FREIGHT 21

INTEGRATING FREIGHT WITH RAIL

Rail Freight in the East:

Cost and Performance Analysis

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Abstract

We compare the costs and performance for rail container freight travelling from Felixstowe to Nuneaton using three possible routes: (1) the existing route via Ely; (2) the proposed route from Cambridge to Oxford of East West Rail Co; (3) an alternative Freight21 study route via Cambridge and Bletchley. We find that (3) would cost £1.45bn less to build and would emit 0.5Mt of GHG less in construction than (2); and that (3) would save about 75% of the GHG emissions and at least 10% of the journey time for the current route (1). We also find that (3) outperforms (2) for passenger services between Oxford and Cambridge.

Introduction.

This paper is a study of three possible rail freight routes from the UK's largest container port, Felixstowe, to Nuneaton:

A. The existing route via Ely and Peterborough;
B. Using the route proposed by East West Rail linking Cambridge to Oxford;
C. Using a route studied here by Freight21, going from Newmarket to Bletchley, passing close to (but not through) Cambridge and Bedford (*Freight21 study route*).

We pick Nuneaton as the endpoint because it is the place where the three routes re-join.

The motivation for this study is the realization that on the basis of expected increase in overall volume of container traffic up to 2044, the daily number of HGV journeys along the A14 route from Felixstowe to the Midlands would rise from 4,000 to 7,500, and the annual GHG emissions from the transport of Felixstowe's container traffic would rise from 587kt to over 1Mt. Even upgrading the Ely rail route to double its present capacity would still entail a 44% increase in GHG emissions *(See the report Freight to and from Felixstowe and the East Coast in 2044)*. This is incompatible with the UK government's stated intentions on GHG emissions. Moreover, since sales of new diesel HGVs will cease in 2040, with no presently viable road replacement transport alternative in view, it may well be that by 2044 there simply are not enough HGVs to make 7,500 journeys a day.

There are three parts to this study. The first part, in Section 1, considers the excavation costs of constructing the different routes, and the GHG emissions caused by the earthworks required. The methodology here is to suppose that the route has been chosen, but the profile of heights (and thus the amount of cutting and filling) is to be determined. The profile of heights along the route is chosen to minimise the cost of excavation subject to the requirement that the gradient should not be greater than 1 in 130 anywhere.

The second part of the study, in Section 2, calculates the dynamics of a train with given characteristics as it traverses the different routes. This calculation has to account for speed constraints on curves, the overall speed limit of the train, deceleration for any imposed stops on the route, and rolling resistance. The results of the calculations tell us what speed the train will be going at any point of the route, how much energy is expended to make the journey, and how long the entire journey will take. From the energy required and the characteristics of the locomotive in use, it is possible to calculate how much GHG is emitted during the journey. We then compare this with the GHG emitted by the truck journeys which would move the same amount of freight from Felixstowe to Nuneaton.

Finally in Section 3 we present the corresponding analysis for passenger services between Oxford and Cambridge using a 12-car Class 387 EMU. Even though it was not designed with the needs of passengers as the priority, the Freight21 study route outperforms the East West Rail route.

1 Construction.

The rail routes are the same from Felixstowe to Chippenham Junction near Newmarket, and then they proceed differently, as shown in Figure 1. The existing route is shown in black, the EWR route in red, the Freight21 route in yellow. Where the last two join at Kempston Hardwick, the rest of the route is shown in orange.

Excavation costs (and other costs of preparing the track bed such as drains) are low for the existing route, but not zero because we assume that the single-track sections of the route around Felixstowe and from Soham to Ely must be rebuilt to offer a fair comparison. The costs used in our calculation are taken from p19 in the report [2]. We also assume that the entire length of track would need to be upgraded to compare with the other 2 Figure 1: Three routes, via Ely in black, EWR in red, F21 in yellow. two routes. The track costs are based on an assumed £12000/m. The estimated build costs are shown in Table 1. These costs do not account for building/upgrading stations, bridges and tunnels, nor do they account for the costs of building crossings of roads and rivers, nor for possible chords to join the proposed track to existing tracks. These are all extra costs peculiar to the particular routes chosen; for want of more detail, we suppose that they will be broadly similar for each of the routes studied.

