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PB99-175077

Evaluation of KFB-funded Research of Freight Transport

Peter Klaus, Tage Skjøtt-Larsen,
Luk N. Van Wassenhove

REPRODUCED BY:
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

KFB-Information
1999:2

TITEL/TITLE
Evaluation of KFB-funded research on freight transport
FÖRFATTARE/AUTHOR
Peter Klaus, Tage Skjøtt-Larsen, Luk N. Van Wassenhove
SERIE/SERIES
KFB-Information 1999-2
ISBN

ISSN 1401-4859
PUBLICERINGSDATUM/DATE PUBLISHED
Februari 1999
UTGIVARE/PUBLISHER
KFB – Kommunikationsforskningsberedningen, Stockholm
KFBs DNR
1998-726

REFERAT (Syfte, Metod, Resultat)

Utvärderarnas allmänna bedömning är att de tre institutionerna utför vetenskaplig forskning av hög klass och är mycket produktiva. Utan tvekan har KFBs stöd främjat forskningen och ökat den vetenskapliga kvalitén i de tre institutionerna. Å andra sidan ger utvärderingen ett antal frågor relaterade till temaprogrammen själva samt minimumstorleken för forskargrupperna, samt en del övergripande frågor.

Denna rapport är resultat av utvärderingen av de tre temaprogrammen som Kommunikationsforskningsberedningen (KFB) finansierade inom området "godstransporter och logistik". Projekten på Chalmers TH, Lund TH och Linköping TH granskades av en grupp av tre oberoende forskare från Danmark, Tyskland och Frankrike.

Forskningsgruppen på Chalmers levererar värdefulla bidrag till utvecklingen av metod och datainsamlingsteknik för analys av materialflöden i industriella anläggningar. De företag gruppen samarbete med (i första hand Volvo och SAAB), drar direkt nytta av forskningsresultaten. Resultaten borde spridas även till andra industriföretag, både i Sverige och internationellt.

Gruppen på LTH koncentrerar sitt arbete på tillämpad matematisk modellering (stochastic multi-echelon inventory models). Det vetenskapliga arbetet är internationellt välkänt och uppskattad i akademiska grupper. Forskningens relevansen för transportsektorn kan bara vara indirekt. Det skulle vara värdefullt att överföra deteoretiska kunskaperna till verktyg som kan användas för företagens mangement.

Linköpinggruppen koncentrerar forskningen på förändringar i logistik management samt tillämpning av nya organisatoriska koncept. "Best practice" fallstudier används för att studera nya logistikapplikationer. Forskningsgruppen arbetar explorativt. Gruppen arbetar tätt tillsammans med industri- och transportföretagen i Sverige och internationellt. Detta innebär att den utförda forskningen och utvecklingen är relevant i praktiken.

ABSTRACT (Aim, Method, Results)

The overall assessment of the evaluators is that all three institutions demonstrate high quality scientific research and also high productivity. There is no doubt that the funding from KFB has encouraged and leveraged the quality of scientific research. However, the evaluation raises a number of questions related to the theme programmes and the critical mass of the research groups, and to some overall questions.

This report is the result of the evaluation of the three theme programmes (tema) funded by the Swedish Transport and Communications Research Board (KFB) in the field of "freight transport and logistics". The projects at Chalmers, Lund and Linköping Institute of Technology were reviewed by an independent team of researchers from Denmark, Germany and France.

The Chalmers Group has made valuable contributions to research methodology and data acquisition techniques for material flow analyses in industrial settings. The dissemination of results has benefited the companies involved (primarily Volvo and SAAB) directly. The research could be disseminated to even broader industrial settings, both in Sweden and internationally.

The Lund Group focuses on applied mathematical modelling techniques (stochastic multi-echelon inventory models). The scientific work is internationally recognised and well disseminated in academic circles. The practical research relevance for the transport sector can only be indirect. The increased insights may prove to be useful if translated into useful managerial knowledge.

The Linköping Group focuses on analyses of emerging changes in logistics management and on supporting applications of new concepts. Best practice case studies are used for conceptualisation of logistics applications. The research approach is exploratory. The group has a collaborative connection to the industry in Sweden and internationally. Therefore research projects performed are considered relevant.

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Evaluation of KFB-funded Research of Freight Transport

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Luk N. Van Wassenhove

FOREWORD BY KFB

The Swedish Transport and Communications Research Board (KFB) has to evaluate 20 % of the funded research projects every year. KFB supports a) high quality scientific research and b) such research-, development and demonstration projects that support to achieve the goals set up for the transport- and communication policy. Thus the evaluation covers both the scientific quality and the societal relevance of the projects.

In 1993 KFB started theme programmes (tema) that allowed the researchers to formulate projects. In the field of "freight transport and logistics" the following three theme programmes were funded::

- New system solutions for integrated transport and materials flow, Materials Handling Centre, Chalmers Technical University
- Co-ordination and information exchange in logistics chains, Division of Production Management, Lund Technical University
- New conditions for effective physical distribution, Logistics and Transport System, Linköping Institute of Technology

These theme programmes were evaluated in 1998. The following report is the result of the evaluation performed by the international team consisting of

- Peter Klaus, Friedrich-Alexander-University, Erlangen-Nürnberg,
- Prof Tage Skjoett-Larsen, Copenhagen School of Economics and
- Prof Luk N Van Wasserhoven, INSEAD, Fontainebleau

The views expressed in the report are those of the evaluation team. The recommendations given will be taken into account in future decisions about KFB-funded research in the field of "freight transport and logistics".

Stockholm, February 1999
Swedish Transport and Communications Research Board

Urban Karlström, Director General

FOREWORD BY THE REVIEW TEAM

This report has been prepared by a team of independent evaluators with the objective of evaluating KFB-funded research on three theme programmes in Sweden. The evaluation was intended to cover scientific quality and societal relevance of the research. Also, the role of KFB was to be examined in order to find improvements in ways of supporting research. The research programmes were evaluated, together with the potential of the research groups to continue the accumulation of scientific knowledge and competence.

The report has been based on the self assessment reports from the research teams, publications submitted and visits at the three universities by the assessment committee and a representative from KFB.

We would like to thank the research groups from Chalmers, Lund and Linköping Universities for an open and constructive discussion of the projects and the research results. A special thanks to Inge Vierth from KFB, who has taken care of all the practical logistics problems during our stay in Sweden.

It is our hope that the assessments and recommendations can contribute to a fruitful and constructive dialogue between the research institutions and KFB.

December 1998

Peter Klaus Tage Skjøtt-Larsen Luk N. Van Wassenhove

TABLE OF CONTENT

0 EXECUTIVE SUMMARY

THEME PROGRAMMES

The evaluation encompasses three theme programmes supported by KFB. The theme programmes were:

- New system solutions for integrated transport and materials flow. Materials Handling Research Group, Chalmers Technical University. KFB-funded with 2,2 mill SEK. Project leader associate professor Tomas Engström.
- Co-ordination and information exchange in logistics chains. Division of Production Management, Lund University. KFB-funded by 3.9 mill SEK. Project leader professor Sven Axsäter.
- New conditions for effective physical distribution. Logistics and Transport System (LoTS), Linköping Institute of Technology. KFB-funded by 1.9 mill SEK. Project leader professor Lauri Ojala.

ASSESSMENT OF SCIENTIFIC QUALITY AND RELEVANCE

There are big differences between the three project teams in terms of research methodology, research issues and practical applicability of the research results. Therefore, it makes no sense to make direct comparisons between the three groups.

The Chalmers Group has made several contributions to research methodology and data acquisition techniques for materials flow analyses in industrial settings, which are valuable to the research community. The research approach is action oriented research in large Swedish companies, mainly in the automobile industry. The research group has also developed materials handling techniques, such as a unit load concept, kit assembly and alternative materials feeding and order picking methods. The project team has produced four licentiate theses and 2 doctoral dissertations, partly funded by KFB. Besides, they have produced a large number of working papers, conference papers and articles in international journals.

The Lund Group has focused on stochastic multi-echelon inventory models. The methodology falls within applied mathematical modelling techniques. The scientific quality of the research is high. The work is internationally recognised and well disseminated in international academic circles. Three licentiate theses and one dissertation have been completed during the four years project period. Besides, several articles have been published in the better international academic journals.

The Linköping Group is focusing on analyses of emerging changes in logistics management and on supporting applications of new concepts and ideas. Best practice case studies are used for conceptualisation of logistics applications. The research approach has been exploratory. The research issues have been Third Party Logistics and Time Based Distribution. The research group has published three licentiate theses and two doctoral dissertations during the project period. Besides, they have produced several articles and papers at international refereed journals and conferences. The research group has an extensive academic network both in Europe and the USA. They have established a high international recognition in applied logistics research within the two focus areas.

ASSESSMENT OF RELEVANCE TO THE INDUSTRY, ECONOMY AND GOVERNMENT

The Chalmers Group has been conducting research in "real world" industrial environments, primarily at Volvo and SAAB plants in Sweden. Therefore, the dissemination of research results has benefited these companies directly. The research methods developed for internal materials flows have been extended to external flows, illustrated by several case studies in various industries.

However, it is our assessment that the research results could be disseminated to even broader industrial settings, both in Sweden and internationally. The Chalmers group should have an excellent position to participate actively in the international discussion about new production concepts, such as just-in-time production systems and lean manufacturing. One way could be to publish a book in English on the Swedish experi-

ences in "Reflexive production". Also the research group should put more efforts in securing patent rights on prototypes developed.

The Lund Group's research is based on mathematical modelling, which explains why the practical relevance can only be indirect. However, the increased insights from the research may prove to be useful if translated into useful managerial knowledge. This can be done in at least two ways. One way is to use simple examples, simulations and business cases. Another way is to embed the mathematical results into optimisation or simulation software which would allow for analyses of real-life supply chains. The development of software should be done in co-operation with software consulting companies.

The Linköping group has a close and collaborative connection to the industry, both in Sweden and internationally. The research performed by the group is considered relevant and valuable for practice. This is demonstrated by the research funding from Ericsson and also from the participation of large, Swedish companies in other research programmes within logistics. Members of the research group are frequent speakers at national and international conferences for practitioners.

OVERALL ASSESSMENT AND RECOMMENDATIONS TO THE RESEARCH GROUPS

The Chalmers Group has made a broad, intensive and creative use of the resources provided by KFB. The research efforts and results and the dedication of the group to the research objectives are impressive. Therefore, the results from the project funded by KFB are evaluated positively. In the future, the research group is recommended to participate more actively in the "mainstream" international dialogue and to make more efforts to disseminate their work into more systematic and concrete outputs, such as patents, curricula, and monographs and articles that address a broader management audience.

The Lund Group is recommended to maintain their high academic standard and build upon their international reputation. However, they should seriously consider enlarging

the size of the group, since it is below critical mass. This could be done by establishing virtual partnerships with other research groups or real partnerships with industrial firms. The group should also seriously consider making an effort in translating the results and knowledge into useful pedagogical materials and effective managerial insights.

The Linköping Group has developed a good platform for collaboration with industry. The relevance of the research to the industry is high and the research group belongs to several international networks, composed by both leading-edge companies and universities. The research group is recommended to establish a more profound scientific approach, to give higher priority to publications in international refereed journals, to encourage exchange of international logistics professors and PhD-students and to continue their efforts to increase the funding from private companies to general research themes.

RECOMMENDATIONS TO KFB

KFB follows mainly two goals:

- to support high quality scientific research
- to fund such research, development and demonstration projects that support to achieve the goals set up by the state for the transport and communication policy.

In 1993 KFB started theme programmes. Within these theme programmes the researchers had freedom to formulate projects and to choose scientific methods. The theme leader and the senior researchers were responsible for the quality of the research performed within the theme.

The overall assessment by the evaluators is that the first goal of KFB has been reached in the three theme programmes. All three institutions have demonstrated high quality scientific research and also high productivity. The number of licentiate theses, dissertations and international articles produced is quite impressive. There is no doubt that the funding from KFB has encouraged and leveraged the quality of scientific research at the three institutions.

However, the evaluation raises a number of questions, which KFB has to discuss and decide on in the near future. Some are related to the theme programmes funded by KFB, and some are related to the long term accumulation of knowledge and relevance to society.

First, it can be discussed whether the second goal of KFB has been fulfilled by the theme programmes. It seems that the three research groups have continued their research very much along the same line as before the theme programmes were introduced. The relevance of the research for the Swedish transport and communication policy seems in some instances rather limited and only indirect. KFB has to ask what type of research it will support in the future. Does KFB want to support projects that lead to medium or long-term scientific knowledge building, or is it mainly interested in short to medium term applicability to industry and society?

Another question is related to the research issues funded by KFB. Is KFB interested in promoting research of high international standard and recognition or is KFB more interested in research issues related to a Swedish context. A related question is, whether the research should focus on large, international Swedish companies, or on small and medium sized companies.

A third question is related to the critical mass of the research groups and the long-term accumulation of scientific knowledge. As pointed out in the report, the Lund group is below the critical mass and very much dependent on the project leader. The Linköping group has the critical mass right now, but may run into recruiting problems in the future, if the assistant professors currently on leave are not returning to the research group. KFB has to make sure that they are stimulating research environments which are vigorous in the long run.

1 INTRODUCTION

This report presents the results of the evaluation of KFB-funded research on freight transport. The evaluation encompasses three theme programmes (projects), which have been financed fully or partly by KFB. The three theme programmes are:

- New system solutions for integrated transport and materials flows (Dnr 93-328-22) at Department of Transport and Logistics, Materials Handling Research Group, Chalmers Technical University.
- Co-ordination and information exchange in logistics chains (Dnr 1993-0478, 1997-0443) at Department of Industrial Engineering, Division of Production Management, Lund Institute of Technology.
- New conditions for effective physical distribution (Dnr93-293+-22) at Logistics and Transport Systems (LoTS), Department of Management and Economics, Linköping Institute of Technology.

The evaluation is intended to cover scientific quality of the research and relevance to the academic world, industry and society. The evaluation will also cover the efforts to disseminate the research results to various user groups. Finally, the report will evaluate the potentials for continuation and development of research in areas relevant to KFB.

The three project teams have been requested to write a self-assessment report of the work done in the theme programme and to submit copies of relevant publications from the project.

The evaluation committee has visited the three institutions where the project teams have presented the main results and discussed research methodology, dissemination, international networks and other relevant questions with the members.

