
A Process Perspective on the Timber Transport Vehicle Routing Problem

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Abstract

The aim of this study was to map how the timber transport vehicle routing problem was solved in practice and which consequences different ways of solving the problem had for service and efficiency. A process perspective was employed for the mapping and the ways of solving the routing problem were expressed in terms of a series of planning and control activities. Fifteen haulage contractors from the Södra Skogägarna forest owners association were selected for the mapping. The mapping resulted in a basic process model and 2 main variants. Key performance indicators for both service and economic efficiency were collected for a one-year period. The contractors' service levels to suppliers were measured by the proportion of transport orders completed within a specified period. The contractors' economic efficiency was measured by their net operating margin. The results show that contractor net operating margins decreased (from 15% to 1%) with increasing levels of supplier service (from 89.5 to 97% of orders completed within 5 weeks). Within this gradient, those using the complete process model had an average net operating margin of 4.1%. Those using a simplified model (with fewer service restrictions) had an average margin of 9.2%.

Keywords: haulage contractors, truck routing, service levels, economic efficiency.

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Introduction

In Sweden, truck transport of roundwood is estimated to account for an annual emission of 428 000 tons CO₂ (Andersson & Frisk 2013). These emissions are in direct proportion to logging truck fuel consumption. Studies of logging truck fuel consumption (Svenson & Fjeld 2012) show that gross vehicle weight and road grade are the main influencing factors. Given that gross vehicle weight for each truck load unavoidably varies between the empty (tare) weight of approx. 20 tons and fully loaded weight of 60 tons, development efforts to reduce emissions should be focused on reducing empty travel, choosing suitable routes for the loaded transport from forest to mill and further reducing tare weight.

Vehicle routing is often described as having the goal of maximizing capacity utilization or minimizing total costs for a given service (Haksever et al. 2000). In roundwood trucking, with its potentially high proportion of unloaded transport from the mill back to the forest, routing studies are often focused on the reduction of the unloaded distance through backhauling. Some companies have introduced software for vehicle routing and scheduling (Weintraub et al. 1996, Savola et al 2004). These solutions have gradually been adapted to capture the restrictions handled by haulage contractors in practice (Karanta et al. 2000). Few studies, however, have been published documenting how these contractors solve their routing problems in practice.

Swedish transport management is an integral part of wood supply management. The high proportion of wood from non-industrial private forest owners and distribution of saw and pulp mills requires the coordination of a number of assortments from scattered harvesting sites to multiple mills. These operations are typically managed by the supply organization (transport service buyer) where central administration contracts transport capacity and then distribute periodic-specific transport goals to regional transport managers and their respective contractors (transport service providers). At the operational level vehicle routing becomes the responsibility of the service provider. The supply organization, however normally retains close control over truck deliveries as a possibility for compensating for disturbances in the other parts of the transport system. For a haulage contractor the goal is then to maximize the economic result, within the restrictions of the agreed service level. Payment is done according to a tariff formula calculating the price per transported unit based on a fixed rate per unit and variable rate per unit. The fixed rate per unit is intended to cover the indirect transport work (loading/unloading) and the variable rate is intended to cover the direct transport work given the loaded

distance from mill to forest and an accepted proportion of loaded and unloaded driving.

Much literature is found recommending process improvement both within and between organizations for the purpose of increasing income and reducing costs, however, only a few forest-sector studies have been done on this topic. Mäkinen (1993, 2001) and Soirinsu and Mäkinen (2009) examine transport contractor profitability from a business strategy perspective. Erlandsson (2008) examines contractor profitability in terms of the task environment which also includes some interfaces with service buyers, but without examining process configuration as an influencing factor.

Aims of This Study

The first aim of this study is to map contractor-level processes for routing of self-loading logging trucks. The second aim is to identify main variants of the process model and see if these differences are linked to service and economic efficiency levels.

Methods

The study was done in two parts. The first was process mapping and the second was the search for links to service and economic efficiency levels. The process mapping started with personal interviews and the formation of draft processes for individual contractors. When the draft maps for individual contractors were ready the search began for common features linking the different drafts to a general model. The main variants of the general model were then defined and the corresponding service and profitability levels were compared.

