

Supply chain planning of harvest operations and transportation after the storm Gudrun

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Abstract

The storm Gudrun hit southern Sweden in January 2005 and approximately 70 million cubic meters of forest was wind felled. The existing logistic planning at forest companies in the damaged area had to be changed over night. There was a direct shortage of both harvest and transportation capacities. Key questions that arised were which terminals to use, where to harvest, where to store, which transportation modes (truck, train, ship) to use. In this paper we describe how the forest company Sveaskog made use of Operations Research (OR) as an important decision support in their supply chain planning in the aftermath of the storm.

Keywords: Operations Research in Practice, Forestry, Mathematical models, Linear programming, Transportation, Logistics Planning.

1 Introduction

At the weekend of January 8-9, 2005, the storm Gudrun hit an area in southern Sweden with hurricane winds. During these days an estimated 70 million m^3 of forest was wind felled. This volume amounts to one annual harvest volume of the whole of Sweden. Most forest damages were concentrated to a region close to the west coast, see figure 1. The monetary value of the wood alone was approximately 3.2 billion Euros. Beside the forest damages, considerable damages occurred also for the infrastructure. Parts of the electricity and communication network were set out of order, e.g., 341,000 homes lost their power supply.

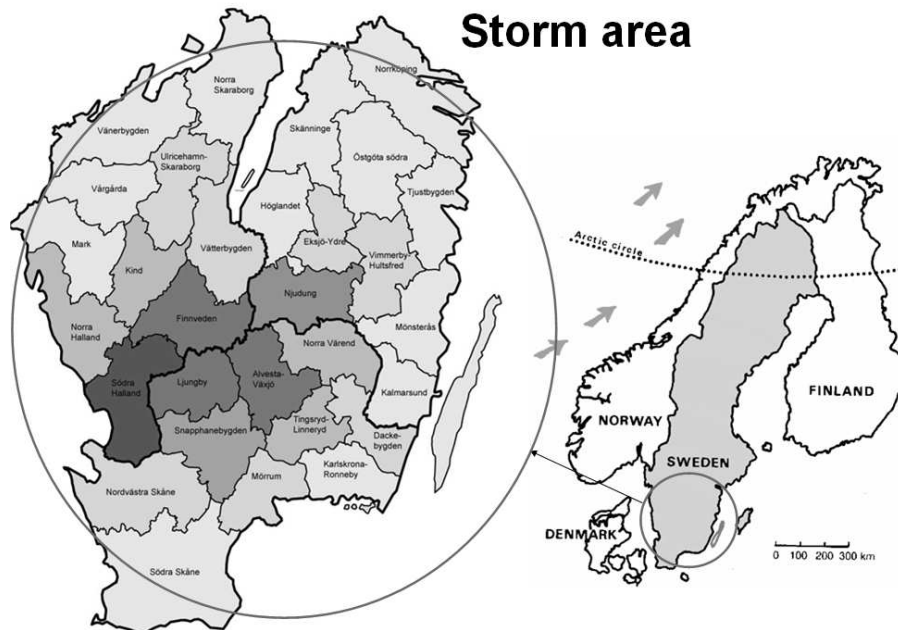


Figure 1: Storm damaged area in the southern part of Sweden. Darker areas have more damages.

There are a number of forest companies operating in this region, each having detailed plans for their logistic operations. At the same time as Gudrun hit the region, all plans for became obsolete. Much of the plans depended on historical harvesting from previous years. A number of questions emerged directly.

- How much volume was down and where?
- Is the available harvesting capacity enough?
- Is the available transportation capacity enough?
- How to supply existing customers?
- Where to store the extra wood?
- What are the affects on the wood market?

Damages and area

The storm hit an area of Sweden where the forest land is owned mainly by private forest owners. The main forest companies operating in the area is Södra Skogsägarna and Sydved, both heavily affected by the timber market. Land owning forest companies such as Stora Enso, Holmenskog and Sveaskog have their larger forest areas in other parts of Sweden. However, they too were affected. Sveaskog had almost 3 million m^3 wind felled timber to take care of. At the same time they had to continue with normal forest operations in other areas.

About 80% of the damages could be found on spruce stands and 20% referred to pine stands. The damages were concentrated to old forests. Also very young stands were struck hard. The damages were often confined to local geographical areas. One area could be unaffected and in an adjacent all trees were wind felled. Because of this, many small forest owners experienced a very different situation. In addition, some owners were insured and others not. Insurances were in turn based on the market value and this was for some assortments cut in half in a very short time.

