10102 Executive Summary
Grand Challenges for Discrete Event Logistics Systems
— Dagstuhl Seminar —

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Abstract. In March 2010, the Dagstuhl Seminar 10102 explored the grand challenges confronting research and practice in the domain of discrete event logistics systems. This Executive Summary describes the process of the seminar and discusses the key conclusions regarding grand challenges for research and practice. Abstracts of the presentations given during the seminar are put together in the online proceedings.

Keywords. Logistics Systems, Modeling, Simulation, Coordination, Design of Decision Support Systems

Introduction

Discrete Event Logistics Systems (DELS) are networks of resources through which material flows. Each node of the network corresponds to some resource (or set of resources) by which the materials are either converted in some way (refined, shaped, assembled, disassembled, etc.), moved (transported within one facility or between facilities), or simply held for some period of time (as work-in-process or stored in a warehouse). Material handling and transportation are key components of DELS. DELS are 'discrete' in part because they move material in discrete quantities, and in part because their behavior can be characterized effectively in terms of events happening at discrete points of time, i.e., the start or end of some conversion, transport, or storage process. A DEL system may take the form of a single warehouse, a portion of a factory, a complete factory, or a global supply network.

DELS have been the subject of a large body of analytic research. A huge variety of specific models exists that generally require application by model and/or

solver experts to answer narrowly-defined logistics questions about inventory, sourcing, scheduling, routing, etc. It has proven difficult to integrate these models in any comprehensive way into information systems like Enterprise Resource Planning (ERP) systems, Advanced Planning and Scheduling (APS) systems, Manufacturing Execution Systems (MES) or Supply Chain Management (SCM) systems, because of the lack of conceptual alignment between the models produced by researchers and the information systems deployed in practice with which they should be integrated.

This difficulty is magnified enormously by four factors: (1) the scale and scope of global supply networks, such as those developed to support airplane, automobile or telecommunications systems manufacturing, and service, which may involve literally thousands of individual enterprises; (2) the dynamic behavior of these networks, which are constantly changing as firms enter and leave, products change, markets change, etc.; (3) the broad range of information and communication systems deployed; and (4) the very high density of decisions, partially enabled by software systems but in many of not most cases to be made by humans, often near real-time. Today, although the literature on individual, narrow problems is vast, there is little base of theory or methodology for addressing decision problems that have scope, scale, and complexity of all four factors.

It seems clear that methods from computer science, industrial engineering, information systems, and operations research must be used together to address critical issues in architecting, configuring, planning, managing, and controlling DELS. In the past, researchers in industrial engineering and operations research have quite actively investigated DELS problems, but there has been less direct engagement from computer science and information systems. However, there is an ongoing trend also in computer science towards more business-related application domains, and as a consequence, the main slogan of the 'Gesellschaft für Informatik (GI)', the German Chapter of the ACM, 2007 annual meeting was 'Computer Science meets Logistics'.

Recognizing this, the authors of this report sought to bring together a group of researchers from Europe, North America, and Asia spanning the spectrum of industrial engineering, operations research, and computer science, to consider the following question: What are the grand challenges (for their combined research communities) in supporting decision making in the DELS environment. These efforts were generously supported by the Leibniz Center for Informatics, resulting in a Dagstuhl seminar held March 7-12, 2010, and attended by 28 participants representing universities, research centers, and companies in Europe, North America, and Asia.

The four and half day program of the Dagstuhl Seminar was designed to allow time for description and discussion of individual research or development activities, but also for the participants to spend a significant amount of time in discussions with the goal to create a consensus statement regarding the grand challenges. Specifically, there were four focused breakout sessions: Grand Challenges in Modeling, Grand Challenges in Analysis and Synthesis; Grand Challenges in Network Governance, and Grand Challenges in DELS.

This paper reports on the resulting consensus view of the grand challenges. The presentations by the participants are archived on the seminar website: (http://www.dagstuhl.de/en/program/calendar/semhp/?semnr=10102).

The Process

In the opening session, a definition of 'grand challenge' was proposed, namely, that to be a grand challenge, the following conditions must apply:

- The problem is demonstrably hard - requires order of magnitude improvement in some area.
- The problem cannot be known to be unsolvable.
- The problem's solution must have some social or economic value.
- Solving the problem requires collaboration - one researcher or one lab can't do it alone.
- Solving the problem requires 'new technology' - i.e., it is not simply clever use of what already is known.
- Solving the problem requires expertise in previously unexplored topics/areas.