Process Mapping

The study was hosted by Södra Skogsägarna, a forest owners association in south Sweden. Multi-truck contractors were randomly selected from each of the organization's 3 regions (East, West, South). The distribution of contractors per region was 6 in the East, 6 in the West and 3 in the South (15 in total). Each of the respondents were contacted first by mail (to explain the aim of the study) and later by telephone (to book time and place for the interview). Participation was agreed to under conditions of anonymity.

The process mapping was based on the methods and nomenclature described by Larsson and Ljungberg (2001) who specify a variant of mapping called design-process where complex structures must be formulated from

semantic descriptions in the absence of physically observable activities. Larsson and Ljungberg (2001) refer to three levels of detail: process, sub-process and activity. Within this hierarchy any process is assumed to include a number of components including input (which triggers the start of the process/sub-process or activity), activity (which transforms the input), resources (which are needed to do the activity), information (which supports or controls the activity) and output (which is the result of the activity and may be the input for the next activity).

The personal interviews with each contractor also covered a number of themes other than the explicit mapping of the routing process. These included descriptive information on the contractor's enterprise, their cooperation with the service buyer's transport managers and other parameters influencing the contractor's task environment. The interviewer asked direct and simple questions according to a pre-prepared structure allowing the respondent complete freedom to formulate complex answers. The interviewer used a series of empty process diagrams to help formulate the process during the interview. Interviews were recorded on a Dictaphone for future reference. After the completion of the 15 interviews, each contractor's routing activities were defined and named. The draft process maps which were filled in during the interviews were then compared to the recorded protocol and adjusted if required. After this the activities were categorized into sub-processes according to similarities in purpose and level of detail. After this the sub-processes and activities were defined and named.

Key Performance Indicators

Key performance indicators were collected for both service and efficiency. The chosen service level indicator was the proportion of assigned transport orders completed (all volumes for assortments delivered) within 5 weeks of initiation. This variable is therefore a measure of service offered to suppliers (forest owners with a delivery contract to Södra Skogsägarna). Average values were taken from the service buyers database (based on input from SDC, the central database for Swedish wood transactions). Data was missing for one contractor. The chosen indicator for contractor economic efficiency was net operating margin defined as the net operating surplus (after financial costs) as a proportion of annual turnover. Net operating margin is a relative term and therefore robust when comparing enterprises of different sizes. Values were available for limited stock companies through the Swedish national database. This data was not available for 4 contractors which had other forms

of ownership. The analysis of how enterprise-level service and profitability corresponds with process configuration was done quite simply. Average values of contractor service and profitability were compared between the variants of process configuration. Scatter plots between variables from individual contractors were used to visualize eventual relationships.

Results

The contractors in the study had between 2 and 12 trucks per enterprise and delivered wood to between 5 and 15 mills. Each truck delivered approx. 40 000 m³/yr with a typical utilization of 4500 hrs/yr (Table 1).

The average annual turnover per contractor in the study was approx. 12 million SEK. The average net operating margin (profit before financial costs as a proportion of annual turnover) was 5% but varied from -3% to 15%. The average service level (% of transport orders completed within 5 weeks) was 93% but varied from 84 to 97% (Table 2).

The Contractor Routing Process

After a comparison of all the individual contractor models, a basic model was formed consisting of all the activities which the majority of contractors (8 of 15) used to solve their own routing problems. These activities were

Table 1 Descriptive statistics for operating context (no. of trucks and no. of mills being serviced, typical delivery distances) and truck utilization (m³, km and hrs per yr and truck) for the contractors in the study

	Mean	Median	Max	Min	N
trucks/contractor	4,87	4	12	2	15
mills/contractor	9,4	8,5	15	5	14
delivery distance (km)	80	80	120	50	15
m ³ /yr/truck	47606	39743	100000	32000	14
km/yr/truck	185890	180000	230000	135000	15
hrs/yr/truck	4525	4500	5405	4000	12

Table 2 Descriptive statistics for some economic indicators (turnover, profit, net annual margin) and supplier service parameters (% of transport orders completed within 5 weeks) for the contractors in the study

	Mean	Median	Max	Min	N
Net annual turnover (1000 SEK)	12 606	12 873	19434	6309	11
Annual Profit (1000 SEK)	295	206	1123	2	11
Net annual margin (%)	5%	3%	15%	-3%	11
Supplier service level (%)	93,2	94,3	96,9	84,1	14

aggregated into the 4 sub-processes (Figure 1). These and their respective activities are described below.