Harvesting and storage

Due to the risk of decreasing timber quality it was important to take care of the wind felled volumes as soon as possible. Increased risk of pests and fires when temperature rises in the Spring required a quick handling of the timber. Due to the lack of resources the forestry companies had to focus on transportation of the most valuable assortment, pine timber. Time is also critical for fresh spruce pulp wood which is required by pulp and paper mills. Some pulp mills that require pine pulp wood tolerate older wood with more quality losses.

Given that there is a need to harvest and to clear the damaged areas as soon as possible, a critical question is where all logs will be stored. Most customers (saw, pulp and paper mills and heating plants) do not have enough storage space. A large number of storage terminals had to be established and taken into operation. It is important to water stored wood continuously. A number of alternatives are possible, ranging from storage in the forest (that is, not to harvest), at road sites, in lakes, at old airfields, on farm land etc. There is no precise answer for how long logs can be stored. It varies depending on assortment, place of storage and possibilities of watering. If the timber is stored properly and watered it can be stored between two and three years. In figures 2 and 3 we illustrate the storage of large volumes at an airfield and in a lake.

The harvest operations in wind felled forests differ from normal since the trees no longer are standing. Many trees are blown down into log jams. The most cost effective method for processing is to use heavy-duty harvesters and forwarders combined with motor manual work. However due to the lack of machinery also personnel working on ground with chain saws were used. Working manually in log jams is a dangerous work and a relatively large number of accidents and deaths were reported.



Figure 2: Storage at the airport Byholma where VIDA AB stores up to 800,000 m^3 . Photo by Per Groth.



Figure 3: Storage in the lake Kindasjön where Södra Skog stores up to 460,000 m^3 .

Need of new logistic structure and planning

As the volumes to be transported away from the areas increased, forest companies contracted logging trucks from other regions, mainly from the middle part of Sweden. Moreover, trucks were contracted from Finland, Germany, Poland and the Baltic States. The number of logging trucks operating in the area more than doubled. The transportation of logs by train and ship to mills outside the area increased. This was based on that new contracts, due to the over supply, had to be made.

The options to truck transportation were to increase the usage of train systems and start up with ships. One early belief among managers in the companies was to use trucks for short haulage to train terminals, harbors or storage terminals. Then train and ship transportation were to be used for the longer distances. Discussions with shipping companies and train providers started early. A complicating factor was that each company was dealing with its own problem and hence co-ordination was not considered.

It was important to deliver wood to existing customers. At the same time it was also important to take care of the wind felled areas as quick as possible. There were several reasons for this as mentioned earlier. In overall there were many logistical issues to consider and below we give some.

- Where to harvest/ not harvest?
- Which type of harvest teams/machines to use?
- Where to locate new storage terminals?
- Which train systems should be used?
- Which ship routes should be used?
- How to find more transportation and harvest capacities?
- Which customers are most important?

Project StormOpt

Sveaskog approached the Forestry Research Institute of Sweden (Skogforsk) to set up a supply chain/ logistics project. The aim was to develop a support tool for its logistics planning. Sveaskog had experiences from an earlier project where a new train and terminal system was evaluated using an OR support tool. The project, called StormOpt, had to be done in a short time period. Sveaskog aimed to harvest most of the damaged forest in the period February-June and this became the planning horizon. The necessary data collection, model development and to establish a set of scenarios were carried out in about one month. This was possible by extending models used in a flexible planning system called FlowOpt developed by Skogforsk. In the next sections we describe the situation for Sveaskog, the support tool and results and experiences from the project.

2 The Sveaskog situation

Sveaskog is a Swedish forestry company responsible for 4,6 million hectares of forests of which 3,5 millions are productive. This corresponds to 16% of Sweden's total productive area. About 500,000 hectares are located in the area which were affected by the storm. This resulted in a wind felled volume of 2,5-3 million m^3 of several different assortments. To be able to take care of the timber before the summer they had to substantially increase the harvesting resources. All planned harvesting operations in the middle of Sweden were reduced or stopped and the majority of the machines were sent to the affected areas. Within a couple of weeks there was enough harvesting resources working in the area but a great lack of transportation resources. The managers had to work hard to contract new trucks and to create new train routes, including finding new loading places.

Supply and demand

For Sveaskog the average transportation distance was normally about 100 km in the region and with the new situation it was estimated to increase substantially with a large increase in transport work. After the storm, the geographical distribution of the supply was very different from the demand, see figure 4. The total supply used in the analyses were 3,1 million m^3 . The supply was divided into 22 assortments depending on variety of tree, type of harvesting operation (thinning or final felling) and timber quality. The corresponding demand at the mills during the planning period was 2,3 million m^3 .



