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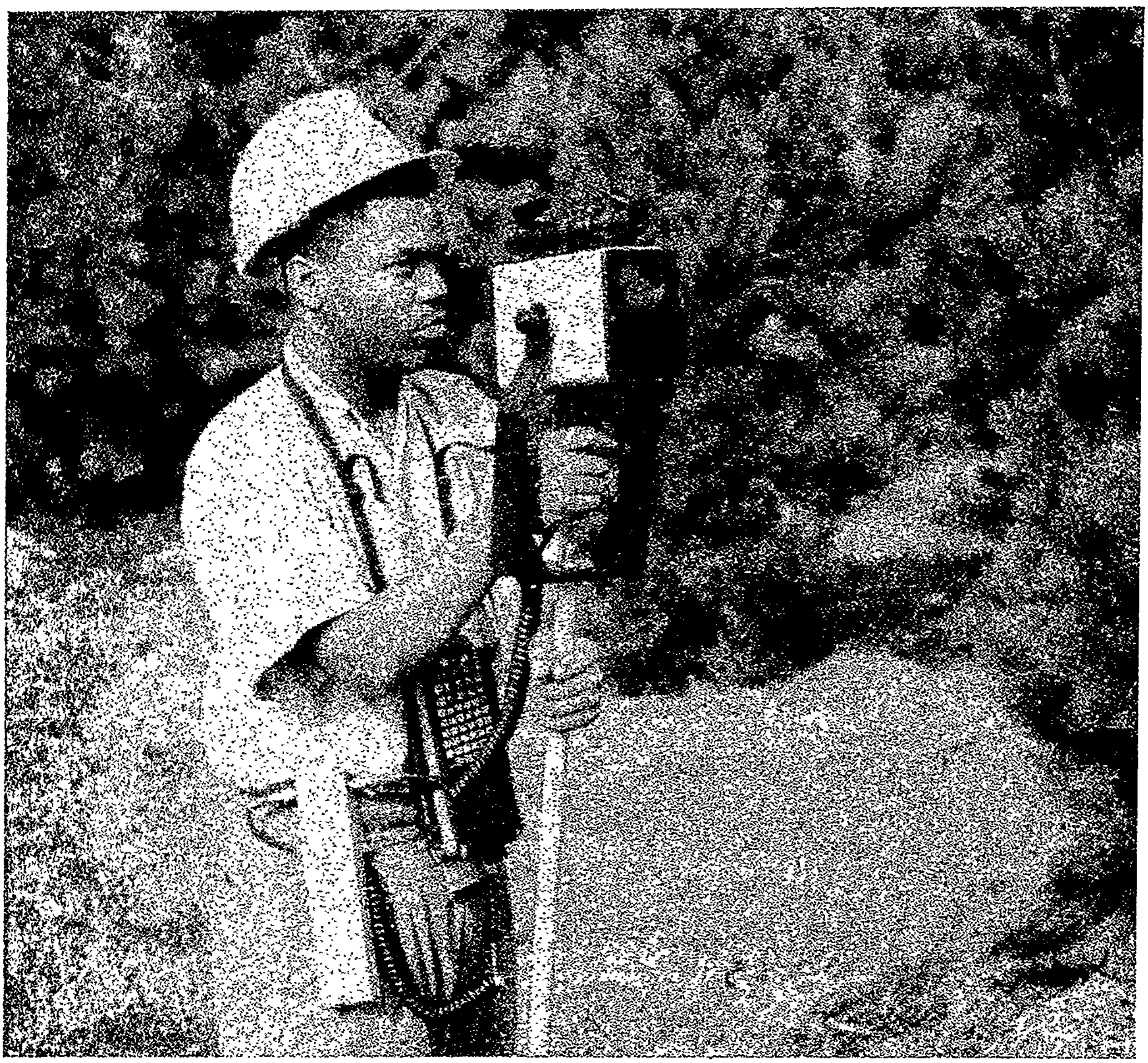
Low-Volume Roads Survey Laser



Low-Volume Roads Survey Laser

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Survey Instrument for Low-Volume Roads

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ABSTRACT

The San Dimas Technology and Development Center (SDTDC) has developed a low-volume road survey method for use with the Laser Technology, Inc. (LTI), Englewood, Colo., Criterion 400 Survey Laser and the Corvallis Microtechnology, Inc. (CMT), Corvallis, Oreg., MC-V (MC-"five") data recorder. A brief overview of both the standard and laser survey methods for low-volume roads is given. The economics of laser surveying versus the standard method is examined in a time and cost savings study. Test results on the precision and accuracy of the laser device are presented, along with the precision considered acceptable for low-volume road surveying.

