

The Evaluation of a National Forest Harvest Scheduling System for Ireland – Two Case Studies

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ABSTRACT

Coillte Teoranta (the Irish Forestry Board) harvested approximately 2.0 million m³ in 1994. By the year 2000 this annual harvest is projected to increase to approximately 2.8 million m³ and to 3.7 million m³ by the year 2011. To facilitate the management of these increased timber flows more efficiently and effectively, the Harvest Scheduling System (HSS) was developed.

In order to evaluate the HSS's solutions, five case studies were carried out, two of which are presented in this paper. Initially, the HSS model was solved without any management constraints, resulting in a theoretical maximum net present value (NPV) (case study 1). Subsequently, the effect of imposing national and regional level volume fluctuation constraints was examined (case study 2).

The investigations in the "no constraints" study resulted in a theoretical optimal harvest schedule for Coillte over the period 1998 to 2002. The solution showed great volume fluctuations from year to year, in terms of total volume, species, harvest type and product. It would be impossible to implement such a schedule, due to management, harvesting resources and industry requirements. However, the NPV achieved was used as a base to estimate the cost of applying management constraints in the second case study. This second study also showed that Coillte's production smoothing process results in harvest schedules that are not feasible, as no adjustments for volume are included.

Keywords: *harvest scheduling, decision-support, constraints, optimisation.*

INTRODUCTION

The total forest area in the Republic of Ireland has increased from 100,000 ha at the beginning of the century to 570,000 ha or 8% of the land area in 1998. The national timber supply is expected to grow from 2.2 million m³ in 1997 to 3.8 million m³ by 2010 and, provided current planting levels are maintained, should grow to about 10 million m³ by 2030 [2].

Coillte Teoranta (The Irish Forestry Board) is the largest forest landowner in Ireland. By the end of 1995, the Board owned 390,000 ha of forest estate [1]. The estate comprises 117 forests, consisting of 5,600 properties and 125,000 stands. However this estate is very unbalanced in terms of "age class" due to the very large planting programme over the last 20 years [2]. Figure 1 illustrates the state's planting programme from the 1920's to 1998 for the main species. Coillte currently supplies 97% of all timber processed in Ireland.

The increasing volume of timber harvested and the more specific requirements of the processing industry have made current planning procedures inadequate. Traditionally timber harvest scheduling has been conducted in isolation from timber allocation and no optimisation techniques have been used. The production of an efficient and cost effective harvest schedule that takes into account the forest management constraints, the processing sector requirements and the location of the demand and supply, has become an extremely difficult task.

To facilitate the effective and efficient management of these increased and more complex timber flows, new integrated management procedures for harvest scheduling are required. Currently a Harvest Scheduling System (HSS) prototype, incorporating timber allocation procedures, is being evaluated as a decision-support tool. The model has been formulated within the framework of linear programming (LP) and mixed integer programming (MIP) to produce optimal solutions. The model is linked to ARC/INFO (a geographic information system) which extends the post-allocation analysis and interpretation capabilities of the HSS and combines the output with the existing information systems.

During the development of the HSS, research carried out on similar type systems internationally was analysed to identify components that could be of relevance in the Irish situation. The systems studied included MELA [13, 14, 15] in Finland, FOLPI [3, 4, 5] and REGRAM [6, 7] in New Zealand and LOGPLAN [8, 9] in the United States of America.