Figure 4: Description of new supply (dark circles) and existing demand (light circles).

Harvest and storage

In April (after the storm) Sveaskog had 145 harvesting teams working in the area. More than 90 of these were external resources i.e. from other parts of Sweden or from other countries. Both small, medium and large harvesters and forwarders were used. The harvest operations were divided into harvesting seed trees, normal final felling and thinning of stands with high and low average diameter respectively. Each of these four forest types provide a set of assortments. Also, each harvester type require different amount of time to harvest in the different forest types.

The areas were aggregated into 27 regions where all harvesting types were represented in almost all places. Sveaskog had no existing locations for storage in the area. Due to the fact that the transportation capacity were not enough they had to organise ten storage locations. In total they had a capacity of 400,000 m^3 . At these places the timber could be watered and by that reduce the risk of quality losses.

Transportation possibilities

As the harvest operations started there was an immediate lack of transportation capacity, especially in logging trucks. Sveaskog quickly organised a train transportation network to move 25,000 m^3 per week to mills in other parts of Sweden. Six harbours were used to ship timber to long distance receivers, both in Sweden and other countries. Figure 5 illustrates some potential routes for train and ship systems and figure 6 gives an example of a ship transportation.

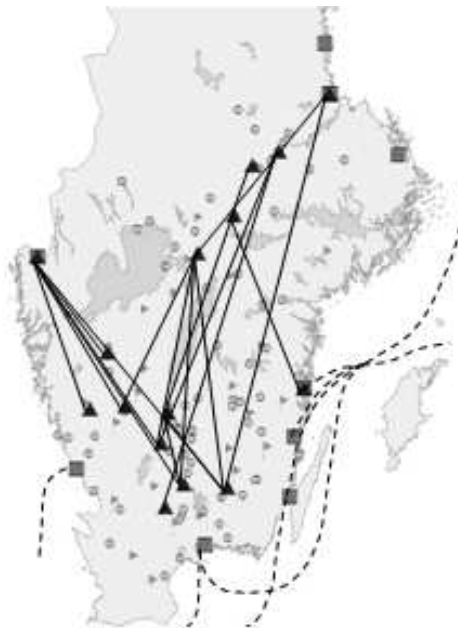


Figure 5: Illustration of a number of potential train systems (solid lines) and ship routes (broken lines).

To increase the transportation capacity three options were studied. The first was to increase the truck capacity by moving trucks from northern Sweden and to contract international trucks



Figure 6: A ship carrying logs. Photo by Mikael Frisk.

(mainly from Finland and Germany). The second was to study additional train systems with related train terminals. Twenty train system were considered. The third was to study the possibilities to use ship transportation and about 100 ship routes were considered. We note the multi-modal aspect where we may have truck, train as well as ship transportation.

Typically, a train system has one or more possible terminals where timber can be loaded and often just one where it is unloaded. At each terminal, there is a fixed cost for opening and another for handling i.e. loading and unloading. There is also a cost depending on volume and distance travelled. The capacity of a system is decided by how many wagons in use and the frequency of the trips. A ship transport is a simplified train transport. As such we can therefore model the ship systems as train system.

Wood market and extra customers

A large part of the timber were sold to ordinary customers in the southern and middle parts of Sweden. Some were stored in large timber storage places and some were sold to new customers. Since Sveaskog did not have enough orders for all volumes they had to find new customers, both in Sweden and abroad. A difficult issue was to prioritize potential customers considering the cost for transportation and the market price.

3 Decision support system and models

The problem is a combined strategic and tactical problem. It is a strategic problem because it involves decisions about which transport modes to use and which systems and terminals to

use. It is also a tactical problem because it involves decisions about destination of logs (to combine supply and demand points), harvest decisions and storage levels. Figure 7 illustrate the supply chain network. First the trees are harvested in stands and bucked into logs. The logs are then moved to storage points adjacent to forest roads. Here the logs are picked up by logging trucks and transported to industrial mills, terminals or harbours. From these locations they are transported by train and ships to mills or mill adjacent terminals.

