RENO: A Computerized Solution Procedure and Decision Support System for Forest Biomass Recovery Operations

Rene Zamora-Cristales[1] and John Sessions[2]

Abstract

A computerized decision support system, Residue Evaluation and Network Optimization (RENO) is presented to estimate the optimal mix of methods and equipment for conducting forest biomass recovery operations given a harvest residue assortment, road and landing access and product deliverables. The model was developed using the JAVA platform is able to read spatial data (vector) and simulate the dynamics of the productive system. The problem to be solved is classified as a special case of the multi-commodities, multi-facilities problem. The computerized model uses spatial information of the road network and residue pile locations in order to determine travel distances and calculate costs. The solution procedure represents the problem as a network and creates the routes for each residue pile and their processing and transportation costs. At each point of comminution, equipment of different sizes can be used, with different mobilization costs and production costs. Similarly not all trailers types can reach all forest residue locations. In some operations the processing of forest biomass is closely coupled to transportation and others are not. RENO incorporates the use of geographic information systems (GIS), mathematical optimization (mixed integer programming and ant colony heuristics), simulation and economics to support decisions of land owners and forestry managers at the operational level. The simulation model provides support to calculate cost accounting for truck-machine interactions expressed as waiting times.

Key Words: Forest biomass, economics, optimization, simulation.

1. Introduction

In forest biomass recovery operations from forest harvest residues, an important task for forest managers, land owners and contractors is to select the most cost-effective equipment given the spatial distribution of the residues, road access and available machinery. In-field operations require the use of expensive machinery with high fixed cost to reduce the particle size in order to facilitate handling and transportation. Transportation is required to haul the processed residues to a bioenergy facility but is affected by road characteristics such as horizontal and vertical curve geometry, road grade and road standard that limit the type of the truck-trailer configuration that can be used for an operation (Sessions et al. 2010). Additionally, forest biomass from residues

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[1] Faculty Research Assistant, Department of Forest Engineering Resources, and Management, Oregon State University, rene.zamora@oregonstate.edu .

[2] University Distinguish Professor, Strachan Chair in Forest Operations, Department of Forest Engineering Resources, and Management, Oregon State University, john.sessions@oregonstate.edu.

is considered a low value product in the forest although forest harvest residues have few competing uses.

The literature provides significant contributions related to this problem at the tactical and strategic level. Spinelli and Magagmotti (2010) developed a model to estimate productivity and cost of decentralized wood chipping. The authors developed a Microsoft Excel workbook where different equations were developed to calculate costs and productivity. The model was validated comparing the model results with real data. The model presented the long term performance of a given machine rather than the operational individual performance. Frombo et al. (2009) developed a decision support system (DSS) for long term planning for biomass-based energy production. The model includes a graphical user interface capable of reading spatial data. The model calculates optimal woody biomass sources and potential plant locations that minimize cost at the strategic level. Flisberg et al. 2012 developed a decision support system for forest fuel logistics. The model takes into account different processing machines and different transportation systems. Their linear programing model maximizes profit.. The model was developed and validated at the tactical level and provided considerable savings when compared with actual operations in Sweden. Although different decision support systems have been developed for forest recovery operations, most of them were developed at the tactical or strategic level. At the operational level, road accessibility can greatly affect productivity especially on steep terrain forest where in-forest road distance can reduce productivity by limiting the access of high capacity trucks and increasing the round-trip times. Road characteristics can also affect machine waiting times by limiting the number of trucks that can reach a processing site on time. Given the reduced actual marginal income of this operation an efficient cost management is required. The operational level improvement target is to ensure the long term success of this emerging supply chain in the United States.

The main objective of this paper is to develop a decision support system to minimize cost of processing and transport of forest biomass from harvest residues at the operational level. Specific objectives are to develop a friendly graphical user interface that enables the forest managers, land owners and contractors to analyze their operations and to decide which sites and residue piles are the most profitable to process and transport. It will also help analysts to decide the optimal location of processing sites such as centralized landings (within the forest) or centralized yards (located in nearby locations out of the forest unit). The main scope of the study is for steep terrain regions where road access is often difficult, but it can be applied in other less constrained operations in terms of access

2. Description of the Problem

Forest biomass processing and transportation from residues involves different machinery, truck-trailer configurations and systems. In the U.S. Pacific Northwest residues are usually processed following harvesting operations using a stationary grinder that is located adjacent to the residue pile. Residues are fed with an excavator. The processed material is directly conveyor fed into chip vans. Chip vans consist of a tractor (truck) and a trailer of different lengths. Trailers are usually light and open in the top to maximize hauling capacity. They may also contain an extension in the bottom known as the drop center. Grinders reduce the particle size of the residues by hammering the material. The particle reduction process requires the use of large engines (700-1200 hp) that consume considerable amounts of fuel per hour. As an alternative to stationary grinders, mobile chippers (Figure 1) are also used in recovery operations. Mobile chippers are capable of reaching more residue piles but are greatly affected by the type and cleanness of the material. Residues with high contents of dirt and stone negatively reduce productivity causing excessive wear of the cutting knives.

