

## Final report

**Project title: Decision support systems in forestry based on optimization**

**Project leader: Mikael Rönnqvist**

**Project time: 1999-2004**

### Summary of scientific results

During the Ceniit project there has been a close cooperation with other projects related to decision support based on optimization for forestry. The funding from Ceniit has been critical when it comes to actually get these other projects funded. The other funding sources are Vetenskapsrådet, Vinnova, Formas and direct funding from participating companies / organisations. A short description of each of the main projects is given below.

#### **Optimal control of bleaching process at Billerud**

We have developed a support system at the paper mill Skärblacka for its bleaching process. This is put in production together with Eurocon Automation AB and has shown large savings both in terms of chemical costs and time savings for the staff. This work has also led to co-operation with NPI (Network for Process Intelligence) at Mitthögskolan for a study if the same support tool could work at Domsjö fabriken in Örnsköldsvik. This work involves Patrik Flisberg.

#### **Production planning at Södra Cell**

We have together with Södra Cell developed models and solution methods for their integrated production planning and supply chain planning. One of the highlights was that we won a prestigious award in July 2001, *The EURO Excellence in Practice Award*. This work involves David Bredström, Jan Lundgren, Dick Carlsson (Södra Cell) and Andrew Mason (Auckland University).

#### **Ship routing and terminal location at Södra cell / Södra Shipping**

We have developed models and methods for their terminal location in Europe. This in order to decide which terminals to use (and size) in their distribution system. In a related project we have also developed models and methods for their distribution planning where ship schedules are an important part. This work is a joint work together with Professor Maud Göthe-Lundgren (Optimeringslära) and Professor Peter Värbrand and PhD student Henrik Andersson at ITN (Campus Norrköping). This work involves David Bredström and Helene Gunnarsson.

#### **Production planning at saw mills**

In a project called CustOpt we developed a prototype system which was tested at Scaninge Timber. The project is to develop detailed optimization models for production planning at saw-mills. The production involves transportation of logs from several harvest areas, sorting, sawing, drying, grading, planning and fulfilment of customer orders. This work involves Bertil Liden from Skogforsk.

### **Route generation**

We have developed an advanced route generation system that is in use in "Åkar-web" a web-page based planning system at Holmen Skog (for their own transport planners).

### **Roll cutting**

In this project we have been involved with the development of two industrial systems at Pepto Systems. The first problem is to cut paper reels into smaller product rolls. An overall demand of rolls is used to decide cutting patterns of reels. The second problem is to optimize each individual reel when defects must be taken into account. This work involves Johan Bergman (Master Student).

### **Forwarding operations**

We have together with SkogForsk developed a system that can be used in forwarding operations. Tests have shown that it is possible to build a working system where GPS, optimization, radio communication can be used in real time. This work involves Patrik Flisberg and Mathias Forsberg (Skogforsk).

### **Logistic support**

In a Vinnova financed project we are working on development of a planning model, FlowOpt, for integrated transportation planning involving both trucks and trains. This system is based on the new Swedish road database NVDB. It is a joint project between LiU, Skogforsk and four forest companies; StoraEnso, SCA, Holmen Skog and Södra Skog. We are currently testing the system in some case studies. This work involves Patrik Flisberg and Mattias Lindqvist (Master student).

### **Applied routing**

Within the research group we also has a project regarding transportation in forestry where the main research topic is to find efficient routes for the logging trucks. This is a project that is financed by VR but there are several issues and subprojects that are linked to other Ceniit-project. We are together with Skogforsk developing a system, called RuttOpt, based on NVDB and where we are responsible for the optimization modelling and methods. This work involves Myrna Palmgren, Bertil Liden (Skogforsk) and Gert Andersson (Skogforsk).

### **Road investments**

In a Formas financed project we are working on development of a planning model, VägRust, for strategic road investments. This system is also based on the new Swedish road database NVDB. It is a joint project between LiU, Skogforsk and six forest companies. In an earlier project we developed methods and models for harvest planning. This work involves Jenny Karlsson and Mathias Henningsson.

