System Architecture for Spatial Decision Support in Wood Supply Chain Management

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Abstract: The contemporary Wood Supply Chain is shaped by legal aspects. Overcoming those legal aspects paves the way for a future Supply Chain that offers more flexibility concerning the relations between stakeholders of the Wood Supply Chain. Hence, optimization methodologies can be employed to develop an optimized plan covering the logistic operations as well as the selling process itself. In order to provide spatial decision support for the Wood Supply Chain, a system architecture is necessary that covers the requirements of the stakeholders and is capable of collecting data and delivering results in real-time.

1 Introduction

The term Wood Supply Chain (WSC) describes a special Supply Chain (SC) that is present in contemporary forest industry. A SC describes a flow of goods from producer to customer [Wannenwetsch 2005]. Associated with any flow of goods is an information flow that has to be managed within a SC. Additionally, SCs can create monetary value. In general, the WSC describes the flow of timber from production – in forest enterprises – to the end customer, which includes several production steps and transportation processes in between.

In this work, the WSC under investigation is limited to the part from timber production to the first production step – taking place in a saw or paper mill. This WSC section requires transportation processes, as forest enterprises (i.e. locations where timber is produced) and saw mills are geographically distinct features. Vehicles – i.e. trucks – combine the production and processing locations interactively by haulage processes. Thus, the following stakeholders are identified [Scholz 2010]:

- Forest enterprises
- Saw mills

- Haulage companies (with associated vehicles)

The part of the WSC under investigation in this article – in future denoted as WSC – is visualized in Figure 1. In this figure the connection between the stakeholders is depicted in a simplified way. In this graphic two forest enterprises and two saw mills are connected via two haulage companies that manage the haulage processes. The connections between the stakeholders are only exemplarily. Hence, any other connection would be possible. Additionally, the properties of supply, demand and haulage are given. For timber supply any forest enterprise wants to get a certain price for their produced amount of timber expressed in €/m^3. Any timber has a certain quality class that defines the value – i.e. price – of it. A date is necessary in order to specify when produced timber has to be hauled completely. Timber demand is defined by saw mills respectively. Any saw mill demands a certain quantity of timber fulfilling predefined quality classes. The saw mills are willing to pay a certain price for a defined quality class. Additionally, the temporal dimension is reflected through a due-date, denoting the distinct point in time when a timber quantity with defined quality has to be fully delivered to a saw mill. These definitions of timber quantity, quality, price, and due-date are regarded as delivery profiles. The time to fulfill such delivery profiles usually spans over several weeks. Haulage companies perform the timber transportation with their vehicles. Each vehicle associated with a haulage company has a certain capacity and costs per driving distance unit – usually €/km.

The research question addressed in this article deals with the development and evaluation of a system architecture, providing the basis for spatial decision support in the context of WSC management. In order to be able to react to immediate events, like a vehicle breakdown, in an appropriate manner, real-time data of the stakeholders of the WSC have to be collected. They serve as basis for a Spatial Decision Support System (SDSS), which utilizes an optimization methodology to identify and evaluate decision alternatives.

The contribution of this paper lies in the development and evaluation of a system architecture for WSC management, that follows a service oriented approach. Additionally, this architecture inherits a real-time spatial optimization methodology for optimizing the WSC in a dynamic way.

The organization of the publication is as follows. Chapter 2 lists the shortcomings of the contemporary WSC and introduces an intended future WSC. This approach overcomes the problems of the current WSC and paves the way for optimization. Chapter 3 describes a system architecture for WSC management following a service oriented approach and a comparison with two alternative system architectures. A discussion of the results and a conclusion is given in chapter 4.