A breakeven analysis indicates the laser method results in positive cash flow at 4.4 miles of road surveyed and keypunched per year. A forest unit with 50 miles of roadwork per year could expect a possible 59% reduction in surveying and keypunching costs.

Test results show the laser device meets precision and accuracy requirements for low volume road surveying.

The laser survey method is discussed in detail; instructions for its use and a description of required software is presented in an appendix. Data for an example cross section, in addition to that for a traverse link, are furnished, along with the step-by-step keystrokes required during measurement. Also discussed are limitations of the laser survey method, and areas for potential improvement. NOTE: The report assumes the reader is familiar with road location, surveying, design, and software such as KERMIT, LUMBERJACK, FLRDS, and the QUICKBASIC environment.

INTRODUCTION

Standard Survey Method

The standard survey method now widely used in the Forest Service for low-volume and single-use road construction includes cloth tape and hand- or staff-compass traverses, with vertical control and topography information supplied by clinometers or abney levels *(9)*. Survey measurements are made and manually recorded in a field book at the time of survey; then, at a later time, they are keypunched into the data input portion of road design software. Some crews enter data into data recorders during the survey for later uploading into a PC. At the conclusion of data entry, the road can be designed, slope staked, and constructed.

Laser Survey Method

The laser—the Laser Technology, Inc. (LTI), Englewood, Colo., Criterion 400 Survey Laser—is basically a handheld total station that makes surveying measurements at the pull of a trigger (figs. 1 and 2). It was originally offered by LTI for forestry applications, including tree measurement, and the laser survey method was first discussed as an engineering survey method in the November-December 1992 issue of the USDA Forest Service's *Engineering Field Notes [EFN] (11)*. The laser survey method is detailed in appendix A.

Figure 1. Laser operator making survey measurements.

MC-TRAVERSE, a program available from Corvallis Microtechnology, Inc. (CMT), Corvallis, Oreg., provides a user-friendly environment for data downloading from the laser to their MC-V (MC-"five") data recorder; remarks are also keyed into the MC-V, eliminating handwritten field notes (figs. 3 and 4). A reflector carried by a rodperson is used in conjunction with a filter on the laser to ensure measurement only to the desired target.