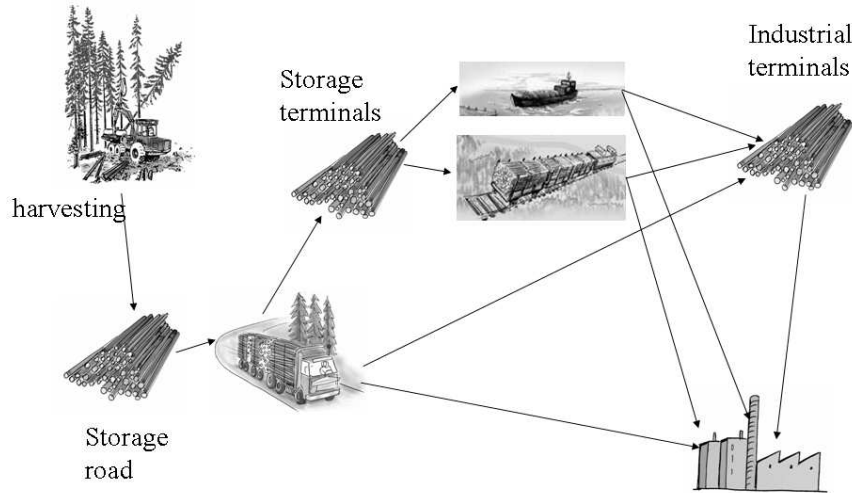


Figure 7: Structure of the supply chain network.

It is difficult to come up with efficient plans as there are many related decisions. In a normal situation, experienced planners have a fingertip feeling for what is correct based on experiences from similar situations earlier years. This is not valid here as the situation is totally new. The need to support the planners was very clear for Sveaskog.

System Description

Skogforsk has done a number of case-studies to evaluate the efficiency of transport organizations at forest companies. These studies were often time consuming in collecting data and generating result files, for example, flow maps. In a research project the system FlowOpt (see Forsberg *et al.* [1]) was developed together with several participating companies and organizations. The FlowOpt system makes it easier to handle data and interpret results. The time used for an analysis is considerably decreased when using the system. Basically, the process to make a wood flow analysis has four separate parts:

- Collecting data
- Pre-processing before optimization
- Optimization
- Processing and interpreting the results, report generation

Each of the process steps are supported in the system, see figure 8. The "Main application" is the central part of the FlowOpt system. The application is connected to a database storing the data about supply, demand, nodes, railway system etc. The interface offers different functionality for viewing geographical data and results, report generation and editing the data.

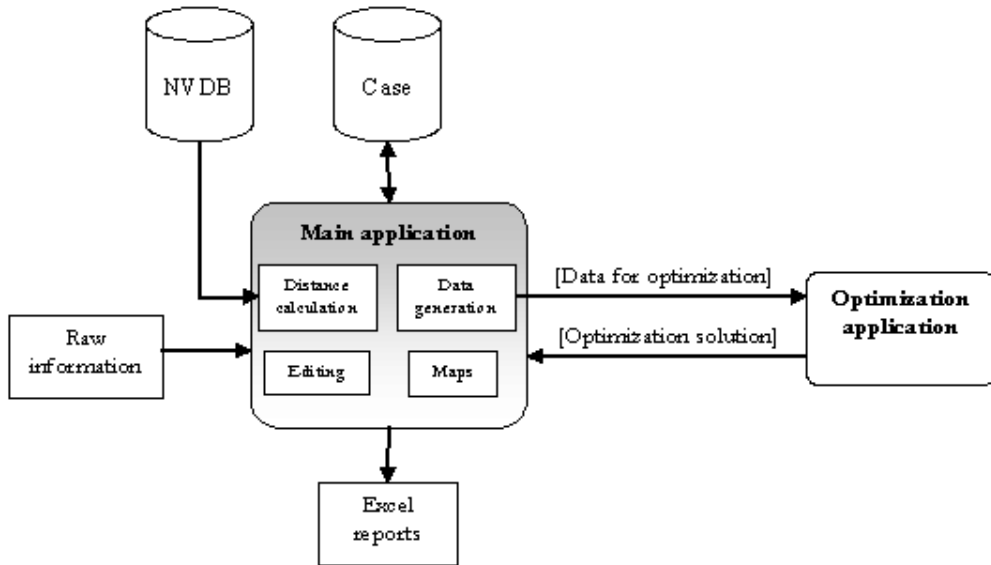


Figure 8: Overview of the FlowOpt system.

Information about, for example, supply and demand is company specific and denoted "Raw information". Road information from the National Road database (NVDB) is used when distances are calculated. All information necessary for the analysis is stored in a separate database, denoted "Case". The optimization module is located in a separate application. All data generation for the model including decisions about filtering of variables are done in "Data generation". All data is then translated into a mathematical model by use of a set of input/output routines and the AMPL modeling language (see [3]). As a solver we make use of the Cplex-optimization system (see [4]). Results from the optimization module are then imported back into the main application where different report options are possible.