To calculate the GHG emissions associated with excavation, we refer to the spreadsheet of UK government conversion figures, where it is reported that the CO2 emissions associated with the closed-loop disposal of 1t of soil is 0.985 kg, and for landfill it is 17.577 kg of CO2. According to this website, the density of soil is in the range 1.2 - 1.7 t/m3 , so for our calculations we shall take a middle figure of 1.5 t/m3 . We suppose that transporting soil to/from a distant location will produce 17 kg per tonne, whereas reusing soil elsewhere on the construction will produce 2 kg per tonne (which is based on a rough estimate of the relative transportation distances involved).

	Ely	EWR	Freight21
Excavation etc	£ 144M	£2045M	£ 846M
Track etc	£3174M	£3303M	£3062M
Total	£3318M	£5348M	£3909M
Excavation GHG	38.20 kt	851.16 kt	333.08 kt
Distance	265 km	275 km	255 km

Table 1: Felixstowe-Nuneaton routes

We see from Table 1 that the proposed EWR route is the most expensive, costing £1.45 bn more than the Freight21 study route, which in turn costs £0.6 bn more than upgrading the existing Ely line. These differences are mainly due to the cost of additional earthworks, which also impacts the GHG emissions due to excavation; the EWR route causes 0.5Mt more GHG emissions than the Freight21 study route. This is about 0.1% of the UK's annual GHG emissions.

2 Freight operation.

The standard maritime freight container is 40 feet in length; 20-foot containers are also quite common, so the industry measures the quantity of container freight in TEU = Twenty-foot Equivalent Units. Information about the volume of container traffic through Felixstowe comes from the Department for Transport's maritime statistics dashboard. This source tells us that on average over the period 2010-2021 there are 1.89M TEU inbound and 1.82M TEU outbound through Felixstowe each year, and that the average load of a TEU inbound is 7.61t and outbound is 4.83t, so the average load per TEU is 6.22t.

Information about container sizes, weights and capacities is also obtained from this *website*. A 20-foot container weighs 2.23t and will carry up to 28.2t, a 40-foot container weighs 3.68t and will carry up to 29.8t. Based on this, we suppose that the weight of a TEU is 2t; in view of the average load of a container, the weight limit is unlikely ever to be reached in practice. Combining these sources, we arrive at an average gross weight for a loaded TEU to be 8.22t. Table 12 in the *Network Rail freight forecasts report* says that the average total load of a container train is 507t (this is gross weight), so this would be about 62 TEU.

2.1 Container freight wagons.

To calculate the dynamics of the freight train, we shall need to know the weight, length, capacity and top speed of the wagons. We select the modern *VTG Ecofret 2 wagon* for our examples; this has a top speed of 120km/h, which is higher than a lot of older wagons. Individual wagons weigh 21t, and the wagons are coupled in 3-wagon units of overall length 40.8m, capable of carrying three 40-foot containers on each three-wagon unit. For later calculations, we need to specify a representative example of a typical container train. For comparative purposes and based on the information just summarized, we shall suppose that our standard container train consists of:

Eleven (11) 3-wagon VTG Ecofret 2 units, each unit carrying six TEU of 8.22t.

This standard train carries 66 TEU (33 × 40-foot containers), carries 542t, and is 450m long. The overall load carried is quite light for a freight train (loads of 2000t are not uncommon), so we have also considered a longer train with seventeen 3-wagon units, carrying 102 TEUs, that is, 51 × 40-foot containers. This train is almost 700m in length, which is achievable; in 2021, container services with trains of length 775m were begun - *see here*.

2.2 Locomotives.

Specifications for various locomotives are found on the DB Freight website. In the examples we calculate and present here, we shall be considering either the diesel-electric Class 66 locomotive, or the overhead-electric Class 90 locomotive. Table 2 presents some of the key characteristics of these two types of locomotive. Fmax is the maximum tractive force and vmax is the maximum speed of the locomotive.

	Class 66	Class 90
Weight	130t	84t
Power	2.5MW	3.73MW
Fmax	4.1e5 N	2.58e5 N
vmax	120 km/h	176 km/h

Table 2: Class 66 and Class 90 locomotives compared.

It is worth noticing that for our standard container train with VTG Ecofret 2 wagons, the maximum speed is 120 km/h; (*although the Class 90 is capable of more, the wagons are not*).

2.3 Calculating the dynamics.

To determine the dynamics of the train, we firstly identify the forces acting on the train, which will be

I. The tractive/braking force of the locomotive;
II. The component of gravitational force acting on the train;
III. The rolling resistance.