Information gathering (1). This sub-process consists of one activity. Receipt of new transport orders (1.1) is a daily activity where the contractor receives new transport orders (delivery responsibility for a specific harvesting site) from the forest owners association. This occurs, either through direct contact with the service buyers transport manager or by downloading the new assignments directly from the service buyer's information system. After this sub-process the contractor has a complete list over his transport orders (all harvesting sites where he is responsible).

Preparatory planning (2) consists of 4 activities. This sub-process gives the contractor an overview of the restrictions, priorities and possibilities for vehicle routing. Mill quota follow-up (2.1) is for tracking the contractor's weekly quota for volumes per assortment to be delivered to the respective mills. This activity monitors the volumes delivered so far and how much is left for the days remaining. This activity can also include increases or decreases in the quota if supply or demand conditions require so. Ranking of transport orders (2.2) is when the contractor ranks all the transport orders based on a selection of priority factors. Unless special conditions exist the default priority is based on the date the transport order was assigned (oldest first). Analysis of geographic flow patterns (2.3) is when the contractor examines the patterns of wood flow to see where there exists potential for backhauling. Contact with other contractors (2.4) is for when a suitable wood flow pattern for backhauling exists between contractor transport orders and the contractor makes contact with another contractor to request an exchange of volumes to realize the backhaul. After this sub-process the contractor has a ranked list of transport orders indicating the sequence they should be delivered to meet both supplier and mill service requirements while reducing the proportion of unloaded driving.

Problem solution (3). This sub-process consists of 3 activities. These activities determine how the vehicle routing will be done during the planning period in question. Filtering of infeasible transport orders (3.1) is when the contractor filters out harvesting sites which are temporarily unavailable due to weather conditions or limited opening hours for wood receipt at the mill. Clustering of small volumes into whole loads (3.2) is when the contractor locates smaller volumes (of the same mill destination) within acceptable distances to aggregate into whole loads. Search for load sequences (3.2) is when the contractor factors in the working hours of the individual operator and combine loads into sequences that give the operators full shifts that conclude

