Improving Forestry Transport Efficiency through Truck Schedule Optimization: a case study and software tool for the Australian Industry

Mauricio Acuna
Harvesting and Operations Program
CRC for Forestry – University of Tasmania
Private Bag 12, Hobart, 7001, Australia
mauricio.acuna@utas.edu.au
Mark Brown
Harvesting and Operations Program
CRC for Forestry – University of Melbourne
1 Water St., 3363, Creswick, Australia
mwbrown@unimelb.edu.au
Luke Mirowski
School of Computing and Information Systems - University of Tasmania
Private Bag 87 , Hobart, 7001, Australia
luke.mirowski@utas.edu.au

Abstract:
An important problem for forestry in-field chipping operations is the efficient daily truck transportation of chips from different coupes being harvested, with known supplies, to customer destinations with known daily demands.
This paper presents initial results from a trial with FastTRUCK, a software tool that uses a simulated annealing approach to optimise truck schedules. The software was developed by the Cooperative Research Centre (CRC) for Forestry, to evaluate some of the factors that affect transportation efficiency within Australian in-field chipping operations. The analysis of results focused on: chipper productivity and utilisation; number of chipping operations accessible to each truck; truck loading and unloading time; net payload on daily transportation costs; number of truck;, and finally, average truck utilisation. Results obtained on synthetic data, derived from expert knowledge, suggest payload and chipper utilisation are the main factors affecting transportation efficiency, and thus limiting cost savings. The estimated potential savings are 52% and 29% from current levels, respectively, and are thought obtainable from better control and management of the investigated factors. Future work shall consider ways of validating the feasibility of implementing changes in forestry operations which may work towards achieving the identified efficiencies, and thus, cost savings.

Keywords: In-field wood chipping, truck scheduling, simulation, software, supply chain, transport efficiency

1 Introduction

Global transportation of logs and chips using logging trucks constitutes a major part of the operational costs in the forest industry. It is therefore important to organize the scheduling of trucks efficiently as they have a high initial investment cost in their purchase, and high operational cost over their daily operations and ownership lifetime. Many forestry transport managers are aware that their fleets could be improved, through such approaches as computer aided dispatching, routing or scheduling systems, and consequently, the research described in this paper introduces the concept of a software based approach which may go some way in achieving such optimisations, and thus, associated cost savings.

In general, the main goal of routing and scheduling systems, whether software based or through some other approach, is to minimize transportation costs and waiting times within such constraints as technical, policy and labour. A specialised aspect of this is the vehicle routing problem (VRP), which focuses on the efficient movement of vehicles. This problem is difficult to solve and the more specialised subproblem, Timber Transport Vehicle Routing (TTRVP), is even harder to solve as the latter has specialised features (Karanta et al. 2000). The closest problem class to TTRVP in vehicle routing literature is freight pickup and delivery with time windows (Dumas et al. 1991). Although these problems share many features, there are other elements that make TTRVP a unique problem, these include: pickup sites vary on a daily basis; there are strict time intervals to when a truck can enter an unloading (delivery) site; there are different types of product (timbers); and a given forestry mill needs a specific types of timber for processing; and finally, not all trucks in an operation can serve all pickup or delivery nodes For these reasons, the problem of optimised scheduling in forestry, reported in this paper, is seen as a more specialised problem than the general case of vehicle routing problem, and therefore requires a specialised approach.

