Developing an Annual Harvest Operations Planning Model for Turkish State Forest*

Mehmet EKER¹ and H. Hulusi ACAR²
¹Assistant Professor, Süleyman Demirel University, Faculty of Forestry, Isparta - TURKIYE
²Professor, Karadeniz Technical University, Faculty of Forestry, Trabzon - TURKIYE
Email: meker@orman.sdu.edu.tr

Abstract
Sustainable management of forest resources requires doing planning for all forestry operations such as harvesting etc. Hierarchical planning approach consisting of strategic, tactical and operational level is an efficiently way for integrated forest planning problems. In this concept, harvest operations can be planned in tactical and operational level. Tactical harvest plan may be equivalent to forest management and silviculture plans. Operational harvest plan is also short-term and detailed, which can encapsulate range from daily to two years planning period. As well, harvest planning is inherently a complex task because of economical, technical, environmental, and socio-economical objectives and constraints. Thus, to optimize decisions on harvest planning for example in Turkish Forestry System, it was developed an Annual Harvest Operation Planning (AHOP) model based on annual budget for 12 and/or 18 months harvesting decisions. In this study, it was aimed to introduce AHOP methodology to display that how the AHOP model had been set up for state forestry, which planning steps had been followed, how operational decisions had been optimized, how model results could have been adapted to real application problem and what the probable advantages obtained from solving of test problem was. The planning model includes the steps that (1) (spatial) database projection, (2) technical and topographical analysis, (3) cost analysis, (4) modeling of operational decisions, (5) solution, (6) synthesis, and (7) operation schedule and/or plan. In this planning context, it was used GIS for the first and second steps. Cost analysis was carried out by standard calculation methods via available equation. For fourth and fifth step, it was used Linear and Mixed Integer (linear) Programming for optimization of operational decisions in this planning manner. AHOP methodology could pan out to successfully use of time, money, work and machine force for optimal harvesting operations in the test problem.

Keywords: annual harvest planning, operational planning, LP, MIP, optimization, hierarchical planning

1. INTRODUCTION

The total area of Turkey is 77,056,192 hectares and approximately 27% of this area is forests. In Turkey, in the past 15 years an annual average of 7 million m³ of industrial wood and 9 million m³ of firewood have been produced. The majority of total forestland (99.9% of) belongs to Ministry of Forestry. One of the most significant features that separates Turkish forestry from the forestry in western countries is the presence of 18,358 forest villages living 8,5

million persons, either within the forest or at the edge of the forest. The forest villagers compose 49.5% of the rural population. For all that, the forestry sector takes place among the most employment provider (13 million man/day per year). Turkish constitution, Forestry Law, and Regulations dictate that forest villagers ought to be worked in harvest operations. Therefore, general means of subsistence of 300.000 villagers are provided from forest operation workmanship (ÖİKRT, 2005). The harvest and the other forestry operations are executed by forest cooperatives consisting of forest villagers, as monopoly by traditional methods disregarding of mechanization and without any analytical harvest planning conception (Bayoğlu, 1996; Eker, 2004).

The timber harvesting expenditures capture the majority of the total forestry expenditures per unit costs that amounts to 35 percent of total expenditures, which is highly proportion. (Eker and Acar, 2002). Furthermore, when harvest operations are carried out, various environmental impacts occur in residual stand, soil, and water resources. It can also be done a quality and quantity losses in forest products to be harvested (Gürtan, 1975; Acar, 1994).

Harvest planning bases on decennial forest management plans and quinquennial silvicultural prescriptions or detailed plans, in Turkey. The planning decisions are for mid-time horizon. The annual allowable cut (AAC) is estimated with respect to thinning and final felling to maximize total harvested volume and value, on a 10-year time horizon. Forest management plans are prepared to each planning unit that is application area of state forest enterprises and enumerate harvesting blocks to be harvested in each year within planning horizon. The main objective of the management plan is typically to maximize net present value.