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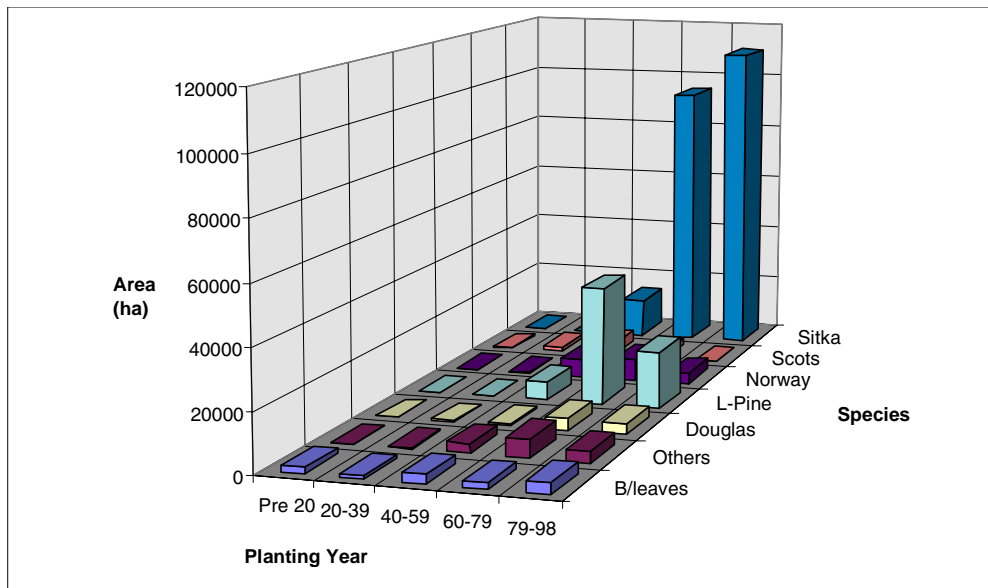


Figure 1. The state's planting programme for the main species.

The objectives of the current research project are:

1. To produce a system which is capable of supporting the management of the increasing and complex timber flows efficiently and effectively.
2. To identify constraints that need to be incorporated into the HSS in order to reconcile the solutions produced by the HSS with Coillte's requirements.
3. To evaluate the solutions produced by the HSS in a number of case studies.

The following studies have been carried out with a view to evaluate the HSS [6]:

- *The "no constraints" study*: The objective was to see what the maximum NPV and the associated NPV/m³ is that can be attained when no management constraints are applied.
- *Models that conform to Coillte's harvest forecast*: The objective was to see if the HSS could produce a forecast that is in line with Coillte's harvest forecast and to determine the associated decrease in NPV and NPV/m³ as compared with the "no constraints" study.
- *Periodic fluctuating volume constraints*: The objective was to produce an even supply of timber volume over all periods within each region and to determine the associated decrease in NPV and NPV/m³ as compared with the "no constraints" study.
- *Periodic increasing volume production models*: The objective was to create an increasing supply of volume from year to year within each region and to determine the cost of imposing these constraints when compared with the "no constraints" study.

- *Regional study*: The objective was to produce detailed harvest schedules for one of Coillte's 7 regions.

This paper presents the results of the first two studies.

THE HARVEST SCHEDULING SYSTEM

Past Development

Williamson [17] developed the Harvest Scheduling System prototype which is used in this study. The HSS has been formulated within the framework of LP and mixed integer programming (MIP) to optimise solutions. The model is linked to ARCINFO (Geographic Information System) which extends the analysis and interpretation capabilities of the HSS and combines the output with existing information systems.

The model was developed to help optimise the allocation and transportation of Coillte's annual timber supply of 1.4 million cubic meters in 1990. The study also compared the actual timber allocation and haulage routes with the optimal routes suggested by the study [10, 11]. The programme created a 38% improvement on overall transport costs [18].

The HSS was tested in a case study for a time span ranging from 1994 to 1998 [17, 19]. The system was used to produce optimal production targets, harvest schedules and timber allocation plans for the five year period. The formulation and solution of these models proved very successful. The system contains considerable flexibility in the

type of industry requirement constraints and forest management constraints that can be specified and solved successfully.

To improve Coillte's current methods of production target determination and timber allocation, a number of problems were addressed in the developed Harvest Scheduling System. Firstly, the processing industry demand was included in the HSS prototype, to change the emphasis from a production driven approach to a demand driven approach. Secondly, the spatial distribution effect of the market demand and timber supply and the associated haulage cost was included in the production target determination process. Thirdly, the economic consequences of selecting a particular production year for a particular stand were evaluated with respect to value increment, harvesting cost and transport cost. In addition, the HSS provides the manager with an optimal solution, whereas in the past the production of a stand harvest schedule was a "trial and error" process.

