 108, crew #2

changing methods were used on identical machines. The operations in this case were the two Washington 108 running skylines. Unless it can be demonstrated that SPAN influences road changing on these operations in a different degree, the data should be pooled to form a combined regression equation for road changing on both operations. A statistical test was used to determine that the slope and level of observation on the two operations were not significantly different.[2]

$$DFCT = 12.688 + 0.04254\ SPAN\ (.01) \qquad R^2 = 0.392$$

Based on the scatter of the observations in Figures 42 and 43, relationship between delay-free road changing time and $SPAN^2$ is implied. That is, as SPAN increases, the time required to change yarding roads increases at an increasing rate. Initially separate regressions were made for each operation followed by a pooling of the data to form a total regression equation. This was done after the regressions were tested to see if they were significantly different. The following relationship was found:

$$DFCT = 19.321 + 0.000057219\ SPAN^2 \qquad R^2 = 0.486$$

A plot of the individual and combined regressions is found in Figure 44. It is interesting to note that the

[2]If the slopes of the two groups differ significantly, the residuals about the common slope regression will be considerably larger than the mean square residual for the separate regressions. If the levels of the groups differ significantly the residuals about the single linear regression for the combined data will be significantly larger than the regression that assumed the same slopes but different levels. An F test was used to test for significance in both cases.

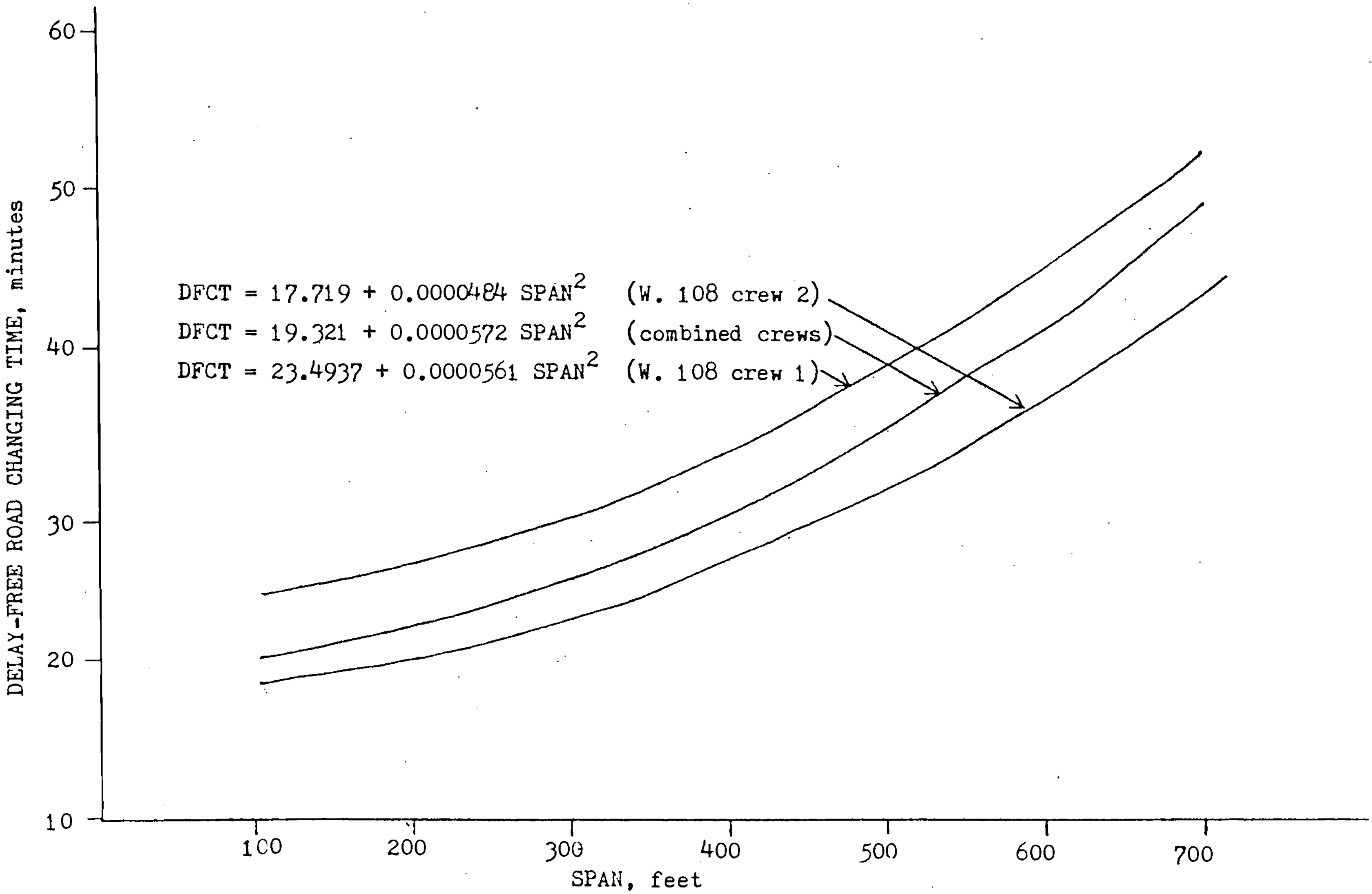


Figure 44. Delay-free road changing time vs $SPAN^2$
Washington 108 running skyline operations

equation using $SPAN^2$ is statistically a better predictor of delay-free road changing time and that the slopes of the individual regression equations are closer than in the equation using SPAN.

Summary and Conclusion

This report has considered road changing on ten yarding operations in the Pacific Northwest. On four of these operations a detailed analysis of road changing was possible. All of the operations involved uphill yarding except the two balloon systems. Road changing was considered a productive delay essential to the continuation of yarding.

