

# **Forest Operations in Mountainous Conditions**

**Conference Proceedings  
IUFRO Unit 3.06**

**June 2-5, 2013 Honne, Norway**



Proceedings of the  
International Conference on Forest  
Operations in Mountainous Conditions

Honne, Norway June 2-5, 2013

International Union of Forest Research  
Organizations IUFRO

Unit 3.06

*Sponsored by*

The Norwegian Forest and Landscape Institute

The Research Council of Norway

Editors: Bruce Talbot & Hamish Berkett

ISBN 978-82-311-0184-0



The Research Council  
of Norway



skog+  
landskap  
NORWEGIAN FOREST AND  
LANDSCAPE INSTITUTE

# Foreword

These Proceedings reflect the content of the presentations made at the IUFRO Unit 3.06 conference held at Honne, Norway June 2-5, 2013.

Over 50 delegates from 16 different countries participated in the meeting despite the long lasting effects of the global economic downturn still being felt in academia and research around the world. This bears witness to both enthusiasm and resilience amongst researchers concerned with forest operations in mountainous conditions.

The conference was organized in seven thematic areas as follows:

- National Perspectives – papers presenting the status of operations in mountainous terrain at a national or large scale level in participating countries
- Productivity Studies – essentially presenting both methodological approaches, meta-analysis and results of productivity studies on specific machines and systems
- Planning – this theme includes papers primarily using terrain and topographic data from multiple sources in planning machine accessibility, roads, or systems selection
- Ergonomics, Safety, & Contractors – this includes study on work load, work organization, safety issues and contractor's machine selection
- Biomass from Steep Terrain – a number of papers address ways in which harvesting slash from operations in steep terrain can be accumulated and harvested.
- Forest Roads & the Environment - this area covers both the planning, construction, improvement, and assessment of environmental impact of forest roads
- Harvesting & the Environment – this session included presentations on both the planning and implementation of harvesting systems, with a special emphasis on environmental consequences.

IUFRO Division 3, and Unit 3.06 in particular, recognize the importance of maintaining an active research network through the encouragement of international workshops and seminars. IUFRO supports active working parties on any relevant aspect of accessing and harvesting in mountain forests, closes down those that are redundant, and proposes others in response to changing world conditions in accordance with Section VIII of IUFRO Statutes Article VIII. The present conference is testament to a healthy and active Unit 3.06, as we move toward the 2014 World Congress to be held in Salt Lake City, USA.

On behalf of IUFRO Unit 3.06, I would like to express my appreciation to the Norwegian Forest and Landscape Institute for their efforts in arranging the conference, and especially to the many delegates whose participation contributed to this successful event.



Prof. Raffaele Cavalli

Coordinator: Unit 3.06

### **Acknowledgements-**

We wish to acknowledge:

The County of Sogn & Fjordane, and Sogn & Fjordane's forest owner's association, for sponsoring, arranging and hosting the pre-conference tour

Mjøsen Skog SA for arranging and hosting the conference excursion

Trygve Owren AS and T. Frivik Taubane AS, for their efforts in demonstrating machines and equipment in connection with the conference

The Scientific Committee for their work with reviewing abstracts and manuscripts

The Organizing Committee for their work in making the event happen

To the Delegates for their respective outstanding contributions to both the scientific and social program

## **Scientific Committee**

Hans R. Heinimann, Coordinator Division 3, Swiss Federal Institute of Technology

Jean-Francois Gingras, Deputy Coordinator, Div. 3, FPInnovations, Canada.

Hideo Sakai, Deputy Coordinator, Div. 3, University of Tokyo, Japan.

Raffaele Cavalli, Coordinator Unit 3.06, University of Padua, Italy.

Karl Stampfer, Deputy Coordinator Unit 3.06, University of Natural Resources and Life Sciences, Austria.

John Garland, Oregon, USA

Hulusi Acar, Karadeniz Technical University, Turkey

Pierre Ackerman, Stellenbosch University, South Africa

Ola Lindroos, Swedish University of Agricultural Sciences.

Chris LeDoux, USDA Forest Service, Northern Research Station

Bruce Talbot, Norwegian Forest and Landscape Institute

## **Organizing Committee**

Bruce Talbot, Norwegian Forest and Landscape Institute

Raffaele Cavalli, University of Padua.

Morten Nitteberg, Norwegian Forest and Landscape Institute

Nils Olaf Kyllø, Norwegian Forest and Landscape Institute

Torkel Hofseth, County of Sogn og Fjordane

Johannes Bergum, Mjøsen Skog SA

# TABLE OF CONTENTS

|                                                                                                                                              |           |
|----------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| <b>SESSION 1: NATIONAL PERSPECTIVES .....</b>                                                                                                | <b>12</b> |
| 1.1 DIRECTION OF DEVELOPMENT OF THE TOWER YARDER IN JAPAN                                                                                    |           |
| <i>Sakai, H.<sup>1</sup>, Sakurai, R.<sup>1</sup>, Oikawa, R.<sup>2</sup>, and Chisaka, O.<sup>3</sup> .....</i>                             | <i>13</i> |
| 1.2 UPDATE ON STEEP SLOPES OPERATIONS RESEARCH AT FPINNOVATIONS IN CANADA                                                                    |           |
| <i>Jean-François Gingras .....</i>                                                                                                           | <i>15</i> |
| 1.3 A SURVEY OF YARDING COMPANIES IN THE ITALIAN ALPS                                                                                        |           |
| <i>Spinelli, R., &amp; Magagnotti N.....</i>                                                                                                 | <i>18</i> |
| 1.4 STEEP GROUND HARVESTING PROJECT – FORESTRY COMMISSION SCOTLAND:<br>EVALUATION, INNOVATION AND DEVELOPMENT IN SCOTTISH SKYLINE OPERATIONS |           |
| <i>Kate Tuer<sup>1</sup>, Colin Saunders<sup>2</sup> &amp; Grant MacIntosh<sup>3</sup> .....</i>                                             | <i>21</i> |
| 1.5 DEMAND FOR MECHANIZED STEEP TERRAIN LOGGING SYSTEMS IN SOUTHERN CHINA<br>DUE TO CHANGING OPERATIONAL CONDITIONS                          |           |
| <i>Hoffmann, S.<sup>1</sup>, Jaeger, D.<sup>1</sup>, Engler, B.<sup>1</sup> &amp; Pierschkalla, S.<sup>2</sup> .....</i>                     | <i>24</i> |
| 1.6 GUIDELINES FOR DIFFICULT TERRAIN GROUND-BASED HARVESTING OPERATIONS IN<br>SOUTH AFRICA                                                   |           |
| <i>McEwan, A.<sup>1</sup>, Brink, M.<sup>1</sup> &amp; van Zyl, S.<sup>1</sup> .....</i>                                                     | <i>27</i> |

## SESSION 2: PRODUCTIVITY STUDIES..... 29

|                                                                                                                           |    |
|---------------------------------------------------------------------------------------------------------------------------|----|
| 2.1 CABLE YARDING PRODUCTIVITY MODELS: A REVIEW OVER THE PERIOD 2000-2011                                                 |    |
| <i>Cavalli, R.<sup>1</sup> &amp; Lindroos, O.<sup>2</sup></i> .....                                                       | 30 |
| 2.2 A METHODOLOGICAL APPROACH TOWARDS SPECIFIC COST AND PRODUCTIVITY MODELS<br>FOR CABLE YARDING IN THE FRENCH ALPS       |    |
| <i>Magaud, P</i> .....                                                                                                    | 32 |
| 2.3. PRODUCTIVITY ANALYSIS OF THINNING OPERATIONS USING A SWING YARDER ON STEEP<br>SLOPES IN WESTERN JAPAN                |    |
| <i>Yoshimura, T.<sup>1</sup>, &amp; Noba, T.<sup>2</sup></i> .....                                                        | 35 |
| 2.4 COMPARING CABLE LOGGING PRODUCTIVITY BETWEEN NATURAL PINE AND PLANTATION<br>SPRUCE STANDS ON NORWAY'S WEST COAST      |    |
| <i>Fjeld, D. &amp; Laukeland, A</i> .....                                                                                 | 37 |
| 2.5 MULTIFUNCTIONAL TRACTOR WINCH SKIDDING IN FOREST OPERATIONS ON STEEP SLOPE<br>AREAS                                   |    |
| <i>Yoshida, M</i> .....                                                                                                   | 39 |
| 2.6 MECHANIZATION OF HARVESTING IN EUCALYPTUS SPP. PLANTATION FORESTS USING A<br>HARVESTER IN MOUNTAINOUS AREAS IN BRAZIL |    |
| <i>Robert, R.C.G.<sup>1</sup>, Jaeger, D.<sup>2</sup>, Becker, G.<sup>2</sup></i> .....                                   | 41 |

## SESSION 3: PLANNING ..... 44

|                                                                                                                                              |    |
|----------------------------------------------------------------------------------------------------------------------------------------------|----|
| 3.1 AUTOMATIC HARVEST AND CABLE ROAD LAYOUT PLANNING FOR MULTIPLE OBJECTIVES                                                                 |    |
| <i>Bont, L.<sup>1</sup>, Heinimann, H R<sup>1</sup>, &amp; Church, R. L.<sup>2</sup></i> .....                                               | 45 |
| 3.2 EVALUATION OF FOREST MACHINERY GROUND MOBILITY USING LiDAR DATA                                                                          |    |
| <i>Pellegrini, M.<sup>1</sup>, Grigolato, S.<sup>1</sup>, Cavalli, R.<sup>1</sup>, Lingua, E.<sup>1</sup>, Pirotti, F.<sup>1</sup></i> ..... | 48 |
| 3.3 MEASURING MACHINE SLOPE WHEN HARVESTING ON STEEP TERRAIN                                                                                 |    |
| <i>Berkett, H &amp; Visser, R</i> .....                                                                                                      | 50 |
| 3.4 ALGORITHMS FOR LANDING EVALUATION AND DETECTION                                                                                          |    |
| <i>Søvde, N.E.</i> .....                                                                                                                     | 53 |
| 3.5 EXAMINING THE OPTIMAL EXTRACTION RATE OF EXTRACTING THINNED WOODS IN NASUNOGAHARA AREA, TOCHIGI PREFECTURE, JAPAN                        |    |
| <i>Nakahata, C.<sup>1</sup>, Saito, M.<sup>2</sup>, &amp; Aruga, K.<sup>1</sup></i> .....                                                    | 55 |
| 3.6 OPPORTUNITIES FOR DEVELOPING EXCAVATOR BASED CABLE LOGGING OPERATIONS IN IRELAND – A PRODUCTIVITY ANALYSIS                               |    |
| <i>Ger Devlin<sup>1</sup> and Radomir Klvac<sup>2</sup></i> .....                                                                            | 58 |

## **SESSION 4: ERGONOMICS, SAFETY, & CONTRACTORS..... 62**

### **4.1 A LOOK AT LOGGER TRAINING AFTER 35 YEARS**

*Dr. John J. Garland PE* ..... 63

### **4.2 OPERATOR PERFORMANCE IMPROVEMENT THROUGH TRAINING IN A CONTROLLED CABLE YARDING OPERATION**

*Ottaviani Aalmo, G. & Talbot, B.* ..... 64

### **4.3 CONTRACTOR EQUIPMENT SELECTION FOR MOUNTAINOUS LOGGING OPERATIONS IN WEST VIRGINIA**

*Ben Spong<sup>1</sup>, Dan Magil, and Shawn Grushecky* ..... 67

### **4.4 AN OWAS-BASED ANALYSIS OF MOTOR MANUAL TIMBER HARVESTING OPERATIONS**

*Manavakun, N.<sup>1</sup>* ..... 68

### **4.5 PRODUCTIVITY AND ERGONOMIC STUDY OF A MOTORIZED HYDRAULIC GRAPPLE CARRIAGE**

*Visser, R<sup>1</sup>, S. McFadzean<sup>1</sup> & S. Hill<sup>2</sup>* ..... 72

### **4.6 SAFETY MANAGEMENT SYSTEM FOR MOUNTAINOUS FORESTRY OPERATION**

*Yamada, Y., Funasaka, Y., & Higashi, K.* ..... 75

## **SESSION 5: BIOMASS FROM STEEP TERRAIN HARVESTING..... 78**

|                                                                                                                                  |           |
|----------------------------------------------------------------------------------------------------------------------------------|-----------|
| 5.1 HARVESTING LOGGING RESIDUES FOR ENERGY IN A COMBINED SYSTEM IN STEEP TERRAIN                                                 |           |
| <i>Becker, G.<sup>1</sup>, Cremer, T.<sup>1</sup>; Spinelli, R.<sup>2</sup>, Sauter, U. H.<sup>3</sup>.....</i>                  | <i>79</i> |
| 5.2 RECOVERY OF LOGGING RESIDUES FROM FINAL HARVEST IN STEEP TERRAIN                                                             |           |
| <i>Eirik Nordhagen.....</i>                                                                                                      | <i>82</i> |
| 5.3 A NEW EQUIPMENT FOR PRODUCTIVE COLLECTION OF FOREST RESIDUES BESIDES CABLE LOGGING: LOGISTICS WHEN YARDING SPACE IS LIMITED. |           |
| <i>Naud, O.<sup>1</sup>, &amp; Rombaut, M., Bonicel, J.-F., &amp; Prouvot, A. ....</i>                                           | <i>85</i> |
| 5.4 WHOLE-TREE YARDING AND MECHANISED PROCESSING IN COPPICE OPERATIONS                                                           |           |
| <i>Magagnotti N.<sup>1</sup>, Becker G.<sup>2</sup>, Suchomel C.<sup>2</sup> &amp; Spinelli, R.<sup>3</sup>.....</i>             | <i>88</i> |
| 5.5 ADDRESSING THE LAYOUT AND LOGISTICAL CHALLENGES OF A BARGE BASED YARDING OPERATION IN THE NORWEGIAN FJORDS                   |           |
| <i>Belbo, H. &amp; Talbot, B.....</i>                                                                                            | <i>92</i> |

## SESSION 6: FOREST ROADS & THE ENVIRONMENT ..... 94

|                                                                                                                                                            |            |
|------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| 6.1 STUDY OF A FOREST ROAD NETWORKD PLANNING MODEL WITH LiDAR DATA FOR FUNYU EXPERIMENTAL FOREST, UTSUNOMIYA UNIVERSITY, JAPAN.                            |            |
| <i>Saito, M.1, &amp; Aruga, K.2.....</i>                                                                                                                   | <i>95</i>  |
| 6.2 ENVIRONMENTALLY SOUND ROAD NETWORK PLANNING AND ANALYSIS IN MOUNTAINOUS FOREST                                                                         |            |
| <i>Hayati, E.<sup>1</sup>, Majnounian, B. &amp; Abdi, E. ....</i>                                                                                          | <i>99</i>  |
| 6.3 STUMP REMOVAL AND ITS UTILIZATION UNDER FOREST ROAD CONSTRUCTION                                                                                       |            |
| <i>Rianthakool,L , Sakai,H , &amp; Sakurai,R .....</i>                                                                                                     | <i>103</i> |
| 6.4 UNTREATED WOOD ASH AS A STRUCTURAL STABILIZING MATERIAL IN FOREST ROADS                                                                                |            |
| <i>Bohrn, G. &amp; Stampfer, K.....</i>                                                                                                                    | <i>106</i> |
| 6.5 ATTAINING THE PRINCIPLES OF MITIGATING ADVERSE FOREST ROAD EFFECTS; A STUDY ON PLANT SPECIES DIVERSITY IN A MANAGED MOUNTAINOUS CASPIAN FOREST IN IRAN |            |
| <i>F. Berenji Tehrani, B. Majnounian, E. Abdi, Gh. Zahedi Amiri.....</i>                                                                                   | <i>109</i> |
| 6.6 EVALUATION OF SITE IMPACT AFTER HARVESTING IN STEEP TERRAIN WITH EXCAVATOR ASSISTED GROUND BASED SYSTEMS                                               |            |
| <i>Bjerketvedt, J<sup>1</sup>, Talbot, B<sup>1</sup>, Kindernay, D<sup>2</sup>, Ottaviani Aalmo, G.<sup>1</sup>, Clarke, N.1.....</i>                      | <i>113</i> |

## SESSION 7: HARVESTING & THE ENVIRONMENT ..... 115

- 7.1 TIMBER HARVESTING AND RESIDENTIAL DEVELOPMENT IN A MOUNTAINOUS APPALACHIAN WATERSHED: INTERACTIVE IMPACTS ON SUSPENDED SEDIMENT CONCENTRATIONS  
*Fulton, J. B.<sup>1</sup>, Petty, J.T.<sup>2</sup>, Grushecky, S.T.<sup>3\*</sup>, Harouff, S.<sup>4</sup>, Hartman, K.J.<sup>2</sup>, McGill, D.<sup>3</sup>. & Spong, B.<sup>3</sup> ..... 116*
- 7.2 SIMULATING TOPOGRAPHIC POTENTIAL FOR AUTOMATED EROSION DETECTION: AN EVALUATION OF STEEP FOREST ON OKINAWA ISLAND  
*Azita, A.Z.<sup>1,2,3</sup>, Masami, S.<sup>1</sup>, & Noor, J.N.J.<sup>1,2</sup> ..... 117*
- 7.3 UNCONTROLLED SKIDDING OF LOGS USING A CHUTE SYSTEM IN A MOUNTAIN REGION  
*Acar, H. & Unver, C. .... 121*
- 7.4 TOPOGRAPHIC ANALYSIS FOR FOREST MANAGEMENT USING SAGA GIS IN STEEP TERRAIN AREAS  
*Itaya, A. .... 122*
- 7.5 APPLYING THE ANALYTICAL HIERARCHY PROCESS IN SELECTING AMONG EXCAVATOR BASED YARDER CONFIGURATIONS  
*Talbot, B. & Nitteberg, M. .... 124*

## **SESSION 1: NATIONAL PERSPECTIVES**

**Chair: Prof. Raffaele Cavalli**

## 1.1 DIRECTION OF DEVELOPMENT OF THE TOWER YARDER IN JAPAN

*Sakai, H.<sup>1</sup>, Sakurai, R.<sup>1</sup>, Oikawa, R.<sup>2</sup>, and Chisaka, O.<sup>3</sup>*

<sup>1</sup> Department of Forest Science, The University of Tokyo, Japan. sakaih@fr.a.u-tokyo.ac.jp , sakurai@fr.a.u-tokyo.ac.jp

<sup>2</sup> Research Laboratory of Forest Engineering, Miyagi, Japan.

<sup>3</sup> IHI Construction Machinery Limited, Yokohama, Japan.

### Introduction

Japanese forest terrain is very steep. About 45 % of forest lands exceeds 25 degrees of slope. Harvesting planted conifers on steep and difficult sites is a problem of national concern. After discussing history so far of cable logging in Japan, the direction of development of tower yarder is discussed.

### History of cable logging in Japan

Cable logging by yarder with a steam engine was introduced in Alishan, Taiwan, from United States at the beginning of 20<sup>th</sup> century. Many engineers were trained there and spread the technology of cable logging to Kiso Imperial Forest on the central part of Japan. Later, changing engine power from steam to gasoline was attempted, but the World War II occurred and the development of forest engineering stopped temporarily.

After the World War II, a light weight yarder with a gasoline engine was developed by mechanic engineers who were formerly airplane engineers during the war. The essence of airplane was applied to the concept of design, for example, monocoque structure for drums, continuously variable transmission and hydraulic brakes. It took about ten years to spread over the country, and then became a main logging system on the mountainous slopes. North American Tyler system and north bend system were used, and Tyler with three drums and endless Tyler system were invented later suited for Japanese conditions.

In 1964, E. Pestal's article "Kardinal punkt 500 m! -Rückungsmethade entscheiden Wegnetzdicke-" was introduced to Japan, but making forest road was difficult at that time, because mechanized road construction had been generalized since early 60's.

In 1970's, Japanese plantation forests which were made by expansive afforestation from deciduous trees to soft trees after 1950's fuel revolution had become facing with thinning. Running skyline system and zigzag system with small diameter of wire ropes and a small engine were used. On the contrary, small vehicles like a mini-forwarder had begun to spread on temporal strip roads after an opportunity of oil crisis in 1973. Later, these vehicles were equipped with a crane or a winch, and begun to prehaul thinned logs in the forest from roadside. In 1991, a mobile tower yarder mounted on such a four-wheel-drive mini-forwarder

equipped with a 60 horsepower engine with an interlocked hydraulic winch was developed (Shishiuchi et al. 1993). The winch was composed of a haulback drum and a mainline drum which had a pair of grooved drums interlocked by a magnetic clutch and transferred torque between the haulback drum and the mainline drum. It was capable of yarding both uphill and downhill on slopes by perfect interlock mechanism. It could move on strip roads 2 m in width, and harvest thinned logs within a distance of 150m using simple cable systems such as running skyline system. Unfortunately, forest workers did not like to rig guylines of tower yarder, and they inclined to use swing yarders. But practical yarding distance of swing yarders was shorter than that of tower yarders, and the operational efficiency faced a limit. Again, more advanced three drums interlock tower yarder which was examined and discussed here was developed by IHI Construction Machinery Limited in 2012.

### New developed tower yarder

Figure 1 shows the tower yarder examined and Figure 2 shows the mechanism of three drums interlock. We report the results and discuss the future direction of cable logging.

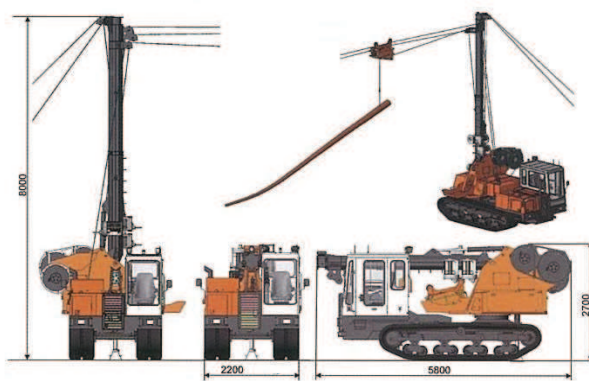


Figure 1. Tower yarder examined.

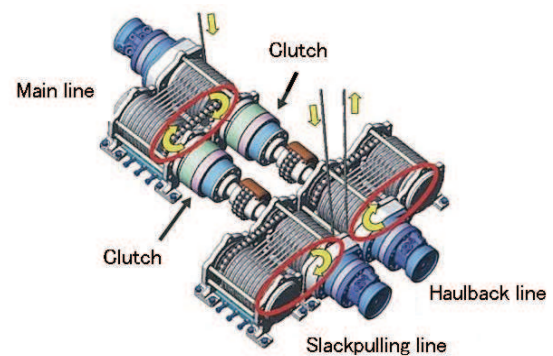


Figure 2. The mechanism of three drums interlock.

## 1.2 UPDATE ON STEEP SLOPES OPERATIONS RESEARCH AT FPInNOVATIONS IN CANADA

*Jean-François Gingras*

FPInnovations 570 St-John Blvd, Pte-Claire, Quebec Canada H9R 3J9 Jean-Francois.Gingras@fpinnovations.ca

### Introduction

This presentation will provide an update to the forest engineering community regarding research projects and other steep slope initiatives spearheaded by FPInnovations, Canada's forest sector R&D institute.

The steep slope research program at FPInnovations is driven by the need to develop safe and cost-effective means of harvesting additional fiber from slopes greater than 40% mainly in Western Canada. In British Columbia for example, timber growing on slopes greater than 40% represents 24% of the overall fiber supply. One factor increasing the need to push harvesting up the slopes results from the recent AAC downfall caused by the severe destruction of the pine stands by the Mountain Pine Beetle (*Dendroctonus ponderosae*). Overall, it is expected that the AAC in the BC interior region will drop to 10.6 million m<sup>3</sup> from a pre-epidemic average of 17 million m<sup>3</sup>, with dramatic implications on timber supply to the many sawmills operating in the region.

While large-scale cable yarding systems have been used extensively in British Columbia over the years, especially in the coastal region, the high logging costs associated with these systems especially in second growth or smaller timber stands are pressuring operations managers to look for cheaper alternatives, for example ground-based systems adapted to steep slope operations. In recent years, FPInnovations has managed an active R&D program in the area of steep slopes, mainly out of its Vancouver, B.C. office. The projects that will be described in this presentation cover safety, technological and operational aspects.

### Safety aspects

- *Static stability test procedure for forest machines*

In British Columbia, it is permitted to use ground-based machines on slopes greater than 40% if the manufacturer's declares a higher limit. However, most manufacturers will not declare a limit for their machines. FPInnovations has developed a static tilt test procedure that will compare the static roll-over thresholds for forest machines. Initial tilt tests will be conducted in 2013.

- *Planter safety and productivity on steep slopes*

Slips, trips and falls are the number one cause of injuries in the silviculture industry, and these can be compounded on steep terrain. A recent study has quantified the occurrence of these events as a function of increasing slope (0-60%) and also increasing obstacle/slash load (which is often high on steep harvested sites).

- *Steep grade descent guidelines for logging trucks*

Trucking in mountainous conditions often involves descending steep grades with large loads, creating high risks of brake overheating and potential accidents if descent speeds are not well managed. FPInnovations has developed a descent guideline model for trucks that can run on various smart phone platforms. The model considers several parameters including brake heat

transfer, drum brake fade, configuration dynamics, road conditions and road geometry.

- *On-board slope thresholds warning system*

FPInnovations developed procedures to identify microrelief from Lidar data, and building on this capability, the proposed work is the next step in a long-term vision to provide more automated terrain and safety assessment tools for operators on slopes. Automated assessment and in-cab display of the current roll-over resistance, or predictive maps of the best travel routes through difficult terrain are planned for development.

## **Technology Aspects**

- *Lidar maps to produce high-resolution slope profiles*

Airborne Lidar scans produce high-resolution terrain micro-elevation maps. These maps can be used to assess the micro-slopes exceeding certain threshold on slopes featuring broken or complex side slopes where the overall average slope may be reasonable but occasionally presenting localized high-risk areas for forest machines to operate on. These risk maps combine DEM data (slope, slope length, ground roughness) and soil type data to generate an overall risk assessment.

- *Potential of tethered equipment*

Tethered machines, which are attached by cable to a fixed anchor for additional stability and safety, are used on an operational basis in many European countries mainly with CTL equipment. However, the CTL system is not used in BC because of timber size and tethering technology has not been used to this point. The Climb-Max Steep Slope Harvester, an innovative large-tree felling machine developed in New Zealand could have some applications in Canada. Through an MOU with Future Forest Research, FPInnovations will be studying the potential of this technology for Canada in 2013.

- *Small-scale cable yarding systems*

Because traditional cable yarding systems require long setup times and are slow to move between operating areas, costs can become prohibitive in smaller operating areas and isolated patches of timber that will be more and more frequent in the future. This project is identifying and testing new technologies that can operate without guy lines or that have other features to reduce their setup time.

- *Leveling cab excavator-forwarders*

Excavator-forwarders (hoe chucking) are widely used in BC on gentle to moderate slopes. A levelling-cab loader-forwarder may expand the range of sites where ground-based equipment can replace cable yarding equipment, thus improve fiber access.

## **Operational aspects**

- *Best practices guide for ground based equipment on slopes*

Combining operational experience from many years of research and field studies, FPInnovations is working with experts in steep slope harvesting to produce a best practices guide for safe operations in these conditions. The guide will include sections on risk assessment, planning and organization, assessing the site, machine selection, operator selection and operating methods.

- *Increase value recovery by banding cedar trees prior to felling*

Large cedar trees (>100 cm DBH) often split when felled and dropped on steep slopes,

creating large value and fiber losses. This project examined the effectiveness of banding cedar trees with single, double or triple metal straps prior to felling. The results indicate that the banding costs can be more than offset by reductions in value losses.

- *Effects of slopes on log sorting costs*

This project examined the impact of slopes on sorting efficiency with various forest machines, including feller-bunchers, processors and forwarders. With forwarders, steeper slopes (>25%) increased loading time (min/m<sup>3</sup>) and this effect was compounded with an increasing number of sorts. With processors, a 20% productivity reduction was measured on steep slopes when producing five assortments compared with two.

### 1.3 A SURVEY OF YARDING COMPANIES IN THE ITALIAN ALPS

*Spinelli, R., & Magagnotti N*

CNR IVALSa, Italy. [spinelli@ivalsa.cnr.it](mailto:spinelli@ivalsa.cnr.it) , [magagnotti@ivalsa.cnr.it](mailto:magagnotti@ivalsa.cnr.it)

#### **Introduction**

For years, the EU has supported the modernization of rural enterprises through recurrent grant schemes, fed with structural funds. Logging companies have received substantial benefit from these subsidies, granted for replacing older machines or for starting new companies. Therefore, it is likely the new grant schemes will be issued for supporting the forecasted dramatic growth of the new bio-based economy. However, the general principle of efficiency and the contingent economic situation suggest optimizing any new efforts. With little money to waste, the public administration must put every cent to its best effect. Accurate targeting of any support efforts implies a good knowledge of the target itself, but we believe that this knowledge is still very limited. The goal of this study was to draw a comprehensive description of logging companies active in the Italian Alps, offering a first contribution to an effective support strategy. In particular, we set out to determine the number of companies and their distribution in terms of enterprise type, annual work volume and total workforce. We also looked for information about the number, type and age of their machine fleets.

#### **Methods**

In Italy, regional forest offices do keep updated files for the logging companies active in their territory, and these files often contain much detail. Therefore, we contacted the Forest Service administrations of all the seven Italian Regions whose territory includes a portion of the Alpine mountain range. From west to east, these are: Piemonte, Valle d'Aosta, Lombardia, Trentino, Alto Adige, Veneto, Friuli Venezia Giulia. The files were relatively heterogeneous, since each administration had run its own independent survey. However, they all contained a common core of information about the fundamental characteristics we were looking for. In order to increase homogeneity, detailed follow-up surveys were conducted in Valle d'Aosta and Veneto. Updated files were organized into a master database, used to extract fundamental descriptive statistics, including distribution charts. Meaningful differences were analysed with parametric and non-parametric techniques, depending on the distribution of data. Much attention was also given to characterizing the machine fleet, in order to gauge both the need and the possibility for modernization.

#### **Results**

Active logging companies based in the Italian Alps count 1206 units, with a total workforce of 3563 loggers. These companies harvest an estimated 3.3 million m<sup>3</sup> of wood per year. Two Regions alone – Piemonte and Veneto – account for about two thirds of the companies and the workforce. These Regions also account for about 60% of the total harvest. The machinery fleet is largely based on modified farm tractors (1872 units), equipped with forestry winches (1115 units) or forestry trailers (1366 units). Modern forest machinery is still relatively rare. The current value of the machine fleet rounds to 130 million €, returning the overall average of 107,000 € per company.

Single ownership is the most common firm type, and represents between two thirds and three quarters of the total number. Compared to partnership companies, single owner companies employ fewer people (1.8 vs. 4.8) and have a lower annual harvest (2000 m<sup>3</sup> vs. 5200 m<sup>3</sup>). Overall, three-quarters of the companies do not harvest more than 2500 m<sup>3</sup> year<sup>-1</sup>, each. Micro-companies harvesting no more than 500 m<sup>3</sup> year<sup>-1</sup> represent over one-third of the total count. Barely 10% of the companies harvest more than 5000 m<sup>3</sup> year<sup>-1</sup>.

Conifers represent slightly more than half the total harvest, except for Trentino, where they account for over 90% of the total harvest. Contract harvesting is quite popular in Val d'Aosta and Trentino, where the logging company configures as a service business, geared to satisfy the technical needs of forest owners and wood traders. In contrast, most companies from Friuli VG buy, harvest and sell, thus integrating both the technical and the trade function.

Chainsaws and modified farm tractors are the backbone of the north Italian forest machine fleet. About 12% of the tractors are tracked, while the rest is rubber-tired. Tracked models are older (15 vs. 11 years) and less powerful (43 vs. 63 kW) than rubber-tired models. Economic life is assumed to reach or exceed the upper quartile level for age, i.e. 23 and 16 years for tracked and rubber-tired tractors, respectively. The market is dominated by Italian brands.

**Table 1** – Yarder fleet, yarding capacity and yarder characteristics

|                         |             | Piemonte | VdA    | Lombardia | Trentino | Veneto  | FVG    | Total   |
|-------------------------|-------------|----------|--------|-----------|----------|---------|--------|---------|
| Yarders                 | n           | 60       | 8      | 105       | 73       | 68      | 45     | 359     |
| Sleds                   | n           | 34       | 6      | 78        | 39       | 45      | 28     | 230     |
| Towers                  | n           | 26       | 2      | 27        | 34       | 23      | 17     | 129     |
| Towers                  | %           | 43       | 25     | 26        | 47       | 34      | 38     | 36      |
| Yarding capacity        | % companies | 11       | 55     | 44        | 41       | 19      | 31     | 24      |
| Age sleds               | years       | 11       | 6      | 17        | 17       | 22      | 14     | 15      |
| Age towers              | years       | 4        | 4      | 5         | 4        | 7       | 12     | 6       |
| Mann-Whitney            | p           | 0.0041   | 0.8465 | <0.0001   | <0.0001  | <0.0001 | 0.3887 | <0.0001 |
| Skyline length - sleds  | m           | NA       | NA     | 1300      | 1300     | NA      | 1100   | 1270    |
| Skyline length - towers | m           | NA       | NA     | 600       | 850      | NA      | 650    | 750     |
| Mann-Whitney            | p           | NA       | NA     | <0.0001   | <0.0001  | NA      | 0.0012 | <0.0001 |

Cable logging is especially popular in the Italian Alps. North Italian loggers have a long tradition with cable yarding, and several yarder manufacturers operate their plants in northern Italy. One logging company out of four has both the skills and the equipment for cable yarding (Table 1). Overall, we counted 230 traditional sled-mounted winches and 120 tower yarders. Tower yarders are especially popular in Piemonte and Trentino, where they are often

associated with a processor. Tower yarders are the modern counterpart of the traditional sled-mounted winches, and they are generally half as old. On the other hand, sled mounted yarders can work with longer skylines and are especially useful when no roads are available. In fact, new long-distance tower yarders are narrowing the gap between the two models. Over 70% of the north Italian yarder fleet is Italian-made, while the rest is equally divided between Austrian-made (14%) and Swiss-made (15%) models. Greifenberg and Valentini are the most popular brands. Companies equipped with a yarder harvest almost twice as much wood as the other companies (4059 vs. 2340 m<sup>3</sup> year<sup>-1</sup>), and the difference is statistically significant ( $p < 0.0001$ ). They also target significantly larger lots, although the difference is not very high (678 vs. 565 m<sup>3</sup>).