### **Transportation planning**

From our earlier experience in developing support systems for transportation planning we have managed to get a project to develop one module for Sveaskog's overall planning system. The work is done together with Skogforsk and Sveaskog. This work involves Kennet Melin and Patrik Flisberg.

### **Transportation of fuel wood**

Together with Sydved energileveranser we have studied an annual planning problem where selection of harvest areas, use of chipping technique/strategy, use of terminals and transportation are integrated. This work involves Helene Gunnarsson.

### **Figure sawing**

Together with Soliton Elektronik we have developed a prototype system for figures sawing. The main application was for furniture manufacturing. This work involves Magnus Johansson.

### **Sorting strategies in harvest areas**

Together with Södra Skog we have developed a model and solution method where transportation is integrated with sorting decisions. This is interesting when the demand requires sorting in e.g. pine and spruce. This work involves Carl-Gustaf Carlgren and Dick Carlsson (Södra Skog).

## **Degrees resulting from the project**

Helene Gunnarsson, Optimization approaches to tactical planning problems in the forest industry, Licentiate thesis, Linköping University, 2004.

David Bredström, Optimization models and methods for production planning and ship scheduling in the pulp industry, Licentiate thesis, Linköping University, 2003.

Jenny Karlsson, Optimization models and methods for tactical and operative harvest planning, Licentiate thesis, Linköping University, 2002.

Myrna Palmgren, Optimisation methods for log truck scheduling, Licentiate thesis, Linköping University, 2001.

Beside these degrees the plan is that the following persons will finish their PhD thesis as follows:

Jenny Karlsson, Spring 2005  
Patrik Flisberg, Winter 2005/2006  
David Bredström, Summer 2006  
Helene Gunnarsson, Winter 2006/2007

## **Master of Science projects**

Joakim Gåfväls, Bestämning av styrprislister och styrning för apteringsdatorer i skördare, Examensarbete E287 i optimeringslära och systemteori, KTH, 2004.

Anders Brännvall, Fiberanpassat råvaruflöde – En studie av råvaruflöden till pappersbruken I Braviken och Hallstavik, LiTH-MAT-EX-2004-09.

Andreas Larsson, A model for multiperiod route planning and a tabu search method for daily log truck scheduling, LiTH-MAT-EX-2004-01.

Christer Holm, A model for multiperiod route planning and a tabu search method for daily log truck scheduling, LiTH-MAT-EX-2004-01.

Mattias Lindqvist, An optimization-based system for planning of forestry transportation, LiTH-MAT-EX-2003-10.

Monika Wolf, An optimization model and method for a forest harvesting problem including mature habitat patches, Diploma Thesis, Germany.

Joakim Isaksson, Generering av effektiva returflöden och kostnadsdelning i skogsindustrin (Generation of efficient backhaulage tours and cost allocation in forestry), LiTH-MAT-EX-2001-05.

Peter Broström, Solving the forwarding problem using Taburoute, LiTH-MAT-EX-2001-03.

David Bredström, Supply chain optimization at Södra Cell, with concentration on production planning, LiTH-MAT-EX-2000-10.

Johan Bergman, Paper roll cutting, planning. LiTH-MAT-EX-2000-05.

## **Personnel / staff financed (partly) in project**

Mikael Rönnqvist, Professor, project leader  
Helene Gunnarsson, PhD student  
Patrik Flisberg, PhD student/ Forskningsingenjör  
Carl-Gustaf Carlgren, Forskningsingenjör  
David Bredström, PhD student/ Forskningsingenjör  
Magnus Johansson, Forskningsingenjör  
Peter Igeklint, Forskningsingenjör  
Marcus Claesson, Forskningsingenjör

Staff in research group funded by other organisations:

Jenny Karlsson, PhD student  
Myrna Palmgren, PhD student  
Mathias Henningsson, Lecturer  
Kennet Melin, Forskningsingenjör