Previous work has considered the problem of optimised scheduling of log trucks and thus a number of truck scheduling and dispatching systems for commercial operations have been developed. In Chile, for example, a computerized system called ASICAM has been in use since 1990. It uses simulation with an embedded *heuristic* to produce a complete trucking schedule for one day of operations for more than 100 trucks in a (Epstein et al. 2007). Through the use of ASICAM, reductions in costs of between 10% and 20% were achieved (Weintraub et al. 1996). Similar systems can be found in other countries. In Finland, a system called EPO was developed to deal with all stages of planning, from strategic to operative and this solution is reported by Palmgren et al. (2004). Moreover, in Sweden, Skogforsk developed a system called FlowOpt (Flisberger et al. 2007). It is a system that integrates Geospatial Information Systems (GIS) with a database and uses a heuristic approach based on a *tabu search* algorithm. In general it seems that from these commercial systems, tests usually report savings of between 5% and 20% when compared with manual based approaches. From a research perspective, however, the ability to develop specialised tools which allow for customisations to localised conditions, such as those experienced in Australia, are constrained by the proprietary limitations on these above commercialised products which is why a customised software program, called FastTRUCK, for optimisation is introduced in this research.

In Australia, in-field wood chipping operations are common in Blue Gum (Eucalyptus globulus) plantation harvests. For this country, harvesting systems usually consist of: one feller buncher; one or two grapple skidders; and a delimber-debarker-chipper (DDC) - illustrated in Figure 1. The system produces woodchips at the roadside in the forest and is particularly sensitive to planning and logistics as the DDC is unable to work unless a truck is on site to be loaded. For this system, therefore, the use of truck scheduling systems could be valuable in evaluating the required level of receiving capacity at the woodchip terminal - especially due to the very high capital expenditure which could be avoided based on a favourable scheduling assessment – one that identifies efficiencies - of the required number of hydraulic dumpers (unloading platforms) which affects number of trucks further down the schedule (Figure 1).

To this end, the objective of this research was to evaluate some of the factors, like those described above, that affects transport efficiencies in Australian in-field chipping operations, and forecast the potential cost savings. It was therefore decided that a limited case study with known potentials for optimisation would be examined through the use of a customised schedule optimisation software program. The structure of this paper is as follows: section 2 describes the problem in more detail and lists the materials and methods used to explore the problem. Section 3 describes the results obtained when a software program, FastTRUCK, is applied to the problem. Finally, this paper concludes with a look towards further work.

2 Material and Methods

This section begins by describing in more detail the specific case study that was used to investigate the optimisation of truck schedules for Australian conditions. Following this, the specialised software program that was developed, FastTRUCK, is described in some detail, to give clear indications as to how it was developed for this study.

2.1 Problem Description

In investigating the general feasibility of implementing a software based approach that allows for optimisations of truck scheduling in Australia, a relatively limited case study was examined. The problem to be solved has been limited to the transportation of a single product (wood chips) from eight different in-field chipping operations at two receiving facilities (dumpers) located at shipping ports. For scheduling of operations, the decisions to make involve: when and where to deliver the wood-chip loads to mills; and creating the log-truck schedules for routes that meet customer orders at minimum operational cost.

At an operational level, on a daily basis, a fleet of chip-van trucks (single configuration) have to perform a number of transportation orders (typically one per hour) during the shift hours of the chippers (Figure 2). Trucks depart from different depots located close to the dumpers and must then travel to any of the in-field chipping operations. The chippers are unable to work unless there is a truck on site which can be loaded with its chip output. Consequently, this constraint means that trucks must arrive regularly at chipping operations to maximise the productive working time of the chippers, and thus, it is one of the factors responsible for affecting truck scheduling.

In addition to maintaining regular truck arrivals to the chipping operations, there are other constraints that must be satisfied in this specific scheduling problem. These include: Dumpers and chippers have specific operating hours over which they can receive trucks; dumpers also have a specified truck receiving capacity per hour; truck capacity cannot be exceeded and after the specified working time, they must return empty to the depots from the last visited dumper; working time consists of time travelling empty from a depot or dumper to a chipping operation, time travelling loaded from a chipping operation to a dumper, waiting time at dumpers and chipping operations, loading time at chipping operations and unloading time at dumpers; finally, the cost of each route and truck is a function of the above working times, plus a daily fixed cost per truck.

All of these factors were considered in the specific case of optimising schedules for this case study, and consequently, were modelled in the software program that was developed called FastTRUCK. It is to this end that the next subsections of this paper report on the underlying design and assumptions of the model which produced the reported results to make it clear how optimisations, reported later, were achieved.

