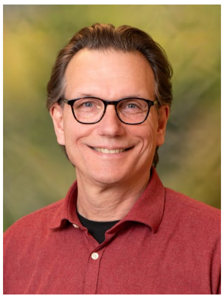
A new payment model for forest transports



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Abstract

The truck cost of transporting between two points is influenced by various factors, including direct costs such as driving time and fuel consumption, as well as indirect costs like maintenance, service, capital expenses, and depreciation. However, remuneration is typically determined by simpler agreements, often based on the loaded driving distance. While these standard agreements can accurately reflect the average cost across numerous transports, they may not adequately represent the cost of individual trips. This paper introduces a pricing model for truck transportation that enhances traditional distance-based models. The new model incorporates a measure of cost-driving factors along the route, such as hills, curves, intersections, speed changes, and steep ascents, which contribute to the physical difficulty of the journey. This measure is derived from the Calibrated Route Finder (CRF), a route selection support system used for roundwood transportation in Sweden. The proposed pricing model, which combines both distance and a resistance measure, provides a more accurate alignment between remuneration and the true cost of transportation compared to a model that focuses solely on distance. The model has been tested using a dataset of detailed transport from a major forest company.

Keywords: Transport, Tariffs, Routing

1. Introduction

Forestry transport takes place in many various transport environments. Around the year, timber trucks drive on low-quality forest roads, special timber trails in forests, county roads, national roads, motorways and in urban environments. Each year in Sweden, two million transports take place, with 75 million tons of roundwood, wood chips, and forest fuel and an average transport distance of 91 kilometers. Transport takes place from just over 200,000 new felling places to over 1000 industries annually. Forestry accounts for 18% of commercial road transportation work, which uses roughly 170 million liters of diesel.

In practical routing and transport, it is important to secure the contractual agreement for payment between the transportation service company owner and the client who agrees to use the services. Also, every aspect of transport management and service payment assumes an efficient route choice between forest and industry. Loaded distance is the most common agreement. Typically, a linear function

$$c(d) = a_1 + a_2 d, \qquad (1)$$

where $c(d)$ is the unit price for each ton transported between two points with a distance d, and where a_1 and a_2 are negotiated parameter values between the organisations. We assume full truck loads as this is the most common transport in natural resources. Although negotiated agreements can provide an acceptable representation of total average costs, the loaded distance poorly represents the actual cost of routes that have different transport environments. For example, one route may take a motorway for 120 km, and another uses low quality private roads for 60 km. The time and fuel consumption may be similar, but the payment is very different (factor of two) as the same linear function is used.

Companies typically have a set of ad hoc compensation rules that can be applied as a complement, e.g., an additional monetary compensation if the truck operates in a hilly area with increased average fuel consumption. Such rules work well on average but again cannot give a detailed description for a single route which is needed when routes are used in collaboration with another company. A challenge is therefore to identify a transparent, simple and easy to use from an administration point of view. In this paper, we aim to use a quantitative measure based on the weighted objective and its relation to the actual cost.

Today there exist standards to define the distance or best route used based on multiple objectives. The system Calibrated route finder (CRF) is used as a standard in Swedish forestry (Rönnqvist et al., 2017). It is managed by Biometria (biometria.se), which is an independent logistic and information hub for Swedish forestry. The weighted multi-objective provides information for finding the best route and distance given as CRF points. However, this quantitative measure from the weighted objective does not necessarily represent the actual cost of the route as there are parts, e.g. regulations, safety and stress, which are not cost drivers. Hence, using CRF points is not suitable as it does not provide any description of the real “difficulty” (quantitative measure from weighted objective) of the individual route.

We provide an illustrative example. Figure 1 has four routes (denoted A, B, C and D) that start in four different harvest areas but end at the same mill. The four routes have a similar distance and the standard distance-based payment function; the base remuneration is the same.