In a comparison of road changing times for the ten operations observed, road changing time varied widely. Even among similar systems a wide range was observed. This variability was most likely due to the differences in the road changing methods themselves, varying characteristics of the logging units and lengthy delays encountered during road changing. This could not be confirmed for six of the operations as road changing was not recorded in detail. However, among those operations observed in detail this influence could be seen.

A segregation of road changing into machine intensive activities, labor intensive activities and delays, shows that a large percentage of road changing time is occupied by delays. The greatest portion of delay-free time in this study involved labor intensive activities. This was expected on the operations where pre-layout of roads was not done. On the operation where roads were pre-layed (BU-199), other activities requiring labor intensive activities were required.

Some of the delays encountered may have been due to characteristics of the particular yarder or yarding system being used.

A quantitative analysis was made of four operations. Road changing time, excluding delays and the time required to relocate the yarder was used as the dependent variable. Delay-free road changing time was found to be a function of the distance from the landing to the tailhold (SPAN) and groundslope. For two of the operations, identical machines and methods were used. A combined regression equation was formed based on the independent variable SPAN. Also, based on the scatter of observations for these systems, an equation using $SPAN^2$ as the independent variable was found to be a better predictor of delay-free road changing time than SPAN.

Road changing may or may not be a critical activity on a particular yarding operation. However, based on the results of this study, it is evident that road changing time can vary widely and that much of this time is consumed by delays and operations dependent on the work of crewmen rather than on the yarder itself. If delays which occur during road changing are preventable, a careful consideration of the nature of these delays could lead to a reduction in total road changing time. For example, if re-changing of roads or excessive clearing of timber consumes a large percentage of road changing time, an improved method of flagging the new road could be used rather than the common "line-of-sight" method.

Also, the large amount of time consumed by labor intensive activities suggests that pre-layout of yarding roads should be considered. An efficient method of assigning tasks to crew members during road changing could also reduce time by fully utilizing the work force.

When estimating production on a yarding unit a method of estimating road changing time is useful. Dykstra (1976) suggests that local experience in cable yarding should be relied on to gather estimates of average road changing time. This study has shown that, at least for running skyline systems, it is possible to predict road changing time using SPAN as the independent variable. With this estimate, combined with an estimate of the time required to move the yarder (if landings are frequently changed) and the portion of road changing time occupied by delays, it is possible to predict total road changing time on a logging unit.

Suggestions For Further Research

As an initial study on road changing, this project has suggested where additional work could be done in the area of road changing such as the following:

1. Due to the large amount of time occupied by non-productive delays, it may be useful to carefully consider their nature and means of prevention during road changing.

2. An analysis including the measurement of factors hypothesized to influence move time would be useful in formulating predictive equations for this activity.

3. A comparison of road changing time with and without pre-layout of yarding roads would be useful. This would involve a tradeoff between production lost by temporarily reducing the size of the rigging crew (Dykstra, 1976) and production gained through reduced road changing time. This could be critical, particularly on operations with long spans.

4. A comprehensive catalogue of road changing methods could indicate techniques used in the field to reduce road changing time and would in any case be a useful reference.

Data used in this study was gathered during a study of yarding production, and road changing information gathering was supplemental to the major task of obtaining measurements of each yarding cycle. The areas of suggested research imply a constant monitoring of road changing activities which may occur during yarding.

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Appendix

Equipment Specifications

1.

Yarder	West Coast Falcon
System	Highlead, North Bend (Figures 45 and 46)
Engine	Detroit Diesel, 6-71
Drum capacities:	
Skyline	2,000' of 1" (610 m of 25 mm)
Mainline	1,200' of 3/4" (366 m of 19 mm)
Haulback	2,700' of 1/2" (823 m of 13 mm)
Strawline	2,500' of 3/8" (762 m of 10 mm)
Guylines	3, 3/4" (3, 19 mm)
Line speed	2,120'/min. (main drum, full) (646 m/min.)
Line pull	67,000 lbs.[3] (main drum, empty) (30,391 kg)
Tower	49' (15 m) square, steel box const.
Undercarriage	Terex, C6 crawler tractor
Weight	72,780 lbs. (without line) (33,013 kg)
Interlock	none

2.

Yarder	Smith-Berger Planet-Lok L-1
System	Grabinski (Figure 47)
Engine	Caterpillar D 334-TA diesel
Drum capacities:	
Mainline	2,200' of 7/8" (671 m of 22 mm)
Slackpulling ...	2,300' of 5/8" (701 m of 16 mm)
Haulback	4,400' of 7/8" (1,341 m of 22 mm)
Strawline	4,500' of 7/16" (1,372 m of 11 mm)
Guylines	3, 3/4" (3, 19 mm)
Line speed:	
Mainline	425'/min. (half full) (129 m/min.)
Haulback	1,800'/min. (half full) (549 m/min.)
Line pull:	
Mainline	62,000 lbs. (half full) (28,123 kg)
Haulback	29,000 lbs. (half full) (13,154 kg)
Tower	50' (15) steel tube
Undercarriage	Caterpillar D8, crawler tractor
Weight	99,500 lbs. without line (45,133 kg)
Interlock	Planetary

3.

Yarder	Skagit BU-90
System	Shotgun (Figure 48)
Engine	Caterpillar D 343 diesel

[3] Line pull is often expressed in kilograms, a unit of mass. As line pull is a force, it is correctly expressed in newtons (N). A newton is that force which gives a mass of one kilogram an acceleration of one meter per second per second. To convert kilograms to newtons, multiply by 9.807.