Figure 1: Hydraulic dumper at the port

Figure 2: Chip-van truck in in-field chipping operation

2.2 Simulation Routine

The simulation routine, encoded in the FastTRUCK software, emulates the movement of trucks during the day and provides solution in a few seconds – encoded from a domain model derived as result of discussions with individuals with knowledge of scheduling operations. It also keeps track of all performance metrics as the truck takes a route through depots, chipping operations, and dumpers. The simulation conducted is somewhat deterministic as the events for the trucks (departures, arrivals, loading, unloading) are derived from known routes which are used as inputs, which was itself constrained by experts knowledge of the underlying supply chains operations. Other inputs include: number of trucks, dumpers, chipping operations available, and finally the distance matrix between all these points.

The simulation uses three basic types of trip: depot to chipping operation; chipping operation to dumper, and finally, dumper to chipping operation. The first trip to a chipping operation must be completed before or at the latest starting point of the chipper's time window. Once a truck arrives to a chipper, the distance travelled, time, and cost between the chipping operation and the corresponding depot for the truck are calculated and their total distance, time and cost are updated accordingly. The same occur in subsequent trips when a truck visits a chipping operation after having visited a dumper, when it visits a dumper after having visited a chipping operation, or when returns to its depot on the last trip. If during the arrival to a chipping operation or dumper there is another truck being loaded or unloaded, the truck must wait until the chipper or dumper becomes available. This waiting time is added to the total time and cost for the truck and the first in first out (FIFO) strategy is adopted for that purpose.

The truck delivers a load from a chipping operation to a dumper. As the loads are delivered, the system updates the total number of loads delivered to dumpers and compares them with the total number of loads to be delivered for the day from each chipping operation. Once all the loads are delivered, the system calculates the following performance metrics: total cost, total volume to dumpers, average truck utilisation and average waiting time.

It is worth noting that the domain model described above was derived through interviews with individuals familiar with scheduling operations. A metaphor based approach to its derivation was chosen as this afforded an easy way to validate existing operations, in discussion with experts, for the modelled scenario. In the future, it may be worth considering alternative ways in which the domain model itself could be optimised or made more generic for improved exploration of the solution space for other case studies.

2.3 Simulated Annealing Algorithm

It was decided that a Simulated Annealing (SA) approach to optimisation of the scheduling would be used. It is a simple meta-heuristic whose approach that is similar to the random descent method in that the neighbourhood is sampled at random, but one that is good-enough for our purposes. It differs in that it is possible to escape from being trapped at a local optimum by accepting worse solutions, with a small probability, during its search iterations (Reeves 1993). The customisations of this algorithm to this problem's domain model are briefly described and yield useful insights in validating the obtained to be explained later.

In general the chosen algorithm uses a heuristic to solve complex large combinatorial problems which have a large solution space and produce results close to the optimum value in a short period of time (Haridass, 2009). The name and inspiration come from annealing in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects. By analogy with this physical process, each step of the SA algorithm replaces the current solution by a random "nearby" solution (move), chosen with a probability that depends both on the difference between the corresponding function values and also on a global parameter T (called the temperature). As T gradually decreases during the process, the probability of accepting worse solutions also decreases (Kirkpatrick 1983).The initial solution at the beginning of the process starts with a temperature that is hot enough to allow moves in all the neighbourhood and conduct a random research for a period of time. The search of solutions is conducted for a number of iterations at each temperature. Notionally, simulated annealing has a strong affordance to the assumptions we found existed in the process of improving the efficiency of a truck schedule when talking to expert schedulers.

2.4 FastTRUCK Scheduling Software

The domain model, algorithm, and use of Simulated Annealing (SA) presented in Figure 3 were encoded in a software program entitled, "FastTRUCK." Developed for the Microsoft Windows platform and using Visual C++. It uses input from the existing parameters of the transport component of an operation, and generates a range of alternative schedule solutions to determine the optimal operating scenario based on its known inputs (Acuna 2011).