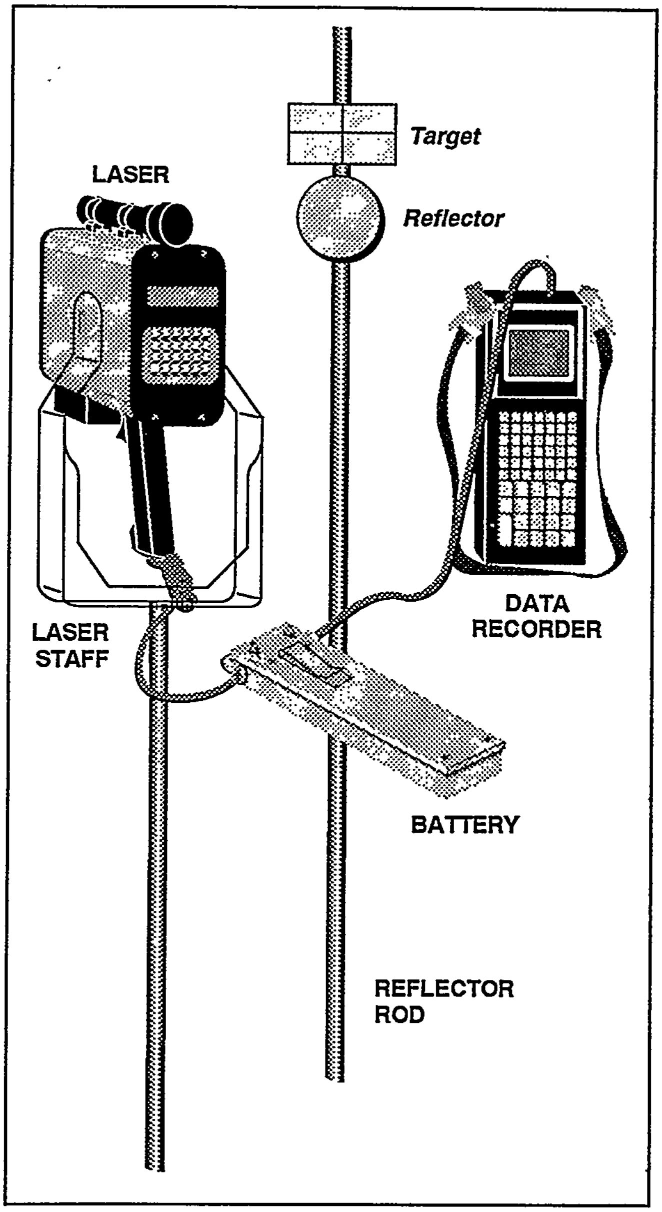

Figure 2. Survey laser field hardware configuration.

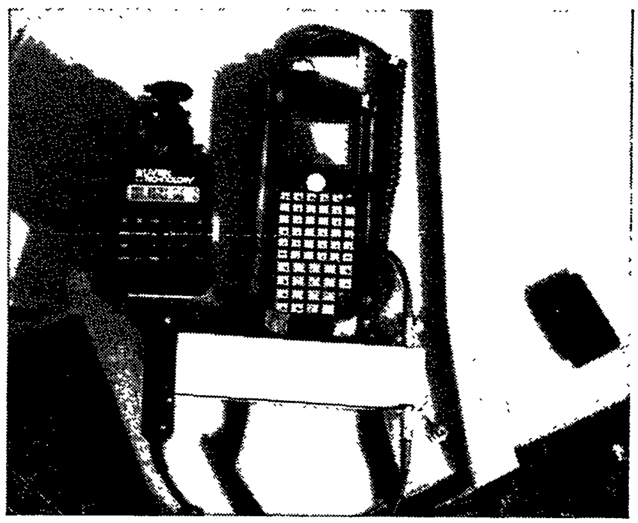

Figure 3. Laser unit (left) and the MC-V.

Figure 4. Entering remarks into the MC-V.

Keypunching of data is replaced with electronic import of specially prepared ASCII files into the data input portion of LUMBERJACK, an existing road design software system (fig. 5). LASER123, a QUICKBASIC program, was written specifically to prepare the data files, uploaded to the PC using KERMIT SERVER, for import to LUMBERJACK. A "front end" program has also been prepared to modify the data for import to the Forest Level Road Design System (FLRDS) and is available by RIS from R-6.

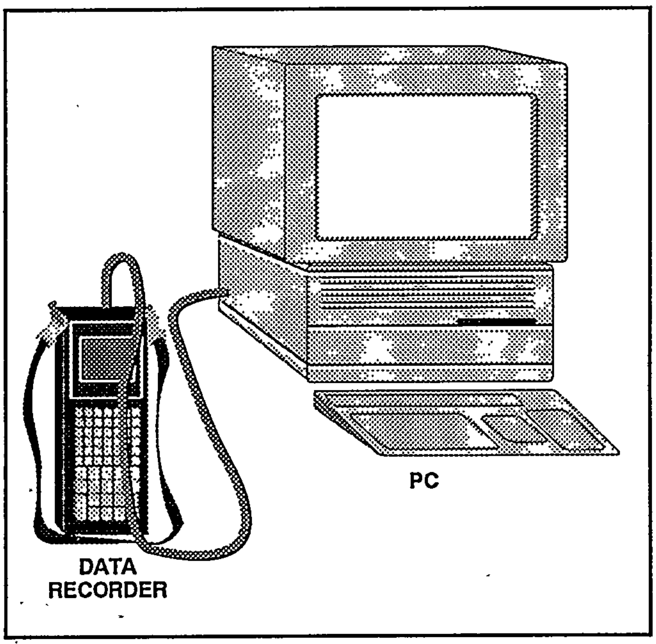

Figure 5. Data processing hardware configuration.

TIME AND COST SAVINGS STUDY RESULTS

The following study results are condensed from the November-December 1992 *EFN (11)*, and are provided here as background information. Significant savings in survey time and cost result from use of the laser survey method, in addition to a reduction in the effect of human error during instrument reading, data recording, and keypunching. The laser surveying method allows a national forest to complete its workload with reduced staff and budget.