Hierarchical Structure of the HSS

A three level hierarchical model was used in the development of the present timber Harvest Scheduling System [17]. This approach requires the production of a national level model, 7 regional level models and 117 forest level models.

The national model determines optimal regional production targets which satisfy both the requirements of the processing industry and national, regional and forest management constraints. Production targets are specified by year, product, species, harvest type and demand node. The targets that were produced in the national model are used to run the seven regional models. Each region produces optimal production targets for each forest within that region. A forest level model is produced for 117 forests. The targets that were produced in the regional models are used to produce a stand harvest schedule for each forest.

The requirements of the processing industry on a national scale are identified and grouped into 7 main demand nodes. A demand node identifies the aggregated demand of a number of mills which are located at or near the location of the node. The reason for using aggregated demand nodes instead of individual mill demand nodes was the reduction in complexity of the models, while at the same time the accuracy of the solutions was not significantly affected.

Due to the scale and complexity of the scheduling and allocation problem, it is necessary to aggregate stands, for the national and regional level models, into logical management units based on a number of factors, includ-

ing species, stage of development and administrative unit. The 117 forest level models schedule individual stands and do not use aggregated management units.

The national and regional level models are formulated as linear programming (LP) problems. The forest level models are formulated as mixed integer programming (MIP) problems. In LP formulations, if an aggregated stand option is selected, stands can be partially thinned or felled. In MIP formulations, if a stand option is selected, the entire stand must be thinned, clearfelled or left untreated. It was decided to use the more computational complex and demanding MIP formulation for the stand level models as it is essential at this level of harvest scheduling that management units (i.e. stands) are treated as indivisible.

The Data Requirements

The data requirements of the model are extensive and consist of:

- Supply data;
- Demand data;
- Revenue data;
- Cost data.

The supply data consist of the forest inventory data for each stand that is potentially due for thinning or clearfelling in the planning period. Management alternatives are produced for each stand. A management alternative is an alternative production year (i.e. thinning or clearfell year) or combination of production years, from that specified in the thinning and rotation classification (TRC). The TRC is carried out by the local forest manager. The basic approach used to produce management alternatives is to calculate the production year(s) as per the TRC and to produce alternative production years either side of the TRC year(s).

For each demand node an annual round timber estimate (minimum and maximum) is required for the planning period. This should be specified by period, product, species and harvest type. The mill demand files consist of demand information for the twenty largest sawmills and the wood processing plants [16]. The delivered price of each product is also required. The delivered price of each product is the price of the product delivered at mill gate and includes the purchase price, as well as harvest and transportation costs. The prices used are based on actual recently recorded sales. The net revenue to the timber producer (i.e. Coillte) is presently calculated as follows:

$$\text{Net revenue} = \text{Delivered price} - (\text{Harvesting cost} + \text{Transport cost})$$

Net revenue is discounted by 5% per year to obtain net present value (NPV). Transport costs were set at "0" for this study as the actual allocation of timber was considered outside of the scope of this study. The harvesting cost for a stand is determined by the harvest type and the mean tree volume. Four harvest types are identified as the basis of costing the harvesting operation. These harvest types are (1) first, (2) second, (3) subsequent thinnings and (4) clearfell. Regional harvesting cost adjustments are also included.

Constraints

Constraints are used to control the level of production and can be applied at national, regional, district and forest levels. Within each level, constraints can be applied to volume, revenue and area. For the purposes of this study all constraints were applied to volume. For example, a constraint controlling the volume of Sitka spruce sawlog from first thinnings in district 11 in period 4 can be specified. Constraints can be applied to total volume or to individual products. For the purpose of this study specific constraints were not applied to species. An example of a constraint that could be applied to revenue would be that the income obtained should increase by a certain percentage every year. Equally, a forest manager might specify that the area of clearfell in a region should be less than 70% of the total harvest area. In general terms, constraints may be internal, management related or industrial related.