As output, FastTRUCK reports, for the encoded information and based on the domain model, the optimal: number of trucks required for the operation; total transportation cost; total volume of chips hauled to dumpers; average truck utilisation; average truck waiting time and average loaded running percentage (travel loaded /total travel distance). Detailed results by truck have the option of being exportable to Microsoft Excel, a spread sheet program, and this output also includes: total time; total cost; trips to dumpers; waiting time; utilisation; running loaded percentage; arrival times at forests and dumpers; and optimal schedule for one day.

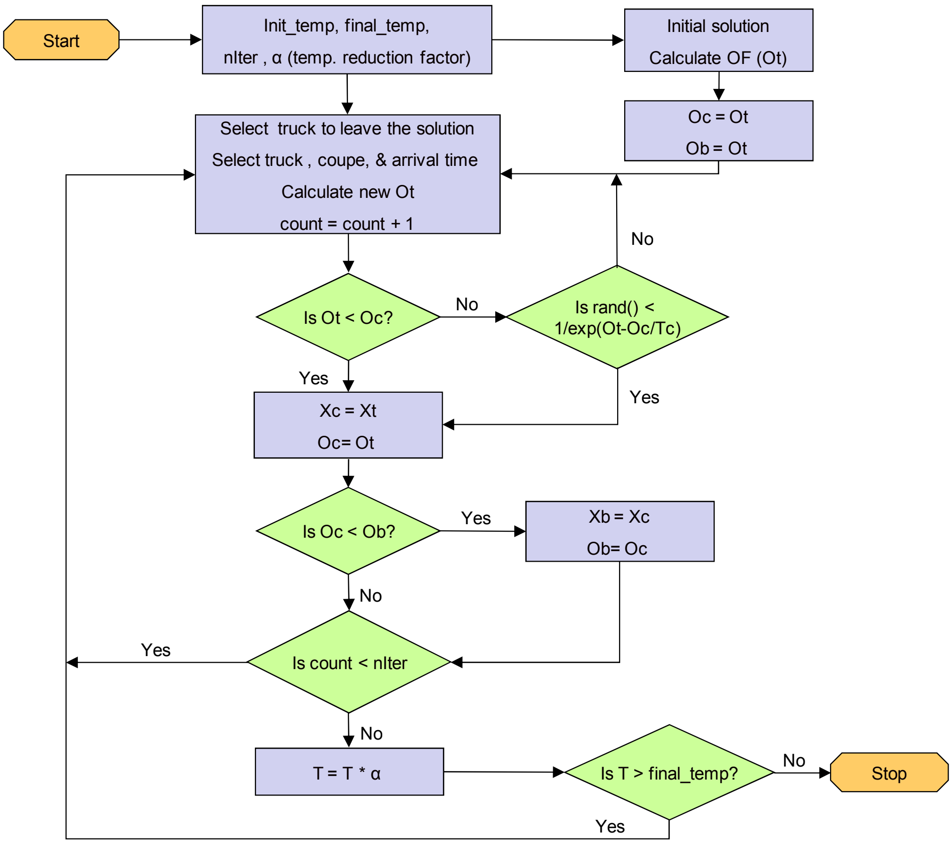

Figure 3: Simplified version of the simulated annealing algorithm adapted for use in FastTRUCK.

2.5 Parameter Values Set within FastTRUCK for Analysis

The specific case of in-field chipping operations within an Australian chipping operation was examined using FastTRUCK. The various values that were encoded into the software, derived through expert interviews, are now briefly summarised.