The first of these is relatively straightforward to deal with. We shall assume that the locomotive is working at full power output at all times when braking is not necessary. Braking will be needed if we have imposed stops on the route, if there is a risk of exceeding the speed limit on a downhill stretch of track, or if some part of the train is going round a bend and there is the risk that the centripetal acceleration on some part of the train will exceed safe limits, which in our calculations we take to be 5% of gravitational acceleration.

The second simply requires resolving of forces. We will assume for this part of the calculation that the train is a point mass at the current location of the locomotive; this ignores situations where the front part of the train is going downhill while the rear part is going uphill, but the effect of this will be small over the entire journey.

The third force is altogether more difficult to deal with. There does not appear to be any theoretical analysis of the rolling resistance forces which successfully explains what happens in practice. Railway engineers rely on quadratic formulas based on evidence from experiments known as the Davis formula (and its variants). We have taken the Canadian National variant of the Davis formula - see this website for a full explanation.

2.4 Results.

For each of the three routes considered, we shall suppose that there are stops where the route passes pinch points:

A. For the existing route via Ely, the stops are at Ely, Peterborough and Nuneaton;
B. For the EWR route, the stops are at Cambridge (Coldham's Common), Bedford and Bletchley;
C. For the Freight21 study route, there is one stop at Bletchley.

The assumption of a single stop for the Freight21 study route is appropriate because this route is designed to be a fast trunk line that passes near to, but not through, Cambridge and Bedford, allowing freight to run at a steady cruising speed all the way to Bletchley, where it joins the West Coast Main Line. We suppose it must stop there waiting for a gap. For comparison purposes the waiting time at all stops on all routes is assumed to be zero.

The results of the calculations are presented in Table 3. Energy is in GJ, time in minutes, speed in km/h and GHG in tonnes. The first three of these attributes are directly calculated when the dynamics of the train are solved. In order to convert these into GHG emissions, we have firstly to understand the efficiency of a diesel-electric locomotive, and of an electric locomotive. Using figures from [1], we suppose that the efficiency of the diesel-electric Class 66 is 24% and of the electric Class 90 is 75%. Turning the first into GHG emissions is done by using the relevant factor from the Fuels tab of the *UK government conversion figures spreadsheet*, and the conversion factor for the electricity used by the Class 90 is taken from the UK electricity tab of the same spreadsheet. The final row of Table 3 gives the corresponding results if the load was carried by HGV. There would need to be 33 HGV journeys to shift the load carried by an 11-unit train, and we assume (generously) that the 240km route would be travelled at an average speed of 80km/h. The Freighting goods tab of the UK government conversion spreadsheet gives a figure of 0.12415 kg/t-km of GHG emissions for an articulated HGV up to 33t when 50% laden, and the GHG emissions figure in Table 3 is obtained by multiplication. This is a crude estimate, but gives an indication.

Route	Locomotive	Energy	Time	Speed	GHG
Ely Rail	Class 66, 11 units	14.64	169	93.9	4.49
Ely Rail	Class 66, 17 units	19.97	189	84.0	6.13
Ely Rail	Class 90, 11 units	15.09	160	99.5	1.08
Ely Rail	Class 90, 17 units	21.25	172	92.5	1.52
EWR Rail	Class 90, 11 units	16.11	168	98.4	1.15
EWR Rail	Class 90, 17 units	22.78	182	90.8	1.63
Freight21 Rail	Class 90, 11 units	14.07	152	101.0	1.01
Freight21 Rail	Class 90, 17 units	19.90	163	93.9	1.42
A14 **Road**	HGV, 11 units		180	80	16.16

Table 3: Performance of different routes.

Figures 2-5 show in their four panels

1. The topographical profile along the route (in blue), with the height of the track in red;
2. The curvature along the route;
3. The speed along the route;
4. The tractive force along the route.

The results in Table 3 make three points clear:

- Diesel HGV transport produces about four times the GHG emissions of diesel-electric rail freight;
- Diesel-electric rail transport produces about four times the GHG of electric rail transport;
- Assuming all three routes are electrified, the Freight21 study route performs best for emissions - the Ely route has about 7% more emissions than the Freight21 study route, the EWR route about 14% more; *(At the moment, the existing Ely route is not electrified, EWR is planned to be electrified, but not initially installed)*.
- Switching freight from HGV to electrified rail will save well over 90% of the GHG emissions.