In one year time horizon, it is prepared harvesting programs for harvesting operations. These programs are designed to balance the annual budget and to supply annual or monthly wood demands. But, these programs cannot describe harvesting time and schedule of block to be harvested and allocate harvesting system types and crews within one year.

This situation indicates that the annual harvest planning strategy is necessary for Turkish State Forestry. This planning strategy should offer a consistent plan that is applicable as technically, profitable for economically, and acceptable for environmentally and socially. Therefore, an AHOP methodology was developed to achieve annual planning objectives. But, the planning of forest harvesting activities is a complex task requiring integration of technical/topographical, economical, environmental, and social-institutional factors. This planning problem is one of the most important issues in forest resources management.

Forest harvest planning was generally dealt with in hierarchical planning approach (Robak, 1984; Weintraub and Cholaky, 1991; Gunn, 1991; Epstein et all., 1999; Laroze and Greber, 1991; Martel et all, 1998), which is three levels as strategic, tactical, and operational. Short-term harvest operation planning was generally inserted into operational planning level But, when the scope of the harvest operations planning could be enlarged and it was taken into consideration in tactical planning level (Karlsson et all., 2002; Dykstra ve Heinrich, 1996). Especially, planning horizon, planning area and planning objectives have changed to place and level of harvest planning.

The planning problem mentioned in this paper is annual harvest operation planning (AHOP) problem. AHOP means that planning of; which harvesting unit/block is to be harvested in each planning season/period, which harvesting system is to be used to harvest, how many harvesting crew is to be employed, which forest roads are to be used, where harvested assortments are to be transported to which state forest storage. AHOP corresponds to 12 or
maximum 18 months harvesting, in a forest district. This planning method is affected from technical-topographical conditions, economic limitations, environmental restrictions, and social-institutional expectations. However, AHOP problem is considerably complex because of including versatile goals and constraints (Eker, 2004).

To solve complex harvest operation planning problem, it was used macro (10 years) and micro (1 year) level transportation planning method based on harvesting system selection to physical/topographical conditions of harvesting area (Bayoğlu, 1972; Acar, 1994). As considerable as physical dimension of harvest operation planning, its economical dimension is important, as well. Therefore, to optimize as economically harvest plans, it was used mathematical-statistical methods and productivity-cost analysis functions. But, conventional evaluation techniques connected with economy were disqualified for harvest planning problem (Reimer, 1979). For that reason, it was eventually used operations research that is quantitative decision support systems (Oborn, 1996). When published a bibliography on operations research in forestry by Martin and Sendak (1973), it was referenced that 45 items OR techniques had been used to make a decision on forestry planning for harvesting and 28 items for timber transport. In addition, Schuster et al. (1993) quoted that there were many computer programs based on dynamic, linear (LP), integer (IP), and mixed integer programming (MIP), network analysis, heuristic process, simulation, Monte Carlo, artificial intelligence /expert systems, etc modeling techniques. Recently, many harvest operation planning model have been developed relevant to all of harvesting process or a part of the process such as logging, hauling, or skyline route planning (Rönnqvist et all, 1999; Shemwetta, 1997; Chung and Sessions, 2000). Additionally, it was preferred qualitative decision tools like AHP (Engür, 1996; Saaty, 1989) and knowledge based system (Lan, 2001), in order that some qualitative criteria could be added to decision process of the harvest planning.

In this study, it was aimed to introduce the conceptual framework of AHOP methodology to display that how the AHOP model had been set up for state forestry, which planning steps had been followed, how operational decisions had been optimized, how model results could have been adapted to real application problem and what the probable advantages obtained from solving of test problem was.

2. METHODOLOGY OF AHOP MODEL

It is benefited from transportation planning (Bayoğlu, 1996; Acar, 1994), and hierarchical planning concept (Weintraub and Cholaky, 1991; Gunn, 1991) to develop AHOP methodology, consisting of mainly three module that are; (1) Setting up database system and technical-topographical analysis, (2) Cost analysis of harvesting systems, and (3) Modeling of operational decisions, solutions, synthesis, and plan draft (Eker, 2004).