- Trucks:
  - 82.5 tonne GVM road trains (50 tonne payload)
  - Truck working shift limit: 6 hour minimum to 12 hour maximum
  - Average road speed 75 km/h empty and 65 km/h loaded
  - Annual freight task of 900,000 tonne
  - Centrally dispatched fleet (any truck can go to any chipper)
  - Average haulage distance of 72 Km with lower and upper lead distance of 29 Km and 150 Km respectively
- Infield chippers:
  - 8 active harvest operations on single 10 hour shift
  - Loading time 60 min per truck
  - Chipper utilisation at 90%
- Receiving facility:
  - One facility with two dumpers
  - Capacity per dumper of 250 gross metric tonne/hour (i.e. unload up to 5 trucks per hour)
  - Facility open 14 hour per day

The above parameter values represent one parameter set encoded in the software which was part of a broader exploration of the solution space that was conducted to determine the impact of chipper productivity and utilisation, number of chipping operations accessible to each truck (routing option), truck loading and unloading time, and net payload on four performance metrics: 1. Fleet size, 2. Daily production (tonnes), 3. Average truck utilisation (%), and 4. Transportation cost ($/tonne). In addition, total cost savings for an annual freight task of 900,00 tonnes were calculated by operational factor. The results presented in the next section illustrate the findings derived from this data.

3 Results

This section reports on the outcomes produced for the encoded of values described in the previous section and identifies some strategies which may be grounded in an actual system for their actual derivation. Although the results are optimistic – as a result of the level of abstraction employed in the software – they are interpreted as aspirational for our current intended use of the software – as a way of beginning a discourse on the identification of scheduling optimisations in order to derive cost savings.

3.1 Impact of Reduced Chipper Utilisation

Table 1 shows the effects of reduced chipper utilisation. In each case the chipper was scheduled for 10 hours. There was a strong increase in the number of trucks (29%) required when the chipper utilisation was increased from 75% to 90%. This was a consequence of the productive working times associated, which are 450 min (7 truck arrivals), 510 min (8 truck arrivals), and 540 min (9 truck arrivals), for a chipper utilisation of 75%, 85%, and 90%, respectively. Due to the increased number of arrivals with 90% chipper utilisation, there was a substantial impact on the number of trucks required for the operation, which in turn increased the transportation cost per ton of chips. Conversely, savings of around $1/tonne were found for the chipper when its utilisation increased from 75% to 90%.

Table 1: Effect of chipper utilization

Performance metrics	**Chipper utilization**		
	75%	85%	90%*
Fleet size (number of trucks)	20	24	28
Unit cost ($/tonne)	9.49	9.71	9.90
Daily production (tonne)	2,800	3,200	3,600
Average truck utilization (%)	88.3	87.6	86.4

*Control scenario

3.2 Impact of Increased Dispatching Restrictions

Table 2 shows the effects of restricting the number of in-field chipping operations an individual truck could service. There was a 7% reduction in the number of trucks required for the operation when multiple chipping operations were available to service. Given that the two dumpers are in the same geographical location, the running loaded percentage was always 50% as there was no possibility for backhauling in the scenario examined. Thus, the transport cost reduction attributed to multiple destinations was around 3%.

Table 2: Effect of the number of operations available to service by each truck

Performance metrics	Number of in-field chipping operations available to service		
	1	2	Multiple*
Fleet size (number of trucks)	30	29	28
Unit cost ($/tonne)	10.16	10.03	9.90
Daily production (tonne)	3,600	3,600	3,600
Average truck utilization (%)	87.9	87.0	86.4

*Control scenario

3.3 Impact of Increased Loading Times

Table 3 shows the effects of loading time changes. Increasing the loading time from 50 min/truck to 60 min/truck resulted in an increased cost of around $0.39 per tonne. A further rise in loading time from 60 min/truck to 70 min/truck resulted in a reduced cost per tonne (compared to 60 min loading time) due to the substantial reduction in the fleet size. Loading time also had a direct effect on the number of daily truck arrivals (10 with 50 min/truck, 9 with 60 min/truck, and 7 with 70 min/truck) and number of trucks required for the operation. Consequently, the daily production was reduced by about 30% when loading time increases from 50 min/truck to 70 min/truck.