With the requirements for a grand challenge in mind, three keynote presentations and seven panels addressed issues related to the seminar goal. The keynote presentations were:

- Academic Keynote: Stéphane Dauzère-Pérès, EMSE, St. Etienne/France,
- Software Vendor Keynote: Jörg Dickersbach, Wassermann AG, Munich/Germany
- Industry Keynote: Heino Ostermeier, Airbus Spares, Hamburg/Germany

In each panel, short presentations by the panelists were followed by discussions. The panels and panelists are listed in Table 1, and their presentations are archived on the seminar website.

Interleaved with the panel presentations were four breakout sessions, in which the seminar participants were divided into three teams (different teams for each session) and charged to discuss a specific topic and suggest grand challenges for that topic. The breakout topics descriptions and charges are given in the appendix.

Consensus Statement

As might be expected, when assembling a group of active and engaged researchers and practitioners, unanimity of opinion is not a realistic goal. However, after four days of intense discussion, a very broad and strong consensus was achieved on the essential nature of the grand challenges in DELS. This consensus was strongly influenced by a consensus vision of the future of the field, namely:

Table 1. Panels

Panel Topic	Panelists
State of the Art/Practice in DELS: Successes & Failures	Horst Zisgen, Peter Lendermann, Benoit Montreuil
State of the Art/Practice in DELS: Successes & Failures	Christian Almeder, Scott Mason, Sven Spieckermann, Arnd Schirrmann
State of the Art/Practice in DELS: Successes & Failures	Russell D. Meller, Lars Mönch, Oliver Rose
Modeling–How We Think About DELS	Cathal Heavey, Volker Nissen, Hans Ehm
DELS Analysis/Synthesis Methodology	John Fowler, Martin Grunow, Stefan Nickel
Network Governance and Decision Aiding	Herbert Kopfer, Paul Valckenaers, Andreas Fink
Future of DELS Research and Practice	Dirk Mattfeld, Leon McGinnis

The fundamental goal of research and development in DELS is to enable models-based engineering and management of DELS.

With this vision as the unifying theme, the seminar participants identified four grand challenge themes - three that are related to the development, deployment and use of models, and one related to cross cutting issues.

Grand Challenge Theme: DELS modeling
The development of large scale, complex models has always been a challenge, especially in terms of teaching model development. The breakout sessions identified three fundamental themes that need to be addressed.

Unified DELS Language. There was very strong consensus that a fundamental challenge to the future success of DELS research and development is the creation of a unifying language for the description of DELS problems. Clearly, the model driven architecture movement in computing provides at least one example of how this grand challenge might be approached. The breakouts specifically identified three desirable outcomes:

- Creating high-level but universally useful abstraction of DELS (comprising resources, objects, decision and physical flows, interactions), applicable across a broad range of industries, organizations, geographic and temporal scales.
- Using these abstractions to identify domain-specific attributes of particular classes of DELS, such as warehouses, wafer fabs, assembly factories, etc.
- Exploiting the universal abstraction and the domain specific models to create modeling libraries for decision based application development.

Multiple Levels of Abstraction. DELS span from the boardroom the shop floor, and involve time spans from milliseconds to decades. While DELS models exist

today across both dimensions, integrating those models remains a major challenge. The breakouts identified two key requirements:

- Ability to develop models of an entire supply network at various levels of abstraction of various level of detail from a common data description, including time-dependent and/or stochastic behavior for several stakeholders for performance assessment; this ability is essential for achieving horizontal integration of models (i.e., integration across the flow of material from initial supplier to final customer, including any closed loop recycling).
- Consistent methods for model aggregation (reduction) to derive strategic models from available operational models (and vice versa); this capability would be essential for achieving vertical integration of models (i.e., integration from the strategic decision level down to the real time operational level).

Non-DELS Specific Modeling Issues. There are generic issues in decision support modeling that are important across a broader domain than DELS, yet also critical in meeting the DELS grand challenge. These include:

- Modeling approaches that can cope with systems when there is incomplete (or even conflicting) knowledge of logistics policies, or logistics participant information, or incomplete data in very large-scale networks.
- Modeling approaches that can cope with combination of lumpy (discrete) and continuous systems, e.g., the lumpy decisions associated with capital expansion versus the more continuous decisions associated with real time control.
- Modeling approaches that can address non-technical aspects (e.g., contracts, behaviours, principal agent issues) of DELS operations.
- Modeling approaches for portraying human involvement and decision-making in using decision support tools.

Grand Challenge Theme: DELS model deployment

Deploying models in practice means adapting them to a particular application in two important ways: (1) adapting them to the available data; and (2) adapting them to the decision making process. Because models invariably require data, to be useful they must be integrated with existing (or planned) information systems. This presents challenges on several levels, from understanding clearly what information should be available to the details of the specific software interfaces needed to access the information that is available. On the other hand, models are intended to support decision making, but the decision making process itself is often somewhat ad hoc, especially with regard to strategic decisions. A model that can only answer one very specific and/or narrowly defined question may have limited utility, if the strategic decision making processes requires answering other questions as well. Considering these factors, the breakouts identified four types of grand challenges associated with model deployment.

