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Optimizing the Wood Supply Chain – Concept and Methods*

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Abstract
Traditional Wood Supply Chain Management has several shortcomings that limit the performance. Thus we propose a Spatial Decision Support System that supports the operations planning within the Wood Supply Chain. The intended system comprises several aspects of GIScience and Operations Research. Among them there are Location Based Services and Web Services and further standardization issues that arise in this context. In order to solve the scheduling task within the Wood Supply Chain several theoretical models and solution methods originating from Operations Research are discussed. The architecture of the intended Spatial Decision Support System collects the concepts within one system.

Keywords: Spatial Decision Support System, Wood Supply Chain, Location Based Services, Web Services, Standards

1. INTRODUCTION

The term Wood Supply Chain comprises the linkage between customers, suppliers and shippers in the forest business and is characterized as a process in which organizations participate to produce a result. Within forestry there is a demand for intelligent decision support tools optimizing the Wood Supply Chain (Gronalt et al., 2005). The problem of Wood Supply Chain Management is complex and spatial in its nature, due to the great number of participants and the complex information that have to be processed. Therefore Spatial Decision Support Systems (SDSS) in combination with intelligent methods originating from mathematics, namely Operations Research (OR) are appropriate to support Supply Chain Management.

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The results obtained by SDSS can be additionally calibrated by establishing real-time feedback capabilities between the decision-making center and the actors in the field (e.g. the trucks or dispatchers at haulage companies) and between geospatial servers. This is being achieved via Location Based Services (LBS) (see section 3.3) and other Web Services (see section 3.4)

Any flow of products and information relies heavily on standards and the corresponding infrastructure (see section 3.3, 3.4 and 3.5). For the flow of information, the required standards pertain to communication facilities as well as to information structure and semantics, while infrastructure questions relate to communication networks and to the ubiquitous availability of common and ready-to-use geospatial data. In this paper, from the scope of standardization and infrastructure aspects that was just outlined, attention will be restricted to geospatial information standards and infrastructures. In section 3.5, the current state-of-the art in standardization and infrastructure for geospatial data will be outlined.

2. WOOD SUPPLY CHAIN

The term Wood Supply Chain as described above comprises the logistics system from timber to final product that is delivered to a customer. In this paper we will focus on the logistic operations from timber production to the first processing step – usually taking place in a saw or paper mill.

Figure 1 shows a brief description of the Wood Supply Chain that is the subject of this paper. Saw mills have a demand for timber with a number of special constraints, like quality, quantity, due-date and a price per cubic meter the saw mill is willing to pay. Timber arriving from a forest enterprise must meet the criteria of quality and due-date. The quantity may be met by a number of forest enterprises. For simplicity reasons it can be assumed that forest enterprises produce timber if a demand exists. Produced timber has several attributes: quality, quantity, completion date and a price per cubic meter the forest enterprise wants to receive. Haulage companies transport timber from various forest enterprises to saw mills and have the following criteria: price per driving unit, capacity constraints. The striking questions concerning the Wood Supply Chain are the following:

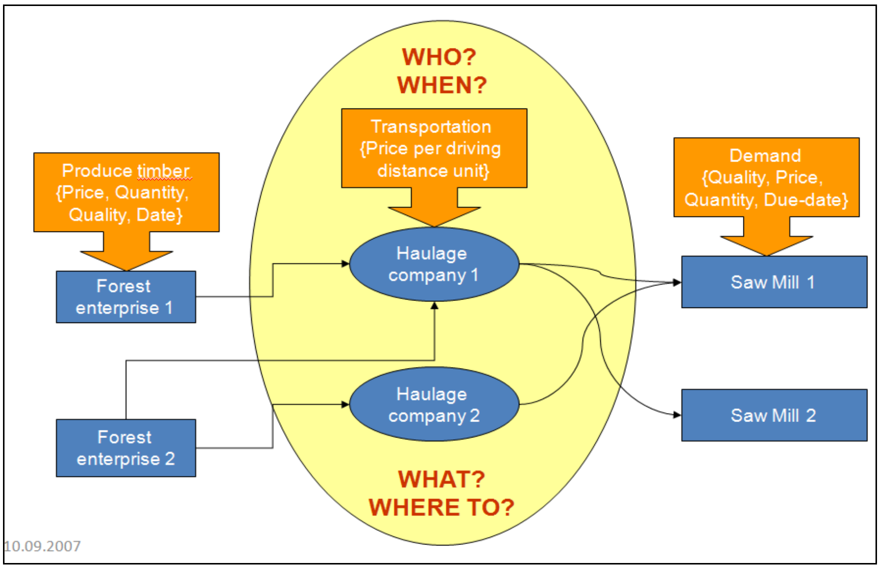
WHAT should be transported? e.g. timber with quality class A, from forest enterprise 1
WHO should transport? e.g. haulage company 1
WHEN should it be transported?
WHERE TO? e.g. saw mill 1

To ensure an efficient transportation process relevant information must be passed on throughout the whole process. Due to the great number of participants, a great variety of information media and devices within the Wood Supply Chain media disruptions occur (Bodelschwingh et al., 2003), see Figure . Moreover the truck drivers and dispatchers hardly ever use information systems to maintain an overview of the situation. Thus the uncoordinated handling of logistic operations is very likely.