In this respect, we may need to define what is modern technology and how it should be used. The Alps offer different work conditions compared to most Nordic countries, especially for what concerns terrain morphology and forest access. Forwarding can be applied to a relatively small proportion of the productive area, and processors are best teamed with yarders. Under these conditions, yarding capacity is crucial to effective harvesting, and represents a main asset of Alpine logging companies. Yarding skills are more difficult to acquire than yarding equipment, and the north Italian logging firms seem to possess these skills to a very high degree. The maintenance, improvement and expansion of the already pervasive Italian yarding skill should be supported by all available means, including subsidies.

## **Conclusions**

The north Italian logging industry is dominated by small-scale companies, largely equipped with obsolete tractor-based technology. Opportunities arise from a very strong competence with cable yarding, which is a crucial skill in the Alpine mountain region. A main strength of the north Italian logging companies is in their continued capacity to attract local labour and entrepreneurs, as demonstrated by the relatively small reliance on immigrant labour. In many cases, the shift towards newer tower yarders has been widely supported with public subsidies, thus mitigating the strain on entrepreneurs. With local adaptations, similar mechanisms are available all over Europe and have already been used to promote mechanization. A suggestion to the decision-makers is to prioritize grants to the acquisition of modern technology, rather than to the renewal of the obsolete. Yarding capacity is crucial to effective harvesting, and represents a main asset of Alpine logging companies. Yarding skills are more difficult to acquire than yarding equipment, and the north Italian logging firms seem to possess these skills to a very high degree. The maintenance, improvement and expansion of the already pervasive Italian yarding skill should be supported by all available means, including subsidies. The study also found an inverse relationship between investment in modern machinery and entrepreneur age, hinting at the social benefit of public support measures in favour of effective mechanization

## 1.4 STEEP GROUND HARVESTING PROJECT – FORESTRY COMMISSION SCOTLAND: EVALUATION, INNOVATION AND DEVELOPMENT IN SCOTTISH SKYLINE OPERATIONS

*Kate Tuer<sup>1</sup>, Colin Saunders<sup>2</sup> & Grant MacIntosh<sup>3</sup>*

<sup>1</sup>. Forest Enterprise Scotland, Lochaber Forest District, Fort William, Scotland. [Kate.tuer@forestry.gsi.gov.uk](mailto:Kate.tuer@forestry.gsi.gov.uk)

<sup>2</sup>. Forest Research, Technical Development Unit, Roslin, Scotland. [Colin.saunders@forestry.gsi.gov.uk](mailto:Colin.saunders@forestry.gsi.gov.uk)

<sup>3</sup>. Forest Enterprise Scotland, Forest Enterprise Head Office, Inverness, Scotland.

[Grant.macintosh@forestry.gsi.gov.uk](mailto:Grant.macintosh@forestry.gsi.gov.uk)

### Abstract

The management of timber on steep ground is of significant importance to the Scottish Forest industry. Currently 7% of the productive coniferous forest area is on steep ground ~ 266k m<sup>3</sup> per annum. More steep ground is being brought into production, and the project aims to provide qualitative data to forest managers and operators.

The Steep Ground Harvesting project identified the operational limits of currently available skylines, the key factors for future development in steep ground harvesting operations, and alternative options for extreme felling sites.

The project works in partnership with Forest Research, skyline contractor **Duffy Skylining** and skyline design and fabrication unit **A & B Services**. A trial and evaluation of the most common current skyline available in Scotland was carried out in 2011. The limitations identified in this trial allowed specification of an improved design. This improved machine was built in 2012 and is now in effective timber production on the national Forest Estates most difficult steep ground.

### Introduction

In 2007 Forest Enterprise reviewed the volume available on steep ground – that is ground inaccessible to standard harvesting machinery due to slope and terrain. It was found that 7% of the annual forecast was on steep ground, equivalent to 266,000m<sup>3</sup> per annum. Much of this volume was mature and over-mature large diameter conifer species, which had been retained on site as there was no effective method of harvesting.

With an increasing interest in home-grown timber products, and support from the Scottish and UK Government for sustained timber production and increased woodland cover, it was necessary to identify a methodology for steep ground harvesting.

A census of available equipment and skilled operating teams in 2008 showed that the average skyline was between 6 and 10 years old, not in full production (averaging 2000-11000m<sup>3</sup> per year), and the majority of operators were 41-50 years old. There had been recent investment in excavator based skyline conversions and purpose-built tracked hillclimbers.

This Project aimed to evaluate the limits and full capacity of a working standard skyline set up in 2011. After this was completed it was clear that this type of machine would not be suited to the most extreme and difficult sites, with large trees and long extraction distances as well as steep slopes. A further trial was designed to test an ‘improved specification’ designed and built by Duffy Skylining and A & B Services.

## Methodology

Two trial machines were evaluated on steep slopes and rough terrain – sites chosen to test the equipment to its limits.

### Trial 1: Evaluation of the Standard Scottish skyline

The ‘standard’ skyline was a Daewoo 220 LC-V excavator base, converted to a 3m tower skyline with (Timbermaster) Igland 8000 double drum winches, and using a Smiths locking carriage on 15mm steel cable. Chokering was using bump-release chain chokers.

In total five men work on the team – 2 x chokermen, 1 x feller, 1 x forwarder operator, 1 x winch operator. All men are trained to do more than one role.

### Trial 2: Evaluation of the Super-Skyline – built to counter the limitations identified in Trial 1.

The Super-Skyline was a 35 tonne Volvo EC 360 excavator base, converted to a 4m tower skyline with hydraulically controlled, unsynchronised, Poclain double drum winches, using a Koller USKA 1.5 accumulator carriage on 18mm hammered dieform steel cable. Chokering was using electronic release Ludwig chokers.

The same team and distribution of work was used as in Trial 1.

Work was measured by the Forest Research Time Study methodology – using a stop watch and observer.

## Results

### **Trial 1: Daewoo base**

- Slope ranged from 45% to 82%.
- Tree size was from 0.2 to 10.88m<sup>3</sup>.
- The average volume extracted per week was 150m<sup>3</sup>.
- The average productive rate was 12.37m<sup>3</sup> per hour.

#### Identified Limitations:

- Maximum load capacity 3.36m<sup>3</sup> uphill
- Ineffective braking system in downhill extraction
- Maximum breaking strain on 15mm steel cable
- Bump-release chokers do not always work, requiring winch operator to leave cab and ascend log pile to release them

### **Trial 2: Volvo base**

- Slope ranged from 66% to 88%.
- Tree size was from 0.5 to 6.0m<sup>3</sup>.
- The average volume extracted per week was 320m<sup>3</sup>.
- The average productive rate was 14.70m<sup>3</sup> per hour uphill and 16.20m<sup>3</sup> per hour downhill

Improvement on previously identified limitations:

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

- Maximum load was 4.47m<sup>3</sup> uphill.
- Hydraulically controlled braking system removed need to reduce load sizes or off-set skyline.
- Electronic chocking removed need for operator to leave cab and un-choke manually. This allowed closer working proximity to the harvester in the landing zone, and reduced risk.



**Left: Volvo based excavator at trial 2**



**Right: Daewoo based excavator trial 1**

### **Acknowledgement:**

This trial was funded by Forestry Commission Scotland. The Skylines are wholly owned and operated by Duffy Skylining and we are indebted to them and our partner A & B Services.

## 1.5 DEMAND FOR MECHANIZED STEEP TERRAIN LOGGING SYSTEMS IN SOUTHERN CHINA DUE TO CHANGING OPERATIONAL CONDITIONS

*Hoffmann, S.<sup>1</sup>, Jaeger, D.<sup>1</sup>, Engler, B.<sup>1</sup> & Pierschkalla, S.<sup>2</sup>*

<sup>1</sup>Faculty of Environment and Natural Resources, University of Freiburg, Germany  
stephan.hoffmann@fobawi.uni-freiburg.de , dirk.jaeger@fobawi.uni-freiburg.de , benjamin.engler@fobawi.uni-freiburg.de

<sup>2</sup>Faculty of Forest and Environment, Eberswalde University for Sustainable Development, Germany  
sabrina.pierschkalla@hnee.de

### Introduction

China is showing one of the fastest GDP growth rates worldwide, going along with an annual increasing high domestic consumption of forest products for -housing and construction materials, furniture and paper products, but also a high demand for the export orientated wood processing industry. This ongoing development has today already turned China into a major timber importing nation since its domestic forest resources are not able to supply the amount of timber needed (Zhang & Gan 2007).

The formerly overexploitation of natural forests and low yielding forest plantations currently limit the domestic supplies of round logs. A new protective national forest policy further reduces access to the natural forests but promotes new strategies for efficient and sustainable use of forest plantation estates and to increase the yields on such sites (Zhang et al. 2000).

With the allocation of plantations usually on sites less favorable for settlements and other land-use because of steep terrain and reduced growing conditions, combined with low productive manual forest operation methodologies, currently it will be hard to meet timber supply targets. In respect to ongoing socio-economic changes in rural areas of China, such as work force migration, increasing salaries, restrictions due to new environmental and health standards, a further increase of operation costs create additional needs for new, mechanized harvesting techniques, appropriate for the sites and in conformity with the new forest policy (Zhang et al. 2000, Yang et al. 2010). Considering the terrain, existing logging infrastructure and plantation structures, short to medium distance cable crane mobile yarders would be a suitable system (Engler 2011).

The goal of this pilot study is to analyze terrain and stand structure of a typical sub-tropical plantation area in Southern China for the potential use of cable crane harvesting systems. More specifically, we wanted to estimate timber volume available on sites with high terrain slope predestinated for timber harvesting including cable crane extraction.

### Material and Method

The survey is conducted in collaboration with the Experimental Centre of Tropical Forestry (ECTF) in Pingxiang as part of the bilateral German-Chinese research project Lin2Value and will focus mainly on the ECTF's plantation estates in the subtropical South-West of China, Guangxi Province.

In a first phase of the project a preliminary survey will be conducted to assess the terrain situation of the ECTF forest estates to draw conclusions about the share of yarder suitable sites and to specify the most appropriate yarder system. This will be done mainly by remote

sensing techniques through available satellite images and Digital Elevation Models (DEM) and additionally verified through terrestrial measurements in selected model stands.

Based on the findings of the terrain survey, in consolidation with literature review and interviews with stakeholders of the regional forestry sector and with respect to the expected socio-economic developments, a suitable mobile cable yarder system from Europe will be selected and if required modified and adapted according to the Chinese needs in cooperation with the machine manufacturer. After implementation of the system into the operations of the ECTF, work and time studies will be conducted to draw conclusions about the economics and productivity of these systems, environmental impacts, work safety and ability to fulfill the new silvicultural target of yielding bigger tree dimensions compared to the conventional manual harvesting operations limited to small tree DBH.

### **Preliminary Results**

Analyzing forest inventory records of sub-compartment information of the ECTF (2012) exposes that 79.6 % of the total forest estates of 22,976.1 ha are located on terrain slopes > 20% which allows also gravitation based yarding systems to operate and where ordinary conventional ground based skidder operations are already a safety risk and during rainy weather conditions even a severe environmental threat due to soil disturbance and erosion damages. Currently timber extraction is performed 100% manually throughout the involved processes in all terrain situations, which severely limits the productivity and creates high ergonomic pressure on the laborers. This is also reflected in the low average per capita log output at landing within ECTF forest operations of only 0.7-1.0 m<sup>3</sup> per man day (ECTF 2012). The low performance requires high input of work force which under changing socio-economic conditions will be more and more difficult to recruit for the forest sector, since better paid and socially ensured employment options of the industrial processing and emerging service sector already generate high competition for work force recruitment in the forestry sector (e.g. Engler 2011, Yang et al. 2010) With an average plantation age of 25 years, the current annual harvest of 45,000 m<sup>3</sup> will increase due to maturities of the stands and required thinning operations. Particular for the stands of final harvest, which due to extended rotation periods reach already high DBH values with individual records > 25 cm, the manual logging operation will reach its physical limitation. According to Engler (2011) a DBH of 15 cm is already marking a threshold beyond which manual log extraction becomes inefficient. Our analysis showed that 94.8 % of the current standing volume of the ECTF's forest estates is located on steep slopes > 20 %. Furthermore, about 67% of this volume pertains to stands exceeding manual extraction limits due to DBH ranging from 15 cm to 25 cm revealing the need for alternative mechanized extraction techniques such as cable crane. Engler (2011) identified factors which allow predictions through development scenarios that with the trend of increasing labor costs and the shortage of available work force a mechanization of the harvesting operations are unavoidable. During his survey he investigated that up to 40.7 % of the harvesting time is required for the manual yarding; a mechanization of this process through a cable crane system most likely has the biggest effect on improvement of the logging efficiency going along with environmental sound and for the region suitable logging techniques.

**Table 1 Percentages of standing volume at ECTF forest estates as subject to diameter and slope**

| Terrain slope (%) | Standing Volume (%) |                  |             | Total (%) |
|-------------------|---------------------|------------------|-------------|-----------|
|                   | DBH < 15 cm         | DBH 15.1 – 25 cm | DBH > 25 cm |           |
| < 20              | 1.1                 | 3.7              | 0.5         | 5.2       |
| 20.1 - 50         | 13.4                | 41.0             | 6.9         | 61.4      |
| > 50              | 6.8                 | 21.2             | 5.4         | 33.4      |
| Total             | 21.4                | 65.8             | 12.8        | 100.0     |

## **Conclusions**

A changing socio-economic situation in the Chinese forestry sector going along with new silvicultural aims and increasing demands for domestic forest products require new technologies in the field of forest operations. Currently particular technologies suitable to work safe and efficient in difficult terrain, such as cable yarding systems, barely exist in China. The introduction of such established technologies from Europe could meet the requirements to support the transition of the Chinese forestry sector in an efficient and professional land-use management industry. But such technologies need to be modified according to the Chinese needs and its suitability has to be verified through intensive research in the field of work science.

## **Literature cited**

Experimental Centre of Tropical Forestry, 2012. Sub-compartment inventory information. Pingxiang, unpublished

Engler, B. 2011. Gestaltung von Arbeitsprozessen bei der Bewirtschaftung von Eukalyptusplantagen in Süd-China : Analyse gegenwärtiger Arbeitsverfahren und Modellierung eines höheren Mechanisierungsgrades in der Holzernte zur Beurteilung der ökonomischen Auswirkungen. Dissertation University of Freiburg, Freiburg i. Brg.

Yang, D. T., V. W. Chen, and R. Monarch (2010), Rising wages: Has China lost its global labor advantage? *Pacific Economic Review*, 15 (4): 482–504.

Zhang, J. & Gan, J. 2007. Who will Meet China's Import Demand for Forest Products? *World Development* 12: 2150-2160

Zhang, P., Shao, G., Zhao, G., Le Master, D.C., Parker, G.R., Dunning, J.B., Jr. & Qinglin, L. 2000. China's Forest Policy for the 21st Century. *Science* 288 (5474): 2135-2135

## 1.6 GUIDELINES FOR DIFFICULT TERRAIN GROUND-BASED HARVESTING OPERATIONS IN SOUTH AFRICA

McEwan, A.<sup>1</sup>, Brink, M.<sup>1</sup> & van Zyl, S.<sup>1</sup>

<sup>1</sup>Nelson Mandela Metropolitan University, South Africa. Andrew.McEwan@nmmu.ac.za

### Introduction

South Africa faces a challenge with current mechanisation developments due to the lack of cost effective, safe and environmentally acceptable difficult terrain harvesting systems. Southern Africa's forestry areas consist of terrain ranging from flat areas that can easily be accessed by ground-based equipment, to the very steep areas that require cable yarding systems to be used. Terrain has the greatest influence on system selection, with slope being the most important (MacDonald, 1999). The process of harvesting trees on difficult terrain is complex and requires special technology within the machinery (Heinimann, et al 1998). Gentle terrain provides the most system options, and as terrain becomes increasingly difficult, so the options reduce (Parker and Bowers, 2006). The preferred systems to apply on easier terrain are ground-based systems because of their higher productivity and lower costs compared to aerial systems and cable yarders. Cable yarding was traditionally used in areas that are steep, have excessive ground roughness or are sensitive sites (Oberholzer, 2000). Even though ground-based harvesting in the past has been associated with excessive ground disturbance on steeper slopes, the equipment and techniques available today are able to reduce machine ground pressures and reduce disturbances (Kosicki, 2003). Because of improving equipment technology and planning techniques, the terrain limitations of many ground-based systems are gradually being overcome.

Forest Engineering Southern Africa (FESA) commissioned the Nelson Mandela Metropolitan University to investigate difficult terrain harvesting in South Africa. The main objective of the research was to thoroughly investigate the solutions available to address the problem of difficult terrain harvesting with ground-based systems in South Africa. The research was required to identify and review existing and available harvesting equipment and systems in *Eucalyptus* and pine difficult terrain harvesting operations, as well as identify techniques to harvest difficult terrain areas.

### Materials and Methods

A literature review was carried out to identify the harvesting equipment and systems available for harvesting difficult terrain areas. An analysis of various research results was conducted. FESA members, other industry networks and equipment manufacturers were consulted. Specific machine types with different configurations were identified and defined. The safety and environmental limitations for harvesting equipment operating on different terrain types were identified.

Using a panel of international forest engineering experts and two sets of questionnaires, systems that are currently being used, or could be used; to increase the percentage of difficult terrain areas being harvested with ground-based systems were identified. The research also focussed on reducing the amount of pockets of standing trees left on steep slopes or difficult terrain after harvesting. Current system improvement opportunities were identified. The selected systems were evaluated according to the costs involved, the extent of the environmental impact and the social impact.

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

Guidelines for machine and systems operating on difficult terrain were developed. The techniques identified are applicable for South African conditions.

## **Results**

The results are presented according to the knowledge areas required to identify, select, implement and manage ground-based systems on difficult terrain. Different categories and configurations of ground-based machines are described (harvesters, feller bunchers/feller directors, skidders, forwarders, agricultural tractors and other), with specific reference to their difficult terrain handling properties.

The machine components and characteristics which aid or allow the machine to operate on steeper slopes are described. These are tractive systems (ground pressure, wheeled machines, traction aids for wheeled machines, tracked machines and flex tracks), cabs and upper structures, booms and boom configuration, and the machine as a whole.

Operating techniques and specialised niche equipment for difficult terrain is described. Innovative techniques and equipment for difficult terrain are listed and described. Examples of these include the use of synthetic ropes, shovel logging, tethering of forwarders and specialised wheeled machines. Operator experience and training is also described.

Harvesting planning activities necessary to harvest difficult terrain areas are presented for each planning level. Tactical and operational planning are identified as the most important planning levels, and the salient planning activities for each are highlighted and described.

## **Literature cited**

Heinimann, H.R.; Visser, R.J.M.; Stampfer, K. 1998. Harvester - Cable Yarder System Evaluation on Slopes - a Central European Study in Thinning operations. *In*: Proceedings of the Annual Meeting of the Council on Forest Engineering, Harvesting Logistics: From Woods to Markets. Schiess and Krogstad (eds.). July 20-23, 1998, pp. 39-44. Portland, Oregon.

Kosicki, K. 2003. Evaluation of a Timberjack 660D grapple skidder working on moderately steep slopes in coastal British Columbia. Forest Engineering Research Institute of Canada, Advantage Report Vol. 4, No. 21.

MacDonald, A. J., 1999. Harvesting systems and Equipment in British Columbia. Forest Engineering Research Institute of Canada. British Columbia Ministry of Forests, Victoria, British Columbia.

Oberholzer, F., 2000. Cable yarding. South Africa. *In*: Owen, D.L. (Ed.). South African Forestry Handbook Vol. 1, pp. 323. The Southern African Institute of Forestry, Pretoria

Parker, R. and Bowers, S., 2006. Timber Harvesting Options for Woodland Owners. Oregon State University Extension Services. The Woodland Workbook: Logging, EC 1582, August 2006.

## **SESSION 2: PRODUCTIVITY STUDIES**

**Chair: Prof. Rien Visser**

## 2.1 CABLE YARDING PRODUCTIVITY MODELS: A REVIEW OVER THE PERIOD 2000-2011

*Cavalli, R.<sup>1</sup> & Lindroos, O.<sup>2</sup>*

<sup>1</sup>Forest Operations Management Unit, Department TESAF, University of Padova, Italy.

raffaele.cavalli@unipd.it

<sup>2</sup>Department of Forest Biomaterials and Technology, Swedish University of Agricultural Sciences, Sweden. ola.lindroos@slu.se

### Introduction

The efficiency of cable systems has been found to be of high interest in recent research on cable logging operations (Cavalli 2012). Such research most often addresses the productivity and the cost efficiency of separate machines and/or harvesting systems. To produce productivity models is one of the more common outputs of forest operations related research. Productivity models are used to a multifold of uses in both research and operation management, but the development of productivity functions is laborious. Thus, an efficient use of the existing productivity models is essential. However, there is a lack of overview since the existing models seldom are compiled and compared. To have recently produced models compiled generates several advantages:

- i) it enables comparisons, evaluations and synthesis of various models and influential parameters.
- ii) it allows easy accessibility to models for anyone interested (practitioners, modelers etc.)

Thus, a compilation enables analysis of how productivity models are produced (mathematical forms, parameters, units etc.) and visualize trends and needs for harmonization. The aim of this study was to conduct such a productivity model compilation for cable logging in general, with special attention to cable yarding productivity models.

### Material and Methods

In this study we build on the literature review conducted by Cavalli (2012), in which international scientific literature on cable logging was extracted from the main databases, scientific journals and conferences of forest engineering for twelve years of 2000 – 2011. A total of 244 references were retrieved and used to create a library implemented in Thompson Reuter EndNote® software. From that population, all references containing productivity models were selected and the models were compiled to visualize model features, parameters included and the used units. Work conditions were also briefly reported. When possible, estimated productivities under the same conditions were compared between different models. Moreover, references in which there were productivity measures (point observation and not model) and the reported costs were also compiled.

### Preliminary results

In total, 33 references had productivity related content, out of which 17 included some kind of productivity models. Those references were distributed on 4 continents, with the majority reporting studies of cable logging in Asia, mainly from Turkey. The majority of references were from conference proceedings (20 references), followed by journal articles (13) and reports (2). From the models compilation, many similarities were found but also many

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

discrepancies in terms of model features, included parameters and the units used. The compilation provides and suggests future efforts and harmonization needs in the area of cable logging productivity studies in general and of cable yarding in particular.

### **Literature cited**

Cavalli, R. 2012. Prospects of research on cable logging in forest engineering community. Croatian Journal of Forest Engineering 22: 339-356.

## **2.2 A METHODOLOGICAL APPROACH TOWARDS SPECIFIC COST AND PRODUCTIVITY MODELS FOR CABLE YARDING IN THE FRENCH ALPS**

*Magaud, P*

Technology Institute FCBA, France. Paul.magaud@fcba.fr

### **Introduction**

In the French Alps, logging operations with cable crane are not common (Grulois 2007, Pischedda et al 2012). Less than 50,000 m<sup>3</sup> are harvested annually by five French alps companies and some teams from Switzerland, Austria, Italy and Slovakia that occasionally perform in the area.

Harvesting delivery prices (wood purchase not included) are about 40 €/m<sup>3</sup> and are generally considered as “higher than they should or could be”. Taking into account the high degree of uncertainty regarding productivity (under the influence of bad weather conditions, limited market for large timber, organizational and planning difficulties due to insufficient road network, landing places, truck’s availability), logging contractors voluntarily increase the logging service price, which is finally quite disconnected from productivity.

A Swiss software, Hepromo (WSL), does exist and could be utilised to determine the harvesting cost. The principle of the software has been validated (Becuwe et al. 2010, Frutig et al. 2010, Mine 2008). But the lack of data on full trees harvesting does not validate its use in French conditions, where this kind of organisation is almost never done. Consequently, it cannot be used as a relevant reference by contractors and logging companies.

The purpose of this study is to compare the values provided by this software to data measured in the field, in order to identify potential differences and the main parameters for the development of specific productivity and cost models for cable crane operations in the French Alps, if needed. This study is done in the frame of the European project NEWFOR, and financed by the European Territorial Cooperation (Alpine Space programme).

This presentation will present the approach used in this study.

### **Material and Methods**

Hepromo software was created in 2003, from field studies in cable crane operations. Using data from a single skyline, the software calculates the time of installation of the line, the productivity, and the cost of harvesting (€/m<sup>3</sup>). It doesn’t take into account the felling costs. The result is a prevision, based on existing productivity models.

In the NEWFOR study, measurements on different timber yards from French enterprises in the Alps are gathered. All logging sites are visited (description of the stand, the logging operation, field conditions), and time studies are done for at least one line, according to the European harmonized protocol AIR3-CT94-2097. Time sheets are provided to enterprises for documenting their schedules and activities (installation time linked with the number and type of supports, productivity, length of the line ). Regular contact gives the opportunity to validate the collected data. At the end of 2013, data from 80 skylines on more than 30 logging site are expected.

The collected data are used as needed inputs to calculate the harvesting cost with the Hepromo software.

The other cost calculation approach is based on the real duration and the global harvested volume of the logging operation in the field, associated to the daily cost of materials and men (methodology FAO, 1992).

$$\text{Costs of harvesting (€)} = \frac{\text{material's daily cost (euros/day)} * \text{duration (number of days)}}{\text{global volume (m3)}}$$

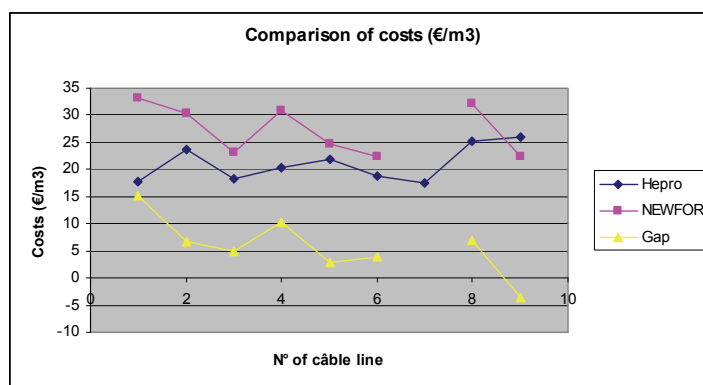
Beyond the comparison of operating costs, field data are also compared to other results from the Hepromo software: installation time, duration of the total cycle of the carriage, productivity. Factor analysis is used to identify the main parameters to be taken into account in the development of specific or adapted productivity models.

Moreover, a part of the data set will be put aside and used for the final validation of these new productivity models.

### Preliminary results

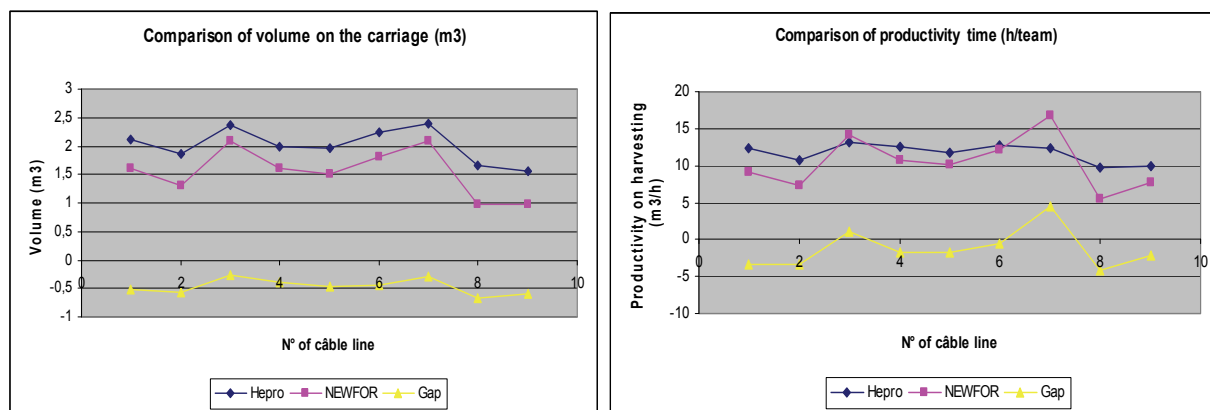
Final results are not available yet as time studies and data integration are still in progress. However, some trend appears from the already collected data.

For example, costs calculated from the software Hepromo are systematically below the one calculated on material's daily cost, with an average of 21%, or 6 € / m<sup>3</sup> (see Figure 1). But horary cost of men and machines must be compared to know and analyse its impact on the overall cost.



**Figure 1: Comparison of costs from Hepromo software and Newfor time studies**

In France, most of trees are harvested as whole trees. This way, the commercial volume carried on the trolley is less important. Measured productivity of French teams is often lower than Hepromo.



**Figure 2: Comparison of volume and productivity from Hepromo software and Newfor time studies**

## Conclusions

This study is still in progress, but already reveals the need to adapt or develop specific models for productivity and costs determination. The study of the installation time linked with the type and the number of supports should also help the contractors for the elaboration of the previous price.

Moreover, the comprehension of the impact of external factors (roads, trucks logistics) should lead to recommendations for improving the global system and reducing the cost of cable yarding operation in the French Alps.

## Literature cited

- Becuwe, M., Brochier, C., Prevost, G., Rouyer, E. 2010. Automatisation des calculs de coûts de mobilisation des bois en zone de montagne au moyen du logiciel de cartographie GRASS. Rapport d'étude AgroparisTech
- Frutig, F., Erni, V., modifié par Bruciamacchie, M., 2010. Hepromo.xls – version française de Hepromo. Calcul des temps de travail et des coûts de câblage avec une grue à câble mobile de grandeur moyenne
- FAO. 1992. Cost Control in forest harvesting and road construction
- Grulois, S. 2007. Cable yarding in France: past, present and perspective. International mountain logging and 13th Pacific Northwest skyline symposium.
- Grulois, S., Magaud, P., 2009. MOBIPE tests de nouvelles méthodes d'exploitation. FCBA
- Mine, FX., 2008. Evaluation du logiciel Hepromo pour estimer les coûts du débardage par câble mât dans la région Rhône Alpes. Rapport d'étude AgroparisTech
- Pischedda, D., Descroix, L., Magaud, P. 2012. Mobiliser du bois en montagne, le défi du câble aérien. RDVT n°35 (Rendez Vous Technique de l'ONF). ONF, FCBA

## 2.3. PRODUCTIVITY ANALYSIS OF THINNING OPERATIONS USING A SWING YARDER ON STEEP SLOPES IN WESTERN JAPAN

Yoshimura, T.<sup>1</sup>, & Noba, T.<sup>2</sup>

<sup>1</sup> Faculty of Life and Environmental Science, Shimane University. t\_yoshimura@life.shimane-u.ac.jp

<sup>2</sup> Faculty of Life and Environmental Science, Shimane University. a092033@matsu.shimane-u.ac.jp

### Introduction

In Shimane prefecture, western Japan, a large number of logs have been harvested from natural forests until recent years to produce woodchips for pulp and paper. On the other hand, more and more logs are thinned and harvested from plantation forests as those planted after the world war II have grown enough to be used for industrial purposes. Generally in this area, the slope is very steep, and trees are harvested using a cable system. For thinning operations in plantation forests, a swing yarder, processor and chainsaws are typically used on steep terrain in Japan. However, the productivity of this production system is quite low compared to the European steep-slope countries such as Austria, Germany, Switzerland and Norway probably due to the low performance of Japanese forestry machines, poor infrastructure such as forest and spur roads and inappropriate methods of harvesting trees. Therefore, we identified what causes the low productivities on steep terrain in western Japan through time study.

### Materials and Methods

We conducted the time study of thinning operations in Japanese cypress (*Chamaecyparis obtusa*) plantations on steep terrain located in Yasugi city, Shimane prefecture. The area and maximum slope of the study site was 0.30 ha and 33 degrees, respectively. The number of trees within the area is 378, and thus tree density is calculated to be 1260 trees/ha. The tree age was uneven ranging from 40 to 60 years old. In this operation, trees were cut manually by chainsaw, and harvested by swing yarder, delimbed and bucked by harvester, and transported by forwarder. Figure 1 shows the swing yarder, harvester and forwarder used for thinning operations in this study. In Japan, excavators are the most common base machine used for swing yarders, processors and harvesters. It also should be noted that harvesters are often used on forest/spur roads as a processor and do not work inside forests due to steep slopes. The cable system used in this operation is a kind of simple gravity system without any special capabilities of lateral yarding: a choker setter just had to pull out a main line by his own power.

### Results and Discussion

The results of time study are shown in Table 1, and the average cycle time of harvesting by using a swing yarder was 606 seconds. It was found that time for yarding accounted for 71.6% and additional work specific to swing yarders accounted for 28.4%. Most of such additional work time occurred due to the rotation and log piling of the swing yarder and could be eliminated by adding a grapple crane to carry and pile logs yarded by the swing yarder. The overall productivity was found to be 3.62m<sup>3</sup>/worker/day. This is lower than the average productivity (4.35m<sup>3</sup>/worker/day) for mechanized thinning in Japan (Forestry Agency 2010). In conclusion, low efficiency of thinning operations was caused by insufficient power of the swing yarder, whose base machine was originally developed not for forestry but for construction. We also found that there is the disadvantage of using a swing yarder, whose

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

cycle time of yarding logs is lower than that of a tower yarder due to extra time for relaying logs from the carriage to landing. By introducing a grapple crane for relaying logs yarded by the swing yarder, the productivity of yarding logs could be higher by 31.6%.