Drum capacities:
    Skyline .... 1,450' of 1-1/4" (442 m of 32 mm)
    Mainline .... 1,250' of 1" (381 m of 25 mm)
    Haulback .... 3,580' of 7/8" (1,091 m of 22 mm)
    Strawline ...... 3,900' of 7/16" (1,189 m of 11 mm)
    Guylines .... 6, 1-1/4" (6, 32 mm)
Line speed:
    Mainline .... 400'/min. (half full) 122 m/min.)
Line pull:
    Mainline .... 81,700 lbs. (half full)
Tower .... 90' (27 m) telescoping, steel tube
Undercarriage .... Trailer
Weight .... 78,000 lbs. (35,381 kg)
Interlock .... none

4. Yarder .... Washington 208
System .... Balloon, inverted skyline (Figure 49)
Engine .... Cummins VT 12700C diesel
Drum capacities:
    Skyline .... 5,500' of 1" (1,676 m of 25 mm)
    Mainline .... 7,000' of 1" (2,134 m of 25 mm)
    Strawline ...... 7,500' of 7/16" (2,286 m of 11 mm)
    Tiebacks .... 2, 1-1/8" (2, 29 mm)
Line speeds:
    Skyline .... 1,750'/min. (maximum) (533 m/min.)
    Mainline .... 2,000'/min. (maximum) (610 m/min.)
Line pulls:
    Skyline .... 67,000 lbs. (maximum) (30,391 kg)
    Mainline .... 34,000 lbs. (maximum) (15,422 kg)
Balloon volume ...... 530,000 cubic feet (15,010 cubic meters)
Lifting gas .... Commercial helium
Balloon dimensions .. 105' diameter, 113' high (32 m) (34 m)
Net design lift ..... 25,000 lbs. (sea level, 90% inflation) (11,340 kg)
Undercarriage .... military tank
Interlock .... hydraulic (not used)

5. Yarder .... Washington 608 Aero-yarder
System .... Balloon, haulback configuration (Figure 50)
Engine .... Detroit Diesel, 12V-71N65
Drum capacities:
    Mainline .... 5,100' of 1" (1,554 m of 25 mm)
    Haulback .... 7,600' of 1" (2,316 m of 25 mm)
    Strawline ...... 9,700' of 7/16" (2,957 m of 11 mm)

Line speeds:
    Mainline .... 1,591'/min. (full) (485 m/min.)
    Haulback .... 2,156' (full) (657 m/min.)
Line pulls:
    Mainline .... 90,000 lbs. (empty) (40,824 kg)
    Haulback .... 46,000 lbs. (empty) (20,866 kg)
Balloon volume ...... 530,000 cubic feet (15,010 cubic meters)
Lifting gas .... Commercial helium
Balloon dimensions .. 105' diameter, 113' high (32 m) (34 m)
Net design lift ..... 25,000 lbs. (sea level, 90% inflation)
Undercarriage .... Caterpillar D-9
Weight .... 149,600 lbs. (without lines) (67,859 kg)
Interlock .... hydraulic

6. Yarder .... Skagit GT-3
System .... Running skyline
Engine .... Cummins NH-220 hp diesel
Drum capacities:
    Mainline .... 2 side by side - 1,200' of 5/8" (366 m of 16 mm)
    Haulback .... 2,200' of 3/4" (671 m of 19 mm)
    Strawline ...... 3,200' of 3/8" (975 m of 10 mm)
    Guyline .... 140' of 7/8" (43 m of 22 mm)
Line speed:
    Mainline .... 1,410'/min. (full) (430 m/min.)
    Haulback .... 2,275'/min. (full) (693 m/min.)
Line pull:
    Mainline .... 71,000 lbs. (empty) (32,206 kg)
    Haulback .... 35,700 lbs. (empty) (16,194 kg)
Tower .... 44' (13.4 m) swinging boom
Undercarriage .... Rubber-tired, self-propelled
    Length .... 234" (594 cm)
    Width .... 125" (317 cm)
Weight .... 88,800 lbs. (40,280 kg)
Gradability 25%
Travel speed .... 18 mph (29 kmh) maximum dependent on terrain
Miscellaneous .... Mechanical interlock (link main and haulback) planetary differential on main drums, walking guylines
Carriage .... Ross three drum slack pulling carriage

7. Yarder .... Washington 108 Skylok
System .... Running skyline
Engine .... 315 hp diesel, GMC-8V-71
Rated engine power .. 295 hp @ 2,100 RPM

Drum capacities:
- Mainline .... 1,100' of 7/8" (335 m of 22 mm)
- Front .... 1,100' of 7/8" (335 m of 22 mm)[4]
- Haulback .... 2,200' of 3/4" (671 m of 19 mm)
- Strawline ...... 2,300' of 3/8" (701 m of 10 mm)
- Guyline .... 270' of 3/4" (82 m of 19 mm)

Line speed:
- Mainline .... 1,300'/min. (full) (396 m/min.)
- Front .... 1,300'/min. (full) (396 m/min.)
- Haulback .... 1,730'/min. (full) (527 m/min.)

Line pull:
- Mainline .... 96,000 lbs. (empty) (43,546 kg)
- Front .... 37,000 lbs. (empty) (16,763 kg)
- Haulback .... 24,700 lbs. (empty) (11,204 kg)

Tower .... Boom height to ground @ 60^{o}= 50' (15.2 m)

Undercarriage .... Rubber-tired, self-propelled
- Length .... 290" (737 cm)
- Width .... 154" (391 cm)

Working weight ...... 129,700 lbs. (58,831 kg)

Gradability 25%

Travel speed .... 13 mph (21 kmh) maximum dependent on terrain

Miscellaneous .... Infinite ratio interlock on haulback drum, hydraulically controlled, main and front drums are mechanically interlocked

Carriage .... Papé shuttlebug three drum slack pulling carriage

8. Yarder .... Skagit BU-199

Engine .... 556 hp, Caterpillar D-346

Drum capacities:
- Skyline .... 2,800' of 1-1/2" (853 m of 38 mm)
- Mainline .... 3,900' of 1-1/8" (1,187 m of 29 mm)
- Haulback .... 6,500' of 7/8" (1,981 m of 22 mm)
- Strawline ...... 5,750' of 7/16" (1,753 m of 11 mm)
- Utility .... 3,750' of 7/16" (1,143 m of 11 mm)
- Guyline .... 392' of 1-3/8" (119 m of 35 mm)

Tower .... Skagit T-110 HD, vertical telescoping steel tube

Tower height .... 110' (33.5 m) fully extended

Undercarriage ...... Rubber-tired, self-propelled
- Length .... 221" (561 cm) between axles
- Width .... 146" (371 cm)

[4] For the yarders observed in this study, approximately 2,200' of 7/8" line was used. This caused some spooling problems which was discussed earlier in this paper.