A standard survey on Road 111A in the Rock Creek watershed (belonging to the city of Corvallis, Oregon) was duplicated with the laser to provide the basis for a time and cost comparison of methods. Although this laser survey used a different data recorder and software program to prepare the ASCII files for import to the road design system, the methodology and time requirements are not appreciably different from the laser survey method described in this report.

Results of this study indicate a 25 percent increase in the production rate of the survey crew using the laser, coupled with a 63 percent decrease in cost (detailed in tables below). A two-person laser crew did the job of a five-person standard crew in 80 percent of the time. An 81 percent savings in keypunch cost resulted, since data are electronically manipulated and formatted for automated import to the road design system, rather than field or office keypunching of data as required by the standard method.

For purposes of determining crew costs, the General Schedule (GS) pay table (January 1992) for Federal employees was applied. The five-person standard crew was modeled by using a GS-7/Step 1 party chief supervising four GS-3/Step 1 engineering aides. This is not to say five persons are required to perform a standard survey, but rather that this particular road was surveyed by a five-person crew. Survey crews consisting of between two and seven persons have been reported *(5)*. The two-person tree laser crew was modeled by a party chief and one engineering aide. The effective working time for each crew is estimated at 5.5 hours per day, as driving, hiking, and break time must be subtracted from the 8-hour work day.

To provide a comparison of time and cost for surveying and keypunching between survey methods for a longer road than Road 111A, the time required to prepare data from an 8,600-foot long traverse with 200 cross sections for design was extrapolated from the Road 111A survey. The ratio of traverse length to number of cross sections is the same for this hypothetical road as it is for Road 111A.

Table 1 compares a five-person standard and a two-person laser survey crew on Rock Creek Road 111A for a length of 1,631 feet; 38 cross sections. The data show a 20 percent savings in time for the laser over the standard survey for a road of moderate length. Production rates, portrayed by cross section or traverse length per unit time, show approximately a 25 percent increase for the laser. Production per hour is simply the work expected of a crew in one hour; production per day is based on 5.5 hours of work.

Table 1. Time comparison of survey methods

Data	Standard method	Laser method	Percent change
Time (hours)	3.5	2.8	-20
Cross section/hr	10.9	13.6	25
Cross section/day	60.0	74.8	25
Feet/hr	466	583	25
Feet/day	2,563	3,207	25
Mile/hr	0.09	0.11	25
Mile/day	0.49	0.61	25
Time to survey 8,600-ft traverse; 200 cross sections			
Hours	18.3	14.7	-20
Days	3.3	2.7	-20

Table 2 presents the same comparisons as in table 1; this time using cost, instead of time, data. These data show a 54 percent savings in cost per hour when using the laser. Unit costs, portrayed either by dollars per cross section or per unit length, show about a 63 percent decrease for the laser method. Dollars per unit are based on crew cost for an 8-hour day with 5.5 hours available for work. Thus, the 5-person crew completes 10.9 cross sections per hour, or 60 in 5.5 hours, costing $300 and resulting in a unit cost of $5 per cross section. The total cost to survey the hypothetical 8,600-foot road with the laser is $368, while the standard cost $1,000.

Table 2. Cost comparison of survey methods

Data	Standard method	Laser method	Percent change
$/hour	37.50	17.25	-54
$/day	300.00	138.00	-54
$/cross section	5.00	1.84	-63
$/foot	0.12	0.04	-63
$/mile	600.00	226.00	-63
Total cost ($)	190.00	69.92	-63
Cost ($) to survey 8,600-ft traverse; 200 cross sections	1,000.00	368.00	-63

The time comparison of the two methods is provided both in terms of cross sections per day and length of traverse surveyed per day (table 1). Each comparison includes the time required to complete all tasks involved with each method. The cost comparison results in dollars per cross section, and dollars per unit length of traverse surveyed (table 2).

The actual time required to keypunch the standard survey data into LUMBERJACK's data entry program, and check the keypunch job, was recorded *(8)*, as were the times required to bring up the program software on the PC, prepare project files, and reduce and save the data. These times, rounded to the nearest whole minute, are seen in table 3.