Concluding, the characteristics of the Wood Supply Chain are as follows:

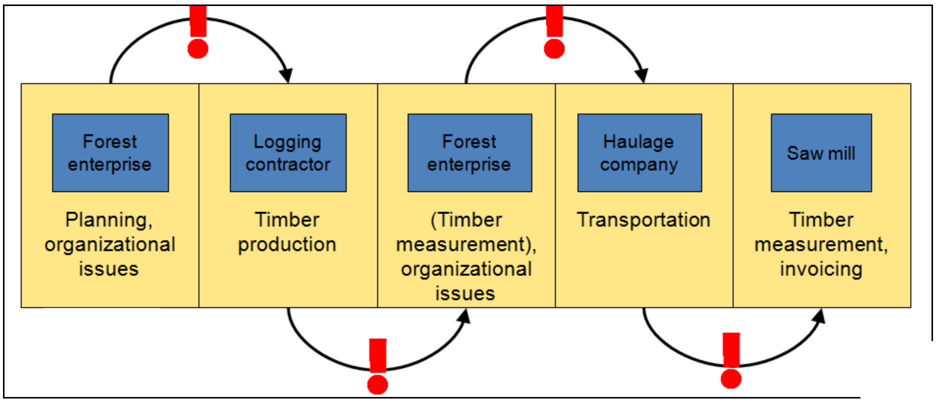
- Great number of participants
- Bidirectional flow of products and information
- Voluminous and complex information has to be processed
- Spatial in nature
- Problem is not entirely solvable by computers – human knowledge has to be involved in managing the Wood Supply Chain operations.

Figure 1: Simplified illustration of the Wood Supply Chain.



Traditional shortcomings are: media disruptions and uncoordinated logistic operations. Thus the problem of Wood Supply Chain Optimization may be regarded as a semi-structured decision problem, which will be described in the next chapter. Generally speaking information systems (i.e. GIS) can help the dispatcher to manage the supply chain operations but can never replace the human involvement in this process

Figure 2: Information path and possible media disruptions (marked with red exclamation marks) derived from Bodelschwingh et al. (2003).



To clarify where different components and concepts presented in this paper will have an impact, two scenarios shall be used:

- Scenario 1 (long-term): A new saw mill, a new forest enterprise or new haulage company enters the market. All processes have to be revised and for this purpose, a multitude of geospatial datasets has to be taken into account. Standardized Web Services allow query, overlay and analysis of up-to-date data from different sources, also ad-hoc and on-demand, providing the necessary inputs for SDSS.
- Scenario 2 (short-term): Varying weather conditions, road construction, traffic incidents or saw mill breakdowns call for temporary revisions of strategies. LBS being utilized in the field and being coupled with Web Services in the dispatching center will improve the quality of such strategy amendments.

In both scenarios, a high degree of standardisation as well as rich and well-documented geospatial data infrastructure are essential ingredients.

3. THEORY AND METHODS

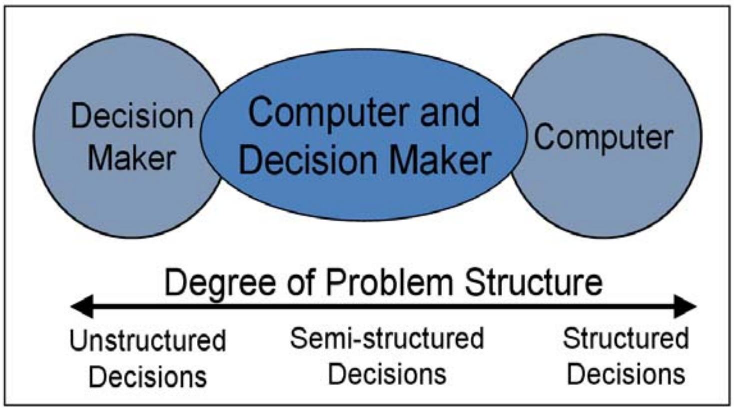
3.1 Spatial Decision Support Systems

Spatial Decision Support Systems (SDSS) are “interactive, computer-based systems designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem“ (Malczewski, 1997). The goal of SDSS is to reach a higher effectiveness by blending decision makers' knowledge and intelligent algorithms from computer science or mathematics. The term effectiveness can be summarized as "getting things done", whereas efficiency may be defined as the ratio of the useful output to the total input in any system.

Generally speaking SDSS should be applied in semi-structured problems. Every real world problem can be found within the continuum ranging from structured to unstructured problems (see Figure 3). Structured problems are completely solvable by a computer, whereas unstructured problems are problems which cannot be formulated by a machine. Semi-structured instances have some computer solvable parts as well as unstructured parts that need human knowledge being involved to come up with a solution.

Basically we can distinguish three phases in a decision process: Intelligence, Design, and Choice. Intelligence phase discovers the problem, whereas in the Design phase the problem is analyzed and alternatives are generated. The Choice phase evaluates the alternatives and recommends the "best" alternative. Geographical Information Systems (GIS) are useful in every of the three phases, due to sophisticated analysis, model building, simulation and visualization capabilities.

Figure 3: Problem structures and intended corresponding problem solver (Malczewski, 1999).



SDSS's consist of three components: Spatial Database Management System (DBMS), Model Base Management System (MBMS) with models from OR and the Dialog Generation and Management System (DGMS). The DBMS contains the spatial database and provides data access, storage and management functions. MBMS interacts with the model base, i.e. the mathematical optimization models. In order to ensure communication with the user the DGMS provides user interfaces.

Concerning the integration of the MBMS in a GIS environment, Malczewski (2006) distinguishes between four categories: no integration, loose coupling, tight coupling and full integration. In the loose coupling approach a GIS and the MBMS communicate using files that are exchanged between the systems. Tight coupling involves a shared data model and user interface – although the two systems are not completely merged. Through adding user specified routines to a GIS that encompass the model base and MBMS the two systems are fully integrated. In this paper we focus on the tight coupling approach for several reasons:

- we intend to use a third party numerical solver package to implement OR algorithms and solve the optimization problems accordingly. Such numerical solvers are appropriate to solve complex and large scale problems described in section 3.2 while maintaining efficient calculations.
- a full integration approach lacks the flexibility to compare numerical solvers and different optimization methods.