The visits took place from 9 November to 11 November 1998.

The evaluation report is based on the self-assessment reports from the project teams, the materials submitted to the evaluation committee and the "hearings" at the three institutions.

The evaluations and recommendations presented in this report are those of the reviewers and do not necessarily represent the views of KFB.

2 DEPARTMENT OF TRANSPORTATION AND LOGISTICS, CHALMERS UNIVERSITY OF TECHNOLOGY

2.1 BACKGROUND

The Materials Handling Research Group, Department of Transportation and Logistics, was established in 1978. The research group is mainly focused on three main areas:

- Flow structures, including product design and information technology
- Interaction between technical, organisational and social aspects regarding work structuring, materials feeding techniques, etc.
- Development of analytical tools connected to the basic value activities in the manufacturing process.

The research group consists of eight persons with backgrounds in various fields of engineering, work sociology and work psychology:
Associate Professor Tomas Engström, project leader
Associate Professor Mats Johansson
Lars Medbo, PhD student
Per Medbo, PhD student
Birgitta Öjmertz, PhD student
Bertil Johansson, research engineer
Jan Johansson Hanse, PhD, (work psychology),
Dan Jonsson, PhD (work sociology).

The group maintains a network of colleagues and institutions in Sweden and elsewhere from which it draws additional competencies when required. In the area of ergonomics a co-operation exists with Lund University.

Financing of the group comes – outside of KFB –from sources such as the Swedish Council for Work Life Research (RALF) and the Swedish Board for Industrial and Technical Development (NUTEK).

2.2 RESEARCH THEME

Prior to the current KFB-project, between 1988 and 1993, Professor Engström and his group had been working for six years in a predecessor project on production system design in a socio-technical perspective, which was financed by KFB (25%), RALF (25%) and NUTEK (25%).

In 1994 KFB 93-328-22 was approved and the sum of 2.2 million SEK was awarded for a start of the project in April 1994. Originally the project was to end in June 1996. Upon request of the team the date of completion of the project was extended by one year into 1997.

According to the project teams own statement the project aims at:
Integrating knowledge about external and internal material flow systems in an industrial context. It is based on the assumption that the border line between what is traditionally defined as internal flow (i.e. within a plant) respectively external flow (i.e. outside a plant) is in many respects artificial. This border line shall be eliminated.

Furthermore, research methods and a theoretical frame of reference shall be developed which are suitable to address materials flow systems efficiency and unit load design in complex materials flow systems by combining:

- State of the art research concerning external logistics trends with
- Theoretical and practical frames of reference concerning internal flow.

Four specific research questions are stated:

- Analysing efficiency in complex materials flow systems
- Integrating functions, processes and load carriers

- Planning technically advanced products with numerous product variants
- Internal production scheduling in relation to the performance of the internal materials flow systems.

3.1 SCIENTIFIC PUBLICATIONS

Between 1993 and October 1998, the following „output" in publications had been produced by the group (which includes all publications by the group that are related to the subject, since there is no meaningful way to separate out the KFB-funded publications):

Four licentiate theses and two dissertations have been completed. In addition, 99 working papers, manuscripts, and publications in journals and conference proceedings related to the project have been published. Of these, about 25 appeared in generally accessible international journals and conference proceedings, such as International Journal of Production Economics, International Journal of Operations & Production , International Journal of Human Factors in Manufacturing, International Journal of Material Processing Technology. The others appeared in trade journals and various media (see appendix 2).

Among other outputs and achievements of the workgroup are significant applications of research results in the:

- Layout and materials flow designs of the Volvo Autonova plant at Uddevalla,
- Development and testing of mobile prototype equipment for new material picking and feeding equipment at Volvo KSO, Autonova, and SKF,
- The successful start of the Småmaterial AB, a newly created company at the Swedish West Coast, which assembles customised materials kits for Volvo and other industrial manufacturers based on technology and prototypes for automatic kit-assembly developed in the project,
- The prototype development and testing of video-equipment and related software that is used as a research tool by the team and others (e.g. at the Berifors Company)

2.4 ASSESSMENT – SCIENTIFIC RELEVANCE

The scientific contributions by the group may be grouped into contributions to research methodology and related data acquisition techniques, and additions to content knowledge about best practices in the field of materials handling.

2.4.1 RESEARCH METHODOLOGY

In the course of the project the group made several contributions to research methodology and data acquisition techniques for materials flow studies in industrial settings, which are valuable to the research community:

- They took on the task of preserving and organising the archives of the Volvo plants at Uddevalla and Kalmar after the closings of these facilities. At Uddevalla and Kalmar major, internationally recognised experiments in industrial organisation and materials flow technologies had taken place. Therefore, the Chalmers archive is a potentially valuable research base for the group and other researchers in the future.

Furthermore, the group was active in the development of own research technologies which are specifically suited to the research goals set, such as:

- Loss analysis, based on Wild (1975), which was first applied in 1978. The method was later elaborated to suit the evaluation of materials flow systems (Engström, Johansson and Lundberg 1988, Engström et al. 1989);
- VIDEOLYS, utilising synchronised video recorder equipment which has been under development since 1988 (Engström, Lundberg and Petzäll 1988). This methodology served as an advanced stopwatch suitable for work-study analyses in materials flow systems;
- Utilising an action oriented research approach in the industrial organisation environment (e.g. through the use of prototyping, questionnaires, scenarios of schematised materials flow systems), under development since 1984 (Bramberger et al 1985);

- Development of virtual reality techniques (compare lic. thesis by P. Medbo, 1998) with applications in traditional materials flow analysis and self-evaluation and improvement activities among workers;
- Development of Materials Flow Efficiency Analysis Method (compare PhD dissertation by Birgitta Öjmertz).

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2.4.2 CONTRIBUTIONS TO „CONTENTS" OF MATERIALS FLOW KNOWLEDGE

The group has also made significant contributions by pushing forward conceptual understanding and knowledge about best practices in the industrial materials handling field. Contributions that were presented to the evaluators were:

- A conceptual model of flow activities, developed by Engström, which identifies four generic issues to be addressed in improvement efforts of material flows:
- optimal number (of SKU's)
- optimal mix of objects
- optimal orientation of objects (relative to the handling agent)
- optimal sequencing of objects.
- The application of this model and other know how from industrial materials handling research in a transport and truck-loading environment, leading to an innovative and efficient Unit Load concept for steel bars (Sandvik Corporation - M. Johansson).
- Identification of best practices in managing the interactions between kitting, alternative order picking, and parallel flow assembly setups in the automotive industry – which leads to the elimination of traditional boundaries between external and internal flow operations in industrial value chains (Volvo Uddevalla - T. Engström, M. Johansson).
- Design of a new central Buffer concept for the materials supply of 40 parallel assembly teams in long-cycle parallel flow assembly systems (Volvo Autonova -T. Engström)
- Development of the Assembly Variant concept for massive reduction of product identities in highly customised automotive production environments (Volvo - L. Medbo and T. Engström).

- Prototype development and application of semi-mechanised, highly efficient materials kit assembly method (SKF and Smamaterial AB – T. Engström) .
- Experiment based efficiency comparisons of alternative materials feeding and order picking methods (Volvo L. Medbo and M. Johansson).

2.4.3 DISSEMINATION TO THE ACADEMIC COMMUNITY

The group has produced a large number of publications, although these appear to be somewhat narrowly distributed in terms of the range of publications (International Journal of Production Economics, Control Engineering Practice, International Journal of Industrial Ergonomics) and also some redundancies in their contents (many B-publications). The impact of the work, undoubtedly, could be much greater if the group had also published in more general management journals and/or sought to bring together their findings in a monograph that would be to accessible more broadly than the academic theses.

There has been a broad, internationally followed discussion about new developments and the comparative advantages and disadvantages of alternative materials and general management concepts in the international automotive industry (e.g. the Toyota production System, lean management, and future of industrial work studies by Japanese, American and European companies, including Volvo). The Chalmers group would have had an excellent position to actively and constructively participate in these discussions and benchmarking comparisons. Their work, most likely, could also have been even more creative and relevant if they had placed more emphasis on this kind of international exchange (even though it is recognised that they are involved in some international exchange, such as the global logistics research initiative GLORI of seven international universities).

The evaluators, finally, did not learn about any systematic efforts of the research group to make use of their research results in their academic classwork, which also provides an important opportunity for dissemination of research results.

2.5 ASSESSMENT RELEVANCE TO INDUSTRY, ECONOMY AND GOVERNMENT

Since most of the research has been conducted in real world industrial environments, it has had apparent, immediate visibility within this environment. Volvo and several other companies mentioned above, apparently, have had most benefit.

As argued above, dissemination of results to an even broader industrial audience – both in Sweden in internationally - might have been possible.

The group showed the principal potential for applications of some of their work to the transport industry through the Sandvik/unit load-example.

It is also apparent, that broader uses of the kitting concept in the manufacturing industries will offer significant new business opportunities to logistics service providers, which should be communicated and demonstrated even more broadly. There is widespread consensus in the transportation industry, that new opportunities for value added services to basic transport and warehousing need to be identified and broadly made use of in order to maintain a profitable, modern transportation industry in Sweden and elsewhere.

Beyond this , the research - by its focus on industrial production process improvements - may not have any direct implications for national or international government transport policies.

2.6 ORGANISATION OF THE PROJECT

The group appears to work as a well integrated team. Professor Engström makes a point in not allowing explicitly commercial consulting activities to be pursued in connection with the research, in order to not impoverish the process of knowledge accumulation within the Department of Transportation and Logistics or to distract the team members dedication to the research.

But more contract research, more efforts in securing patent rights and – as has been indicated above – more systematic efforts in transforming research results into "harder" forms of academic courses, publications, aiming at a broader range of industries with clearly defined output requirements, could be beneficial.

2.7 POTENTIAL FOR FURTHER DEVELOPMENT OF PROJECT

There are some promising next questions and the team has the potential to do further research successfully. They

- plan to write a book on materials flow experiences
- continue enhanced prototype building (kitting assembly process)
- continue to develop mobile laboratory for material flow analyses

In addition, the evaluators recommend that the group actively work to further develop and still more systematically and broadly disseminate their know-how to:

- Transport/Logistics service industry applications
- Students and academic teaching, and
- Participate more actively and broadly in the international dialogues and benchmarking efforts for the future of industrial production.

2.8 OVERALL JUDGEMENT AND RECOMMENDATIONS

Overall the group had shown to the evaluators that it has made broad, intensive, and creative uses of the resources provided by KFB. The richness, variety, and creativity of research efforts and results, as well as the dedication of the research team to the goals that they have set for themselves are impressive.

There is no question that the immediate research partners in the research effort, such as Volvo and the other partners mentioned, have drawn significant and immediate benefits:

- Insofar the results of KFB-project 93-328-22 are evaluated positively.
- The group's work in the future will be even more effective, if they actively look for integration into the mainstream international dialogue and make more efforts to tie together and disseminate their work into more systematic and harder outputs, such as patents, curricula, and monographs and articles that address a broader management audience.
- KFB's immediate benefit from the research may be in the demonstration of opportunities to the transport industry how new business opportunities and better integration of industry internal and external logistics might be achieved for the benefit and enhanced competitiveness of all parties involved.

3 DIVISION OF PRODUCTION MANAGEMENT, DEPARTMENT OF INDUSTRIAL ENGINEERING, LUND INSTITUTE OF TECHNOLOGY

3.1 BACKGROUND

The Department of Industrial Engineering belongs to the Lund Institute of Technology, Lund University. The group we are interested in is the Division of Production Management. The Division, consisting of about 10 people (including PhD students), is active in three research areas: production and inventory control, investment processes and managerial accounting, and quality and maintenance. It teaches about eight courses largely as a service to the Engineering School. Lund University also has a Business School but there appears to be little formal co-operation between similar groups in Industrial Engineering and the Business School largely because the Division of Production Management favours a quantitative approach while the Business School seems to be mostly qualitative in its approach to research and teaching. Likewise, there appears to be little formal co-operation between the Division of Production Management and the Department of Engineering Logistics.

The project under evaluation is embedded in the Production and Inventory Control Group of the Division of Production Management. The group is led by professor Sven Axsater. It further contains the PhD students Jonas Andersson and Johan Marklund, both of which started August 1, 1994 and are relatively close to finishing their dissertation. There is also Rolf Forsberg who left the group after finishing his PhD. He is currently working for IMI (a software consulting firm) after having spent a year as a post-doctoral student with professor Paul Zipkin's group at Duke University in the USA. Finally, Peter Liljenberg stayed with the project from Jan 95 till March 97 but accepted a position as a logistics manager in industry before even completing his licentiate thesis. Of course, Peter's early departure caused some disruption in the logical flow of the project. It is useful to mention that professor Kaj Rosling, a colleague of Sven Axsater in the Division of Production Management is also working with a PhD student on another KFB

funded project. The two groups seem to be working closely together even though the subjects are not immediately linked.

The project was originally planned to start April 94 and to end April 97. Eventually, the project started July 94 and was extended another year until July 98. The total budget was about 3.90 million SEK. The resources were mainly used for salaries. These covered Rolf Forsberg and Peter Liljenberg as well as the current students Jonas Andersson and Johan Marklund for a total of 2.79 million. Computers, travelling and other costs, and university overheads explain the use of the remaining funds.

3.2 RESEARCH THEME

The objective of the project was to develop methods and models for co-ordination and information exchange in a logistic chain. The key word here is information exchange. The idea was to explore which kind of information would have most effect on supply chain cost and performance. Although the original intent was to look at information in supply chains from a rather broad perspective, the actual range of supply chains and information exchanges studied has been more narrow since all the work has concentrated on some specific multi-echelon supply chain settings.

It was natural to start the work with multi-echelon inventory systems given the group's excellent reputation in this field. The main activities of the project all relate to the analysis of the behaviour of multi-stage inventory systems under different assumptions of information availability. For practical purposes, the work can be divided into three broad categories: decentralised multi-stage inventory control with restricted information availability, policies for centralised inventory control with extended information availability and finally, methods for exact cost evaluation of multi-level inventory policies.

3.3 SCIENTIFIC PUBLICATIONS

So far, the project has led to the completion of three licentiate theses (Rolf Forsberg, Johan Marklund and Jonas Andersson) and to the completion of one doctoral dissertation (Rolf Forsberg). Both remaining doctoral students (Jonas Andersson and Johan Marklund) seem to be well-underway in their work and are expected to complete their PhD dissertations in about a year's time.