Inherent distributed nature of DELS. DELS are by their nature distributed systems, and inherit all the challenges associated with distributed systems. Some key requirements for model deployment include:

- Establishing standards for re-usable plug-and-play model components and data structures in information systems and their interoperation.
- Better methods and tools for distributed modeling of supply network operations and control; solving the 'System of Systems' problem for DELS.
- Developing approaches for the integration of different modeling techniques (e.g. simulation, MIP, queuing models), even hybrid approaches.
- Closing the gap (with respect to modeling the system state) between the real, physical, base system and the information system and associated decision support systems.

Model Persistence. To support decisions across the spectrum from operational, through tactical, to strategic, DELS decision support models need to be persistent, i.e., existing in parallel with the DELS systems they represent. This goals leads to four specific challenges:

- Developing approaches, methods, and tools that allow us to take into consideration the fact that there are soft boundary conditions in a model that can be violated, up to some unknown limit.
- Not only do we need to shorten the cycle time for model generation and maintenance, we need technology to keep models persistent, i.e., to maintain them so that they are always consistent with the system being represented.
- Approaches and methodologies are needed to support the evolution of planning and control systems, leading to the creation of models to design systems with the ability to learn - so they do not break abstractly.
- New theories and approaches that enable highly sustainable and robust performance by exploiting dynamic networks in open supply webs.

Data Availability and Quality. In practice, data is the lifeblood of any DELS, and thus any decision support model of a DELS. This leads to two challenges that are common with all decision support models:

- Methods and tools are need to take advantage of the wealth of empirical data that are collected during the operation of DELS; these data should inform the design of future DELS, even if it is different from past experience.
- Theories, methods and tools for dealing with multiple data sources, high-density data streams, errors, uncertainty conflict, etc.

User Friendliness. The industrial participants gave numerous examples of information systems intended to support the operation of DELS, but with interfaces so complicated that human error is almost guaranteed. There is a continuing grand challenge to:

- Achieve an appropriate level of ease of use - visual appeal, simplicity, etc - given the range of users, user requirements, user knowledge and understanding, with 'intelligent' user assistance.

Grand Challenge Theme: DELS model-based decision making
In the literature of DELS decision support models, there are two broad categories

of models: those that assess a system (or decision) in terms of some criterion or set of criteria, and those that optimize a system (or decision) in terms of some criterion (or, rarely, some small set of criteria). In both categories, there are a few criteria that clearly dominate, e.g., cost related (i.e., cost minimization/profit maximization, etc.), schedule related (i.e., makespan, tardiness, etc), utilization related (i.e., maximize, minimize, balance, etc.), etc. However, as DELS grow and change in scale and scope, our view of decision making needs to change as well. Two examples illustrate this point. First, the emergence of sustainability as a major concern means that decision support models need to consider criteria that may be quite different from those in the large body of legacy models, e.g., energy or water consumption, carbon emissions, or total environmental footprint. Second, the fundamental conceptual framework (single decision maker with well defined decision problem) may need to be revised to account for emerging concerns such as the principle agent problem. The seminar participants called out three categories of grand challenges:

Decision Algorithms

- Approaches for automatically finding the appropriate type of (meta) heuristics and parameters (including auto-calibration) for a given DELS decision problem.
- Approaches and specific methods for describing the capabilities of solution approaches in order to select appropriate decision support methods.
- Despite the existing body of theory and applications, there still is a need for useful techniques for multi-objective problems.
- There is a great need for an integrated framework that enables the simultaneous use of both Simulation and Optimization.
- Decision making algorithms covering collaborative environment were independent actors have to align their local interests under common interests (if one fails - all together will fail).

Quality of Decisions

- There is an unmet need for metrics and methods to assess the quality of solutions coming from decision support models (including risks, stability, etc.).
- It is becoming ever more crucial to be able to quantify the monetary value generated by decision support systems.
- Real-time, robust, decision making tools are needed that explicitly consider performance measure trade-offs, rather than simply optimizing some criterion.
- As DELS and their decision support systems become even more complex, it is important for decision support systems to explain what they suggest when the suggestion is not intuitive.
- As DELS become more complex, they need capabilities for self diagnosis and automated error checking; they should be capable of automated analysis of results, and for providing explanations of the results to their users.