## **Industrial contacts**

We have had industrial contacts with the following companies/ organisations:

Billerud, process control  
Eurocon Automation, process control  
Holmen Skog, Routing, logistic planning, harvest planning  
NPI, process control  
Pepto Systems, paper roll cutting  
Scaninge Timber, production planning  
SCA, logistic planning  
Skogforsk, transportation, production, logistics, etc  
Soliton Elektronik, figure sawing  
Stora Enso, logistic planning  
Sveaskog, transportation planning  
Sydved energileveranser, transportation planning  
Södra Skog, transportation planning, harvest planning  
Södra Cell, production planning, supply chain management, terminal location, ship routing

## **Interaction with other Ceniit projects and new research group**

There has been a co-operation with the Ceniit-project: *Combinatorial optimization models and methods for cyclic sequencing* (Maud Göthe-Lundgren). We have developed solution methods for two routing applications: Generation of back-haulage tours and Extraction of logs. There has been a continued co-operation and the most important result is the Vinnova funded project *Design and control of advanced distribution system for ship scheduling*.

With the Ceniit funding it has been possible to establish a research group working with forest related research and development. Since the beginning of the project there has been an increased acceptance and recognition, both from Swedish companies and international research groups, of the work done in forestry by the group at the Division of Optimization.

## Publications

### Refereed Journals

D. Carlsson and M. Rönnqvist, Supply chain management in forestry – case studies at Södra Cell AB, *European Journal of Operational Research*, Vol 163, pp. 589-616, 2005.

J. Karlsson, M. Rönnqvist and J. Bergström, An optimization model for annual harvest planning, *Canadian Journal of Forest Research*, Vol 34, No. 8, pp. 1747-1754, 2004.

M. Puodziunas, M. Rönnqvist and D. Fjeld, The potential of improvement for tactical planning of roundwood transport in Lithuanian state forest enterprises, *Baltic Forestry*, Vol. 10, No. 1, pp. 79-88, 2004.

H. Gunnarsson, J. T. Lundgren and M. Rönnqvist, Supply chain modelling of forest fuel, *European Journal of Operational Research*, Vol 158, No 1, pp 101-123, 2004.

D. Bredström, J. T. Lundgren, M. Rönnqvist, D. Carlsson and A. Mason, Supply chain optimization in the pulp mill industry – IP models, column generation and novel constraint branches, *European Journal of Operational Research*, Vol 156, pp 2-22, 2004.

M. Palmgren, M. Rönnqvist and P. Värbrand, A near-exact method for solving the log-truck scheduling problem, *International Transactions of Operations Research*, Vol. 11, No. 4, pp 447-464, 2004.

J. Karlsson, M. Rönnqvist and J. Bergström, Short-term harvest planning including scheduling of harvest crews, *International Transactions of Operations Research*, Vol. 10, pp 413-431, 2003.

M. Palmgren, M. Rönnqvist and P. Värbrand, A solution approach for log truck scheduling based on composite pricing and branch and bound, *International Transactions of Operations Research*, Vol. 10, No. 5, pp 433-448, 2003.

M. Rönnqvist, Optimization in forestry, *Mathematical Programming*, Ser. B, Vol. 97, pp 267-284, 2003.

C.L. Todoroki and M. Rönnqvist, Dynamic Control of Timber Production at a Sawmill with Log Sawing Optimization, *Scandinavian Journal of Forest Research*, Vol 17:1, pp. 79-89, 2002.

C.L. Todoroki and M. Rönnqvist, Log sawing optimisation directed by market demands, *The New Zealand Journal of Forestry*, February, pp. 29-33, 2001.

T. Allsopp, M. Rönnqvist and C.L. Todoroki, Usage of 3D geometry descriptions in log bucking and curve sawing, *Annals of Operations Research*, Vol. 95, pp 93-113, 2000.