Working weight	228,500 lbs. (103,648 kg)
Gradability	18%
Travel speed	17 mph (2y kmh)
Carriage	Skagit RCC-15 Torpedo
Engine	96 hp diesel
Weight	6,900 lbs. (3,130 kg)
Drum capacity ..	350'-380' of 7/8" (107 m - 116 m of 22 mm)

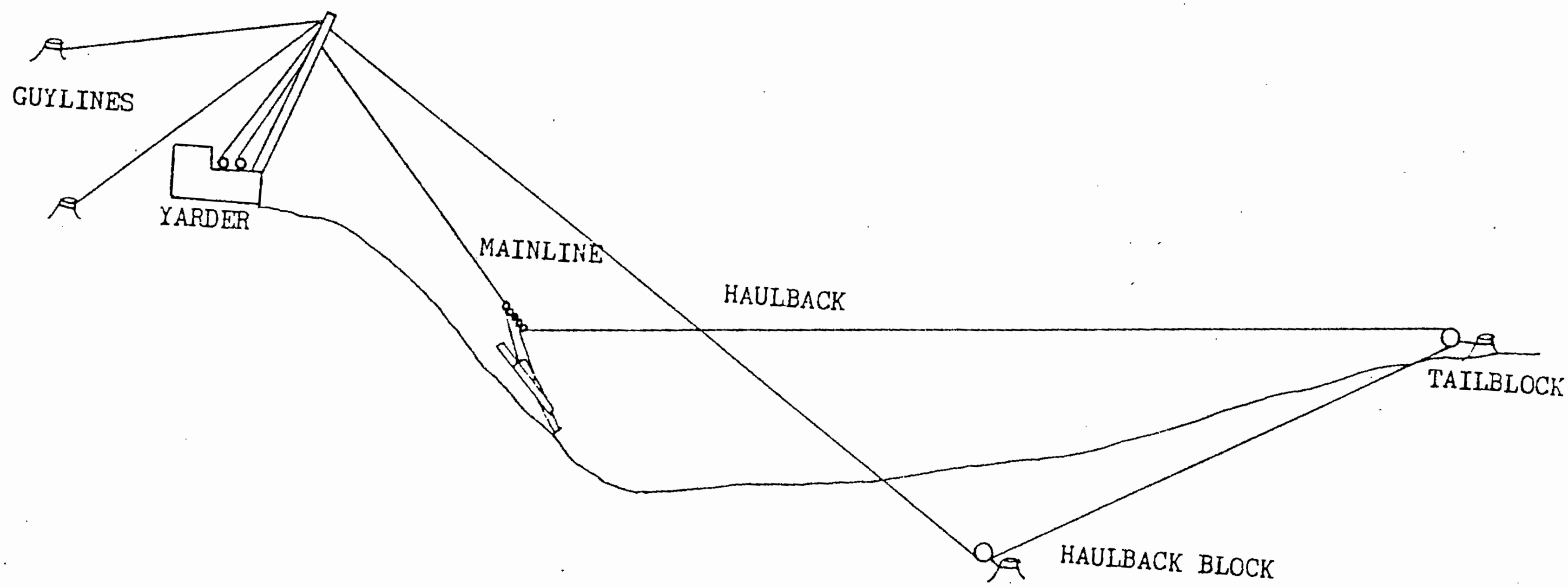