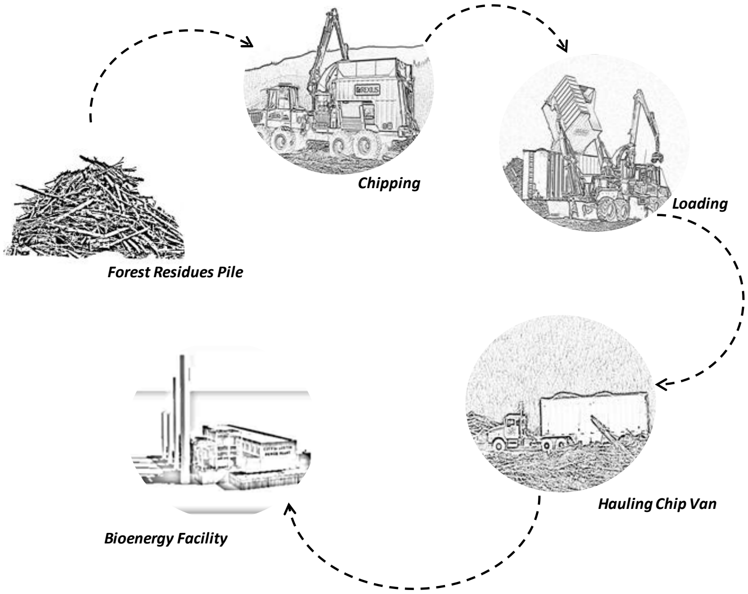


Figure 1. Chipping of forest residues at road side with a mobile drum chipper and transporting the chips to a bioenergy facility.

3. Material and Methods

The DSS is composed of a graphical user interface (GUI), capable to read spatial data (vector), a simulation model to account for the system dynamics of forest biomass recovery operations, and a mixed integer programming (MIP) solver. It also includes an ant colony heuristic (Dorigo 1996). The ant colony heuristic was primarily developed to make the program available for users who do not have a linear programming solver. It also provides the lower bound for the objective function to decrease the MIP solver solution times.

3.1 Program architecture

The program was developed using the JAVA platform. JAVA was selected as the programming language because it is well supported, and is capable of running on different operating systems. JAVA also provides access to different libraries that improve and facilitate the design of certain processes (Figure 2). The GIS component of the program is based on the Geotools JAVA code library (2012). Geotools library enables the program to read ESRI shapefiles. The simulation model was developed based on a simulation JAVA library for process-based discrete-event simulation developed by Helsgaun (2000). The program also makes the use of JFreeChart (Gilbert and Morgner, 2012), to produce the graphical representation of the results. Additionally lp_solve package (Berkelaar et al. 2004) is used as the MIP solver engine.

