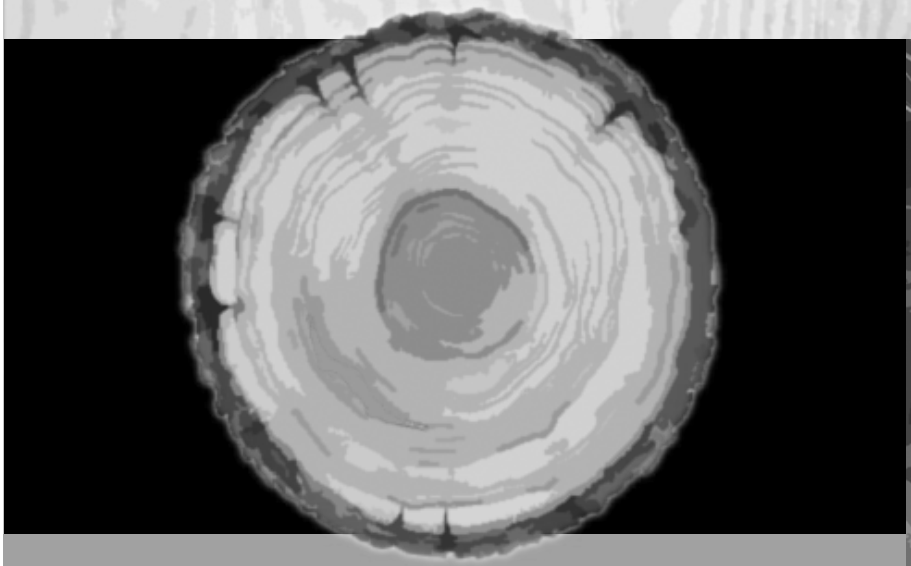
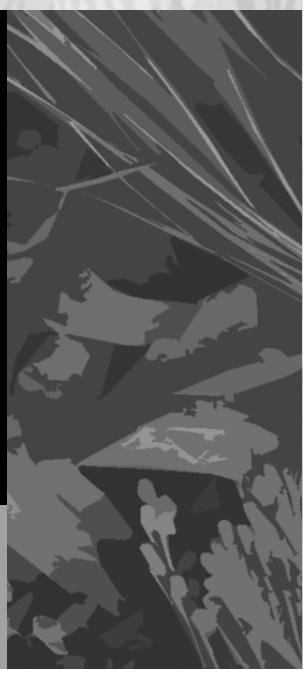
Progress Report for FY 2006

Center for Wood Utilization Research

at Oregon State University





Corvallis, OR 97331 • (541) 737-4257 • USDA Special Grant

PROGRESS REPORT FOR
FISCAL YEAR 2006

CENTER FOR WOOD UTILIZATION RESEARCH

AT OREGON STATE UNIVERSITY

A USDA CSREES Special Research Grant Program

CONTENTS

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Executive Summary

The USDA Special Grant for Wood Utilization Research (WUR) is developing the science, technology, management approaches, and business practices that (a) enhance the domestic and global competitiveness of the broad U.S. wood products industry; (b) maintain or expand sustainable and environmentally acceptable forest operations and product manufacturing; and/or (c) lead to more efficient use of renewable wood-based materials for the benefit of Americans.

Wood utilization research is critical to national needs because the U.S. is the world's largest consumer of wood products and the largest importer. In Oregon, the global competitiveness of our domestic industry is essential to providing jobs, especially in rural areas; reducing dependence on nonrenewable materials; and sustaining incentives for landowners to maintain private and public forests.

The vast majority of U.S. wood product manufacturers are small- to medium-sized businesses that have little capacity for research. With the WUR Special Grant, Oregon State University is part of a larger national program to address critical wood utilization research needs that vary across the U.S. and by discipline. Our principal focus is on the utilization of western species and the economic heath of the Pacific Northwest industry. This report summarizes grant activities for FY2006.

Three active projects were supported by the USDA Special Grant to Oregon State University in 2006. *Eight new projects* began and *eight projects* were completed. Project research *generated 40 publications*, including *29 in peer-reviewed scientific journals,* and *8 graduate student theses*. Technology transfer continued at a high level of activity, with research results conveyed through *49 activities to scientists and practitioners* in industry, academe, and government agencies, as well as to policy and decision makers and the public.