2.1. Database System and Technical Analysis

In the first module of the AHOP model, it is followed steps mentioned below (Figure 1).

1. A spatial database system is firstly designed by means of GIS, which should include topographical, stand, road network, and geology maps and georeferenced information relevant to their attributes. Harvesting compartment to be harvested in planning horizon is flagged. Information about each compartment such as standing volume, silvicultural
prescription, tree species, and background in previous plan horizon, are added to GIS database system.

![Database system and Technical Analysis Diagram]

Figure 1. Work flow of database system and technical analysis (Eker, 2004)

2. By using of GIS technology (like ArcGIS), the harvesting compartment ground is functionally classified (Samset, 1979; Acar, 1994) according to slope groups to determine appropriate extraction techniques used in each slope limitation.

3. It is calculated forest road density and opening up proportion. This is accessibility analysis that defines which road opens up each compartment to be harvested.

4. Before starting to technical analysis, alternative harvesting technology can be used in planning district is fixed. Possible cutting, extraction and hauling techniques, which forms harvesting system combination, are selected to topographical conditions, accessibility, and silvicultural intervention of the stands.

5. Transportation boundaries are drawn in each harvesting compartment that is divided to harvesting unit/blocks. The skidding distance and direction is calculated for each alternative extraction technique and point out landing locations via Digital Elevation Model. The real average skidding distance (Erdaş, 1997) for each block is estimated with respect to extraction technique, location of forest road, skidding direction, and length of slope of hill.

2.2. Cost Analysis

The main objective of the AHOP model is to minimize average harvesting unit cost varying of ground features, stand characteristics, assortment types and volume, harvesting method, time, and system. The most appropriate harvesting system for harvest operations is that system has the cheapest fixed and variable/operational cost. Thus, it is obtained a comparison table with respect to economical criterion. This stage of calculation harvesting cost is called as quantitative cost analysis phase (Figure 2).

1. Counting up cutting, felling, bucking, debarking, measuring, skidding, loading, hauling, and unloading cost of per cubic meter of each harvested tree are called harvesting unit cost that is function of standard working time and unit price.
2. Harvesting unit cost for each harvesting system constitutes of cutting and extraction costs. Hauling/transportation cost constitutes of loading, waiting, trip, and unloading cost. Hauling cost is called transportation or physical distribution cost. Both harvesting and transportation cost is calculated with quantitative values to per cubic meter of production.

In this stage, if it requested the most economical harvesting system, road route, and storage can be quantitatively selected. Unfortunately, it is unknown whether or not this harvesting system is acceptable for environmental and societal criterion. For that reason, micro level technology selection procedure (Engür, 1996) is used to compare the harvesting systems for multi-dimensional selection and made use of multi criteria analysis like AHP and Ranking techniques. It is followed the steps mentioned below for this strategy;

1. The influential criteria are to be used to select appropriate harvesting systems and indicators that is sub-criteria are determined by objectives of the state forest enterprise and effective factors on harvesting. These criteria are based on economical, technical-topographical, environmental, ergonomics, and social-institutional goals. To fix the most important criterion, it is used Ranking technique and obtained the weighted value.

2. Afterward, 5 main criteria and 17 sub-criteria that is indicators are evaluated by Analytical Hierarchy Process (AHP) (Saaty, 1989; Engür, 1996; Eker, 2004). In result of the methodology, AHP offers the relative weightiness vector. By reversing of which, it is obtained environmental and institutional impact coefficient including ergonomics and technical impacts. Thus, it is put forward a penalty coefficient appearing although a harvesting system is economically suitable and acceptable but not environmentally is selected.