Table 3: Effect of Effect of loading time

Performance metrics	Loading time		
	50 min/truck	60 min/truck*	70 min/truck
Fleet size (number of trucks)	29	28	21
Unit cost ($/tonne)	9.54	9.90	9.73
Daily production (tonne)	4,000	3,600	2,800
Average truck utilisation (%)	87.7	86.4	88.2

*Control scenario

3.4 Impact of net payload

Table 4 shows the effects of increasing net payload for trucks. Assuming the same loading time, there was no substantial effect observed on fleet size when net payload increased from 47 to 53 tonnes/truck. If that is not the case, the advantages of hauling bigger payloads (i.e. chips) might be offset by the extra time required to load the trucks. Increasing payload from 47 to 53 tonnes had the largest single impact on transportation cost per tonne (more than $1.1/tonne) and daily production (432 tonnes).

Table 4: Effect of net payload

Performance metrics	Net payload		
	47 tonne/truck	50 tonne/truck*	53 tonne/truck
Fleet size (number of trucks)	28	28	28
Unit cost ($/tonne)	10.53	9.90	9.34
Daily production (tonne)	3,384	3,600	3,816
Average truck utilization (%)	86.4	86.4	86.4

*Control scenario

3.5 Annual Cost Savings

If we extrapolate the above results to the notional scenario of a freight task of 900,000 tonnes, which corresponds to the volume hauled by one forest company in Western Australia, some interesting findings arise. The total savings resulting from a better control of the operational factor estimated in this study would be in excess of two million dollars. More than 50% of these savings are to be explained by the increase in payload. Moreover, notionally increasing the payload from 47 tonnes to 53 tonnes, would result in a reduction in transportation costs of around $1.2 per tonne which translates to an estimated value $1,080,000 per year for an annual volume of 900,000 tonnes. These results are consistent with those obtained in previous studies carried out by the Cooperative Research Centre (CRC) for Forestry (Brown 2008).

The second major operational factor is chipper utilisation. Increasing chipper utilisation from 75% to 90% would represent a slight increase in transportation costs of around 4%, but would also result in a drop in chipping costs from improved chipper utilisation. Through increased chipper utilisation it is estimated that an overall saving of approximately $600 000 could be made annually for the operation presented in above case study.

Overall the findings suggest that it is worthwhile continuing to develop FastTRUCK as a way to identify cost savings, and thus, improvements in transport efficiency. Although the limitations on experimentation in a limited case study are apparent, in the future it will be necessary to explore the solution space more broadly.

4 Conclusions and further work

This section reports on the outcomes produced for the encoded of values described in the previous sections. This paper has introduced the concept of optimization of truck schedules for the purpose of improving transport efficiency in forestry supply chains for the Australian forestry industry. A case study in the Australian forestry industry was explored using a customized software tool which implements an optimization algorithm, based on simulated annealing, for the intent of finding optimizations in truck schedules.

Through expert interviews, a domain model was synthesized and encoded into the software and a simulated annealing algorithm adapted for the derivation of an optimized schedule. This encoding was presented as an initial form of validation in order to illustrate its adaptation to this specific problem. Based on an optimized schedule, derived from the software, some cost savings were identified, for example, as a result of increased truck utilization. The results are interesting when applied to a broader yearly operational plan for an actual forestry company in Western Australia.

The results in the evaluated case study are promising, and demand further work to ensure their realization in the forestry industry for Australia. To this end, we realize that they are based on a limited domain model, algorithm, and data set, and therefore we are actively exploring ways of improving predictive accuracy and translatability. To this end, we are considering: a generalized domain model and algorithm; a more extensible "second version" of FastTRUCK; in addition to field trials which will involve software derived forecasts compared against expert human scheduler forecasts for validation purposes.

Overall, this research illustrates through the use of a software based approach to schedule optimization, information can be derived that can inform on the efficiency of forestry truck scheduling operations, and if applied, lead to cost savings for the Australian industry.

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