Figure 45. High lead yarding configuration

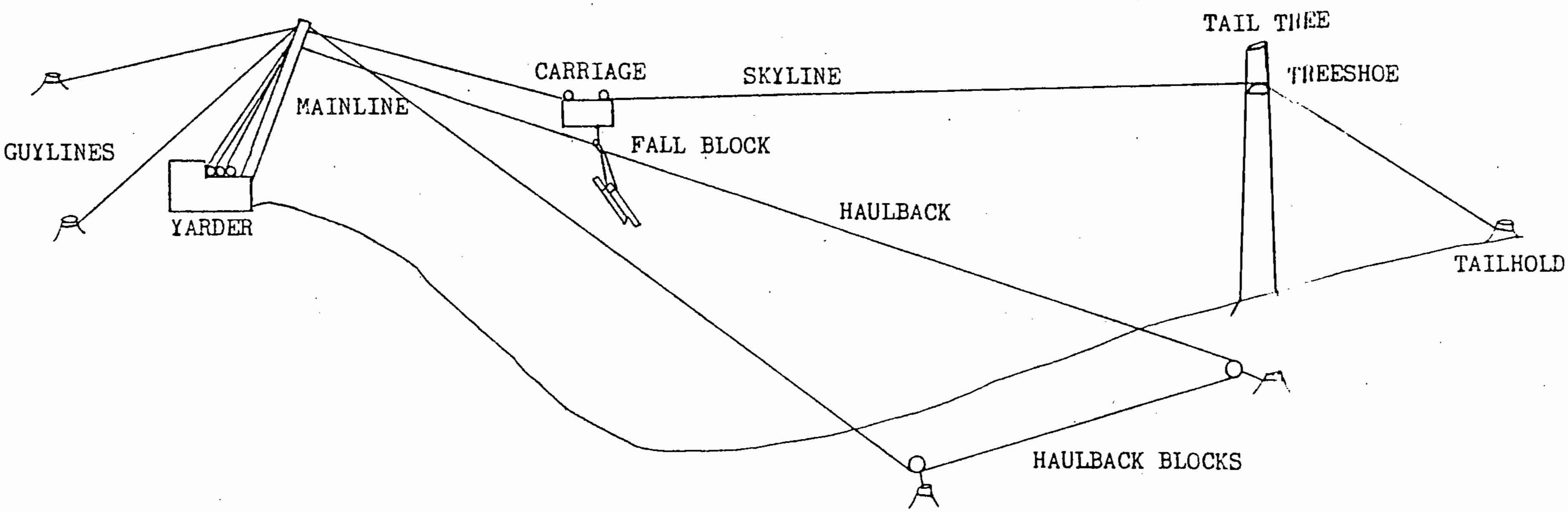

Figure 46. North Bend yarding configuration

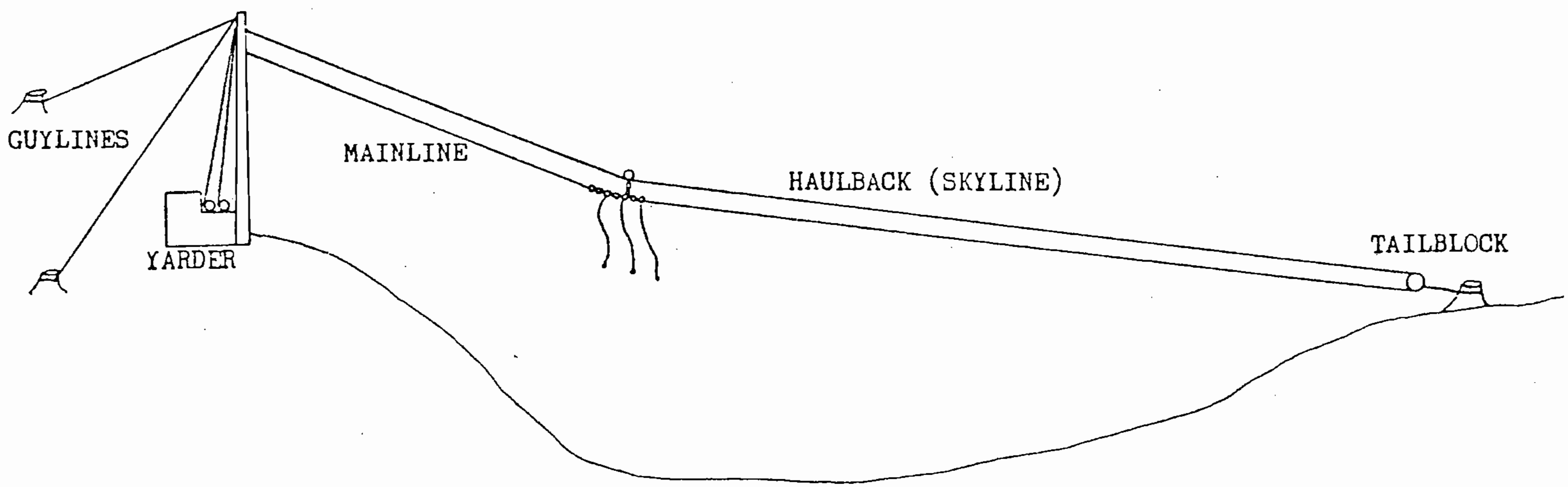

Figure 47. "Grabinski" yarding configuration

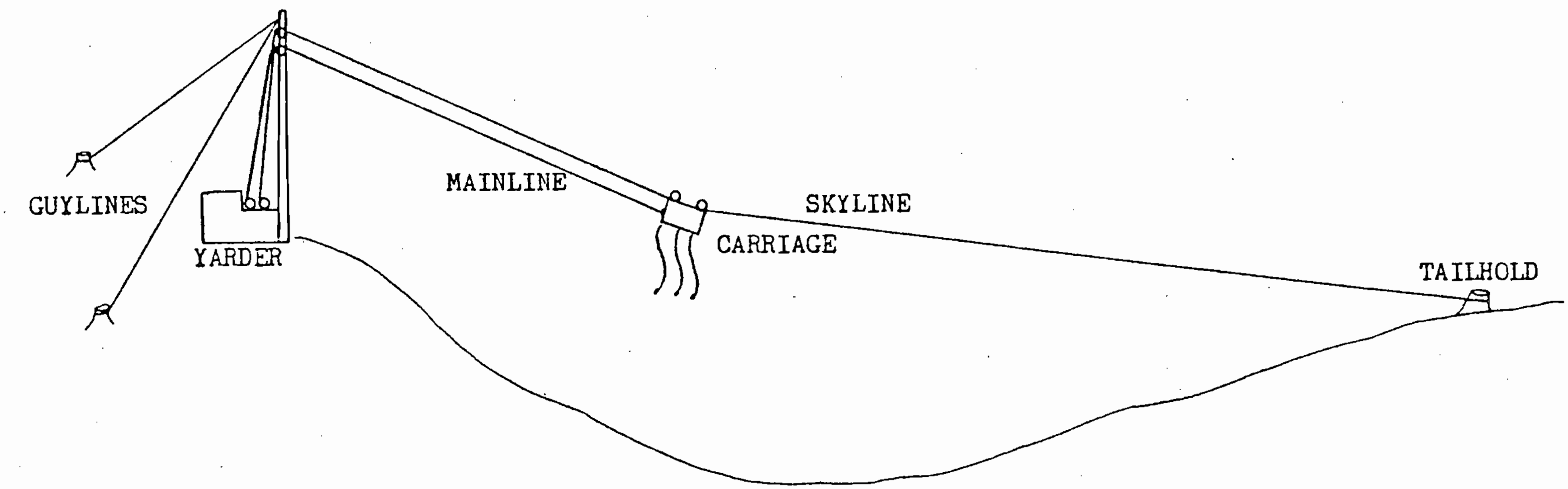