The research has led to quite a few research reports. More specifically, three papers relate to decentralised multi-stage inventory control with restricted information availability, six papers deal with policies for centralised inventory control with extended information availability and six papers are concerned with exact cost evaluation of multi-level inventory policies. Although it is hard to say which papers are a direct result of this particular project as opposed to other projects or continuation of earlier work, it should be noted that quite a few of the papers are authored or co-authored by current or former doctoral students like Johan and Jonas. The latter are obviously direct outputs of the work. Some single authored publications by Sven Axsater should perhaps not be counted since he was not directly sponsored by the project funds. It should also be mentioned that most papers are either published by or submitted to respectable international academic journals.

The work of the group has also been presented at national and international academic conferences. The project leader co-organised an international symposium on mathematical models of inventories in 1996 and presented results to practitioners at a meeting organised between the Department and the Swedish Association for Production Logistics.

3.4 ASSESSMENT - SCIENTIFIC RELEVANCE

The methodology used falls within the realm of applied mathematical modelling techniques. The focus is on stochastic inventory models that rely upon applied probability

theory as well as optimisation theory and business administration. There is a long tradition in operations research and in production management of this type of approach to study inventory management problems.

The multi-echelon problems studied have gained renewed interest lately because of the increasing importance business attaches to good supply chain management and integration and because of the increasing role played by information availability and exchange. Therefore the topic of the research project is very timely and interesting.
Studying the role of information in multi-echelon inventory models using mathematical modelling techniques has a few big advantages. First, the topic is both relevant and well-focused. Second, the methodology is standard and well-accepted. This allows one to obtain results rather quickly as shown by the large number of papers produced. The methodology also has its drawbacks. First, the assumptions made in the mathematical models are fairly restrictive. That is, in order to allow for mathematical tractability and elegance, quite a few simplifying assumptions need to be made. These assumptions may, of course, not be satisfied in a particular real-life case experienced by a company. Second, the fact that the methodology relies on pretty sophisticated mathematics does not simplify dissemination. On the other hand, the discipline of capturing major trade-offs in simple mathematical models allows one to develop deep understanding of the underlying phenomena and to sharpen intuition. Given the complexity and importance of multi-echelon inventory systems in practice, developing increased understanding and intuition is very valuable.

To illustrate the group's activities, Johan Marklund and Jonas Andersson presented their work to the evaluators. Johan Marklund talked about decentralised multi-echelon inventory control. The work develops the nice idea of using a transfer price to be paid by the central warehouse to the retailers in case it cannot deliver the requested order in time. This transfer price idea allows one to decentralise control. Jonas Andersson presented his work on exact evaluation of general performance measures in multi-echelon inventory systems. This work is innovative in that it does not consider the classical holding and backordering costs but instead uses modern business measures like time in the warehouse, backorder time or general system throughput time. Both examples show

the scientific relevance of the work as well as the competence of the group. They are very well tied-in with work going on in the best schools (Wharton, Stanford, Duke, Columbia) in this field and their work is of sufficiently high quality to be accepted in the better international academic journals. For example, Jonas Andersson's work has been awarded the student competition prize at the 1998 International Society for Inventory Research (ISIR) conference and has been submitted for publication in Operations Research. Both are highly credible academic achievements and will give Jonas Andersson visibility early in his career. The same academic quality is apparent in the rest of the group's work. The group's leader is a well-respected academic in the international community. He is visible and active in international societies and a member of quite a few editorial boards of international journals.

As a general conclusion with respect to scientific relevance one can safely state that the work adds to scientific knowledge in an important and timely field of research. The work is internationally recognised and well disseminated in national and international academic circles. It also appears that the work is, at least indirectly, contributing to education (through master theses and courses).

The work is not very interdisciplinary at the current time and one would not expect this conventional mathematical modelling of multi-echelon inventory control problems to be interdisciplinary. However, the information issues tackled by the group in the current project assume the players to be well-behaved, i.e. to disclose the correct information. Of course, in reality, different partners in a supply chain may wish to withhold information or even to provide false information if they believe this will lead to specific gains. These issues of information and incentive asymmetries provide an interesting avenue for research which would also offer the opportunity to bring in expertise from other disciplines.

3.5 ASSESSMENT - RELEVANCE TO INDUSTRY, ECONOMY AND GOVERNMENT

The nature of the work (fairly streamlined mathematical modelling in order to increase insights and intuition) explains why the relevance to industry/economy/government can only be indirect. Of course, it is unlikely that a company or sector will be able to directly use results from the research. However, the increased insights and intuition may prove to be very useful. Indeed, industrial practices can sometimes be far from optimal simply because of tradition and reluctance to change outdated routines. A simple but powerful example coming out of most multi-echelon inventory control research is that the central warehouse can easily have fairly low inventory levels (and hence service levels) without jeopardising the service levels at the retailers' end (provided retailers follow adequate stocking policies). This by now fairly general result from theory is rather counter-intuitive and this explains why so many central warehouses are overstocked in many industries.

However, insights from mathematical modelling need to be translated into useful managerial knowledge in order to be practical. This can be done in at least two steps. One is to translate the fairly theoretical insights into clear managerial language by using simple examples, simulations, business cases, and so on. These can then be used in executive courses and in general managerial articles (in journals like Sloan Management Review or Harvard Business Review). This step is done by some top USA research groups at Wharton and Stanford with a lot of success and recognition by the business world (leading in turn to funding of research, student placement and consulting jobs). The Production Management Division at Lund should be much more pro-active in this respect.

A second way to link mathematical results to practice is to embed them into optimisation or simulation software which would allow for analysis of real-life supply chains. This type of software is, of course, largely developed and used by management consulting firms. A research group would not be expected to develop commercial software but it

could reasonably be expected to build prototypes or to be working together with software consulting firms developing such software. Again, the Production Management Division at Lund could be much more pro-active in this respect. Although several former members of the Department have joined industrial firms and software consulting companies, the links with the research group do not appear to be actively maintained or nurtured which definitely impoverishes the group's grip on real-life.

As far as relevance to the economy and government are concerned, it should again be emphasised that this is not the primary nature or purpose of this type of research. As such, the impact or relevance can only be indirect at best. Efficient supply chain management and integration will be of utmost importance to industry and therefore Swedish industry and government should develop adequate advanced competencies in this field. The work of the research group contributes to the advancement of scientific knowledge. The group is very well integrated in international research networks and therefore very up to date on new developments. Through the training of its graduate as well as undergraduate students the group will obviously contribute to increasing the Swedish competencies in this field in the future. Again, these effects are of vital importance but they are indirect and medium to long term.

It should be clear from the above that this dissemination may not occur so easily and therefore a pro-active effort to translate theoretical results into useful managerial insights and convincing pedagogical materials (cases, simulations) is a must. The group should be asked to develop more initiatives in this respect.

3.6 ORGANISATION OF THE PROJECT

This project was well organised. This is partly due to its clear focus and methodology and partly due to the rather small size of the group (essentially the project leader and two PhD students). The advantage is that the project has obtained tangible academic results. The drawback of a small group is obviously that it becomes more difficult to have cross-fertilisation and to do cross-disciplinary work. Both become increasingly important in modern research. It may also be much more difficult to develop adequate initiatives to

ensure dissemination (for instance to develop simulation tools or pedagogical materials) since this would take away scarce resources from the scientific objectives of the project. The group should seriously consider these issues of critical mass and would be well-advised to look for co-operation or partnerships with other groups in the University, other schools, software consulting firms and industrial firms.

3.7 POTENTIAL FOR FURTHER DEVELOPMENT OF PROJECT

From an academic perspective, this work is very interesting and relevant. It is definitely important to continue solid research work on the use of information in supply chains (with the associated centralisation/decentralisation issues) and to continue the highly relevant work on exact evaluation of general performance measures related to through-put times and waiting times. The team is well-placed to play a pioneering role in Sweden in this respect (as well as a leading role in Europe) but its small size makes it very vulnerable to even a single person leaving and not being replaced.

The results of the group should be generalised and disseminated more widely. This would require the use of other methodologies including simulation and perhaps even case work with industrial companies. Even if the group feels this is not part of their agenda, it should consider teaming up with other groups or organisations to which it could play the role of scientific advisor or consultant. There is no doubt that supply chain management and integration issues will be extremely important in the years to come and that there are an awful lot of issues to be researched. Our fundamental knowledge in this field is lagging industrial and economical needs imposed by advances in technology and globalisation of business. Given this lag between industrial needs and knowledge, it is all the more important to attach special care to rapid and efficient dissemination.

3.8 OVERALL JUDGEMENT AND RECOMMENDATIONS

The recommendations to the project team are clear:

- They should absolutely maintain their high academic standard and build upon their international reputation.

- They should seriously consider enlarging the size of the group since it is below critical mass.
- Since hiring seems to be difficult and budgets are limited, the group would be well-advised to look for partnerships. These partnerships could lead to a virtual increase of the group's size (being part of a network with potential exchange visits) or to a real increase through sponsoring (by industrial firms).
- The group should also seriously consider making a deep effort in translating its results and know-how into useful pedagogical materials and effective managerial insights which could then be efficiently disseminated. Needless to say that effective dissemination may lead to increased (industrial) recognition and therefore increased income.

The recommendations to KFB are equally clear. This is a well-focused, highly academic and competent group. It has managed the original research questions quite adequately and has, at least partially, delivered on this specific project. Indeed, with the exception of Peter Liljenberg who left prematurely, the funds were adequately used to train three PhD students (one graduated and two others are nearing completion). Their training and their work has been excellent. Their scientific output is being published in top international journals. The group has managed to tackle difficult but interesting research questions and has produced a sizeable amount of academic output. In that respect, the result is clearly positive. However, in terms of dissemination to a non-academic audience, the efforts appear to have been minimal.

Of course, KFB should ask a number of additional questions. Some are related to the group that was funded rather than the project itself. For instance, how did the project allow the group to further develop itself? In this particular instance, the group has continued its excellent academic track record and has extended its competencies in multi-echelon inventory theory. The group has not grown, however. It is still very much dependent on the leader and would pretty much collapse were he to leave. It is also questionable whether such a small group will be able to continue to attract good PhD students in the future.

The group did not extend its influence in the School nor did it leverage its size through co-operation with other groups or through attracting students to exciting new course offerings based on the research findings. Some other questions KFB should ask is how this type of work (mathematical modelling) fits into its mission and agenda. Since the orientation of KFB has changed rather seriously over the last couple of years it would not be fair to judge the current project on this. However, the question should be asked with respect to future projects. Does KFB wish to sponsor projects that lead to medium to long-term scientific knowledge building, or is it mainly interested in immediate applicability to industry and society? Is it interested in international competence or does it wish to concentrate on Sweden? Is its focus on big firms or small ones? On companies or societal problems? The answer cannot be "all of these". Some clear priorities will need to be set.

As a final word one could say that in the end one is interested in funding excellent work. Excellence in this context is academic excellence (international publications in good refereed journals), cumulative improvement of competencies (such that the group has longe-vity and does not depend on one person staying or leaving) and adequate dissemination to different constituencies. The current group scores very highly on the first component (excellent academic research on questions highly relevant to business). It should definitely worry about the future in terms of the second component and it could easily improve on the third component by developing some concerted initiatives.

4 LOGISTICS AND TRANSPORT SYSTEMS (LOTS), LINKÖPING INSTITUTE OF TECHNOLOGY

4.1 BACKGROUND

Logistics and Transport Systems (LoTS) is a division under Department of Management and Economics. The department has about 110 lecturers and researchers of which 9 are professors. The total number of students are close to 5.000. LoTS has been in operation since the foundation of Linköping Institute of Technology in 1969. The division has about 20 employees of which 1 is professor, 3 are adjunct professors, 3 are assistant professors, and 9 are PhD-students.

LoTS is responsible for courses in logistics and transportation, mainly for the Master of Science programme *Industrial Engineering and Management (I)* and *International Industrial Engineering (Ii), Mechanical Engineering (M), the Business Programme (E), and International Business Programme (Ei).* Every year about 260 students are attending courses offered by LoTS. About 50 students each year are finishing their master thesis within logistics, mostly as 3-5 months internships in industry. The division strives to integrate technical, economic and organisational sciences.

The division's Ph.D.-programme is organised as part of Integrated Graduate School of Management and Industrial Engineering (IMIE). IMIE offers an interdisciplinary research education programme in close collaboration with industry. IMIE is funded from the Foundation of Strategic Research. IMIE is an alliance of 13 divisions from five departments. IMIE offers three research programmes:

- Supply Chain Management – An Interorganisational Perspective
- Information Technology for Process Management
- Innovation, Change and Customer Focus.

The Supply Chain Management research area is directed by Sten Wandel and offers 5-6 interconnected research tracks, each consisting of one or several projects.

The project was originally formulated and submitted to KFB for funding with Dr. Nils G. Storhagen as a project leader. Shortly after the project had been funded Nils G. Storhagen decided to leave the project for private reasons. Professor Lauri Ojala at Turku School of Economics and Business Administration, at that time acting as assistant professor at LoTS, took over the project leadership from Nils Storhagen. Professor Sten Wandel and adjunct professor Mats Abrahamsson continued as responsible for most of the scientific tutoring and guidance during the project. The change in project leadership seems not to have changed the objectives, although the direction of the project and the theoretical perspective to some extent might have changed reflecting the different research focus of the new project leader.

The project team working with the KFB funded project consisted of the following researchers:
Profesor Sten Wandel
Adjunct professor Mats Abrahamsson (50% at LoTS, 50% as consultant)
Adjunct professor Lauri Ojala (from 1 November 1998 back as full-time professor at Turku School of Economics and Business Administration)
Adjunct professor Hans Sarv
PhD Andreas Normann (from mid 1997 absent leave and working as a consultant in A.T. Kearney) .
PhD Dan Andersson (from June 98 until June 99 full-time assignment at Ericsson)
PhD candidate Magnus Berglund, licentiate

4.2 RESEARCH THEME

The project (theme) is " New conditions for effective physical distribution – development of theories (Dnr: 93-293-22 and DNR 93-135-43). The total KFB funding is 1.9 mill SKR. The project has been carried out from the beginning of 1994 to the end of 1996.