The road information is taken from the Swedish National Road database (NVDB). The database contains digital information on all Swedish roads; the state road network, the municipal road and street network and private road networks. All roads, approximately over 500,000 km, are described geometrically, topologically and with detailed information about each road segment. This include road manager, road classification, road designation, height restrictions, load bearing obstacles, surface material, width and traffic regulations. Another application using NVDB is given in Frisk *et al.* [2] where a road investment problem is studied. An illustration of the geographical information is given in figure 9.

To calculate the actual driven distance between two locations is not straightforward. The transport agreements are typically not based on the shortest distance. Instead it depends on a combination of distance, speed limits, road owner, road width and road surface. In the system we can choose a combination of these factors in order to establish a distance table between all pairs of



Figure 9: The Swedish National Road Database includes all Swedish roads. Here an illustration of the network around the city of Uppsala.

nodes used in the planning process. In practice, we choose a weighting for each attribute that are combined into a single value for each road segment.

4 Operations Research model

In the project we use the FlowOpt system. However, there are some important differences to the OR model used. We need to include decisions on the harvesting operations in order to know the supply and add capacity restrictions in transportation and harvesting. Another difference is that we do not know the actual demand and hence we need to maximize the net profit in the model. In the project we have the following additional decisions and constraints to consider:

Decisions:

- which type of harvest team to use in each harvest area and forest type
- which parts not to harvest
- storage at terminals without demand

Constraints:

- limited transportation capacity
- limited harvest capacity
- linking between supply and harvesting decisions

The model is formulated as an Integer Programming (IP) problem. However, in most cases it is ok to solve it as an Linear Programming (LP) problem. The reason is that the additional binary variables relating to harvesting can be represented by continuous variables. This is motivated by the fact that several type of teams or machines can be used at the same time in the areas. Moreover, the possibility to get correct sensitivity analysis from a LP model as compared to an Integer Programming (IP) formulation is advantageous.

Mathematical model

In this section we describe the optimization model. The index sets used in the LP-model are:

- I : Set of supply points
- J : Set of demand points
- H : Set of assortments
- G : Set of assortment groups
- M : Set of terminals
- Q : Set of train sets
- L_q : Links in the railway system used by train set q
- K : Set of harvest machine types
- F : Set of Forest types

The truck flows are characterized by its starting point (supply point or terminal), its end point (demand point or terminal), the assortment and the assortment group the assortment is sorted to. We introduce the set L as all possible start and end locations, i.e. $L = I \cup J \cup M$. The train flows are defined in such a way that all combinations of flows on a train set is defined. The flow and storage variables are defined as

- x_{ijhg}^A = Flow from location i to location j with assortment h to assortment group g
- x_{qijhg}^T = Flow with train set q that load at terminal i , unload at terminal j with assortment h to assortment group g
- l_{ih}^S = Stock at supply point i of assortment h at the end of the period
- l_{jg}^D = Stock at demand point j of assortment group g at the end of the period
- l_{mgh}^S = Stock at terminal m of assortment h for assortment group g at the end of the period

The binary decisions associated with combining harvest machine type with harvest areas:

$$y_{kif}^H = \begin{cases} 1, & \text{if machine of type } k \text{ is used to harvest area } i \text{ and forest type } f \\ 0, & \text{otherwise} \end{cases}$$

$$y_{if}^0 = \begin{cases} 1, & \text{if harvest area } i \text{ and forest type } f \text{ is not harvested} \\ 0, & \text{otherwise} \end{cases}$$

In order to get a robust model we include penalized variables that can handle any shortage appearing at the demand points, as given below. If these are not included in the model we might not find any solution and then no possibility to identify the problem. If any of these variables are non-zero in the solution it is easy to find out what the problem is, e.g. an error with the input data.

w_{jg}^P = Unfulfilled demand of assortment group g at demand point j

The definitions of the data needed in the model are given below.