3.2 Operations Research

In a nutshell, "operations research (OR) is the discipline of applying advanced analytical methods to help make better decisions" (INFORMS, 2004). A variety of mathematical models are discussed in literature, but in this paper we focus on basic Graph Theory which serves as basis for further considerations as well as Travelling Salesman Problems (TSP), Vehicle Routing Problems (VRP) as a special case of TSP's and Rolling Schedule approaches. Additionally we briefly explore relevant solution methods.

3.2.1 Graph Theory

A graph is an ordered pair of $G = (V, E)$, where V is the set of vertices and E is the set of edges. We distinguish between undirected and directed graphs. The edges $e = (x, y)$ of directed graphs have a distinct direction from vertex x to vertex y. A weighted graph exists if the edges are assigned weights $w: E \rightarrow \mathbb{Z}^+$, which are also called costs or lengths.

Two vertices are adjacent if they share the same edge, and two edges are adjacent if they share one vertex. Loops are edges with the same vertex as start- and endpoint $e = (x, x)$. If there is more than one edge between vertices x and y then these edges are multiple edges. Graphs with multiple edges or loops are called multigraphs, otherwise simple graphs.

A walk W is an alternating sequence of vertices and edges $v_1, e_1, v_2, e_2, \ldots, v_{k-1}, e_{k-1}, v_k, e_k$ where vertices and edges are not distinct. A trail t is a walk where edges are distinct. A path is a trail with no repeated vertices. Except for a cycle, which is a trail with one vertex as start - and endpoint $x_1 = x_n$. A graph is connected if a trail exists from every vertex $x \in V$ to every vertex $y \in V$. A tree is a connected acylic graph with $|E| = |V| - 1$.

3.2.2 Travelling Salesman Problem (TSP)

The classical TSP tries to find a minimum cost tour in a graph, so that all vertices are visited exactly once. We are given a set of vertices n and each pair of distinct vertices $\{i, j\}$ is assigned a distance d_{ij}. Jungnickel (2005) gives a detailed TSP problem definition. Moreover Jungnickel (2005) and Aarts and Lenstra (1997) prove that TSP problems are NP - complete or NP - hard to solve. NP is the set of decision problems solvable in polynomial time by a non-deterministic Turing machine. An algorithm is considered NP - hard, if the corresponding problem cannot be solved well, i.e. has worse than polynomial complexity. To overcome this, researchers develop and apply heuristics and metaheuristics to solve NP - hard problems. Subproblems of the TSP are as follows:

- Travelling Salesman Subset Tour Problem (TSSTP): The objective is to find a minimum cost tour among a subset of vertices – the customers.
- Time Constrained TSP (TCTSP): Is similar to the TSSTP with the additional constraint of total travel time.
- Orienteering Problem (OP): The OP is exactly the same as the TCTSP, whereas the start - and endpoint may differ.

In order to solve the mentioned problems we assume that the vertices that have to be visited are known in advance.

3.2.3 Vehicle Routing Problem

Vehicle Routing Problems (VRP) are a class of problems in which “a set of routes for a fleet of vehicles based at one or several depots must be determined for a number of geographically dispersed cities or customers. The objective of the VRP is to deliver a set of customers with known demands on minimum cost vehicle routes originating and terminating at a depot” (Dorronsoro, 2007). Due to this definition the VRP is closely related to the TSP and vice versa.

The VRP is divided into several variants (Bramel et al., 1997; Dorronsoro, 2007, Toth et al., 2002) where demands, customers and depots are known in advance. We focus on a combination of the VRP with Time Windows (VRPTW) and the VRP with Pickup and Delivery (VRPPD).

The VRPTW specifies a situation where each customer demands that the delivery has to occur within a certain time period – the time window. The objective is to find a set of routes for vehicles where each route begins and ends at a certain depot and serves a number of customers. Additionally, the time window and vehicle capacity constraints must not be violated while minimizing the total length of routes.

The VRP with Pickup and Delivery (VRPPD): This is a VRP with the possibility that customers get and return commodities. So in VRPPD it needs to be taken into account that the goods that customers return to the delivery vehicle must fit into it. Here each customer is associated with two quantities: the demand of commodities to be delivered and to be picked up. The objectives are to minimize the vehicle fleet as well as the travel time with the restriction that the vehicle must have enough capacity for transporting the commodities to be delivered and to be picked up.

3.2.4 Rolling Schedule Approaches

Rolling Schedule Approaches are scheduling approaches under uncertain and dynamic conditions. In the case of VRP, future demands of customers are only known for the near future and are subject to change. In order to come up with an "optimal" solution the time is divided into discrete time intervals and a solution is calculated for each interval. These approaches are discussed in literature and especially mentioned in Wagner et al. (1958), Teng et al. (2006) and Spitter (2005).