3. The environmental and institutional impact (penalty) coefficient of the each possible harvesting system is multiplied by quantitative cost of harvesting system, result of which is added to quantitative cost. It is produced environmental and institutional cost (EIC) symbolizing to technical, ergonomics, societal and economical selection criteria. For this methods used in the step, it was inspired from Shemwetta’s (1997) methodology (Eker, 2004).

4. Furthermore, seasonal variations in one year can change work productivity, machine usefulness, workforce supply, harvesting cost, and etc. Therefore, 12 criteria such as climate, workforce, market demand, accessibility, etc. are used to examine performance of each season, 4 items in one planning year. There is used a single level comparison matrix in AHP context. According to relative weightiness vector, it is obtained the seasonal impact coefficient. As well, it is added quantitative cost same as mentioned second item and got a seasonal cost (SC) coefficient for each harvesting system (Eker, 2004).

5. On the other hand, harvesting method is influenced to operational productivity and cost, mechanization level, and workforce. In this respect, a cost variation ratio (CVR) is determined to harvesting method that may be short or long assortment in cut-to-length method. The CVR is multiplied by operational cost of harvesting system to define which harvesting method can be appropriate.

6. In the end of the process, quantitative cost that is operational cost of a harvesting system, is collected with EIC, SC, and CVR value. It is newly exposed a qualitative cost of each harvesting system. In the beginning of the strategy, whatever harvesting system that is
appropriate for economical criterion; now, may be inappropriate because EIC, SC, and CVR can qualitatively increase unit cost of harvesting system to be used. Thus, all alternative harvesting systems can be compared with as quantitatively and qualitatively to select acceptable one.

Figure 2. Work flow of harvesting (quantitative and qualitative) cost calculation

2.3. Modeling of the Operational Decisions

In order that operational decisions can be modeled, it is used mathematical modeling method (Dykstra, 1976; Rardin, 2000; Taha, 2000). The objective function of the model is; minimization of operational harvesting unit cost per harvested volume, in annual planning horizon. The cost coefficient is to be used in the model are produced by calculating of cutting, extraction, hauling/transportation costs, which are quantitative harvesting cost of each system. But, in some models, it is used qualitative cost coefficient for multi criteria evaluation to select the best harvesting systems. The modeling process is summarized in Figure 3.

Decision model of AHOP was firstly set up as Linear programming (LP) model (Main Model). Value of the decision variables in the main model were symbolized with continuous, semi-continuous, and integer variables. Afterwards, a hard obligatory constraint, which is that a harvesting block to be harvested in a planning horizon must be harvested in any season, with any harvesting system and method, was added to main LP-based model. This constraint conditioned that a harvesting block or compartment must be opening up at once in a planning year. So,
decision variables had to be taken [0/1] binary integer variables. The main LP-based model was subsequently converted to “0/1 Mixed Integer (linear) Programming (MIP)” model. At result, LP and MIP-based two models were developed for AHOP (Eker, 2004).

\[
Z_{\text{min}} = \sum (PM_p + T_p) \quad \forall p \in P; \ (p = 1, 2, 3, 4) \tag{1}
\]

Subject to:
- Harvesting volume to be harvested in one compartment or block is limited by AAC volume allowed by forest management and silvicultural plans.
  \[
  \sum_{p=1}^{3} \sum_{u=1}^{3} \sum_{x=1}^{10} X_{bpx} \times ETA_{bpx} - \text{BETA}_{bpx} = 0 \quad \forall b \in B; \ (b=1, 2, \ldots, 12) \tag{2}
  \]
- Total harvesting volume to be harvested in a planning horizon, is equal to total volume of harvesting compartment or block, all told.
  \[
  \sum_{b=1}^{12} \text{BETA}_b - \text{TOPETA} = 0 \quad \forall b \in B; \ (b=1, 2, \ldots, 12) \tag{3}
  \]
- Each harvesting compartment has to be harvested in one season of the planning horizon.