C.L. Todoroki and M. Rönnqvist, Combined primary and secondary log breakdown optimisation, *Journal of the Operational Research Society*, Vol. 50, No. 3, pp 219-229, 1999.

### Technical Journals

M. Rönnqvist, Integrerad produktionsplanering för massabruk, *Nordisk Papper och Massa*, No. 5, pp. 61, 2002. (in Swedish)

D. Bredström and M. Rönnqvist, Integrerad produktionsplanering för massabruk, *ORbit*, No. 2, pp. 2, 6-9, October 2002. (in Swedish)

### Section in books

J. Bergström, J. Karlsson and M. Rönnqvist, Annual harvest planning integrated with crew assignment and transportation planning, G.J. Arthaud and T.M. Barrett (eds) *Systems Analysis in Forest Resources*, pp. 27-33, Kluwer, 2003.

H. Gunnarsson, J. Lundgren and M. Rönnqvist, Supply chain modelling of forest fuel, G.J. Arthaud and T.M. Barrett (eds) *Systems Analysis in Forest Resources*, pp. 27-33, Kluwer, 2003.

A. McNaughton, M. Rönnqvist and D. Ryan, A model which integrates strategic and tactical aspects of forest harvesting, in M.J.D. Powell and S. Scholtes (eds) *System Modelling and Optimization: Methods, Theory and Applications*, pp 189-207, Kluwer Academic Publishers, Boston, 2000.

## Proceedings

M. Rönnqvist, M. Forsberg and M. Frisk, FlowOpt – A flexible decision support tool for strategic and tactical planning in forestry, Proceedings of TRISTAN 2004, Triennial Symposium on Transportation Analysis, Guadalupe, French West Indies, June 13-18, 2004.

M. Rönnqvist, M. Forsberg and M. Frisk, FlowOpt – A new decision support system in the forest supply chain, Proceedings of NOFOMA 2004, Linköping, Sweden, June 7-8, 2004.

M. Rönnqvist, Modeller för operationsanalys, Skogsindustrins råvaruförsörjningskedja – pågående utveckling och utblickar mot andra branscher, Kungliga Skogs- och lantbruksakademins tidsskrift, pp 27-32, Årgång 142, No. 19, 2003.

H. Gunnarsson, J. Lundgren and M. Rönnqvist, Proceedings of the 2nd Forest Engineering Conference, Växjö, May 12-15, Sweden, 2003. Decision support system/tools: Optimization of transportation, storage and chipping of forest fuel, 74-82, 2003.

M. Forsberg and M. Rönnqvist, Proceedings of the 2nd Forest Engineering Conference, Växjö, May 12-15, Sweden, 2003. Decision support system/tools: Integrated logistics management in the forest supply chain, 64-73, 2003.

J. Eriksson and M. Rönnqvist, Proceedings of the 2nd Forest Engineering Conference, Växjö, May 12-15, Sweden, 2003. Decision support system/tools: Transportation and route planning: Åkarweb – a web based planning system, 48-57, 2003.

P. Flisberg, S. Nilsson and M. Rönnqvist, Optimized control of the bleaching process at pulp mills, Proceedings of the Control Systems 2002, June 3-5, Stockholm, Sweden, 210-214, 2002.

J. Bergman, P. Flisberg, and M. Rönnqvist, Roll cutting at paper mills, Proceedings of the Control Systems 2002, June 3-5, Stockholm, Sweden, 159-163, 2002.

P. Flisberg, M. Forsberg and M. Rönnqvist, Forwarding in harvest areas, Symposium on Models and Systems in Forestry, Punta de Tralca, Chile, March 4-7, 2002.