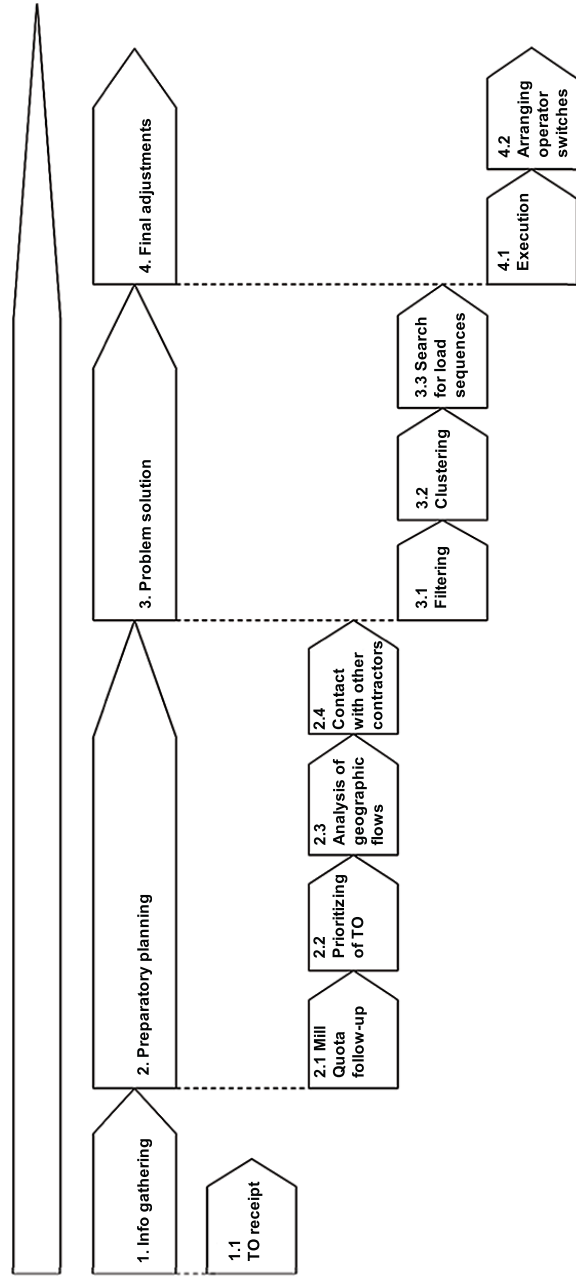


Figure 1 A basic process model for routing of self-loading logging trucks with 4 sub-processes and 10 activities. The model consists of the activities that the majority of haulage contractors used in their vehicle routing.

close to their home bases. After this sub-process the contractor has solved the daily routing for his trucks.

Final adjustments (4) – consists of 2 activities. Execution (4.1) is the operators' execution of the individual delivery and detailed planning of the path to each harvesting site for loading. Arranging operator switches (4.2) is when the operators contact each other and agree to an exact meeting place for changing operators between shifts. After this sub-process the contractor's routing solution has been executed and operator schedules are coordinated in detail.

Key Performance Indicators for Variants of the Routing Process

Seven contractors of the 15 studied used another variant of the basic model than described in Figure 1. These had a simplified preparatory planning sub-process (2) where follow-up of mill quotas (2.1) was not taken into consideration. Two contractors of the 15 studied used a simplification of the problem solution sub-process (3) where clustering of small volumes (3.2) and the explicit search for optimal load sequences (3.3) was not included.

Figure 2 shows that for those contractors working with either the basic model or the variant with simplified preparatory planning (2) profitability decreased (from 15% to 1% net operating margin) with increasing levels of supplier service (from 89.5 to 97% of orders completed within 5 weeks).

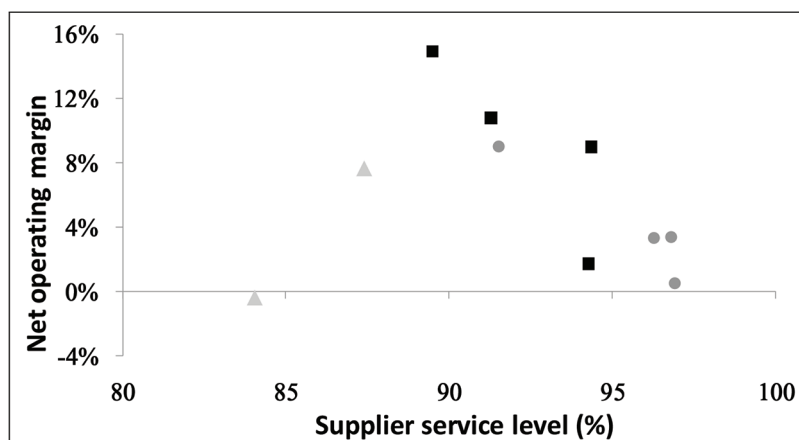


Figure 2 Scatter plot between net operating margin and supplier service levels for 10 contractors (circles = contractors with the complete basic process model, squares = contractors with simplified preparatory planning, triangles = contractors that have a simplified solution sub-process).

Within this gradient, those using the complete basic process model had an average net operating margin of 4.1% while those not limited by quota follow-up (2.1) had an average margin of 9.2%. Those contractors working with the complete model had higher supplier service levels in all three regions (Figure 3). Figure 4 shows that profitability decreased with increasing annual operating hours per truck, regardless of which process model the contractor