Figure 48. Shotgun yarding configuration

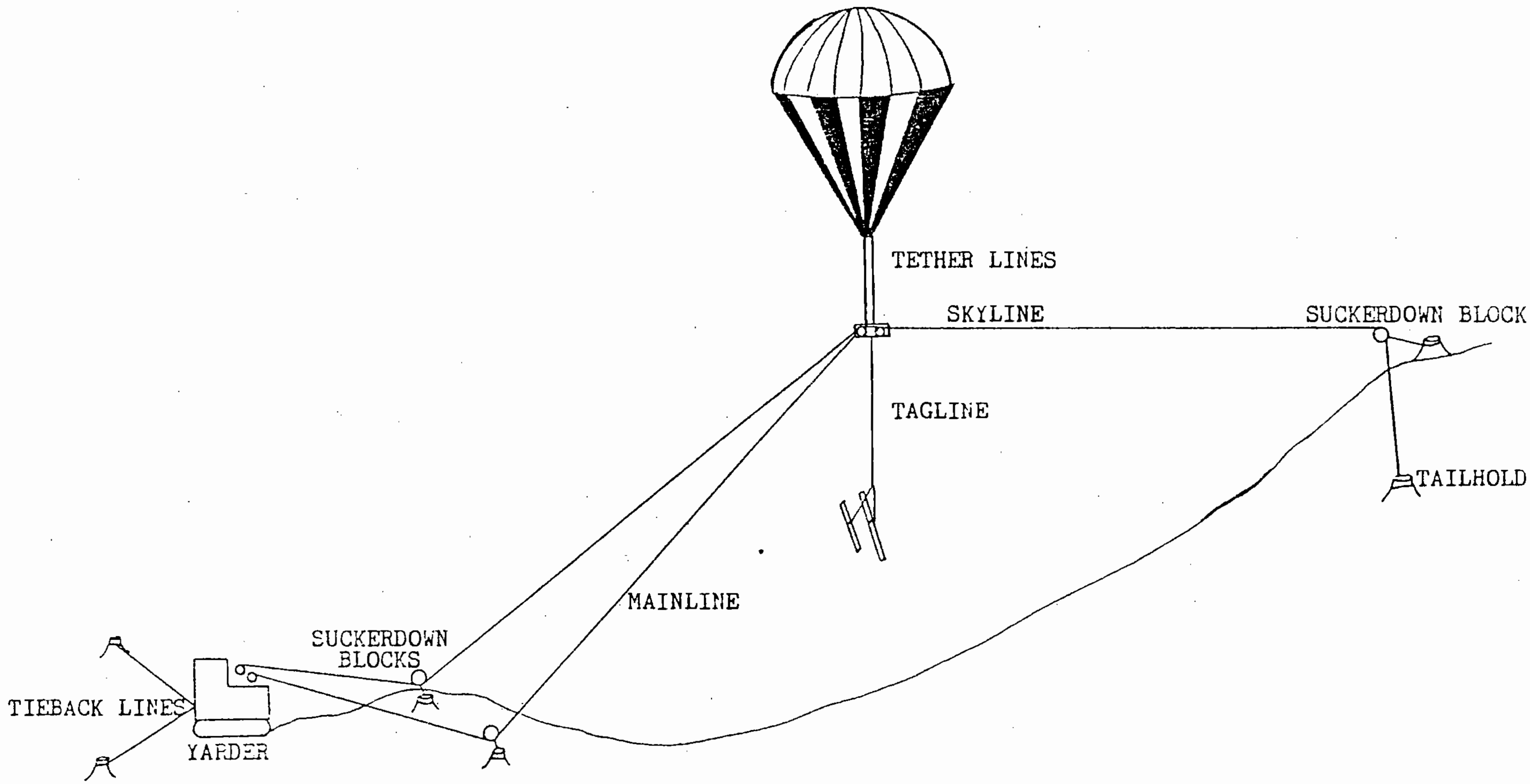

Figure 49. Balloon, inverted skyline configuration

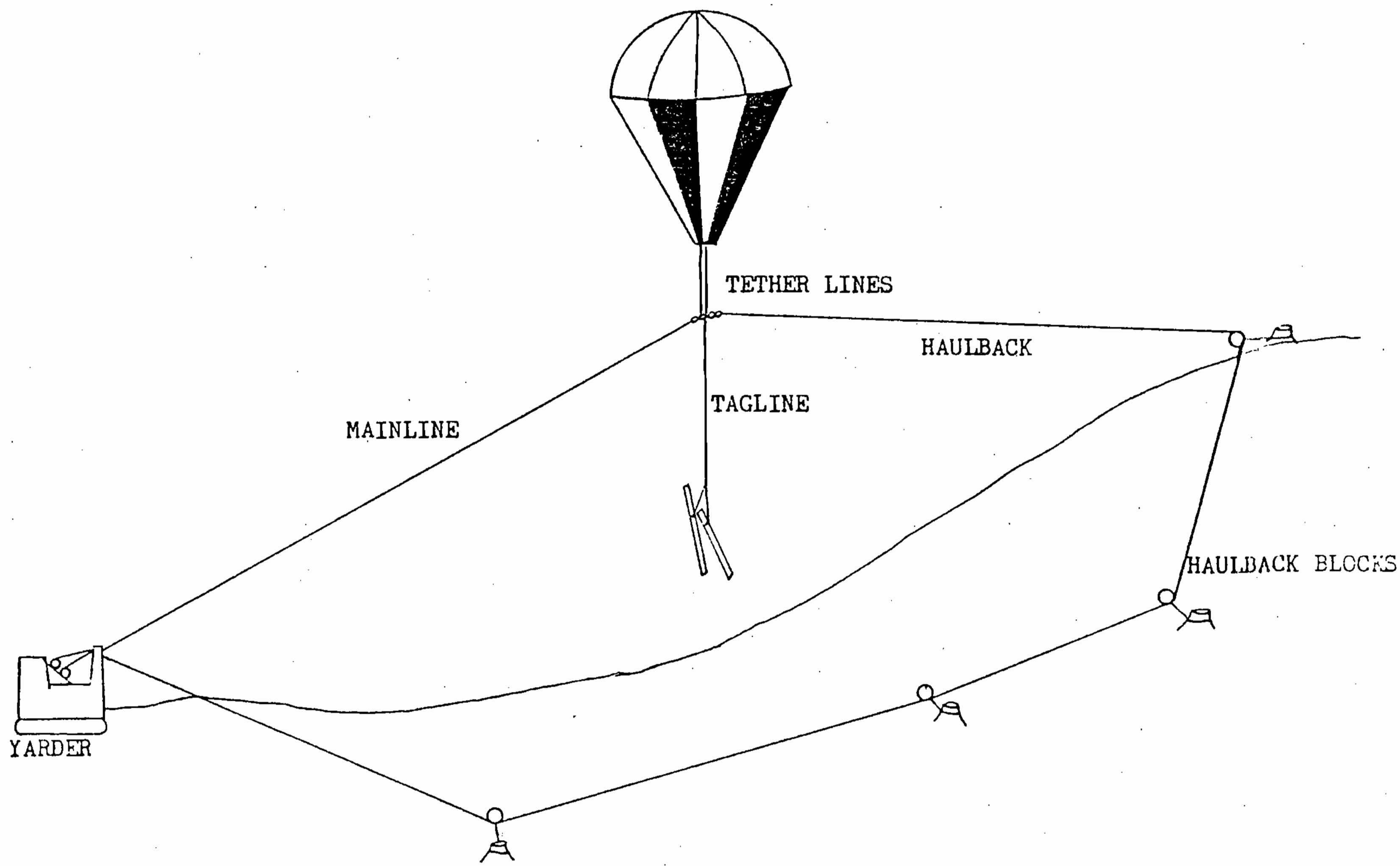

Figure 50. Balloon, haulback configuration

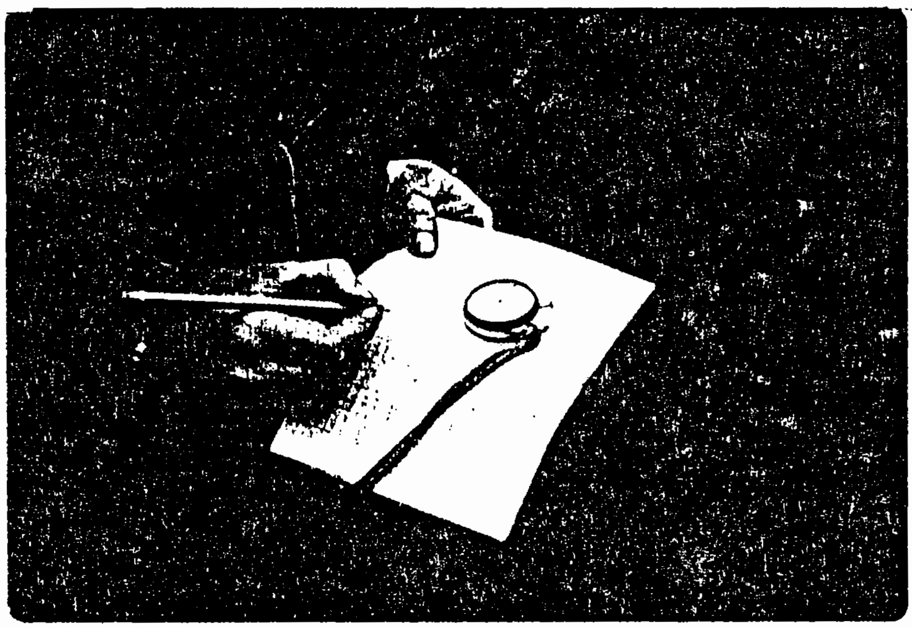

Illustration 1. Data gathering in the field,