- s_{ifh} : Forest supply at supply point i in forest type f of assortment h
- d_{jg} : Demand at demand point j of assortment group g
- h_m : Harvest capacity for harvest machine type m (number of machine hours)
- b : Transportation capacity (expressed in ton*km)
- t_{ifk} : Time to harvest area i and forest type f by harvest machine type k
- d_{ij} : Distance between locations i and j
- u_q^T : Upper bound for total volumes on each railway link (l) in train set q
- u_m^M : Inflow (unloading) capacity at terminal m
- v_{jg}^D : Unit value at demand point i with assortment group g
- v_{ih}^S : Unit value of not harvested forest in area i of assortment h
- c_{ijh}^A : Unit cost for truck transportation of assortment h from node i to node j
- c_{ijq}^M : Unit cost for train transportation on train set q from terminal i to j
- c_k^H : Unit time cost to use harvest machine type k
- c_{jg}^P : Penalty per undelivered unit of demand of assortment group g at demand point j

A very important aspect is what variables are included in the final model. Many variables are removed because they do not satisfy company rules or restrictions. Others are removed because they are unpractical. We can, for example, set up conditions like

- Limit connections between supply points and demand points
- Limit connections between supply points and terminals
- Limit connections between terminals and demand points
- Limit connections between companies and/or forest areas

In order to keep track of the filtering we can define coefficients

$$a_{rijhg}^A = \begin{cases} 1, & \text{if flow that starts at location } i, \text{ ends at location } j \\ & \text{with assortment } h \text{ to assortment group } g \text{ is defined} \\ 0, & \text{otherwise} \end{cases}$$

In order to keep the notation simple, we introduce a set R^A which represents all variables x_{rijhg}^A defined. In the same way we introduce sets R^T for train (and ship) flows. We also use the following simplified notation to represent a summation over index sets. The same is also used for set R^T .

$$\sum_{i \in I} \sum_{j \in J} \sum_{h \in H} \sum_{g \in G} a_{ijhg}^A x_{ijhg}^A : \sum_{i,j,h,g \in R^A} x_{ijhg}^A$$

In order to keep track of physical flow of train system q that passes a certain link r in the railway system we use the set R_{qr}^T . This is simply the subset of variables in R^T where we have fixed indices q and r .

The objective consists of several parts and we have defined as follows.

$$\begin{aligned}
z_1 &= \sum_{i,j,h,g \in R^A} v_{jg}^D x_{ijhg}^A && \text{(value of deliveries)} \\
z_2 &= \sum_{i \in I} \sum_{f \in F} \sum_{h \in H} (v_{ih}^S s_{ifh}) y_{if}^0 && \text{(value forest not harvested)} \\
z_3 &= \sum_{i,j,h,g \in R^A} c_{ijh}^A x_{ijhg}^A + \sum_{q,i,j,h,g \in R^T} c_{qijh}^T x_{qijhg}^T && \text{(cost of transportation)} \\
z_4 &= \sum_{j \in J} \sum_{g \in G} c_{jg}^D l_{jg}^D + \sum_{m \in M} \sum_{g \in G} \sum_{h \in H} c_{mgh}^M l_{mgh}^M + \sum_{i \in I} \sum_{h \in H} c_{ih}^S l_{ih}^S && \text{(cost of storage)} \\
z_5 &= \sum_{i \in I} \sum_{f \in F} \sum_{k \in K} (c_k^H t_{ifk}) y_{ifk}^H && \text{(cost of harvesting)} \\
z_6 &= \sum_{j \in J} \sum_{g \in G} c_{jg}^P w_{jg}^P && \text{(penalty cost)}
\end{aligned}$$

In order to take into account the value of logs at forest roads we use a negative cost for the storage cost at harvest areas. The full model can be formulated as

$$\begin{aligned}
\max \quad z &= z_1 + z_2 - (z_3 + z_4 + z_5 + z_6) \\
\text{s.t.} \quad & \sum_{j,g \in R^A} x_{ijgh}^A + l_{ih} = \sum_{f \in F} \sum_{k \in K} s_{ifh} y_{ifk}^H, \quad \forall i, h && (A) \\
& \sum_{i,h \in R^A} x_{ijhg}^A - l_{jg}^D = d_{jg} - w_{jg}^P, \quad \forall g, j && (B) \\
& \sum_{i \in R^A} x_{imhg}^A + \sum_{q,i \in R^T} x_{qimhg}^T - \sum_{j \in R^A} x_{mjhg}^A - \sum_{q,j \in R^T} x_{qmjhg}^T - l_{mgh}^M = 0, \quad \forall g, h, m && (C) \\
& \sum_{i,j,g,h \in R_{qr}^T} x_{qijhg}^T \leq u_q^T, \quad \forall q, r \in L_q && (D) \\
& \sum_{i,h,g \in R^A} x_{imhg}^A \leq u_m^M, \quad \forall m && (E) \\
& \sum_{i,j,h,g \in R^A} d_{ij} x_{ijhg}^A \leq b, && (F) \\
& \sum_{i \in I} \sum_{f \in F} t_{ifk} y_{ifk} \leq h_k, \quad \forall k && (G) \\
& y_{if}^0 + \sum_{k \in K} y_{ifk}^H = 1, \quad \forall i, f && (H) \\
& x_{ijgh}^A, x_{qijhg}^T, l_{ih}^S, l_{jg}^D, l_{mgh}^M, w_{jg}^P \geq 0, \\
& y_{if}^0, y_{ifk}^H \in \{0, 1\}
\end{aligned}$$