Table 3. Keypunch time, standard survey method

Task	Time (min)
Turn on PC and initialize LUMBERJACK	5
Prepare data files	1
Keypunch and check data	76
Reduce and save data	1
Total:	83

The actual time required to transfer data from the laser survey in the data recorder to the PC is shown in table 4. Time for running the program to modify and format the data, and importing the resulting ASCII file into LUMBERJACK, in which it is reduced and saved, are also shown. The software used to transfer data from data recorder to PC (KERMIT), and to modify and format the data for import (LASER123), in support of this report, are described in appendix A. The times were rounded to the nearest whole minute and are presented in table 4.

Table 4. Data processing time, laser survey method

Task	Time (min)
Turn on PC, and initiate program to transfer data files	5
Initialize program to modify and format data	5
Import formatted data into LUMBERJACK and reduce and save data	5
Total:	15

The total time in table 3 will vary according to traverse length and number of cross sections. The total time shown in table 4, however, will vary by only a few seconds with different length surveys; it can thus be considered a fixed quantity. The extrapolated total time for the hypothetical 8,600-foot long road with 200 cross sections is shown in table 5.

Table 5. Keypunch time, standard survey method

Task	Time (min)
Turn on PC and initialize LUMBERJACK	5
Prepare data files	1
Keypunch and check data	400
Reduce and save data	1
	Total: 407

As can be seen in tables 6 (data for Rock Creek Road 111A) and 7 (data for hypothetical 8,600-foot traverse with 200 cross sections), the savings in keypunch costs for the laser over the standard method reaches phenomenal proportions as the length of road surveyed increases.

Table 6. "Keypunching" cost comparison of survey methods for Road 111A

Data	Standard method	Laser method	Percent change
$/cross section	0.38	0.07	-82
$/foot	0.01	0.0016	-82
$/mile	47.02	8.50	-82

Table 7. "Keypunching" cost comparison of survey methods for a hypothetical road

Data	Standard method	Laser method	Percent change
$/cross section	0.36	0.013	-97
$/foot	0.01	0.0003	-97
$/mile	43.73	1.61	-97

A yearly surveying and keypunching cost comparison of standard and laser methods was prepared for a forest unit that surveys 50 miles of road per year. Surveying and keypunching costs in dollars per mile from tables 1 and 2, respectively, were used. Assumptions in the yearly cost comparison include 5-year life for surveying instruments with no salvage value remaining; instrument costs of $500 for standard method and $8,500 for the laser; an interest rate of 5 percent and, thus, a capital recovery factor (A/P) of 0.23097; and an average road length of 8,600 feet.

Results of the cost comparison are displayed in table 8. A forest unit surveying and keypunching 50 miles of road per year could expect to have costs reduced by almost 59 percent when using the laser rather than the standard survey method.

Table 8. Annual cost comparison of survey methods and "keypunching" for 50 miles of road/year

Task or Instrument	Standard method	Laser method	Percent change
Survey, $/50 mi	30,000	11,300	-63
Keypunch, $/50 mi	2,187	81	-97
Annual instrmt cost ($)	115	1,963	+1,607
Total annual cost ($)	32,302	13,344	-59

A breakeven analysis based on the above assumptions shows the laser method resulting in positive cash flow at 4.4 miles of road surveyed and keypunched per year.

To determine the number of years (n) at which the laser method pays for itself on a forest unit surveying and keypunching "x" miles of road annually, plug "x" into the following equation:

$$A/P=0.052x$$

Interpolate a value of n years from the following table using the calculated A/P factor.

n	A/P
1	1.05
2	0.53780
3	0.36721
4	0.28201
5	0.23097

For example a forest unit with 10 miles of roadwork annually, and therefore an A/P factor of 0.52, can expect the laser hardware and software to pay for itself in slightly more than 2 years.

SURVEY LASER ENGINEERING TEST RESULTS

Precision, for the purpose of this report, means repeatability, while accuracy depicts nearness to the truth. The true value of a measurement is never known, but measurements from a low-order survey may be compared to those of a high-order survey, one with finer division size and better reliability. Such a control survey was supplied by a Nikon Top Gun A5 *(6)*, as summarized in table 9.

Table 9. Survey acceptable precision, specified accuracy, and test results

Measurement type	Precision considered acceptable(1)	LTI Criterion 400 System (2) Spec	Test results
Distance (ft	Nearest whole foot	±0.3	±0.14 E95=0.06
Azimuth (deg)	Nearest whole degree	±0.3	±0.75 E95=0.11
Vertical angle (%)	Nearest whole percent	±0.35	±0.34 E95=0.08

(1)Precisions in survey measurements considered acceptable for low-volume and single-use roads (1).
(2)Criterion 400 Survey Laser Operator's Guide (10).