data recording

Illustration 2. Data gathering in the field,
measuring groundslope

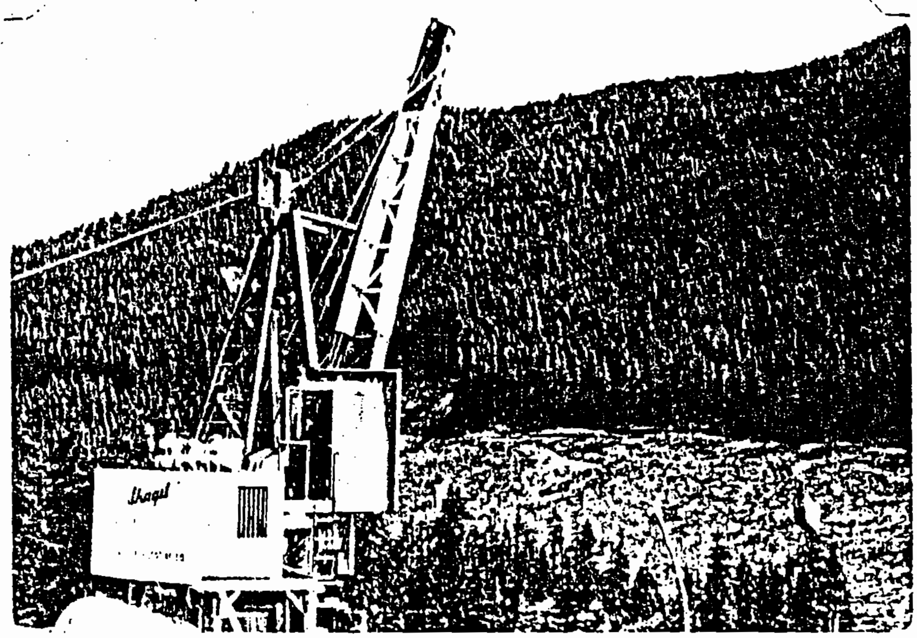

Illustration 3. Skagit GT-3, running skyline

Illustration 4. Washington 108, running skyline, skyline corridor during road changing

