DEVELOPMENT AND IMPLEMENTATION OF NEW FEATURES IN A ROUTE SELECTION AND DISTANCE MEASUREMENT SYSTEM

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Abstract

In Sweden, road transport payments in the forestry sector are based on the distance driven. Since 2010, the Calibrated Route Finder system has been in practice, a system developed jointly within the forestry sector. A number of road features and weights for road attributes are used to establish the preferred route and distance between landings in the forest and mills or terminals. To find accurate weights, between forest and haulage companies, best practice 'key-routes' are used as the optimal solutions to define an inverse optimisation problem where the unknown weights are variables. The system uses road data from the Swedish national road data base.

Deviation reports over time from forest and haulage companies have indicated certain areas that need improvement. Examples are curvature, topography, and stop and start in junctions, all of which increase both time and fuel consumption. Other problems that arise are geometrically impossible or illegal turns in the network. Improving the system is essential for accurate distance measurement and for the credibility of the system.

Keywords: Calibrated Route Finder, Key Routes, Forest Road Transport, Optimisation, Road Feature, NVDB, Curvature, Topography, Junction

1. Introduction

Finding the most efficient route from the landing in the forest to the delivery point at mill or terminal requires many decisions. There are a number of objectives to balance, e.g. distance, time, fuel consumption, topography, road safety and working environment (Figure 1). Also, establishing the correct travelled distance is important because distance (km), together with payload (tonnes or m^3sub, solid under bark), forms the basis of payment to the haulage company. Therefore, the route selection must be agreed between the haulage and the forest company ordering the transport.

Figure 1. Finding the most efficient route from landing to mill is a matter of balancing several objectives, some of which are shown in the illustration.

Historically, forest companies have used a number of different ways of measuring travelling distance. This lack of standard procedures caused problems for haulage companies working for different forest companies because an identical assignment could be paid differently depending on customer. The distance was also often determined manually, leading to unnecessary administration and possible errors.

Since the first pilot project in 2009, a system called Calibrated Route Finder (CRF) has been in operation in Sweden. CRF is owned and administrated by SDC, the IT company of the forest industry. SDC manages and administers forestry data and acts as an independent organisation, ensuring that accurate information is used in invoicing between forest and haulage companies. CRF was developed as a joint project by SDC, Skogforsk (The Forestry Research Institute of Sweden) and forest companies in order to improve uniformity for payment, but also to establish a transparent, automatic and objective distance measurement and routing system on which all stakeholders could agree.

A prerequisite for the development of CRF was the emergence of NVDB, the National Road Data Base administrated by the Swedish Road Administration, which came into use in the 1990s. NVDB contains road feature and attribute information about all roads in Sweden (Swedish Road Administration 2008). CRF has been developed over the years, incorporating an increasing number of road features described in NVDB.

Table 1 shows the road management structure in Sweden. Swedish roads are categorised into functional road classes, on the basis of a road's importance in facilitating connections within the entire national network. Public roads are typically categorised into classes 0-6, where classes 0 and 1 represent key European highways, classes 3-5 are rural main roads and class 6 often comprises urban roads. Low-volume private roads are typically categorised into classes 7-9 and account for more than 80% of the national road network (Flisberg et al. 2012). Road classes 8-9 are mostly roads constructed for forestry activities.

Table 1. NVDB, the Swedish National Road Data Base contains road feature and attribute information about all roads in Sweden.

Roads managed by:	km
Government	102 000
Local authorities	56 000
Private owners	384 000
(of which forest roads	240 000)
Total	542 000

2. System design

An important component and first step in the design of CRF were the 'key routes', 1500 routes, evenly spread over Sweden. The key routes are negotiated between forest and haulage companies, and provide examples of which route should be chosen from landing to mill (Figure 2). By representing best practise in finding the most efficient route, the key routes capture the objectives presented above.

Figure 2. Roads used by the 1500 'key routes', evenly spread over Sweden represent best practice in finding the most efficient route from landing to recipient point.