Figure 1. Swing yarder (left), harvester (center) and forwarder (right) used in this study

Table 1 Results of time study

| Work element for yarding | Time (sec) / cycle | Additional work element | Time (sec) / Cycle |
|--------------------------|--------------------|-------------------------|--------------------|
| Carriage travel (empty)  | 50                 | Arm lowering            | 9                  |
| Walk (choker setter)     | 27                 | Log grappling           | 12                 |
| Choker setting           | 36                 | Rotation (loaded)       | 15                 |
| Lateral yarding          | 90                 | Log piling              | 62                 |
| Carriage locking         | 24                 | Rotation (empty)        | 16                 |
| Carriage unlocking       | 15                 | Waiting                 | 30                 |
| Carriage travel (loaded) | 153                | Arm rising              | 16                 |
| Unloading                | 39                 | Moving (swing yarder)   | 12                 |
| Total                    | 434 (71.6%)        | Total                   | 172 (28.4%)        |

## Literature cited

Forestry Agency. 2010. Annual report on trends in forests and forestry fiscal year 2009, pp. 16. Forestry Agency, Tokyo.

## 2.4 COMPARING CABLE LOGGING PRODUCTIVITY BETWEEN NATURAL PINE AND PLANTATION SPRUCE STANDS ON NORWAY'S WEST COAST

*Fjeld, D. & Laukeland, A.*

Norwegian Forest and Landscape Institute, Bergen, Norway

### Introduction

Light cable logging equipment has been a traditional alternative for harvesting farm forests in steep terrain. In this respect, a unique aspect of forestry on Norway's west coast is the extreme variation in stand conditions between natural forests of pine and plantation forests of spruce. The purpose of this study was to compare yarding productivity between these stand types when using light equipment.

### Materials and Methods

Three logging teams were studied using two-drum high-lead logging winches mounted on agricultural tractors. Each team used the same type of winch (Igland 4002) and was studied in stands of both natural pine and plantation spruce (top-end chokering of de-limbed stem-lengths). A total of 795 loads were studied with yarding distances varying between 20 and 160 m per load. The average standing volumes in the studied stands were 175 m<sup>3</sup>/ha and 600 m<sup>3</sup>/ha for pine and spruce, respectively.

### Results

Chokering, winching and unhooking represented approximately 30, 50 and 20 % of the effective time consumption ( $E_0$ ) per load, respectively. Chokering time per load was modeled as a function of the distance from the skid road to the first log and the number of logs per load. Time per load was modeled as a function of the distance between the logs and the skid road and the distance back to the winch. The unhooking time per load was modeled as a function of the distance between the winch controls and the deck as well as the number of logs per load. A number of key variables varied between the two stand types which influenced the sum time consumption. These are shown in the table below.

**Table 1. A comparison of some key variables for yarding operations in the studied pine and spruce stands.**

| Description                           | Pine   | Spruce |
|---------------------------------------|--------|--------|
| Average stem volume (m <sup>3</sup> ) | 0.356  | 0.520  |
| Stems per load (no.)                  | 1.63   | 1.45   |
| Load size (m <sup>3</sup> )           | 0.58   | 0.76   |
| Distance to first chokerpoint (m)     | 5.4    | 4.4    |
| Sideways reach (m)                    | 17.41  | 9.67   |
| Time for skid road changes (min)      | 56 min | 32 min |
| Time for set-up/down (min)            | 48/18  |        |

Even though rigging times operation were similar between the two stand types, the lower standing volumes in pine stands resulted in higher rigging time per cubic meter. Given the average conditions in the respective stand types, the time consumption per cubic meter ( $W_0$  including rigging) was 35 to 40 % higher in natural pine stands than in plantation spruce. It should be noted, however, that considerable variation exists between pine stands of the outer and inner fjord regions and yarding productivity will vary correspondingly.

## 2.5 MULTIFUNCTIONAL TRACTOR WINCH SKIDDING IN FOREST OPERATIONS ON STEEP SLOPE AREAS

Yoshida, M.

Graduate School of Agriculture and Life Science, The University of Tokyo, Japan. yoshida@fr.a.u-tokyo.ac.jp

### Introduction

To use small volume trees as a fuel resource, skidding in young forest on steep slope areas with low cost is necessary in Japan because large part of Japanese mountainous area is steep. Cable yarding system is appropriate on steep slope area but skidding by tower-yarder and yarder resulted in high cost in young forests (Toyama and Tatsuhara 2007). Then, wheel tractors with winch attachment were imported. The skidding distance will become longer on steeper sloped areas because of the difficulty of road construction and resulted in higher skidding cost. Taking into consideration the advantages of multi-functionality of tractor, a mini-yarder operation was selected to skid for long distance on steep slopes because of its low capital cost. The effects of terrain condition on winch skidding and the impacts of multi-use of a tractor on forest operations were analyzed.

### Materials and Methods

Two investigations of uphill winch skidding were separately observed. One was at flat terrain area; and, the other was where the slope was 35 degrees on average. The average volume of tree was set as 0.2 m<sup>3</sup> to represent a young forest. The winch attachment was Schlang & Reichrt's double-winch with 35,000€ (currency rate equaled 1€ = 100 yen) in both areas. The tractor was Fendt Werner's Wario 714 on the flat area, whereas John Deere 6930 was used on steep area, respectively. Tractor cost was benchmarked with the cost of the Wario 714 tractor. Skidding cost of mini-yarder whose price was 20,000€ for uphill skidding was calculated with data from a similar overseas forest operation studied by Spinelli et al. (2010). The data of such attachment technique is currently not available in Japan. Efficiencies and costs were analyzed against the average skidding distance.

### Results

The skidding cost on steep slope area could be kept low across the longer averaged skidding distances by changing tractor attachments (Figure 1). There was significant difference ( $p < 0.05$ ) only in uphill walking velocities for workers (Table 1).

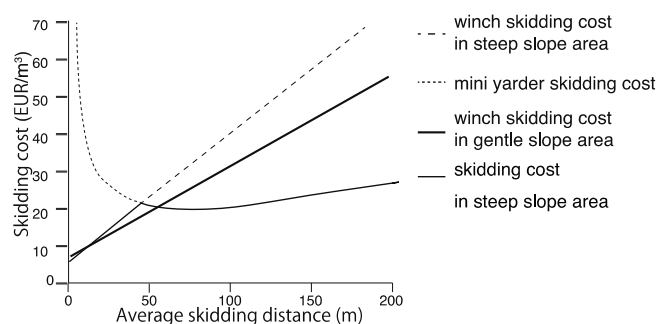


Figure 1. Skidding costs on both slope areas over average skidding distance.

Table 1. Average velocities of walking down or uphill on two sites with different slope areas.

| Site | Downhill walking velocity (m/sec) | Uphill walking velocity (m/sec) |
|------|-----------------------------------|---------------------------------|
|------|-----------------------------------|---------------------------------|

|             |      |      |
|-------------|------|------|
| Flat        | 0.53 | 0.63 |
| Steep slope | 0.43 | 0.26 |

## Discussion

Lower skidding cost under 10 m of the average skidding distance on steep slope area was caused by work-related elements, which did not depend on slope condition. Walking velocities on each terrain condition measured on strip roads tended to reduce velocities of walking (Imatomi 1997). Compared with those results, velocities obtained in this study were much lower and were affected by terrain condition only during the uphill walking. It was assumed that walking velocities of actual operation was much affected by the surface of walked path and its soil condition. Related to this result, there was a slight difference between skidding costs on both areas in shorter averaged skidding distances.

## Conclusion

Winch skidding was efficient across short distances on steep slope area. The multi-use of tractor should be fully utilized in Japan where single-function machines are common.

## Literature cited

- Imatomi, Y. 1997. An ergonomic study on the geometrical design and density of tractor skidding-roads. Bulletin of the Forestry and Forest Products Research Institute 373: 1-71
- Spinelli, R. Magagnotti, N. & Lombardini, C. 2009. Performance, capability and costs of small scale cable yarding technology. Small Scale Forestry 9: 123-135
- Toyama, K. & Tatsuhara, S. 2007. Stand and setting conditions required for efficient cable logging. Japan Society of Forest Planning 41 (2): 169-178

## 2.6 MECHANIZATION OF HARVESTING IN EUCALYPTUS SPP. PLANTATION FORESTS USING A HARVESTER IN MOUNTAINOUS AREAS IN BRAZIL

Robert, R.C.G.<sup>1</sup>, Jaeger, D.<sup>2</sup>, Becker, G.<sup>2</sup>

<sup>1</sup> Forest Engineering and Technology Department, Federal University of Paraná, Brazil.  
renatorobert@ufpr.br

<sup>2</sup> Institute of Forest Utilization and Forestry Work Science, Albert Ludwigs University - Freiburg, Germany.  
institut@fobawi.uni-freiburg.de

### Introduction

The forest sector plays a fundamental role in the Brazilian socioeconomic scenario by contributing with the production of goods and services, adding value to forest products and generating jobs, increasing tax revenue and income. In 2011, the area planted with *Eucalyptus* totaled 4,873,952 hectares representing an increase of 2.5% (119,617 hectares) from 2010. This establishment of new plantations anticipates future demand from projects in the paper and cellulose and also pellets industry. The respective plantation establishment and management costs (Total BRL 7.76 billions) are dominated by planting operations (44%) and harvesting and transportation (26%)(Abraf 2012). Due to profitable land use alternatives from agriculture and livestock in flat terrain, new forest plantations can occupy in the future more degraded land in steep terrain consequently there is a need to search for technological alternatives to harvest plantation forests in mountainous areas in Brazil (Bantel 2010). These plantations are dominated by *Eucalyptus* spp. and *Pinus* spp..This paper aims to assess the performance of Harvester Komatsu Forest 911.3 X3M (Figure 1.) at different slope classes of the terrain.



Figure 1 Harvester 911.3 X3M (photo: Kauê Nascimento)

### Material and Methods

The research was conducted in a forest company, in stands located in the state of Minas Gerais, Brazil. The experiment was carried out in an *Eucalyptus* spp. forest of first cut, in homogenous and seeded stands, with age varying between 80 and 90 months. The plantation spacing was 3 x 3.33 meters, with slope of terrain between 7° to 38°. The predominant soil type of the region is sandy-clay color red (Munsell 10R 5/8), with mountainous topography (Embrapa 1999). The time and motion data of the tested harvester were obtained through Multi-Moment Technique with time intervals of 15 seconds between observations. The values related to productivity (volume in cu.m. per ha) were measured through the machine's information and control system (MaxXplorer). Sampling intensity was calculated for all variables studied according to Equation 1 assuming normal distribution of the measurements:

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

$$n \geq \frac{t^2 \times S^2}{E^2} \quad (1)$$

where: n= number of sampling units needed (plots); t= Student's t-value with significance level and (n-1) degrees of freedom; S<sup>2</sup>= variance; E= acceptable error of 5% (%).

To assess the influence of the slope on the Harvester's productivity the experimental area was subdivided into plots. Each plot consisted of, on average, 60 trees (4 rows of 50 m length and 15 trees per row) covering three slope classes: from 0° to 20°; from 20,1° to 27°; and higher than 27°. An electronic clinometer (Haglöf) was used to measure the slope. The Harvester productivity was assessed separately while it conducted the harvesting operations moving upwards and downwards.

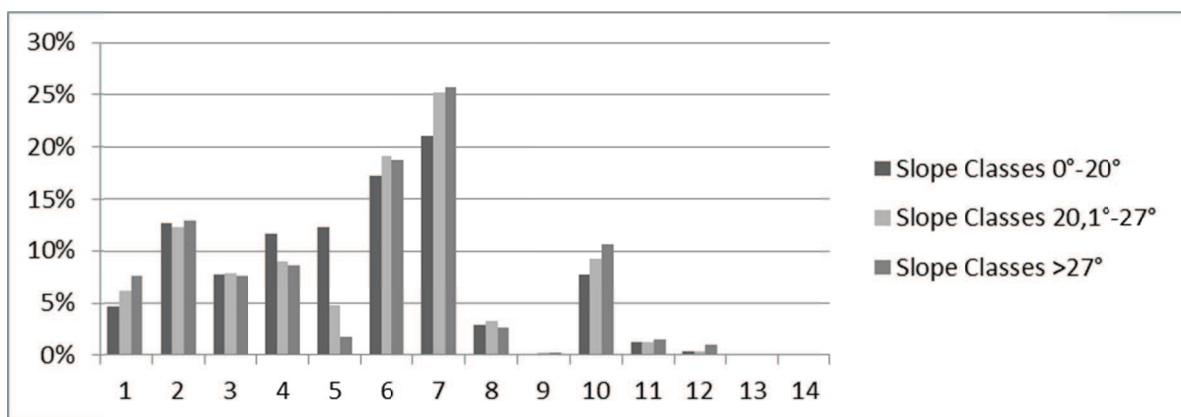
The operational cycle was subdivided into 14 partial operations. The mean values of partial operations at different log lengths and operation directions were assessed statistically through Student's t-test for independent sampling averages of different number of observations, with 95% of significance.

## Results

**Productivity:** the analysis of the data showed that the Harvester productivity did not decrease with the increase in slope of the terrain in the plots. The mean volumes, obtained through the machine's electronic system at different slope classes in the plots, were the following: from 0° to 20°, 26.5 cu.m. per hr; from 20.1° to 27°, 28.5 cu.m. per hr; and higher than 27°, 27.3 cu.m. per hr.

Student's t-test indicated that also stem dimension on the displacement during the Harvester operations in the plots did not statistically influence productivity. The mean volume harvested upwards was of 29.9 cu.m. per hr, whereas it was of 27.5 cu.m. per hr downwards. The mean slope grade was of 19° and 22° in upward and downward direction, respectively. The average number and individual volume for upward operations was 125 trees per hr with of 0.243 cu.m. per tree, whereas downwards it was 121 trees per hr with 0.230 cu.m per tree.

**Proportion of partial operations:** The mean constitution of partial operations of the Harvester is displayed in figure 2. As can be seen, in all assessed slope classes, bucking is the activity which takes the longest, with an average of 23% of the total time of the operational cycle, followed by the harvester head scrolling with 18%.

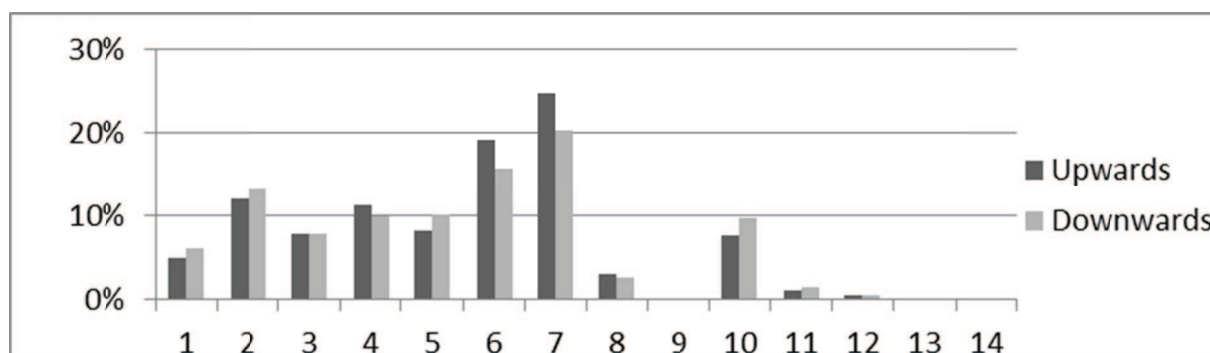


**Figure 2.** Time percentage of activities of harvester X3M in three slope classes. (1)- Machine displacement; (2)- Harvester head positioning; (3)- Tree Cut down; (4)- Tipping; (5)- Debarking; (6)-

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

Haverster head scrolling; (7)- Bucking; (8) - Delimbing; (9)- Stacking; (10)- Discard; (11)- Recuperation; (12)Stack support; (13)- Technical pause; (14)Personal pause

The partial operations in upwards and downwards displacement can be analyzed in figure 3, and it can be observed that there is not a great difference between the values of operating in both directions. The upward bucking showed a value 4.3% higher than downward bucking. This difference can be explained by the greater ease, safety and ergonomics of the upward operations (Stampfer and Steinmüller 2004).



**Figure 3. Time percentage of activities of harvester X3M in upward and downward directions. (1)- Machine displacement; (2)- Harvester head positioning; (3)- Tree Cut down; (4)- Tipping; (5)- Debarking; (6)- Haverster head scrolling; (7)- Bucking; (8) - Delimbing; (9)- Stacking; (10)- Discard; (11)- Recuperation; (12)Stack support; (13)- Technical pause; (14)Personal pause**

## Conclusions

In all slope classes assessed, Harvester productivity did not indicate statistically significant differences, showing a mean volume of approximately 27.5 cu.m. per hr in the plots. The displacement direction of the Harvester operations did not influence the productivity. The most time consuming single operational cycle activity studied is the bucking followed by the harvester head scrolling.

## Literature cited

ASSOCIAÇÃO BRASILEIRA DE PRODUTORES DE FLORESTAS PLANTADAS (ABRAF). Anuário estatístico da ABRAF 2012 ano base 2011. Brasília, 2012. 150p.

BANTEL, C.A. Estudo de diferentes sistemas de colheita de Eucalyptus spp. em área montanhosa. [Tese de Doutorado]. Botucatu: UNESP; 2010.

EMBRAPA. Serviço Nacional de Levantamentos de Solo. Sistema Brasileiro de Classificação de Solos. Brasília: EMBRAPA. Produção da Informação. Rio de Janeiro: Embrapa Solos, 1999. 412p.

STAMPFER, K. & STEINMÜLLER, T. Leistungsdaten Valmet 911.1 X3 M – Endbericht. Universität für Bodenkultur Wien – Department für Wald- und Boden- Wissenschaft. November, 2004.

## **SESSION 3: PLANNING**

**Chair: Prof. John Garland**

### 3.1 AUTOMATIC HARVEST AND CABLE ROAD LAYOUT PLANNING FOR MULTIPLE OBJECTIVES

*Bont, L.<sup>1</sup>, Heinimann, H R<sup>1</sup>, & Church, R. L.<sup>2</sup>*

<sup>1</sup> ETH Zurich, Switzerland, leo.bont@env.ethz.ch , hans.heinimann@env.ethz.ch

<sup>2</sup> UC Santa Barbara, USA, church@geog.ucsb.edu

#### Introduction

Cable-yarding is the most common technique for harvesting timber from steep terrain in Central Europe. During the planning process, one important task is to define the cable road layout. This means that the harvesting technology and cable road location must be specified for a given timber parcel. Although managers must minimize harvesting costs, it is even more important that such work on the forest reduces the potential for damage to the residual stand, and ensures that environmental conditions remain suitable for regeneration. Certain areas targeted for logging may require several cable roads, often run in parallel, because each cable road can access trees only within a limited distance from side to side. The ideal harvest plan includes a set of cable roads that can be used for efficiently harvesting an area for 20 to 30 years, while also identifying parcels that might be better harvested by other methods.

Dykstra and Riggs (1977) proposed that facility location theory be used to design the layout for a forest harvesting system. Their modeling goal was to minimize costs when allocating cable roads and associated harvest units. More recently, Chung (2002) described a model that optimized both the cable-logging operation and road network plan, and suggested several heuristic approaches. Epstein et al. (2006) also developed a means for simultaneously minimizing the costs of both network and operations by assigning a harvesting technology to each unit. This and the model by Chung (2002) were meant to identify a road network that optimized harvesting costs.

All these approaches focus on a sequence of clear cut-harvesting activities within a project area. In contrast, forests in regions such as the Alps (the focus of our research) must be managed for a set of goods and services. This requires a different harvesting regime of single- and group-selection activities that necessitate certain design traits. For example, to minimize residual stand damage during harvesting, one must limit the harvest width of a cable road, therefore cable roads are usually running parallel to each other and emanate from numerous small landings rather than following a pattern of cable roads that radiate from a few, huge landings.

However, because all existing optimization tools were developed for clear cut harvesting activities, they do not take in account the requirements of “multifunctional managed forests”, therefore, have the following shortcomings.

- (1) Cable road lengths currently are defined in those models for a maximum feasible distance and cannot be varied. However, because the problem can be mis-stated, this often leads to overlapping cable road routes in the solutions.
- (2) They are not adapted to European yarding technology, for which one can neglect the costs of tower installations compared with those of cable road set-up and dismantling. The former approach can result in formulations with unnecessary decision variables that make the model difficult to solve to optimality and often necessitate heuristic solutions.

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

(3) The harvest width (distance skyline – timber parcel) is not limited. By contrast, to minimize residual stand damage during harvesting, one must limit the harvest-width of a cable road to less than 40 to 60 m. By including that restriction, one can then take advantage of the “basic structure” feature found in the location set-covering model, which results in a computationally more efficient formulation.

(4) These models do not incorporate the objective to minimize the negative impacts to residual trees, but are geared only toward reducing harvesting costs.

Therefore current approaches to solving the challenge of cable road layouts are rules-based. For example, Heinimann (2003) has formulated the harvest-planning problem as one of optimization, and has developed a rule-of-thumb approach for its solution.

Our general research goal is to develop an approach for designing an optimal harvest plan that focuses on placement of cable towers and cable roads and that is appropriate for multifunctional managed forest in steep terrain. (alpine conditions)

We previously presented an approach, referred to as CaMLOC, to incorporate different feasible lengths of a cable road as well that was adapted to the European harvesting technology (shortcoming (1) and (2) mentioned above) and reported the benefit of such a formulation (Bont, Paper in work).

We recently presented a paper (Bont, Paper in process) that focuses on providing a new, computational efficient model formulation based on concepts found in weighted benefit covering (shortcoming (3) mentioned above). This new approach is based on the fact that the harvest width of a cable road is limited in order to minimize residual stand damage during harvesting. Compared with the CaMLOC approach, we reported accelerations in calculation time up to factor of 100 while obtaining the same accuracy of the solutions.

## **Material and Methods**

The present paper aims to overcome shortcoming (4) mentioned above and focuses on [I] expanding the existing cable road layout optimization models with an objective function component that maps the environmental impact of harvesting operations (so that there are multiple objectives available, harvesting cost and environmental impact); [II] a discussion of the decision process (how to set the different weights of the objective functions), which consists of an evaluation of the Pareto frontier for this objective configuration at specific test sites; and [III] analyze the calculation efficiency of the new multi objective model formulation. We first describe the methodology and then provide an assessment of optimal harvest and cable road layouts for different single- and multi-objective configurations.

To assess the environmental impact we identified two factors for a layout that might influence site conditions and the state of future reforestation. First, the horizontal length must first be minimized for any cable road running in the same direction as the slope line for slopes steeper than 25°. An aisle within that line bears the risk of avalanches, snow-creeper, landslides, or rock fall. All of these cautionary processes become valid at a slope of 25 to 30°; if one of those risks materializes, tree growth is either hindered or made impossible. To accommodate regeneration, expensive technical solutions (e.g., snow fences) are required. Second, the horizontal length must be minimized for any cable that is proposed for down-hill logging. Yarding of whole trees downhill significantly increases the risk of injury to the remaining stand compared with yarding uphill.

Our project site was located at St. Gallenkirch (Austria), on the northern slope of the Alps close to the Swiss border (coordinates: 47.000890, 9.988933). This region is characterized by steep terrain (average slope gradient of more than 30°) and a forest that provides a variety of services such as wood production and protection against natural hazards (avalanches, rock fall, and landslides). Therefore, it is an ideal study site for investigating scenarios with multiple, conflicting objectives.

## **Results & Conclusions**

Our study produced the following major findings: First, single-objective alternatives proved to have no practical relevance whereas the multi-objective alternatives are preferable in real-world applications. Second, we suggest that the solution process for a planning unit include the following steps: 1) compute the Pareto frontier for a unit on a 10-m grid, 2) choose the appropriate Pareto optima, and 3) determine the harvesting layout for the desired Pareto optima on a detailed grid (e.g. 5m x 5m resolution). And third, calculation time was significantly reduced when considering multiple objectives.

## **Literature cited**

DYKSTRA, D. P., & RIGGS, J. L. (1977). An Application of Facilities Location Theory to the Design of Forest Harvesting Areas. *IIE Transactions*, 9(3), 270 - 277, doi:10.1080/05695557708975155

CHUNG, W. (2002). Optimization of cable logging layout using a heuristic algorithm for network programming. Oregon State University, Corvallis, OR.

EPSTEIN, R., WEINTRAUB, A., SAPUNAR, P., NIETO, E., SESSIONS, J. B., SESSIONS, J., et al. (2006). A Combinatorial Heuristic Approach for Solving Real-Size Machinery Location and Road Design Problems in Forestry Planning. *Operations Research*, 54(6), 1017-1027.

HEINIMANN, H. R. (2003). *Holzerntetechnik zur Sicherstellung einer minimalen Schutzwaldpflege* (pp. 44). Zürich: ETH Zürich.

### 3.2 EVALUATION OF FOREST MACHINERY GROUND MOBILITY USING LiDAR DATA

*Pellegrini, M.<sup>1</sup>, Grigolato, S.<sup>1</sup>, Cavalli, R.<sup>1</sup>, Lingua, E.<sup>1</sup>, Pirotti, F.<sup>1</sup>*

<sup>1</sup>Dept. TESAF, University of Padova, Italy.

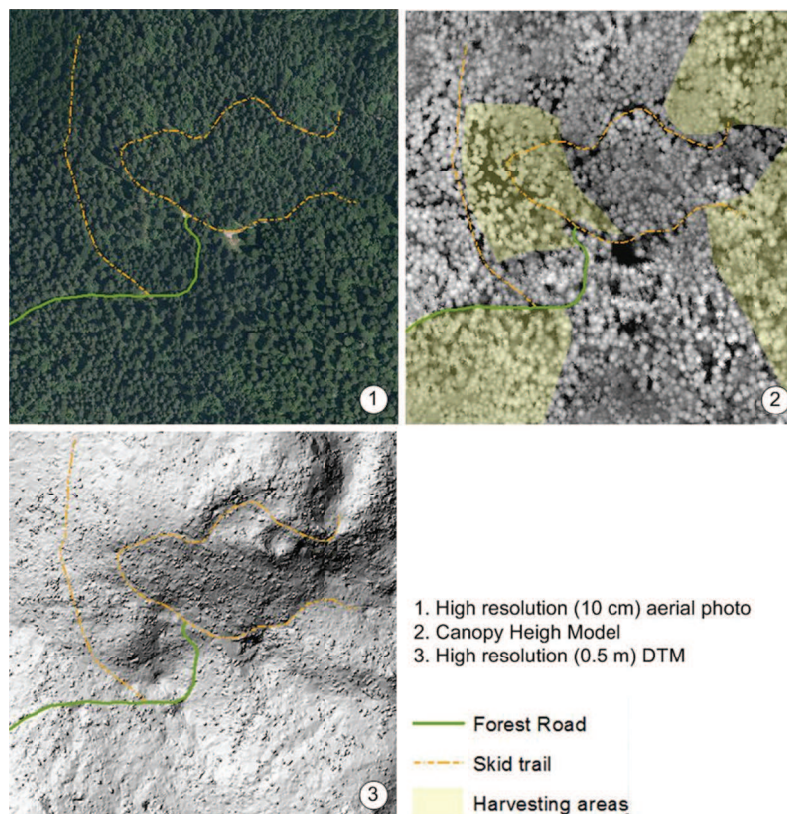
Corresponding author: marco.pellegrini@unipd.it

#### Abstract

The research on possible applications of Light Detection and Ranging (LiDAR), and especially the use of data acquired by Airborne Laser Scanner (ALS) sensors on forestry and environmental application, has provided significant results in recent years (Pirotti et al, 2012). Most of these studies in the forestry field focus on the extraction of structural parameters and on forest biomass estimation (Montaghi et al. 2012, Wulder et al. 2012) while the applications in the field of forest operations are still limited.

Contreras et al. (2012) proposed methods to estimate the earthwork volume in forest road construction using a LiDAR derived high resolution DTM. Heinimann and Breschan (2012) used a single-tree approach based on LiDAR data to make a pre-harvest assessment on areas where a cable-crane will be installed.

Off-road mobility of forest machinery has been extensively studied (Suvinen A. 2006, Suvinen A. and Saarilathi M. 2006, Mohtashami et al. 2012). In the recent years the increased utilization, even in Alpine mountain areas, of forwarders and harvesters have highlighted the necessity to better understand the ground mobility of such heavy machinery.



**Figure 1. example of products derived from LiDAR data to evaluate machinery ground mobility**

This paper will explore the possibility of using LiDAR data and derived Digital Terrain Models (DTMs) on the evaluation of ground mobility for forest machinery in mountain areas, by defining an index which considers both terrain slope and roughness

A Roughness Index (RI) will be derived from a DTM that keeps the presence of objects which are low on the surface (Figure 1). This DTM is obtained after filtering the LiDAR point-cloud using specific software for assigning points to the ground class with user-defined parameters. The accuracy of the index will be evaluated under different canopy conditions and considering different LiDAR point densities.

The following analysis will aim to determine the possible paths for the harvester and the forwarders in off-road mobility. All the processes for the identification of such areas will be integrated within a model in ArcGIS 10.1.

The methodology will be tested in an area located in North-Eastern Italy where LiDAR data was acquired in July 2012. The test site area is completely covered by a mixed Norway Spruce, Silver Fir and Beech forest and with a high variability in morphologic conditions. The study area is designated as a test-site within the Alpine Space Project named NEWFOR ([www.newfor.net](http://www.newfor.net)).

The reliability of the resulting maps will be verified in the field through a GPS survey of the existing skid-road and through the comparison with the harvesting operations that took place in the area in the last 10 years.

## Literature Cited

- Contreras, M.A., and Chung, W. 2012. Improving accuracy in earthwork volume estimation for proposed forest roads using a high-resolution digital elevation model. *Croatian Journal of Forest Engineering* 33: 125-142.
- Heinimann, H.R., and Breschan, J. 2012. Pre-harvest assessment based on LiDAR data. *Croatian Journal of Forest Engineering* 33: 169-180
- Mohtashami, S., Bergkvist, I., Löfgren, B., and Berg, S. 2012. A GIS approach to analyzing off-road transportation: A case study in Sweden. *Croatian Journal of Forest Engineering* 33: 275-284.
- Montaghi, A., Corona, P., Dalponte, M., Gianelle, D., Chirici, G., and Olsson, H. 2012. Airborne laser scanning of forest resources: An overview of research in Italy as a commentary case study. *ITC Journal* (In press).
- Pirotti, F., Grigolato, S., Lingua, E., Sitzia, T., and Tarolli, P. 2012. Laser scanner applications in forest and environmental sciences. *Italian Journal of Remote Sensing / Rivista Italiana di Telerilevamento*. 44: 109-123.
- Suvinen, A. 2006. A GIS-based simulation model for terrain tractability. *Journal of Terramechanics* 43: 427-449.
- Suvinen, A., and Saarilahti, M. 2006. Measuring the mobility parameters of forwarders using GPS and CAN bus techniques. *Journal of Terramechanics*. 43: 237-252.
- Wulder, M.A., White, J.C., Nelson, R.F., Næsset, E., Ørka, H.O., Coops, N.C., Hilker, T., Bater, C.W., and Gobakken, T. 2012. Lidar sampling for large-area forest characterization: A review. *Remote Sensing of Environment*. 121: 196-209.

### 3.3 MEASURING MACHINE SLOPE WHEN HARVESTING ON STEEP TERRAIN

*Berkett, H & Visser, R*

School of Forestry, University of Canterbury, Christchurch, New Zealand. [rien.visser@canterbury.ac.nz](mailto:rien.visser@canterbury.ac.nz)

#### **Abstract**

Harvesting on steep terrain can be both expensive and have higher safety risks. The utilisation of ground-based machines on steep terrain has the potential to decrease harvest costs and improve safety. There is currently a push to increase the operating range of mechanised ground-based machinery, both in New Zealand as well as internationally. To better understand the true range of slopes on which forest machines are operating a digital accelerometer was attached to 22 forest machines and captured real-time measurements of machine slope. The evaluated machines were grouped into one of four machine types; felling (n=4), shovelling (n=5), skidder (n=9) or 'European' (n=4). The 'European' machines tested were purpose built steep terrain machines. The machine types were then analysed with respect to machine slope (actual) and terrain slope (predicted) based on a digital terrain map and using machine GPS coordinates that were captured simultaneously. Defining slope in GIS is difficult and two methods of calculating terrain slope were used, one was based on a triangular irregular network (TIN) file and one based off a raster file. Although linear regression indicated that there was a relationship between machine slope and terrain slope for all four machine types, the variables showed a poor coefficient of determination. New Zealand based machines were shown to exceed the guidelines for terrain slope much more frequently, and by a greater margin, than European based machines.

#### **Introduction**

Steep terrain harvesting are currently characterised by lower productivity and higher cost. Cable yarding, our current preferred steep terrain harvest system, has higher levels of manual or motor manual tasks such as setting chokers or tree felling, with a corresponding higher safety risk. Extending the operating range of ground-based machinery onto steep slopes has the potential to decrease harvest costs and improve safety (Bell 2002; Raymond 2010). However, currently the New Zealand Department of Labour Approved Code of Practice for Safety and Health in Forestry Operations (ACOP) (NZDOL 1999) guideline states that forestry machines on slopes should not exceed 22 degrees (40%) for tracked machines and 17 degrees (30%) for wheeled machines when manufacture's limits are not given.

#### **Methods**

A digital accelerometer was attached to 22 forest machines and provided real-time measurements at a frequency of 2 Hz of machine slope. The machines were also tracked with a GPS unit to give machine location. The study sites were effectively selected by the supporting forest company at the time of visit, with preference given to crews operating on steep sites and the type of machinery operated. The study areas in New Zealand included Canterbury, Nelson/ Marlborough and Otago. The study areas in Europe were located in the Lillehammer region in Norway and the states of Carinthia and Lower Austria, Austria.