This Special Grant enables faculty to leverage funding from industry and other sources to develop intellectual capacity and new knowledge. Support for graduate students is especially critical in the face of a looming shortage of well-trained scientists, engineers, managers, and teachers in the field.

Important highlights of completed projects this year include

- new insight into how fungi reduce building strength after flood or other moisture damage;
- development of a new grade estimator for automated manufacturing systems;
- new opportunities for developing and marketing high-value materials from low value residues;
- new understanding of how to improve the strength of the interface between wood and plastic in a new generation of high-value engineering materials;
- assessment of the behavior of wood buildings subject to earthquake based on simple wall tests;
- improved understanding of the potential for adaptively controlling log merchandising by mechanical harvesters to improve value recovery;
- improved understanding of how to design and construct low-volume forest roads used for log transportation so as to improve environmental performance, especially in preventing delivery of fine sediment to streams.

This report covers activities conducted under the following USDA/CSREES Special Grants: 2004-34158-14679, 2005-34158-16380, and 2006-34158-17189.

Progress Reports

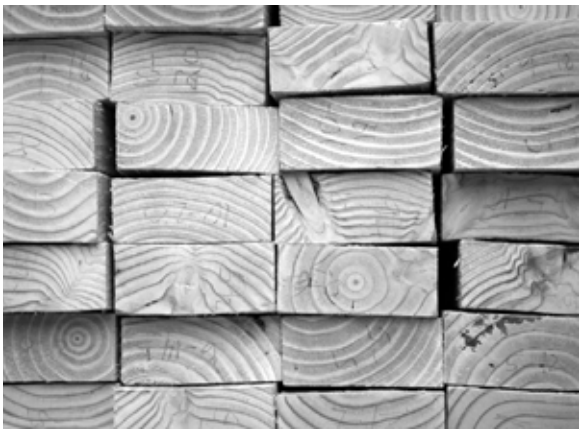
Improving Products and Processes to Enhance the Global Competitiveness of Oregon's Wood Products Industry

New Projects

Business Systems Innovation in the Global Forest Products Sector: Paths to Competitiveness

Eric N. Hansen

Objectives: (1) to enhance understanding of the potential for increased competitiveness resulting from business systems innovations; (2) to investigate innovations focusing on corporate responsibility, branding, and lean thinking in the forest products industry; in particular, (a) to assess stakeholder demands of forest industry companies about corporate social responsibility; (b) to document and evaluate principal branding strategies and frameworks in the forest products industry; and (c) to identify challenges to and benefits of implementing lean-thinking principles in the secondary wood products industries in the U.S. and Germany.



Duration: 8/1/06–7/31/08

Identification and Improvement of Wood and Log Quality

Barbara Lachenbruch (formerly Gartner)

Objectives: to improve our ability to recognize the xylem and log traits that contribute to high commercial wood quality and value, specifically through (1) examination of the effects of fast growth on strength factors and stem form in Douglas-fir, as well as the heritability of strength factors, and (2) examination of log form and quality through a field test on tree form and log dissection for insights into silvicultural management to improve log quality.

Duration: 8/1/06–7/31/08

Ongoing Projects

Environmental Management of Bio-Based Product Manufacture to Reduce Energy Use and Global Warming

James B. Wilson

Objectives: to assess (1) impacts of technology advances in energy and material use efficiency in the wood products industry from the CORRIM I (circa 1970) to CORRIM II (circa 2000) studies; (2) impacts of technology selection on the life cycle inventory and life cycle assessment of biobased composite panels manufacture; (3) management opportunities for reducing energy use, global warming, and emissions in the manufacture of biobased composite panels.

Progress and Future Activities:

- A technical review of technology innovations for processing wood products over the last 30 years assessed advancement in the environmental benefits of products produced for home building. The effort focused on three products common to CORRIM I and CORRIM II: softwood lumber, sheathing plywood, and oriented strand board.

- Wood usage by the softwood lumber industry improved markedly. The industry has shifted to a more integrated use of wood, with a significant portion of wood fiber (as opposed to bark) either being used in the primary product itself or sold to other wood product producers as raw furnish. Bark is now being used much more as fuel, instead of being burned without heat recovery, as in the seventies.
- Increased wood utilization, in combination with more energy-efficient and productive harvesting and transportation practices, has lowered harvesting energy use dramatically for all three products. Overall manufacturing energy has also generally decreased over the last 30 years.