The next step in the design of CRF is to assign weights to different road features available in the NVDB. In the weight setting, the key routes are crucial; they capture the objectives presented earlier, and they can be described by road features (Figure 3). The weights are derived through an inverse optimisation process where the key routes act as the optimal solutions. The goal of this inverse optimisation problem is to find as many of the key routes as possible as the solutions to a minimum-cost route problem, where the weights are used to define the arc costs in a general network. These will then reflect the general objectives addressed. Some objectives can be described in the attributes measured, such as distance, whereas other are not, for example, stress. In total, 107 unknown weights for attributes in 13 road feature classes must be determined. Even deciding two weights for different objectives can be difficult.

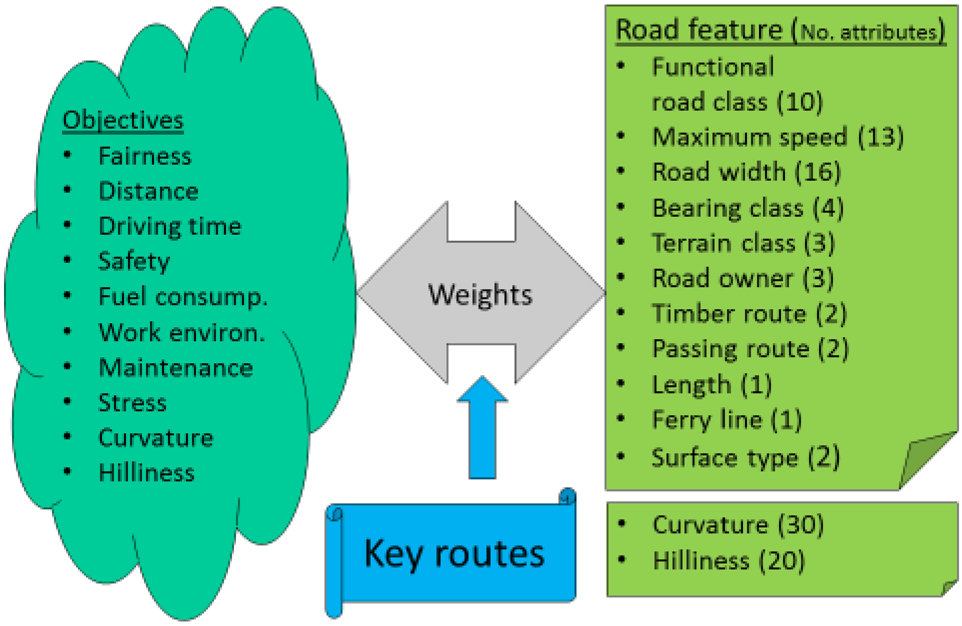

Figure 3. The key routes are essential in establishing weights for the different road features used to capture the route selection objectives.

Not all road feature information needed in CRF (Figure 3) is explicitly available in NVDB. For curvature and hilliness, coordinate data in NVDB (x, y and z) was used to derive measures for how topography affects travelling time and fuel consumption of logging trucks (Svenson et al. 2016). For curvature, maximum travelling speed for negotiating curves was estimated, and deceleration and acceleration in relation to curves was calculated (Figure 4). The difference in driving time between a curved and straight road section was used to distinguish different levels. Each of these levels becomes an attribute in the subsequent weight setting.