#### **Results**

### Evaluation of Terrain Slope

Deriving a continuous slope surface in ArcMap from contour data can be achieved in two ways; from either a TIN or a raster. Both of these data models were used to calculate terrain slope and they were contrasted to determine which was more appropriate for comparison with measured machine slope. Figure 1 provides an example of a TIN file showing the movement of the machine as tracked using GPS. The shaping indicates terrain slope, whereas the colours associated with the GPS tracking shows the slope of the machine as it traverses the terrain.

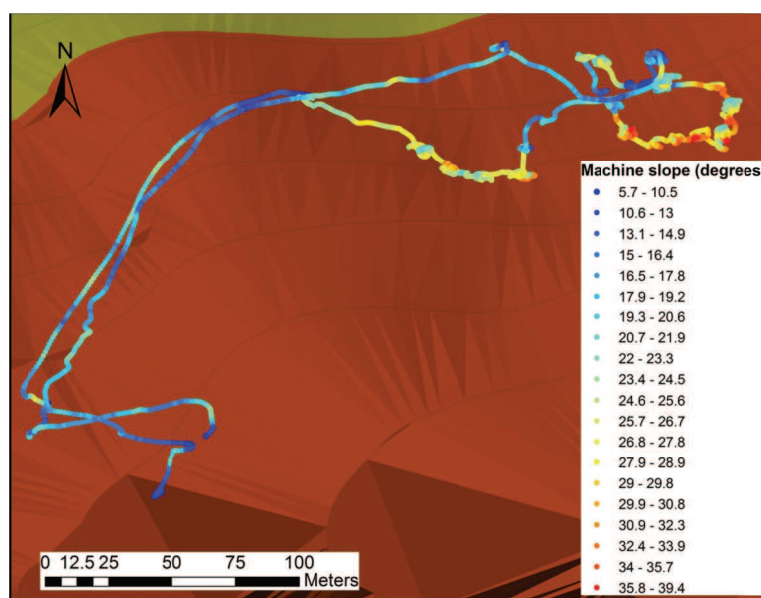


Figure 1: GIS map that combines the TIN slope file generated from available contours maps and the slope of the machine (colour coding as per legend) as it tracks across the terrain.

As an example, Figure 2 presents a bar graph that compares the distribution of actual machine slope and the terrain slope as predicted using the TIN shape in GIS based on 10 meter contours for all the felling machine data. The terrain slope data is not well distributed which is an artefact of creating the TIN file in GIS. Overall it can be seen that the actual machine slope is on average greater than the terrain slope. Table 1 shows a summary of all the machine categories and their average slope (plus 5<sup>th</sup> and 95<sup>th</sup> percentile).

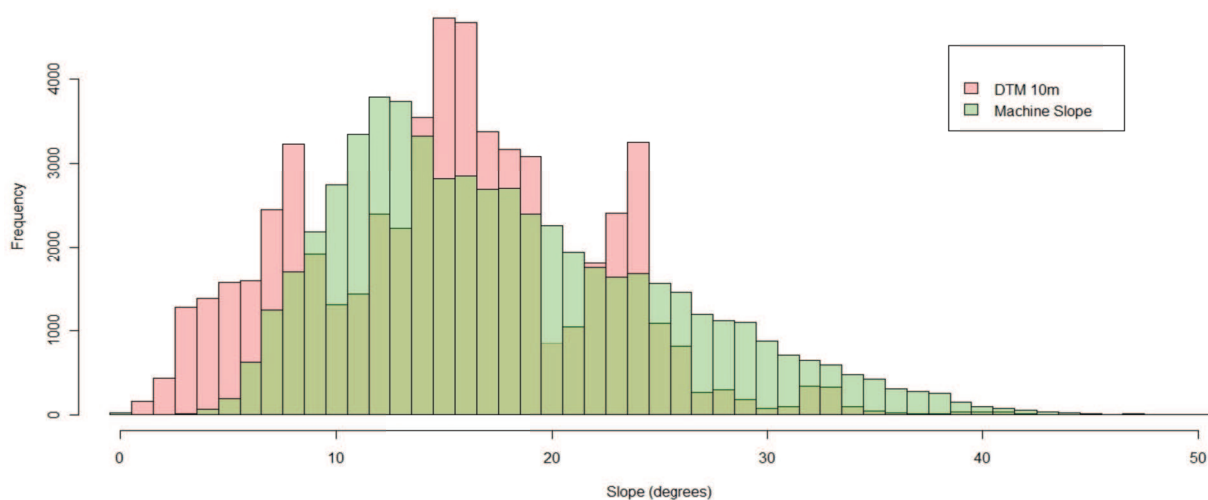


Figure 2: The frequency of slopes experienced by all felling machines monitored (Machine slope and 10m DTM slope).

**Table 1: Individual machine and DTM slopes (method 1) with 5th and 95th percentiles and the machine slope minus the respective DTM slope (\* used 20m DTM data, \*\* used 5m DTM data)**

|                    | Average Machine Slope (5th, 95th percentile) | Average DTM slope (5th, 95th percentile) | Machine slope minus DTM slope (5th, 95th percentile) |
|--------------------|----------------------------------------------|------------------------------------------|------------------------------------------------------|
| Feller Ave (n=4)   | 18.6 (9.5, 29.1)                             | 16.2 (2.9, 24.2)                         | 2.4(6.6,4.9)                                         |
| Shovel Ave (n=5)   | 17.9 (9.4, 28.1)                             | 15.9 (9.3, 23.3)                         | 2.0(0.09,4.8)                                        |
| Skidder Ave (n=9)  | 14.3 (6.2, 22.7)                             | 14.4 (6.6, 23.7)                         | -0.01(-0.4,-1)                                       |
| European Ave (n=4) | 17.0 (7.0, 28.5)                             | 19.5 (13.2, 26.7)                        | -2.5(-6.2,1.8)                                       |

Results of the study showed that most machines spent considerable periods of their operating time in excess of internationally acceptable guidelines. So while increasing the operating range of these machines may decrease harvesting costs, careful consideration needs to be given to the roll-over risk associated with this activity. However, with most machines operating successfully on steep terrain, consideration should also be given to revising the guidelines given the significant development associated with purpose built steep terrain machines.

### Acknowledgements

This project was supported by Future Forest Research, based in Rotorua, New Zealand. It combines industry and government support to facilitate the completion of applied research projects.

### Literature cited

- Adams, J.D., R. Visser and S.P. Prisley. 2003. GIS risk management support system for strategic harvest planning. in 2nd International Precision Forestry Conference, Seattle, WA.
- Bell J.L. 2002. Changes in logging injury rates associated with use of feller-bunchers in West Virginia. *Journal of Safety Research* 33:463-471.
- Drushka, K. and H. Konttinen. 1997. Tracks in the forest: the evolution in logging machinery. Timberjack Group. Helsinki. 254 p.
- Eger R, Kiencke U. Modeling of rollover sequences. *Control Engineering Practice* (2003) 11:209-216.
- Heinimann, H.R. 1999. Ground-based harvesting systems for steep slopes. In *Proceedings of the International Mountain Logging and 10th Pacific Northwest Skyline Symposium*.
- Hunter AGM. 1993. A review of research into machine stability on slopes. *Safety Science* (1993) 16:325-339
- ILO. 1998. *Safety and Health in Forestry Work: an ILO Code of Practice*. International Labour Office, Geneva. 132p.
- Joint Committee. 1971. *Symposium on forest operations in mountainous regions*. Technical report. Joint FAO/ECE/ILO Committee on Forest Working Techniques and Training of Forest Workers. Krasnodar (USSR), August 31 to September 11. TIM/EFC/WP.1/1, 90 p.
- NZ DOL. 1999. *Approved Code of practice for Safety and Health in Forest Operations*. NZ DOL Occupational Safety and Health Service.
- Raymond K. 2010. Steep country harvesting - 'innovative harvesting solutions' A step change harvesting research programme. *New Zealand Journal of Forestry* (55):9.

### 3.4 ALGORITHMS FOR LANDING EVALUATION AND DETECTION

*Søyde, N.E.*

Norwegian Forest and Landscape Institute, Norway. [nis@skogoglandskap.no](mailto:nis@skogoglandskap.no)

#### Introduction

Planning of cableway layout is a facility location problem, and difficult to solve if the number of variables is large. In addition, a hierarchical problem formulation also including road and landing location will be even more difficult to solve (Dykstra and Riggs 1977). One factor determining the number of variables is the number of possible landings, and early approaches required that landings were specified by the user (Dykstra and Riggs 1977, Chung 2002). On the other hand, Stükelberger (2008) used the work of Chung (2002) to calculate the “landing attractiveness” of each grid cell, and directed new roads through attractive cells. This “landing attractiveness” was some function of the total volume of timber that could be yarded to the cell in a radial pattern. Although this is an important feature of a good landing, the method disregards the importance of the terrain close to the tower. The timber has to be released, processed and stored at the landing, and if the landing is too small, the timber has to be temporarily moved e.g. by a truck. This use of the method also illustrates that European yarding systems are different to those in other parts of the world. In Europe, the yarding systems are typically tower yarders mounted on trucks, and they operate in a parallel pattern along roads (Bont 2012). In other parts of the world, larger yarders operating in a fanning pattern are more common, and landings are often constructed simultaneously with the road.

The aim of this study is to investigate whether different algorithms can predict how good a landing is on a local scale. This will be useful for automatic detection of landings for the cableway location problem, and can also be utilized for the road location problem.

#### Materials and Methods

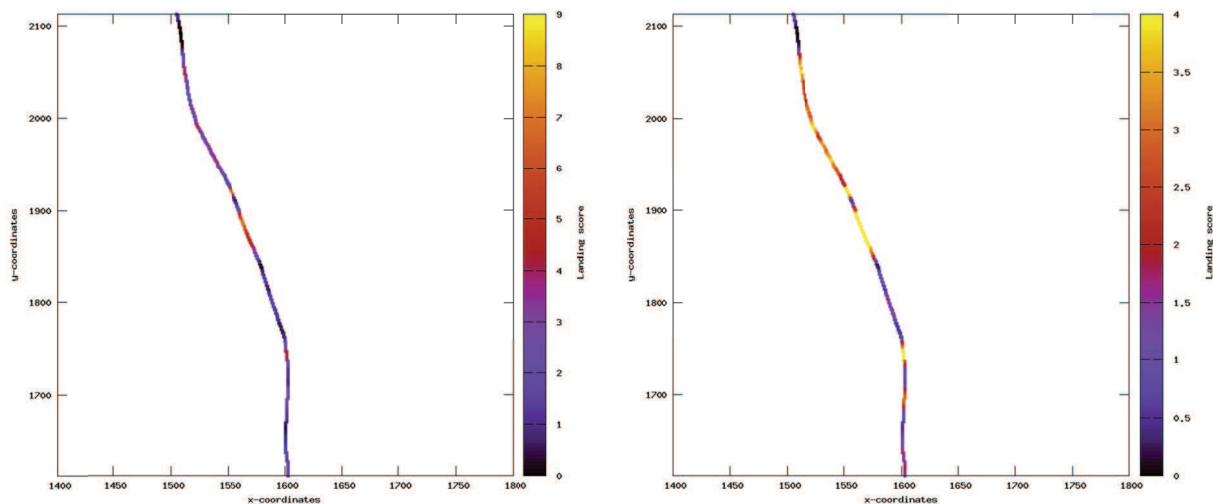
Assume that a digital terrain model (DTM) is given as a grid of vertices. A fast and simple algorithm for evaluating how good a landing at a vertex  $v_i$  is to calculate the mean elevation  $\bar{z}$  of all the vertices within a radius of a certain distance, and then calculate the sum of squared differences of the vertices.

$$\text{Landing score} = \frac{\sum_{i=1}^n (z_i - \bar{z})^2}{A} \quad \text{Here } A \text{ is the covered area.}$$

This method was tested with a radius of 15 m for an existing road in Kvam in Gudbrandsdalen in Norway. The DTM was generated from airborne laser scanned data, and 1 m × 1 m grid was used.

#### Results

The landing score varied from 0.0326 to 8.371, and is plotted in figure 1.



**Figure 1. Landing score of existing forest road. Right plot has rescaled colors.**

## Conclusions

This simple algorithm illustrates that the local topography of an existing roads vary. Other algorithms may improve the ability to find good landings, and a classification by experts may help for evaluation of the algorithms and for finding limit values for good landings.

## Literature cited

- Bont, L. G. 2012. Spatially explicit optimization of forest harvest and transportation system layout under steep slope conditions. ETH, Zürich.
- Chung, W. 2002. Optimization of cable logging layout using a heuristic algorithm for network programming. Department of Forest Engineering, Oregon State University, Corvallis OR, USA.
- Dijkstra, D. and J. Riggs. 1977. An application of facilities location theory to the design of forest harvesting areas. *AIIE Transactions* **9**:270-277.
- Stückelberger, J. A. 2008. A weighted-graph optimization approach for automatic location of forest road networks. ETH Zurich.

### 3.5 EXAMINING THE OPTIMAL EXTRACTION RATE OF EXTRACTING THINNED WOODS IN NASUNOGAHARA AREA, TOCHIGI PREFECTURE, JAPAN

*Nakahata, C.<sup>1</sup>, Saito, M.<sup>2</sup>, & Aruga, K.<sup>1</sup>*

<sup>1</sup> Department of Forest Science, Utsunomiya University, Japan. aruga@cc.utsunomiya-u.ac.jp

<sup>2</sup> Frontier Agriscience and Technology Center, Shinshu University, Japan. m\_saito@shinshu-u.ac.jp

#### Introduction

Feed-in tariffs (FIT) were introduced in Japan since July 1, 2012. Power generation with unused materials such as logging residue were offered as incentives. Therefore, the use of logging residue must be promoted in the near future. Nasu-machi Forestry Cooperative has conducted the extraction of smaller diameter logs for pellets or pulp in addition to the extraction of larger diameter logs for sawn timber or laminated lumber.

The extraction of smaller diameter logs could increase revenues, but would also increase costs, subsequently would decrease profitability. Numerous studies have been conducted to examine the optimal bucking for increasing revenues. However, bucking methods affected efficiencies of bucking operation as well as extracting operations after bucking operations. Thus, costs would be increased and profitability would be decreased. Therefore, the optimal bucking should consider costs and profitability as well as revenues.

In this study, forestry operations around Nasunogahara area where Nasu-machi Forestry Cooperative was located were investigated and the relationships between log sizes and operational costs were analyzed. Then, the equations to estimate operational costs according to log sizes and the optimal bucking methods to maximize profits were developed. Finally, the optimal bucking methods were applied to two operational sites of Nasu-machi Forestry Cooperative and feasibility of the extraction of small sized logs was discussed based on extraction rates.

#### Development of the equations to estimate operational costs according to log sizes

Forestry operations included chainsaw felling, grapple-loader bunching, processor processing, and forwarder forwarding. Productivities of chainsaw felling and grapple-loader bunching were not affected by log sizes because of these operations before processing operations. Therefore, productivities and costs of only processor processing and forwarder forwarding were analyzed. Productivities and costs of chainsaw felling and grapple-loader bunching have been analyzed in our previous paper (Nakahata et al. 2011).

The direct expense of processor processing,  $OE_P$  (USD/m<sup>3</sup>) was derived using average log volumes,  $Vla$  (m<sup>3</sup>/log) and the average number of logs per stem,  $n$  (logs/stem) with labor and machinery expenses (maintenance, management, depreciation, and fuel and oil expenses).

$$OE_P = \frac{(2.42Vla + 0.22)n + 1.90}{Vla \times n} \quad (1)$$

Then, the direct expense of forwarder forwarding,  $OE_F$  (USD/m<sup>3</sup>) was also derived using forwarding distance,  $L_F$  (m) with labor and machinery expenses.

$$OE_F = \frac{(-34.30Vla + 16.77) + 0.012L_F}{1.74Vla + 1.71} \quad (2)$$

### **Development of the optimal bucking method to maximize profits**

In this study, the optimal bucking method to maximize profits were developed in the following order: 1) estimation of thinning volumes; 2) determination of the taper-curve formula; 3) estimation of extracted volumes; 4) estimation of revenues; 5) estimation of expenses; and 6) estimation of economic balances and determination of the optimal bucking method to maximize profits.

### **Examination of the optimal extraction rate of extracting thinned woods**

The extraction rate was estimated as the ratio of extracted volumes to thinned volumes in the stands. Then, the optimal extraction rates were examined with applying the optimal bucking method to two commercial thinning operation sites where small sized logs were extracted in addition to saw logs and logs for laminated lumber.

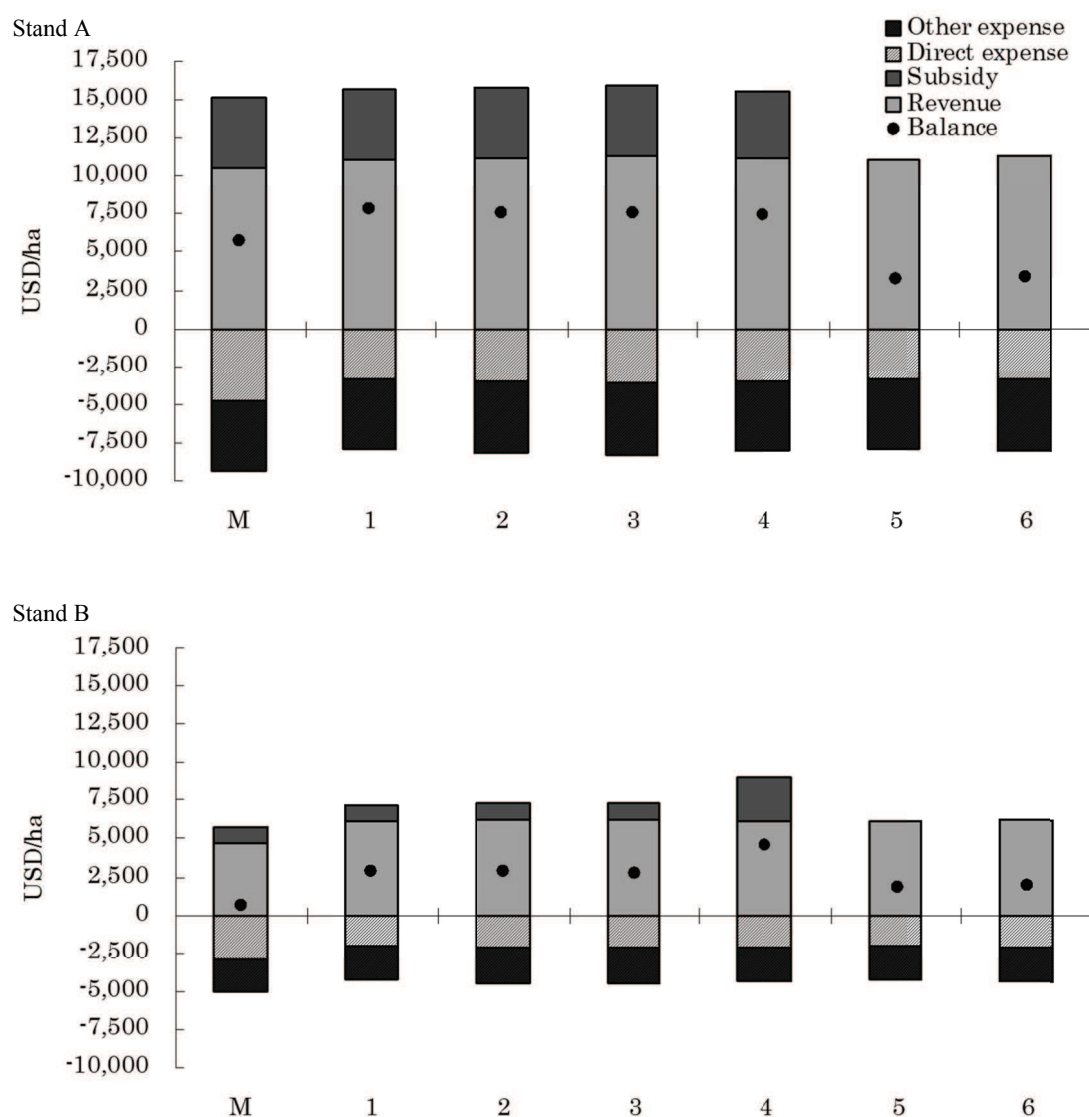
Site A was a 55-year old Japanese cedar and Japanese cypress stand. Area was 7.12 ha. Forest road was 268 m long. Strip road was 3.5 m wide and 1,870 m long. Therefore, road density was 300.3 m/ha. Grapple-loader bunching operations were conducted within 20-m from roads and thinned woods beyond 20-m from roads were left in the forest (pre-commercial thinning operations were conducted in the forest beyond 20-m from roads). Therefore, extraction were assumed to be within 20-m from roads. Rates of bunching areas to the study site area were 83.0% for Japanese cedar and 88.2% for Japanese cypress, respectively.

Site B was a 52-year old Japanese cedar stand. Area was 6.70 ha. Forest road was 587 m long. Strip road was 3.5 m wide and 952 m long. Therefore, road density was 229.7 m/ha. Grapple-loader bunching operations were conducted within 20-m from only strip roads. Therefore, the rate of bunching area to the study site area was only 43.9%.

As a result, the extraction rates with the optimal bucking method were similar to the actual results compared with other methods such as the optimal bucking method without considering log sizes and the existing optimal bucking method with maximum revenues (Figure 1). Therefore, the optimal bucking method with maximum profits using the equations to estimate costs according to log sizes would be effective for a forest planner to establish forest plans with extraction of small sized logs.

However, small sized log volumes with the optimal bucking method were smaller than actual ones because this model did not consider the contracts with factories about annual supply obligation and stable prices. Furthermore, this model did not consider log quality. If log quality was low, logs were sold to factories other than log markets. Therefore, the next study should consider supply obligations and log quality.

Then, a new subsidy system and unit prices for small sized logs were discussed. As a result, a new subsidy system and unit prices with FIT would both contribute to increase extracted volumes of small sized logs. However, subsidies would be reduced due to the limited budget of Japanese government. Therefore, low-cost harvesting system should be developed to establish the forest-road networks and to improve forestry operation system.



**Figure 1. Revenues, costs, and economic balances per ha (M: Measurement, 1: The optimum extraction rate, 2: The optimum extraction rate with the direct expenses estimated using the equation (Nakahata et al. 2011), 3: The extraction rate with maximum revenues, 4: The optimum extraction rate with a new subsidy, 5: The optimum extraction rate with unit prices of small sized logs, 40.80 USD/m<sup>3</sup>, 6: The optimum extraction rate with unit prices of small sized logs, 68.00 USD/m<sup>3</sup>).**

## Literature cited

Nakahata, C., Aruga, K., Takei, Y., Yamaguchi, R., Ito, K., Murakami, A., Saito, M., Tasaka, T., & Kanetsuki, K. 2011. Improvement on operational efficiencies and costs of extracting thinned woods using a processor and a forwarder in Nasunogahara area (II)-based on comparative analyses of current operations and mechanized operations-. Bull. Utsunomiya Univ. For. 47: 27-34 (in Japanese with English summary)

### 3.6 OPPORTUNITIES FOR DEVELOPING EXCAVATOR BASED CABLE LOGGING OPERATIONS IN IRELAND – A PRODUCTIVITY ANALYSIS

*Ger Devlin<sup>1</sup> and Radomir Klvac<sup>2</sup>*

<sup>1</sup> School of Biosystems Engineering, University College Dublin, Ireland. [ger.devlin@ucd.ie](mailto:ger.devlin@ucd.ie)

<sup>2</sup> Faculty of Forestry and Wood Technology, Department of Forest and Forest Products Technology, Mendel University, Brno, Czech Republic. [klvac@mendelu.cz](mailto:klvac@mendelu.cz)

#### Introduction

The Irish Government is dedicated to increasing the forested land area in Ireland from 10% to 17% by 2030 (Energy White Paper. 2007). (Phillips et al. 2009) developed a tool for forecasting timber volumes in Ireland for the years 2011 to 2028 based on standing volumes and net realisable volume (volume to the end user). The total stand volume is forecasted to increase from 4.46 Mm<sup>3</sup> to 7.38 Mm<sup>3</sup> which equates to a net volume of 3.79 Mm<sup>3</sup> in 2011 to 6.95 Mm<sup>3</sup> in 2028. The majority of this is to come from the private estate with an 8 fold increase forecasted from 0.38 Mm<sup>3</sup> to 2.95 Mm<sup>3</sup> in 2028.

In terms of tree species, Spruce (Norway and Sitka) dominate the forecast accounting for 84% (70.36 Mm<sup>3</sup> of total inclusive production) followed by 9% for Lodgepole Pine (7.84 Mm<sup>3</sup>) and 7% classed as other conifers ( 5.66 Mm<sup>3</sup>). Approximately 100,000 to 150,000 m<sup>3</sup> from Coillte's own annual forecast is inaccessible to mechanised harvesting mainly due to slopes above 30% gradient. This implies a potential of these sites to be cable logged and to create the opportunity to recover high value sawlog timber in a whole tree cable logging clearfell process.

There are currently only a small number of cable operators logging timber in the Republic of Ireland. Two cable logging systems were reviewed to compare the time study of productive machine hour (PMH). Both systems are excavator based and similar in operation.

This paper aims to quantify the current productive machine hours of two excavator based cable logging contractors in Ireland and to help develop a niche cable log timber harvesting opportunity for areas deemed as in accessible for mechanised harvesting within the annual forecasted timber volume production.

#### Methodology

The time studies and PMH of both systems were carried out with a Husky Hunter 16 data logger and SiWork software. For the first system, two independent scenarios were observed;

- Site I - Three-man crew (one man choking logs, one man unhooking chokers and one man operating the carriage).
- Site II - Two-man crew (carriage operator exits machine to unhook the choker at landing with one man choking logs below).
- Site III - For the second system, one scenario could only be observed – a two man crew operating with electronic chokers (one man hooking and carriage operator).

#### Site I & II – Macroom, Co Cork

This site used two excavators, one fitted with winches and used for uphill hauling and the second excavator is used as an end-mast for anchoring where the boom is used as a tower for attaching the main skyline cable (Fig 1).



**Figure 1 Timberjack 1070 Harvester and excavator based cable log wholetree system.**



**Figure 2 Panoramic view of Clonmel cable log site.**

The Sherpa model carriage used on this site is designed for a 1.5 ton payload. The two rope gravity system (skyline and mainline) and full tree harvesting method is applied. The crew comprises three men, one felling trees ahead with chain saw, second man operating the excavator and the third operator is the choker setter. If the chainsaw operator has spare time he starts hooking the chokers while the third operator will move uphill to unhook the chokers from the logs on the landing. The total length of the skyline/slope was circa 130m (meters), the width of the site circa 300m.

#### **Site III - Clonmel, Co Tipperary.**

The Konrad carriage is designed for 1.5 ton load and was used here. A two rope gravity system and full tree harvesting method is applied here also. Because electronic remote control chokers are being used, which can be released with a signal by the carriage operator, they do not need the third man in the crew for unhooking and hence this system on initial viewing looked much more efficient. The site length was approximately 150 m on the bottom part and very steep when reaching the lowest point of the valley and a width of about 200 m (Fig 2).

#### **Results**

The hauling out/in and pulling out/in activities are effectively the same. The hooking activity correlates with side distance and again is comparable for all time studies. The significant difference was found in time consumption during unhooking activity and moving activity. Unhooking for the Site III was 23 secs while Site I and II was 51.7 and 78.2 secs respectively. While moving and landing ordering time differs with site, the unhooking process was related to the crew and to the equipment used.

**Table 1: Mean Values and Standard Deviation of Cable Logging Time Study.**

| Activity                          | Site I       |                | Site II      |                | Site III     |                |
|-----------------------------------|--------------|----------------|--------------|----------------|--------------|----------------|
|                                   | Time (s)     | Std. deviation |              | Std. deviation |              | Std. deviation |
| <b>Hauling out (sec)</b>          | 26.8         | 13.87          | 22.7         | 10.6           | 26.8         | 11.79          |
| <b>Pulling out (sec)</b>          | 26.8         | 13.06          | 25.4         | 12.7           | 28.1         | 12.57          |
| <b>Hooking (sec)</b>              | 51.2         | 27.71          | 66.2         | 24.83          | 66.5         | 29.35          |
| <b>Pulling in (sec)</b>           | 31.3         | 33.6           | 31.6         | 14.01          | 25.5         | 17.93          |
| <b>Hauling in (sec)</b>           | 26.1         | 15.23          | 23.9         | 9.66           | 30.6         | 14.92          |
| <b>Unhooking (sec)</b>            | 51.7         | 34.51          | 78.2         | 49.3           | 23.0         | 37.74          |
| <b>Cycle without delays (sec)</b> | <b>240.4</b> |                | <b>286.4</b> |                | <b>209.9</b> |                |

Using the third man on Site I can reduce the total cycle time by 46 secs (19%). The average increase in volume of timber extracted per shift as a result was 17 m<sup>3</sup>.

Site III had a total cycle time of 209.9 secs, 76.5 secs (36%) quicker than Site II and 30.5 secs (14%) quicker than Site I. This was primarily down to the use of the electronic chokers. The decrease in volume extracted from Sites I and II versus Site III as a result was 15.69 m<sup>3</sup> (15%) and 32.97 m<sup>3</sup> (36%) respectively. In value terms, the unit cost (€ / m<sup>3</sup>) varied from 3.59 (site I) to 3.22 (site II) to 2.49 (site III).

The simulation of remote controlled chokes is shown in Table 2. In this table the authors take the average volume of trees as 0.40 m<sup>3</sup> (0.35 m<sup>3</sup> for Sites I and II and 0.45 m<sup>3</sup> for Site III) and the average number of trees per cycle on the same level to calculate the daily output. The utilization was assumed to be 75% based primarily on observations and information from the logging contractors.

**Table 2 - The Simulation of Daily Productivity**

|                                                 | Site I | Site II | Site III |
|-------------------------------------------------|--------|---------|----------|
| No. Of cycles per shift<br>(8 SMH or 6 PMH)     | 90     | 75      | 103      |
| Av. Tree volume                                 | 0.40   | 0.40    | 0.40     |
| Trees per cycle                                 | 3.0    | 3.0     | 3.0      |
| Volume extracted per<br>shift (utilization 75%) | 107.80 | 90.52   | 123.49   |
| Volume per PMH                                  | 17.97  | 15.09   | 20.58    |

\* 75% utilization - 8 SMH (Scheduled Machine Hours) is equal to 6 PMH (Productive Machine Hours).

### **Acknowledgement**

This study was funded by COFORD (National Council for Forest Research and Development in Ireland) and under the Charles Parsons Energy Research Program (Grant Number Grant Number 6C/CP/E001) of Science Foundation Ireland [www.sfi.ie](http://www.sfi.ie).

### **Literature cited**

Energy White Paper. 2007. Delivering a Sustainable Energy Future for Ireland [Internet]. Available from: <http://www.dcenr.gov.ie/NR/rdonlyres/54C78A1E-4E96-4E28-A77A>

Phillips H, Redmond J, Siurtaín M Mac, Nemesova. A. 2009. Roundwood Production Forecast from Private Forests 2009 - 2028. A geospatial forecast [Internet]. Available from: <http://www.coford.ie/media/coford/content/publications/projectreports/forecast-final.pdf>

## **SESSION 4: ERGONOMICS, SAFETY, & CONTRACTORS**

**Chair: Prof. Karl Stampfer**

## **4.1 A LOOK AT LOGGER TRAINING AFTER 35 YEARS**

*Dr. John J. Garland PE*

Consulting Forest Engineer, Garland & Associates; Professor Emeritus, Oregon State U.; Affiliate Professor, U. Washington

Nearly thirty five years ago an assessment was made of logging training in the Pacific Northwest for the Pacific Logging Congress. Today logging training is still a paramount concern of the industry. With 55% of Oregon's logging workforce over age 45 there will be changes coming in the near term. Logging training has not been successful in institutions, in special training programs funded by government grants, nor in most firms who lack the resources to conduct the training they need. What has been tried? What had success? What failed? What are the best prospects for the future? What are the obstacles to training? What are the economic and other benefits of training for the firm and the forestry sector? This review covers 35 years of activities in the U.S., Europe and other countries. What will work in the future is also discussed and prospects for success are outlined.

### **Literature cited**

Garland, J.J. 1979. A Look At Logger Training. Loggers Handbook Vol. XXXIX, 6p.

## 4.2 OPERATOR PERFORMANCE IMPROVEMENT THROUGH TRAINING IN A CONTROLLED CABLE YARDING OPERATION

*Ottaviani Aalmo, G. & Talbot, B.*

Norwegian Forest and landscape Institute, Norway. [gio@skogoglandskap.no](mailto:gio@skogoglandskap.no)

### Introduction

In Norway, some 150 million m<sup>3</sup> (solid under bark) of timber is mature or maturing on slopes with an inclination steeper than 33% (steep), of which 62 million m<sup>3</sup> are on slopes exceeding 50% (very steep). The lack of skilled yarder operators is a recognized bottleneck to achieving a higher efficiency level and running professional, year round operations. Many agricultural and forest workers also employed in Norwegian steep terrain harvesting sites, are migrant workers, seldom with an experience in this field. Higher productivity levels can be achieved through providing new/better equipment or tools, developing and implementing work standards or improving the performances of the harvesting crews. The skill levels of the workers can be improved through specific training. Training of new yarder operators traditionally takes place under normal working conditions but involves a certain level of risk to the personnel and equipment. This practice also presents several disadvantages mainly concerning decreased productivity, while sudden tension spikes can break the rigging, uproot tail spars, or snap one of the lines. Instead the use of a test rig could decrease down-time, repair and re-rigging costs while improving the safety conditions of the trainee operating the cable yarder. The effect of training can be evaluated using a learning curve, which illustrates the rate of learning for a given task .

The main objective of this study was to investigate to what extent consecutive replications of the same yarding exercise improved operators' skill levels.