3 Oxford to Cambridge.

In this section, we present the corresponding results when considering passenger services from Oxford to Cambridge, using either the East West Rail proposed route, or the Freight21 study route. We assume the service is operated by a 12-car Class 387. The East West Rail route approaches Cambridge from the South, the Freight21 study route approaches Cambridge from the North, joining the existing line from Ely between Waterbeach and Cambridge North.

We calculate and present results for stopping services, and for non-stop services. Results are shown in Table 4; the times taken exclude dwell times at the stops. The stopping service via the East West Rail route stops at Bletchley, Bedford, St Neots, Cambourne, Cambridge South and Cambridge Central. The stopping service via the Freight21 study route stops at Bletchley, Kempston Hardwick, St Neots, Cambourne, Cambridge North and Cambridge Central.

Route	Energy	Time	Speed	GHG
EWR stopping	7.39 GJ	58 min	141 km/h	0.53 t
Freight21 stopping	7.51 GJ	56 min	143 km/h	0.54 t
EWR non-stop	5.40 GJ	53 min	153 km/h	0.39 t
Freight21 non-stop	5.23 GJ	51 min	156 km/h	0.37 t

Table 4: Performance of passenger services on EWR and Freight21 routes.

Plots of the four journeys are shown in Figures 6-9. We see from Table 4 that the Freight21 service is two minutes quicker than the East West Rail service, and produces 5% less GHG when travelling non-stop, and 2% more GHG on the stopping service. Excluding dwell times, all journeys are comfortably under one hour.