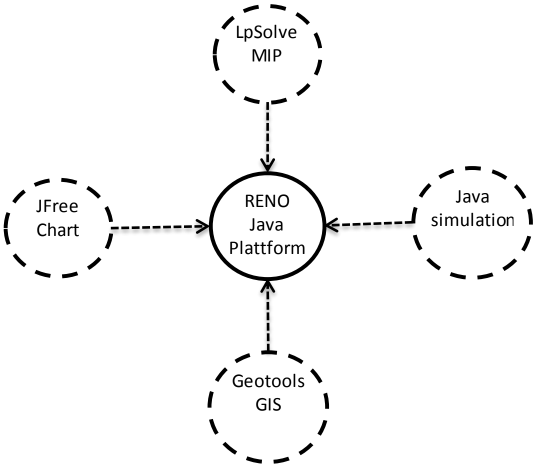


Figure 2. RENO components with different JAVA code libraries

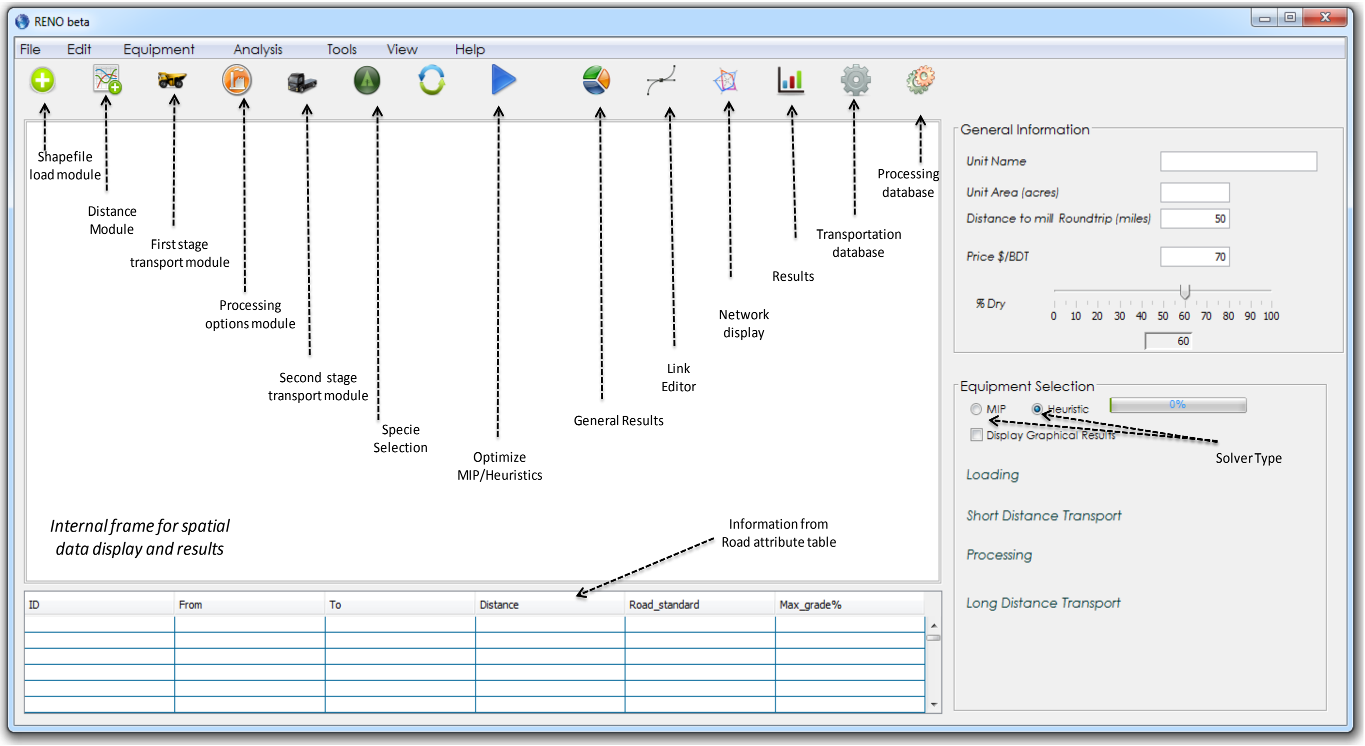
3.2 Graphical user interface

RENO's GUI is composed by several dialog windows that allow the analyst to choose different processing and transportation options and also to access to different menus that provide information to the user (Figure 3). Menus are complemented by tool bars that give access to different modules. Available modules include a shapefile reader to input the road network, road features such as available turn-out and turnaround and pile location into the system.

Transportation options are divided in first and second stage transport. First stage transport is related to the use of bin trucks or hook lift trucks. Second stage transport comprised different conventional trailers with payloads ranging from 17 to 31 tons. Non-conventional trailers are also available to be selected. RENO includes the option for a 48 ft long, rear-steered axle trailer with a capacity of 25 tons. A 42 ft long stinger steered trailer can be also selected from the dialog window.

4. Application of results

The model was applied to a harvest unit located 15 miles northwest of the city of Sutherlin. The forest in characterized by a mix of Douglas-fir and white fir. The actual operation used a mobile chipper to process the residues and two double trailer trucks to transport the material to a bioenergy facility located 32 miles south of the harvest unit. Actual results were compared to model outputs under the same conditions. Fifteen forest residue piles at roadside were located and the road network identified. It was estimated that a total of 1100 green tons of forest residues were available in the forest unit.



Unit Name
Unit Area (acres)
Distance to mill Roundtrip (miles) 50
Price $/BDT 70
% Dry 60

ID	From	To	Distance	Road_standard	Max_grade%

Figure 3. RENO graphical user interface

Available processing options were: (i) a 750 hp horizontal grinder (H-750) with an average productivity of 50 green tons (GT) per productive hour; (ii) a 1000 hp horizontal grinder H-1000), with an average productivity of 60 GT per productive hour; (iii) a 1000 hp tub grinder with an average productivity of 32 GT per productive hour; and (iv) a mobile drum chipper with an average productivity of 15 GT per productive hour. Available transportation configurations were: (i) two 6x4 trucks hauling two double 32 ft long trailers with a capacity of 30 tons; (ii) two 6x4 trucks hauling a single 32 ft long trailer with a capacity of 17 tons and (iii) two 6x6 trucks hauling a rear steer axle 48 ft long trailer with a capacity of 24 tons.