### Materials and Methods

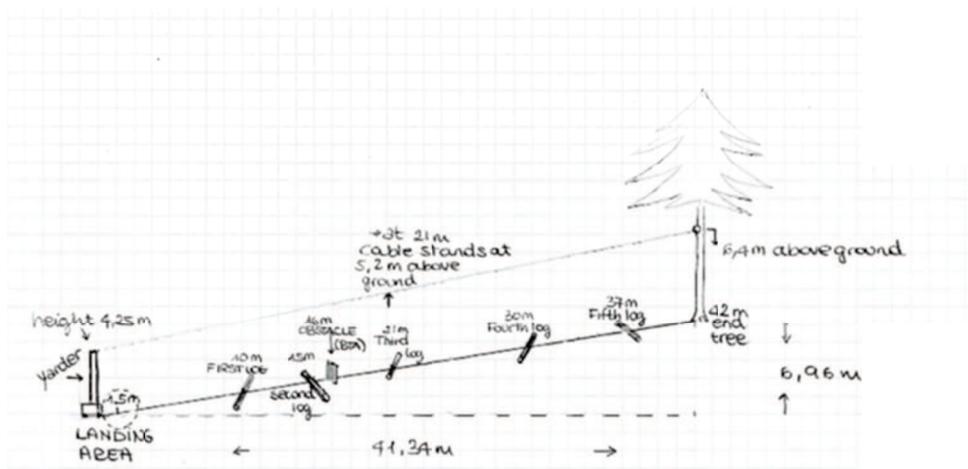
The test was performed over two days; each participant was assessed 6 times. The time required for the yarding exercise and the subjects' improvements in relation to their cumulative experience (six consecutive replications of the test) were investigated.

Five subjects with varying levels of experience in operating similar joystick controls participated in the test. The machine used was a 1:3 true scale of an Owren 400 which is a popular tower yarder in the boreal zone, and was used in a running skyline configuration (Figure 1).



**Figure 1: The Owren mini 400 used as a test rig in the trials, detail of the tower and the drums (photo: Morten Nitteberg)**

The yarder was rigged in a 42 m long corridor with a 17 % slope (Figure 2). The end-block was fixed 6.4 m above the ground. Maximum deflection at mid-slope was 5.2 m. Five small logs were laid out on permanently marked course.



**Figure 2: The schematic representation of the corridor layout, on a 17 % slope 42 meters long, five logs were placed on permanently marked course, two between the tower yarder and the obstacle and three between the obstacle and the end tree.**

This study employed a repeated measure experimental design with two independent variables. The dependent variables in this study were the total time to perform the task and the tension measured during the exercise. Each of the subjects had to yard all five logs to the landing area individually, giving one replication of five cycles. In total there were 6 replications of the 5 logs per subject where both time and corresponding tension were measured. The five cycle IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013

times (1 for each log) were summed to give the replication time. In measuring the tension, 6 replications of the five logs were recorded. The tension (N) was quantified using a wireless 3.5 kN dynamometer with continuous logging. This was attached to the end block to monitor the tension in the haul-back line (equivalent to that in mainline), and provide some indication of the ‘smoothness’ of the operation. Tension spikes should be avoided as they can cause system failure, breaking the guy-lines or snapping the mainline or haul-back line. The ability to operate with low tension is one of the main advantages of the running skyline.

We analyzed the data by using linear mixed effects models. We used Subjects as random effects. As fixed effects, we included Trial number, Previous Experience and the interaction of the two into the model. We checked for normality and homogeneity by visual inspections of plots of residuals against fitted values. To assess the validity of the mixed effects analyses, we performed likelihood ratio tests comparing the models with fixed effects to the null models with only the random effects.

## Results

The expectation that the mixed model would show a decrease in total time according to the different categories of ‘previous experience’ was confirmed. The plot shows a learning pattern with subjects improving their performance (less time used to perform the same task) for each replication over the previous one. The improvement looks fairly linear. The intercept is higher for subjects with less experience and closer to zero for the control (Instructor).

The standard deviation of the Tension for the 6 trials decreases with increasing trial number, getting into the range of the control by the 6<sup>th</sup> repetition (Figure 3).

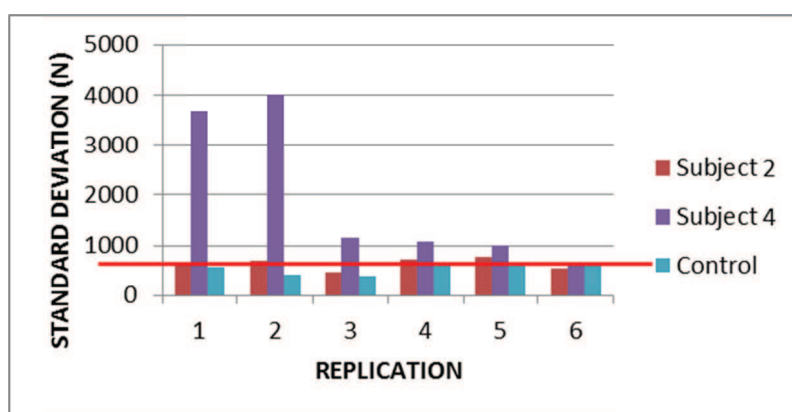


Figure 3: Standard deviations around the mean tension, by subject and replication

## Conclusions

The improvement in task completion time as a function of replication number and previous experience, together with the reduction in tension variability, provide support for the utility of learning curve theory in the prediction of future productivity with a training intervention.

### **4.3 CONTRACTOR EQUIPMENT SELECTION FOR MOUNTAINOUS LOGGING OPERATIONS IN WEST VIRGINIA**

*Ben Spong<sup>1</sup>, Dan Magil, and Shawn Grushecky*

West Virginia University, Appalachian Hardwood Center, United States of America. <sup>1</sup>ben.spong@mail.wvu.edu  
dmagill@wvu.edu, sgrushec@wvu.edu

#### **Introduction**

Located in the Appalachian Mountains of the Eastern United States, the state of West Virginia is almost completely covered by diverse hardwood forests. These forests support an active forest products industry, supplying logs to a range of primary, secondary, and biomass industries. Nearly all timber harvesting occurs on private lands by harvesting contractors. These contractors supply the labor, equipment, and expertise required to fell the timber and move it to a processing facility or mill.

#### **Materials and Methods**

In the spring of 2011, the West Virginia Division of Forestry compliance foresters surveyed all 385 active operations in the state to identify contractor demographics, logging equipment used, maintenance practices, and other general business activities. These survey data were summarized and analyzed to characterize the logging workforce and identify trends throughout the state regarding equipment selection and harvesting methods.

#### **Results**

86% of contractors are non-mechanized, while 54% of the mechanized contractors use a “Timbco” type harvester. As operations are almost exclusively ground based, the mountainous terrain requires the use of constructed skid roads, typically (87% of operations) using tracked bulldozer type equipment. Similarly, most (82%) use rubber tire skidders for log skidding to the landings. Truck and fixed platform mounted log loaders are used by 84% of contractors and 90% of the loggers handle their own log trucking. Additional analysis combined digital elevation model derived site characteristics with the survey data in order to identify potential relationships with specific equipment model/size use.

#### **Conclusions**

Results from this project illustrate the current status of harvesting operations in West Virginia and illustrate the reliance on ground based equipment use, even in steep slope logging conditions. Education and training opportunities exist for alternative harvesting equipment use, such as aerial based systems (cable based types) and improved skid road construction and maintenance practices to minimize site impacts.

## 4.4 AN OWAS-BASED ANALYSIS OF MOTOR MANUAL TIMBER HARVESTING OPERATIONS

Manavakun, N.<sup>1</sup>

<sup>1</sup> Department of Forest Sciences, University of Helsinki, Finland. nopparat.manavakun@helsinki.fi

### Introduction

Work-related musculoskeletal disorders (WMSDs) constitute an important occupational problem, which increased costs of wage compensation, medical expenses, reduced productivity, and provided a lower well-being status (Kee and Karwowski 2007). In developing countries, physical labour still plays an importance role. Often job causes workers to exert forces in an uncomfortable or unhealthy body posture. Forest work is also considered as a physically demanding job, particularly labour intensive operations that mainly employs in Thailand. The research techniques for WMSDs can be divided into observational and instrument based techniques (Kee and Karwowski 2007). The observational methods are probably the most common approach to evaluate physical workload (Takala et al. 2010). There are plenty of observational techniques which have been introduced, for instance, RULA, REBA, LUBA, OCRA, OWAS, among others (David 2005, Takala et al. 2010). The Ovako Working Posture Analysing System (OWAS) has been widely applied in several occupations, such as health care services, constructions, industries, agricultural and forest sciences. There were several studies relevant to OWAS method have been applied in forest operations (Väyrynen and Kononen 1991, Granqvist 1993, Lee and Park 2001, Zanuttini et al. 2005, Stempski 2008, Calvo 2009, Fiedler et al. 2011). In an attempt to improve workers well-being, work safety, and work efficiency in long term, this study aims to assess the risks of the WMSDs in eucalyptus harvesting operations in Thailand, through application of OWAS method.

### Material and Methods

The observations were carried out during the final felling in eucalyptus stands. There are three conventional logging systems applying of the cut-to-length (CTL) methods but differ in the order of the working processes. The workflows of the three conventional harvesting systems are as follows:

- System 1: felling (brush saws/chainsaws), delimbing (hand tools), bucking (brush saws/chainsaws), stacking (manual) and loading (manual),
- System 2: felling (brush saws/chainsaws), delimbing (hand tools), bucking (brush saws/chainsaws), stacking (manual) and loading (loader),
- System 3: felling (brush saws/chainsaws), bucking (brush saws/chainsaws), delimbing and stacking (manual) and loading (loader).

Data was collected using video recording and was afterwards analyzed with the WinOWAS (Tampere University of Technology, 1996) computer software for analysis working postures on the basis of OWAS method. Analysis included felling, bucking, delimbing, stacking, manual loading, and mechanized loading operations. The random time interval for coding posture was 30 seconds (Mattila and Vilkki 2003, Stempski 2008). OWAS method allows estimating the degree of static load of the workers by analysing their posture identifying four work postures for the back, three for the arms, seven for the lower limbs, and three for the weight of load handles (Schilden 1989). Each classified posture is defined by a four-digit code in which the numbers indicate the postures of the back, the arms, the legs, and the external load.

The degrees of the assessed harmfulness of these posture–load combinations are grouped into four action categories which indicate the urgency for the required workplace interventions (Mattila and Vilkki 2003, Kee and Karwowski 2007). Category 1 is the normal postures with no harmful effect on musculoskeletal system – no actions required. Category 2 is the slightly harmful postures – corrective actions required in the near future. Category 3 is the distinctly harmful postures – corrective actions should be done as soon as possible. And category 4 is the extremely harmful postures – corrective actions for improvement required immediately.

The OWAS risk indicator (I) is expressed as a weighted value that ranges from 100 to 400 and the value obtained corresponds to a proportional level of risk and a consequent intervention to be implemented [Eq. 1]. The hazard increases as a function of risk index.

$$I = [(a \cdot 1) + (b \cdot 2) + (c \cdot 3) + (d \cdot 4)] \cdot 100 \quad (\text{Eq. 1})$$

Where a, b, c, and d are the observation frequency percentage in risk class 1, 2, 3, and 4 respectively.

## Results

The frequencies of body postures and risk indicator for different work operations indicate that most of the time operators work in normal postures (Table 1). Even though, there are some work phases; felling by chainsaws, bucking by chainsaws, and manual delimbing are indentified as slightly harmful operations due to back position was evidently bent down most of the time. The stacking, delimbing & stacking, and manual loading was accounting for over 20% of the time classified as category 3 in which distinctly harmful postures, the corrective action should be done as soon as possible. From the risk indicator perspective, manual loading, felling and bucking by chainsaws were identified as slightly harmful postures for the workers (risk index  $\geq 200\%$ ). This study confirmed that tools selection had the influence on risk of WMSDs. The felling and bucking can operate either by using chainsaws or brush saws, but chainsaws usage provides more critical task to the operators regardless of the operations, due to often *kneeling* while working and back noticeably *bent down*. Moreover, the overall risk index was 169.33%, this may be considered as minimal risk level in which corrective actions will be required in the near future.

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

**Table 1. The OWAS category and risk indicator of each work phase**

| Operations           | Categ.1 (%) | Categ. 2 (%) | Categ. 3 (%) | Categ. 4 (%) | I (%)  |
|----------------------|-------------|--------------|--------------|--------------|--------|
| Felling (Brush saws) | 88.18       | 9.09         | 1.82         | 0.91         | 115.45 |
| Felling (Chainsaws)  | 35.45       | 32.73        | 13.64        | 18.18        | 214.55 |
| Bucking (Brush saws) | 85.83       | 7.50         | 0.83         | 5.83         | 126.67 |
| Bucking (Chainsaws)  | 19.17       | 63.33        | 8.33         | 9.17         | 207.50 |
| Delimbing            | 24.17       | 68.33        | 3.33         | 4.17         | 187.50 |
| Stacking             | 62.50       | 10.83        | 24.17        | 2.50         | 166.67 |
| Delimbing & Stacking | 52.73       | 16.36        | 22.73        | 8.18         | 186.36 |
| Manual loading       | 46.43       | 17.86        | 25.00        | 10.71        | 200.00 |
| Mechanized loading   | 97.00       | 2.00         | 1.00         | 0.00         | 104.00 |
| Total                | 55.81       | 25.81        | 11.62        | 6.76         | 169.33 |

It is obviously noticed that most of body postures assign as normal posture, category 1 (greater than 60%) for all three systems. Whereas, the category 3 and 4 exist in all systems, though there are small proportions. This notifies the stakeholders to pay attention and increase awareness on WMSDs prevention and work safety. In addition, system 1 is the largest risk operations among three systems with risk index of 161.31%, whereas system 3 has the smallest risk (I = 133.64%).

## Conclusions

The felling and bucking by chainsaws provides more critical task to the operators. Using chainsaws classifies as a slightly harmful task, the corrective action may be required in the future. For this reason, brush saws recently become commonly used for eucalyptus felling in Thailand instead of chainsaws, due to low investment, fairly small tree sizes, and improvement work postures. However, there are some negative opinions since it is inherently dangerous; the workers are unable to totally control the saw, the open blade is on the end of a wand, and can snag and swing violently to the side, making it more prone to injure other workers. The Personal Protective Equipment (PPE) is required. The manual tasks like stacking, delimbing, and loading were considerably more risk among other work phases. Based on the results, it can conclude that the mechanized harvesting system (system 3) is safer than others. Therefore, mechanization has a potential to improve work safety. However, it should keep in mind that mechanized harvesting always requires higher operating cost. In addition, the operators should be trained and informed about the correct working positions and loading methods before operational, particularly for manual loading, stacking, delimbing, stacking and felling by chainsaws. It is not only the training which should be implemented, but also the supervision should be regularly monitored.

## Literature cited

- Calvo, A. 2009. Musculoskeletal disorders (MSD) risks in forestry: A case study to suggest an ergonomic analysis. *Agricultural Engineering International: The CIGR Ejournal*. Manuscript MES 1149, Vol.XI. April 2009.
- David, G. C. 2005. Ergonomic methods for assessing exposure to risk factors for work related musculoskeletal disorders. *Occupational Medicine* 55: 190-199.
- Fiedler, N. C., Barbosa, P. B., Andreon, B. C., Goncalves, S. B. & Silva, E. N. 2011. Evaluation of the postures adopted in forestry operations in Declivous areas. *Floresta e Ambiente* 18(4): 402-409.
- Granqvist, A. 1993. Productivity, loading and work safety in preparing firewood. *Työtehoseuran Metsätiedote* 9(517).
- Kee, D. & Karwowski, W. 2007. A comparison of three observational techniques for assessing postural loads in industry. *International Journal of Occupational safety and ergonomics* 13(1): 3-14.
- Lee, J. W. & Park, B. J. 2001. Analysis of working posture using OWAS in forest work. *Jour. Korean For. Soc.* 90(3): 388-397.
- Mattila, M. & Vilkkki, M. 2003. OWAS methods. *Occupational Ergonomics Principles of Work Design*, CRC Press.
- Schilden, M. 1989. The OWAS system for analysing working postures. *Acta Horticulture* 237: 129-136.
- Stempski, W. 2008. Workers's physical load when harvesting logs on clear cuts. *Acta Sci Pol. Silv. Colendar. Rat. Ind. lignar.* 7(3): 37-45.
- Takala, E. P., Pehkonen, I., Forsman, M., Hansson, G. A., Mathiassen, S. E., Neumann, W. P., Sjogaard, G.,
- Tampere University of Technology. 1996. WinOWAS - software for OWAS analysis. 15 p.
- Väyrynen, S. & Kononen, U. 1991. Short and long-term effects of a training programme on work postures in rehabilitees: A pilot study of loggers suffering from back troubles. *International Journal of Industrial Ergonomics* 7(2): 103-109.
- Zanuttini, R., Cielo, P. and Poncino, D. 2005. The OWAS method. Preliminary results for the evaluation of the risk of work-related musculo-skeletal disorders (WMSDs) in the forestry sector in Italy. *Italia Forest@* 2: 242-255.

## 4.5 PRODUCTIVITY AND ERGONOMIC STUDY OF A MOTORIZED HYDRAULIC GRAPPLE CARRIAGE

Visser, R<sup>1</sup>, S. McFadzean<sup>1</sup> & S. Hill<sup>2</sup>

<sup>1</sup>School of Forestry, University of Canterbury, Christchurch, New Zealand. rien.visser@canterbury.ac.nz

<sup>2</sup>Scion, Rotorua, New Zealand

### Abstract

Currently New Zealand timber harvests 23.5 million m<sup>3</sup> per year. This volume is expected to increase significantly over the next decade, with much of this on steep, difficult terrain. While cable yarding is a long term mainstay of extraction operations, a significant safety risk is the exposure of choker-setters on these slopes. A new hydraulic motorised grapple carriage has been developed that can be used on tower yarders, labelled the Falcon Forestry Claw (FFC), to remove the reliance on choker-setters for improved safety but also increased productivity. Another non-motorised grapple carriage, called the Alpine, has also been recently imported from South African and modified for New Zealand conditions. Both systems include integrated video technology to improve the operator's ability to 'see' the stems in the cut-over.



Figure 1: Falcon Forestry claw motorised grapple carriage operating in the Nelson region of New Zealand.

### Method

An elemental time study was completed on three FFC system configurations; (1) extraction manually felled trees, (2) extracting pre-bunched trees and (3) the grapple being 'fed' by an excavator on the slope. A comparison of the FFC with the conventional system using chokers

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

was also included. Key stand and terrain variables included extraction distance, piece size, and a descriptor of the location (front face, gulley or back face). Heart-rate data from the operator was also captured to indicate operator stress levels. Delay free cycle time and productivity regression functions for the FFC were established. Average piece-size was 1.65m<sup>3</sup>, which is low for average New Zealand conditions. Average extraction distance was 225m. All four sites studied can be considered difficult because approximately 10-20% of the stand was affected by wind-throw.

## **Results**

The average productivity was 32.7 m<sup>3</sup>/PMH when extracting manually felled trees. This was lower than productivity just using chokers (41.8 m<sup>3</sup>/PMH). While the grapple has a faster cycle time (4.2 versus 5.3 min), the lower productivity can be explained by a reduced average payload. This effect is highly dependent on piece size; in larger piece size productivity is matched. Significant increases in productivity were recorded when pre-bunching and feeding, averaging 63.3 and 76.3 m<sup>3</sup>/PMH respectively. Both a decrease in cycle time (2.6 and 2.1 min respectively), and increase in payload, attributed to the overall increase in productivity.

Actual productivity per scheduled machine hour is significantly lower with 44% of the total time being delays. Operational type delays of line shifts, rigging changes and interaction with other machines on the landing amounted to 34% of the total. Delays associated with the repair and maintenance of both the carriage and the yarder were 35% of the total. While it is a new system and these delay values may not reflect the long term expected delays, clearly the full potential of this will only be achieved by reducing these delays.

A cost-benefit analysis is not included because of the complexity of the changes in the system. While operating the FFC eliminates the need of choker-setters on the slope (normally 2 or 3 workers), both pre-bunched and 'fed' variations required a machine to operator on the slope. However this machine will also replace the manual felling component of the operation.

In terms of ergonomics, monitoring the heart-rate of the operator of the earlier version of the FFC and its video system indicated concern about the stress level of the yarder operator with both high and increasing heart-rate values over the day. This can be attributed to both the reduced amount of down-time for the operator in comparison to operating with chokers, as well as the need to view a small computer screen inside the yarder cab. The latest series of studies, by which time the experience of the operators had increased, as well as the video technology and the operation of the FFC improved, showed little concern for the operator.

## **Acknowledgements**

This project was supported by Future Forest Research, based in Rotorua, New Zealand. It combines industry and government support to facilitate the completion of applied research projects. Moure Logging also provided considerable in field support during the study, and we gratefully acknowledge that.

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

## Literature cited

Department of Labour. 2011. Forestry Section Action Plan 2010-13, in Workplace Health and Safety Strategy for New Zealand to 2015 - 2011.

Evanson, T. and D. Brown, Improved Grapple Control using a Grapple Restraint. Future Forest Research, 2012. Technical Note HTN04-10.

Evanson, T. 2011. International Grapple/Carriage Developments: A Review of the Literature. Future Forest Research: Rotorua.

Harrill, H. and R. Visser, 2011. What is the best Rigging Configuration to in New Zealand Cable Logging Operations? Future Forest Research: Rotorua.

Harrill, H. and R. Visser, Matching Rigging Configurations to Harvesting Conditions. Future Forest Research, 2012. Technical Note HTN04-06.

MAF, 2011. National Exotic Forest Description Ministry of Agriculture and Forestry: Wellington, New Zealand.

Olsen, E.D., M.M. Hossain, and M.E. Miller. 1998 Statistical Comparison of Methods used in Harvesting Work Studies. Forest Research Laboratory Oregon State University, 1998(Research Contribution 23).

Palmer, W. and P. Robinson. 1998. The use of Motorised Slackpulling and Skycar Carriages in New Zealand. New Zealand Logging Industry Research Organisation (LIRO), Technical Note 45 (1998).

Prebble, R., Madill 171 Hauler. 1989. New Zealand Logging Industry Research Association 1989. Volume 14.

Raymond, K., 2012. Innovation to Increase Profitability of Steep Terrain Harvesting in New Zealand, in proceedings of NZ Institute of Forestry.

Yelle, L.E., 2008. The Learning Curve: Historical Review and Comprehensive Study. University of Lowell, 2008.

Wood, W. 1970. Radio-Directed Grapple Aids Efficiency for Western USA Logging Operation Battery-powered carriage, opens and rotates grapple in system. World Wood - An international Journal for Loggers, Foresters, Manufacturers of Wood Products. March 1970, Mouton & Co: Springfield, Oregon, USA.

## **4.6 SAFETY MANAGEMENT SYSTEM FOR MOUNTAINOUS FORESTRY OPERATION**

*Yamada, Y., Funasaka, Y., & Higashi, K.*

Graduate School of Bio-agricultural Sciences, Nagoya University, Japan. [yozo@agr.nagoya-u.ac.jp](mailto:yozo@agr.nagoya-u.ac.jp)

### **Introduction**

In Japanese forestry, the accident rate per 1000 workers remains 30, and approximately 50 workers have been lost annually. Although the forest mechanization is expected to reduce work accidents, most of Japanese forests locate on steep and intricately folded terrain, and those terrains prevent preparing more road networks and higher mechanization in Japanese forestry. Especially, felling operations mainly depend on chainsaws, and it is difficult to change to the other machines such as harvesters as a characteristic of mountainous forestry. Thus we must construct a more stable safety management system to reduce work accidents, and promote a more effective safety education and training to improve workers' safety consciousness.

In this report, in order to construct a more stable management system in mountainous forestry operations, we analyzed work accident data, implemented a questionnaire research about a site supervisor for logging companies, and developed a safety apparatus with wireless communication.

### **Methods**

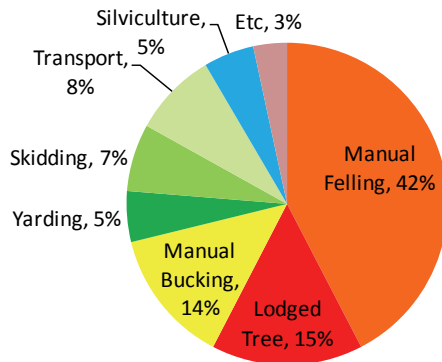
59 fatal accidents in 2010 were classified by operation, and the number of adjacent workers at the time of fatal accident was clarified. Questionnaires about a site supervisor were sent to 282 healthy logging companies in all Japan, and we analyzed statistically 92 valid responses from them. Then, we developed a safety apparatus with wireless communication for a site supervisor to keep track of workers' locations and conditions of his working group. Moreover the safety apparatus was added an alarm function with a proximity sensor.

### **Results**

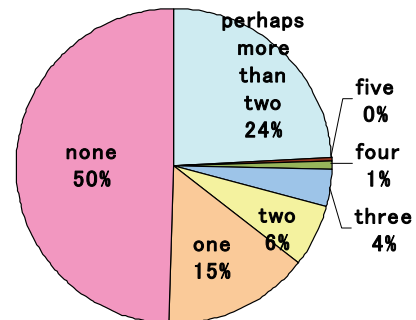
Fatal accidents occurred 42% in manual felling, 15% in treating lodged tree, and 14% in manual bucking in steep terrain (Figure 1). All of those operations were carried out with chainsaw, so fatal accidents with chainsaw accounted for totally 71%. It is not too much to say that the manual work with chainsaw in steep terrain is a main obstacle to work safety in Japanese forestry.

At the time of fatal accident, how many workers were there around or near the victim? Surprisingly, half of victims had none around or near at the time of accident (Figure 2). Moreover the folded terrain hampered sight and sound of the victim's working site from the

other workers. Thus it was too late when they found the absence of victim at the lunch time or the end of work. Unfortunately, there are many forests where we can't use cell- phones.

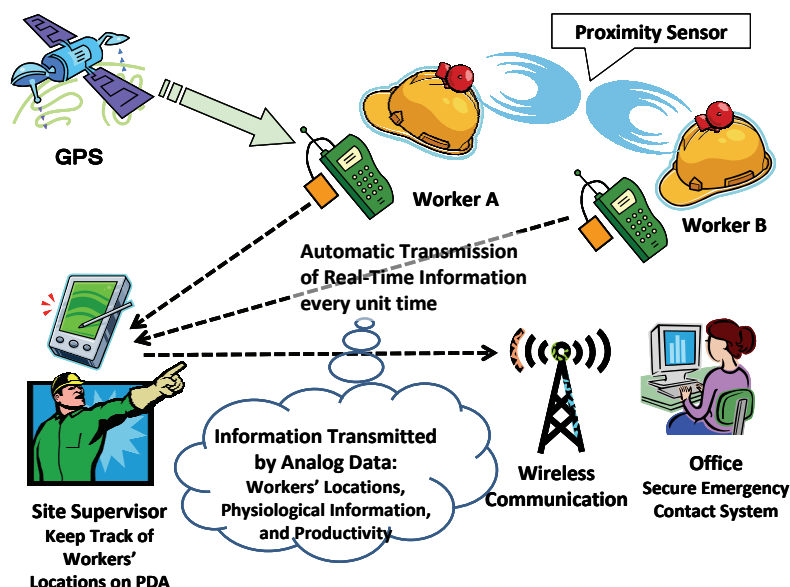


**Figure 1. Fatal accident in 2010, totally 59 fatal victims**



**Figure 2. The number of adjacent workers at the time of fatal accident**

Such a tragedy may be caused mainly by insufficient safety management system in Japanese forestry. According to the questionnaire survey, 80% of logging companies assigned the site supervisor responsible for safety, but a leader of working group assumed the role of the site supervisor in 35% of logging companies. There was no full-time site supervisor. The leader is also workers, and oversees the other workers while working together, so he can't supervise his working group sufficiently.



**Figure 3. Safety management apparatus with wireless communication**

To improve safety management in Japanese forestry, we developed a safety apparatus with wireless communication for a site supervisor. Each worker carries a walkie-talkie which has a GPS receiver and an analog converter. The converter changes digital data of position coordinate and heart rate in analog data, and transmits automatically those analog data to the site supervisor every unit time. Moreover the walkie-talkie has an alarm function with a proximity sensor. The site supervisor can keep track of workers' locations and conditions of his working group on the PDA. Thus, if an accident occurs, the site supervisor can go to the rescue and administer first aid as soon as possible. Moreover the site supervisor can call on the office for help with the precise location data of the injured worker.

## **Conclusions**

To fully utilize this safety apparatus, the site supervisor should be a full time, and should not perform the same work with the other workers. The site supervisor should focus entirely on supervisory activity for safety, productivity, and environment. We advocate to set a full-time site supervisor in each working group to construct a more stable safety management system in Japanese forestry.

## **SESSION 5: BIOMASS FROM STEEP TERRAIN HARVESTING**

**Chair: Dr. Jean-Francois Gingras**

## 5.1 HARVESTING LOGGING RESIDUES FOR ENERGY IN A COMBINED SYSTEM IN STEEP TERRAIN

Becker, G.<sup>1</sup>, Cremer, T.<sup>1</sup>; Spinelli, R.<sup>2</sup>, Sauter, U. H.<sup>3</sup>

<sup>1</sup> Institute for Forest Utilization and Forest Work Science, University of Freiburg, Germany  
gero.becker@fobawi.uni-freiburg.de

<sup>2</sup> CNR IVALSA, Florence, Italy

<sup>3</sup> FVA, Abt. Waldnutzung, Freiburg

### Introduction

With renewable energy policies, the demands on the forest sector to deliver logging residues for energy increase. For flat and hilly terrain a number of feasible and economical energy wood procurement systems have been developed and are operating successfully.

Today, in Central Europe the greatest reserves and potential for both industrial wood and energy wood is located in forests on steep terrain due to lack of transport infrastructure (roads), adequate harvesting technology and high costs. Especially for low value assortments, like logging residues, it is a challenge to design and operate technically feasible and economically viable procurement chains. Things get even more complicated, if selective logging is applied, which is the standard management procedure in Central-Europe.

In flat or hilly terrain where fully mechanized systems can operate, logging of industrial assortments and of residues, is usually carried out in a two-step operation (1. harvester and forwarder for industrial wood, 2. harvester / chipper for residues). Both machine systems operate on the same strip roads but de-coupled. Given the low piece / volume rate of residues and the high forwarding costs in steep terrain, a combined harvesting method, forwarding full trees uphill or downhill to the next road by cable supported systems, and processing them separately to the different products afterwards seems to be a better solution.

### Materials and methods

A combined full tree system was tested in steep terrain (>35%) in the Black Forest near Freiburg. In three mixed stands (age 40 years, 80% spruce, 20% beech) trees were selectively felled motor-manually with chain saw. The average dbh of the removed trees was 21cm for spruce and 12cm for beech. A short distance cable crane (Ritter KSK) was operated on a forest road pulled the full trees uphill on cable lines 2m in width, 15m in distance and 75m in length on average.

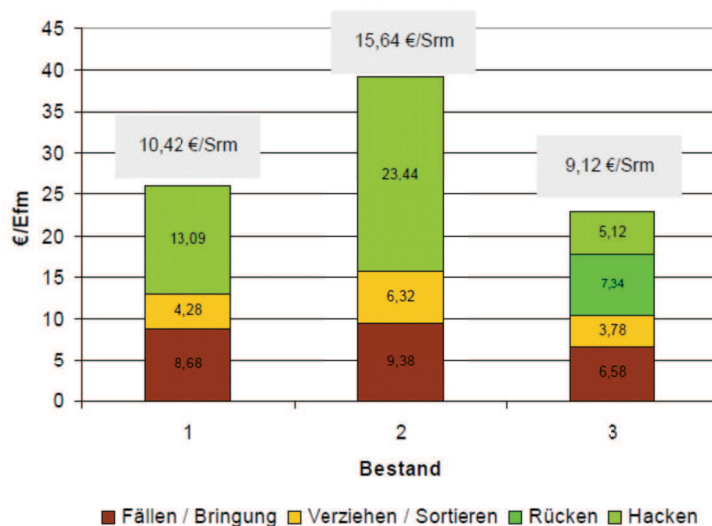


**Fig.1: Short distance cable crane RITTER KSK**

After forwarded by the cable crane, the full trees were pulled sideward and sorted with a grapple skidder on the road. A harvester (working as a processor) de-branched and crosscut the bigger trees into industrial logs. In two stands a mobile chipper chipped the remaining material (small trees, crowns and residues) directly at roadside into standard container trucks. In stand No. 3 the space on the road was too small and a forwarder was therefore employed to transport the material over 600m to a central location to be chipped. Detailed time studies covered all phases of the operation.

### **Results:**

The total production per ha of logs and residues was 69m<sup>3</sup> and 61m<sup>3</sup> (152m<sup>3</sup> loose) respectively. Due to combined full tree forwarding with the cable crane, the forwarding of the residues was (relatively) productive (9-15m<sup>3</sup>/h). Also the skidding on the road with grapple skidder was quite productive (15m<sup>3</sup>/h). The productivity of the chipper operating at road side was very variable (18-33m<sup>3</sup> loose per hr.) depending on the logistics: Feeding enough material to the chipper and exchanging the empty and full containers turned out to be very difficult on the narrow roads in mountain terrain and caused delays in chipping. The chipper productivity increased significantly up to 84 m<sup>3</sup> loose per hr., if the residues were transported to a central location where material feeding, chipping and chip transport could be organized in a more favorable way (stand No. 3).



**Fig. 2: Total cost of residue chip procurement at roadside for 3 stands**

Fig. 2 shows, that the total costs for stand Nr. 3 were the lowest (23,-- €/m<sup>3</sup> (= 9,12 € / m<sup>3</sup> loose chips)) even if an additional activity (forwarding of the residues) was included.

Depending on the actual market prizes for green chips (which vary in the moment between 10,-- and 20,-- € per m<sup>3</sup> loose free mill gate) the combined system turns out to be technically feasible and economically viable even on steep slopes. Furthermore it can be concluded, that the combined harvesting of logs and residues resulted in cost advantages also for the procurement of the logs due to a better usage rate of the cable crane.