Laser SLOPE DISTANCE (SD) measurements exhibit excellent precision and accuracy when compared to the requirements for low-volume road surveying. It can be anticipated that, on average, 95 percent of the time an SD measurement will fall within a range of ±0.06 foot of the mean of measurements, and that the mean of measurements will be within 0.14 foot of control.

Laser AZIMUTH (AZ) measurements are subject to instrumental error and natural error. The instrumental error arises from compass calibration problems *(3)*, while the natural error stems from the local attraction and magnetic declination problems common to all magnetic compass readings. The compass is extremely sensitive to local attraction, and variation in readings occurs as the laser is panned through vertical angles. On average, AZ measurements are repeatable 95 percent of the time to ±0.11 degree of the mean, and the mean is within 0.75 degree of control. The accuracy of an AZ reading may be expected to be midway between that expected of a staff and a handheld compass (7). AZ measurements are successfully made only when the laser is maintained within a tilt angle of ±15 degrees (26.8 percent) with the horizontal. Overall, AZ readings meet the requirements for low-volume road surveying, subject to mitigation as described below in "Method Limitations."

Laser INCLINATION (VI) measurements exhibit systematic error, as the value is almost always less than control would indicate; that is, the VI is a smaller number. Systematic error presents the potential for simple correction. VI readings exhibit excellent repeatability, and accuracy is within the requirements of low-volume road surveying. On average, ninety-five percent of the time a VI reading will be within ±0.08 foot/100 feet of the mean value, and the mean will be within 0.34 foot/100 feet of control.

Specifications provided by the manufacturer for the tilt sensor are ±0.2 degree (0.35 percent) throughout a measurement range of ±60 degrees (173 percent) with the horizontal.

METHOD LIMITATIONS

Limitations of the laser survey method are based on the limitations of the laser and include:

1. Minimum SD measurement capabilities of approximately 10 feet.
   To mitigate this problem, which would be especially acute on single lane road reconstruction surveys requiring frequent measurement from centerline to the edge of the road, the measurements may be made manually and keyed into the MC-V. It may also be possible to locate the traverse PI's along one edge of the road rather that centerline to increase the minimum distance measured. LTI engineers have reduced the minimum SD to less than 5 feet, available in production lasers in June, 1993.

2. AZ measurements made only when the laser is inclined within the window of +15 degrees (+26.8 percent) with the horizontal.
   To mitigate this problem, the measurements may be made manually and keyed into the MC-V. Alternatively, the laser is equipped with a peep sight, adjustable in a vertical plane, that allows the instrument person to sight the target while maintaining the laser within the prescribed inclination. AZ measurements may thus be made and downloaded successfully.

3. AZ measurements are marginal in terms of the accuracy required for low-volume road surveying.
   Poor AZ readings result in problems lining up traverse plots on maps or photos, ensuring the required curve radius exists, and office design of turnouts, curve widening, and sight distance. To mitigate this problem, on critical portions of the traverse (such as tight horizontal curves), the AZ readings may be checked manually and, if necessary, keyed into MC-TRAVERSE. Normally the road locator ensures that the flagline meets road design standards and criteria, circumventing this need. AZ readings are not critical in terms of roadbuilding quantities, clearing limits, and construction staking notes, as are SD or VI readings.

POTENTIAL IMPROVEMENT AREAS

1. The potential exists for manipulation of AZ readings made on the cross section to ensure the section is taken close to the angle bisect in the traverse. Skewed cross sections lead to incorrect VI readings, resulting in erroneous construction quantities, clearing limits, and construction staking.

2. The measurement and manipulation of Height of Instrument (HI) and Height of Object (HO), for unequal values, might reduce the amount of clearing required and facilitate surveying in brushy terrain.

3. The provision for backsight measurements, as well as foresights, would allow for averaging—increasing the accuracy of measurements for higher order surveys, and would provide for identifying locations having magnetic local attraction, as well as adjusting the AZ readings made at such locations.

4. Expansion of LASER123 to prepare input files for multiple road design and data manipulation stems.

5. Preparation of software to allow data downloading from the laser to other data recorders widely used by the Forest Service would be advantageous, and increase the utility of the laser device.