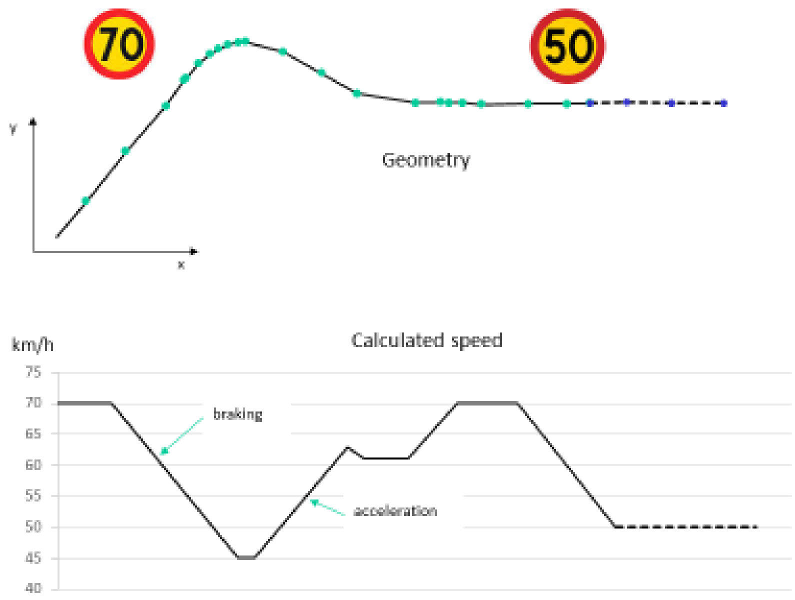

Figure 4. The effect of curvature on travelling speed (lower diagram) for the logging truck is calculated on the basis of x and y coordinates (green dots, upper diagram) to describe road geometry in the National Road Data Base.

To establish a value that describes the resistance to driving along roads with hills, we assumed that this was strongly correlated to the increased fuel consumption. This was also supported by interviews with truck drivers. We used a combination of previous work on developing the European models HeavyRoute and Artemis and combined it with detailed fuel consumption data from a forest logging truck. We then made a linear approximation to establish a customised curve for 60-tonne logging trucks running on Swedish roads. The different models are compared in Table 2.

Table 2: Relative fuel consumption for different gradients in HeavyRoute and Artemis models and the gradient factors used in this study, together with proportion of roads in Sweden.

Gradient (%)	HeavyRoute	Artemis	Our factor	Proportion of roads (%)
- -6	0.11	0.4153	- 0.4	6.60
-6 - -4	0.11	0.4153	0.4 - 0.5	5.43
-4 - -2	0.19	0.5555	0.5 - 0.7	10.13
-2 - 0	0.41	0.7603	0.7 - 1.0	21.46
0 - 2	1	1	1.0 - 2.34	30.71
2 - 4	1.84	1.2664	2.34 - 3.67	10.61
4 - 6	2.75	1.5447	3.67 - 5.01	6.00
6 -	3.70	1.8566	5.01 -	8.20

Finally, the established weights for all road features on a certain network arc (4.4 million arcs in the network representing Sweden) are added together and then multiplied by the length of that arc. The result of this calculation comprises a measure of the relative resistance if the system uses this arc. Once we know all arc costs, the CRF network is ready to be used to find any distance between a start and end point of the network. It is worth noting that these points do not need to be nodes in the network but can be any point projected down to the closest point to any road.

3. CRF compared to shortest and fastest path

The use of weights for a large number of road features enables fine tuning of the best route from a large number of possible route alternatives. Commercial route selection devices also use weights, for example road section length or posted speed limit, but lack most of the resolution and complexity inherent in CRF. Figure 5 shows a number of alternative routes from a landing (the triangle in the southeast) to a mill (the star in the northwest). The black route is the shortest path, and the green route is the fastest. Red routes are generated by using different weight settings in CRF, and the green route represents the current weight setting in CRF, KV3.1. The shortest and fastest paths are both shorter and faster than the CRF route (see Table 3), but the reason for not using either of them is seen in the other road features; the amount of curvature, hilliness and gravel road is much lower for the CRF route, which would reduce, for example, fuel consumption in litres/100 km. The route is mainly on roads that are wider and of higher class, improving both road safety and the working environment. The overall quality improvement in route selection can be seen in the lower total resistance.