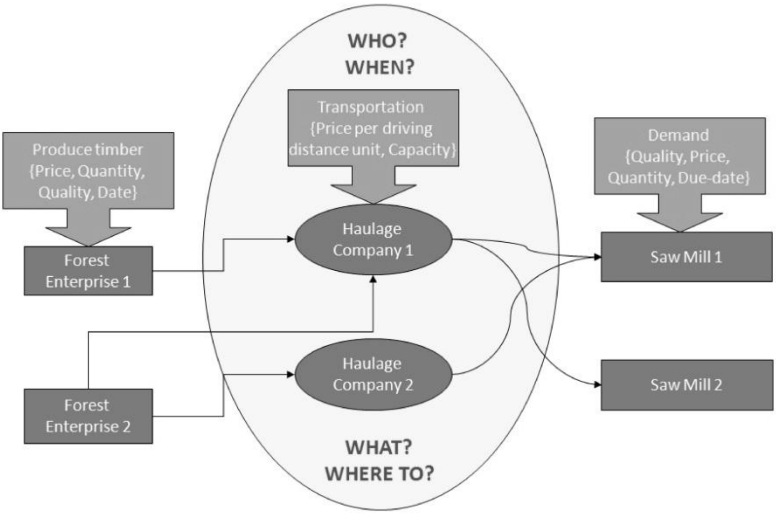


Figure 1: Illustration of the WSC: the stakeholders, connections as well as properties of demand, supply and haulage are given [Scholz 2010].

2 Comparison of contemporary and intended future Wood Supply Chain

Given the basic description of the WSC in chapter 1, this section elaborates on the contemporary WSC and the intended future WSC. This comparison lists the drawbacks of the current WSC, which is shaped to a large extent by legal aspects. Getting rid of certain legal restrictions paves the way for the intended future WSC that shows more flexibility and provides a number of optimization opportunities.

The current WSC is strongly influenced by legal aspects. Thus, produced timber cannot be transported to any saw mill that looks convenient before making a contract. This contract contains an agreement of the forest enterprise and the saw mill to deliver an amount of timber with a certain quality class for a defined price per m^3. Hence, the connection between each pair of stakeholders – saw mill and forest enterprise – in the WSC is fixed, and is rarely broken up. The cardinality of the relation forest enterprise to saw mill equals 1: n, due to the fact that different timber qualities – even if produced at one site in one forest enterprise – may be sold to different saw mills. Due to legal and practical aspects, the transportation process between forest enterprise and saw mill is of static nature. Transportation is organized by forest enterprises or by saw mills which is defined in the contract between them. Regardless of who is responsible for organizing the transport process, there is a fixed assignment of a haulage company to the relation forest enterprise to saw mill (see Figure 2).

Critical in the context of human transport planning is the fact that small forest enterprises participate in the market, but do contribute only minor timber quantities. Thus, trucks do not utilize their full capacity and the haulage process lacks efficiency.

In chapter 1 the information realm is mentioned as part of any SC. Due to the fact that the WSC is a special SC, information on the SC are of importance. This involves data on the goods itself, as well as the "state" of stakeholders – e.g. quantity of timber left in the forest, quantity that should still be delivered to saw mills. In the contemporary WSC these data are rarely collected in a systematic, standardized way and thus, are not available for all stakeholders. Up to now logistics operators – either at forest enterprises or saw mills – collect or process the information of the WSC. In addition, they are responsible for directing the vehicles. In the course of this process several media breaks happen, that raise the probability of errors and uncoordinated logistic operations [Gronalt et al. 2005]. Figure 3 shows an overview of possible media breaks occurring in the WSC from timber production to saw mill.

In contrast to the contemporary WSC, which shows a static behavior in combining stakeholders and is prone to errors in data transmission, the future WSC avoids these shortcomings. Due to the fact that it is not influenced by current legal aspects, the static combination of forest enterprises and saw mills is not present any more. This flexibility enables optimization methodologies to unfold their potential.