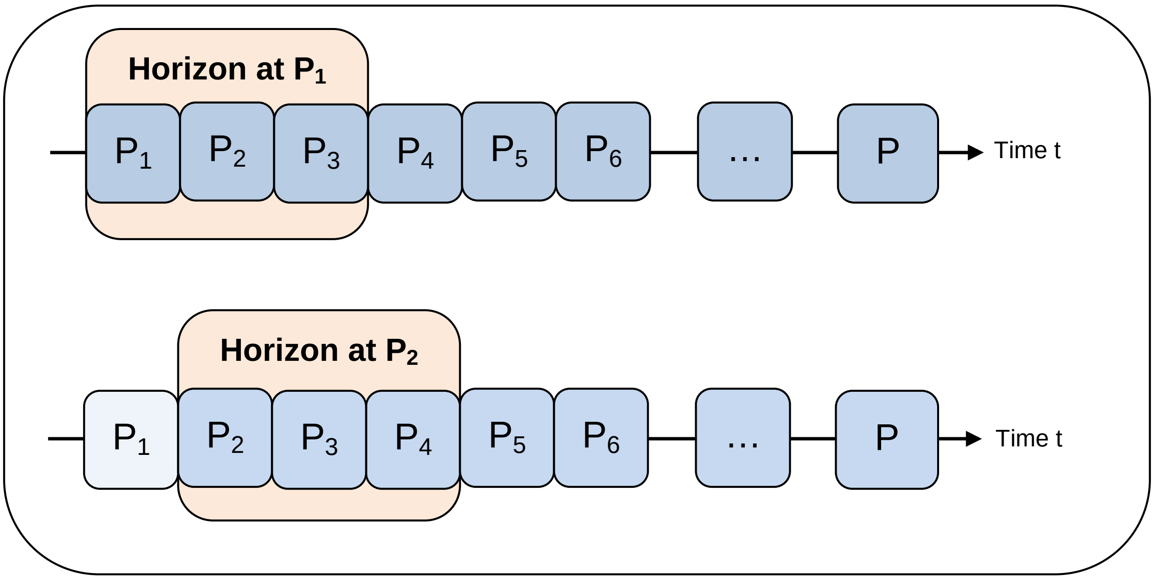
In systems where Rolling Horizons are appropriate, data of the phenomena to be optimized are accurate in the near future. In the far future, data are not present or not accurate. Thus a global optimization which covers near and far future is not adequate and has to be altered due to dynamic environments. This results in computationally complex and time consuming calculations.

Rolling Horizon approaches work as follows (see Figure 4) (Teng et al., 2006; Spitter, 2005):

- Step 1: Divide the time into n periods (e.g. days, months, years)
- Step 2: Define the planning horizon, i.e. the number of periods that we plan ahead
- Step 3: Solve the optimization task for the planning horizon starting at period 1
- Step 4: Roll horizon forward by one period and solve optimization task for the planning horizon starting at period 2
- Repeat step 4 and iterate until the best solution is found

The optimization task to be solved in Step 3 or Step 4 can be any optimization task that is appropriate for rolling schedule approaches, typically any machine scheduling or VRP and TSP's. This approach is highly flexible and is able to react to dynamic environments like Wood Supply Chain Management.

Figure 4: Illustration of the Rolling Horizon Schedule. The timeline is divided into discrete periods P_1, …, P_n . The Planning Horizon is three periods long and rolls forward by one period as P_1 is over.



3.2.5 Mathematical solution techniques for outlined optimization problems

To solve the optimization task mentioned in section 3.2.4 we propose several methods that have been discussed in literature. Among them there are Heuristics and Metaheuristics like Tabu Search (Glover et al., 1997) as well as an exact solution technique like Branch and Bound or Branch and Cut (Zimmermann, 2005). We will give a brief description of the techniques and assess their advantages and disadvantages in the field of Wood Supply Chain Management.

Branch and Bound (Zimmermann, 2005) is a method to find an exact solution for a given discrete or combinatorial optimization problem (usually a function $f(x)$). The algorithm utilizes a systematic enumeration of all possible solutions, as well as a mass discarding of fruitless solutions. It consists of three steps: a) Branching, b) Bounding and c) Pruning. Branching splits the set S of candidate solutions into smaller sets $S_1, S_2, \ldots, S_n$. A tree structure is the result of the recursive application of Branching, where nodes are subsets of S. The step

Bounding delivers upper and lower bounds for the optimization problem $f(x)$. The idea behind Pruning is to discard nodes from the tree, whose lower bound is greater than the upper bound of any other node in the tree.

Branch and Cut is similar to Branch and Bound but uses the Linear Program (LP) relaxation of the problem as lower bound. Additionally the algorithm finds upper bounds by heuristics and facilitates the Simplex algorithm for solving the LP. If the solution is not the optimum, the candidate solution is discarded.

Metaheuristics are techniques that combine a number of heuristics to solve computational or mathematical problems efficiently. They are usually applied to problems where an exact solution is not existing or not efficient. In general Metaheuristics, as well as Heuristics, deliver only near optimal solutions without any statement about quality or optimality of the solution found. Nevertheless, these techniques are popular due to their time efficiency. Popular Metaheuristics are Local Search, Tabu Search, Genetic Algorithms or Simulated Annealing. Here we focus on Local Search and Tabu Search.

Local Search (Jungnickel, 2005) is a method that finds maxima among a set of candidate solutions. Therefore the algorithm "searches in the neighborhood" of a candidate solution until an optimal solution is found. Briefly this algorithm works as follows:

- Step 1: Create an initial solution i
- Step 2: Create a neighbourhood of solutions "similar" to i
- Setp 3: Search through the neighbourhood and find the best solution

The termination is dependent on a time bound or number of iterations where no optimal solutions are found or a combination of both.

Tabu Search (Glover et al., 1997) is a method that is similar to Local Search but assumes that there is just one neighbourhood solution. Moreover it facilitates the usage of memory structures – a tabu list – to overcome cycles in the search process. Tabu Search procedure is as follows:

- Step 1: Create an initial solution j e.g. by a heuristic
- Step 2: Create neighbourhood solutions of j
- Step 3: Select the best solution k among the neighbourhood solutions of j. Select k as current best solution if it is not member of the tabu list. Add the last best solution j to the tabu list. Assign $j \leftarrow k$
- Step 4: Return to step 2 and iterate until a termination criterion is fulfilled

Heuristics are widely discussed in literature and provide proper solution techniques to special optimization problems. We don't want to give any details, but refer to the relevant literature. Teng et al. (2006) developed a heuristic for visiting customers in a rolling schedule environment. Pisinger et al. (2007) created a general heuristic for the VRP as well as Kytöjoki et al. (2005) and Bianchesini et al. (2005) have created Heuristics for VRP variants. Montane et al. (2006) published a tabu search algorithm for the VRP with simultaneous pickup and delivery service using local search and advanced neighborhood definitions.