The overall objective of the project was to identify new ways of organising logistical activities in leading-edge firms, and to understand what type of changes has taken place in

the internal and/or external organisation and division of these activities. The project was also aiming at improving the existing theories and models used in the context.

During the project period it was planned to produce 2 licentiate theses and 1 dissertation. The theses should establish the foundation for development of models which describe and explain which factors should be guiding the design of new distribution systems. Besides recommendations should be given to how a change from today's traditional distribution systems should take place. Within the following 2-3 years period it was expected that one more dissertation should be finished, the hypotheses empirically tested and the models refined.

The theoretical perspectives were to be found within managerial economics, marketing channels theory, logistics management, system analysis and interorganisational theories.

The research work was divided into two major areas:
Third party logistics (TPL)
Time-based direct distribution (TBD)

The first area was a continuation of a KFB funded project which was carried out from July 1992 to August 1993. The second area was a continuation of time-based direct distribution introduced by Mats Abrahamsson in his dissertation from 1992.

4.3 SCIENTIFIC PUBLICATIONS

Within the programme three licentiate theses and two doctoral dissertations has been published. Besides, three articles have been published in international refereed journals and recently one further article on Third Party Logistics has been accepted for international publication. Besides a number of refereed and non-refereed conference papers at various international logistics conferences have been produced. Dan Andersson's paper was awarded an Honorary Mention as being the second best paper out of more than 60 at the NOFOMA 98 conference.

4.4 ASSESSMENT – SCIENTIFIC RELEVANCE

4.4.1 RESEARCH METHODOLOGY

According to LoTS "Business Plan" the research group is working with applied research. Their research is focused on analyses of emerging changes in logistics management and on supporting applications of new concepts and ideas. Best practice case studies are used for conceptualisation of logistics applications.

Most of the research performed within the research group at Linköping has been based on multiple case studies. The case companies are so-called leading-edge companies within TPL or TBD and deliberately selected due to their status as pioneers in implementing new logistics concepts in their organisations. The multiple case studies have to some extent been supplemented by a more quantitative analyses, e.g. by personal interviews according to a structured interview guide and mail surveys followed up by telephone interviews.

The overall research approach has been exploratory due to the fact that both TPL and TBD at that time were new concepts and hardly known by most companies. The basic idea has been to explore emerging trends in leading-edge companies and analyse the driving forces behind the trend and the possible impact and potentials for other companies.

The research approach can be described by the following steps:

- The researchers identify together with their business network interesting research projects within the focused areas of the research group.
- The phenomena are described and analysed by using logistics knowledge, theories and research methodologies.
- The research results are conceptualised in application models and frameworks.
- The research results are disseminated to the academic world and the industry.
- The industrial uses of the research are followed up to ensure organisational learning.

4.4.2 *INTERNATIONAL ORIENTATION*

The research is to some extent interdisciplinary. The research topics are analysed from technical, organisational and management perspectives. However, most of the members in the research group have a background in industrial economics, which limits the extent of multidisciplinary approach. In the future, the Marketing division and LoTS will be integrated, which opens up for a more interdisciplinary approach. A professor from the Marketing division has participated in joint publications with researchers from LoTS and in tutoring PhD-students.

The research group has a high degree of international orientation. Most of the publications are in English. The research group is participating with papers at international conferences and seminars. They are working actively together with other research groups both in Europe and USA. In Europe, they have had a long-term co-operation with CELO, a group of 6 European universities. This group has been active in case studies and surveys within TPL. In the USA, members of the research group have spent longer study periods at both Stanford University and M.I.T.

The research team has established a high international reputation in the academic world. This is a very valuable asset for the research environment, because it makes it easier to attract visiting professors from abroad and to establish common research projects with other universities. It should also facilitate study periods at foreign universities for the PhD-students, which is highly recommended.

4.4.3 *SCIENTIFIC CONTRIBUTIONS*

The focus of the research falls into two areas: Third party logistics and Time-based distribution. The research group has been pioneering in these areas. Dan Andersson started research in 1992 on third party logistics, at a time where this issue was just starting to be put on the research agenda in the logistics academic community. The research group has developed this research theme both from the shipper's (Dan Andersson) and provider's perspective (Magnus Berglund) and has participated in joint research programmes with

leading universities in both Europe and USA. The theoretical framework for the analysis of TPL has mainly been transaction cost analysis. The TPL researchers have contributed both to knowledge building and a more differentiated view of TPL. The research in this area is of a high international level both compared to research in Europe and in USA.

Also the research within time-based distribution and the organisational changes following time-based distribution has a high relevance and has increased the knowledge of how international corporations are organising their logistics and administrative activities when they are centralising physical distribution structure. The research is based on Mats Abrahamsson's dissertation from 1992 and is continued by Andreas Norrman in his licentiate thesis (1995) and dissertation (1997). Norrman is contributing to the organisational issues of logistics management – especially an updating of the contingency approach. He has also developed an interesting stage model of transition from a decentralised distribution structure to a time-based centralised structure with new structures for responsibility and ownership. The organisational aspect of logistics management has been an almost neglected area within international logistics research. Therefore, Norrman's contribution is outstanding also in an international context.

4.4.4 DISSEMINATION TO THE ACADEMIC COMMUNITY

Members of the research group have participated in under-graduate, graduate and post-graduate teaching. There are individual courses in introductory logistics, purchasing and transport, and an advanced course in integrated logistics. Every year, about 50 engineering students write their master thesis within logistics. All researchers are participating as tutors on the thesis work.

The research group has taken active part in international logistics conferences. Thus they have been active in the Nordic logistics network (NOFOMA), and participated in ELA and CLM conferences. They have also presented papers at the International Symposium on Logistics. Members of the research group have participated in post-graduate courses, e.g. CLM's doctorate workshop, ELA's doctorate workshop and at the Nordic doctoral sessions (Nordlog). Besides several senior researchers and PhD-students have partici-

pated in the first Nordic PhD-seminar on Scientific Science in Logistics. Thus the group has a high visibility and recognition in logistics academic circles.

4.5 ASSESSMENT – RELEVANCE TO INDUSTRY, ECONOMY AND GOVERNMENT

Members of the research group have presented results from the project at professional conferences , internal company seminars and in trade journals. Examples mentioned in the self-assessment report are SILF, Ericsson, Posten, AiC Conferences, Nordic Business Institute, and Åhléns Company.

There is no doubt that the research group has a very close and collaborative connection to industry. It is also evident that the research group has a high credibility among practitioners and that their research is considered relevant and valuable for practice. This is recently documented by a large funding from Ericsson Radio Systems to a research programme in recycling.

IMIE has initiated several research programmes within logistics, e.g. Global Production and Logistics, Lean Aircraft Programme, and Recycling. Each of the programmes is done in collaboration with companies, including manpower, financing and steering groups. Some of the participating companies are: Ericsson, Volvo, SAAB, Norsk Hydro, and McKinsey & Co.

Internationally, they are active in both the American Global Supply Chain Forum and the European Global Supply Chain Forum which are formed by leading-edge American and European companies respectively in conjunction with leading universities.

The research on TPL and TBD has also relevance for the economy and government policies. It has been documented that TPL contributes to a higher degree of consolidation and other types of operational efficiency. This has an impact on energy consumption, congestion and emission. Also, TBD is claimed to have a positive impact on traffic, congestion and emission due to less emergency and expedited transport.

The results of the research have also been used by various Swedish and international organisations, such as the Swedish Competition Authority, OECD, The World Bank, United Nations and EU.

4.6 ORGANISATION OF THE PROJECT

The project has changed project leader in the beginning of the project. This seems not to have had a negative impact on the organisation of the project or a change in the research objectives. However, the start of the project was delayed because of the change in project leadership, which meant that the project could not be finalised within the date stated in the contract. Another reason for the delay was a heavy teaching load.

The two PhD-students had already started their work when the KFB project was launched and there has been no discontinuity in their tutorship. The two PhD dissertations and a licentiate thesis have been finalised and defended during 1997 after the end of the project. This has caused some problems of financing in the intermediate period.

4.7 POTENTIAL FOR FURTHER DEVELOPMENT OF PROJECTS

The research group has a potential for establishing an excellence in logistics research in Sweden. The IMIE doctoral programme offers a good opportunity for financing and educating PhD-students within logistics. The research group has a good reputation both in the academic world and among large international companies. The research is highly relevant to the industry, and the researchers are in demand as consultants.

However, the close connection to the industry has an built-in drawback. In order to keep the international recognition it is vital to keep the senior researchers at the university and to recruit new PhD-students. The recognition is related to people and personal contacts, not to the institution in itself. If academic staff members are absorbed by the industry the recognition can rapidly disappear. This is not a special phenomenon at

LoTS, but is caused by better conditions in the industry. However, the problem is accentuated by the close collaboration between LoTS and the industry.

4.8 OVERALL ASSESSMENT AND RECOMMENDATIONS

4.8.1 OVERALL ASSESSMENT

The research group is emphasising their role as facilitators and disseminators of logistics knowledge from best practice companies (pioneers) to other companies (laggards) and to the academic world including education programmes. During this transformation process the research group is conceptualising the logistics applications. The overall objective of the research is to enlarge and enrich the knowledge of modern logistics management. The research has a clear objective of being useful for the business community. The research group is using existing theories, e.g. marketing channels theories, transaction cost analysis and strategic management theories. They have no ambition of developing new theories, but strive to refine and extend existing theories where appropriate.

This approach has its strengths and weaknesses. The major strength is that the research is highly relevant for the industry. The research group has established a strong platform for interaction with the industry, both in Sweden and internationally. This makes it easier to get access to relevant logistics issues and also to get supplementary funding from the industry. Another strength is that it attracts students at all levels to the logistics area.

A weakness of this approach is, however, that the borderline between research and consultancy is becoming blurred. The researchers are on the one hand doing research, but on the other hand making consultancy for the same or other companies. It is hardly possible to separate the two tasks in practice. The difficult balance is illustrated by the fact, that one of the adjunct professors is working as a consultant, an assistant professor has left the institution to work as a consultant, and another assistant professor has taken a one-year leave to work full-time in a large Swedish corporation. There seems to be a risk that the researchers are absorbed by the industry which is a threat towards the long-term continuity of the group and the accumulation of scientific knowledge. Another

weakness is that this approach has a tendency to give practical applications a higher priority than the development of scientific theories and methods.

4.8.2 RECOMMENDATIONS TO THE RESEARCH GROUP

Based on the self-assessment report and the visit at LoTS the evaluation committee shall give the following recommendations to the research group:

- The research group has developed a very good platform for collaboration with the industry. The relevance of the research to the industry seems to be high and the research group is participating in international research networks. The next logical step would be to establish a more profound scientific approach, e.g. by formulating and testing hypotheses, by operationalising and measuring theoretical concepts and by developing simulation and analytical models of logistics systems.
- The research group should give a higher priority to publishing in international refereed journals. The group has the potentials of doing so, but is recommended to devote more time and resources in revising conference papers and submit them to international journals. Several of the conference papers could without big efforts be revised and most likely accepted for publication.
- The research group should give a high priority to inviting international professors and PhD-students to Linköping and also to encourage own PhD-students to study abroad. The good academic network, which the group has developed, and the IMIE programme, should facilitate the international exchange of professors and PhD-students.
- The group should continue their efforts to increase the funding from private companies without being too much involved in direct applications. The funding from Ericsson Radio Systems to recycling seems to be a promising approach. Another approach could be to define relevant and interesting research areas and then invite a group of companies interested in the research areas to participate with funding. The motivation for the companies could be to participate in workshops and discussions with the research group.

4.8.3 RECOMMENDATIONS TO KFB

It is our assessment that the research group at LoTS has been very productive and effectively has disseminated the research results both in education, at national and international conferences and to the industry. The research group has a potential for leveraging the academic output by emphasising publication in international refereed journals. This leverage should be encouraged and supported by KFB.

Recently, there have been changes in the research group which might influence the continuity and knowledge accumulation in the future. The research group has a lack of senior researchers compared to the workload of teaching, administration and tutoring of PhD and master students. The research environment is very vulnerable if one or two senior researchers are leaving the group, or if the assistant professors currently on leave are not returning to the department within the next year.

KFB has a natural interest in supporting research environments with a capability of making research of high relevance for the industry and the academic world. LoTS seems to have this capability, but it is essential for the future development that the department is able to attract and keep qualified and experienced logistics researchers. Therefore, KFB should support initiatives which can enhance the academic research environment at LoTS, but also carefully evaluate the potential of future projects.

Appendix 1: Programme for the evaluation

Sunday, 8 November 1998
Arrival of the team in Göteborg
ca 21.00 Informal get-together and light evening meal with Tomas Engström

Monday November 9, 1998
Chalmers University of Technology ca 9.00 – 17.00

"Stations" are:
1) Basics on losses and theories for assembly system.
2) Methods for materials flow system design focused on assembly systems.
3) Materials feeding and kitting.
4) Variant codification and materials flow structures, so-called "assembly variants".
5) Materials flow efficiency.
6) Logistics and aspects on unit load design.

The following "stations" are optional:

7) Evaluation of different assembly systems including comments on the defunct Volvo Uddevalla and restarted Autonova plant as well as some historical aspects.
8) The computer synchronised video equipment used for technical, ergonomic and psychosocial evaluations.
9) Production models and social context.
10) Multidisciplinary methods (comprising technology and work sociology and work psychology (including evaluation results and methods.
11) Results of ongoing industrial co-operations and implementations of research results.
12) Examples of materials flow analysis (general as well as examples from industrial co-operations).

Monday November 9, 1998
ca 17.27 Departure Göteborg, 20.26 Arrival in Lund
ca 21.00 Informal get-together and light evening meal with Sven Axsäter

Tuesday, November 10, 1998
Lund Institute of Technology

09.00 - 09.30 Coffee.

09.30 - 10.00	Overview of Project (*S. Axsäter)*
10.00 - 10.45	Decentralised Multi-Echelon Inventory Control.(*J. Marklund)*
11.00 - 11.45	Exact Evaluation of General performance Measures in Multi-Echelon Inventory Systems. (*J. Andersson)*
12.00 - 13.30	Lunch.
13.30 – 14.00	Supply Chain Management: Pricing and Costing. (*K.Rosling)*
14.00 – 17.00	Discussion.