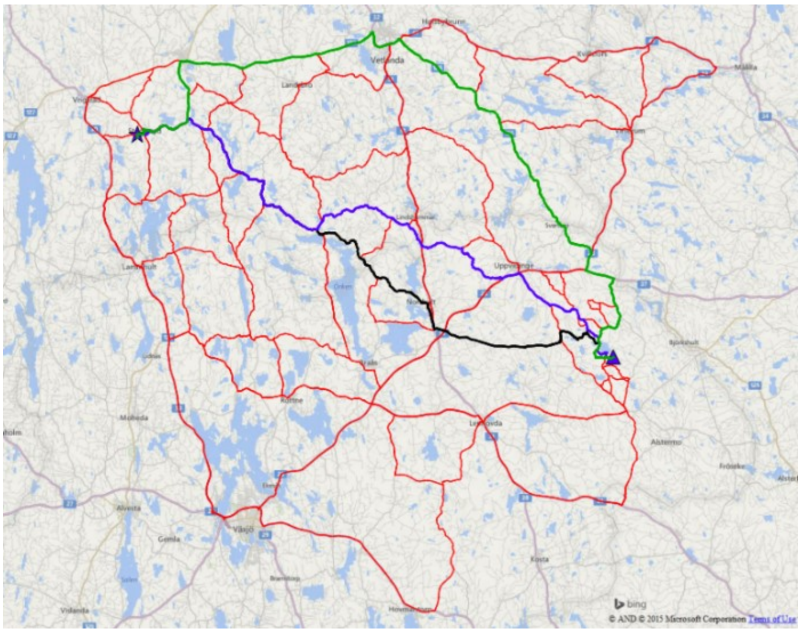

Figure 5. Different route alternatives depending on weight setting principles. Black is the shortest path, blue is the fastest. Red and green are CRF routes for different weight settings, where green represents the current setting.

Table 3. The CRF route improves the quality of the route selection compared to the shortest or fastest paths. A longer and slower route by CRF is compensated by less driving on lower-class roads.

Feature	Shortest path	Fastest path	CRF
Distance (km)	84.3	85.8	105.6
Total resistance (points)	2094	2407	1492
Time (min)	74.7	72.6	87.1
Curvature (points)	161	190	55
Hilliness (points)	74	36	3
Road width 3-3.5m (km)	8	19	0
Gravel road (km)	20	33	9
Road class 0-3 (km)	1	2	74
Road class 4-6 (km)	71	56	20
Road class 7-9 (km)	13	27	10

4. System improvement

The experiences of the system users, such as the driver or a transport manager, sometimes suggest that some routes are not the best. In these cases, a deviation report can be submitted to VMF, the impartial Swedish timber measurement organisation. There may be a number of reasons for the deviation, such as data quality, road contruction or road maintenance. Sometimes the deviation reports indicate where improvements are needed in the system. One earlier example was deviations regarding hilly and curved sections of a suggested route that the users wanted to avoid due to increased time and fuel consumption, as well as road safety aspects (Figure 6).

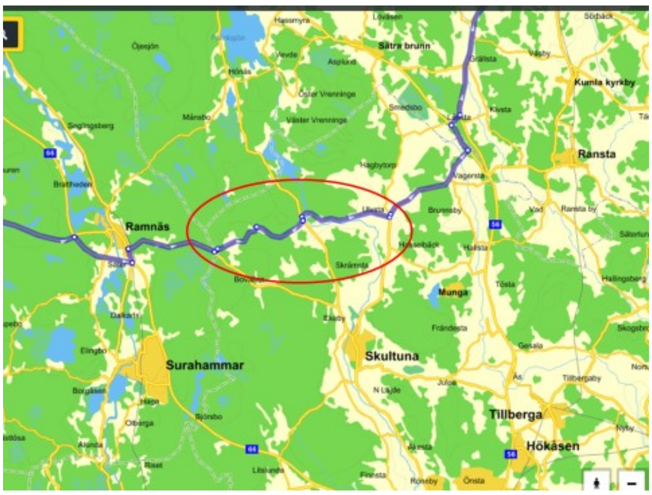

Figure 6. Example of a deviation report where a user of CRF feels that the suggested route is not suitable, in this case due to a high degree of curvature and hilliness.

In Figure 7, different versions of weight settings in CRF applied on the key routes are compared to the length of the 1500 key routes, whose length is normalised to 1. The shortest and fastest paths are also presented. Even the 2009 weight setting was successful in obtaining the same length as the key routes for many routes, and the improved 2015 weight setting is even better. The average distance of deviant routes is close to zero. It is also clear that neither the shortest nor the fastest path is the desired route in these examples. One explanation of this is that CRF considers many more important objectives than the shortest or fastest path.