6. The potential exists for uploading survey measurements directly into a road design program residing in the data recorder. This would update field design methods and allow for all field work required prior to construction—including construction staking—to be completed in one trip to the field by the survey crew, increasing further the economic benefits of laser surveying.

7. Development of road location, survey, and design procedures that are especially tailored to the functionality of the laser. The standard survey method was developed for use with tapes and handheld, manually read instruments and, thus, is outmoded with the advent of the laser device. A "repeating radial" type survey providing data for a strip contour map is one possibility. The repeating radial would maximize the economic benefits of laser surveying. Design from the map would allow optimization of centerline and cross section locations, as well as turnouts and curve widening. The road location may be fine tuned to minimize length, cuts and fills, or environmental impacts, while maximizing sight distance and monitoring other safety concerns.

APPENDIX A—LASER SURVEY METHOD

To start a survey, the MC-V is attached to the laser battery pack through COM 2 and turned on, and the MC-TRAVERSE program is initiated—as described in Section 2, Traversing *(2)*. As per Section 2.1.1, the following inputs are suggested for the fields in the project ID screens:

TRAV.TYPE: O
DIST.CODE: F
DIR.CODE: A
SLOPE.CODE: D
DIST.PREC: 1
ANG.PREC: 1
ANG.NOTE: D
ANG.SYS: F

The other fields may be filled at the operator's discretion. The operator is then prompted to begin data entry. Pressing ENTER at the "Y" default on the MC-V places the operator in the ".trv" file; the file to be used for downloading traverse data, and prompts for a DIST entry. An S is keyed, placing the cursor at the DIST prompt in the ".trs," or sideshot mode. The sideshots, or cross section, are measured and downloaded prior to the traverse data ahead so that the rodperson is not required to walk to the forward Point of Intersection (PI) for traverse data measurement, and then back again for cross section measurement. The laser power button is pressed, followed by the down arrow, and the ENTER key twice. The system is now ready for surveying.

Generally, measurements are made with the laser screen showing HD-AZ as follows:

HD:————.- FT
AZ:———.- DEG

The laser is now sighted on the target, which is placed on the cross section break, and triggered. All required measurements are downloaded to the MC-V with one press of the laser's ENTER key. SD, VI, and AZ are downloaded (referred to on the MC-V screen as DIST, SLOPE, and FORE, respectively). Each break on the cross section is measured and downloaded separately in this fashion. Information concerning breaks on the cross section needed for design purposes, but not visible from the centerline, is collected from a Turning Point (T). The T is another break measured to on the cross section, between the PI and the point not visible.

When a Turning Point is encountered, a T must be keyed into the REMARK column on the line with the data for the break that is the T. To access the REMARK column, after measuring and downloading the data for the break that is the T, press the MC-V up arrow, then the MC-V ENTER key three times. Then simply key a T and press the MC-V ENTER key again to place the cursor at the DIST prompt for the next break. The road design systems used here require identification of T's regardless of the survey techniques utilized, and automatically consider them in the reduction of cross section data *(4)*.

The breaks are measured from left to right. Zeros must be loaded into the ".trs" file to document centerline location, which is accomplished by keying a 0, followed by ENTER, on the MC-V; this sequence being repeated three times, once for each data field. After the last ENTER, an additional ENTER must be keyed at the REMARK prompt to place the cursor at the DIST for the next break. To key in a REMARK for a particular break, measure and download the data for the break; then press the MC-V up arrow, followed by the MC-V ENTER key three times. This places the cursor at the REMARK column, at which time the REMARK may be keyed in, followed by the MC-V ENTER key. After completing the section, the MC-V - ["minus"], Y, and ESC keys are pressed, returning the operator to the ".trv" file. See appendix B for a step-by-step cross sectioning example.

Traverse data (also composed of SD, VI, and AZ ahead to the next PI), are also measured from the HD-AZ screen and downloaded by pressing the laser ENTER key. A remark such as BOP (Beginning Of Project) may be keyed into the MC-V using the same procedure for REMARK's outlined above. Section 2, which is located at the second PI, is then occupied by the laser operator and, after pressing S to enter the ".trs" file again, cross section data are measured and downloaded (as were data on Section 1). The survey of subsequent PI's and cross sections is performed, and their data downloaded, in a repetition of the activities described above.