Tuesday, November 10, 1998

19.53 Arrival in Linköping.
ca. 20.30 Informal get-together and light evening meal at the Hotel Ekoxen (SW, MA, LO, MB).

The persons from Linköping university are SW = professor Sten Wandel, LO = adjunct professor Lauri Ojala; MA = adjunct professor Mats Abrahamsson; DA = Dr. Dan Andersson; AN= Dr. Andreas Norrman; MB= Ph.D. student, Lic.Sc. Magnus Berglund, MW = Ms. Mona Wickell, secretary, CD = Ms. Cristina Dalberg, department secretary

Wednesday, November 11, 1998
Linköping University

9.00 – 10.00 Presentation of the Linköping University and the Dept. of Logistics and Transport Systems (LoTS) at the Department in the university Campus Building A, 2nd Floor (SW, LO, MB, DA, AN, CD, MW).

10.00 – 10.15 Coffee with the head of the institution, prof. Jörgen Dahlgren, under which LoTS is organised.

10.15 – 12.00 Objectives of the project and the work done (SW, LO, MB, DA, AN).

- Work done in the TPL-study and in the TBD-study
- Other work done in connection to the project
- Problems encountered and changes to the project plan

12.00 – 13.00 Lunch at the University Restaurant (SW, MA, LO, DA, AN, MB, CD, MW).

13.00 – 14.30 Internal Evaluation and Discussion on Dissemination.
Contribution to the application domain
Dissemination and exploitation activities (SW, MA, LO, DA, AN, MB)

14.30 – 15.00 Coffee break.

15.00 – 16.00 Contribution to transport policy, and to activities not directly related to the KFB-funded research projects at hand during 1994 – 1998
OECD.(CEMT/ECMT), The World Bank, UN / UNCTAD, The European Union / European Commission
(SW, MA, LO, DA, AN, MB)

16.00 – 17.00 Conclusions by the participants and the evaluators.

Appendix 2: Publications Materials Handling Research Group, CTH

Below are the publications during 1993 to 1998 summarized. Though the KFB-theme program (project) has been running for three years plus extra years extension within the original economic frames due to complementary financing. This means that there is some overlapping in the publishing corresponding to approximate plus minus half a year. However, we feel it important express clear the research context and the resources build up at Chalmers University.

There are also, due to our way of organising the research and development work, some time delay in publishing results, i.e. since we have not been able to take fully academic advantage of our present data which to some extent might have explicit academic publishing on topics which are rationally are assumed to be within KFB sphere of interest. These facts is elaborated further in the main text.

1 Doctoral and licentiate thesis as well as other academic qualifications:

[II:A] Brynzér H (1995). "Evaluation of Kitting Systems – Implication for kitting system design". Department of Transportation and Logistics, Chalmers University of Technology, Gothenburg (licentiate thesis).

[II:B] Mathisson B[1] (1995). "Activity Analysis to Achieve Increased Materials Flow Effectiveness" Department of Transportation and Logistics, Chalmers University of Technology, Gothenburg (licentiate thesis).

[II:C] Medbo L (1994). "Product and Process Descriptions Supporting Assembly in Long Cycle Time Assembly". Department of Transportation and Logistics, Chalmers University of Technology, Gothenburg (licentiate thesis).

Future thesies:
[II:D] Medbo L (1998). "Assembly System Design" (preliminary title). Department of Transportation and Logistics, Chalmers University of Technology (Ph.D.-thesis in press November 1998).

[II:E] Medbo P (1998). "Input Quality in Materials Flow Analysis". Department of Transporttattion and Logistics, Chalmers University of Technology (licentatiate thesis in press September 1998).

[II:F] Öjmetrz B (1998). "Materials Handling in Materials Flow Systems from a Value-Adding Perspective". Department of Transporttattion and Logistics, Chalmers University of Technology (Ph.D. thesis in press September 1998).

[1] Birgitta Mathisson has married and changed name into Brgitta Öjmertz.

Miscellaneous:[2]

[II:G] Johansson M I (1995). "Oavlönad docentur i Transportteknik" vid Sektionen för Teknikens Ekonomi och Organisation. Chalmers Tekniska Högskola.

[II:H] Engström T cooperation in special guiding group for the thesis: Christmasson M (1997). "Production System for Manual Repetitive Jobs - Effects on Autonomy and Variety of Work and Prevalence of Musculoskeletal Disorders in Upper Limbs". Department of Operations Management and Work Organization, Chalmers University of Technology (Ph.D. thesis). Together with professor Ulf Karlsson and professor Roland Kadefors from Department of Operations Management and Work Organization respectively Lindholmén Development.

[II:I] Medverkan i externa examinationer:
- Glimstedt H (1993). "Mellan teknik och samhälle - Stat, marknad och produktion i svensk bilindustri 1930 – 1960", Historiska Institutionen, Göteborgs Universitet (doktorsavhandling). I betygskommitté: doc Tomas Engström.
- Kjellström K (1995). "Small-Volume Batch Production of High TechnologyProducts in the Electronic Industry". Institutionen för Arbetsorganisation, Chalmers Tekniska Högskola. Opponent vid licentiatseminarium: doc Mats I Johansson.
- Jansson L (1995). "En ansats till verksamhetsinriktade produktstrukturer". Institutionen för Produktionsteknik", Chalmers Tekniska Högskola (doktorsavhandling). I betygskommitté: doc Tomas Engström.
- Lidström-Widell G (1995). "Organisationsbilder –Om tanken som bas för handling". Business Admninistrative Studies – BAS, Göteborg. I betygskommitté: doc Tomas Engström.
- Johansson K (1997). "Autonomous Mobile Robots in the Factory of the Future". Avdelningen för Monteringsteknik, Kungliga Tekniska Högskolan (liv centite uppsats).

2 Scientific and popular publications:

1993

[II:1] Adlemo A, Andreasson S A, Johansson M I (1993). "Fault Tolerance Strategies in an Existing FMS Installation". Presented at the 7th IFAC Symposium on Information Control Problems in Manufacturing Technology, Toronto, 1992. Published in Control Engineering Practice, Vol 1, No 1, pp 127 – 134.

[II:2] Adlemo A, Andreasson S A, Johansson M I (1993). "Information Accessibility and Reliability Improvement in an Automated Kitting System". Presented at 12'th World Congress of the Federation of Automatic Control, Sydney, 1993 (submitted to Control Engineering Practice).

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[2] The financing at the research group has also helped Jan Johansson Hanse to qualify for "oavlönad docentur" in work psychology at Department of Psychology at Gothenburg University.

[II:3] Bengtsson J, Johansson M I (1993). "Unit Load Size as a Function of the Degree of Overtaking". Presented at the 12'th International Conference on Production Research (ICPR 12), Lappeenranta, August 1993. Published in Production Research 1993, Orpana V, Lukka A (eds.), Elsevier (1993), proceedings, pp 357 – 358. Published in International Journal of Production Economics, Vol 41 (1995), pp 103 – 108.

[II:4] Brynzér H, Engström T, Medbo L (1993). "Method Aspects on Multi–level Interactive Work Process Mapping". Presented at the IEA Industrial Ergonomics and Safety Conference, Copenhagen 1993. Published in Advances in Industrial Ergonomics and Safety. Nieslen R, Jørgensen K (eds.), Taylor & Francis Ltd. London, proceedings, pp 293 – 300.

[II:5] Brynzér H, Johansson M I (1993). "Design and Performance of Materials Kitting Systems." Presented at the 12th International Conference on Production Research (ICPR12), Lapeenranta, Aug 1993. Production Research 1993, Orpana V, Lukka A (eds.), Elsevier, proceedings, pp 421 – 422.

[II:6] Ellegård K, Engström T, Johansson B, Johansson M I, Medbo L, Nilsson L (1993). "Produktionssystem som tar människan till utgångspunkt vid förnyelse av teknik". Publicerad i Nordisk Ergonomi i forskning och praksis, No 3, pp 2 – 7 (in Swedish).

[II:7] Ellegård K, Engström T, Jonsson D, Medbo L, Nilsson L (1993). "Developing Unique Production and Work Structuring Principles Trough a Creative Search and Learning Process: The Uddevalla Final Assembly Plant". Enquiry on Emerging Patterns of Qualification and Learning in Modern Manufacturing Industries, Eurotecnet, the Commission of European Communities (in press).

[II:8] Ellegård K, Engström T, Nilsson L (1993). "Produktionssätt för framtiden". Göteborgsposten 21 april, pp 5 (debattartikel, not included).

[II:9] Engström T (1993). "Reorganisation of Material Flow for Natural Grouped Assembly Work – some principles and results from action research". Presented at the Sixth OMA – UK International Conference, Birmingham 1991, "Achieving the Competitive Edge – Getting Ahead Trough Technology and People", Bennet D, Lewis C (eds.), Springer-Verla, proceedings. Published in International Journal of Technology Management, Vol 8, No 3 – 5, pp 384 – 395.

[II:10] Engström T, Jonsson D (1993). "Principles of Perception and Structuring of Long Cycle Time Assembly Work". Presented at the 26th International Symposium on Automotive Technology and Automation – ISATA, Aachen 1993, proceedings, pp 119 – 125.

[II:11] Engström T, Jonsson D, Medbo L, Medbo P (1993). "Reforming the Product Variant Codification to Support a Holistic Perception of Product and Work Processes in Motor Vehicle Assembly". Presented at the 12th International Conference on Production Research (ICPR12), Lapeenranta 1993. Production Research 1993. Orpana V, Lukka A (eds.), Elsevier. Amsterdam, proceedings, pp 461 – 462.

[II:12] Engström T, Lundberg A, Medbo L (1993). "Evaluation Methods for Assembly Work and Product Design in Radically Different Production Systems: Results from case studies and action research in Swedish industry". Presented at the Fourth International Conference on Productivity & Quality Research, Miami 1993. Published in Productivity & Quality Management Frontiers – IV, Suthmanth D J, Edosomwan J A, Poupart R, Sink D S (eds.) Industrial Engineering and Management Press, Norcross, Georgia, Vol 2, pp 333 – 342.

[II:13] Engström T, Medbo L (1993). "Design Criteria and Production Principles for Parallellized Flow Assembly Work". Presented at the First International Colloquium – "Trajectories of Automobile Firms". International Network GERPISA, Paris 1993. Permanent Group for the Study of Automobile Industry and its Employees, Universite d´Évry-Val d´Éssonne – Centre de Recherches Historiques, Paris.

[II:14] Engström T, Medbo L (1993). "Naturally Grouped Assembly Work and New Product Structures". Presented at the Sixth OMA – UK International Conference, Birmingham 1991, "Achieving the Competitive Edge – Getting Ahead Trough Technology and People", Bennet D, Lewis C (eds.), Springer-Verlag, proceedings. Published in International Journal of Technology Management, Vol 7, No 4/5, pp 302 – 313.

[II:15] Engström T, Medbo L (1993). "Production System Design a Brief Summarisation of some Swedish Efforts". Published in "Enriching Production – Perspectives on Volvo´s Uddevalla Plant as an Alternative to Lean Production", Sandberg Å (eds) Avebury, Aldershot, pp 61 – 73.

[II:16] Engström T, Medbo L (1993). "Some Important Principles and Findings Concerning Long Cycle Time Assembly". Presented at the 26th International Symposium on Automotive Technology and Automation – ISATA, Aachen 1993, proceedings, pp 111 – 117.

[II:17] Engström T, Medbo L, Jonsson D (1993). "An Assembly–Oriented Product Description System as a Precondition for Efficient Manufacturing with Long Cycle Time Work". Presented at the Fourth International Conference on Productivity & Quality Research, Miami 1993. Published in Productivity & Quality Management Frontiers – IV, Suthmanth D J, Edosomwan J A, Poupart R, Sink D S (eds.), Industrial Engineering and Management Press, Norcross, Georgia, Vol 2, pp 453 – 462.

[II:18] Johansson J Å, Kadefors R, , Rubenowitz Z, Klingenstierna U, Lindström I, Engström T, Johansson M I (1993). "Musculoskeletal Symptoms, Ergonomic Aspects and Phychosocial Factors in Two Different Truck Assembly Concepts". International Journal of Industrial Ergonomics. Vol 12, No 1 – 2, pp 35 – 48.

[II:19] Johansson M I (1993). "Efficiency Losses in Production Systems Having Utilities Shared Between Workstations". Presented at the Fourth International Conference on Productivity & Quality Research, Miami, Feb 1993. Published in Productivity and Quality Management Frontiers – IV, Vol 2, Sumanth D J, Edosomwan J A, Poupart R, Sink D S (eds.), Industrial Engineering and Management Press, 1993, pp 284 – 293.

[II:20] Johansson M I, Almström C, Dahlman S, Örtengren R (1993). "Causes of Ergonomic Problems in Materials Handling and Transportation." Paper presented at the IEA World Conference on Ergonomics of Material Handling, Warsaw, June 1993. Published in The Ergonomics of Manual Work, Marras W S, Karwowski W, Smith J L, Pacholski L (eds.), Taylor & Francis, proceedings, pp 487 – 490.

[II:21] Johansson M I, Örtengren R (1993). "Workload when Stowing Parcels in Trailers". Paper presented at the workshop "Arbeit und Technik in Internationalen Spedition", Stralsund, 1993. Published in Logistik und Arbeit, November 1993, pp 27 – 32.

[II:22] Jonsson D (1993). "Monteringens Logik". Arbetsvetenskapliga Kollegiet. Göteborg (not included).

[II23:] Jonsson D (1993). "Stannar löpande bandet". Arbetsvetenskapliga Kollegiet. Göteborg (not included).

[II:24] Örtengren R, Almström C, Dahlman S, Johansson M I (1993). "A Research Program with a Systems Approach to Ergonomic Development of Materials Handling Technology and Work Procedures in Transportation." presented at the IEA World Conference on Ergonomics of Material Handling, Warsaw, June 1993. Published in The Ergonomics of Manual Work, Marras W S, Karwowski W, Smith J L, Pacholski L (eds.), Taylor & Francis, proceedings, pp 491 – 494.

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[II:25] Brynzér H, Johansson M I (1994). "Storage Location Assignment: Using the Product Structure to Reduce Order Picking Times". Presented at the 8th International Working Seminar on Production Economics, Igls/Innsbruck, 1994, proceeding, pp 147 – 159. Published in International Journal of Production Economics, Vol 46 – 47, 1996, pp 595 – 603.