Consecutively, in the intended future WSC any stakeholder "publishes" its data in a standardized digital manner: supply (forest enterprises), demand (saw mills) and transportation parameters (haulage companies). No contract is made and thus, there is no fixed allocation of timber to any saw mill or to a haulage company up to that stage. An optimization methodology uses the published data of the stakeholders and develops a "plan" that considers the following:

- supplied timber must be hauled within the due-date
- demand has to be fulfilled within the due-date (exceeding the demand to a limited amount is possible)
- a finite set of vehicles with given capacity hauls timber from forest enterprises to saw mills
- timber is regarded as "sold" when it arrives at any saw mill
- the overall profit of the WSC – i.e. turnover from timber sales minus transportation cost – should be optimized

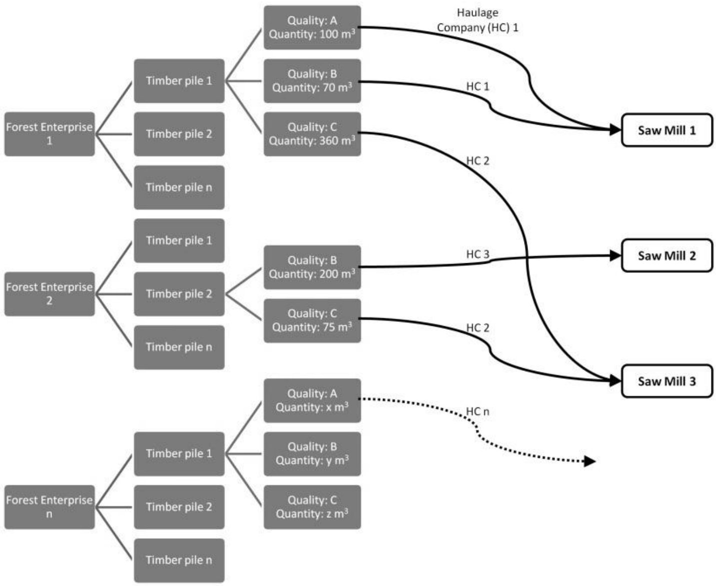


Figure 2: Relation between forest enterprises and saw mills with haulage companies (HCs) performing the haulage process. The relations between timber having a certain quality class and saw mills are static and defined even before timber is produced. The assignment of HCs is of static nature too. Conceptual design: Scholz [2011].

The resulting "plan" should consist of a detailed schedule for each existing truck/vehicle answering the four questions listed in Figure 1: Who? When? What? Where to? These questions are a synonym for the schedule for each vehicle present in the WSC, including a) when to leave the truck depot located at associated HC, b) when and where to pick up which timber c) when and where to unload which timber d) when to return to the truck depot.

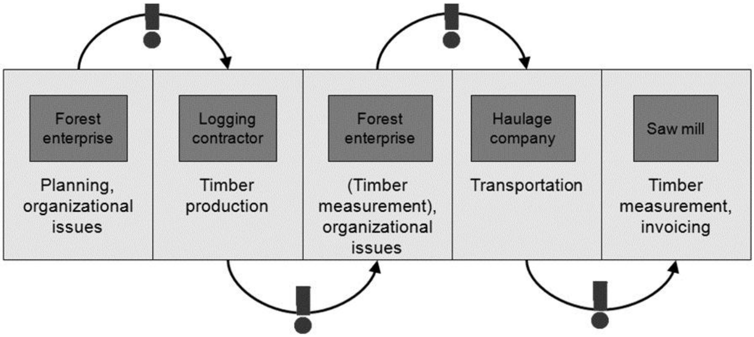


Figure 3: Possible media breaks in the WSC starting from timber production to saw mill. The arrows represent information to be passed on to the next element in the WSC. The exclamation points highlight the possibility of media breaks which increase the probability of erroneous transmission of data. Graphic derived from von Bodelschwingh et al. [2003].