Constraint set (A) represent actual supply. Here the available supply is determined by the harvesting which in turn is a decision. Set (B) describes the demand, set (C) terminal balance, set (D) link capacity, set (E) terminal capacity and set (F) truck capacity in terms of ton*km. Constraint set (G) express the harvest capacity in terms of available harvesting hours and set

(H) express the harvest decisions i.e. a forest type in an area must either not be harvested or be harvested by a harvest machine type.

5 Results

The data was collected from forest managers and logistics managers at Sveaskog. The information was continuously updated during the project. A number of scenarios were set up. These included a number of "what if " scenarios around both transportation and harvesting capacities and different value/ cost structures.

Optimization model

Given the data we were able to formulate the model. Some aggregated information expressing the dimension of the model is given in Table 1. To solve the resulting LP model was less than one minute on a standard PC. The time period represent February - June. One difficult problem in collecting the data was to estimate the value of deliveries and the value of logs in different storage locations. However, testing different scenarios showed that small changes did not affect the overall solution.

Aspect	Size	Aspect	Size
Number of of areas	27	Number of assortments	22
Number of harvest machine types	3	Number of assortment groups	23
Number of train systems	21	Number of ship systems	110
Number of harvest teams	135-200	Number of trucks	77-122
Volume million m^3	3,1	Number of constraints	4,500
Number of variables	195,000		

Table 1: Key data about the case study.

The solution from the model and the most relevant scenario became the approach taken by Sveaskog. Some important factors are as follows:

- The storm felled forest for Sveaskog was not "harbour close".
- The logistics costs associated with deliveries to/from harbours were relatively high.
- Truck and transportation capacity was the most limiting factor.

The above factors provided limited prerequisites for export using ships. It soon also became clear that if Sveaskog would finish before other companies, the harvesting would need to be in non storm felled forests but with a price that is based on storm felled. Therefore, there was not a focus to increase the harvesting capacity as much as possible. Instead, there was decisions taken not to move smaller harvest units in the north of Sweden southwards. In the model a number

of potential customer orders were added. From the results it was easy to establish a customer ranking list based on the shadow prices from the LP solution. This had a very practical impact of the work with finding new customers and negotiate the agreements.

Experiences and what happened

The overall strategy taken was to find as many customer as possible in the storm felled area and to ensure volumes on trains and trucks for prioritized customers. In the beginning, the harvest operations were focused on the infrastructure, e.g., clearing roads and telecommunication lines. The weather conditions with deep snow made the operations difficult. After some time, when the snow depths was less, the harvest level increased rapidly.

More medium and large units than expected arrived and contributed to the large increase. Instead of 54-59-32 (large-medium-small harvest units) there were 64-74-14 units. In figure 10, we show the harvesting, delivery and storage levels. Increase in the number of trucks was slower and it was not until the middle of April when there was a balance between truck and harvesting capacities (84 trucks were in operation). This is the reason why the storage, as shown in the figure, increased until April.

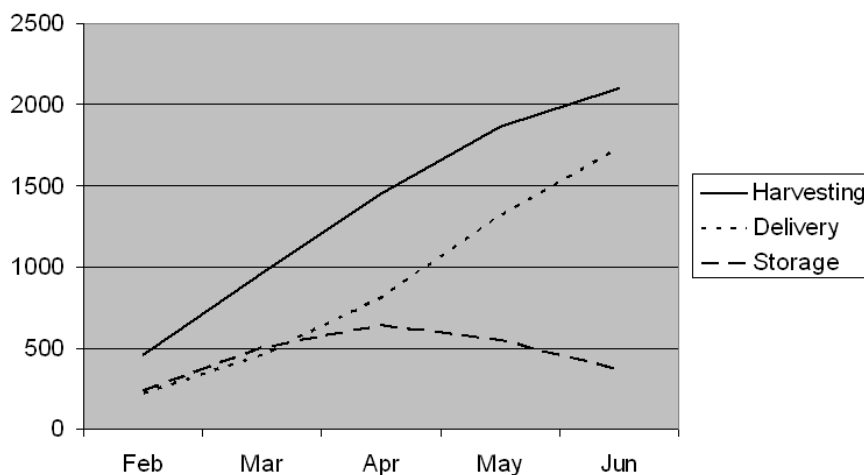


Figure 10: Actual harvesting, delivery and storage levels (all in 1000 m^3).