[II:26] Brynzér H, Johansson M I, Medbo L (1994). "A Methodology for Evaluation of Order Picking Systems as a Base for System Design and Managerial Decisions". Presented at the 4th International Production Management Conference on Management and New Production Systems, London, April 1993, proceedings, pp 139 – 152. Published in International Journal of Operations & Production Management, Vol 14, No 3, pp 126 – 139.

[II:27] Ekström O, Ellegård K, Engström T, Fredriksson G W, Gustafsson G, J-Å Granath, Klarqvist B, Lidgren H, Lindahl G, Lundberg A, Marcus T A, Peyronson G, Rehal S, Strömberg C, Torell G, Törnqvist A, Wilhelmsen A-M (1994). "Performance of Industrial Buildings – Pilot Study in Bilprovningen Plant Aröd, Göteborg, Sweden". Department for Industrial Architecture and Planning, Chalmers University of Technology (not included).

[II:28] Ellegård K, Engström T, Nilsson L (1994). "La reforme du Travail Industriel Principes et Realites de la Planification d´Usine de Montage d´Automobiles Volvo a Uddevalla". Actes du Gerpisa – reseau international, No 9. Permanent Group for the Study of Automobile Industry and its Empoyees, Universite d´Évry-Val d´Éssonne – Centre de Recherches Historiques, Paris (not included).

[II:29] Engström T (1994). "Alternativ till det löpande bandet - Produktionsprinciper i Volvos slutmonteringsfabrik i Uddevalla" . Arbetsmiljödagar 1994, Program och skriftliga sammanfattningar. Dahlner B (redaktör) Arbetsmiljöinstitutet, Utbildning 1994:3 (in Swedish).

[II:30] Engström T, Johanssson B (1994). "Layout Planning and Work Structuring Methods for Parallellized Flow Assembly Work". Conference on Learning and Research in Working Life – Collaborative Experiences, Adebo T, Brattgård B, Westerlund U (eds.) Lund, proceedings, pp 35 – 36.

[II:31] Engström T, Jonsson D (1994)."Finns det en specifik svensk produktionsmodell?". Genomförande av förändring, Palmerud G (redaktör), Nordiska Ergonomisällskapets Årskonferens, Stenungsund, proceedings, pp 162 – 164 (in Swedish).

[II:32] Engström T, Jonsson D, Johansson B (1994). "Design Assumptions and Empirical Evidence Concerning Parallellized Long Work-Cycle Assembly". Presented at the 4th International Symposium on Human Factors in Organizational Design and Management – ODAM, Stockholm 1994. Published in Human Factors in Organizational Design and Management –IV, Bradley G E, Henrick H W (eds), North-Holland. London, proceedings pp 249 – 254.

[II:33] Engström T, Jonsson D, Medbo L (1994). "Development of Assembly Competence in Parallellized Flow Assembly Systems". Presented at the 4th International Symposium on Human Factors in Organizational Design and Management – ODAM, Stockholm 1994. Published in Human Factors in Organizational Design and Management – IV, Bradley G E, Henrick H W (eds), North-Holland. London, proceedings, pp 255 – 260.

[II:34] Engström T, Medbo L (1994). "Finns det en vidareutveckling av Volvos Uddevallafabrik?". Genomförande av förändring, Palmerud G (redaktör), Nordiska Ergonomisällskapets Årskonferens, Stenungsund, proceedings pp 166 – 169 (in Swedish).

[II:35] Engström T, Medbo L (1994). "Intra–group Work Patterns in Final Assembly of Motor Vehicles". Presented at the 4th International Production Management Conference on Management and New Production Systems, London 1993, proceedings. Published in International Journal of Operations & Production Management, Vol 14, No 3, pp 101 – 113.

[II:36] Engström T, Medbo L, Jonsson D (1994). "Extended Work Cycle Assembly – A Crucial Learning Experience". International Journal of Human Factors in Manufacturing, Vol 4, No 3, pp 293 – 303.

[II:37] Engström T, Medbo P (1994). "Datainsamling och analys av serieproduktionsystem genom att kombinera video- och persondatorteknik". Genomförande av förändring, Palmerud G (redaktör). Nordiska Ergonomisällskapets Årskonferens, Stenungsund, proceedings pp 262 – 265 (in Swedish).

[II:38] Johansson B (1994). "The Development Process of Automated Kitting Technique for Small Parts – From participation to a private company". Genomförande av förändring Palmerud G (ed) Nordiska Ergonomisällskapets Årskonferens, Stenungsund, proceedings, pp 75 – 78.

[II:39] Johansson B (1994). "Utveckling av ett automatiskt satsningssystem för småmaterial, från medinflytande till eget företag". Genomförande av förändring, Palmerud G (redaktör), Nordiska Ergonomisällskapets Årskonferens, Stenungsund, proceedings, pp 75 – 78 (in Swedish).

[II:40] Mathisson B, Ingelgård A, Johansson M I, Nonås K (1994). "Mechanical Aids in Manual Materials Handling – Technical context and attitudes". Presented at the 12th Triennial Congress of the International Ergonomics Association, Toronto, 1994, proceedings, pp 243 – 245. Paper presented at the Nordic Ergonomic Association Conference, Stenungsund, 1994. Genomförande av förändring, Palmerud G (redaktör), Nordiska Ergonomisällskapets Årskonferens, Stenungsund, proceedings, pp 38 – 41.

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[II:41.a] Brynzér H, Johansson M I (1995). "Design and Performance of Kitting and Order Picking Systems". Published in International Journal of Production Economics, Vol 41, pp 115 – 125.

[II:41.b] Engström T, Johansson J Å, Jonsson D, Medbo L (1995). "Empirical Evaluation of the Reformed Assembly Work at the Volvo Uddevalla Plant – Psychosocial Effects and Performance Aspects". International Journal of Industrial Ergonomics. Vol 16, No 4 – 6, pp 293 – 308.

[II:42] Engström T, Johansson M I, Jonsson D (1995). "Finns det en skandinavisk produktionsmodell?". KFB Kommunike, No 3, pp 12 – 14 (in Swedish).

[II43] Engström T, Johansson M I, Jonsson D (1995). "Två utvecklingslinjer för integrerade materialflöden", KFB Kommunike (in Swedish).

[II:44] Engström T, Jonsson D, Medbo L (1995). "Kalmar, Uddevalla and beyond: Volvos Factories of the Future". The Third GERPISA International Colloquium, "Towards a New Organisation in the Automobile Industry", Chanaron J J, Lung Y, Raff D (eds.), proceedings, Paris.

[II:45] Engström T, Jonsson D, Medbo P, Medbo L (1995). "Inter-relation between Product Variant Codification and Assembly Work for Flexible Manufacturing in Autonomous Groups". ~~International~~ Journal of Material Processing Technology. Vol 52, pp 133 – 140.

[II:46] Johansson M I, Karlsson H, Mathisson B, Örtengren R (1995). "Work Load Dose and Materials Handling Efficiency – A method to evaluate the design of materials flow systems". Presented at the 13'th International Conference on Production Research (ICPR 13), Jerusalem 1995, Dar-El E M, Karni R and Herer Y T (eds.), Global Frontiers in Manufacturing, 1995, Freund Publishing Company Ltd, propceedings, London, pp 739 – 741.

[II:47] Johansson M I, Medbo P (1995). "Materials Flow Effectiveness in Press Operations". Presented at the 13'th International Conference on Production Research (ICPR 13), Jerusalem 1995, Dar-El E M, Karni R and Herer Y T (eds.), Global Frontiers in Manufacturing, 1995, Freund Publishing Company Ltd, propceedings London, pp 352 – 354.

[II:48] Johansson M, Öjmertz B (1995). "The Packaging as a Carrier of Materials Flow Effectiveness". Presented at the 7th World Conference on Transport Research, Sydney, July 1995. World Transport Research Proceedings of the 7th World Conference on Transport Research, Vol 4, Hensher, D, King, J and Oum, T H (eds.), Pergamon, 1996, proceedings, pp 57 – 71.

[II:49] Jonsson D (1995). "Fabriken i Uddevalla ger Volvo försprång". Göteborgs Posten, 24 januari (debatt artikel not included).

[II:50] Jonsson D (1995). "Lean Production in the Automobile Industry: Second Thoughts". Published in "Enriching Production – perspectives on Volvo's Uddevalla plant as an alternative to Lean production", Sandberg Å (eds.) Avebury, Aldershot, pp 367 – 381.

[II:51] Karlsson H, Johansson M I, Mathisson B, Örtengren R (1995). A Method for Determening the Worlk Load Dose Whitinn m Materials Handling". Presented at the 13'th International Conference on Production Research (ICPR 13), Jerusalem, August 1995. Dar E M et al. (eds), Freund Publication House. London, proceedings, pp 739 – 741.

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[II:52] Engström T, Johansson J Å, Kadefors R (1996). "Work Organization, Ergonomics and Musculosketal Symtoms Among Workers Performing Long Cycle Time Assembly Work". International Conference of Occupational Health – ICOH96, Book of Abstracts, Stockholm p 261.

[II:53] Engström T, Jonsson D, Johansson B (1996). "Alternatives to Line Assembly: Some Swedish Examples". International Journal of Industrial Ergonomics, Vol 17, pp 235 – 245.

[II:54] Engström T, Jonsson D, Medbo L (1996). "Implication on Improving the Flexibility of the External Material Flow System Based on Experiences, Theories and Experiences from Transforming the Assembly Line". Freyssenet M, Boyer R (eds.) GERPISA, Paris, (unpublished book).

[II:55] Engström T, Jonsson D, Medbo L (1996). "Production Model Discourse and Experiences from the Swedish Automotive Industry". International Journal of Operation and Production Management, Vol 16, No 2, pp 141 – 158.

[II:56] Kadefors R, Engström T, Petzäll J, Sundström L (1996). "Ergonomics in Parallelized Car Assembly: A Case Study with References Also to Productivity Aspects". Applied Ergonomics, Vol 27, No 2, pp 101 – 110.

[II:57] Wassenius O, Järvholm B, Engström T (1996). "Simpler Work Practices are Less Wetting" (manuscript, not included).

[II:58] Wassenius O, Lillienberg L, Järvholm B, Engström T, Jonsson D (1996). "Analysis of Relationship Between Dermal Contact with Fluids and Machine Operator Productivity". International Conference of Occupational Health – ICOH96, Book of Abstracts, Stockholm, p 107.

[II:59] Winkel J, Engström T, Kadefors R, Mathiassen S E, Skerfving S, (1996). "Cooperative for Optimization of Industrial Production Systems Regarding Productivity and Ergonomics – A Swedish industrial research program". Preseneted at Risk Assessment for Musculoskeletal Disorders, Nordic Satellite Symposium Under the Auspices of ICHO 96, Sjøgard G, Fallenius N (eds.), National Institute of Occupational Health, Copenhagen, proceedings, pp 77 – 78.

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[II:61] Engström T, Johansson Hanse J, Medbo L (1997). "Finns det praktiska möjligheter att integrera ergonomiska aspekter i utformningen av produktionssystem genom ett tvär- och mångvetenskaplig samarbete?", Arbete människa miljö & Nordisk Ergonomi, No 4, pp 212 – 220.

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[II:65] Engström T, Medbo L (1997). "Is it Possible to Take Advantage of the Product Structure to Improve Shop Floor Ergonomics? Work Characteristics of Collective Working in Long Cycle Time Assembly Systems." Presented at the International Ergonomcis Association 13th Trennial Congress – IEA 97, "Organizational Design and Management", Seppälä P, Luopajärvi T, Nygård C-H, Mattila M (eds.), Tampere. Proceedings, pp 573 – 575.

[II:66] Engström T, Medbo L, (1997). "Empirical Analysis and Assessment of Automotive Assembly Work: An analyse procedure for work efficiency and ergonomic aspects". Presented at the International Ergonomcis Association 13th Trennial Congress – IEA 97, Organizational Design and Management", Seppälä P, Luopajärvi T, Nygård C-H, Mattila M (eds.), Tampere, Proceedings, pp 171 – 173

[II:67] Engström T, Medbo P (1997). "Data Collection and Analysis of Manaual Work Using Video Recording and Personal Computer Techniques". International Journal of Industrial Ergonomics, Vol 19, pp 291 – 298.

[II:68] Johansson Hanse J (1997). "Arbetsförhållanden och hälsa ur psykologisk synvinkel". Arbete Människa Miljö & Nordisk Ergonomi, No 1, pp 7 – 14.

[II:69] Johansson Hanse J (1997). "Personality, Job Strain and Musculoskeletal Symtoms". Presented at the International Ergonomci Association 13th Trennial Congress – IEA 97, Seppälä P, Luopajärvi T, Nygård C-H, Mattila M (eds.), Tampere, proceedings, Vol 5, pp 304 – 306.

[II:70] Johansson M I, Mathisson-Öjmertz, Rislund C, Örtengren R (1997). "Knowledge of Activities and Co-actors and a Value-adding Perspective on Handling Operations in a Materials Flow Chain: a Pilot Study". Presented at the 14th International Conference on Production Research, ICPR, Osaka 1997, proceedings, pp 130 – 133.

[II:71] Johansson M I, Medbo L. (1997). "Efficiency in Order Picking and Kitting Systems". Presented at the 14th International Conference of Production Research – ICPR, Osaka Japan, 1997, proceedings, pp 1682 – 1685.

[II:72] Johansson M I, Medbo P (1997). "Aspects on Input to Materials Flow Analyses. Presented at the 14th International Conference on Production Researcj – ICPR, Osaka, 1997, proceedings, pp 58 – 61.

[II:73] Jonsson D, Engström T, Johansson Hanse J (1997). "Competence, Workload and Work Cycle Length in "Collective Working": Findings from two Innovative Automobile Assembly Plants" (manuscript).

[II:74] Jonsson D, Engström T, Medbo L (1996). "Production Models and Social Contexts". Presented at The Sixth International Confenece on Management of Technology – MOT 97, "The Creation of Prosperity, Business and Work Opportunities Trough Technology Management", Mueller H, Persson J-G, Lumsden K R (eds.), Göteborg, pp 274 – 283.

[II:75] Mathisson-Öjmertz B. (1997). "Materials Handling from a Value-Adding Perspective". Presented at the 14th International Conference of Production Research – ICPR, Osaka, 1997, proceedings, pp 134 – 137

[II:76] Wassenius O, Järvholm B, Engström T, Jonsson D, Lillienberg L (1997). "Integrated Assessement of Dermal Wetness and Work Method Efficiency in Metall Cutting Work". Applied Ergonomics (submitted).