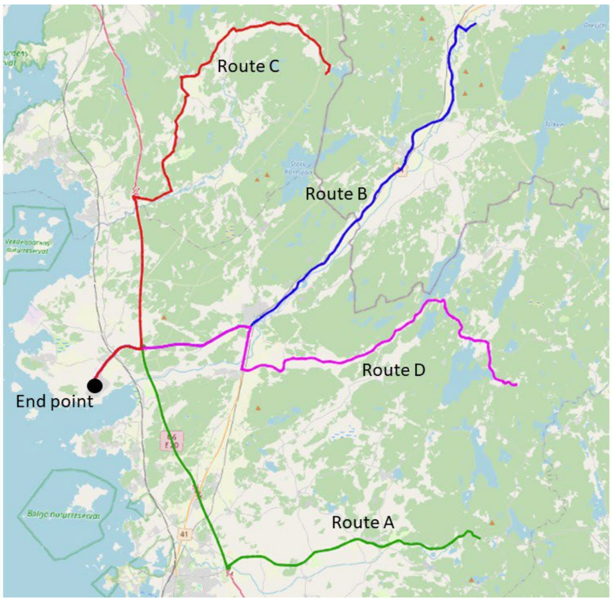

Figure 1. Illustration of four routes with different starting points but the same end point and similar route distances.

Table 1 provides key characteristics of the four routes. Trucks stop at road crossings because of a stop sign or yield sign. CRF points are the weighted objective used in CRF to find the best-practice route. CRF points demonstrate a basic understanding of the complexity of managing the many objectives of the route. Clearly, route A can be considered easier because route time is lower. The fuel consumption depends on many factors, for example, vertical elevation, stops, and speed. All routes have diffeent characteristics and costs but the payment is the same due to the same distance. This unfairness in payment has been acknowledged by the parties operating these routes.

Table 1. Selected characteristics of four routes in the illustrative example with a specific selection of parameter values a_1 and a_2 for remuneration.

	Route A	Route B	Route C	Route D
Route distance (km)	35.76	36.07	36.38	36.41
Distance on forest roads (km)	2.00	1.95	2.22	2.33
Route time (min)	34.22	35.46	43.38	40.55
Fuel consumption (l)	22.15	21.11	27.76	24.47
Number of crossings with stops	9	12	15	13
CRF scaled points	674	702	885	848
Load (tons)	44	44	44	44
Current distance model (SEK), c	2 866	2 879	2 893	2 894

From the example, the current remuneration neither represents the actual cost nor is fair. We propose a new payment model where the CRF system is used to define the route and where we use selected CRF points and distance as a basis for computing a new price modeling. We demonstrate its usefulness on an illustrative case and detailed analyses on routes provided by one of the largest forest companies in Sweden.

2. Materials and Methods

2.1 Calibrated Route Finder

The CRF online system relies on a set of servers to provide real-time information about routes and their characteristics. On a typical day, approximately 20,000 server requests are processed. The base servers manage a network composed of arcs and nodes, where arcs represent different road segments and nodes signify intersections or changes in road features or attributes (such as speed limits). Many road features are categorized into subclasses, see Table 2. For instance, road features include functional road classes and speed limits. In Sweden, roads are classified from RC0 to RC9, with RC0 indicating European motorways and RC9 representing lower-quality forest roads. RC7-9 specifically categorizes private forest roads. Similarly, speed limits range from 20 to 120 km/h, encompassing 12 different limits. In total, the network incorporates 108 attributes as provided in Table 2. Here, we also indicate what type of weight is used and if the attribute is considered as a cost driver. To determine the optimal route, a scalar weight is assigned to each attribute to balance them, as they cannot be directly converted into a common unit (e.g., monetary values). These weights are then used to compute an aggregated arc cost (without unit measure). Finding the shortest or minimum cost route is efficiently accomplished using variations of Dijkstra's algorithm.

Table 2. Road features used in CRF and their main characteristics.

Road feature	No. subclasses or weights	CRF weight (either weight, bonus, or penalty)	Cost driver
Functional road class	10	Weight	Yes
Owner	3	Weight	Yes
Bearing class	4	Weight, Penalty	Yes
Curvature	30	Weight	Yes
Hilliness	20	Weight	Yes
Terrain class	5	Weight, Penalty	Yes
Speed limit	12	Weight	Yes
Road width	16	Weight	Yes
Passing route	3	Bonus	Yes
Timber route	2	Bonus	Yes
Approach route	2	Bonus	Yes
Availability	1	Penalty	No
Ferry line	1	Penalty	No
Prohibited bridge	1	Penalty	No
Limited axis pressure	1	Penalty	No
Limited total weight	1	Penalty	No
Prohibited transport	1	Penalty	No

The network model in CRF uses an expanded network. This network includes turns and crossings with respect to possibility and permissibility to turn. Currently, no road feature or attribute with a weight in CRF for different turning options in different types of crossings is available. Since crossings involve braking and acceleration with increased fuel consumption and waiting times for cost drivers, a contribution for these aspects must be included.