Generally speaking, exact methods can only be applied to relatively small problems due to an exponential complexity. Metaheuristics and heuristics are flexible and capable of handling big problem instances. Thus metaheuristics and heuristics are promising solution techniques for solving the optimization tasks within Wood Supply Chain Optimization.

3.3 LOCATION-BASED SERVICES AS A TOOL FOR WOOD SUPPLY CHAIN MANAGEMENT

3.3.1 Location-based Services

A Location-based Service (LBS) offers a service for mobile clients focused on location depending information and applications (ISO, 2005). To fulfil these requirements, a system integration of three essential components is demanded: Geo-Information, Navigation and Communication (Hofmann-Wellenhof et al, 2003). Nevertheless the importance of dynamic mapping as a tool for information transmission, especially for spatial data, should be kept clearly in mind. Standardized internet technologies like Web Map Services (WMS) and Web Feature Services (WFS), specified by the Open Geospatial Consortium (OGC), are indicative of extended spatial information transmission. The OpenGIS Location Service (OpenLS), likewise specified by the OGC, concerns a complete framework for LBSs. The core services, offered by OpenLS, include Directory Services, Gateway Services, Location Utility Services, Presentation Services and Routing Services.

Primarily, the direction of the information flow starts at the LBS provider and finishes at the Mobile Client. A system upgrade concerning data collection can be realized with the help of the Mobile Clients. In the case of a Reverse LBS, Mobile Clients are involved in the (spatial) information creation process. Thus, there are two different approaches: First, the Mobile Client stays anonymous and the information is statistically evaluated (e.g. traffic situations). Second, personalized information is presented by the user of the Mobile Client to an interested audience (e.g. travel reports, internet blogs with spatial content).

In the field of LBS the terms location and position are commonly used for spatial descriptions. In contrast to position the location represents a more general description of a site, including place names like addresses (e.g. road names, road junctions,…) or topographic objects (e.g. rivers, mountains,…) (see ISO 19133). Unlike location, the term position implies an underlying geodetic reference system or projection method. Thus a position consists of coordinates, depending on the required dimensions, marking a unique site (Legat, 2002). Ambiguities, as they are appearing in place names or topographic objects, are excluded in most cases.

3.3.2 Service Modes

Information access
The information approach in an LBS system is separated into two groups: Pull Services and Push Services. Both methods handle the information flow between the service providers, who make spatial information available, and the mobile clients, who request this information. The classification into Pull and Push Services is based on the type of mobile client activity.

If the mobile client queries actively for information, this constitutes a Pull Service. Within this system configuration a two way communication link, connecting service provider and mobile client, is necessary. Moreover a Pull Service can be seen as a synchronous service, because the creation of the information message follows the information request. In contrast, a Smart Pull Service belongs to the a-synchronous services. The creation of the information message takes place independently from the client-side request. For example a software tool that advises the user of an incoming email can be seen as a Smart Pull Service. The user request to subscribe to this service is set prior to the returned information message, which is caused by an incoming email.

To the contrary, a Push Service submits information messages without a client request. Comparable to this service architecture is the Teletext service on a television receiver. The content is broadcasted continuously and no active user request is needed. For traffic and transportation the Traffic Message Cannel (TMC) represents a commonly used Push Service.

Elementary Actions
A list of elementary actions offered by an LBS (Reichenbacher, 2004) is given consecutively:

- *Orientation and Localisation*: The position of a mobile client is set into context with a reference frame (e.g. digital map). This information is fundamental for nearly every service.

- *Navigation*: Route planning and route guidance is based on navigable maps and implies a permanent position update of the mobile client.

One of the most important tools for navigation tasks is map matching. By means of map matching the actual position of the mobile client is set into context of the navigable map. This is the basic prerequisite for route checking algorithms and adaptations of the manoeuvre list (Hofmann-Wellenhof et al., 2003).

- *Search Services*: This class of services provides a basic search functionality for spatial objects. A prominent question would be: "Where is the next object ?" An example for search services is given by people search services like Childlocate (http://www.childlocate.co.uk/).

- *Identification*: The capability of identifying unknown spatial objects can be seen as great advantage for orienteering in unfamiliar areas (e.g. tourism, military operations,…).

- *Event Check*: Activating a spatial or temporal trigger causes an event message on the mobile client or at a service centre. This functionality can be used for route guidance (e.g. "Turn left!"), security applications (e.g. "Armoured Car has left the route!") or logistic processes (e.g. "Truck has reached the logistic terminal!"). Especially for spatial triggers the definition of geo-fences is of prime importance. A geo-fence represents a predefined area, where an infiltration or a break-out triggers events.

3.3.3 Selection of applications concerning Wood Supply Chain Management

Consecutively, four LBS applications are identified which can be applied in Wood Supply Chain Management.