Crossing Boundaries. Increasingly, DELS grow organically, joining distinct DELS (at least temporarily) to accomplish some goal. In this setting, there are many boundaries crossed on a routine basis - not only between organizations within a single firm but across firm boundaries. This leads to three types of challenges:

- Coordinating decision-making when crossing the boundaries of firms requires embedding quantitative decision support into collaborative decision making within the DELS domain
- Collaboration across DELS boundaries requires an ability to smoothly integrate information/decisions in multiple DELSs.
- Effective collaboration requires consistent re-usable key performance indicator (KPI) classes with (dis-)aggregation functionality.

Grand Challenge Theme: DELS cross-cutting issues
The seminar participants identified a number of other grand challenge issues that did not fit neatly into the decision-centric framework, but were thought to be critical for the future success of modeling and analysis of DELS:

- Better curricular materials are needed for Logistics Science and Engineering.
- Greater diversity is needed in the community of DELS research and development.
- New business models (e.g. service orientation) are emerging, and the existing modeling approaches may be inadequate to these new business models.
- The concept of the Physical Internet (PI), which is analogous to the information internet - i.e., using standardized transportation units (foldable, re-configurable object-oriented concept) - may provide a platform for 'clean sheet' rethinking of the modeling and analysis of DELS.
- We should begin to think of DELS as a strongly interdisciplinary domain, and consider simultaneous development of physical products, their logistics systems and associated services.
- We need a web of pervasive persistent representative models and components (types & instance).

Conclusion

Perhaps the strongest message from this Dagstuhl seminar is that the future of research and development in DELS is different from the past in four important ways:

- The future contributions that are needed are unlikely to come from a single researcher or group, but rather to combine the insight and knowledge of groups that cut across the traditional boundary between the IE/OR community and the computing community. For example, the creation of a unified, open, object oriented language is such a contribution.
- The future contributions that are needed will be characterized by a significant degree of integration - across model types, horizontally across a supply network, vertically through levels of decision making, across organizational boundaries, across time, etc. (end-to-end solution)

- The future contributions that are needed will deal explicitly with data - the quantity of data in modern DELS, the quality of data, the persistence of data, and the use of data.
- The future contributions that are needed will address not only the technical aspects of DELS (inventories and flows, e.g.) but also the sociological aspects (group decision making, principal agent problems, contracting and network governance, etc.).

The challenge for the research and development communities working on DELS is to create a platform to support the kinds of future contributions that are needed. This means establishing a broad network of collaborations, with appropriate venues for presenting and discussing results, and appropriate archival journals for publishing results. It also means creating an information technology infrastructure that will support and enable the kinds of collaboration required.

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APPENDIX A: Breakout Charges

Breakout I: Grand Challenges in Modeling
In order to think about DELS, or to provide analysis to support DELS decision making, we must use models, or formal representations of DELS. These models can be implicit (not articulated) or explicit. Here, we are mostly interested in explicit models, which may address the physical structure and behavior of the DELS of interest (the DELS 'plant') or its operational, tactical, or strategic decision making (the DELS 'control'), or even the decision support process itself. The models may be crude approximations or high fidelity representations. Of course, to be useful, the models must be populated with instance data. The focus in this breakout is on the models and modeling processes per se and not on the methodology used to analyze the resulting models. If we imagine a time in the future when the DELS grand challenges have been met, what modeling capabilities will be available (e.g., model creation, model validation, model communication, integration of models with corporate IS), and what challenges will have been overcome to attain those capabilities?

Breakout II: Grand Challenges in Analysis/Synthesis
It is not enough to have representations of DELS, we must be able to use those representations to support decisions, i.e., to predict the results from taking specified decisions, to identify the 'best' decisions to take, etc. If we imagine a time in the future when the DELS grand challenges have been met, what analysis/synthesis capabilities will be available, and what analysis/synthesis challenges will have been overcome to attain those capabilities?

Breakout III: Grand Challenges in Network Governance and Decision Aiding
One way in which DELS are changing is the emergence of global networks for producing and support a product or family of products, from design and manufacturing, through sustainment and to end-of-life treatment. Examples abound, whether it is the Ford 'world car', the Airbus 380, Lockheed Joint Strike Fighter, or the Apple iPhone. These programs invariable grow a network of relationships among firms that may collaborate on the program yet compete outside the program. These networks must be robust, reliable, fast, and efficient. What new challenges do these changes bring in terms of governing these networks and in providing quantitative analysis to support governing decisions? What kinds of R&D is needed to meet these challenges?

Breakout IV: Grand Challenges in Network Governance and Decision Aiding
Repeat Breakout III with different discussion groups, refining the identification of the challenges and of the needed research and development.

APPENDIX B: Participants of the Seminar

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