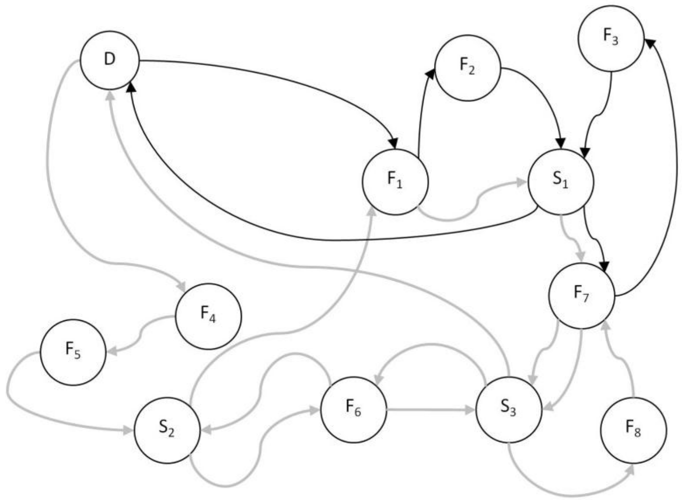
Due to the given flexibility of the future WSC the issue of small-volume timber production and transportation is addressed. Hence, HCs and their vehicles are not solely associated to one relation of timber pile quality class and saw mill. In fact, more HCs are able to haul timber originating from several forest enterprises to one or more saw mills in order to facilitate full truckloads (see Figure 4). This flexible behavior enables any optimization method to evaluate different configurations of timber transportation – i.e. relations of timber pile quality (forest enterprise) to saw mill.

3 System architecture in support of Wood Supply Chain management

This chapter focuses on the system architecture that provides decision support for WSC management. The system architecture explained here follows a service oriented approach, in order to support decision support in (near) real-time. Additionally, a brief review of alternative architectures is given, followed by a comparison of the approaches mentioned.

3.1 System architecture

The system architecture supporting the intended future WSC – described in section 1.1 – should be able to collect real-time data from stakeholders and deliver results in real-time – due to the existence of unexpected events that have to be managed. The system architecture follows a service oriented approach utilizing standards (OGC/ISO), where applicable. This service oriented architecture (SOA) makes use of three types of services: simple Web Service (WS), Simple Object Access Protocol (SOAP) and Representational State Transfer (REST).



vehicle no.	vertex sequence
1 (black)	D – F_1 – F_2 – S_1 – F_7 – F_3 – S_1 – D
2 (gray)	D – F_4 – F_5 – S_2 – F_1 – S_1 – F_7 – S_3 – F_6 – S_2 – F_6 – S_3 – F_8 – F_7 – S_3 – D

Figure 4: Possible combinations of timber piles from forest enterprises (F_1 – F_8) and saw mills (S_1 – S_3) with two distinct vehicles. The arrows connecting the WSC stakeholders indicate the tour of each vehicle. Grey arrows mark movements of vehicle 1 and black arrows those of vehicle 2 respectively. The temporal sequence of vertices of each vehicle's tour is given in the table in the figure. Conceptual design: Scholz [2011].

An overview of the system architecture is given in Figure 5. A noticeable fact is that the system consists of modular elements that are connected via services – indicated as numbered bi-directional arrows. The advantage of modularity lies in the possibility to distribute the modules over several servers that results in a failsafe, maintenance friendly design. Especially the central spatial-temporal database containing sensitive and partly confidential data can be dispersed over several servers in a database cluster. If errors occur, any redundancy in the physical layout – i.e. one module is present on more physical machines – facilitate the maintainability of the system itself. Additionally, software errors can easily be traced due to modules having a clear functionality.

In the following paragraphs the modules depicted in Figure 5 are briefly described. The database management system stores spatial-temporal data of all stakeholders and processes of the WSC. Storage of spatial data makes use of OGC simple feature specification (ISO 19125). A detailed data model for WSC optimization has been developed and published respectively [Scholz et al. 2008]. The tracking engine takes positions, delivered from mobile devices – following a location-based principle – either in real-time or in bulk load mode. The bulk load principle is necessary when the mobile device cannot submit its position due to a missing Internet connection. In these cases the mobile devices store the data and send them as an Internet connection is available. The tracking engine takes positions in lat/lon format (EPSG:4326) with associated metadata, conducts a quality evaluation and subsequently sorts out inaccurate points. The remaining ones are submitted to the spatial-temporal database. The web mapping engine is the central mapping engine, serving maps in real-time as requested from clients. The underlying technology makes use of UMN Mapserver and Geoserver utilizing WMS and WFS-t.