In the break between April-May it became evident that the storm felled volumes were less than the estimations (measured 2,45 against estimated 3,1 million m^3). It then became important to reduce the harvesting in order to balance the workload with capacity over a longer period.

The volume carried by train was planned to be at 369,000 m^3 and this was the level in practice. The average distance for the trucks was 83 km which is lower than 2004 when it was 97 km. The total volume carried on trucks were 1,73 million m^3 . The transportation work on train was 47% of the total work with an average distance of 340 km. This transportation work on train represented 64 trucks and was the reason that the average trucking distance could be lower for the trucks.

In figure 11, we summarize some important numbers. Of the harvested volume, 160,000 m^3 was placed in storage at terminals without any customer. A large proportion (1,930,000 m^3) was placed at customers but a part (240,000 m^3) could not be delivered due to insufficient transportation capacity. At the end of June, 560,000 m^3 was still in storage at road sites.

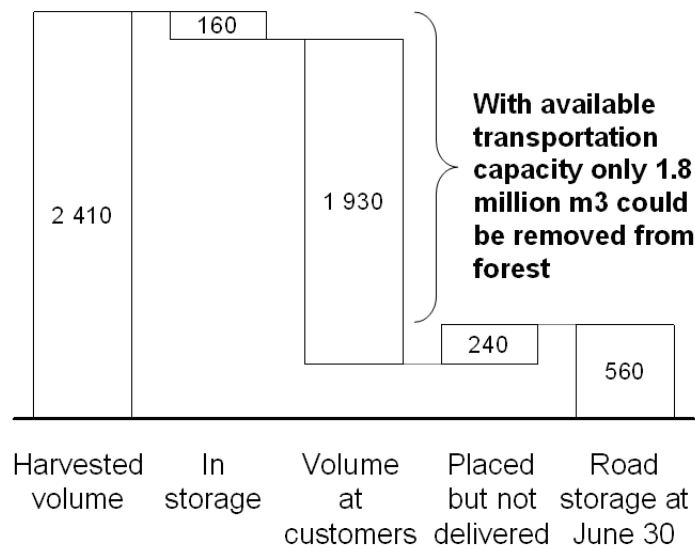


Figure 11: Actual outcome of harvesting and storage (all in 1000 m^3).

Even if the actual volume carried by train was equal the planned, it is the part of the planning that changed most. The flexibility of the train system was overestimated due to limited time on the railway system, limited number of loading/unloading locations, limited area at terminals and a low flexibility by the train providers.

The volume carried by ship was smaller than planned (23,000 against 52,000 m^3). One reason for this was a Finish strike during the period that resulted in less demand for exports. In overall, Sveaskog experienced that the operations carried out during the period was efficient and that the logistic challenge imposed by Gudrun could be met together with organising and carrying out the normal operations.

6 Concluding remarks

In the project StormOpt we successfully were able to develop a support tool to Sveaskog to assist their logistics planning. This is from both a strategic and tactical perspective. It was possible, despite short time, much due to the existing system FlowOpt and making use of the Swedish road database. The process has increased both competence and acceptance in using OR tools at Sveaskog.

The model developed describes the situation in an accurate way and the results provided new and valuable insights for the logistics managers at Sveaskog. The analyses helped Sveaskog to find priority customers and support in negotiations. Basic data have been used in many "what

if" scenarios in order to judge alternatives. This is in particular true for different harvest and transport capacities. The results often confirms practical solutions of the new situations. The experiments and results contributed to the strategy for the operations implemented at Sveaskog. The estimates and plans from the model work was very close to the actual operations carried out in practice.

References

- [1] Forsberg, M., M. Frisk and M. Rönnqvist, 2005, FlowOpt - a decision support tool for strategic and tactical transportation planning in forestry, *International Journal of Forest Engineering*, 16, 101-114.
- [2] Frisk M., Karlsson J. and Rönnqvist M. 2006, RoadOpt - a decision support system for road upgrading in forestry, *Scandinavian Journal of Forest Research*, Vol. 21, Suppl. 7, 5-15, 2006.
- [3] Fourer, R., Gay, D.M. and Kernighan, B.W., 2003, *AMPL – A modeling language for mathematical programming*, 2nd edition, (Thomson)
- [4] ILOG CPLEX 8.0, User's manual, 2002.