M. Rönnqvist, Transportplanering med flera sortiment (Transport planning with several assortments), Proceedings from Skogskonferensen: Effektiv drift i skogen, Uppsala, Sweden, December 4-5, 51-52, 2001 (in Swedish)

D. Bredström, J. T. Lundgren, M. Rönnqvist, D. Carlsson and A. Mason, Supply chain optimization in the pulp mill industry, Proceedings of the Logistics Research Network 6<sup>th</sup> Annual Conference, Heriot-Watt University, 13-14 September, 67-74, 2001

D. Carlsson, M. Rönnqvist, Terminal location integrated with ship routing, Proceedings of the Triennial Symposium on Transportation Analysis: TRISTAN IV, June 13-19, Azores Islands, Portugal, 2001.

J. Bergström, J. Karlsson and M. Rönnqvist, Harvest planning, Proceedings of the workshop: Logistik och optimering, Åre, March 11-14, Sweden, 59-74, 2001.

P. Flisberg, M. Forsberg and M. Rönnqvist, Skottningsplanering, Proceedings of the workshop: Logistik och optimering, Åre, March 11-14, Sweden, 35-48, 2001.

H. Gunnarsson, J. Lundgren and M. Rönnqvist, Supply chain modelling of forest fuel, Proceedings of the workshop: Logistik och optimering, Åre, March 11-14, Sweden, 49-58, 2001.

B. Liden and M. Rönnqvist, Evaluation of a model for customer optimized timber in the wood chain, Proceedings of the workshop: Logistik och optimering, Åre, March 11-14, Sweden, 95-106, 2001.

Proceedings of the workshop: Logistik och optimering, Åre, March 11-14, Sweden, 2001. M. Palmgren and M. Rönnqvist (Eds) LiTH-MAT-R-2001-16, Linköping University, Sweden.

B. Liden and M. Rönnqvist, CustOpT – a model for customer optimized timber in the wood chain, Proceedings of the 12<sup>th</sup> Annual Conference for Nordic Researchers in Logistics, NOFOMA 2000, (eds) A. Thorstenson and P. Østergaard, June 14-15, Aarhus, Denmark, 421-441, 2000.

C.-G. Carlgren, M. Rönnqvist and D. Carlsson, A tactical model for integrated transportation planning and sorting at harvest areas, Proceedings of the 12<sup>th</sup> Annual Conference for Nordic Researchers in Logistics, NOFOMA 2000, (eds) A. Thorstenson and P. Østergaard, June 14-15, Aarhus, Denmark, 92-107, 2000.

J. Karlsson, J. Bergström and M. Rönnqvist, Harvesting planning combined with sequencing of harvest teams, Proceedings of the Symposium on Systems Analysis in Forest Resources, Aspen, Colorado, USA, September 27-30, 2000.

H. Gunnarsson, J. Lundgren and M. Rönnqvist, Transportation of forest fuel, Proceedings of the Symposium on Systems Analysis in Forest Resources, Aspen, Colorado, USA, September 27-30, 2000.

M. Rönnqvist and M. Johansson, Two dimensional packing problems arising in figure-sawing at furniture manufacturing industries, Proceedings of the Sixth Meeting of the Nordic Section of the Mathematical Programming Society, Mälardalen University, September 25-26, Västerås, Sweden, 1999.

D. Carlsson, M. Rönnqvist and A. Westerlund, Extraction of logs in forestry using operations research and geographical information systems, Proceedings of the 32th Annual Hawaii International Conference on System Sciences, January 5-8, Maui, Hawaii, USA, 1999.

D. Howe, M. Rönnqvist, T. Schönbeck, and T. Sjögren, Integrated optimization and defect detection in reel cutting, in Progress in Industrial Mathematics at *ECMI 98*, (eds) L. Arkeryd, J. Bergh, P. Brenner and R. Petterson, 179-187, 1999.

## Reports

M. Henningsson, J. Karlsson and M. Rönnqvist, Mixed integer programming models to support tactical forest road upgrade planning, LiTH-MAT-R-2004-20, Linköping University, Sweden.

H. Gunnarsson, M. Rönnqvist and D. Carlsson, Integrated production and distribution planning of the supply chain for Södra Cell AB, LiTH-MAT-R-2004-19, Linköping University, Sweden.