The decision engine is capable of modeling and providing decision support for WSC based on data stored in the DBMS. Decision support and optimization capabilities require – besides real-time data – a mathematical model of the WSC and a solution/optimization methodology. Scholz et al. [2010] argue that the WSC can be modeled as a Vehicle Routing Problem (VRP). In detail, a variant of the VRP, the VRP with Pickup and Delivery and Time Windows (VRPPDTW) represents the WSC with high accuracy, which has also been mentioned by Kytöjoki et al. [2005]. In the VRPPDTW model used in this work, the timber piles present in the forest represent pickup locations and saw mills delivery locations respectively. Due to the fact that any VRP assumes that pickup and delivery locations are visited exactly once by any vehicle, the VRP used here must be generalized to some extent. The VRP model in the context of WSC management has to allow multiple visits at each pickup and delivery location, because:

- timber quantities located at a pickup location may exceed the capacity of one vehicle – thus requiring to be visited more than once to haul all timber of the timber pile;
- timber quantity demanded by a saw mill may exceed the capacity of one vehicle - thus requiring to be visited more than once to deliver all timber to satisfy the demand accordingly;

The creation of optimized results for the VRPPDTW representing the WSC is depending on appropriate solution techniques. Literature mentions a number of algorithms capable of developing optimized results for any VRPPDTW – starting from exact algorithms to heuristics. Due to the fact that heuristics are computationally faster and are able to cope with larger problem instances compared to exact algorithms, a heuristic is chosen as optimization technique – the author is aware that heuristics do not provide an estimation of the solution quality. To solve the VRPPDTW in the context of WSC management Adaptive Large Neighborhood Search (ALNS) is used [Scholz 2010; Scholz et al. 2010; Ropke et al. 2006]. In the system architecture overview given in Figure 5, ALNS is part of the "numerical solver". Due to the fact that any appropriate solution algorithm could be used, this level of generality is used here. The model management system of Figure 5 contains the generalized VRPPDTW for WSC management. Due to the fact that other representations of the WSC could be used – e.g. VRPPDTW with exactly one visit per pickup and delivery location – the system should offer the possibility to switch between the different WSC models. The results of the optimization can be evaluated by the dispatching offices using a desktop system. After having decided on a "plan" the results are stored in the database management system and thus are available for all stakeholders.

Mobile devices are smart phones capable of establishing an Internet connection to send and receive data in real-time with consideration of their own position. Thus, these items follow the location-based service paradigm and have to be equipped with GPS – which is built-in in most smart phones. These items are used in the vehicles for (a) submitting the status of the vehicle (including position) in real-time and (b) to provide routing and guidance in real-time while carrying out the "plan" for the vehicle developed by the decision engine. Forest enterprises might need mobile devices for submitting their timber supply to the WSC management system.

Any desktop system can access the WSC management system with an Internet browser. This is of importance for the manager of the WSC who is able to visualize the status of the WSC and its stakeholders, and can decide on one of the optimized "plans" the decision engine offers. In addition, the WSC management has access to advanced model parameter of the optimization system. The desktop system is of importance for the saw mills too, as they are able to notify the system of their timber demand and to visualize their status – e.g. how much timber has been delivered so far.

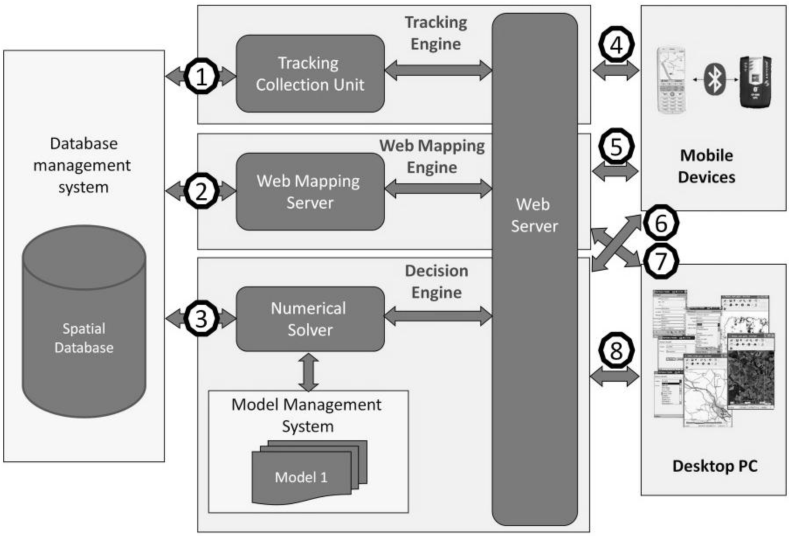


Figure 5: System architecture for WSC management [Scholz 2010].