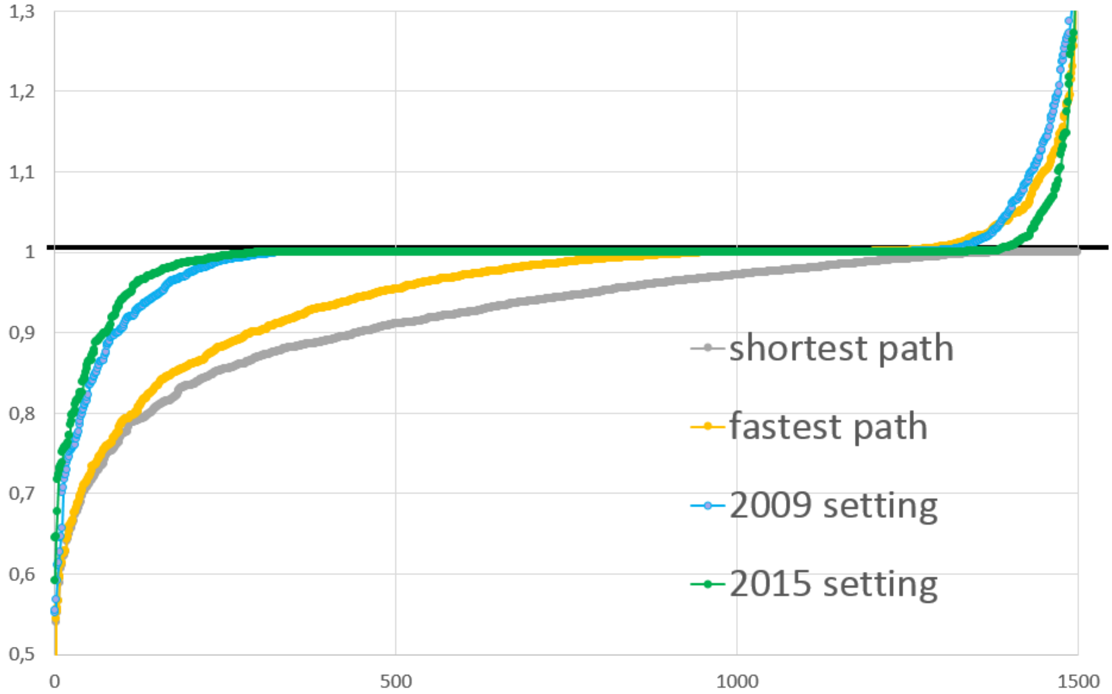

Figure 7. Key routes on the x axis, length (y axis) normalised to 1, compared to different weight settings. The shortest and fastest paths are normally shorter than the key routes. The 2015 weight setting corresponds better to the key routes than the 2009 weight setting.

5. System usage

When CRF is used in practical operation, the system, hosted by SDC, is retrieved from either a web solution or from a company system integrated with SDC. When start and end coordinates are provided, for example representing the landing in the forest and the delivery point, CRF finds the combination of arcs that minimises the total number of (resistance) points. The length of the route is measured, and the route can be visualised on a screen, also in the cab of the truck if a screen is available.

The first pilot projects, involving a limited number of forest companies, started in 2009. Since then an increasing number of companies have joined the system and, today, most forest companies are using the system (Figure 8). Fifty percent of the invoiced distances are currently directly based on CRF, but the system is also indirectly involved in a number of other measurements used in decision support.

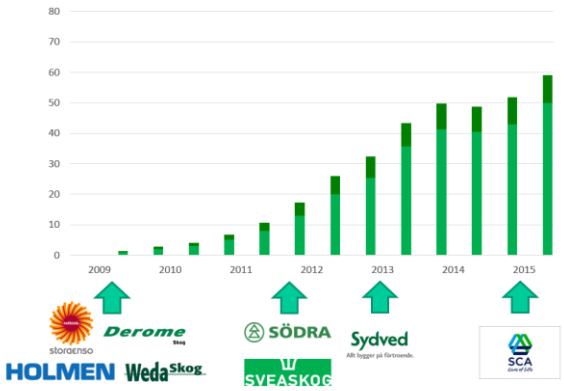

Figure 8. Since the start of the system, a number of companies have joined, and use has increased over time. Light green is confirmed usage as distance measurement, dark green is an educated guess.