■ Studies of the life cycle assessment (LCA) of wood composite panel products were significantly delayed because a major resin manufacturer withdrew from its commitment to provide production data. Another manufacturer has now joined the study, and the life cycle inventory models of manufacturing composite panel products are being completed. When the models of the life cycle inventories of the major wood-product resins and of composite panel production are completed, sensitivity analyses will be conducted to assess management opportunities for reducing energy use, global warming, and emissions in their manufacture.

Duration: 8/15/05–8/14/08

Completed Projects

Durability of Wood-Based Composites Employed in Building Envelopes

Jeffrey J. Morrell, Robert J. Leichti

Objectives: (1) to develop improved systems for assessing durability of water-resistant materials; (2) to assess the effects of various decay fungi on properties of wood-based composites; (3) to evaluate methods for non-destructive assessment of decay of wood-based composites.

Accomplishments and Impacts:

■ The effects of fungal attack on the behavior of a single connector in monotonic loading were examined.

- Various combinations of wood-based composites and solid wood species were exposed to decay fungi for 30 weeks in simulated wall assemblies.
- The fungi had relatively little effect on fastener load. Most of the effect was due to the initial moisture uptake.
- Effects of the early stages of fungal attack on fastener behavior are relatively small; however, the moisture that creates conditions suitable for fungal attack is significantly detrimental to properties.
- Producing moisture-resistant panels may be a more fruitful way to improve building performance, particularly if these materials can also be mold resistant.

■ Engineers assessing potential negative impacts of moisture intrusion into a building must decide whether the structural integrity of the building is compromised and then identify possible solutions.

- This study suggests that, while moisture intrusion inherently weakens a structure, reducing nail-holding capacity by 15% to 25%; subsequent fungal attack was much slower. More of the structural elements therefore could remain in a building that has experienced water intrusion, and more refined assessments about the diminished capacity of the remaining materials are possible.
- Material replacement costs involved in buildings with water intrusion issues could be sharply reduced by application of this information.

Duration: 7/15/04–7/14/07

Softwood Grade Estimator for Inclusion in the CORY and SAW3D Simulation Programs

Charles C. Brunner, James W. Funck, James E. Reeb

Objectives: (1) to develop a lumber grade estimator for the softwood appearance grades found in the Western Wood Products Association rules for factory lumber; (2) to incorporate the estimator into the board-sawing simulator CORY and the log-sawing simulator SAW3D.

Accomplishments and Impacts:

- A softwood appearance grade estimator based on the WWPA Factory Lumber Rules was developed for the most common factory lumber grades of moulding stock and the shop grades. The program permits limited user manipulation of features allowed for grading. The user interface shows the board before grading with color-coded features and after grading with the allowable cuttings indicated. A report is generated that explains the reason for the assigned lumber grade.
- The interface between the computer programs CORY (a board cut-up simulation) and SAW-3D (a log sawing simulation) is being completed.
- The Softwood Grade Estimator will permit users to use digital board data to determine a board's Factory grade for the purpose of training or yield studies.

Duration: 7/15/04–7/14/07

Discovering New Knowledge for Future Opportunities and Benefits

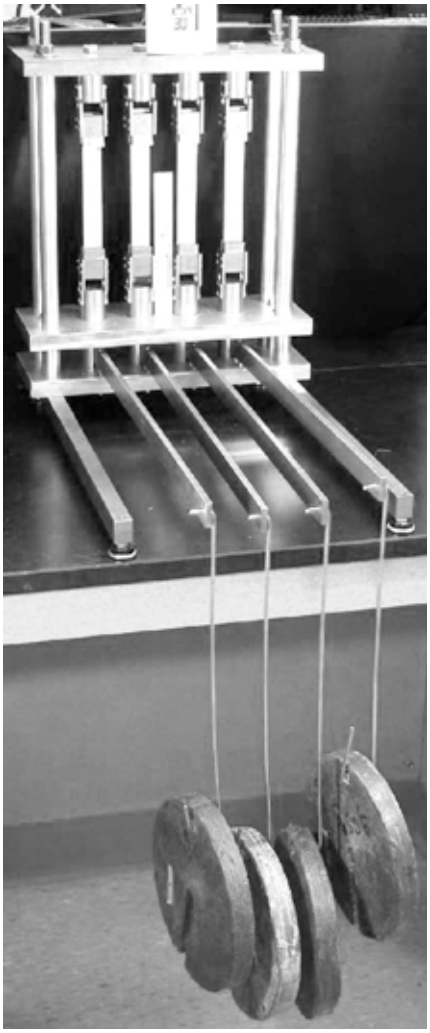
New Project

Three-Dimensional Micron-Scale Characterization of Adhesive Bondline in Wood

Frederick A. Kamke

Objective: Create a technique for quantitative measurement of the three-dimensional adhesive distribution within a wood bondline.