Figure 3. Work flow of mathematical modeling of operational decisions, synthesis, and plan
Harvesting volume to be harvested in each season is limited by minimum and maximum seasonal limitations.

\[ \text{MinHQ}_p \leq \text{HQ}_p \leq \text{MaxHQ}_p \quad \forall p \in P; \quad (p = 1, 2, 3, 4) \]  \hspace{1cm} (5)

Transported timber volume from each harvesting compartment cannot too much more than harvested volume in that compartment.

\[ \sum_{p,b,u} \sum_{s} X_{bps} \cdot \text{ETA}_{bs} - \sum_{p,b,u} Y_{bps} \geq 0 \]  \hspace{1cm} (6)

Total volume to be transported in each season, should be equal or less than harvesting volume in the same season.

\[ \sum_{b,p,u} \sum_{s} Y_{bps} - \text{TRANSPP}_p \geq 0 \]  \hspace{1cm} (7)

Transported volume in each season should fit to minimum and maximum limits of the storage, which is function of the market demands.

\[ \sum_{u,d} \sum_{a} \sum_{d} \text{DTLP}_{pad} \cdot \text{MIN}_{pad} \leq \text{TRANSPP}_p \leq \sum_{u,d} \sum_{d} \sum_{a} \sum_{d} \text{DTLP}_{pad} \cdot \text{MAX}_{pad} \]  \hspace{1cm} (8)

Harvesting capacity of a harvesting system, depending on productivity, is limited to workable time in one season and number of harvesting system.

1) \[ \sum_{b} \sum_{u} \sum_{s} \text{VRM}_{bps} \cdot X_{bps} \cdot \text{ETA}_{s} - S_P = 0 \]  \hspace{1cm} (9)

2) \[ S_P \leq Ad_{s} \cdot PU_{p} \quad \forall s \in S; (s = 1, \ldots, 10) \]

Transported volume in each season depends on number of trucks to be used in transportation and length of workable time in each season.

\[ \sum_{b} \sum_{u} \sum_{r} \text{VRM}_{bpr} \cdot Y_{bps} - \text{KMP}_{p} = 0 \quad \text{KMP}_{p} \leq Ad_{kmyn} \cdot PU_{p} \]  \hspace{1cm} (10)

Transportation decision variables have to be positive

\[ Y_{bps} \geq 0 \quad \forall b, p, u, s, r \]

Harvesting decision variables have to be binary [0/1]. If this constraint is removed from the model, MIP model turn into LP model form.

\[ X_{bps} = \begin{cases} 1 & \text{If harvesting of area } b, \text{ is harvested during season } p, \text{ by harvesting method } u \text{ system } s \\ 0 & \text{Otherwise} \end{cases} \]

In this model defined sets are;

- \( B \) is the set of harvesting compartment \( b \), divided into harvesting block/unit
- \( P \) is the number of time season/period \( p \)
- \( U \) is the set of harvesting method \( u \), symbolizing assortment types
- \( S \) is the set of all alternative harvesting systems \( s \)
- \( R \) is the set of alternative route \( r \), from each landing to national forest storage
- \( PM_p \) = Total harvesting costs during time season \( p \)
- \( TP_p \) = Total transportation costs during time season \( p \)
- \( X_{bps} \) = Decision variables symbolizing harvesting volume (m3) of compartment \( b \), during time season \( p \), by harvesting method \( u \) and system \( s \)
The various packet programs have capacity to solve hard matrix form and special decision support systems can be used to solve this mathematical model. On no circumstances, if a solvable routine is disqualified for integer programming problems in AHOP framework, then it can be used heuristic solution strategy. When it is reached an exact solution, it is checked the model by sensitivity analysis or in different problems. It is tested and synthesized whether or not the operational decision model is appropriate to optimize the main objective function.

The product of the AHOP model is the operational harvest plan. This plan should include information relating to all harvesting operations during a planning horizon, offer operation programs, and conjectural harvesting costs of the systems.