- *Tracking and Tracing*: The major task of Tracking and Tracing is to reconstruct transportation processes of a value chain. Therefore single shipments, bulk containers or transport units are monitored by dispatching centres (Kuhn, 2005). Especially for Wood Supply Chain harvesting vehicles, forwarder and log trucks should be tracked for an optimized machine operation. However there are several limitations of Tracking and Tracing processes (Kuhn, 2005). Enhancements of a Tracking and Tracing System will bring forth Supply Chain Event Management (SCEM). With the aim of SCEM expected events as well as exceptions can be handled. Therefore these systems require an enhancement of status messages, which are generated at the transportation units. The aim is to account these messages as the knowledge about the economic process (Kuhn, 2005). The main features of SCEM are monitoring, message service, simulation, surveillance and performance checks (Kuhn, 2005).

- *Emergency Services*: The fast indication of a casualty situation can save lives. A reasonable combination of positioning module, communication equipment, included in a tracking and tracing system by default, and additional automatic accident sensors or emergency switches fulfil the requirements of an emergency service. First notable is the spatial information of the casualty, because in most cases a place name or description in natural language of this site in a forest surrounding is insufficient.

- *Resource Management*: Resource management goes hand in hand with tracking and tracing. The knowledge about the location of all components of a wood supply chain, like vehicles, harvesting areas, log yards and saw mills, is fundamental for an optimization process. Such systems are known as touring schedule systems (Bartelme, 2005).

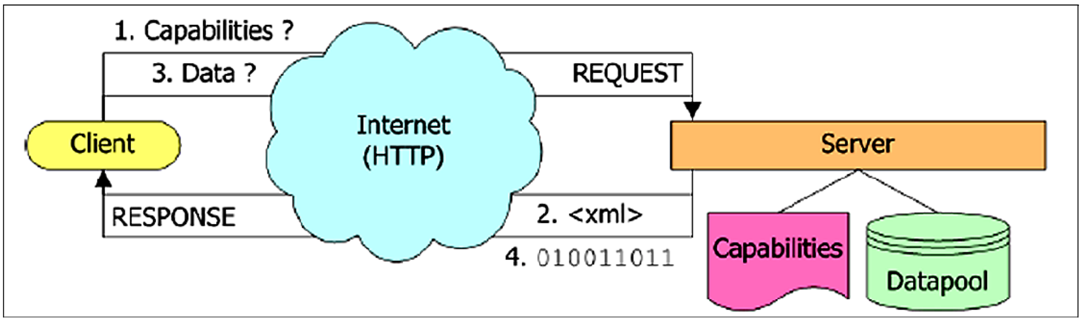
- *Navigation Services*: Especially for large vehicle fleets the coordination of all participants is necessary. A possible approach is represented by a centralized traffic dispatching centre (Hofmann-Wellenhof et al., 2003) for a smooth interaction of all these participants.

3.4 WEB SERVICES

Standardized OGC (Open Geospatial Consortium) Web Services play an important role in the implementation of a tool for optimizing the Wood Supply Chain. They are coupling the different modules of the SDSS system architecture and they are used for visualising results and for routing operations. Web Services are modular built applications which offer functionalities that can be published, found and used via the Internet. Due to standards, Web Services are not fixed to an operating system or a certain programming language (Prüller, 2006).

In the Web Service Common Implementation Specification of OGC (http://www.opengeospatial.org/standards/common) the common structure of various Web Services is defined (Figure). Within our application we use three Web Services. Their description and implementation is explained in the following documents published by OGC (http://www.opengeospatial.org/specs). The whole SDSS system architecture is outlined in Figure 6.

Figure 5: Basic functionalities of OGC Web Services (Annen 2005)



3.4.1 Web Map Service (WMS)

A Web Map Service produces spatial referenced raster maps dynamically from geographic data which can originate from different sources. These raster maps are generally rendered in a pictorial format and can be implemented in various applications.

In the intended application the Web Map Server is realized with the Open Source *UMN MapServer.* It is responsible for providing maps for the Mobile Devices and for the Desktop PC. The data visualized during the workflow are based on information in the spatial database. WMS does not support the manipulation and updating of underlying data which can be realized by the Web Feature Service (WFS) for vector data.

3.4.2 Web Feature Service (WFS)

A Web Feature Service enables an application to read, add, edit and delete vector data to/from a spatial database. The geodata exchange runs via the independent data format GML (Geography Markup Language). A Basic WFS offers the first three of the following operations and a transactional WFS (WFS-T) additionally implements the two operations that can be requested by a user: *Transaction*, which allows the editing of features and *LockFeature* which prevents changes of a feature type by another instance.

Within the intended application the WFS is implemented with the Open Source software *Geoserver* which includes the transactional extension. This allows write access to features in the spatial database which is used for handling and exchanging data between drivers in the trucks and the headquarter managing the timber transportation process. Information about position, on-road conditions or the job status can be sent by the Mobile Devices to the spatial database the central office has access to. In the other direction the dispatcher is able to add or edit routes with timber locations on the Desktop PC and store it in the spatial database. Subsequently Mobile Devices can access the actual data via Web Services. The calculation of the optimal routes is implemented using the OGC's

Open Location Service Specification (OpenLS). Route Service as one out of five Core Services is included.

3.4.3 Open Location Services (OpenLS)

The Open Location Services initiative (also called OpenGIS Location Services) was started in the year 2000 by the OGC with the goal of development and description of standards in Location Based Services (LBS). For requests and responses to these Web Services the XML-based Syntax XLS (XML for Location Services) was created (Neis, 2006). Within OpenLS five Core Services (Service Framework) in conjunction with Abstract Data Types build the GeoMobility Server (GMS) which represents the OpenLS platform (Zipf, 2004).

The route service is of importance within our application. It is responsible for calculating the fastest route between timber locations resulting from the MBMS. These routes are calculated in the central office and are accessible for Mobile Devices via WMS.