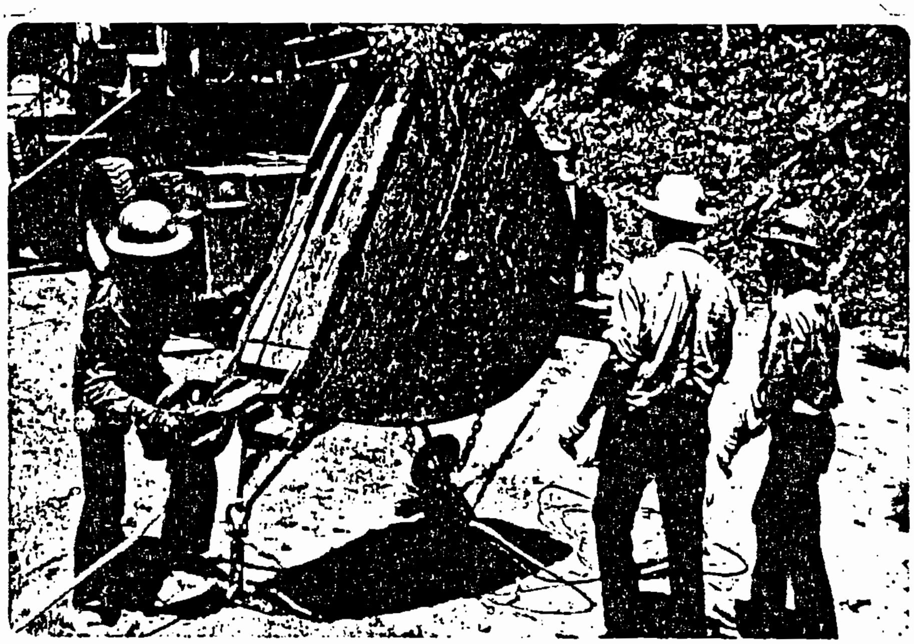

Illustration 5. Washington 108, running skyline, delay during road changing involving slack pulling carriage

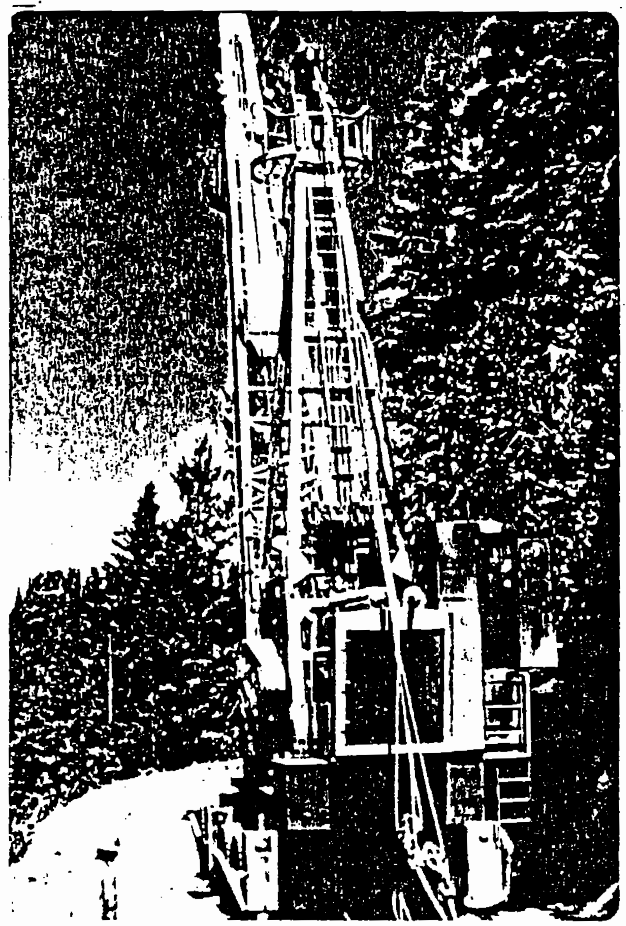

Illustration 6. Washington 108, running skyline, yarder move

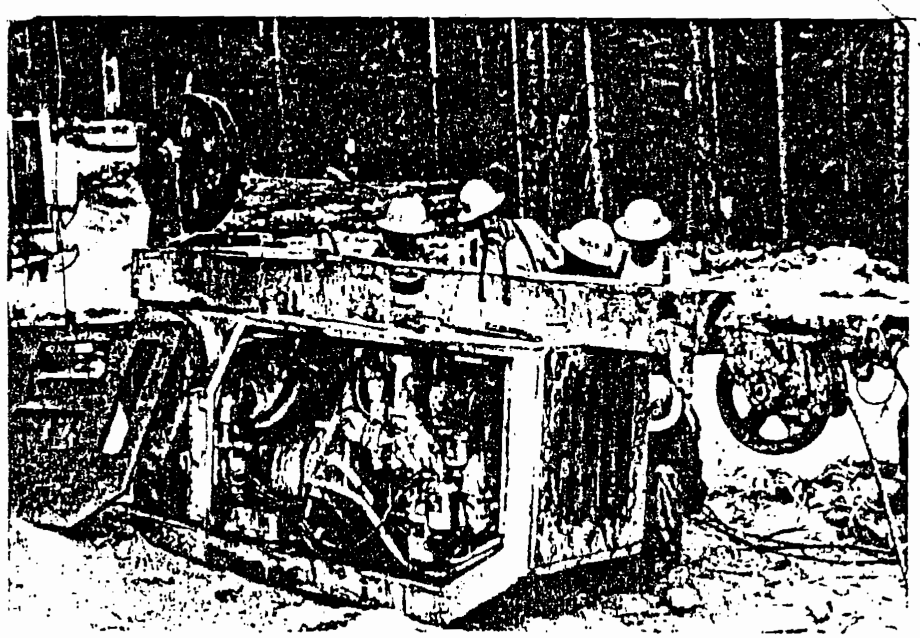

Illustration 7. Repairing radio-controlled carriage during road changing on Skagit BU-199, tight skyline