[II:77] Winkel J, Engström T, Forsman M, Hansson G-Å, Johansson Hanse J, Laring J, Kadefors R, Mathiassen S E. Medbo L, Ohlsson K, Petersson N F, Skerfving S, Sundin A (1997). "Co-operative for Optimization of Industrial Production Systems Regardning Productivity and Ergonomics (COPE)". Presented at International Ergonomcis Association 13th Trennial Congress – IEA 97, "Organizational Design and Management", Seppälä P, Luopajärvi T, Nygård C-H, Mattila M (eds.), Tampere, proceedings, Vol 1, pp 130 – 132.

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Appendix 3: Publications from LTH

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Appendix 4: Publications from LoTS, Linköping

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Appendix 5: Extract of self-evaluation report from CTH

SUMMING UP OF A THEME PROGRAMME FINANCED BY THE SWEDISH TRANSPORT AND COMMUNICATION RESEARCH BOARD (KFB)

KFB registration number: 93-328-22
Title: Development of new "system solutions" for integrated transport and materials flow systems.

1 Background

This theme program (project), sponsored by the Swedish Transport and Communication Research Board (KFB), aims at integrating knowledge concerning external and internal materials flow systems based on the assumption that the border line between what is traditionally defined as internal flow (i.e. within a plant) respectively external flow (i.e. outside a plant) is in many respects artificial and therefore this border line is today dissolving.

This fact implies the need for research methods addressing material flow systems efficiency and unit load design in complex materials flow systems by combining (1) the state of the art concerning external logistics trends with (2) our theoretical and practical frames of reference concerning internal flow. In this connection, the knowledge developed before the theme program (project) initiation in 1993 forms the core knowledge. This is why this specific theme program (project) might in some aspects be perceived as non-traditional from the point of view of problem areas which KFB denotes logistics or freight transport.

The core knowledge emanates from research and development work on production system design within the Materials Handling Research Group at the Department of Transportation and Logistics, Chalmers University of Technology (see appendix I). This research group was initiated in 1976. It has during twenty years been financed by the KFB, the Swedish Council for Work Life Research (RALF) and the Swedish Board for Industrial and Technical Development (NUTEK) as well as by Swedish industry in the form of long term projects, donations, doctoral appointments, materials and products, etc.

In fact, the KFB theme program (project) has a prehistory of a six-year senior research position for T Engström especially aimed at "production system design in a socio-technical perspective", sponsored by KFB (25%), RALF (25%) and NUTEK (25%) during 1988 – 1993. Without this sponsorship it would not have been possible to develop the core knowledge around which the theme program (project) is formed.

The KFB theme program (project) is aimed at long-term development of science on an international standard promoting multi-disciplinary co-operation. Since traditional logistics and external transport are to a great extent a research area which is still under development, there is in some cases a need for defined research methods and theoretical frames of reference (as is stated by Eidhammar, Orpana and Skjøtt-Larsen 1993).

2 Specific aims in relation to research methods

This KFB theme program (project) specifically aims at developing methods for:

(1) Analysing efficiency in complex materials flow systems.

(2) Integrating functions, processes and load carriers.

(3) Planning technically advanced products with numerous product variants.

(4) Internal production scheduling in relation to the performance of the internal materials flow system.

By our research methods we specifically refer to:

(A) "Loss analysis", based on Wild (1975), which we started to use in 1978. These methods were later elaborated to suit e.g. evaluation of materials flow systems (Engström, Johansson and Lundberg 1988, Engström et al. 1989).

(B) Using the products and product information for work structuring and materials flow system design, using methods that we started to develop in 1987.

(C) "VIDEOLYS", i.e. utilising our computer synchronised video recorder equipment which we started to develop in 1988 (Engström, Lundberg and Petzäll 1988).

(D) Utilising our action oriented research approach (e.g. prototyping, questionnaires, scenarios of schematised materials flow systems) resulting in, among other things, extensive empirical materials. Development of these methods was initiated in 1984 (Bramberger et al. 1985).

In figure 1 we have briefly summarised some publications (Ph.D. and Lic.Eng.-theses) according to aims and methods.

	(1) Analysing efficiency in complex materials flow systems	(2) Integrating functions, processes and load carriers	(3) Planning technically advanced products with numerous product variants	(4) Internal production scheduling in relation to the performance of the internal materials flow system
(A) Analyses of losses	[II:B], [II:C] [II:D], [II:F]	[II:B], [II:6]	[II:C], [II:D]	[II:C], [II:D]
(B) Using the products and product information	[II:A], [II:C], [II:D]		[II:C], [II:D]	
(C) Utilising our computer synchronised video recorder	[II:B], [II:E], [II:F],	[II:B], [II:F]		
(D) Utilising our action oriented research approach	[II:C], [II:D]			

*The financing and collected data at the research group have also helped Jan Johansson Hanse to qualify for "oavlönad docentur" in work psychology at the Department of Psychology at Gothenburg University

Figure 1 Overview of some of the personal academic results within the KFB theme programme, grouped according to specific aims and methods. Symbols within square parentheses refer to entries in appendices II and III. This matrix could be elaborated upon or illustrated further on request.

3 Examples of development of research methods and industrial co-operation

As hinted above, the research group has a somewhat autonomous and integrated organisation, where synergy effects between group members and projects are utilised through individual co-operation.

One example of how this integrated organisation has been achieved is the development of our video synchronised computer [II:37], [II:67], which works as an advanced stopwatch. This equipment has been developed still further during the last year in the form of synchronising external signals from inclinometers, electromyography data, etc. See e.g. [II:77] and [II:83]. At present we have just started working on how to get input data from materials flow systems by using bar codes, etc. The reason for starting measurements on human beings was the fact that these methods were readily available through our joint-venture co-operation [III:25] and [III:26]. This development work has to some extent obtained financing in the form of funds for expensive equipment,[3] in this case aimed at Virtual Reality (VR) techniques [III:6], [III:29] and [III:32]. However, there is an input data aspect of this technique that has direct general applications within our problem areas. In order to apply the VR techniques to traditional KFB problem areas, we for

[3] The Wallenberg Foundation has granted us 4 milj Swedish crowns to be shared between Department of Work Environment at Lund University of Technology and The Materials Handling Research Group.

example constructed a prototype for loading refrigerators onto trucks [III:18], a work which was preceded by analyses concerning return load carrier design and ergonomics [II:105].[4]

The VR aspect is professionally handled by our partners at Lund University of Technology who have a long-term experience within this field. This is also the case with our European partners [III:29].

*

Another example is the so-called "assembly variant" used for planning of technically advanced products with numerous product variants.[5] A representative example showing that administrative exchangeability is usually more restricted than the physical one is the sequence bound components delivered to a final assembly plant. Sequence deliveries mean that component individuals are assigned to specific product individuals as early as at manufacturing by the supplier. Two different components which are physically identical and thereby physically exchangeable, but from the production scheduling point of view designated for different product individuals, will therefore be treated as non-exchangeable.

There is, however, an alternative "logic" for external material flows more suited for parallel flow assembly. This approach, mainly aimed at improving flexibility, calls for an administrative exchangeability of products and components at the level of physical exchangeability (Engström and Medbo 1992). See also [III:54] for a more detailed explanation.

*

Still another example of integration is the initiation of co-operation with Volvo Knocked Down and Special Vehicle Operation (KSO) at Torslanda [III:17] and the Autonova plant in Uddevalla [III:19] which allowed us to, in practice, develop new materials feeding techniques for kitting of materials [II:72].

Warehouse design, including materials feeding by means of kitting of materials and order picking, has played an important role in our work. See e.g. [II:A], [II:26], [II:38], [II:71] and [II:83]. The later problem area is especially interesting since it amalgamates our earlier research with the KFB problem areas. On the one hand, kitting is a precondition for parallel flow assembly systems (of which we have extensive earlier as well as ongoing experiences). On the other hand, it also illustrates how the interface between external and internal materials flow systems is dissolving today. We have also broadened this problem area to include material handling efficiency and unit load design along logistic chains outside production systems. See e.g. [II:2] and [II:6]. This aspect has also been generalised into a method for material flow analyses, especially concerning aspects of input data quality [II:5], a work partly based on experiences from work at e.g. SKF

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[4] This technique needs further development work. This has already been initiated but is for the moment focused on data collection and data analysis rather than on the pure animation aspect.

[5] A considerable reduction (approximately 98%) of product identities, compared with using traditional design and market oriented product numbers, could be achieved. I.e. some thousand products numbers (separate vehicle identities) could be complemented with about 20 "assembly variants". In fact e.g. 1 100 products could be transformed into 18 "assembly variants" (e.g. Engström and Medbo 1992).

Sverige AB, for which we during several years have performed computer simulations [II:106], [II:107] and [III:20].

The interface between external and internal materials flow systems formed by the technique for materials feeding by means of kitting has been developed in a practical way by the design of equipment. Three generations of mobile prototype equipment have been manufactured in our workshop at Chalmers University. This equipment has been borrowed and sometimes utilised for full-scale production materials feeding systems, first at the Volvo KSO and later at the Autonova plant.

A similar prototyping and co-operation approach was used predating the KFB theme program (project) in 1989 – 1993 regarding materials feeding of small components for assembly work using plastic bags. See enclosed brochures at the end of binder no. 2, [II:38] and Johansson and Johansson 1990. The plastic bags contain exactly individual product components. The enclosed brochure illustrates one of the most profitable private enterprises in the West of Sweden.

*

Our research method for design of assembly systems (including materials feeding techniques) is another general result worth mentioning [II:64]. This method has recently been used for the plant design of Autonova where the running-in and performance evaluation was made using our computer synchronised video equipment. In fact, what started as a joint venture where blue-collar operators visited Chalmers University in order to evaluate their own work has now turned into a process where we have stationed the equipment at the plant for their own work making assembly instruction, performing time-and-motion studies, grasping input for materials flow calculations, etc. This method is based on a combination of using the physical product and the product information. See e.g. [II:4].

A similar approach has been used by e.g. Berifors Corporation in Örebro, which has invested in own hardware. We have supplied the software on loan for two years in exchange for data and performed analysis. Berifors in interesting since it is a worldwide supplier of electronic equipment to the automotive industry. They mirror another side of the industries with which we are most familiar, namely the main automotive manufacturers. This result has not yet been published. A similar procedure has for the moment started with L M Ericsson in Söderhamn as an activity within the COPE network [III:26].

In the future we will also have the opportunity to use this method for the redesign of the Volvo Buss plant in Borås, with which we have established co-operation regarding e.g. evaluation of the new advanced product design using space frame, modularisation, pallet assembly, etc. Another industrial partner is the Volvo Components in Skövde. As in many other co-operative projects, students writing their master theses have been involved.

*

As a part of the theme, the research group has been active in building up the GLORI network, Global Logistic Research Initiative. GLORI is a virtual organisation of university-based research institutes conducting co-ordinated research in global logistics. The mission is to develop new tools for managing the increasing complexity and turbulence in today's market place and will bring together academia and industry in an interactive

forum. Presently, the network has eight partner universities in six countries: Sweden, Germany, the Netherlands, United Kingdom, the USA and Singapore.

As a way of forming the network and its methods, a first project has been performed, concerning trends and expectations in the international air and express freight markets. Surveys were conducted simultaneously in Sweden, Germany and the United States. The report provides an in-depth analysis of critical competitive factors in the air and express freight markets. The survey also addresses the current and planned use of information and communications technology as a vehicle for providing customised services (such as world-wide-web, EDI and e-mail for managing the movement of goods and materials worldwide), as well as desired system features from tracking and tracing to on-line billing and customs support services. The survey revealed strong differences between markets in Europe and the United States, as well as some major differences between customer needs and provider offerings.

The future work in the network is focused on the information exchange in the supply chains, applying the perspective of the user of the logistic network. The basic approach is the availability of information, taking the new standards on information exchange as a point of departure.

*

Yet another example is a network of companies, all dealing with parcel handling, forming a common project dealing with efficiency and ergonomics in handling of parcels with high frequencies. Examples of companies are BTL, Posten Logistik and DHL. The idea is to conduct research into these systems, having access to reliable and first hand empirical data, at the same time as the companies themselves are performing development projects in their own system. The problem is that these projects are difficult to handle by the individual company, partly because of internal lack of interest (not highest priority in short-term competition), partly because of lack of strength and conformity in relation to suppliers of equipment and in relation to authorities. By forming a network of companies having common problems, using researchers as a catalyst in the processes, these problems can be overcome.

The original organising idea came from the earlier so-called "Packaging project" in which the research group took an active part and which proved to be very successful, see e.g. [II:B] and [III:5]. The main idea is that the companies are grouped in a number of development teams, dealing with one subproject from each of the participating companies. The development teams are themselves seen as sub-projects, having one of the company representatives as the project leader. This means that resources aimed at a development project in one company can be managed by a person from another company. The development groups also have representatives from a "system group", dealing with research and investigations important for and related to the development projects but being of a more general nature.

4 Some conclusions

Some general experiences from the KFB theme programme (project) are that:

- Based on detailed knowledge of product design and product information, it has proved possible for us to apply our already established internal trans-

portation frames of reference to external transport and communication. One example of such a "carry-over" is the so-called "assembly variant". See e.g. [II:9], [II:54].

- The internal operations and the external materials flow systems have during the time period of the KFB theme programme (project) showed to even more related, or the border even more fussy, due to the increased focus on e.g. outsourcing and direct distribution (eliminating the intermediate nodes in the physical materials flow).

- In the future, the design of information content artefacts (such as alternative product structures) will become even more important than today. Our experiences from the automotive industry underline this fact. In this connection, the research methods have proved to have a direct practical application. However, the researchers need to be on the forefront with respect to methods and empirical data in order to grasp and question industrial trends of interest for KFB.

- Most industrial implementations of e.g. information technology are generally focused on the direct technical aspects, neglecting the content in the data bases. The reformation of that content has played an important part in our research during the last decade. The materials flow system of the future will call for suitable methods for designing information content artefacts in order to e.g. allow other types of perspectives on JIT-deliveries, process locations, modularisation of products, design of the interfaces between internal and external materials flow and interaction between design and third part logistics in order to avoid suboptimisations, including unnecessarily complex industrial networks.