The different parts of the system architecture are connected using services, due to the fact that the whole architecture follows the service oriented paradigm. In the following paragraph the connections between the modules is briefly described including their service type. In order to access the data SOAP and REST services are applied. SOAP forms a protocol that exchanges data via XML, whereas REST services support stateless client-server operations, where each request is handled as a single and independent transaction not related to prior or afterward requests. Due to the absence of XML and associated metadata, the REST service messages show a ratio of metadata to result data that is considerable smaller compared to SOAP. Hence, REST services are suitable for frequent data transactions with small result data volumes to be transmitted. SOAP messages are exchanged between database and tracking collection unit – marked with 1 in Figure 5. Connection 2 is no "real" web service of any kind, as a direct database access using the OGR library integrated in UMN Mapserver and Geoserver is used. The decision engine and database management system are connected with a REST service, due to the fact that the decision engine mainly queries the database in a stateless way (connection 3 in Figure 5). Mobile devices communicate with the tracking engine and the decision engine via SOAP messages. Mobile devices submit their current position to the tracking engine, receive data on the work "plan" developed by the decision engine and submit data on the actual status of the work carried out – e.g. severe breakdown, timber X delivered to Y successfully. The connection of a mobile device with the mapping engine utilizes services following WMS and WFS-t specifications, as published by OGC and ISO. Any desktop system connects to web mapping engine also using the WMS and WFS-t offered. To enable communication between the decision engine and the desktop system SOAP is used (connection 8 in Figure 5).

3.2 Evaluation of alternative architectural approaches

Section 3.1 elaborates on a system architecture following the idea of SOAs. Due to the fact that other architectures are possible, two different approaches are compared to the described SOA driven architecture. Here, monolithic and ubiquitous architectures for WSC management are analyzed, as they mark the "extremes" in the continuum of current system architecture approaches. An evaluation of the approaches in terms of quality parameter, based on ISO 9126 [ISO 2001], is provided.

First, the monolithic architecture is briefly described following the book of Taylor et al. [2009]. Any monolithic architecture represents a system where everything is implemented in "one piece", without any modules or detachable components. Advantages of monolithic systems are as follows. They can handle data internally in any desired format that is "optimal" for the application – e.g. supporting fast data transmission. Additionally, as data can be stored in the memory and do not need to be read from the hard drive, computational process speed can be increased. The main disadvantages of monolithic systems are the lack of a proper multi-user access resulting in problems for simultaneous upload and data reading operations. Hence, the last two operations are only possible if done in a sequential order. Due to the fact that monolithic systems have a static architecture, they cannot be split over several machines. Hence, systems following this approach do not show a failsafe and maintenance friendly behavior. Due to the fact that monolithic architectures can be "opened" with middleware [Naur et al. 1969] a monolithic architecture for WSC management could look like the one depicted in Figure 6. The architecture shows middleware to communicate with desktop systems and mobile devices and connects directly with the database management system.

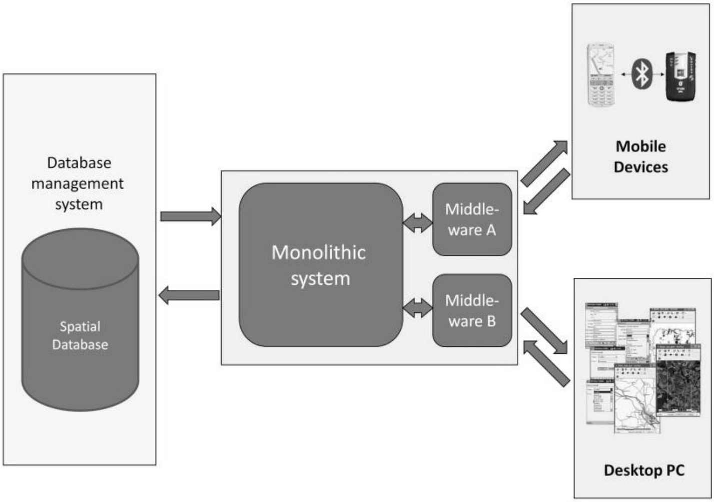


Figure 6: Monolithic system architecture for WSC management [Scholz 2010].