Different methods can determine weights in multi-objective planning problems. In the CRF system, weights are determined using an inverse optimization approach. In the first phase, best-practice routes are identified. Approximately 1,600 routes are chosen by forest companies and transporters to define optimal routes between start and end points (e.g., harvest areas and mills). These routes are reviewed and updated annually. The second phase involves solving an inverse optimization problem to ensure that these 1,600 routes are optimal or near-optimal in the network representation. Legal considerations, such as restrictions on certain bridges or terrain, are handled by imposing significant penalties to identify and select routes where no alternatives exist (e.g., routes with forbidden bearing classes). All weights are used to compute arc cost coefficients in the network formulation for route calculation, employing the Dijkstra algorithm to determine the minimum cost route between general start and end points. Annually, around two million transportation routes are utilized. In the network, the objective of a route, derived from the weighted objective function, is termed resistance or CRF points. These points offer a relative measure of the difficulty associated with covering the routes.

2.2 SkogforskCalc

SkogforskCalc (SFCalc) is a system developed by Skogforsk, the Forestry Research Institute of Sweden, designed to estimate the total execution cost of specific transportation modes. The system calculates two main cost components:

1. *Running Costs*: These include expenses related to fuel, wear and tear, and other factors.
2. *Fixed Costs*: These cover the transportation's share of fixed expenses such as capital costs, salaries, new equipment, tires, insurance, and overheads. Fixed costs are calculated on an annual basis.

SFCalc estimates running costs using a statistical model that predicts time and fuel consumption. The route is divided into short segments with constant road features (e.g., speed limits and curvature). Time and fuel consumption for each segment are determined using a lookup table that was created based on statistical analysis of driving patterns from timber trucks. Data was collected via CAN-bus logging from 20 trucks over a year, providing a higher resolution than standard fleet management systems (1 Hz). This data was matched with road features from the NVDB (the National Road Data Base, administered by Swedish Transport Administration) for binning purposes. The lookup table is divided into three distinct sub-tables:

1. *Arc Table*: This table includes lookup entries for various road features such as road class, curvure, hilliness, surface, load status, speed, and whether the route is intra- or extra-urban. It encompasses 120,000 possible combinations and records speed (km/h) and fuel consumption (l/km) for each combination.
2. *Crossing and Node Behavior Table*: This table covers all possible crossing scenarios. Key factors include the road class approaching the crossing, the highest road class at the crossing, and the type of maneuver (e.g., left or right turns, through traffic). Factors such as speed limits and road class changes at the crossing are also considered. This table includes 230,400 combinations.
3. *Speed Limit Change Table*: This table details the impact of speed limit changes on fuel consumption. When the speed limit increases, fuel consumption temporarily rises before stabilizing; conversely, fuel consumption decreases when the speed limit drops. It includes 2,560 combinations based on changes in speed limits, road class, and load status.

Given that some road feature combinations are rare, a large amount of driving data is needed for a comprehensive and statistically significant database. When data for rare combinations is unavailable, a smoothing approach is used, employing adjacent bins to complete the lookup table.

Fixed costs are calculated using a model developed by Skogforsk (Johansson and von Hofsten, 2017), based on vehicle list prices, estimated depreciation rates, average salaries, and similar factors. Since SFCalc evaluates the potential of a suggested pricing model, the cost estimator does not need to reflect the exact costs of any specific company. The SFCalc model provides an estimated route execution cost, including an average contribution to external factors such as return haulage percentage and a margin for unaccounted costs. The model is calibrated against registered and invoiced costs for all transports, normalizing for the cost levels of selected transports.

2.3 New payment model

The proposed price model, based on the previously described *c(d)* function, can now be extended

$$p(d,r) = a_1 + a_2 d + a_3 \cdot r \quad (2)$$

The new term, $a_3 \cdot r$, is expressed as generic points. The number of points, *r*, assigned to a given route can be determined using different methods. We have chosen two approaches: one based on the current CRF objective function value and another modified version that incorporates additional features not included in the current CRF model.