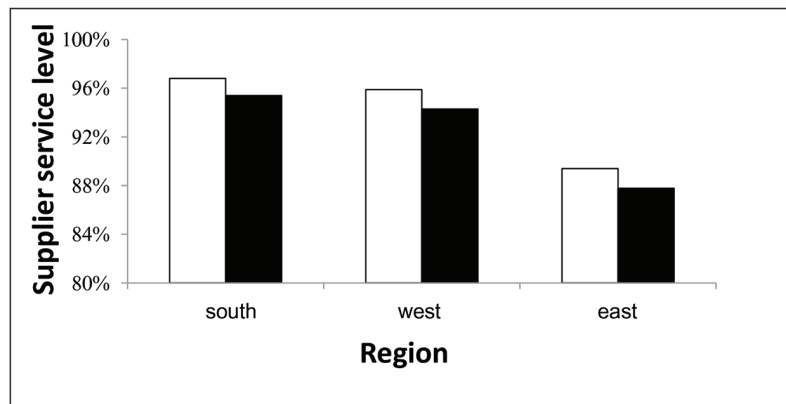


Figure 3 Mean supplier service levels for haulage contractors in each region grouped into whether they had a simplified preparatory planning sub-process or not (black columns = simplified sub-process, white columns = complete sub-process).

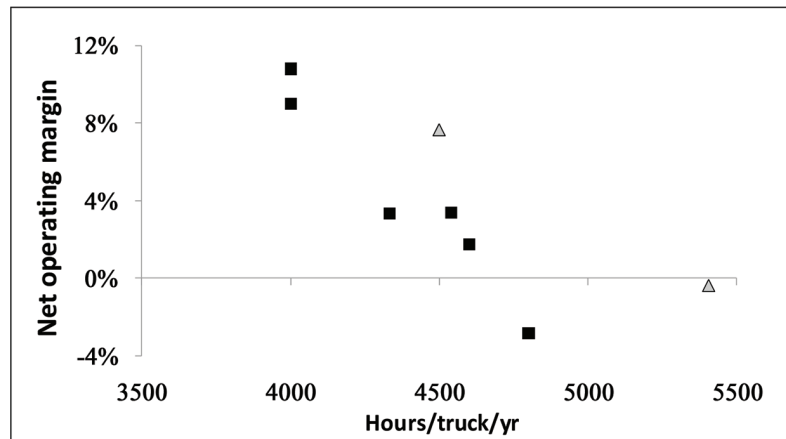


Figure 4 Scatter plot between contractors' net operating margin and the number of annual operating hours per trucks (squares = contractors with a complete problem solution sub-process, triangles = contractors with a simplified problem solution sub-process).

used. However, the contractors with a simplified problem solution sub-process (3) had a higher number of operating hours than other contractors for the same level of profitability.

Discussion

Earlier studies of logging truck routing have been mainly focused on developing mathematical models to give optimal- or near-optimal solutions. In contrast, this study shows how haulage contractors do their vehicle routing in practice. Three main variants were found: a complete process model including all sub-processes/activities, and two variants missing either key activities in the sub-process *preparatory planning* (activity quota follow-up) or the sub-process *problem solution* (activity search for load sequences). Compared to the complete model, the variant with the fewest restrictions (missing quota follow-up) was associated with a higher net operating margin and lower supply service levels. The variant with the least focus on the actual routing (missing an active search for the best load sequences) was associated with a higher number of operating hours per year for the same net operating margin. Regardless of the process model used by the individual contractor, a plot of all observations showed an overall trend of lower net operating margins for contractors with high supplier service levels (% of orders completed within 5 weeks). In practice, higher service levels for mills and supplier service levels represent increasingly tighter restrictions for the contractors' routing. These issues are explored in more detail below.

Karanta et al. (2000) characterizes the logging truck routing problem (otherwise known as the TTVRP) as one of the most difficult problems to solve within the world of operations research (OR). Given this, it seems a paradox that roundwood trucking functions as well as it does. The main difference between mathematical formulations and transport management in practice, however, is the division of large problems/systems into smaller sub-problems/systems (decentralization). While this practice poses the risk of sub-optimization, it makes the problems possible to solve manually without advanced decision support systems. Karanta (2000) mentions two particular challenges of solving this problem with OR methods; first, an unusually high number of constraints which must be taken into consideration and second, the difficulty of specifying a general formulation for the goal function. Regarding the first challenge (number of constraints), problem solving theory would interpret the preparatory planning sub-process as focusing on the most critical factors of the task environment. In this respect the basic process model

(Figure 1) excludes certain potential wood flows already at the outset and enables focus on the most critical constraints. Regarding the second challenge (formulating the goal function), a typical difficulty is conflicting perspectives between different parts of the system (e.g. supplier vs. contractor. vs. mill). In this respect, the preparatory planning sub-process can be interpreted as handling potentially opposing goals between suppliers and mills before beginning to address specific sequences/solutions.