3. CASE STUDY

This AHOP methodology, supporting the operational decision making process through selection of suitable harvesting system in respect of economical, ecological, ergonomic, and social/institutional criteria, was theoretically tested in Turkish Forestry, in Aşağıgökdere State Forest Enterprise located in South of Turkey, as annual harvest operation planning problem. The problem area was amount of 16.352 hectare and the AAC was average 30,000 m$^3$/year. The number of compartment to be cut in the planning period was 12; 3 of which were to be clearcutting and the others were to be thinned. In the planning area, it was determined that 10 harvesting systems (combination) was to be used in. In this area, all forest operations must be done by forest villagers whose number was 430 people forming a family crew with 4 person. At least, one fourth of the forest villagers must have been worked in the harvest operations. Furthermore, it should be orderly supplied wood raw material of forest industry market in each harvesting season. There was 4 season to be made harvesting. Number of harvesting method was two; short and normal log assortment. The forest product must have been transported the two storage. The harvested products could be transported from different through 2 and 8 routes, changeable for each harvesting compartment, to storage. The problem comprised of 960 harvesting decision variables and 768 transportation decision variables (Eker, 2004).
To solve the test problems, it was used industrial LINDO solver. It could achieve to solve LP model and its extensions by semi-continuous variables, and MIP model by 0/1 binary variables and soft constraints. But, when the hard constraints were added to model, module of LINDO solving MIP model couldn’t it. In the case of, it was used optimality tolerance of the solver and developed an optimization-based simple heuristic procedure (Weintraub et all.,1994) in insolvability cases. In each LP and MIP model were modified by using of quantitative and qualitative cost coefficient. Thus, various strategies and scenarios were typically created. But, in this paper, it was not mentioned them.

4. CONCLUSION and RECOMMENDATIONS

AHOP model can offer one-year planning strategy for forest harvesting. The planning arguments of AHOP model are similar to other conventional harvest planning methodology. However, AHOP uses GIS, multi criteria analysis (AHP), and operations research techniques in a unified planning procedure.

It encapsulates three module and each one supports decisions on which harvesting systems are suitable for harvest operations to optimize multi-dimensional objectives. In the first module, it is technically and topographically determined the best utilizable harvesting systems. In the second, it is qualitatively defined which harvesting systems, methods, and season are the best for harvesting in the planning areas. At last module, it is quantitatively made operational decision subject to all constraints. By selecting of the most appropriate harvesting system, season and method, AHOP can enable minimizing of environmental impacts as ecological; reducing of heavy workload, improving of worker health and safety as ergonomics; satisfying of enterprises willing as institutionally; supplying of market demands and satisfying of forest villagers’ expectation as socially and politically.

The mathematical model, based on linear and mixed integer programming, was solved subject to structural constraints of the planning problem, it could be determined the most appropriate harvesting systems-season-method and harvesting costs per cubic meter could be minimized at least 4 % to %30 proportion. Both LP and MIP models could work and put forward the optimized results. But, LP as needed its characteristic, presented fractional solution set, which was not applicable for forest compartment because a part of the compartment was to be harvested in one season, the other part was in any season. LP divided into harvesting seasons, and systems. On the other hand, MIP offered exact solution sets. It permitted to be harvest of a compartment during one season time by one harvesting system and method. Therefore, although LP model could minimize objective function as 11 percent more than MIP models, MIP model was found as applicable for AHOP methodology.

On the contrary to traditional harvesting decision making process irrespective of any planning concept, this AHOP methodology offered the best solution to planners and manager with respect to the most economic and environmental, ergonomic, and societal decisions about harvest operation planning problem.

This planning methodology based on the balancing of annual budget and optimizing of objective function in one year time horizon. If it requested, it is can be enlarged modeling framework to two or five year time horizon or narrowed to one monthly time horizon. In addition, AHOP model should be designed as a computer program routine such as a decision
support system. Qualitative cost of each harvesting system may not be true way to calculate harvesting unit cost, but it can be effectively used in comparison with systems to select the most suitable one.
5. LITERATURE CITED

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