Concerning the organisational considerations in relation to the general aims of all KFB theme programmes (projects) it might be noted that:

- There are some quite long-time perspectives involved in establishing a problem area and a research context (not only consisting of people but also constituted by methods, equipment, facilities, etc.).

- Industrial partnerships require special facilities and procedures, e.g. methods suited for co-working between researchers and practitioners such as engineers, operators etc, possibility to change scientific discipline in order to get immediate industrial acceptance and ability to give fast feed-back on results.

- The fact that we have our own development resources for software/hardware including general computer support within the research group (Per Medbo) has in all respects improved and speeded up the work. A feature that might be of importance for other research groups.

Appendix 6: Extract of the self-assessment from LTH

Synopsis of work undertaken

Objectives of the project

In the original application the objective was to develop methods and models for coordination and information exchange in a logistic chain. Evidently this objective is quite general. The research should be focused on supply chains with varying degrees of information availability. The main part of the research has followed these intentions. There are also some exceptions, though, where project members have worked with extensions and revisions of previous research, e.g. when revising papers for publication after suggestions by referees. This part of the research has also dealt with supply chains but not explicitly with questions concerning information exchange. The range of supply chains studied has been slightly more narrow than what was originally planned. The research has more or less completely been devoted to multi-echelon inventory systems. With respect to the previous research experience of the group, this area was a natural starting point. Furthermore, since the area offers a wide variety of research problems that are interesting both from a practical and theoretical point of view, we decided to continue our research concerning such systems.

Work done

The main activities of the project all have to do with analyzing the behavior of multi-stage inventory systems under different assumptions concerning information availability. Basically, the work done can be divided into three broad categories:

(i) decentralized multi-stage inventory control with restricted information availability,

(ii) policies for centralized inventory control with extended information availability and finally, (iii) methods for exact cost evaluation of multi-level inventory policies. We will soon look at some of the specific work done within these categories but first some words about the methodology.

Methodology

The methodology used falls within the realm of applied mathematical modeling techniques. Since we are focusing on stochastic inventory models this means that we need to cross into the fields of applied probability theory as well as optimization theory and business administration.

There are several advantages with the mathematical modeling approach. The most obvious one is of course that the finished model represents a viable tool for optimizing the performance of the underlying system. However, it also promotes a good general understanding and intuition of why the system behaves in certain ways. The knowledge is attained partly by experimenting with the finished model, but to the largest extent under

the model building phase, when you have to study every detail of how the system operates.

The drawback or weakness with the methodology is that its usefulness is very sensitive to the assumptions made. If the model you build does not capture the main characteristics of the underlying system, it is very hazardous to infer any results obtained from the model to the real world. In other words, the validity of the method hinges on the fact that the system or problem that you want to study, is well defined and well structured.

In our research we do not focus on one particular real world system, instead we work with rather general two-level distribution systems known to frequently occur in practice. The advantage with this approach is that our results are quite general, the drawback is that in order to use the results in a specific company or supply chain, minor modifications are often necessary to customize the model. Generally speaking, inventory control problems are to their nature well defined and well structured. So from that point of view, the validity of our research method is beyond reproach. The crucial question regarding the validity of our research method is instead if the specific assumptions that the models are based on are general enough. Hopefully, this should not raise any grave concerns regarding our models, we use rather general assumptions commonly seen in the inventory literature.

Decentralized multi-stage inventory control with restricted information availability

An important issue in managing a supply chain is to reduce the cost of capital tied up in inventory while still maintaining a high service level towards the end customers. To succeed, the inventory decisions at different installations in the supply chain need to be efficiently coordinated. For small systems where, typically, all installations belong to the same organization and all relevant information about the system is readily available, the natural approach to achieve such coordination is to centralize all inventory decisions. For larger systems, especially when different organizations are involved, centralized control is often not a viable option. The difficulties that arise are both technical and managerial. Technically it is a huge challenge to obtain and process all the relevant data for the entire system centrally. From a managerial point of view it is very difficult to centralize the inventory control if the basic organizational structure is decentralized, which is the case for most large organizations. Installation managers will not accept that an outsider dictates inventory decisions, which have a significant impact on the performance of their local installation. These problems are of course even more accentuated in supply chains where the installations belong to independently owned companies.

Within the project there are three different papers dealing with models for highly decentralized inventory control in multi-level inventory systems:

- AXSÄTER, S. 1995. "A Framework for Decentralized Multi-Echelon Inventory Control", Lund University.

  This paper presents a new cost structure suitable for decentralized inventory control of a one-warehouse multi-retailer system. A basic assumption is that each installation starts with an initial policy. By minimizing its local costs according to the suggested cost structure an installation can reduce its costs. The total system costs are then reduced by the same amount. A performance guarantee assures that no installation needs to face higher costs due to policy changes at other installations.

- ANDERSSON, J. AXSÄTER, S. and J. MARKLUND. 1996. "Decentralized Multi-Echelon Inventory Control", *Production and Operations Management* (to appear).

  This paper considers a model for decentralized control of an inventory system consisting of one central warehouse and a number of retailers. The cost structure includes holding costs at both echelons and shortage costs proportional to the time until delivery at the retailers. We analyze a procedure for coordinated but still decentralized control of the system. The procedure is based on a simple approximation, where the stochastic leadtimes perceived by the retailers are replaced by their correct averages. The approximation enables us to decompose the considered multi-echelon inventory problem into a number of single echelon problems, one for each installation. The information about how a certain decision at the warehouse affects the retailers is conveyed through the marginal cost increase with respect to a change of the expected leadtime. This information about the retailer costs is used as a shortage cost at the warehouse. The procedure can be interpreted as a game or negotiation process, where each installation is a player, which makes its decisions, based on the most recent information regarding the replenishment strategies of the other players. We show that a coordination procedure based on this information can be used for finding near optimal reorder points for the system, and provide bounds for the approximation errors.

- ANDERSSON, J. and J. MARKLUND. 1997. "Decentralized Inventory Control in a Two-Level Distribution System", Lund University.

  This work is an extension of the model presented in Andersson et al. (1996) to a more general system allowing for completely non-identical retailers. Its main contributions are: a new optimization procedure with better convergence properties, a tighter upper bound on the maximum cost increase due to limited information about the lead-time distribution, a method for determining the lead-time distribution, an intuitive approximate expression for the average delay due to stockouts at the warehouse, and finally, numerical evidence indicating that the obtained solutions are of high quality.

To place these three papers into a larger context and to show more clearly how they fit into the literature we round off this section with a brief literature review.

Appendix 7: Extract of the self-assessment report from LOTS

Objectives of the project

The overall research objective of the project was to identify new ways of organising logistical activities in leading-edge firms, and to understand what type of changes had taken place in the internal and/or external organisation and division of these activities. The project was also aiming at improving upon the existing theories and models used in the context.

The research work was effectively divided into two traits: one trait was dealing with the novel issue of Third Party Logistics (TPL). This was a continuation on a KFB funded project (Dnr 92-96-43) which was carried out between July 1992 and August 1993.

Apart from other publications and dissemination to both academics and practitioners, the TPL research has resulted in two licentiate theses (Andersson 1995a and Berglund 1997) and one doctoral dissertation (Andersson 1997a).

The other trait was assessing the way in which (Swedish-based) multinational corporations could make – or had already made use of and implemented the concept of so-called time-based direct distribution (TBD). This concept had been introduced by Mats Abrahamsson in his doctoral dissertation in 1992 in Linköping.

In addition to a number of refereed articles, other publications and dissemination to both academics and practitioners, the TBD research has resulted in one licentiate theses (Norrman 1995a) and one doctoral dissertation (Norrman1997a).

Theoretically, the objective of the project was to improve upon the existing body of knowledge in two emerging areas of research (TPL and TBD). In the planning phase of the project it had become evident that such improvements needed to incorporate theoretical knowledge, say, from organisational theory to neo-institutional economic theory in addition to the "toolbox " traditionally used in logistics and/or transport research.

It was also clear from the onset that the use of traditional statistical and quantitative methods in gathering and analysing the empirical data was not feasible since the empirical evidence of the phenomena under study was scarce and often barely existing. Therefore, the appropriate research method was in-depth studies in a limited number of cases. Hence, applying the multiple case study method turned out to be a very useful point of departure in gathering the initial empirical evidence. Later on, certain survey-based methods could be added in Andersson's case, as was demonstrated in his doctoral dissertation in 1997.

The overall research approach was exploratory since very little research had been done – or at least was presented in public – of these issues at the time when the project objec-

tives were formulated[6]. This was also very much the case when KFB decided to grant funding for the project. A pre-study on TPL had been funded by KFB in 1992 (Dnr 92-96-43; reported in Andersson 1993)[7], but nevertheless the existing literature on the issues was scarce. It also a case, where KFB had the foresight and resources to finance research on an issue that was not certain to bring about substantial new knowledge of relevance.

It has turned out that once the results of the project began to materialise and be made public (from 1995 onwards), they have been readily accepted for publication in refereed journals and they have been cited in a very positive manner by some of the leading scientists in logistics. This indicates that the results have been regarded as innovative and highly relevant by the international research community and by practitioners too.

Work done in the TPL- study

In the third party logistics part, the following sub-projects have been completed:

- Logistics Alliance and Structural Change (licentiate thesis of Dan Andersson)
- Third Party Logistics – Outsourcing Logistics in Partnersships (Dissertation of Dan Andersson)
- Third Party Logistics Providers – Towards a Conceptual Strategic Model (Licentiate thesis of Magnus Berglund)

Andersson's licentiate thesis (Andersson 1995a) is a broad and descriptive study of the use and potential of TPL in European firms. It is based on the results from the previous KFB funded project (Dnr 92-96-43) which was carried out between July 1992 and August 1993 when a final report was submitted to KFB. Some 50 European shippers and 18 providers were interviewed and a data base was established in collaboration between the six CELO[8] universities: Eindhoven, Cranfield, Linköping, Dortmund, Aix au Province, and Rotterdam

The licentiate thesis covers the scope of third-party logistics and the interaction between the shipper and the service provider as well as the set-up of the partnership. It also covers driving forces, concerns and effects of third-party logistics. The realised effects (operational costs and service performance) of third-party logistics were investigated too. However, measurements difficulties (with respect to cost and service) and structural changes made it difficult to find out what the direct effects of the logistics partnerships were (and what was a result of structural change). In all, there was insufficient information about what caused the effects, calling for continued research to determine the causalities in more detail.

The second study on TPL was carried out at MIT in collaboration with a PhD candidate at Stanford. In addition to the European data in the dissertation, there is a more focused, de-

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6 One of the very first reports on the TPL issue – even internationally speaking - was Andersson 1991. Similarly, Abrahamsson (1992) was one of the first to address time as one of the most significant drivers to restructure the physical distribution structures and practices.

7 KFB-funded projects on logistics and goods transport that have been realised in Linköping include the following: Dnr: 93-293-22, 93-135-43 and the above-mentioned 92-96-43.

8 CELO is an informal Circle on Education in Logistics set up by the universities in question to enhance dissemination of best practice in logistics education an resrach among the participating universities. Logisticians from Linköping have been taking part in CELO from the very start of that cooperation.

scriptive and explanatory study of some 60 US firms in automotive and computer industries. The US survey is focused on the effects of third-party logistics and the causes behind the effects, as well as the causes behind successful third-party logistics relationships. However, there is some overlapping with the licentiate thesis (Andersson 1995a), since both concerns and driving forces are considered in the dissertation. The contents of the driving force model from the licentiate thesis was incorporated in the questionnaire for the US study. Here the structural factor was included which was not the case in the European questionnaire. Another purpose with the US questionnaire was to try to find any driving forces which had been overlooked.

While Andersson was approaching the TPL issue from the shippers perspective, a new Ph.D. student, Magnus Berglund, was taken into the project in February 1994 in order to study TPL from the logistics providers point-of-view. His research objective in the licentiate thesis (Berglund 1997) was to identify distinct strategies that TPL providers had developed, and strategies that were likely to be utilised in the future. How TPL providers add value above other alternatives and how they enhance supply chain integration were also studied in the project. Theoretically, the aim of the research was to develop an improved model to study these strategies, based on empirically found variables as well as models and theories previously applied in the context.

Berglund´s thesis (1997, with 385 pages all included) is a thorough piece of work, and it encompasses the strategies of TPL providers in Europe, US and Australia that are considered leading and innovative. As such, it was groundbreaking in that it consolidated and analysed data across continents – something that had not been available before. It has received a lot of positive response both from academics and practitioners.

Berglund is currently working on his PhD dissertation along the line of his licentiate thesis, by focusing on further development and application of positioning theory and a longitudinal 1998 follow up study of the 50 cases from 1993 done by the same CELO universities. He is now funded through KFB and the doctorate programme IMIE at the Linköping University[9]. Dissertation is due in February1999, exactly 4 years after he started with his post-gradual studies.

Work done in the TBD- study

For the strait dealing with time based distribution, the following sub-projects have been realised:

- "Organisation vid tidsstyrd direktdistribution" ("Organising Time Based Direct Distribution in Industrial Firms", the licentiate thesis of Andreas Norrman, 1995a):
  This thesis deals with the question how to organise logistics when centralising physical distribution from a large number of local warehouses to one Pan European distribution centre. The aim was to address issues such as how are the responsibility, control and operative execution of activities in the distribution channel allocated after the change to TBD. Further, the aim was to identify changes – if any - that had occurred during or after

9 For further information about IMIE, see: http://www.liu.se/org/imie/lots.html

the implementation of TBD in the studied cases. The methodology is a multiple case study with four extensive cases. Data has been collected by in-depth interviews with managers representing logistics, production and marketing/sales. The main outcome is a multi-layer model describing a shift of responsibilities in sales, order handling, invoicing, IT, physical distribution and transports, when centralising the distribution.

- Organising time based distribution in Transnational Corporations (dissertation of Andreas Norrman): This thesis continues and completes the licentiate thesis with a theory building approach. The methodology used is an explanation building approach in which the results from the cases in the licentiate thesis are analysed using a theoretical frame of reference based on organisational contingency theories and logistics contingency theories. The outcome is a discussion of how different theoretical approaches can explain the on-going structural changes in logistics in transnational companies.

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Postal address: Box 5706, S-114 87 Stockholm, Sweden
Visiting address: Linnégatan 2, Stockholm
Phone: 08-459 17 00; Int: +46 8 459 17 00
Fax: 08-662 66 09; Int: +46 8 662 66 09
Internet Home page: www.kfb.se

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