Approach 1 – *crf1*: This approach calculates the original CRF points, referred to as "cost drivers" in Table 2, based on their proposed use for the specific route. This gives us the value of *crf1*.

Approach 2 – *crf2*: This approach expands upon the first by including terms that represent the cost associated with crossings and changes in speed limits. It involves the following steps:

1. Start with the value of *crf1* from Approach 1.
2. Compute the total fuel consumption and route time without accounting for crossings, speed changes, and steep ascents.
3. Calculate the additional fuel consumption and route time associated with crossings and speed changes, using the lookup table for arcs and nodes in SFCalc.

The additional time and fuel consumption are used to adjust the total number of points. For instance, if a route has *crf1*=1000 points, and the crossings, speed changes, and ascents increase the weighted time and fuel consumption by 7%, the modified number of points is calculated by applying a factor of 1.07. Thus, *crf2* would be 1070 points.

Parameters a_1, a_2, and a_3 are part of the business contract. When changing to a new pricing model, it should not bring about a drift in the average remunerations. Parameters in the suggested pricing model are ultimately subject to negotiations, but it is possible to "translate" the old pricing model to the new model. When applied to last year's transports, for example, the average remuneration remains unaffected while remuneration at the route level reflects the actual execution cost as highly as possible. One way of mathematically formulating this is through a least square optimization problem. The objective function is to minimize the squared difference between the modelled price per kilometer and the actual cost per kilometer. We add a constraint that the total cost of the new model equals the actual costs.

2.4 Illustrative example

We can now revisit the illustrative example. Table 3 gives the computation of the *crf1* and *crf2* points. The table includes the original CRF route evaluation with original points, fuel consumption, and route time. We add each of the contributions as described in Approach 2.

Table 3. Information of added time and fuel due to crossings, change of speed and long ascents. Included is also the factor and *crf2*.

	Route A	Route B	Route C	Route D
Distance (km)	35.76	36.07	36.38	36.41
Original time (min)	34.22	35.46	43.38	40.55
Original fuel (l)	22.15	21.11	27.76	24.47
CRF scaled points (*crf1*)	674	702	885	848
CRF2 scaled points (*crf2*)	660	719	1 021	905
Number of crossings with stops	9	12	15	13
Number of speed changes	14	17	8	10
Number of meters up	237	142	221	197
Number of meters down	316	160	311	278
Total added time (min)	1.27	1.95	7.98	3.55
Total added fuel (l)	0.66	1.75	4.77	2.91
Factor (*crf2/crf1*)	0.98	1.02	1.15	1.07

We have computed coefficients a_1, a_2, and a_3 ($a_1=23.27$, $a_2=0.59$, and $a_3=0.20$) for a representative case when these four routes are included. Results are provided in Table 4. We have results from three different payment models denoted T_0, T_1 and T_2. The T_0 pricing model based on distance only performs poorly to describe the actual cost. The T_1 is based on only CRF2 points, and T_2 with distance and CRF2 points. Clearly T_2 has values closer to SFCalc.

Table 4. Characteristics of four routes in the illustrative example with specific parameter values for the remuneration of SFCAlc, actually payment, and the three different pricing models. The relative columns show the price model value in relation to the SFCalc cost.

Remuneration	Route A		Route B		Route C		Route D	
SFCalc (SEK)	2 751	--	2 682	--	3 073	--	2 901	--
T_0	2 866	104.2%	2 879	107.3%	2 893	94.1%	2 894	99.7%
T_1	2 520	91.6%	2 665	99.4%	3 415	111.1%	3 127	107.8%
T_2	2 698	98.1%	2 761	102.9%	3 050	99.3%	2 943	101.4%

3. Results

The case study is based on detailed routes provided by one of the largest forest companies in Sweden. The transport manager provided 35 routes that were subjectively viewed as “easy,” “medium,” and “difficult”. For each route, we have distance and payment according to existing pricing model. The total cost of the routes was SEK 133,753. Also, the *crf1* and *crf2* points as well as the estimated execution costs per SFCalc were calculated. From this input, payment model parameters for the company were calculated using the least square model, and these are given in Table 5. These routes were then analyzed according to the current distance system and the proposed T_2 system with a combination of distance and *crf2* points to have a detailed qualitative analysis.