Certain situations require more than one cross section to be recorded from a PI. Examples include fence crossings (for which the extra section is needed for cattleguard or gate and brace panel details), or drainage crossings (in which the extra section provides information for drainage structure design). The extra section is needed when the angle bisect in the traverse line is different than the direction of the fence or drainage, as is usually the case.

Pressing ESC on the MC-V at the conclusion of cross sectioning the bisect, then pressing S again, allows the additional cross section to be measured and downloaded as described above. The two sections will have the same STA number in the MC-V ".TRS" file; the second will be ignored during preparation of the ASCII import file and is available only for manual plotting and design.

At the conclusion of surveying, zeros must be entered into the ".trv" file for the last PI with a cross section. This is accomplished in a similar fashion as for documenting centerline location within the cross section as described above. The survey data files are transferred to the PC using KERMIT SERVER, and the data prepared for import to the road design system as described below.

KERMIT SERVER File Transfer Utility

KERMIT SERVER enables the transfer of files between the MC-V and the PC. Two files must be transferred per survey, one with file extension .TRV, the other .TRS. KERMIT comes with the MC-V; instructions for its use are in the CMT MC-TRAVERSE Owner's Manual.

LASER123 Program

A program named LASER123 was written specifically to prepare laser survey data previously uploaded to the PC for import into the LUMBERJACK road design program. The required format for ASCII files to be imported is furnished in the LUMBERJACK program documentation. Tasks required of the program include:

1. Conversion of vertical encoder output, which is identified by VI, from units of degree of slope, to percent slope units of feet per 100 feet.

2. Cataloguing of the data into the specific format required by the LUMBERJACK program.

LASER123 is available from SDTDC, and is executed by typing LAS123 at the prompt. KERMIT SERVER is built into LASER123 to facilitate file transfer. Function keys provide for directory and file management as well as file editing. Enter the path if needed when the program prompts for the traverse file and the side shot file, both of which were uploaded to the PC using Kermit. Also prompted for is the name of the output file.

LUMBERJACK Program

The LUMBERJACK Road Design System is suited to low-volume road design and has ASCII file import capabilities. The required format for imported files is supplied in the program documentation, as are instructions for the import procedure. The file to be imported is the output road program file created by LASER123 from the traverse and side shot files. The software, along with program documentation and technical support, is available from: Alternatech, Route 1, Box 492A, Bonners Ferry, ID, 83805. Phone (208) 267-7745.

APPENDIX B—DATA COLLECTION METHOD

The following hypothetical cross section is used to illustrate the data collection method:

23/25 13/27T 10/9 0/0 -6/19 -12/44T -14/31

First, the reflector is placed at the point represented by 23/25, the break furthest to the left within the required cross section. The data SD = 25 feet and VI = 23 degrees are measured by the laser operator, who is at the break represented by 13/27T, with the laser screen showing HD-AZ as follows:

HD:————.- FT
AZ:———.- DEG

Since the VI is greater than 15 degrees, the AZ is not successfully measured. The laser down arrow is keyed once, displaying the following screen:

AZIMUTH:
———.- DEG

at which time the AZ (assumed here to be 180 degrees) is measured with the aid of the peep sight. The laser up arrow returns the operator to the laser screen showing HD-AZ as follows:

HD:———25.0 FT
AZ:——180.0 DEG

All required measurements are downloaded with one press of the laser ENTER key. The rodperson proceeds to the break represented by 13/27T, while the laser operator goes to centerline. The measurements 13/27 are made and downloaded, after which the operator presses the MC-V up arrow once and the ENTER key three times, followed by a T and the ENTER key again. The rod person proceeds to 10/9, at which time the operator triggers the laser and presses the laser ENTER key.

The operator then keys the sequence 0 and ENTER three times, followed by an additional ENTER, to document centerline location within the cross section data. The right side is also measured in a left to right direction. The laser operator measures to the reflector at -6/19 and -14/44, the later of which is identified with a T, and then occupied, for the measurement to -14/31. After completing the section, the MC-V - ["minus"], Y, and ESC keys are pressed, returning the operator to the ".trv" file.

This routine requires the crew to realize initially that point 23/25 is required for design purposes, but is not visible from 0/0. Thus, the break at 13/27 must also be identified as a T and occupied by the laser operator prior to data collection on point 23/25. These requirements represent modifications to standard cross sectioning routines, but do not require extra effort or knowledge.

APPENDIX C—LITERATURE CITED

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