Internal constraints are concerned with the formulation and structure of the LP model. One type of internal constraint ensures that the area felled does not exceed the stand area. For example, for a regional model a stand with an area of 6.3 ha with three felling options for 1996, 1997 and 1998, requires a constraint which specifies that: $\text{Areafell96} + \text{Areafell97} + \text{Areafell98} \leq 6.3 \text{ ha}$.

Management constraints specify policy as regards the management of the entire forest estate, regions, districts and for forests. For example, it may be required that a certain level of production is maintained in each region throughout the planning period or that the annual production must be non-declining on a national basis. The demand of the processing industry is expressed by means of demand constraints. Demand constraints specify the maximum and minimum annual volume requirements of a particular industry demand node for a particular product for each year in the planning period.

Evaluation Methods

Coillte supplied up-to-date inventory data and the January 1997 forecast. This forecast was used to compile the management constraint files.

Simple industry demand constraints were applied in each of the five case studies outlined previously. These constraints were applied to an aggregation of all demand nodes, as allocation was not taken into account in this project. The evaluation methods used in the two case studies presented in this paper are outlined below.

The "no constraints" study

Management constraint files were not included in this model. However internal and total industry demand constraints were included. The result is maximum net revenue which is only limited by stand management options and industry demand. The cost of imposing any amount and type of additional constraints can be ascertained when added later. The "no constraints" solution is unlikely to be acceptable, because of the total lack of organisational inputs.

Models that conform to Coillte's harvest forecast

Explicit constraint files were created using Coillte's harvest forecast. Constraints were compiled, whereby the maximum fluctuation of the HSS volumes from Coillte's harvest forecast volumes was set at $\pm 50\%$, $\pm 20\%$, $\pm 10\%$, $\pm 5\%$, $\pm 3\%$, $\pm 2\%$ and $\pm 1\%$.

Table 1 illustrates national volume constraints. For example, the volume produced in period 1, for the whole country, must fall between 2,617,250 m³ and 2,892,750 m³ (line 1). The second constraint illustrates that the volume produced in period 1 from thinnings (harvest type = 1) must fall between 762,850 m³ and 843,150 m³. Similar constraints were applied at regional level. Constraints are applied to all products and harvest types. For each constraint file a national model, 7 regional models and some forest models were solved and analysed.

RESULTS

As pointed out previously, Coillte Teoranta kindly supplied the authors with details of their national production forecasts which range from 1997 to 2006, along with the appropriate regional forecasts, product forecasts and species forecasts. These forecasts were used in the research reported in this paper.

Initially, the HSS model was solved without any management constraints resulting in a theoretical maximum net present value (NPV). Following the completion of the "no constraints" study, the effect of imposing national and regional level volume fluctuation constraints upon the HSS's production was examined. These constraints were

compiled using Coillte's production forecast. A further objective was to examine the associated changes in NPV and NPV/m³. The planning period covered the years 1998 to 2002 (period 1 to 5).

Table 1. Section of a constraint file with volume fluctuations of $\pm 5\%$.

Period	Product	Species	Harvest Type	Minimum Volume (m ³)	Maximum Volume (m ³)	Constraint
1	0	0	0	2,617,250	2,892,750	1
1	0	0	1	762,850	843,150	1
1	0	0	2	1,854,400	2,049,600	1
1	1	0	0	715,350	790,650	1

Table 2. Regional production values (m³) when no management constraints are imposed.

Year	Region							Total
	1	2	3	4	5	6	7	
1998	715,199	385,961	354,412	328,911	415,421	485,844	314,251	2,999,999
1999	448,113	338,524	459,977	349,276	337,538	687,515	379,048	2,999,991
2000	278,973	284,991	290,209	896,953	434,280	455,695	358,898	2,999,999
2001	443,579	421,851	467,171	371,772	376,037	522,563	397,019	2,999,992
2002	419,850	446,023	451,952	597,618	172,076	527,180	385,306	3,000,005
Total	2,305,714	1,877,350	2,023,721	2,544,530	1,735,352	2,678,797	1,834,522	14,999,986

Figure 2. Regional production values (m³) when no management constraints are imposed.