## 5.2 RECOVERY OF LOGGING RESIDUES FROM FINAL HARVEST IN STEEP TERRAIN

*Eirik Nordhagen*

Norwegian Forest and Landscape Institute, Norway. [eirik.nordhagen@skogoglandskap.no](mailto:eirik.nordhagen@skogoglandskap.no)

### Introduction

In the coastal region Norway approximately 30% percent of the volume (90 mill m<sup>3</sup>) is harvestable round wood in steep terrain (Vennesland 2006). Cable crane systems used in steep terrain generally result in higher extraction costs than do ground-based systems, but biomass tops and limbs yarded intact on logs may have little or no incremental extraction costs (Hartsough 2010). However landings on cable units are often quite small and the area available for accumulation of residues is limited. In this study in Saltdalen in Nordland we wanted to estimate the amount of logging residues produced from final harvest in steep terrain and quantitative information about the pile of logging residues and the performance of the forwarder at the landing site. Because we measured the tree biomass it was also interesting to compare the measured biomass with existing biomass functions which are based on easily measurable tree variables like diameter and height (Marklund 1988).

### Materials & Methods

After manual felling the 80 year old stand with planted Norway spruce (*Picea abies*) were winched down to the landing site with an Igland 400 winch. The trees were delimbed and bucked with a processor at the landing site. A forwarder loaded up the residues and placed it in a pile near the road, approximately 25-50 meters away from the landing site. To determine the proportion of forest biomass, 25 trees were weighed with and without top and branches. Diameter at breast height and height of each sample tree was measured. The logging residue biomass was calculated in relation to usable logs (stem wood). The moisture content was measured to determine the dry weight. Stem volume of sample trees was calculated on the basis of the volume function #5 (Vestjordet 1967). To find the cost of loading, transport and unloading of forest residues, time studies of the forwarder were carried out. Two forwarder loads with forest residues were weighed.



**Figure 1. At the logging site with planted Norway spruce in Saltdalen, Nordland.**

## Results

Approximately 330 m<sup>3</sup> of logs were harvested in this operation. The biomass of top and branches (logging residues) in relation to the round wood (stem wood) accounted for 19% more biomass from the logging site (Table 1). It implies that about 63 solid m<sup>3</sup> or 43 tons of fresh logging residues was removed and piled.

**Table 1. Characteristics of the 25 trees studied.**

|                                                     |      |
|-----------------------------------------------------|------|
| Mean height (m)                                     | 18,6 |
| Mean DBH (cm)                                       | 22,8 |
| Total solid stem volume with bark (m <sup>3</sup> ) | 10,3 |
| Total log weight (kg)                               | 8371 |
| Total stem wood (kg)                                | 7013 |
| Total logging residues weight (kg)                  | 1358 |

The forwarder handled and piled about 4 tons of dry biomass per hour i.e. 187 MWh. The forwarder costs were estimated to €135 per hour. The costs for collecting the biomass at the landing site were approximately €0.73 per MWh. Additional costs are storage-to-plant operations such as chipping and transport. The market price for logging residue with moisture content between 40 to 50% is €22.2 per MWh. This price includes transport up to 50 km. The pile was measured to be 30 long and 3 meters wide and 2.5 m high. The pile covered an area of 4 m<sup>2</sup> per dry ton.

## Discussion

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

The quantity of logging residues at this site was estimated to be 19% more biomass in addition to round wood. In similar studies (unpublished) from on cable crane operations at Ørsta and Laukeland on the West coast of Norway, the logging residue mass were measured to 28% and 25%. While in a young Sitka spruce stand manually felled in Steigen in Nordland the percentage was 75. The measured biomass was compared with Marklunds biomass functions #202 and 214 (Zianis 2005). The biomass quantity in Saltdalen was on average 27 kg (dry weight) per tree as Marklunds functions gave 66 kg (dry weight) per tree. Stand density, site type and tree age are factors affecting the shape of the tree crown and hence the quantity of total tree biomass (Repola 2009). Branches and tops are also broken off by felling and winching in steep terrain; this will reduce the actual biomass available. The pile covered an area of 4 m<sup>2</sup> and according to Hartsough (2010) the accumulation of residues require 3-6 m<sup>2</sup> of ground surface per dry ton if stacked to a height of 3 m by a forwarder or processor.

In this region there are few users of logging residues. It will be necessary in the near future to find solutions for a better utilizing of biomass in steep terrain. Cable cranes and sky lines accumulate biomass at the landing site. The logging residues have a free ride to roadside after harvesting round wood and this resource ought to be exploited. New heating plants should be built to turn this biomass resource in to heat.

### Literature cited

- Hartsough, B. R. 2010. The supply chain. In *Guidelines for the development of a forest chips supply chain model.*, ed. R. Spinelli, 104-135. GAL Prealpie Dolomiti, Belluno.
- Marklund, G. 1988. Biomass functions for pine, spruce and birch in Sweden., 75. Swedish University of Agricultural Sciences.
- Repola, J. (2009) Biomass Equations for Scots Pine and Norway Spruce in Finland. *Silva Fennica*, 43, 625-647.
- Vennesland, B. 2006. *Skogressursene i Norge 2006: muligheter og aktuelle strategier for økt avvirkning*. Ås: Norsk institutt for skog og landskap.
- Vestjordet, E. 1967. Funksjoner og tabeller for kubering av stående gran. In *Alf Langsæter: festskrift utgitt til ære for skogdirektør, professor, dr.agr. Alf Langsæter på hans 70-års dag*, S. 539-574. Vollebakk: [Det norske Skogforsøksvesen].
- Zianis, D. 2005. *Biomass and stem volume equations for tree species in Europe*. Helsinki: The Society of Forestry in Finland.

### **5.3 A NEW EQUIPMENT FOR PRODUCTIVE COLLECTION OF FOREST RESIDUES BESIDES CABLE LOGGING: LOGISTICS WHEN YARDING SPACE IS LIMITED.**

*Naud, O.<sup>1</sup>, & Rombaut, M., Bonicel, J.-F., & Prouvot, A.*

Irstea, UMR ITAP, BP 5095, F-34196 Montpellier cedex 5, France. <sup>1</sup>corresponding author

#### **Introduction**

Despite the growing demand in forest residues as an environment-friendly bioenergy source, the lack of direct economic benefit of collecting residues for the forest owner or the logging companies is still a plausible cause for limited mobilization of biomass. It is more specifically the case for mountainous areas, when cable logging is performed. Productivity and logistics are important issues if mobilization levels of wood and bioenergy should rise in a near future. This is why a consortium of French partners conducted an applied research project entitled MOBIPE from 2006 to 2010. In the present paper, we present a patented technological concept proposed during this project (which is a truck combining bundling and processing), the hypothesis that led us to this design, and modeling techniques which were used to investigate logistic issues.

#### **Materials and Methods**

The reference area for the study was the French Alps and the reference conditions were cable logging on steep slopes. The partners in the project conducted a number of visits and field surveys, and collected productivity data. Global data was collected (daily productivities and manpower required) on many sites, and detailed data, with timing of each task, was gathered for a small subset of sites (Grulois et al, 2010). Also, visits and discussions allowed the cable logging experts to define scenarios, including worst-case situations.

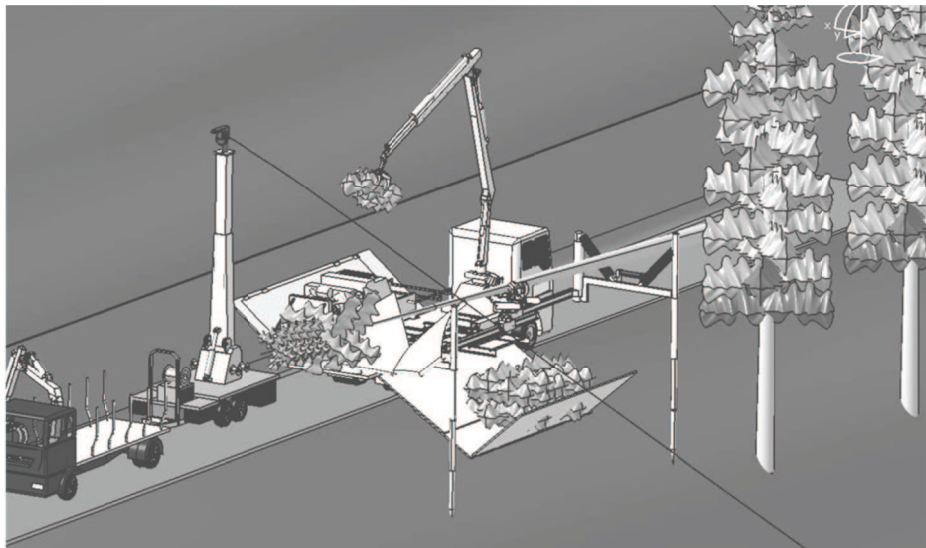
Let us now describe the logging scenario that we considered when proposing an innovative truck: we considered a 4 m wide road or trail where the cable crane was installed. Very often, the trail was a dead-end and the yarding location can be accessed only on one side. In the French Alps, trunks are transported full-length to the mills but cut-to-length logs (4-8 m) could also be considered on the technical point of view if we think of neighbor countries. Because of the single-access and because the steep slopes makes it difficult to store slash besides the trail, residues compete unfavorably with saw timber when it comes to assign space at the yarding place. Priority access to saw timber must be maintained, so residues (branches and crowns) should be conditioned in order to be stored along the trail on the dead-end side.

In order to investigate logistics at the logging site, from felling to storing wood and biofuel, we modeled the production behavior and timing of loggers on the slope, movement of carriage on the skyline, crane operators and loggers at the yarding place. We used the Statecharts modeling language (Stateflow® tool) based on automata (describing states and transitions). Automata and discrete event simulation have now become popular for behavior modeling, including in the forestry domain (McDonald et al, 2001, Asikainen et al, 2010). *IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

The purpose of the modeling was to check if there was a possibility to collect and pack residues without slowing the logging process. Distinct scenarios using some common automata were modeled: (i) logging with cable crane, excavator with processing head, and no collection of residues; (ii) logging with cable crane, and combined truck; (iii) same as (ii) with a small truck to arrange bundles along the roadside; (iv) same as (i) with automatic chokers.

## Results

From the scenario explained above, we designed the truck concept presented in figure 1. This truck combines processing and bundling at the same time. The processing tool is mounted with rollers upwards, as it was the case in the now obsolete two-grips harvesting machines. The head could be of the “Woody” brand, which is popular for processing trees full length. Forward and backward guiding devices are aligned with it in order to process the trees. Slash falls on a collecting plate. The crane with grapple either feeds the bundling tool, or hauls the tree up to the guiding devices and processor. The bundling tool could be the Deere bundler unit, which is usually mounted on a forwarder like the 1490 model but has also been adapted on trucks (Spinelli et al, 2012).



**Figure 1. Truck combining tree processing and slash bundling besides a cable crane**

The key factor for productivity here is that bundling slash does not slow down the trimming and processing. This was checked by simulation. Time parameters were set up using typical data from field operations, with variations to check process dynamics. The hauling and trimming of the trees takes more time than the bundling, which, besides feeding of slash, is automatic. It follows that bundling time is hidden time. Smooth synchronization is also required between work on the slope and work at the cable yarder. Operations such as attaching wire rope with chokers to the trees and hauling the trees were individually modeled.

This also allows analyzing productivity with regards to how many trees are felled per surface unit near the skyline.

## **Conclusion**

New equipment is required besides cable cranes to combine logging efficiency and environment protection in order to collect bioenergy and saw timber. Based on a system analysis, we propose here a new equipment with bundling facility to enhance logistics.

## **Literature cited**

Asikainen, A., Stampfer, K., Talbot, B. 2010. An evaluation of skyline systems in Norwegian conditions using discrete-event simulation. Precision Forestry Symp. Stellenbosch, South-Africa.

Bonice, J.F., Naud, O., Rombaut, M. 2012. Hewing and bundling vehicle. European Patent EP2345323 (published 25.07.2012, priority 19.1.2010 FR 1050318 - Véhicule de façonnage et de fagotage).

Grulois, S. et al. (2010). Final report of MOBIPE project. FCBA, Cemagref (now Irstea), CFPF, ONF, UCFF. Sponsored by French National Research Agency under PNRB program.

McDonald T.P., Taylor, S.E., Rummer R.B. 2001. Influence of bundle distance distribution and assignment sequence on tree length logging system efficiency. ASAE Annual meeting, Sacramento.

Spinelli, R., Lombardini, C., Magagnotti, N. 2012. Annual usage and long-term productivity of a truck-mounted slash bundler under mountain conditions. European Journal of Forest Research 131:821-827.

## 5.4 WHOLE-TREE YARDING AND MECHANISED PROCESSING IN COPPICE OPERATIONS

*Magagnotti N.<sup>1</sup>, Becker G.<sup>2</sup>, Suchomel C.<sup>2</sup> & Spinelli, R.<sup>3</sup>*

<sup>1</sup> CNR IVALSA, Italy. [magagnotti@ivalsa.cnr.it](mailto:magagnotti@ivalsa.cnr.it),

<sup>2</sup> FOBAWI, Germany [gero.becker@fobawi.uni-freiburg.de](mailto:gero.becker@fobawi.uni-freiburg.de)

<sup>3</sup> CNR IVALSA, Italy. [spinelli@ivalsa.cnr.it](mailto:spinelli@ivalsa.cnr.it)

### Introduction

The introduction of mechanized harvesting to coppice stands is progressing slower than expected. This might be related to a number of factors, including: the socio-economic conditions of the Mediterranean mountain, characterized by small enterprises with low investment capacity; the limited density of the forest road network; the strong concern of local forester for environmental impacts; the typical forest management type, based on coppice regeneration. The result is a worrying stagnation of forest activities and a decline of the logging business, as many operations are on the edge of economic survival, and often fill the gaps by resorting to underpaid irregular labour. Modernization is badly needed, and operators are increasingly looking for directions concerning the type of units that are best suited to their work environment, and the conditions required for a successful deployment.



In Central and Southern Italy, several operators have equipped with modern tower yarders, specializing in steep terrain logging. They target steep terrain coppice forests, where competition is weaker: poor accessibility discourages potential bidders and in any case yarder operators can outbid traditional animal loggers, where they still exist. Generally, trees are yarded whole to the landing, where they are handled with a hydraulic loader and processed motor-manually. This operational mode is just one step away from a typical yarder-processor operation, but most loggers still hesitate, not knowing if current technology can profitably handle their trees. In particular, many fear that the typical shape and size of coppice trees is not suitable for mechanical processing. If this was the case, then processing quality could

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

result unacceptable, or the processor could lag behind, slowing down the whole operation. Furthermore, they are torn between different options and ignore which can best suit their own operating conditions.

The purpose of this study was to determine the performance of whole-tree yarding followed by mechanized processing, applied to coppice stands. Three cases were carefully analyzed, each representing a different coppice stand type: chestnut, oak and beech. Technology was appropriate for the specific tree size, and consisted of light tower yarders and small to medium size excavator-base processors.

## Methods

The study was conducted in three coppice stands, considered as representative of the different forest types found at different elevations and latitudes. In altitudinal order, the stands were composed mainly of oak (*Quercus cerris* L.), sweet chestnut (*Castanea sativa* L.) and beech (*Fagus sylvatica* L.). Due to the different ecological needs of these species, the treatments were clearcut for oak and chestnut, and selection cut for beech (Table 1). Whole tree harvesting was applied in all cases. Trees were felled with chainsaws, yarded with light tower yarders and processed at the landing with excavator-base processors.

**Table 1 – Study site and operation characteristics**

|                |                        |                 |                   |                 |
|----------------|------------------------|-----------------|-------------------|-----------------|
| Placename      |                        | Pian di Rossaia | Mello             | Monte Cavallo   |
| Municipality   |                        | Greve           | Gaiole            | Granaglione     |
| Province       |                        | Florence        | Siena             | Bologna         |
| Elevation      | m a.s.l.               | 540             | 620               | 1290            |
| Species        |                        | Oak             | Chestnut          | Beech           |
| Average age    | years                  | 30              | 30                | 45              |
| Treatment      |                        | Clearcut        | Clearcut          | Thinning        |
| Number         | trees ha <sup>-1</sup> | 631             | 1224              | 770             |
| DBH            | cm                     | 15.3            | 10.2              | 13.7            |
| Harvest        | gt ha <sup>-1</sup>    | 233.8           | 66.9              | 163.3           |
| Slope gradient | %                      | 70              | 70                | 65              |
| Terrain Class* | code                   |                 |                   | 2.2.5           |
| Yarder         | type                   | Valentini V550M | Greifenberg TG700 | Valentini V550M |
| Line length    | M                      | 250             | 145               | 230             |
| Processor Base | type                   | CAT 312         | CAT 312           | JCB 8052        |
| Processor head | type                   | Foresteri 25RH  | Foresteri 25RH    | Arbro 400S      |
| Crew           | n°                     | 4               | 3                 | 4               |
| Operation cost | € hour <sup>-1</sup>   | 168             | 149               | 137             |

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

The authors carried out a time and motion study, designed to evaluate machine productivity and to identify those variables that are most likely to affect it - especially tree size. Each processing cycle was stop watched individually, using Husky Hunter hand-held field computers running the dedicated Siwork3 time study software. Productive time was separated from delay time and the diameter of all trees processed in each cycle was also recorded and associated to the observation data. Tree diameter was then converted into firewood and chips weight, by using dedicated tariff tables.

Machine costs were calculated with the costing method developed within the scope of COST Action FP0902, on an estimated annual utilization of 1000 hours and a depreciation period of 8 years. Labor cost was set to 15 and 25 € hour<sup>-1</sup>, respectively for the yarder operators and the processor driver. These figures are inclusive of indirect salary costs. The costs of fuel, insurance repair and service were obtained directly from the operators. The calculated operational cost was increased by 20% in order to include relocation and administration costs.

## Results

Table 2 shows the average productivity and cost recorded for each test. Operation productivity is calculated by including delays, but excluding yarder set up and dismantle times. Operation productivity refers to the productivity of the yarder and the processor, working hot-deck. When felling was performed separately from yarding (i.e. in Pian di Rossaia and Mello), felling productivity was not included in the calculation. Operation productivity ranged from 3 to 4 green tonnes per hour. Harvesting cost varied between 33 and 51 € per green tonne. This cost is relatively high, but within the limits of economic sustainability, since the cost of firewood at the landing is in the range of 55 to 65 € per green tonne, depending on wood quality and season (i.e. market demand).

**Table 2 – Study results: productivity, cost, utilization**

| Placename              |                       | Pian di<br>Rossaia | Mello    | Monte Cavallo |
|------------------------|-----------------------|--------------------|----------|---------------|
| Species                |                       | Oak                | Chestnut | Beech         |
| Line length            | m                     | 250                | 145      | 230           |
| Operation cost         | € hour <sup>-1</sup>  | 168                | 149      | 137           |
| Overall productivity   | gt hour <sup>-1</sup> | 3.3                | 3.6      | 4.2           |
| Overall cost           | € gt <sup>-1</sup>    | 50.9               | 41.4     | 32.6          |
| Processor productivity | gt hour <sup>-1</sup> | 11.9               | 4.6      | 6.7           |
| Processor utilization  | %                     | 28                 | 78       | 63            |

Despite the larger tree size, productivity was lowest with the oak, because most of the trees were further away, near the tail end. Cost was lowest for the beech operation because of the

very simple and inexpensive processor (5 tons vs. 13 tons type). Yet, this small processor was adequate to the trees being harvested, and achieved a very good productivity. As with more conventional yarder-processor operations, processor utilization was relatively low, indicating that processors are generally much more productive than yarders, even with coppice trees. Therefore, operation managers should strive for a better balance, in financial or productive terms. Financial balance could be improved by adopting low-cost processors, like the lightest machine used in the study. Productive balance could be improved by deploying versatile processors that can also be used for other tasks when waiting for a turn to reach them.

## 5.5 ADDRESSING THE LAYOUT AND LOGISTICAL CHALLENGES OF A BARGE BASED YARDING OPERATION IN THE NORWEGIAN FJORDS

*Belbo, H. & Talbot, B.*

Norwegian Forest and Landscape Institute: beh@skogoglandskap.no

### Introduction

The mild and moist climate derived from the gulfstream and immediately adjacent Scandinavian mountains provide good conditions for tree growth along the Norway's North Atlantic seaboard. In these fjordlands, spruce plantations (*Picea abies* & *P. sitchensis*) established in the 1950s-1970s now account for 40 Mm<sup>3</sup> of harvestable timber on steep and very steep slopes alone (Larsson and Hylen 2007). This rugged coastline is the second longest in the world at 83 000 km including islands and fjords. The very low forest road densities in the coastal region – about 5 m ha<sup>-1</sup> on average (Vennesland, Hobbelstad et al. 2006), and recent restrictions imposed on new infrastructure in wilderness areas (Norwegian Agricultural Authority, 2010) have resulted in a need to development novel harvesting systems if political goals of increasing industrial activity in coastal plantations are to be achieved.

Recently, a barge equipped with a yarder and processor began operations in the south-eastern fjords of Rogaland county (fig 1.). However, productivity has been somewhat impeded by operational, layout and logistical challenges. This abstract reports on simulation studies that have been carried out to find good solutions to these problems.



**Figure 2 Barge equipped with yarder and processor in operation in Boknafjord, Norway (photo:Morten Nitteberg).**

## Materials and Methods

We used Extendsim simulation software to model cable yarder productivity and matching processor activity for a range of conditions. The excavator based processor had to travel up and down the 65m by 24m barge while processing and stacking various assortments. The placement of stacks of varying lengths, the travel times, and the orientation of the barge to the coastline were tested in different simulation runs. The logistics challenges include space constraints, layout alternatives for different assortments, the frequency of ship arrivals and their size. Biomass (tops and branches) arising from the harvesting operation is a significant challenge due to its bulk. We simulated alternatives including the installation of a bundling machine and the storage of bundles or loose biomass on the barge and on a smaller floating platform alongside.

## Discussion

As the results of the study were not available, issues are discussed generically here. The depth of the Norwegian fjords is advantageous when considering longer distance shipping as ocean class ships can lie alongside the barge, and intermediate transport is not necessary. This increases the number of possible markets (N. Europe) but also increases demands on storage space as the ships have larger capacity. The carbon footprint of transporting biomass from central Norwegian fjords to e.g. Rotterdam has been shown to be lower than into the Norwegian hinterland (Gustavsson, Eriksson et al. 2011), justifying the supply of biomass from here to Europe. Similar efficiencies of waterway transport are shown by (Karttunen, Väättäinen et al. 2012). In a similar productivity study, but using CTL technology, Asikainen (2001) showed the importance of a high frequency of transport away from operations, finding that a system including 3 transport barges was optimal over a transport distance of 100km.

## Literature Cited

Asikainen, A. (2001). Simulation of Logging and Barge Transport of Wood from Forests on Islands. *International Journal of Forest Engineering* 12 (2) 43-50

Gustavsson, L., L. Eriksson, et al. (2011). "Costs and CO2 benefits of recovering, refining and transporting logging residues for fossil fuel replacement." *Applied Energy* 88(1): 192-197.

Karttunen, K., K. Väättäinen, et al. (2012). "The Operational Efficiency of Waterway Transport of Forest Chips on Finland's Lake Saimaa." *Silva Fennica* 46(3): 395-413.

Larsson, J. Y. and G. Hylen (2007). Statistics of Forest Conditions and Forest Resources in Norway. *Viten fra Skog og landskap. Ås, Norwegian Forest and Landscape Institute.* 1/07: 91.

Norwegian Agricultural Authority (2010). Forest road infrastructure and regard for intervention free wilderness areas. Evaluation and Recommendations. Ministerial Report (In Norwegian).

Vennesland, B., K. Hobbelstad, et al. (2006). *Skogressursene i Norge 2006. Muligheter og aktuelle strategier for økt avvirkning.* Viten fra Skog og landskap, Skog og landskap. 03/2006: 94.

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

## **SESSION 6: FOREST ROADS & THE ENVIRONMENT**

**Chair: Prof. Hulusi Acar**

## 6.1 STUDY OF A FOREST ROAD NETWORKD PLANNING MODEL WITH LiDAR DATA FOR FUNYU EXPERIMENTAL FOREST, UTSUNOMIYA UNIVERSITY, JAPAN.

*Saito, M.I, & Aruga, K.2*

<sup>1</sup> Frontier Agriscience and Technology Center, Shinshu University, Japan. m\_saito@shinshu-u.ac.jp

<sup>2</sup> Department of Forest Science, Utsunomiya University, Japan. aruga@cc.utsunomiya-u.ac.jp

### Introduction

Forest road networks should be properly planned and constructed in accordance with the field condition and the forestry operation system to be used in the area. A variety of forest road network planning models have been developed using DTMs (Digital Terrain Models). However, these techniques have demonstrated a lack of accuracy because of the low reproducibility of geographical features and forest-registration data. Therefore, it has been difficult to plan forest road networks while estimating forest road construction costs and forestry operation costs accurately.

In order to improve the geographical features, Saito et al.(2013) developed a forest road design model using LiDAR (Light Detection and Ranging) data of Funyu experimental forest, Utsunomiya University, Japan, which demonstrated a significant improvement in representing relatively accurate geographical features. Furthermore, Ito et al. (2011) estimated individual stem volumes using LiDAR data of Funyu experimental forest.

Moreover, these forest road network planning models using DTMs employed heuristic techniques, which were suitable for solving large problems and found relatively accurate solutions during a practical time. However, heuristic techniques could not guarantee exact solutions and sometimes trapped in local optimal which were sometimes significantly different from exact solutions. Therefore, this paper established a forest road network planning model with graph theorem which guaranteed a unique solution using LiDAR data of the Funyu experimental forest while estimating forest road construction costs and forestry operation costs accurately.

### Study site and method

The study site was around the terminal point of a main forest road (Site 1: 9.1 ha) and a newly planned forest road (Site 2: 11.4 ha) at the Funyu Experimental Forest of Utsunomiya University in Japan (Figures 1). The vegetation around the study site was about 50-years old planted forests composed of Japanese cedar (*Cryptomeria japonica*) and Japanese cypress (*Chamaecyparis obtusa*). A high-resolution (1-m grid) DTM was made by processing the LiDAR data using the intersection angle method, which was a new technique developed to create ground surfaces from the raw LiDAR data (Saito et al. 2008).

At this site, the operation system included felling with a chainsaw, processing with a processor, yarding with a tower-yarder, and transporting using a truck with a 4-ton loading

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

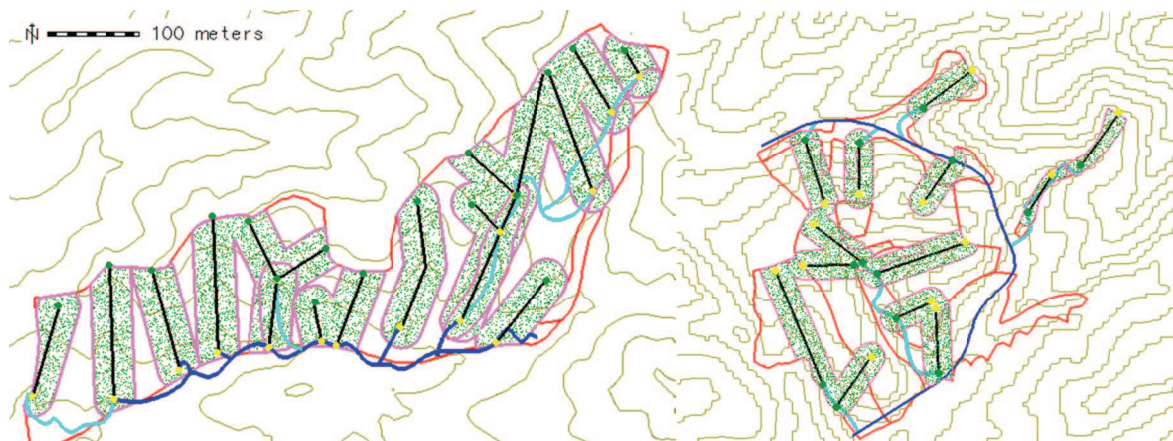
capacity. On terrain where it was difficult to construct forest roads, spur roads were constructed from landings to forest roads and a forwarder with a 4-ton loading capacity was used for transporting.

Yarding operations were assumed to be conducted along stream flow lines. Extracted stream flow lines of which lengths were more than 50 m, were selected as yarding line candidates. Yarding lines were selected from yarding line candidates so as to eliminate overlaps of pre-yarding areas if overlaps were more than 50%. Maximum pre-yarding distances were assumed to be 20 m. Selected stream flow lines as yarding lines did not reached ridges. Therefore, yarding lines were extended until reaching ridges.

Then, forest road networks were determined. Forest road width was assumed to be 4 m for a truck with 4 ton loading capacity used for transportation on forest roads. Maximum gradient was 20%. Forest road networks on which landings were connected directly each other (Steiner tree which was the shortest interconnect for a given set of objects), could be effective for truck transportation. However, forest road construction costs were higher than spur road construction costs. Therefore, cost-effective forest road networks should be established while considering spur road networks. In this study, forest road networks were planned so as to reduce distances to landing using graph theorem.

First, Delaunay triangulation which connected landings directly to each other, were established. If Steiner tree was selected from Delaunay triangulation with landings, forest road networks connected with landings directly each other and could be effective for truck transportation. However, the number of landings was too small to select Steiner tree from Delaunay triangulation with landings in mountainous areas because some links were beyond the gradient limit and higher construction costs were caused by detour to avoid the gradient limit. In order to increase nodes, Voronoi diagram were established. Then, new Delaunay triangulation was established with landings and intersections between the previous Delaunay triangulation and Voronoi diagram. Gradients of connected lines were limited to below 30%. The value of limitation for road gradient was set to be larger than that for existing roads because of the grid-based program. Forest roads were determined so as to minimize distances of paths connected with all points on new Delaunay triangulation. Then, forest roads were designed by the method developed in our previous study (Saito et al. 2013).

Then, spur road networks were determined. Spur road width was assumed to be 3 m for a forwarder with 4 ton loading capacity used for forwarding on spur roads. Maximum gradient was 40%. Spur roads were determined so as to connect from forest road networks to landings by the method developed in our previous study (Saito et al. 2013).



**Figure 1 Study site 1 (left) and 2 (right) -(Red area: Study site, Pink area: Pre-yarding area, Blue line: Forest road, Sky blue line: Spur road, Black line: Yarding line, Yellow or Green circle: Landing, Green dot: Tree)**

## Results

Slopes on the study site 1 were almost parallel and stream flow lines were located at almost same intervals (Figure 1). Subsequently, yarding lines were located at almost same intervals and yarding lines covered almost the whole area of the study site 1. Areas of the study site 1 were 9.1 ha and yarding capable areas were 7.4 ha. Therefore, the ratio of yarding capable areas to total areas was 81%. Forest road networks were established. Then, spur road networks were established so as to connect from forest road networks to landings.

Thinning operation costs excluding road construction costs were about 8,300 yen/m<sup>3</sup> (Table 1, 100 yen/euro). These costs did not include transportation costs from study sites to log markets or sawmills. Considering Japanese cedar prices as 10,000 yen/m<sup>3</sup>, the costs adding transportation costs and handling fees if logs were sold at log markets could be over the prices. However, this showed the current situation for thinning operations in Japan. Therefore, these cost estimations could be accurate. In this current situation, defeats were compensated by subsidy. However, subsidies would be reduced due to limited budget of Japan government in the future. Therefore, thinning operation costs should be reduced especially, relatively higher yarding costs.

The costs including road construction were much higher than Japanese cedar prices. Considering Japanese cypress prices as 20,000 yen/m<sup>3</sup>, the costs could be a little higher than the prices. However, road construction costs were compensated by subsidy and established road network could be used for next thinning operations or final felling operations. Therefore, subsidy for road construction was crucial for future low-cost operations.

Unlike the study site 1, Slopes on study site 2 was round and stream flow lines were not parallel (Figure 1). Therefore, yarding operations could not be conducted on many places. Areas of the study site 2 were 11.4 ha and yarding capable areas were 6.5 ha. Therefore, the

ratio of yarding capable areas to total areas was only 57%. Economic balances for the study site 2 were almost the same situation as with study site 1 (Table 1).

**Table 1 Thinning operation costs (100 yen/euro).**

|                   | Site 1     |                       | Site 2     |                       |
|-------------------|------------|-----------------------|------------|-----------------------|
|                   | (yen)      | (yen/m <sup>3</sup> ) | (yen)      | (yen/m <sup>3</sup> ) |
| Felling           | 577,258    | 892                   | 693,808    | 892                   |
| Yarding           | 3,827,192  | 5,914                 | 6,187,672  | 7,955                 |
| Processing        | 654,268    | 1,011                 | 786,368    | 1,011                 |
| Forwarding        | 202,974    | 314                   | 171,643    | 221                   |
| Transporting      | 110,711    | 171                   | 126,371    | 162                   |
| Subtotal          | 5,372,403  | 8,302                 | 7,965,862  | 10,241                |
| Road construction | 6,728,435  | 10,397                | 7,857,422  | 10,102                |
| Total             | 12,100,838 | 18,699                | 15,823,284 | 20,343                |

### Literature cited

- Ito, T., Matsue, K., Shuin, Y., & Naito, K. 2011. Estimating individual stem volumes of Sugi (*Cryptomeria japonica* D. Don) and Hinoki (*Chamaecyparis obtusa* Endl.) with differing densities using airborne LiDAR. *J. Jpn. Soc. Photogrammetry and Remote Sensing* 50(1):18-26 (in Japanese with English summary)
- Saito, M., Aruga, K., Matsue, K., & Tasaka, T. 2008. Development of the filtering technique of the inter section angle method using LIDAR data of the Funyu Experimental Forest. *J. Jpn. For. Eng.* 22(4):265-270 (in Japanese)
- Saito, M., Goshima, M., Aruga, K., Matsue, K., Shuin, Y., & Tasaka, T. 2013. Study of automatic forest road design model considering shallow landslides with LiDAR data of Funyu Experimental Forest. *Cro. J. For. Eng.* 34(1): in press

## 6.2 ENVIRONMENTALLY SOUND ROAD NETWORK PLANNING AND ANALYSIS IN MOUNTAINOUS FOREST

Hayati, E.<sup>1</sup>, Majnounian, B. & Abdi, E.