Duration: 8/1/06–7/31/08



Ongoing Project

Mechano-Sorptive Characteristics of Three Northwest Softwood Species in Compression Parallel to the Grain

Lech Muszyński

Objectives: long term, to develop a foundation for a systematic database of clearly defined hygro-mechanical characteristics of commercial wood species to be used to solve problems with wood in changing environmental condition; specifically, (1) to determine the hygro-mechanical properties in compression parallel to the grain of three Northwest softwood species, including the material variation within species (juvenile vs. mature wood, and heartwood vs. sapwood), and (2) to examine potential correlations between the mechano-sorptive characteristics and other physical or mechanical properties of wood (e.g., density, elastic modulus, free shrinkage/swelling coefficient).

Progress and Future Activities:

- A literature review focused on the Poisson effect in continuous and cellular solids was completed.

- A simple mathematical model was developed and a parametric study was conducted that included the significance of variability of the Poisson's effect for the accuracy of modeling long-term behavior of wood and wood-based composites and the error assessment. A constitutive model that would reflect this phenomenon was proposed.
- A loading fixture for axial creep experiments was designed, manufactured, and calibrated. Four specimens can be subjected to sustained axial loads (tension/compression) at the same time. A small climate chamber with forced air circulation and controlled humidity was fitted in the loading fixture. The chamber was tested and improved until reliable stable climate conditions were achieved. Optimal climate cycle duration was determined.
- Preliminary sorption tests were performed on the compression specimens of enhanced geometry ("ribbed" sections for optimum lateral stability and enhanced moisture exchange) and plain reference specimens
- Seven presentations at professional conferences and two conference papers plus undergraduate research activities have resulted thus far.
- Plans for the next 12 months (calendar year 2007) include
    - fabrication of test specimens from fresh Douglas-fir, ponderosa pine and western hemlock logs;
    - examination of the significance of the stress level on mechano-sorptive compliance in compression;
    - regular test series in compression and tension is a central systematic task in the project.

Duration: 8/15/05–8/14/08

Completed Projects

Chemistry of Mill Residues for Increased and Improved Resource Recovery in Traditional Forest Products Operations

Joseph J. Karchesy

Objectives: (1) to identify potentially useful chemicals, extracts, or chemical- based materials from traditional mill residues of a western sawmill, plywood, or wood composites operation; (2) in the long term, to provide traditional forest products operations a means to increase the value of their resources and help support the main mill operations of producing lumber and/or wood composites.

Accomplishments and Impacts:

- Alaska, incense, Port-Orford, and western red cedars and western juniper were shown to be potential new sources of biobased materials that may be used in agriculture and forestry to control both arthropods and the microbes responsible for sudden oak death (*Phytophthora ramorum*). Mill residues and forest thinnings of these trees are readily available within current forest products operations.
- The new biobased materials offer safer alternatives to petrochemical-based pesticides. Results have been so promising, that field trials by the CDC are being used to evaluate these materials.
- This work opens new market opportunities for some forest products industries. It has been estimated that California nurseries loss in revenue from sudden oak death alone may have been up to $100 million in 2004 due to restricted shipments and fear of spreading this disease.

Duration: 7/15/04–7/14/07

Investigation of Interfacial Adhesion of Wood-Plastic Composites

Kaichang Li

Objectives: to investigate methods of enhancing the interfacial adhesion between wood and plastics in wood-plastic composites (WPCS) and to investigate the interfacial adhesion mechanisms.

Accomplishments and Impacts:

Wood-plastic composites (WPCs) have many advantages over wood and plastics and are a rapidly growing sector in the wood-based composite industry. Hydrophilic wood is not compatible with hydrophobic thermoplastics, however, and the interfacial adhesion between the two is weak. Currently available WPCs therefore are heavier and weaker than wood. Our research in this area greatly facilitates improved utilization of low-grade woody biomass from forest thinning.