6. Further development

Deviation reports have initiated the current work to improve the system with regard to narrow roads and impossible and/or illegal turns. We are also analysing the effect on route selection if deceleration, stopping, waiting and acceleration related to different kind of junctions, which increase fuel and time consumption, are included in the system (Figure 9). A prerequsisite for this is an expansion of the number of nodes and arcs to transform the current network into an augmented network. Unlike the current network, this expansion makes it impossible to travel between two given nodes in two directions (Figure 10), and all turning options in a road intersection are represented by a unique arc.

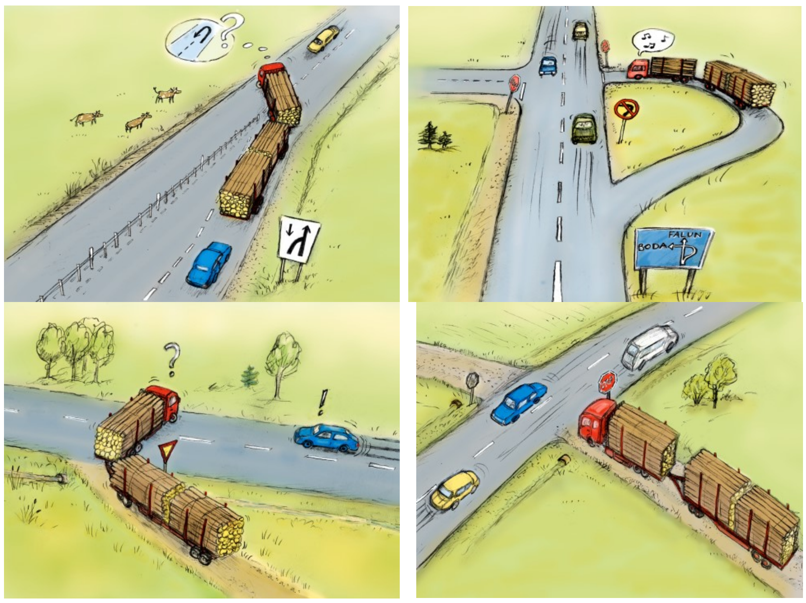

Figure 9. Examples of current development work in CRF: illegal turns (upper diagrams), impossible turns (lower left) and the effect of junctions on route selection (lower right).

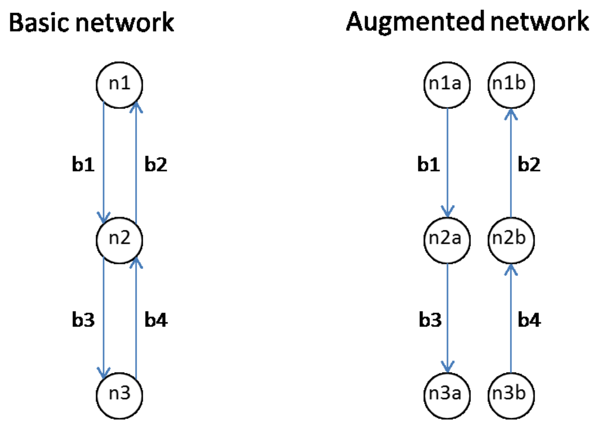

Figure 10: Principal difference between a basic network (left) and an augmented network (right). In the augmented network, an illegal U-turn is not possible because travelling in two directions is not allowed, and there is no connection between the sets of nodes related to the two directions.

The key routes express best practice in routing from the landing in the forest to the recipient point at the mill. Up to now, routing and establishment of key routes has not been explicitly based on time and fuel consumption, probably because of the limited knowledge about the impact of road characteristics on time and fuel consumption, and the lack of accurate models under Swedish conditions. However, models are now available (Svenson and Fjeld 2016) that will make it possible to incorporate these factors into route choice. Possibly in the future, the variables time and fuel consumption, together with the resistance points from CRF, could be incorporated into a developed logging transport pricing system.

7. Conclusions

CRF has proved to be a stable, transparent and objective system for route selection and distance measurement that has led to greater consistency and large administrative savings. CRF is based on key routes, a best practice negotiated between the parties in the Swedish forestry sector on route selection. The key routes are based on a number of objectives, including road safety and work environment, but also directly cost-related factors like distance and fuel consumption. The system is undergoing constant development, in response to observations submitted by the end users. Future development includes real time route decisions affected by detailed measurements of time and fuel consumption.

8. References

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