Ubiquitous architectures follow the concept of ubiquitous computing [Weiser 1991], proposing that "computing is everywhere". To support ubiquitous computing a number of hardware components are necessary, that build up the system itself. In literature, a number of devices of different size are mentioned starting from centimeter sized tabs to nano- and millimeter sized smart dust [Poslad 2009, Weiser 1991]. Any ubiquitous system architecture for WSC management includes that any piece of timber produced has to be tagged with a computerized device, e.g. smart dust. Consecutively, it can be tracked on its way from forest enterprise to saw mill. Additionally, vehicles require a combination of smart dust and tabs on them, to determine the state of the vehicle – e.g. loading status. For WSC management timber could be tagged with RFID tags that could be read by appropriate hardware that submits the data immediately to a tracking service [Korten et al. 2008; Fraunhofer IFF

2009]. The advantages of such a system are that it automatically collects data and passes on data when possible. In order to support ubiquitous computing services are necessary, similar to SOAs. Thus, the system shows a modular structure, that is failsafe and maintenance friendly. A disadvantage, in comparison to monolithic architectures, is security, due to the number of communication channels that have to be secured. In addition, hardware failures of smart dust may arise through the rough conditions the sensors have to withstand in the forest.

A qualitative comparison of SOA, monolithic and ubiquitous system architecture is given in Table 1. The table lists some quality parameters mentioned in ISO 9126 [ISO 2001]. Here, parameters listed in ISO 9126 are not described due to space limitations. Komarkova et al. [2007] and Ortega [2003] comment that one does not necessarily has to work with full parameter set mentioned in ISO 9126. Hence, not all of the parameters listed in ISO 9126 are used here, because of their limited importance for the evaluation of system architectures.

Parameter (ISO 9126)	Monolithic	SOA	Ubiquitous computing
Suitability	6	10	10
Accurateness	5	10	10
Interoperability	1	9	10
Compliance	1	10	10
Security	10	3	1
Fault tolerance	1	8	7
Recoverability	2	8	8
Analyzability	1	10	10
Changeability	3	9	10
Stability	1	8	8
Testability	3	10	10
Adaptability	2	9	9
Installability	10	3	2
Conformance	2	8	8
Replaceability	2	10	10
Overall Score	**50**	**125**	**122**

Table 1: Evaluation of system architecture approaches [Scholz 2010].

In Table 1 scores are given for each evaluation parameter, according to ISO 9126, ranging from 1 to 10, where 1 is the lowest and 10 the highest score. The scores are given based on an evaluation of the architecture alternatives carried out by the author and published in Scholz [2010]. The results listed show that SOA and ubiquitous architecture share a similar rating – 125 to 122. This is the result of the fact that a service oriented and a ubiquitous system show similar properties. Nevertheless, ubiquitous architectures have a greater number of hardware components included which can fail, and a greater number of connections that have to be secured than SOAs. Thus, SOAs for WSC management have a slightly better overall score.

4 Discussion and Conclusion

This paper elaborates on an appropriate system architecture for decision support in WSC management. In this work the surrounding environment of WSC management is discussed in detail in order give the reader a better understanding of the nature of the WSC itself. Additionally, the author wants to emphasize that this work is of interdisciplinary character, because of three involved fields of expertise: geographic information science and technology, forest science and operations research.

The paper describes a SOA for WSC management that shows a modularized layout. The modules communicate utilizing services exploiting simple WSs, SOAP and REST. This architecture fulfills the requirements of an intended, future WSC including the possibility to collect and to deliver data of the WSC in real-time.