H. Gunnarsson, M. Rönnqvist and D. Carlsson, A combined terminal location and ship routing problem, LiTH-MAT-R-2004-04, Linköping University, Sweden.

D. Bredström and M. Rönnqvist, A genetic algorithm for a pulp distribution problem, LiTH-MAT-R-2003-26, Linköping University, Sweden.

D. Bredström and M. Rönnqvist, Supply chain optimization in pulp distribution using a rolling horizon solution approach, LiTH-MAT-R-2003-25, Linköping University, Sweden.

M. Wolf, D. Bredström and M. Rönnqvist, An optimization model and method for a forest harvesting problem including mature habitat patches, LiTH-MAT-R-2002-22, Linköping University, Sweden.

D. Carlsson and M. Rönnqvist, Supply chain management in forestry – case studies at Södra Cell AB, LiTH-MAT-R-2002-21, Linköping University, Sweden.

M. Palmgren, M. Rönnqvist, P. Värbrand, A pseudo column generation algorithm for log truck scheduling, LiTH-MAT-R-2002-20, Linköping University, Sweden.

M. Palmgren, M. Rönnqvist and P. Värbrand, A near-exact method for solving the log truck scheduling problem, LiTH-MAT-R-2002-16, Linköping University, Sweden.

J. Bergström, J. Karlsson, and M. Rönnqvist, Annual harvest planning, LiTH-MAT-R-2002-15, Linköping University, Sweden.

J. Bergström, J. Karlsson, and M. Rönnqvist, Short-term harvest planning including scheduling of harvest crews, LiTH-MAT-R-2002-14, Linköping University, Sweden.

J. Karlsson, P. Flisberg, H. Gunnarsson and M. Rönnqvist, Modelling of road investments, LiTH-MAT-R-2002-13, Linköping University, Sweden.

H. Gunnarsson, J. Lundgren and M. Rönnqvist, Optimering kan sänka produktionskostnader för skogsbränsle, Resultat Nr. 20, SkogForsk, Uppsala, Sweden, 2001.

Proceedings of the workshop: Logistik och optimering, Åre, March 11-14, Sweden, 2001. LiTH-MAT-R-2001-16, Linköping University, Sweden.

D. Bredström, J. T. Lundgren, M. Rönnqvist, D. Carlsson and A. Mason, Supply chain optimization in the pulp mill industry, LiTH-MAT-R-2001-12, Linköping University, Sweden, 2001.

H. Gunnarsson, J. T. Lundgren and M. Rönnqvist, Supply chain modelling of forest fuel, LiTH-MAT-R-2001-08, Linköping University, Sweden, 2001.

C.L. Todoroki and M. Rönnqvist, Linking timber production at a sawmill with log sawing optimisation, LiTH-MAT-R-2000-21, Linköping University, Sweden, 2000.

C.-G. Carlgren, D. Carlsson and M. Rönnqvist, Selection of sorting strategies in harvesting integrated with backhauling, LiTH-MAT-R-2000-18, Linköping University, Sweden, 2000.

B. Liden and M. Rönnqvist, CustOpt – a model for customer optimized timber in the wood chain, LiTH-MAT-R-2000-15, Linköping University, Sweden, 2000.

C.-G. Carlgren, D. Carlsson and M. Rönnqvist, Sorteringsval av massasortiment och transportplanering med returflöden, LiTH-MAT-R-2000-07, Linköping University, Sweden, 2000.

P.-Å. Arvidsson, I. Eriksson, P. Eriksson, M. Rönnqvist, A. Westerlund and P. Igeklint, Smartare vägval i skotningen – bra för både ekonomi och miljö, Resultat Nr. 22, SkogForsk, Uppsala, Sweden, 1999.

M. Rönnqvist and S.-I. Gustafsson, Production control of cross cut operations at wood manufacturing industries, LiTH-MAT-R-1999-09, Linköping University, Sweden, 1999.