- We studied several new compatibilizer systems that result in higher strength than maleic anhydride-grafted PE, one of the most effective compatibilizers. One of these systems is commercially viable. It, like the other systems studied, significantly improves the strength and stiffness of the resulting wood-PE composites. It also is superior to and cost-competitive with maleic anhydride-grafted PE.
- We also studied effects of wood extractives on the interfacial adhesion between wood and PE. Removal of extractives from wood flour before mixing with PE greatly enhanced the strength and stiffness of the resulting composites.
- This study enhanced our understanding of how to improve the interfacial adhesion between wood and plastics. The successful development of superior compatibilizers will enable us to develop wood-plastic composites that are stronger and lighter than those currently on the market. Commercialization of these compatibilizing systems is under way.

Duration: 7/15/04–7/14/07

Enhancing Engineering Applications for Wood and Wood-based Products

Completed Project

Evaluation of Seismic Performance of Code-Prescribed, Wood-Frame Shear Walls

Rakesh Gupta Collaborator*, Thomas H. Miller*

Objective: to evaluate the performance of code-prescribed, wood-frame shear walls under monotonic, cyclic, and real earthquake loads, specifically, (1) to estimate variability in the response of shear walls; (2) to evaluate the effect of anchorage; i.e., hold-downs (engineered or fully anchored walls) versus no hold-downs (prescriptive or partially anchored walls); (3) to evaluate the effect of dead load; (4) to compare the performance of shear walls between monotonic, cyclic, and dynamic loading conditions.

Accomplishments and Impacts:

- A total of 59 walls were tested under various loading conditions.
    - Cyclic tests generally exhibited a coefficient of variation that was lower than monotonic tests. Peak load and deflection at peak load differed significantly between monotonic and cyclic tests.

- Performance parameters for fully anchored walls increased over those of partially anchored walls by ~2.5-fold for peak load and nearly 9-fold for energy dissipation.
- Partially anchored walls with dead load applied exhibited an increase in peak load proportional to the resisting moment applied by dead load.
- Partially anchored walls had a consistent failure mode (edge breakout along sill plate) regardless of test protocol.
- Fully anchored walls demonstrated different failure modes between the monotonic and cyclic testing.
- Earthquake tests had a lower peak load than similar walls tested monotonically, with values approximately equal to those of walls tested with the CUREE cyclic protocol. The initial stiffness of the cyclically tested walls was intermediate between the monotonic and earthquake tests. In fully anchored walls, values of deflection at peak load were more reflective of the earthquake results in monotonic tests than in cyclic tests. The cyclic tests were more reflective of the earthquake results for the partially anchored walls.
- Cyclic tests generally appear to give a more conservative estimate of shear wall performance under actual earthquake loads than monotonic tests.

■ This research has increased understanding of the behavior of shear walls under actual earthquake loads.

Duration: 7/15/04–7/14/07

Extending the Timber Resource through Improved Harvesting, Transportation, and Manufacturing

New Projects

Developing Methods to Incorporate Wood Density and Modulus of Elasticity Prediction into Forest Inventory for Improved Wood Allocation to Sawmills

Kevin D. Boston

Objectives: (1) to use a case study to determine how the measurements of modulus of elasticity (MOE) and wood density vary within an intensively mapped and measured sample second-growth forest stand; (2) to apply wood quality information to the development of efficient sampling systems that characterize wood quality properties in stands.

Duration: 8/1/06–7/31/08

Efficient Processing of Wood Though Improved Process Control and Modeling

Michael R. Milota

Objectives: (1) to develop methods to perform ongoing quality assessment of a drying operation; (2) to develop a model

to simulate the process control required to reduce the moisture variability in kiln-dried lumber.

Duration: 8/1/06–7/31/08

In-Forest-Log Segregation Based on Acoustic Measurement of Wood Stiffness by Harvesting Equipment

Glen E. Murphy

Objectives: (1) to investigate relationships and measurement accuracy between standing, felled supported, and felled unsupported stem acoustic speed measures and the corresponding wood stiffness; (2) to develop economic models to predict potential reductions in transportation and manufacturing costs and increases in end product value achievable through in-forest log classification system; (3) to evaluate the costs, benefits, and design implications of implementing an in-forest acoustic testing tool as a supplement to a harvester head.