Table 5. Found parameter values for the three remuneration alternatives.

Remuneration	a_1	a_2	a_3
T_0	28.25	0.92	
T_1	18.82		0.53
T_2	23.27	0.59	0.20

The current price model based on distance provided a scattered distribution; the objective function value from the least square problem (Table 6) can be considerably reduced with T_2. Standard deviation of the measured deviation is reduced considerably with T_2, clearly indicating that payment using T_2 is closer to SFCalc in contrast to T_0. Figure 2 provides an SFCalc cost illustration, normalized to 1.0, as well as the existing T_0 and proposed T_2 pricing models. The company said that the proposed price model better described the real difficulty of transports, stating it provided a fairer distribution. It also said they had no reason to include special agreements to compensate for inequalities related to route properties.

Table 6. Objective function *z* from the least squares problem, standard deviation, and min and max deviation from SFCalc for price models using distance (T_0) and distance and CRF2 points (T_2).

T_0				T_4			
z (SEK)	St. dev (SEK)	min and max relative cost (%)		*z* (SEK)	St.dev (SEK)	min and max relative cost (%)	
968.42	166.3	85.5	111.2	161.54	67.9	95.4	105.2

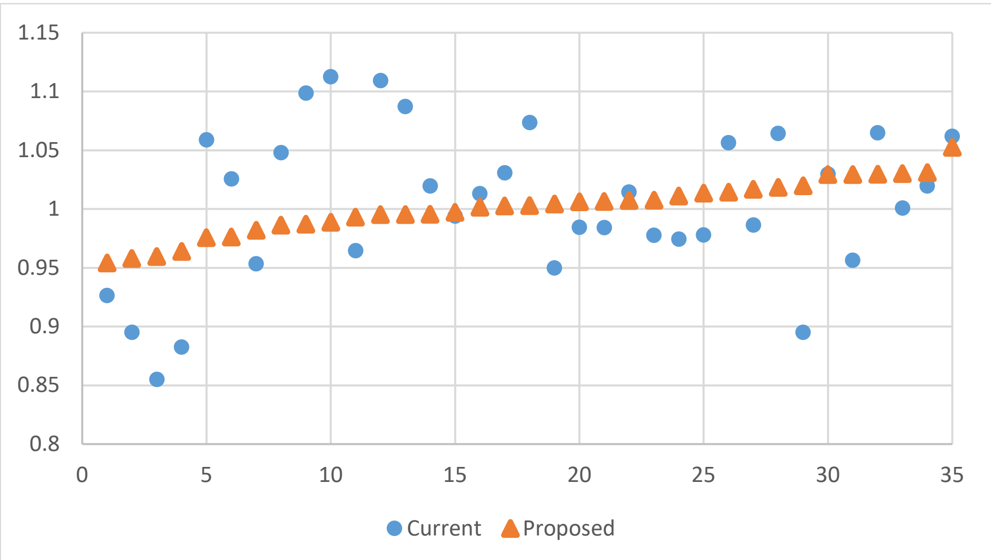

Figure 2. Cost difference distribution of all transports using T_0 (blue dots) and T_2 (orange triangles) compared to SFCalc. The routes are sorted in increasing T_2 cost.

4. Concluding remarks

We have introduced a new transparent and fair transport pricing model that integrates traditional distance measurements with a quantitative point system to describe the difficulty of a route. This model builds on best-practice routing, which accounts for over 80% of all distance calculations across Sweden. This routing considers not only cost but also other non-cost factors such as stress and safety. We have identified and selected components of this objective function as "cost drivers." Additionally, we have included supplementary elements that account for extra costs related to crossings, speed changes, and steep slopes, which are not currently addressed by the existing routing system.

The proposed model was evaluated in collaboration with a transport manager from a large forestry company. The evaluations demonstrated that the new pricing model effectively redistributes overall payments based on the perceived difficulty of transport tasks. The results and experiences were presented to the committee responsible for managing and developing the CRF system at Biometria. The committee decided to fully implement the new pricing model. Consequently, companies will be able to use either the new model, the old model, or a customized combination of both. It is advisable to thoroughly examine a company's diverse cost components during the transition to the new pricing model to ensure accurate cost estimates.

5. References

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