A comparison of alternative system architectures, including monolithic, service oriented and ubiquitous approaches shows that SOA and ubiquitous architectures are appropriate for the application in WSC management. SOAs have a slightly better performance as the number of involved hardware and communication channels to be secured is lower compared to a system following the ubiquitous approach.

5 Literature

Fraunhofer IFF (2009): Intelligentes Holz - RFID in der Rundholzlogistik. URL http://www.intelligentes-holz.iff.fraunhofer.de, last access: 28.03.2011

Gronalt, M.; Chloupek, A.; Greigeritsch, A.; Häuslmayer, H. (2005): WoodLog - Perspektiven der Holzlogistik SupplyChain-Optimierungspotentiale durch ein Logistikleitzentrum Holz. Technical report, Bundesministerium für Verkehr, Innovation und Technologie, Wien.

ISO (2001): ISO 9126: Software engineering - Product quality - Part 1: Quality model. Technical report, International Organization for Standardization.

Komarkova, J.; Visek, O.; Novak, M. (2007): Heuristic Evaluation of Usability of GeoWeb Sites. In: Ware, J.; Taylor, G. (Eds): Lecture Notes in Computer Science: Web and Wireless Geographical Information Systems, 7th International Symposium, W2GIS 2007. Berlin: Springer-Verlag, pp. 264-278.

Korten, S.; Kaul, C. (2008): Application of RFID (Radio Frequency Identification) in the Timber Supply Chain. In: Croatian Journal of Forest Engineering, Vol. 29, pp. 551-569.

Kytöjoki, J.; Nuortio, T.; Bräysy, O.; Gendreau, M. (2005), An efficient variable neighbourhood search heuristic for very large scale vehicle routing problems. Computers and Operations Research, Vol. 34, 2743-2757.

Naur, P.; Randell, B. (Eds) (1969): Software Engineering: Report of a conference sponsored by the NATO Science Committee, Garmisch, Germany, 7-11 Oct. 1968, Brussels, Scientific Affairs Division, NATO, pp. 231.

Ortega, M.; Perez, M.; Rojas, T. (2003): Construction of a Systemic Quality Model for Evaluating a Software Product. Software Quality Journal, Vol. 11(3), pp. 219-242.

Poslad, S. (2009): Ubiquitous Computing Smart Devices, Environments and Interactions. Chichester: Wiley & Sons.

Ropke, S.; Pisinger, D. (2006): An Adaptive Large Neighborhood Search Heuristic for the Pickup and Delivery Problem with Time Windows. Transportation Science, Vol. 40, pp. 455-472.

Scholz, J.; Bartelme, N. (2008): Spatial Decision Support for Wood Supply Chain Optimization - Modelling Issues. In: Car, A.; Griesebner, G.; Strobl, J. (Eds): Geospatial Crossroads @ GI_Forum '08: Proceedings of the Geoinformatics Forum Salzburg, Wichmann Verlag, Heidelberg, pp. 246-251.

Scholz, J.; Bartelme, N. (2010): Spatial-enabled Adaptive Large Neighborhood Search for Optimizing the Wood Supply Chain. In: Proceedings of GIScience 2010, Zurich, Switzerland.

Scholz, J. (2010): Real-Time Spatial Optimization, Ph.D. Thesis, Graz University of Technology, ISBN: 978-3640804672, Grin Verlag.

Taylor, R.N.; Medvidovic, N.; Dashofy, E. (2009): Software Architecture: Foundations, Theory and Practice. Hoboken, NJ: John Wiley & Sons.

von Bodelschwingh, E.; Bauer, J.; Longo, M. (2003): Informationsflüsse in der modernen Holzerntekette. Praxiseinsatz der Logistiksoftware Geo-Mail. AFZ-DerWald, Vol. 17, 2-4.

Wannenwetsch, H. (2005): Vernetztes Supply Chain Management. Berlin: Springer.

Weiser, M. (1991): The computer for the 21st century. Scientific American, 265, pp. 94-104.