Duration: 8/1/06–7/31/08

Ongoing Project

Increasing the Efficiency of Timber Harvesting Plans and the Log Supply Chain Through Improved Inventory Analysis Techniques

Kevin D. Boston, Glen E. Murphy, Jeff Hamann

Objectives: (1) to quantify the risk and uncertainty contained in operational forest plans; (2) to apply spatial statistics to operational inventory data, with the goal of reducing the uncertainty in the volume and value estimates; (3) to design sampling methods that best implement advanced inventory techniques and allow the industry to rapidly adopt this technology.

Progress and Future Activities:

- Both study stands have been stem-mapped with a total station, and individual inventory estimates have been completed on approximately 4000 trees in the two areas.
- Analytical tools are being developed to analyze the potential gains as measured by a reduction in sampling error when spatial data are incorporated into the inventory estimates.
- A prototype of an operational scheduling model has been developed to evaluate sampling methodology and project the financial gains when spatial inventory data are incorporated into forest operations planning.

Duration: 8/15/05–8/14/08

Completed Projects

Adaptive Control of Bucking on Harvesters for Improved Wood Utilization

Glen E. Murphy

Objectives: To evaluate and develop novel procedures for adaptively controlling bucking on harvesters by (1) assessing how well a sample of forest industry production controllers can use new sources of stem information to adaptively control bucking on harvesters in pine stands and determining what decision rules they utilize; (2) comparing adaptive control by production controllers with existing heuristics and developing new heuristics, objective functions, and constraint penalty functions; (3) investigating which data sources (spatially related, temporally related, or most similar) are important and determining what weighting factors should be applied if combinations of data are used; (4) determining how many stems are required in each new set of data to obtain acceptable results; (5) determining the impact of harvester work methods and measurement accuracy on overall success and variability in adaptive control; and (6) establishing an intensively measured 25-acre plot where every tree is spatially located in order to test adaptive control heuristics in a mature Douglas-fir stand.

Accomplishments and Impacts:

- This research evaluated several approaches for controlling bucking (cutting stems into logs). The Pacific Northwest forest sector annually harvests about 7 billion board feet of timber, valued at about $3 billion. Closely matching market needs with stand characteristics will reduce waste, improve utilization, and enhance market competitiveness. Incorporation of adaptive bucking control systems on mechanized harvesters is one area that offers solutions for improving wood utilization.
- Adaptive bucking control approaches were tested in

software (FASTBUCK) developed by OSU for an earlier Center for Wood Utilization project. Several improvements to the software were made. The software was expanded to include a wider range of wood properties and batch processing of data. New objective functions were also tested but not incorporated into the software, since they did not provide significant improvements.

- Good stem measurement data are essential for adaptively controlling bucking of stems to meet market requirements. A very large data set was established for testing adaptive bucking control approaches; thousands of individual trees were measured and spatially located, and a method for capturing and using stem data on mechanized harvesting machines was developed and tested.
- This research found little, if any, advantage in using data from recently harvested stems to update price lists used by optimal bucking software on harvesters. There also was little, if any, advantage in updating prices lists frequently (e.g., every 4 trees) compared with infrequently (e.g., every 512 trees).
- Varying the target proportions for given log types, rather than holding them constant, provided the best overall apportionment degree for success in meeting market requirements in only one of four test stands.
- Adaptively controlling bucking on the basis of spatially close data did not differ significantly from control based on temporally close data in meeting market requirements successfully.
- Ten forest industry people were invited to participate in a log production control game to assess how well they could use new sources of stem information in adaptive control. Five started the game, but after eight weeks only one was still participating, an insufficient sample size. This information will have to be obtained in another way, or the initial sample size will have to be vastly increased.
- Further work is required to incorporate adaptive bucking control systems onto harvesters developed in North America.

Duration: 7/15/04–7/14/07

Science to Support Environmentally Responsible Wood Procurement

New Projects

Planning for Fire-Killed Timber Salvage Considering Wood Utilization Opportunities

John Sessions, Michael G. Wing; Collaborator, Precision Forestry Cooperative, University of Washington

Objectives: (1) to identify and examine alternative strategies for salvaging fire-killed timber from fire-prone forests, with particular emphasis on evaluating rapid salvage of smaller diameter trees; (2) to continue to develop a decision support system for use by forest managers for evaluating wood utilization alternatives for salvaging fire-killed timber; (3) to create techniques for remotely measuring fire-killed timber characteristics and establishing correlations with tree diameter in fire-impacted forests.