Forestry and Forest Economic Department, University of Tehran, Iran. <sup>1</sup> hayati\_fe@ut.ac.ir

### Introduction

Nowadays, road operations in such mountainous forest ecosystem as Caspian forest which can supports many functions (e.g. wood production, conservation, ecotourism, environmental purification, recreation and etc.) are to be concerned much more than those of constructed for wood production, the only objective in the past. Forest road managers need to look for ways on how to plan a road network including all the aspects mentioned above [2, 3, 5]. Multi-criteria analysis techniques are well known decision support tools for dealing with such complicated decision making process where many different factors need to be covered in our analysis [7, 8, 12]. Analytic hierarchy process (AHP) is one of the most widely used multi-criteria decision making techniques, to help decision makers set priorities and make the best decision when both qualitative and quantitative aspects need to be considered [2,7,11].

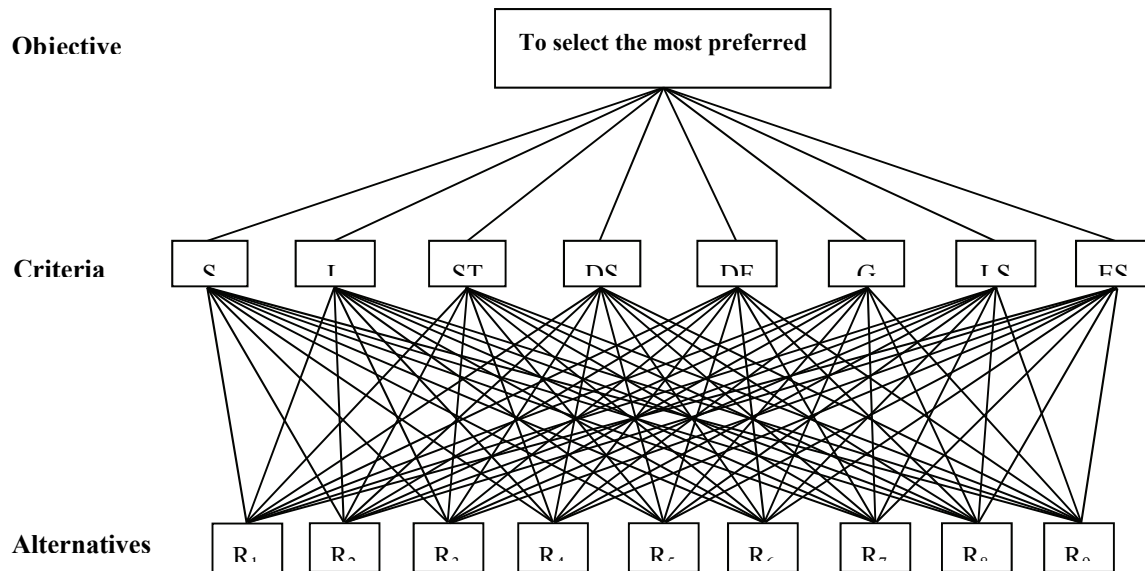
### Material and Methods

Here, in this paper, it is conducted a comprehensive multi-criteria decision making to achieve a road network, *in kheyroud forest located in Iranian Caspian forest*, which assists both road technical optimization and environmental soundness. First all the criteria, already defined by experts as effective ones [6] for such forest ecosystems, were applied. Then, a pair-wise comparison questionnaire for the criteria was prepared and sent to the forest engineering experts who contributed also to previous work [6], to rank the criteria considering their effect and importance in the assessment procedures. The responses were then analyzed in Expert Choice (EC) software, and finally the importance weights of all the criteria were obtained. ArcGIS and IDRISI softwares were then applied to prepare and standardize the map layers of the criteria. The fuzzy set membership functions [4] were used to standardize the map layers into a comparable suitability of values (in a scale of 0 for zero suitability to 255 for 100% suitability), because it avoids setting hard or arbitrarily established thresholds between different levels of suitability. Afterwards, 9 road network alternatives were designed using PEGGER, an ArcView GIS extension [9], and converted to a raster format (the same pixel size as fuzzy map layers of criteria). Each one of the new road networks maps were overlaid with each fuzzy map layer one by one, to find the average standardized fuzzy value of each criterion for the alternatives (i.e. the early score of the alternatives). The EC software was used once more, to compare and analyze the 9 road networks alternatives against each other with respect to their values extracted from each fuzzy map layer, thus the preferred weights of the alternatives were obtained with regard to each criterion in the EC. To determine the final score of the alternatives (i.e. overall preferred weights of the alternative with regard to all the criteria), Eq. [1] the hierarchical composition principle, was used [10].

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

$$\text{Result} = \sum_{j=1}^n \sum_{i=1}^m w_j W_i \quad \text{Eq. [1]}$$

where  $w_j$  is the importance weight of the  $j^{\text{th}}$  criterion and  $W_i$  is the preferred weight of the  $i^{\text{th}}$  alternative with regard to the  $j^{\text{th}}$  criterion, and finally result is the final score of the alternatives (or preferred weights of the alternative with regard to all the criteria). Figure 1 illustrates the decision making process in this study.



R: road network alternatives  $\{R_1, R_2, R_3, R_4, R_5, R_6, R_7, R_8 \text{ and } R_9\}$ . Criteria  $\{S$ : Slope, L: Lithology, ST: Soil texture, DS: Distance from stream, DF: Distance from faults, G: Geology, LS: Landslide susceptibility, ES:

**Fig. 1. schematic of multi-criteria decision making process in this study**

## Results

The following model, obtained by EC, shows the importance weights of the criteria in road networks analysis:

$$\text{Model} = 0.320S + 0.051L + 0.191ST + 0.045DS + 0.068DF + 0.047G + 0.187LS + 0.091ES \quad \text{Eq. [2]}$$

Nine road network alternatives designed and overlaid with the standardized map layers of the criteria were finally assessed considering the early score of the alternatives so that the preference weights (final scores) of the road networks alternatives were obtained as Table 1.

**Table 1. The final score and AHP ranking of the road network alternatives**

| Alternatives | Length (km) | Preference weight (Final score) | AHP ranking |
|--------------|-------------|---------------------------------|-------------|
| No. 1        | 10.197      | 0.033                           | 9           |
| No. 2        | 11.389      | 0.101                           | 6           |

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

|              |               |              |          |
|--------------|---------------|--------------|----------|
| No. 3        | 13.979        | 0.097        | 7        |
| No. 4        | 13.565        | 0.058        | 8        |
| <b>No. 5</b> | <b>17.434</b> | <b>0.174</b> | <b>1</b> |
| No. 6        | 16.859        | 0.119        | 4        |
| No. 7        | 16.638        | 0.144        | 3        |
| No. 8        | 19.484        | 0.105        | 5        |
| No. 9        | 19.073        | 0.168        | 2        |

## Discussion and Conclusion

Analyzing the experts' judgments showed that, the criteria; slope, soil texture and landslide susceptibility were the three most important criteria, respectively (Eq. [2]). According to the result of multi-criteria decision making in evaluation of the 9 road networks, the road alternatives no. 5, 9 and 7 were the three most preferred alternatives, with final scores 0.174, 0.168, and 0.144, respectively (Table 1). Thus, the alternative no. 5 can be introduced as the most preferred road network in our study site.

As a result, combining GIS and PEGGER with multi-criteria decision making techniques applied in this work, make forest road managers able to design and assess forest road networks as many as possible and finally to properly select the most preferred alternative [1]. Also when using this methodology, we can conduct a primary assessment in forest road network planning. In fact by investigating the characteristics of the selected alternatives with regard to their values on each criterion fuzzy map layer (the early score), their weakness and strength can be specified. Therefore, forest road managers can select and design a road network with these characteristics and save time and money in the construction phase.

## Literature cited

- Akay, A.E., Wing, M.G., Sivrikaya, F. and Sakar, D. 2012. A GIS-based decision support system for determining the shortest and safest route to forest fires: a case study in Mediterranean Region of Turkey. *Environ Monit Assess*, 184(3): 1391-1407.
- Coulter, E.D., Coakley, J. and Sessions, J. 2006. The analytic hierarchy process: A tutorial for use in prioritizing forest road investments to minimize environmental effects. *Int. J. For. Eng.*, 17, 51–70.
- Demir, M. 2007. Impacts, management and functional planning criterion of forest road network system in Turkey. *Transportation Research Part A*, 41, 56–68.
- Eastman, J.R. 2003. *IDRISI for Windows Users Guide Version Kilimanjaro*. Clark Labs for Cartographic Technology and Geographic Analysis, Clark University.
- Gumus, S., Acar, H.H. and Toksoy, D. 2008. Functional forest road network planning by consideration of environmental impact assessment for wood harvesting. *Environ Monit Assess*, 142, 109–116.

Hayati, E., Majnounian, B., Abdi, E., Sessions, J., & Makhdoum, M. (2012). An expert-based approach to forest road network planning by combining Delphi and spatial multi-criteria evaluation, *Environ Monit Assess*, DOI 10.1007/s10661-012-2666-1, (Article in Press).

Malczewski, J. 2006. GIS-based multicriteria decision analysis: a survey of the literature. *International Journal of Geographical Information Science* 20(7), 703–726.

Pukkala, T. (2002). Multi-objective forest planning: managing forest ecosystems. Dordrecht: Kluwer Academic Publishers.

Rogers, L. 2005. Automating contour-based route projection for preliminary forest road designs using GIS. [MS Thesis.] Washington, University of Washington, 87.

Saaty, T.L. 1980. The Analytical Hierarchy Process, Planning Priority, Resource Allocation. RWS Publications, USA.

Sener, S., Sener, E. and Karaguzel, R. 2011. Solid waste disposal site selection with GIS and AHP methodology: a case study in Senirkent-Uluborlu (Isparta) basin, Turkey. *Environ Monit Assess*, 173(1-4), 533-554.

Vadrevu, K. P., Eaturu, A., & Badarinath, K. V. S. (2010). Fire risk evaluation using multi-criteria analysis—a case study. *Environ Monit Assess*. 166(1–4): 223–239.

## 6.3 STUMP REMOVAL AND ITS UTILIZATION UNDER FOREST ROAD CONSTRUCTION

*Rianthakool,L , Sakai,H , & Sakurai,R*

Department of Forest Science, The University of Tokyo, Japan. laddawan@fr.a.u-tokyo.ac.jp , sakaih@fr.a.u-tokyo.ac.jp , sakurai@fr.a.u-tokyo.ac.jp

### Introduction

Currently, stump wood is widely used for bioenergy in Northern Europe (Johansson and Hjelm 2012, Lindholm et al. 2010). However, only few research studies of stump removal were reported on its techniques and methods (Coder 2003), machinery design (Mitchell 2009) and environmental impacts (Walmsley and Godbold 2010). In Japan, stumps removed during forest road construction are usually utilized as the top mixture of material in road structures. Clearing width to construct a road is done at the beginning of a road construction followed by the removal of obstacles such as timber, disposal of slash, debris, stumps and roots. Small excavators that can cut and fill, remove stumps, and place woody debris along the road are useful for constructing roads (B.C. Ministry of Forests 2002). Therefore, we analyzed useful stump digging techniques under forest road construction and the subsequent utilization of stumps for road structure.

### Material and Methods

Data was collected from three study sites in Japan. Two of them, i.e. Sites 1 and 2, were in the Tokyo University Forest at Chichibu (UTCF), Saitama Prefecture, whereas Site 3 was located at the national forest in Yamanashi Prefecture. The elevations of the sites were approximately 1154m, 1319m, and 858m, respectively. The forest road construction included stump digging using a small excavator called “Yanmar B3 $\Sigma$ ” on Site 1, “Kubota U55” on Site 2 and “Kobelco SK30UR” on Site 3. At all sites, average diameter of stumps, degree of slope, and distance were measured. A time study was conducted on these sites to measure and record operational time using a stopwatch and a handheld video recording.

### Results

The techniques of digging stumps among sites were different: there were differences of area conditions and work-related experiences. Sites 1 and 3 had flat terrain, but Site 2 was very steep. On Sites 1 and 3, the same operator maneuvered all the small excavators. After obstructed trees on route of the planned road were felled, the operator moved the bucket of excavator over the area around the stump, and then the bucket was leveraged to scoop the soil. After the amount of soil around stump was removed, which depended on the size and root structure of stump, the stump was loosened for soil removal, and lifted. Thereafter, the stump was skidded and usually dropped at the nearest lower surface area along the roadside. On Site 2, two workers operated: one worker operated the excavator while the other skilled laborer used a chainsaw. This area was so steep that the operator applied a full bench technique that *IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

is, cutting the soil equal to the width of road. The road bed depth was about 0.5-1.5 m from the natural top surface of the ground; therefore, the position of excavator became lower than the position of stump causing the bucket to easily scoop the soil and the stump. Additionally, some small stumps were removed during the initial cutting of the soil before scooping.

The result of time study showed an increase of stump diameter increased time consumption (Figure 1). A cubic function ( $y = ax^3$ ) and a quadratic function ( $y = ax^2$ ) with a zero-intercept to represent the work operation where  $y$  is processing time (min) and  $x$  is stump diameter (cm) was used. The coefficients of determination ( $R^2$ ) for each site were 0.84, 0.69 and 0.83, respectively.

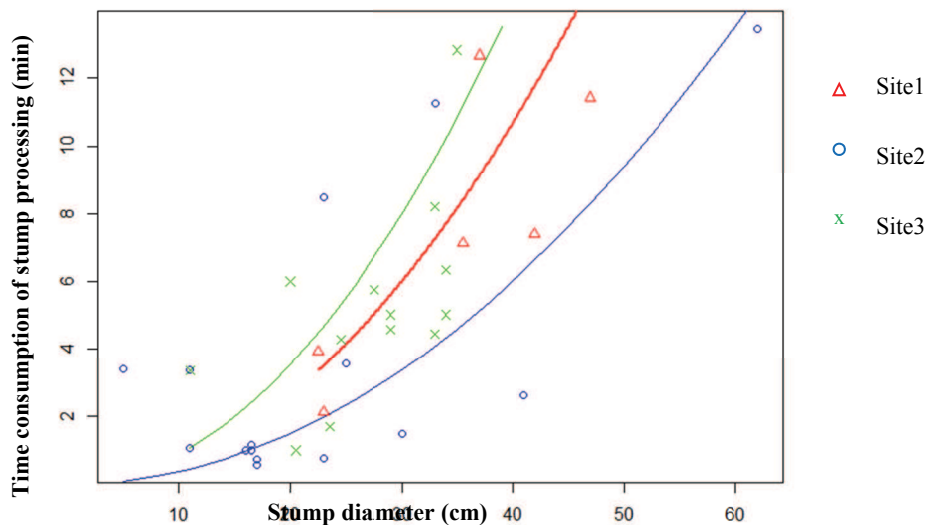


Figure 1 The relationship between stump diameter and time consumption using quadratic function ( $y = ax^2$ )

## Conclusions

Stump removal techniques depend on many factors such as condition of the site area, stump characteristics, position of machine and stump, machine specifications, and level of work and operational experience. Operationally, current removal of tree stumps for bioenergy is uncommon in Japan; however, stumps are placed on the slopes at the roadside to increase slope stability. Of course, larger stumps have more time consumption than smaller stumps because a larger root system must be split into manageable pieces. The quadratic function with the zero-intercept better fit the relationship between processing time and stump diameter than cubic function. Therefore, predicting the operational utilization could show areas of improved process efficiencies of stump removal during road construction.

## Literature cited

B.C. Ministry of Forests. 2002. Forest road engineering guidebook. British Columbia, Canada.

Coder, K.D. 2003. Stump removal methods. University of Georgia Warnell School of Forest Resources Publication FOR03-12.

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

- Johansson, T. & Hjelm, B. 2012. Stump and root biomass of poplar stands. *Forests* 3: 166-178.
- Lindholm, E.L., Berg, S. & Hansson, P.A. 2010. Energy efficiency and the environmental impact of harvesting stumps and logging residues. *Eur. J. Forest Res* 129: 1223-1235.
- Mitchell, D. 2009. Stump Harvesting. In. *Proceedings of 2009 COFE: Environmentally Sound Forest Operations* 32nd annual meeting of the council of forest engineering. Lake Tahoe, California, US.
- Walmsley, J.D. & Godbold, D.L. 2010. Stump harvesting for bioenergy- a review of the environmental impacts. *Forestry* 83(1): 17-38.

## 6.4 UNTREATED WOOD ASH AS A STRUCTURAL STABILIZING MATERIAL IN FOREST ROADS

*Bohrn, G. & Stampfer, K.*

Institute of Forest Engineering, University of Natural Resources and Life Sciences, Vienna, Austria.  
gerald.bohrn@boku.ac.at

### Introduction

Due to euphoric use of “green” energy produced by biomass power plants up to 350.000 tons of ash are produced every year. For this reason utilization methods for wood ash must be found. One solution could be the application as a stabilizing material in forest roads. In this case the pozzolanic characteristic (self-hardening process caused by free lime in wood ashes) is used to bind the gravel in the road base. Expected performance of wood ash could provide the chance to minimize the requirement of gravel on forest roads with a simultaneous enhancement of bearing capacity.

### Materials and Methods

Behaviour of bearing capacity was investigated with an outdoor-trial, where two different untreated wood ashes (fluidized bed ash and dry bottom ash) were applied in two mixture ratios of 15:85 and 30:70, each on a 100 meter long forest road section (Figure 3).



**Figure 3. WR2400 recycler during mixing process (photo: Erwin Stampfer)**

The ashes had been selected by their different properties, emergence and economical concern. Mixing depth was 50 cm and the road base was covered by a 10 cm thick surface layer. Elastic modulus of these sections was measured before the application and according to the concrete testing method 7, 21 and 28 days after construction by using a light falling weight deflectometer (Figure 4).

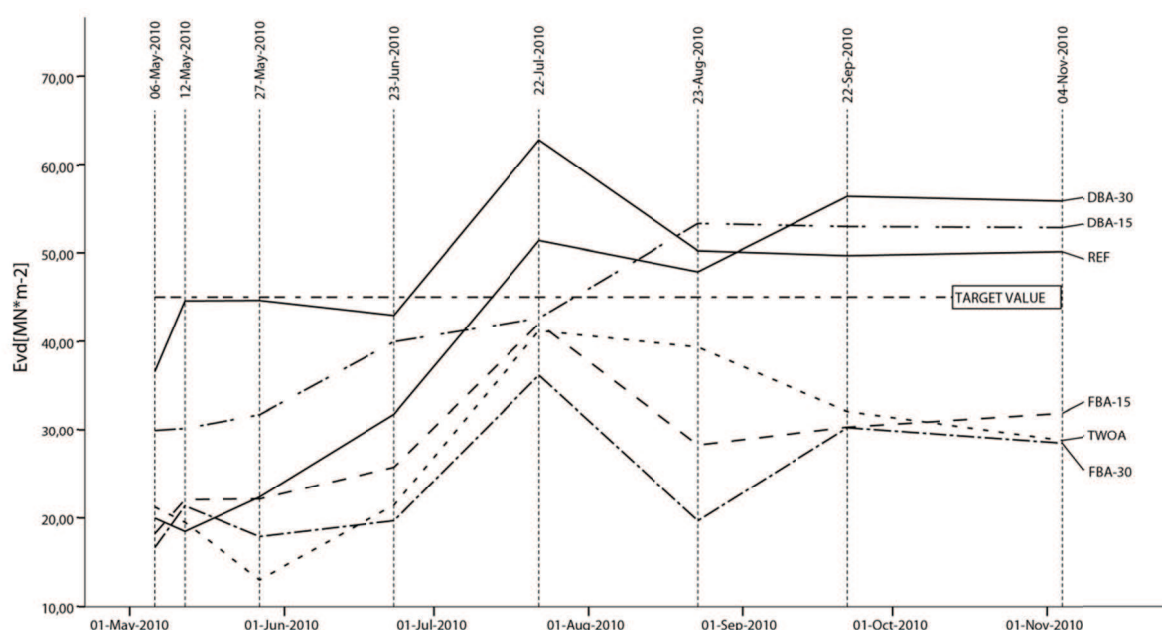


**Figure 4. TerraTest 3000 deflectometer in use**

Measurements had been separated on the lanes and the medial strip for estimating the influence of upcoming traffic which was logged with remote sensor cameras. For long term analyses the measurements were repeated each month during the vegetation period.

### **Results and conclusions**

After the first vegetation period the mean elastic modulus of the zero variant section were 32.0 MN/m<sup>2</sup> and a significant improvement of the elastic modulus of 65 % (52.9 MN/m<sup>2</sup>) for the 15:85 mixing value section and 76 % (56.4 MN/m<sup>2</sup>) for the 30:70 mixing value section for the dry bottom ash was detected. The results for the fluidized bed ash sections fell short of expectation. Only 95% (30.3 MN/m<sup>2</sup>) of the initial value could be reached for both mixing values (Figure 5).



**Figure 5. Development of Evd of all sections over growing season**

## Literature cited

Dietz, P., Knigge, W., Löffler, H. 1984. Germany. Walderschließung. Ein Lehrbuch für Studium und Praxis unter besonderer Berücksichtigung des Waldwegebaus. Parey, Hamburg und Berlin 1984, ISBN 3-490-02116-9. 436 p.

Holzner, H., Obernberger, I. 2011. Austria. Guideline for appropriate usage of biomass ashes on agricultural and forested areas, Advisory Board for Soil Fertility, Federal Ministry of Agriculture, Forestry, Environment and Water Management, 66 p.

Lahtinen, P. 2001. Finland. Fly Ash Mixtures as Flexible Structural Materials For Low-Volume Roads, Finnra Reports 70/2001, 95 p. + annexes 55 p. ISBN 951-726-826-2

Stupak, I., Asikainen, A., Jonsell, M., Karlton, E., Lunnan, A., Mizaraité, D., Pasanen, K., Pärn, H., Raulund-Rasmussen, K., Röser, D., Schroeder, M., Varnagiryté, I., Vilkriste, L., Callesen, I., Clarke, N., Gaitnieks, T., Ingerslev, M., Mandre, M., Ozolincius, R., Saarsalmi, A., Armolaitis, K., Helmisaari, H.-S., Indriksons, A., Kairiukstis, L., Katzensteiner, K., Kukkola, M., Ots, K., Ravn, H.P., Tamminen, P. 2007. Sustainable utilisation of forest biomass for energy—Possibilities and problems: Policy, legislation, certification, and recommendations and guidelines in the Nordic, Baltic, and other European countries, Biomass and Bioenergy, Volume 31 10: p. 666–684

Thurdin, R. 2004. Environmental Impact of Bio Fuel Ash in Road Construction, Mid Sweden University Licentiate Thesis 9, 35 p. ISSN 1652-1064

## **6.5 ATTAINING THE PRINCIPLES OF MITIGATING ADVERSE FOREST ROAD EFFECTS; A STUDY ON PLANT SPECIES DIVERSITY IN A MANAGED MOUNTAINOUS CASPIAN FOREST IN IRAN**

*F. Berenji Tehrani*<sup>1</sup>, *B. Majnounian*<sup>2</sup>, *E. Abdi*<sup>3</sup>, *Gh. Zahedi Amiri*<sup>4</sup>

<sup>1</sup>. M.Sc., Graduated, Department of Forestry, University of Tehran, Iran, fb.tehrani@yahoo.com

<sup>2</sup>. Prof. Department of Forestry, University of Tehran, Iran, bmajnoni@ut.ac.ir

<sup>3</sup>. Assistant Prof. Department of Forestry, University of Tehran, Iran, abdie@ut.ac.ir

<sup>4</sup>. Associate Prof. Department of Forestry, University of Tehran, Iran, ghavamza@ut.ac.ir

### **Introduction**

Forest roads provide access for a variety of activities such as forest management, tending of forest, fire and pests control (Smith, 1986; Queen et al., 1997; Fedkiw, 1998), but they have various direct and indirect effects on their adjacent environment. In fact, since the roads are external factors which are imposed on nature, they can cause a disturbance to ecosystem functions, and alter the natural composition of forest ecosystem, such as plant species composition. Moreover, the network structure of roads divides a vast forest land to some small patches, which results in habitat fragmentation (Noss 1987; A.F.Bennet 1999; Henle et al., 2004). In this study the effect of forest road on plant species diversity, which includes trees, saplings and herbs, was investigated so that some environmentally sound principles for forest road construction can be achieved in order to alleviate their minuses and conserve the natural cycle of forest ecosystem.

### **Materials and Methods**

The research was carried out in Kheyroud mountainous managed forest, a Caspian forest, at the altitude of 50 to 1000 meters (368349-368379N, 51832<sup>9</sup> E, Nowshahr, Iran). At 10 points along the road, toward fill slope and cut slope, ten 100-meter-transect was established perpendicular to the road. Distance was measured from the top of embankment. Within each transect ten 10×10 m plots to record the tree and shrub species and ten 2×2 m plots to record the herbal species were set up.

The species diversity was analyzed by the Shannon index using PAST software for both cut slope and fill slope. The normality of data was tested by Kolmogorov-Smirnov. The significance of the effects was tested by ANOVA. The plant composition variation between cut and fill slope was tested by paired sample T-test.

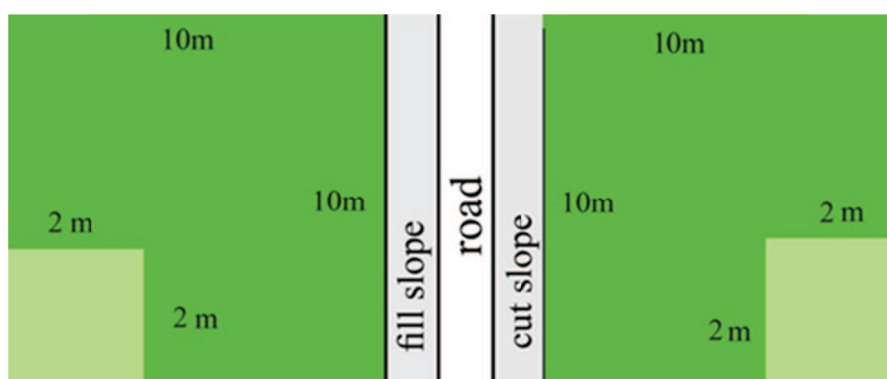


Fig.1.The position of plots scaled to road

## Results

According to the results, the number and diversity of trees, saplings and herbs are not influenced by road (distance from road) on both cut slope and fill slope. The only significant difference is at the first plot on cut slope, which is set up between embankment and 10 meters.

The comparison of tree species diversity between cut slope and fill slope shows that the only significant differences are at 70m and 90m distances. Sapling diversity shows significant interaction at 50m, 60m, 70m from road and the herbal species diversity does not vary significantly by the road distance. The number of tree and herb species are not affected by road distance, however, at the distances of 30m, 50m, 60m and 70m the number of saplings shows significant variations.

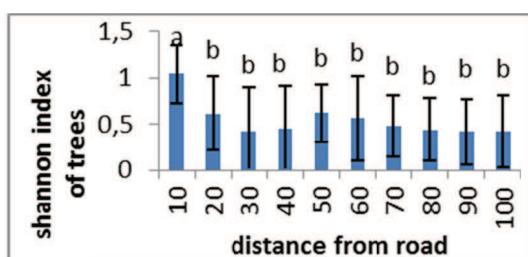


Fig.2. Variation in tree species diversity from road to interior forest in cut slope

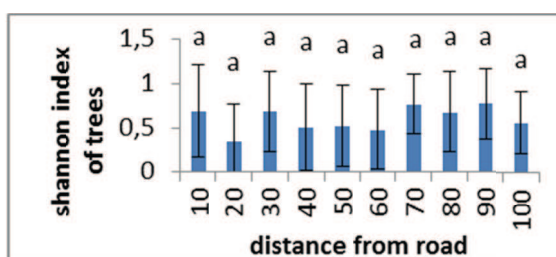


Fig.3. Variation in tree species diversity from road to interior forest in fill slope

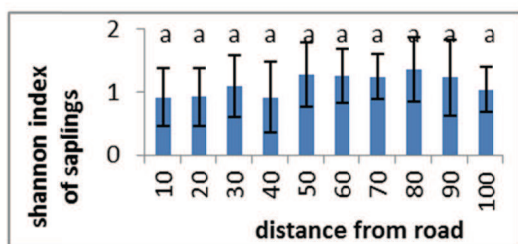


Fig.4. Variation in sapling species diversity from road to interior forest in cut slope

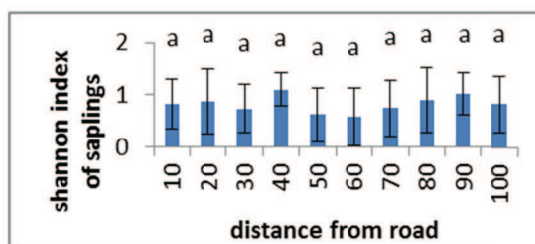


Fig.5. Variation in sapling species diversity from road to interior forest in fill slope

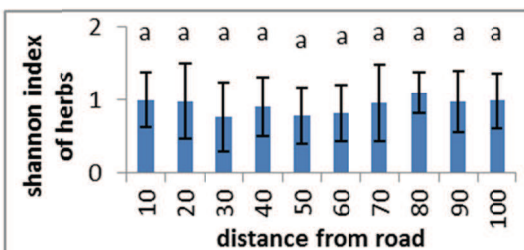


Fig.6. Variation in herbaceous species diversity from road to interior forest in cut slope

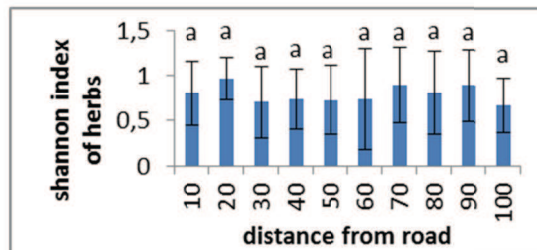


Fig.7. Variation in herbaceous species diversity from road to interior forest in fill slope

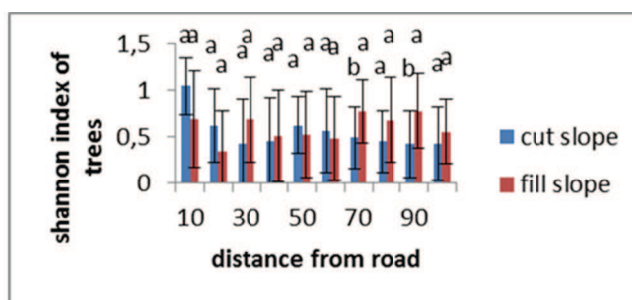


Fig.8. Trees species composition variation between cut and fill slope

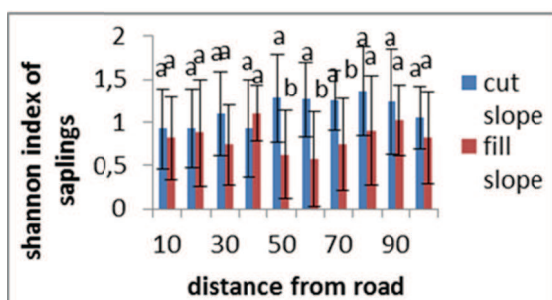


Fig.9. Sapling species composition variation between cut slope and fill slope from road to interior of forest

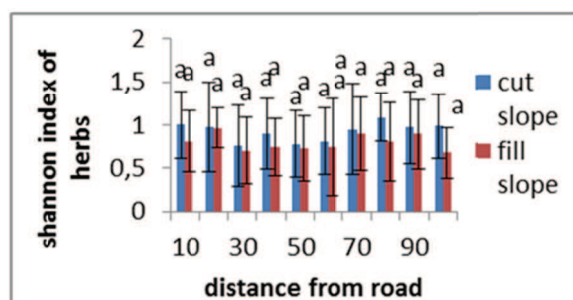


Fig. 10. Herbaceous species composition variation between cut slope and fill slope from road to interior of forest

## Conclusions

The studied road is planned, designed and constructed using environmentally sound techniques and criteria, consequently unnecessary cut and fill operations are avoided. That is to say, not only is nature not sacrificed by the road, but also that is nature which has dictated the route and the road is in sync with nature as much as possible. Moreover, the width of the road is as narrow as possible. As the size of retained patches is an important factor influencing species survival (Jodi A.Hilty, William Z.Lidicker Jr., Adina M. Merenlender; Corridor Ecology,Island Press,2006), thank to the narrow road the new patches are almost as large as before, as a result the habitat fragmentation is not so considerable. The significant variation between cut slope and fill slope at the mentioned points can be justified by the partial differences caused by waterways and paths in the surrounding environment. Furthermore, the limited traffic of this road can be mentioned as another beneficial item for reducing the adverse effects of the roads.

All the items mentioned can mitigate negative effects of this road and compared with previous studies, in which the roads are wider and less in sync with nature (Alisa W,Coffin;2007).

All in all, when the ecological factors are considered as important as road construction standards or occasionally more essential than them, the forest ecosystem can proceed its natural procedure, and major hazardous effects can be prevented.

## Literature cited

*Bennett, A. F.* 1999. Linkages in the landscape: The role of corridors and connectivity in wildlife conservation. Gland, Switzerland: World Conservation Union.

*Fedkiw J.*, 1998. Managing multiple uses on National Forests.1905-1995: a 90-year learning experience and it isn't finishedyet. USDA Forest Service Publication FS-628, 284 pp.

*Henle, K., D. B. Lindenmayer, C. R. Margules, D. A. Saunders, and C. Wissel.* 2004. Species survival in fragmented landscapes: Where are we now? Biodiversity and Conservation 13:1–8.