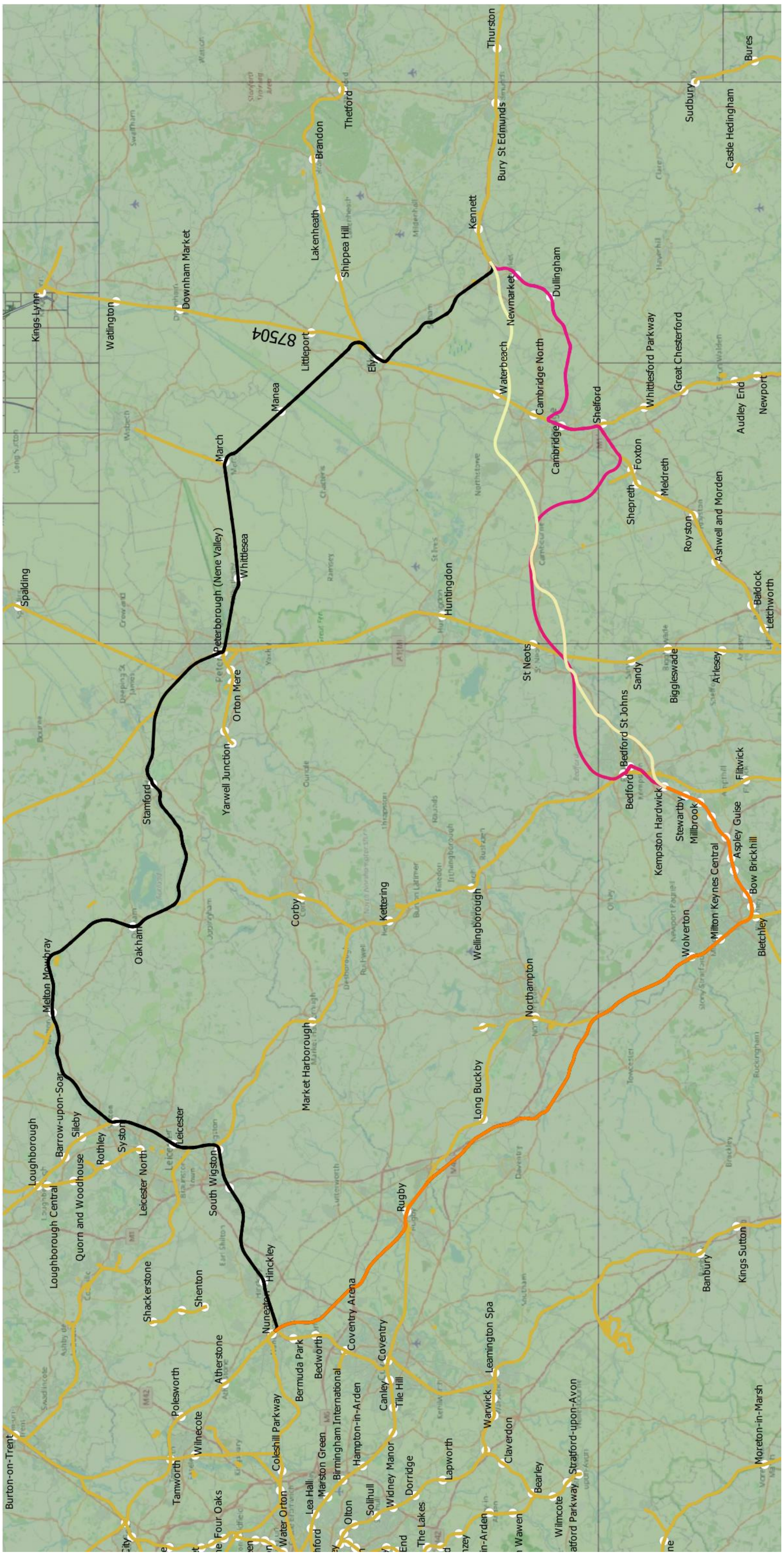

Figure 1: Three routes, via Ely in black, EWR in red, F21 in yellow