Duration: 8/1/06–7/31/08

Utilizing Forest Fuels for Bioenergy Conversion from Wildfire Risk Reduction Silviculture in Central and Eastern Oregon

Loren Kellogg, Chad T. Davis, Michael R. Vanderberg

Objectives: (1) to investigate alternative forest harvesting equipment and operational techniques to reduce costs of forest biomass harvesting and to identify innovative technologies to improve the economics of biomass harvesting; (2) to use a GIS-driven analysis to quantify transportation distances and costs for biofuels from forest restoration projects at a landscape level in order to evaluate overall project economics; (3) to develop an "Oil Consumption Budget" for energy production from a biomass harvesting

operation; (4) to assess the use of remote sensing to estimate the amount of biomass available from forests needing fuels restoration silvicultural treatments.

Duration: 8/1/06–7/31/08

Completed Projects

Development of Methodologies to Evaluate the Impact of Construction Practices, Materials, and Road Use on the Economic and Environmental Performance of Aggregate Forest Roads in the Oregon Coast Range

Kevin Boston, Marvin Pyles

Objectives: (1) to implement the current aggregate road design methodologies from rural roads to determine their suitability for forest roads; (2) to test the potential for improved environmental performance; (3) to determine the changes in road shape based on road use and road strength.

Accomplishments and Impacts:

- The dry-unit weights for the subgrade of the forest road in the study were much lower than expected from published values. The unit weights were far below the standard proctor levels. Water contents from the sample sites varied significantly and differed from water content at optimal density. The Clegg Impact Hammer measurements of road strength demonstrated a high variability in strength. The combination of poor moisture control and low dry-unit weights result in low subgrade strength.
- Several mathematical relationships were attempted to explain the association between material and construction properties and rut formation, but no significant relationships were found.
- According to a simple aggregate surfacing model, improved subgrade compaction can save $11,000 per mile. For timber companies in the Pacific Northwest that build hundreds of miles of roads per year, the potential annual savings is estimated at 1–3 million dollars.
- Roads with improved subgrade compaction are likely to produce lower sediment yields because reduced rut depth is correlated with reduced sediment yields.

Duration: 7/15/04–7/14/07

The Design of Forest Roads to Minimize the Delivery of Fine Sediment While Transporting Logs During Wet Weather

Arne E. Skaugset III, Elizabeth M. Toman

Objectives: (1) to develop and test designs for aggregate pavement structures for low-volume forest roads that will minimize generation of fine sediment from the surface during active use in wet weather; (2) to investigate the role of aggregate quality (geology of the surface aggregate) in generation of sediment from road surfaces during active use in wet weather; (3) to perform a benefit/cost analysis of the design alternatives, comparing the cost of the installed pavement aggregate surface with the savings in sediment from the road surface; (4) to investigate the opportunity to use the road installations to investigate management strategies for roads during wet weather; (5) to use the data generated to verify or perhaps modify the coefficients used to predict the impacts of traffic on sediment yield used in SEDMODL and other models.

Accomplishments and Impacts:

- Data collection was completed from sprinkler experiments on the field research site outside of Arcata, California. Trenches were dug across each of the treatment plots to examine the failure mechanisms. Initial results from this site were presented at two conferences.
  - There was a clear boundary at all treatments between the aggregate and the subgrade. There was no evidence of pumping of the subgrade.
  - Suspended sediment that was measured in the road runoff was thought to originate from fines that existed in the aggregate as placed. This suggests there is a fine line between too much and too little available fine material in the capping aggregate.

- The pavement treatments that held their shape produced less sediment. Aggregate depth was an important factor in sediment production.
- The treatment with greater depth of aggregate did not develop significant ruts. Road managers that want to minimize the production and delivery of sediment from forest roads should design the aggregate surface to resist rutting.

■ Two new replications of the field research were installed on cooperator land. Data collection at these locations was completed in April 2007.

- Alternative designs for the aggregate surface included two control sections, one section designed by the investigators on the basis of theories from soil mechanics, one section that used a geotextile between the aggregate and the subgrade, and one section that included a geocell pavement structure.
- Data analysis for all three experimental locations is ongoing. At the completion of the field work, thesis preparation, and manuscript preparation will be carried out.

■ Knowledge gained by this research of the cost and the environmental performance of alternative designs for aggregate surfacing on low volume roads will help give forest landowners more flexibility in deciding how to minimize the environmental effects of forest roads.

Duration: 7/15/04–7/14/07

Publications, Theses, and Technology Transfer Activities and Presentations

Publications

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