*Hilty J.A., Lidicker Jr. W Z., Merenlender A.M:* Corridor Ecology, The Science and Practice of Linking Landscapes for Biodiversity Conversation, Island Press, 2006. 323.

*Noss, R. F.* 1987. Corridors in real landscapes: A reply to Simberloff and Cox. Conservation Biology 1:159–164.

*Queen L.P., Vlaming, J.C., Arthaud G.J., Lime D.W.,* 1997.Modeling impacts of forest roads on recreation opportunities.N. J. Appl. For. 14, 194-201.

*Smith D.M.,* 1986. The Practice of Silviculture. Wiley. New York. 527 pp.

*Coffin A.W.,* 2007. From roadkill to road ecology: A review of the ecological effects of roads. Journal of Transport Geography 15 (2007) 396–406.

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

## 6.6 EVALUATION OF SITE IMPACT AFTER HARVESTING IN STEEP TERRAIN WITH EXCAVATOR ASSISTED GROUND BASED SYSTEMS

*Bjerketvedt, J<sup>1</sup>, Talbot, B<sup>1</sup>, Kindernay, D<sup>2</sup>, Ottaviani Aalmo, G.<sup>1</sup>, Clarke, N.I*

<sup>1</sup>Norwegian Forest and Landscape Institute [bjj@skogoglandskap.no](mailto:bjj@skogoglandskap.no)

<sup>2</sup>Technical University in Zvolen, Slovakia

### Introduction

This presentation reports on the results of a post-harvest evaluation of stands harvested using excavator-assisted ground based CTL systems, as against tower yarders, in steep terrain. The practice of using an excavator to assist a conventional harvester in gaining access to steep terrain – by excavating a series of temporary strip roads – is expanding rapidly and is now commonly found along the entire coastal region of Norway and in the mountainous parts of Sweden.

Applying this method, the excavator alternates with the harvester after all trees within crane reach have been harvested, and opens up another 6-8 metres of road at an acceptable slope, then once again yields to the harvester. Studies of the technical and economic performance of this system showed the harvesting cost to be roughly 50% of cost of using cable-based systems in similar terrain (Lileng 2007) . However, concern has been expressed as to the sustainability of this practice, as it is commonly performed on steep slopes in high rainfall areas and it includes little or no planning, no drainage, and no stabilization. Cable-yarders by comparison do not require access into the stand, and when the load is suspended on the skyline, there is no impact on the soil surface.

### Materials and Methods

Ten stands, located in Hordaland County in western Norway, were harvested between 0-6 years prior to the evaluation. Factors included in the evaluation were; slope analysis and classification (10mx10m grid), the identification of potential erosion hot-spots (confluences of road run-off) for further monitoring, the calculation of strip road length to area ratios, and cut & fill volumes. The strip roads were measured using a handheld GPS. Analyses were done using ArcGIS 9.3. and Softree's RoadEng®

Intermediate results show that very high strip road densities, over 1500 m ha<sup>-1</sup>, are sometimes necessary in providing sufficient access to the stand and that these could be reduced by increasing the degree of motor manual felling to the machine. Severe point and gulley erosion has occurred in some stands but this has generally been stayed by the underlying rocky colluvium (fig.1).



**Figure 6 (A) high density of strip roads on the steep slope (B) erosion gulley from forwarder wheel track inhibited by underlying material.**

While a significant area of the site is disturbed, those harvested up to six years prior to the evaluation were found to have recovered to a degree where vegetation on and between the strip roads was indistinguishable. Some roads continue to lead water and therefore constitute an erosion threat which could have been alleviated through the construction of simple cross drains at harvesting time.

Erosion losses are initially large from specific points and gullies and do cause increased turbidity and silting in smaller streams, but the combination of high rainfall, and steep and turbulent streams and the very short distance to the fjords make this difficult to quantify. Further comparative studies with cable-yarding systems in similar terrain are needed in order before drawing broader conclusions as inter-site variability is high. The excavator assisted harvesting could be further developed through stricter planning requirements, improved de-activating (Smidt and Kolka 2001) and re-establishing strip roads (Dykstra and Curran 2000), and a higher degree of motor-manual felling to the harvester, thereby reducing the strip road density.

## **Literature Cited**

- Dykstra, P. R. and M. P. Curran (2000). "Tree growth on rehabilitated skid roads in southeast British Columbia." *Forest Ecology and Management* 133(1-2): 145-156.
- Lileng, J. (2007). Harvester and Forwarder in steep terrain. 3rd Forest Engineering Conference - Sustainable Forest Operations. J.-F. Gingras. Mont-Tremblant, Quebec.
- Smidt, M. F. and R. K. Kolka (2001). Alternative skid trail retirement options for steep terrain logging. The 24th Annual Meeting of The Council of Forest Engineering (COFE). Appalachian Hardwoods: Managing Change. J. Wang, M. Wolford and J. F. McNeel. Snowshoe, West Virginia, USDA Forest Service: 6.

## **SESSION 7: HARVESTING & THE ENVIRONMENT**

**Chair: Prof. Hideo Sakai**

## **7.1 TIMBER HARVESTING AND RESIDENTIAL DEVELOPMENT IN A MOUNTAINOUS APPALACHIAN WATERSHED: INTERACTIVE IMPACTS ON SUSPENDED SEDIMENT CONCENTRATIONS**

*Fulton, J. B.<sup>1</sup>, Petty, J.T.<sup>2</sup>, Grushecky, S.T.<sup>3\*</sup>, Harouff, S.<sup>4</sup>, Hartman, K.J.<sup>2</sup>, McGill, D.<sup>3</sup>, & Spong, B.<sup>3</sup>*

<sup>1</sup>US. Environmental Protection Agency, Wheeling West Virginia, 26003, USA, <sup>2</sup>Division of Forestry and Natural Resources, West Virginia University, P.O. Box 6125, Morgantown, West Virginia 26506, USA

<sup>3</sup>Division of Forestry and Natural Resources, Appalachian Hardwood Center, West Virginia University, P.O. Box 6125, Morgantown, West Virginia 26506, USA <sup>4</sup>West Virginia Division of Forestry, Charleston, West Virginia, 25271, USA \*Corresponding author: sgrushec@wvu.edu

### **Introduction**

The upper Elk River, located in mountainous east-central West Virginia, is one of the premier cold-water fisheries in the eastern United States. The surrounding watershed is 95 percent forested and supports an active forest products industry. The forested nature as well as its mountainous terrain and proximity to the United States Capital makes the area a widely visited recreational area. Sediment run-off from disturbance in this watershed has the potential to threaten the quality of wild trout populations.

### **Materials and Methods**

We examined spatial and temporal variation in total suspended solid (TSS) concentrations throughout the watershed and used geographic information systems (GIS) with satellite imagery to identify landscape attributes associated with elevated TSS concentrations. Methodologies were developed to attribute sedimentation to harvesting, development, and their interaction. In addition, through a unique paired sampling design, we tested the hypothesis that increasing levels of disturbance (i.e. timber harvest and development) within a watershed would result in a proportional increase in TSS concentrations.

### **Results**

We found that spatial variation in TSS concentration was primarily explained by human development (partial  $R^2 = 0.66$ ) and secondarily by timber harvest ( $R^2 = 0.13$ ) and road area ( $R^2 = 0.08$ ). Results of a paired sampling design further indicated that significant increases in TSS concentrations were the result of intense development activities rather than timber harvest. These results suggest that forestry related BMPs being used in this mountainous region were effective in reducing sediment loads to nearby waterbodies, and that improved BMP implementation at construction sites may be needed to protect this valuable fishery from sediment related impacts.

## 7.2 SIMULATING TOPOGRAPHIC POTENTIAL FOR AUTOMATED EROSION DETECTION: AN EVALUATION OF STEEP FOREST ON OKINAWA ISLAND

Azita, A.Z.<sup>1,2,3</sup>, Masami, S.<sup>1</sup>, & Noor, J.N.J.<sup>1,2</sup>

<sup>1</sup>United Graduate School of Agricultural Sciences, Kagoshima University. azitazawawi@gmail.com

<sup>2</sup>Faculty of Agriculture, University of The Ryukyus, Okinawa, Japan

<sup>3</sup>University Putra Malaysia, Selangor, Malaysia

### Introduction

Okinawa Island has undergone and threatens under severe forest change and land use conflicts concerning forest operation practices and as well as to maintain conservation priorities. The forest area was characterized by moderately sloping to steep rolling terrain ranging from 0° to 68°. Exposure to strong winds and monsoonal typhoons, road construction in steep area and their combination with environmental factors that include topography, soil and geological type influence the occurrences of erosion (Yamashiro, 2005). This type of forest area requires intensive soil conservation measures to prevent further forest damage. Geographical location of sensitive areas is very important information required for both forest operation activities and conservation planning. However, endangered and poisonous species which inhabits the island has limit accessibility for forest manager to monitor the area directly and this becomes one of the big challenges in managing the mountainous forest. To overcome this issue, terrain analysis and modelling works best to give insight of the forest resource and condition to the managers. The purpose of this study is to identify and to locate unstable sites prone to erosion in Yambaru forest area (YFA), which is located in the northernmost part of the island. Identifying or mapping sensitive sites regarding to erosion is very beneficial for effective forest planning and to support management decision-making.

### Material and methods

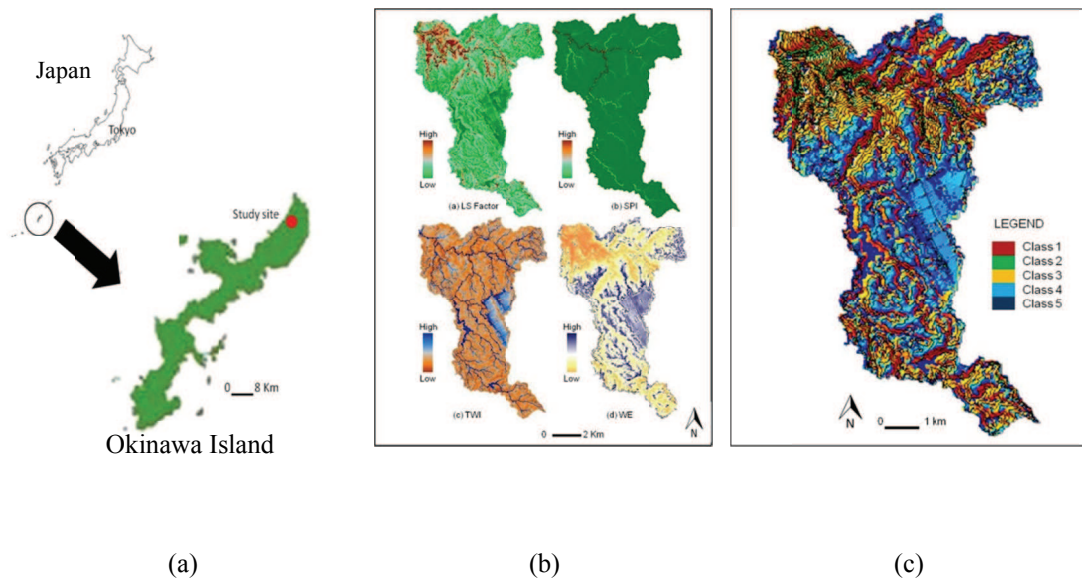
This task is performed through the detailed analyses of elevation grid from DTM of YFA with a spatial scale of 10m x 10m supported by The Geospatial Information Authority of Japan. SAGA GIS Software was used to derive primary terrain attributes (slope, aspect, plan curvature, profile curvature, hill shade, channel, catchment area, wetness index, catchment area above channel). Correlation analysis were done to the primary terrain attributes and several parameters were selected and simulated to produce secondary terrain attributes namely 'Erosion Potential Related Indices (r-EPI). The result of r-EPI are LS factor (slope length-gradient factor), topographical wetness index (TWI), stream power index (SPI), and wind effect (WE), respectively (Figure 1b). These four variables were then clustered to define the spatial similarities and nearest neighbor interpolation method was done. Finally, a map of potential sensitive site was produced (Figure 1c). The combination of SAGA terrain analysis outputs with several map layers allows the potential erosion site for every grid cell to be detected.

## Results and discussions

The research area was divided into 5 classes; differentiated by erosion potential level (Table 1). The reclassified terrain map shows two major erosion classes; class 1 and class 2, while class 3, class 4 and class 5 are within acceptable condition. Class 1 has the highest rate of erosion potential with the highest LS factor and SPI value of  $46.28 \pm 14.93$  and  $1242592.52 \pm 518310$  respectively. High value of LS factor suggests higher rate of soil loss and lower value shows opposite definition (Mitasova, 1996). Class 5 shows a very low value of LS factor but high value in TWI and SPI which indicated that the detected sites have flat terrain and very wet. TWI describes the tendency of runoff dispersion in the watershed; which high value shows the depositional sites (Wilson and Gallant, 2000). Slope in YFA varies from  $0$  to  $68^\circ$  with an average value of  $18.60 \pm 11.52^\circ$ . Higher risk zones were detected mostly at complicated steep terrains which have high values of slope, LS factor and TWI, respectively. SPI value which was computed by hydrological module shows a mean value of  $6541.64 \pm 74332$ , and class 1 has the highest value of  $1242592.52 \pm 518310$ . The meteorological wind direction angle;  $\theta$ , was used to represent wind effect (WE) or topographic exposure which varies from  $0$  to  $360^\circ$ , where in complex terrain,  $\theta$  is not distributed normally (Hauser *et al.* 1994). In YFA, WE produced mean value of  $50.99 \pm 4.56^\circ$  and shows that the most exposed areas are plateaus and mountain ridge with mild slopes, and least exposed is deep valleys with steep slopes.

**Table 1 Basic statistics of cluster analysis**

| Class | Wetness Index (TWI) | LS Factor         | Stream Power Index (SPI) | Wind Effect (WE) |
|-------|---------------------|-------------------|--------------------------|------------------|
| 1     | $13.57 \pm 0.82$    | $46.28 \pm 14.93$ | $1242592.52 \pm 518310$  | $44.12 \pm 1.71$ |
| 2     | $6.82 \pm 2.81$     | $15.23 \pm 5.84$  | $30278.45 \pm 90961.40$  | $44.70 \pm 1.71$ |
| 3     | $4.13 \pm 1.23$     | $5.45 \pm 2.35$   | $243.62 \pm 303.02$      | $48.12 \pm 2.30$ |
| 4     | $4.01 \pm 1.38$     | $2.03 \pm 1.50$   | $47.12 \pm 56.16$        | $55.57 \pm 2.86$ |
| 5     | $10.52 \pm 2.79$    | $2.62 \pm 2.73$   | $7346.89 \pm 2730.31$    | $51.00 \pm 3.43$ |



**Figure 1. a) Location of Okinawa Island and the study area (b) Map of erosion potential related indices (r-EPI) (c) Map of sensitive site derived from the cluster analysis**

The interpolation result shows that for each cluster, erosion extend have the potential to occur up until 30m of contour distance. Character and shape of terrain influence the flow of surface water, sedimentation process, wind exposure and solar radiation which influence the quality and distributions of biodiversity (Blaszczyński, 1997). Our site visit confirmed that severe erosion occurred near forest roads and in steep complicated slopes which significantly effects vegetation distribution. High density of road and extensive forest activities near the steep terrains appears to be influencing erosion in this area. Besides having influence from urban development and agricultural use, we have observed canopy opening in some areas as a result of wind effects in open slopes and steep slopes near the coastal zone, upward to the forested area in the higher elevation. Forest opening and land development on these areas should be restricted, as it could cause soil erosion, thus increasing the surface runoff.

## Conclusion

Erosion and forest damage depends on many factors; soil properties, land use, vegetation cover, climatic variables and terrain condition. In this study we focused on the effect of terrain and hydrological processes by evaluating selected terrain parameters (LS-factor, TWI, SPI, Wind effect) in detecting potential site of erosion. All factors were computed by considering two main terrain attributes which are slope steepness and hydrological effects. These two parameters were proven to have strong influence in erosion development. Simulation result suggested that YFA is threatened under severe erosion potential. Successful evaluation requires detail understanding of the controlling variables contributing to the erosion process. By knowing the controlling factors, affective management action could be taken to prevent further damage to the forest area.

## Literature cited

Blaszczyński, J. S. 1997. Landform characterization with geographic information system. *Photogrammetric Engineering and Remote Sensing* 63(2): 183- 191.

Hauser, R.K., Whiteman, C.D. & Allwine, K.J. 1994. Short - tower measurements in the Colorado plateaus region. *Proceedings: 8th Joint Conference on Applications of Air Pollution Meteorology*, Nashville, TN, American Meteorological Society. 321-328.

Mitasova, H. 1996. Modelling topographic potential for erosion and deposition using GIS. *International Journal of Geographical Information Systems*. 10(5):629-641.

Wilson, J.P. & Gallant, J.C. 2002. In: Wilson, J.P. & Gallant, J.C. (eds.): *Terrain analysis. Principles and applications*, pp. 87-131. John Wiley and Sons.

Yamashiro, S. 2005. What in Okinawa about Okinawan environmental problems: An outline of the Okinawa cross-cultural environmental experiences. *The Okinawan Journal of American Studies* 2: 51-56.

### 7.3 UNCONTROLLED SKIDDING OF LOGS USING A CHUTE SYSTEM IN A MOUNTAIN REGION

*Acar, H. & Unver, C.*

Karadeniz Technical University, Faculty of Forestry 61080 Trabzon Turkey, hlsacar@ktu.edu.tr, and cansu@ktu.edu.tr

#### **Abstract**

Forestry activity that requires the most attention during transportation of wood raw material in terms of economically, environmentally and ergonomically is the extraction of logs. A lot of work has revealed that significant damages have occurred on both the logs and the residual stand during the skidding on the ground of logs in mountainous terrain. In recent years, chute system providing extracting of logs on an artificial wood cutting contact with the ground has been developed. This system provides mitigation of the economic losses on logs and residual stand damages that caused by skidding on the ground, increasing of the efficiency of work and ergonomics. This system is widely used to uncontrolled transporting of thin woods top to bottom in Turkey. In addition, the system might also be used to control extracting of logs power from the bottom up with an additional engine. This study includes that evaluation of sliding of logs as uncontrolled from top to bottom in mountainous terrain in terms of work efficiency, environmental damages and ergonomics. The study has been conducted to two chute route the average of 30% slope and about 140 m distance in Trabzon-Maça region. The log quantities carried on polyethylene chute routes were 9.39 m<sup>3</sup> and 6.37 m<sup>3</sup> respectively. Their work efficiencies have been identified from 79.00m<sup>3</sup>/h and 42.47m<sup>3</sup>/h.

It was important to have the system much more efficient than other commercial methods in terms of cost-efficiency. Transportation of logs on chutes without touching with forest soil eliminated the losses on the residual trees, sapling, forest soil and moved the forest products.

In this technique, forest workers were included in the system only transportation of the logs on chute routes. It has been observed that fatigue resulting from work stoppages or moving for an extended period in the forest decreased to a minimum.

## 7.4 TOPOGRAPHIC ANALYSIS FOR FOREST MANAGEMENT USING SAGA GIS IN STEEP TERRAIN AREAS

*Itaya, A.*

Graduate School of Bioresources, Mie University, Japan. itaya@bio.mie-u.ac.jp

### Introduction

Where is the sensitive area for forest road constructions and forest operations in the steep terrain area? Such information is very important for the sustainable forest management. The slope is deeply related with the forest road planning and the selection of forest operation systems. Sometimes forest road disasters are caused by water. The water quality has to be protected from forest operations. The purpose of this paper was to map the sensitive area for forest road constructions and forest operations in the steep terrain mountainous area using a digital elevation model (DEM) and SAGA GIS. Particularly this paper focused on visualizing water environments.

### Materials and Methods

The study area consisted of about 206.6 km<sup>2</sup> in Misugi village, Mie, central Japan. About 76% of Misugi village's total land area is the plantation of Japanese cedar and Japanese cypress (Figure 1). Topographic indexes were calculated based on the DEM which spatial resolution was 10m. All the data handling was done with SAGA GIS. SAGA GIS has implemented a lot of topographic analysis algorithm.

### Results and Discussions

The slope, SWI (topographic water index was calculated by SAGA GIS), and the stream distance maps was showed as Figure2-4. These indexes were normalized. The sensitive area distribution map was calculated by the arithmetic multiplication using these indexes (Figure 5). Shiba (1996) developed the investigation system of the sensitive area in the route selection process. This system specified the location of sensitive area. But, such maps cannot be understand the status of around the sensitive area. In this study, we could understand the sensitive area for the forest management as a probability. Forest managers can decide locations of forest roads and forest operation systems while understand the status of around the sensitive area using this map.

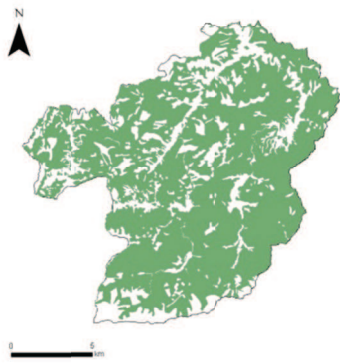


Figure 1. Plantation area

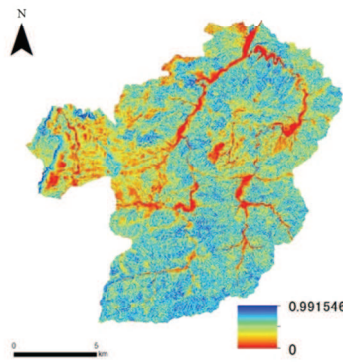


Figure 2. Normalized slope map

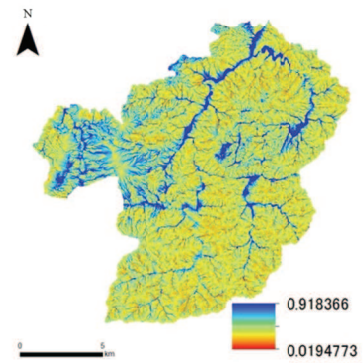


Figure 3. Normalized SWI map

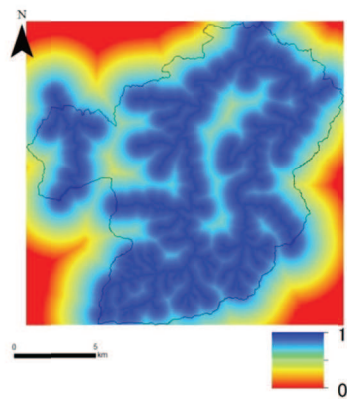


Figure 4. Normalized stream distance map

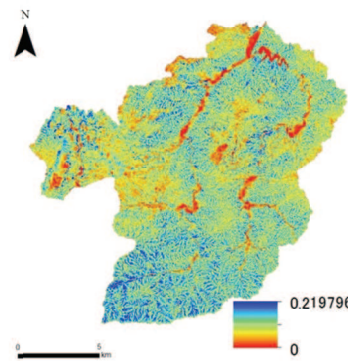


Figure 5. Sensitive area map

## Literature cited

Shiba, M. (1996) Imagery Data Processing System Using Aerial Photography for Sensitive Site Investigations in the Route Selection Process. *Journal of Forest Engineering* 7: 53-65.

## 7.5 APPLYING THE ANALYTICAL HIERARCHY PROCESS IN SELECTING AMONG EXCAVATOR BASED YARDER CONFIGURATIONS

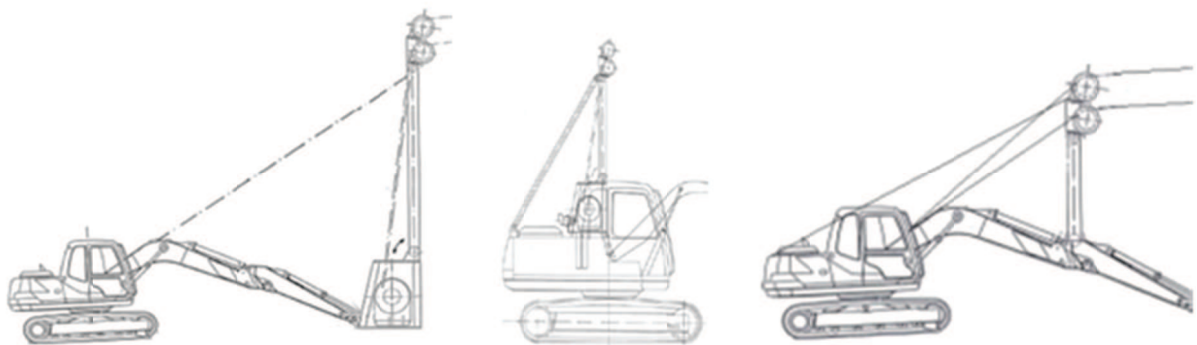
*Talbot, B. & Nitteberg, M.*

Norwegian Forest and Landscape Institute: bta@skogoglandskap.no

### Introduction

In Norway, some 150 million m<sup>3</sup> (solid under bark) of timber is mature or maturing on slopes with an inclination steeper than 33%. Of this, over 60 million m<sup>3</sup> is on slopes exceeding 50% (very steep) (Larsson & Hylen, 2007). While the annual commercial harvest is roughly 8 million m<sup>3</sup> (SSB, 2012), less than 100 000 m<sup>3</sup> are extracted from designated cable yarding terrain. In 2012, only about 8 cable logging teams were active, the best of which produce roughly 15 000 m<sup>3</sup> per annum. Mobilization of the considerable resource of timber therefore requires the implementation of many more cable logging crews in the future.

Excavator based yarders are considered to present some advantages over tower yarders mounted on trucks or other machines. Especially useful in rural settings is their flexibility – the fact that they can be used for other farm- or road maintenance work. The relatively low investment in build-on yarding equipment also allows for lower levels of annual utilization, allowing for seasonal activity which complements agricultural work. The reduced need for rigging (no guy lines on yarder) and increased maneuverability during operation on narrow roads all speak for investment excavator based yarders - yet there are currently none in operation in Norway. Torgersen and Lisland (2002) discussed the merits of some of the many configurations of these yarders, in justifying the construction of a prototype that was tested around 2000-2002.



**Figure 7** Some of the many configurations of excavator based yarders (Torgersen and Lisland 2002)

More recently, the cable yarding fraternity has expressed interest in investing in one or more machines. This generated considerable discussion as to which configuration would be suitable under the expected operating conditions - which indicated the need for decision analysis.

*IUFRO Unit 3.06 Forest Operations in Mountainous Conditions. Honne, Norway June 2-5, 2013*

The aim of this study was to both make explicit the range of attributes that need to be taken into account in a purchasing decision and especially demonstrating the utility of the Analytic Hierarchy Process in supporting a structured ranking of these attributes.

## Materials & Methods

The Analytic Hierarchy Process was developed by Saaty (1980) and has been widely used in selecting amongst alternatives, where attributes of varying mutual importance are evaluated against each other in a structured way. The utility of the method has been demonstrated in a forest operations setting by eg. Shiba (1995) who selected among road networks, Wang (1997) who ranked the suitability of skidding methods, or Perez-Rodriguez and Rojo-Alboreca (2012) who used the method in deciding between harvester makes and models.

## Evaluation of attributes

An electronic survey targeted 6 vocational groups (forest contractors considering diversifying into yarding, current yarding contractors, forest operations managers, county level authorities, instructors and academics, and ‘others’, which included individuals outside of the above groups known to have good insight into technical and organizational issues around cable yarding) in 5 regions considered to experience differing operating conditions. In this abstract, contractors are evaluated against forest operations managers. The questionnaire required the respondents to carry out a pairwise ranking of 10 attributes against each other on a 5-level scale: (i) AtX being absolutely more important than AtY, (ii) AtX being very much more important than AtY, (iii) AtX being much more important than AtY, (iv) AtX being somewhat more important than AtY and (v) AtX and AtY being considered to be of equal importance. The attributes are listed and their motivation for selection described in Table 1.

Table 2 List of attributes and the motivation for their selection

| Attribute | Description                                                                                                                                                                                                                                                                               |
|-----------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| At1       | <b>Purchase price</b> – importance of minimising the purchase price as against the benefit of any other characteristic. A purchase price range of 1.5 – 4 MNOK was provided so the respondent had a framework to relate to, but no direct trade-off of functionality and price was given. |
| At2       | <b>Flexibility</b> – importance of being able to rapidly convert and use the base machine as a normal excavator. In rural Norway, many entrepreneurs have the option of doing other kind of work eg. Road maintenance or farmwork which requires an excavator.                            |
| At3       | <b>On-road Mobility</b> – importance of high on road mobility – generally implies a wheeled machine – which offers the benefit of rapid movement between stands. Rubber tracked machines are also an option on shorter stretches.                                                         |
| At4       | <b>Off road Mobility</b> – importance of mobility in the terrain (off the forest road). With ultra-low road densities this is often an issue for contractors. This favours smaller tracked machines, equipped with a bucket (instead of processing head) and dozer blade.                 |
| At5       | <b>Stability</b> - implies, to varying degrees, either (or a combination of) a large base machine, a                                                                                                                                                                                      |

|     |                                                                                                                                                                                                                                                                                                                   |
|-----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|     | boom tip mounted tower, or use of the boom and/or dozer blades to stabilise the machine during in-haul to a large degree (implying a relatively low utilisation of an eventual processing head.                                                                                                                   |
| At6 | <b>Operating range</b> – importance of having longer range drum capacity – effectively (3-500 m) - Many yarders have limited line capacity - i.e. designed for shorter difficult corridors between conventional yarding and skidding – with working ranges of 200m.                                               |
| At7 | <b>Winch type</b> – importance of a 3 drum vs. a double drum winch (the latter being cheaper and more common on excavators). This influences on the possibility of having a fixed skyline setup or using a running skyline. With a running skyline, the third drum allows for a slackpulling carriage to be used. |
| At8 | <b>Tower</b> – importance of the presence of a tower to purchase extra clearance – this was presented as an alternative to using blocks mounted on the boom – no suggestion of eventual height of the tower, or the placement (centrally over the machine, on the knuckle, or at the boom tip) was given.         |
| At9 | <b>Swingyarder functionality</b> – the importance of being able to be able to function as a swingyarder                                                                                                                                                                                                           |

### *Establishing a database of machines*

A range of 9 excavator based yarders were considered as likely market contenders on the basis of market accessibility and the rough assumption of their suitability for operation in Norwegian conditions. Of these, 4 concepts were eventually selected as being representative of the others. The machines were ranked against the attributes internally by a panel of 3 department members on the basis of information available from trade shows or web based marketing material.

### **Results**

The Overall Preference Matrix (OPM) for the Contractor Group (table 2) shows how all attributes are considered at least as important (1.00) or very much more important (7.00) than purchase price (column 1). Swingyarder functionality and the presence of a tower (7.00) are the predominant wishes of contractors with Alt 5-Stability in second place. When ranking against flexibility (column 2), winch type and stability are the most important attributes, while on-road mobility is the only attribute considered somewhat important ( $\frac{1}{3}$ ).

Table 3 Overall preference matrix for the contractor group (row->column)

|      | At1  | At2  | At3  | At4  | At5  | At6  | At7  | At8  | At9  | At10 |
|------|------|------|------|------|------|------|------|------|------|------|
| At1  | 1.00 | 1.00 | 0.33 | 0.33 | 0.20 | 1.00 | 0.33 | 0.14 | 0.33 | 0.14 |
| At2  | 1.00 | 1.00 | 3.00 | 1.00 | 0.20 | 0.33 | 0.33 | 1.00 | 0.14 | 1.00 |
| At3  | 3.00 | 0.33 | 1.00 | 0.33 | 0.20 | 0.33 | 0.20 | 0.33 | 0.20 | 1.00 |
| At4  | 3.00 | 1.00 | 3.00 | 1.00 | 0.20 | 0.33 | 0.33 | 0.33 | 0.20 | 1.00 |
| At5  | 5.00 | 5.00 | 5.00 | 5.00 | 1.00 | 0.33 | 3.00 | 1.00 | 0.33 | 3.00 |
| At6  | 1.00 | 3.00 | 3.00 | 3.00 | 3.00 | 1.00 | 1.00 | 3.00 | 0.33 | 3.00 |
| At7  | 3.00 | 3.00 | 5.00 | 3.00 | 0.33 | 1.00 | 1.00 | 1.00 | 0.33 | 1.00 |
| At8  | 7.00 | 1.00 | 3.00 | 3.00 | 1.00 | 0.33 | 1.00 | 1.00 | 0.20 | 1.00 |
| At9  | 3.00 | 7.00 | 5.00 | 5.00 | 3.00 | 3.00 | 3.00 | 5.00 | 1.00 | 1.00 |
| At10 | 7.00 | 1.00 | 1.00 | 1.00 | 0.33 | 0.33 | 1.00 | 1.00 | 1.00 | 1.00 |

## Conclusions

This study investigated anticipated machine preference amongst and between various ‘expert groups’ and was evaluated against 4 machines concepts that could be likely contenders for import to Norway. Through a reformulation of the criteria and questionnaire, the AHP could have been used to equally good effect in formulating design specifications for a new hybrid machine that could be purpose built for Norwegian conditions.

It should be borne in mind that this *a priori* evaluation is based almost entirely on experiences with conventional tower yarders, and perceived benefits and functionality of various design parameters on machines - the preferences indicated are not the result of quantitative studies..

## Literature cited

- Perez-Rodriguez, F. and A. Rojo-Alboreca (2012). "Forestry application of the AHP by use of MPC<sup>®</sup> software." 2012 21(3).
- Shiba, M. (1995). Analytic Hierarchy Process (AHP)-Based Multi-Attribute Benefit Structure Analysis of Road Network Systems in Mountainous Rural Areas of Japan. *International Journal of Forest Engineering* 7 (1): 41-50
- Torgersen, H. and T. Lisland (2002). "Excavator-Based Cable Logging and Processing System: A Norwegian Case Study." *International Journal of Forest Engineering* 13(1): 11-16.
- Wang, L. (1997). Assessment of Animal Skidding and Ground Machine Skidding Under Mountain Conditions. *International Journal of Forest Engineering* 8 (2): 57-64