3.5 STANDARDIZATION ISSUES

Decisions aiming at higher effectiveness in the chain of sub-processes discussed in this paper rely heavily on spatial prerequisites. The production of timber relies on the spatial properties of the terrain, on altitude, steepness, land cover and soil properties. The transportation of timber to saw mills requires detailed information on road, railway and waterway networks, their geometry as well as their respective attributes like capacity, usage, restrictions and others. Saw mills may have to observe guidelines and restrictions in their operation which may be due to geospatial aspects, like environmental guidelines specifically imposed in different towns and regions. An overall increase in efficiency in the decision making process will therefore require a high degree of automation in the utilization of geospatial information. This, in turn, relies on geospatial standards and geospatial infrastructure.

ISO standards relating to the issue addressed are currently being developed in ISO/TC 204 “Intelligent Transport Systems” (www.isotc204.com) and ISO/TC 211 “Geographic Information/Geomatics” (www.isotc211.org). In the sequel, attention shall be restricted to the latter since it also comprises aspects pertaining to geospatial data infrastructures and also because the haulage of timber from its production site to the saw mill may in many cases not take place on an established road but rather cross-country.

ISO/TC 211 has since its start in the early 90s produced a sizable number of standards pertaining to geospatial data. Those standards can – in their entirety – be seen as a family where the different parts are closely interrelated. Yet only those standards shall be explicitly mentioned here for which typical examples of applicability seem especially straightforward for the Wood Supply Chain task.

Of overall importance is the ISO 19115 metadata standard, being the central key to existing geospatial databases, their structure, content, accuracy, resolution, and application domain. This is an essential prerequisite for data mining in existing geospatial databases and repositories in the area of interest and for on-the-fly queries on geospatial data being available within this area.

The standards ISO 19107 (for Spatial/Topological Schema), ISO 19108 (for Temporal Schema), ISO 19109 (for Application Schema), ISO 19125 (for Simple Feature Access), address typical components of geospatial data and enable the structured transfer of such data from the geospatial infrastructure to the Wood Supply Chain application. The standards ISO 19111 (for Spatial Referencing by Coordinates) and ISO 19112 (for Spatial Referencing by Geographic Identifiers like zip codes and postal addresses) ensure that the transferred data align to the appropriate geometric references.

The standards ISO 19128 (Web Map Server Interface) and ISO 19142 (Web Feature Service) as well as the series ISO 19132, 19133, 19134 (Location-Based Services) support the current trend leading from monolithic systems to service-oriented architectures (SOA) which are built around loosely-coupled relationships between providers and users of geospatial information, striving for a high level of interoperability. Many of those standards have been established in close cooperation with the OGC, following the guidelines of a collaborative agreement signed by the two institutions. This two-hat policy ensures that standards are both based on a broad ISO consensus and meet practical implementation requirements.

Given the fragmented nature of European political boundaries and the relatively small distances involved, it will often happen that timber originating from country A, needs to be transported via country B to a saw mill that is located in country C – or even back in country A. A seamless geospatial data infrastructure will therefore be needed in order to avoid disruptions in the optimization process. On the European level, INSPIRE (www.ec-gis.org/inspire/) is currently the existing official framework that can help to provide relevant geospatial data.

Given all these prerequisites, a scenario can be envisioned where during any point in time during the flow of information in the Wood Supply Chain process, all the required geospatial data being held in repositories of government administration or private enterprises can be queried, accessed, displayed and introduced into the analysis of the Spatial Decision Support System for optimization purposes.

4. APPLICATION IN WOOD SUPPLY CHAIN MANAGEMENT

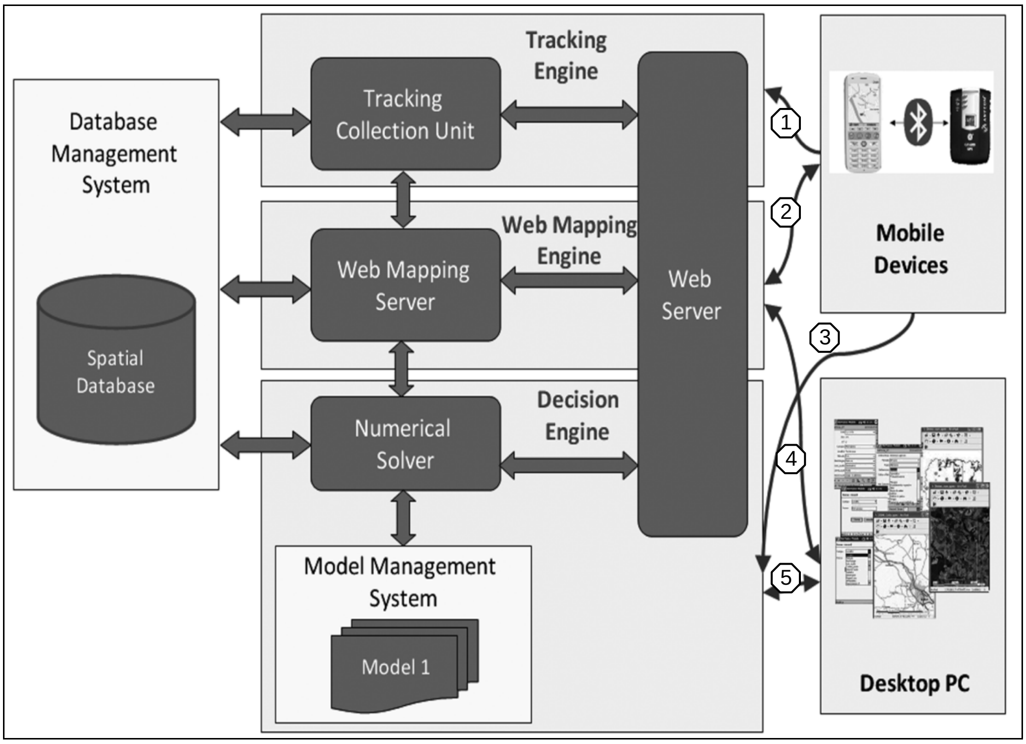
To support the decision process described in section 2, we propose a first draft of a system architecture presented in Figure 6. A multidisciplinary SDSS environment serves as an umbrella for software tools capable of facilitating theory and methods mentioned in the previous chapters. Here SDSS, OR, LBS, Web Services as well as standardization issues play an important role in the intended system. In order to ensure tight-coupling of OR Methods within a SDSS (Malczewski, 2006), the OR methods are an integral part of the MBMS.