The optimal solution indicates that the best option to process the material was to use the H-1000 grinder (Figure 4). The most cost effective transportation option was the use of two double trailers, with an average of six loads per day. For transportation, the available number of trucks was the limiting factor. We performed a new analysis increasing the number of potential available trucks to 9 per day. The optimal solution suggests that depending on the location, from 4 to 6 double trailer trucks must be used to minimize total cost. Total cost decreases 13% because grinder utilization rate is maximized and truck-chipper interaction minimized.

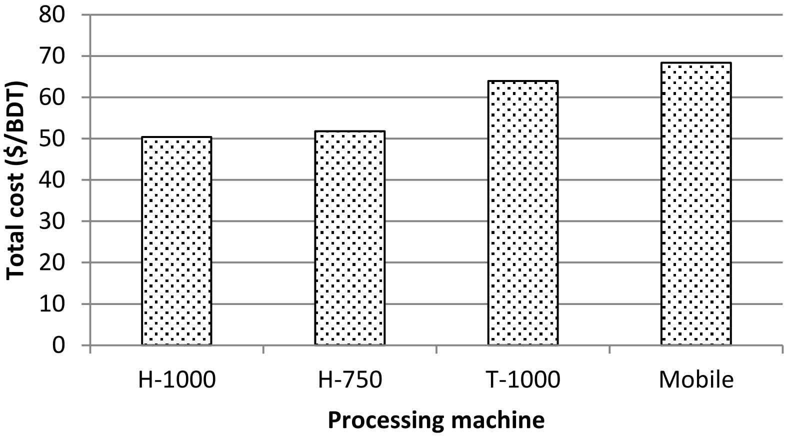


Figure 4. Total cost in dollars per bone dry ton for available processing machinery.

Although using the double trailer configuration implies spending more time in the forest (to hook and unhook the trailers), the hauling capacity under this option (30 green tons) compensates for the increase in round-trip time. The use of the mobile chipper reduces the truck dependence and decreases the waiting time for the truck, however this saving does not compensate the high cost and low productivity of the mobile chipper. However if a premium price exist for chips, rather than grindings, then a cost benefit of each option must be carried out.

RENO also reports the processing and transportation cost associated for each pile (Figure 5). Costs per pile vary because their location is different and their access can be constrained depending on where the closest and feasible turn-around and turn-outs are located. Costs associated to pile 1 were higher than the others because the high fixed cost associated with machine mobilization and site preparation at this location. Hook-lift trucks are assigned to this pile because it is chipper to transport the material to an adjacent pile (pile 2) than process the material in situ.

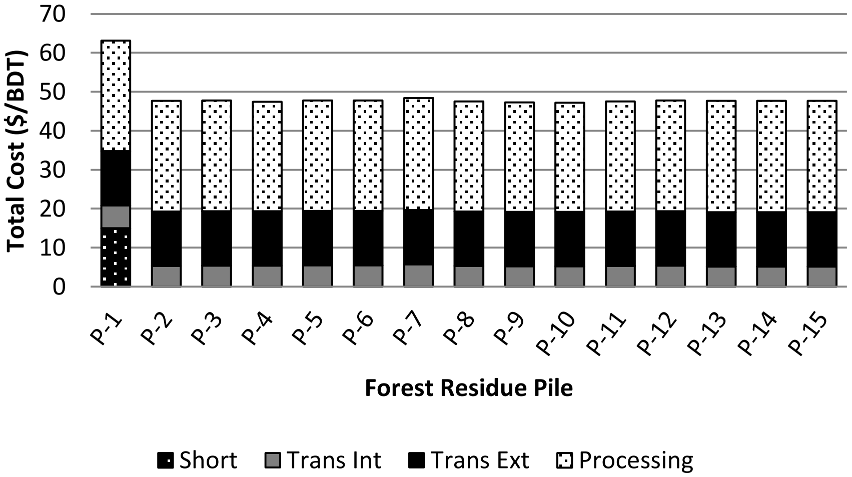


Figure 5. Processing and transportation cost per forest residue pile**.**

5. Conclusions

The decision support system, RENO, can provide decision support to forest managers and landowners at the operational level. RENO combines the use of GIS, mathematical optimization and simulation in order to provide the most cost effective processing and transportation options given the residue pile location, road access and technology available. Considerable savings can be obtained from its implementation as we were able to test the model by comparing their results to actual operations using the same parameters. Future research can be focused in the estimation of truck scheduling programs that can use the RENO solution to schedule trucks based on the available volume at each pile.

6. Acknowledgments

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