The sequence of activities used by the contractors in this study effectively strips down the problem space to its most critical areas. In an extreme case, a few priority mills might require immediate deliveries which are only possible to fill from a few landings where the critical latest date is near. This may limit the number of potential pick-up and delivery points for each truck within the contractor's "home territory" to a relatively short list. In this case, a contractor could arrange an acceptable sequence of loads for the day using only knowledge of average trip times, making the routing problem much easier to solve (Gerasimov et al. 2013). With respect to reducing emissions, however, the need to further exploit backhauling possibilities cannot be ignored. Given free reign, contractors create efficient routes based on stable wood flows. However, how close they can come to the most efficient routes is determined by the preparatory-planning (2) where potentially efficient combinations of landings or mills can be removed from the priority list. Similar removals occur during filtering (3.1) of the problem solution (3) where, for example, mill opening hours may further shorten the hauler's list of feasible deliveries. A typical example of this is when only one of the two geographically opposing flows of a backhaul can be delivered during a second evening shift. Empirical support for this is shown by Erlandsson (2008) with a correlation between contractor operating margins and the proportion of deliveries to 24-hour open mills.

One reason that responsibility for backhaul planning is most often delegated to the contractor level is that a single contractor may work for a number of competing wood supply organizations. The resulting collaboration between contractors to locate potential backhaul flows has been the subject of a number of studies. Audy et al. (2010) mapped alternative collaboration networks. Frisk (2002) examined decision support systems for helping to locate potential backhaul flows and Karlsson et al. (2006) mapped the inter-organizational processes for arranging backhauling between contractors. The operational feasibility of realizing these backhaul potentials have been examined in both simulation studies (Fjeld 2012) and empirical studies (Auselius 2009) where the levels of roadside stocks were shown to be one of the

most critical aspects for high efficiency. It is in this context, when backhauling feasibility becomes dependent on sequences of deliveries, that manual routing begins to resemble an advanced board game. Seen in a game theory perspective, the typical contractors routing process is about moving through a problem space towards a solution which places the whole system in the goal condition. At each step the solver can choose an operator (decision rule) and apply it to get to the next step (state of knowledge) which is hopefully closer to the ultimate goal (in this case, economic efficiency). The way of working mapped in this study has been interpreted as a process which extracts information about the structure of the task environment and uses this for highly selective heuristic search of the problem space for solutions. The particular advantage of the process is that it simplifies a potentially complex problem. The disadvantage is that it may restrict the problem space too much, reducing the degrees of freedom necessary to find the best sequences of pick-ups and deliveries. In this context, both mill quotas and supplier service limits have the same effect – they reduce the number of “legal moves” (degrees of freedom) which can be tested on the way to the next step through the problem space. As a result, the combination of high service demands and a simplified search and solution sub-process clearly reduces the possibility to reach the highest level of utilization and efficiency. In this study the two respondents with the simplified solution sub-process (3.3) worked more hours than the other contractors for the same level of economic efficiency (Figure 4) and this may be consistent with the logic discussed above. At the same time, however, there may other explanations for the absence of explicit solution sub-process (3.3) such as a) this decision may be made by others (higher up in the hierarchy) b) there are few degrees of freedom in the task environment due to other factors or c) the contractor does not have the capacity for further information processing. In general the trend for poorer profitability at high utilization has also been reported by Mäkinen (2001) and has been commonly observed among transport managers. If the above conditions a, b or c are present, increasing hours or volumes cannot compensate for poor planning and may even make the situation worse. So, even though the results can be supported by the logic and earlier studies discussed above, the small sample limits the validity of the results to the context studied.

Final Comments

This study has used a process-perspective to map how the timber transport vehicle routing problem is solved in practice. Although the number of contractors participating in the study was limited, the process perspective

was found to be a suitable approach for identifying state-of-the-art in vehicle routing, illustrating main variants as well as their associated service and efficiency levels.

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Biographies



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