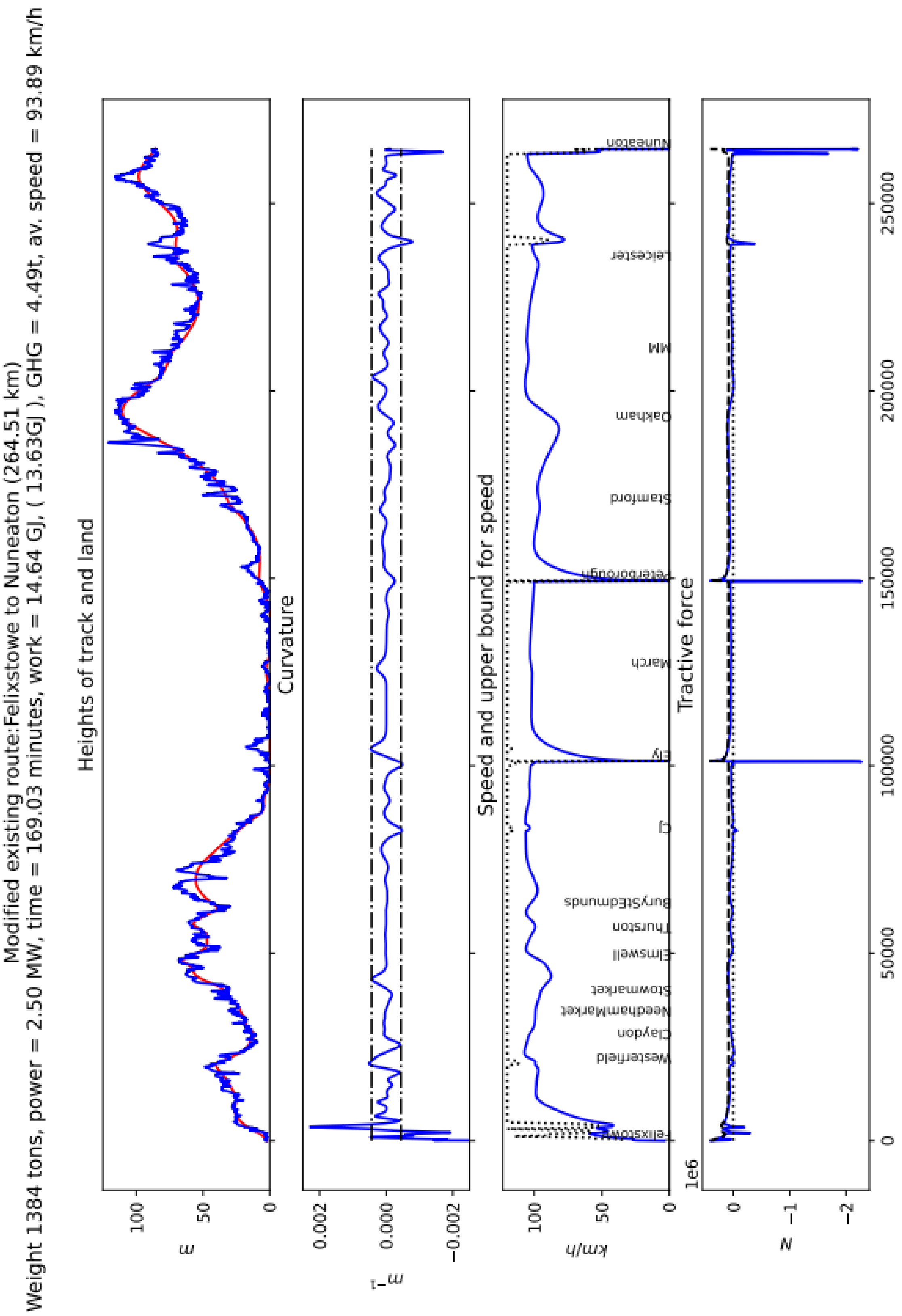

Figure 2: Ely route, Class 66, three stops, 66 TEU

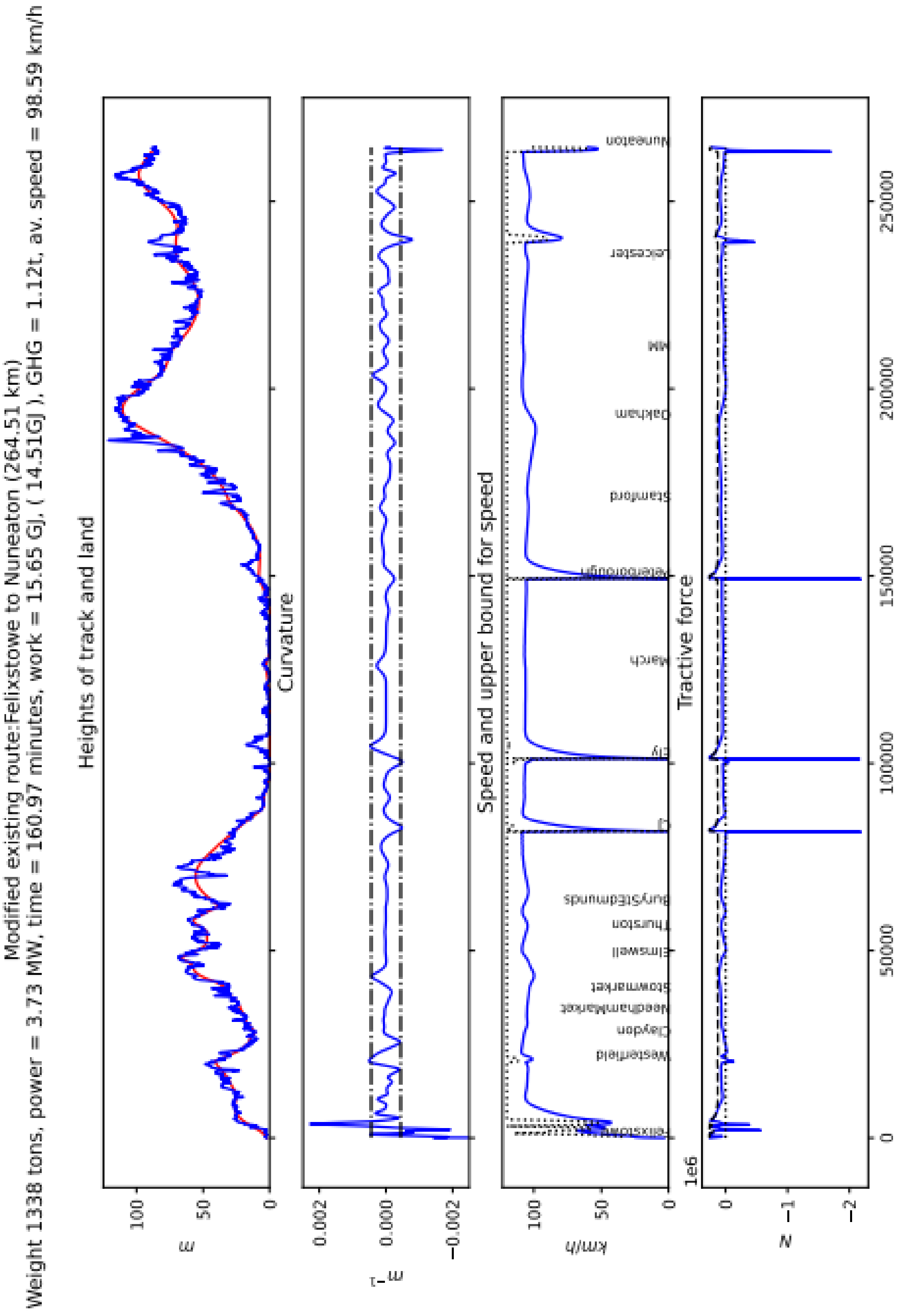