Generally speaking there are six main system components: Database Management System, Tracking Engine, Web Mapping Engine, Decision Engine, Mobile Devices that are located on trucks and Desktop PC's located at the haulage companies. The Database Management System (DBMS) allows the storage, management, and retrieval of spatial and non-spatial data. Here a number of standards have to be considered, notably the OGC Simple Feature Specification. Moreover a metadata system should be implemented that makes use of the corresponding ISO 19115 standard. The Web Mapping Engine serves as a central data visualization and management interface. A WMS, WFS-T and partly Open LS Services are embedded in this engine. The WMS Service delivers maps to the Mobile Devices and Desktop PC's as requested. Through WFS-T of the Web Mapping Engine, data management is possible that allows the creation and modification of spatial data – e.g. the input of new timber piles with several attributes mentioned in chapter 1. The Open LS service delivers driving directions, routes and the route maps to the Mobile Devices – e.g. route to the next timber pile.

The Tracking Engine is responsible for storing of actual truck positions in the spatial database. The actual positions are submitted by Mobile Devices located on the trucks (Reverse LBS, see section 3.3.1). Mobile Devices make use of standardized LBS technology to: a) gather the location by satellite based positioning b) get new timber transport assignments for the truck c) support navigating of the trucks d) alter parameters (e.g.: timber pile is not accessible due to snow) e) input of new timber piles through logging contractors in terms of location and attributive information. The Decision Engine consists of the Model Base Management System containing the mathematical models for solving the optimization tasks, which are discussed in section 3. A numerical solver masters the computational part of the optimization based on the spatial and non-spatial data stored in the DBMS. The results of the optimization process are either stored in the database or directly disseminated to the Mobile Devices or Desktop PC's. It is worth to mention that the results of the rolling schedule optimization are matrices consisting of the trucks and their corresponding vertices to visit per planning horizon. These data are the basis for the Open LS framework to calculate and visualize customized routing information for each truck. Additionally it is possible to alter basic parameters of the optimization models through Desktop PC's (see section 2: Scenario 1: long-term) and Mobile Devices (see. Section 2: Scenario 2: short-term).

The Desktop PC might be any personal computer that has access to the internet. Typically the dispatchers at the haulage companies or forest companies operate the system via the web based interface in order to input new piles of timber or to alter model parameters of the optimization process. Interoperability between the mentioned components is achieved by using Web Services. The Web Services that have to be implemented will be published accordingly. Thus the implementation will not rely on interfaces software tools offer but will rely on services that have to be developed. Hence, it is possible to "plug in" new modules that fit into that service oriented architecture. We are aware of the fact that the number of services may slow down the overall speed of the whole process, but it is the only way to achieve interoperability within the system.

Figure 6: The first draft of the SDSS system architecture.



In Figure 6 above, Arrow 1 indicates the sending of the actual position of the Mobile Devices to the Tracking Engine. Arrow 2 shows the bidirectional communication of the Mobile Devices with the Web Mapping Engine, e.g. getting maps and altering feature data via WFS-T. Arrow 3 indicates that additional data can be sent to the Decision Engine regarding model parameters using a Web Service. Arrow 4 shows the bidirectional communication of the Desktop PC with the Web Mapping Engine – to get maps via WMS and to alter spatial features via WFS-T. With arrow 5 we want to show that the Desktop PC communicates bi-directionally with the Decision Engine in order to alter model parameters and get feedback from the Decision Engine, using Web Services.

5. CONCLUSIONS AND FUTURE PERSPECTIVES

The paper focuses on the methods and relevant theory to support decision making in the environment of Wood Supply Chain management. We propose an interdisciplinary approach for the development of an SDSS comprising GIScience, OR, forestry as well as standardization. Moreover we focus on the tight coupling of SDSS and OR with an emphasis on Rolling Schedule Approaches as a possible method to optimize the Wood Supply Chain.

We elaborate on possible mathematical models to formalize the Wood Supply Chain. We focus on TSP as well as VRP and variants of both. Rolling Schedule approaches are a possible solution method to generate optimal solutions under conditions of uncertainty. In order to solve the optimization task several techniques like Branch and Bound or Metaheuristics are proposed which have to be further investigated, to assess their applicability for Wood Supply Chain management.

LBS are a vital part of the intended system architecture due to their flexibility and ubiquitous availability. Traditionally LBS and mobile data access heavily rely on standards which are of fundamental importance. Based on standards, Web Services can be developed which enable LBS to gather data from servers via standardized interfaces. In this paper we focus on relevant Web Services and standards for Mobile Devices as well as possible applications of LBS that have an impact on Wood Supply Chain Management.

The first draft of the system architecture integrates all relevant components mentioned in this paper within one application. The draft system architecture is a concept and serves as an attempt to support decision making in the field of Wood Supply Chain Management. We think that this concept might be applicable to other areas like waste management too, in order to facilitate ecological as well as economical decisions.

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