Figure 3: Ely route, Class 90, three stops, 66 TEU

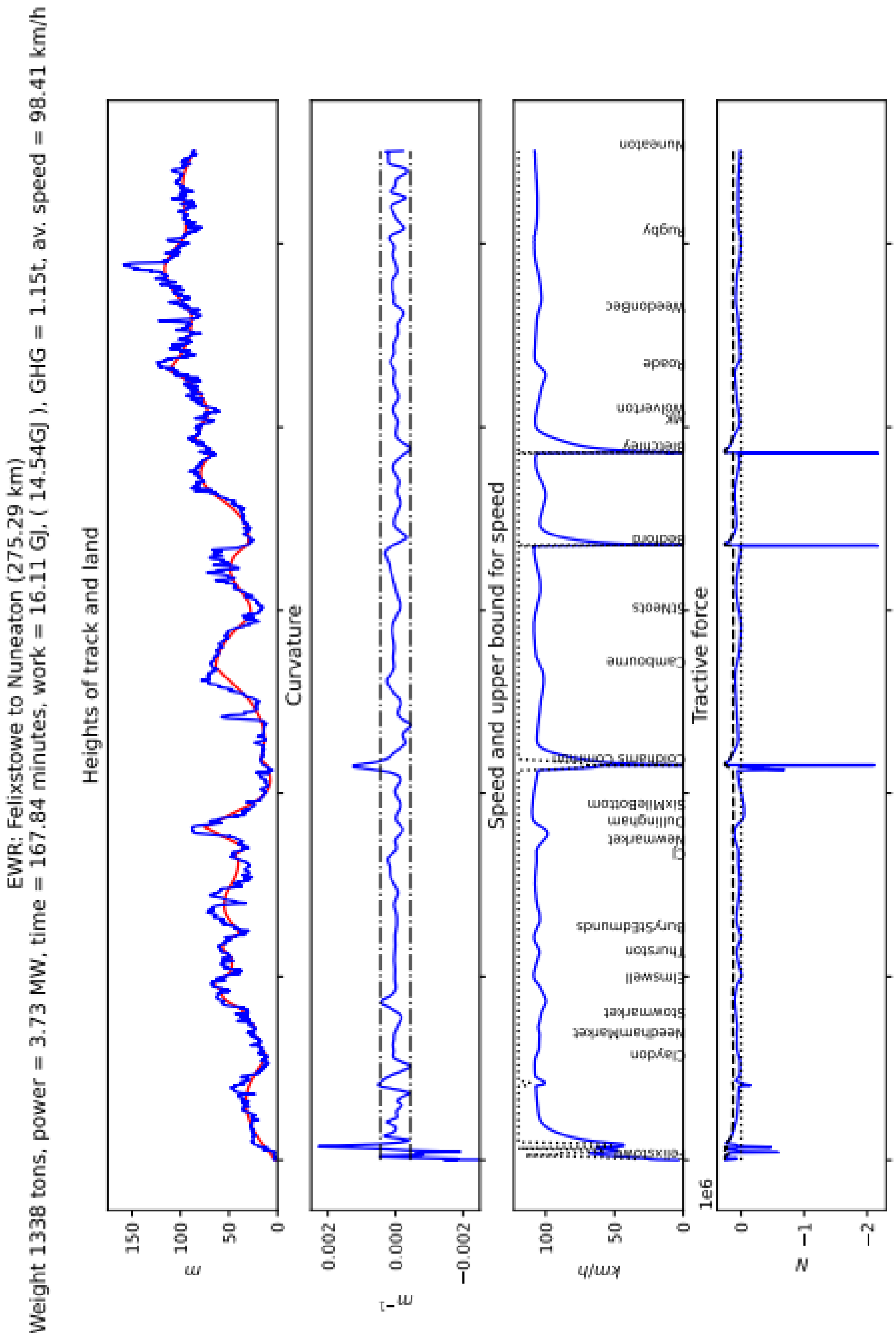

Figure 4: EWR route, Class 90, three stops, 66 TEU

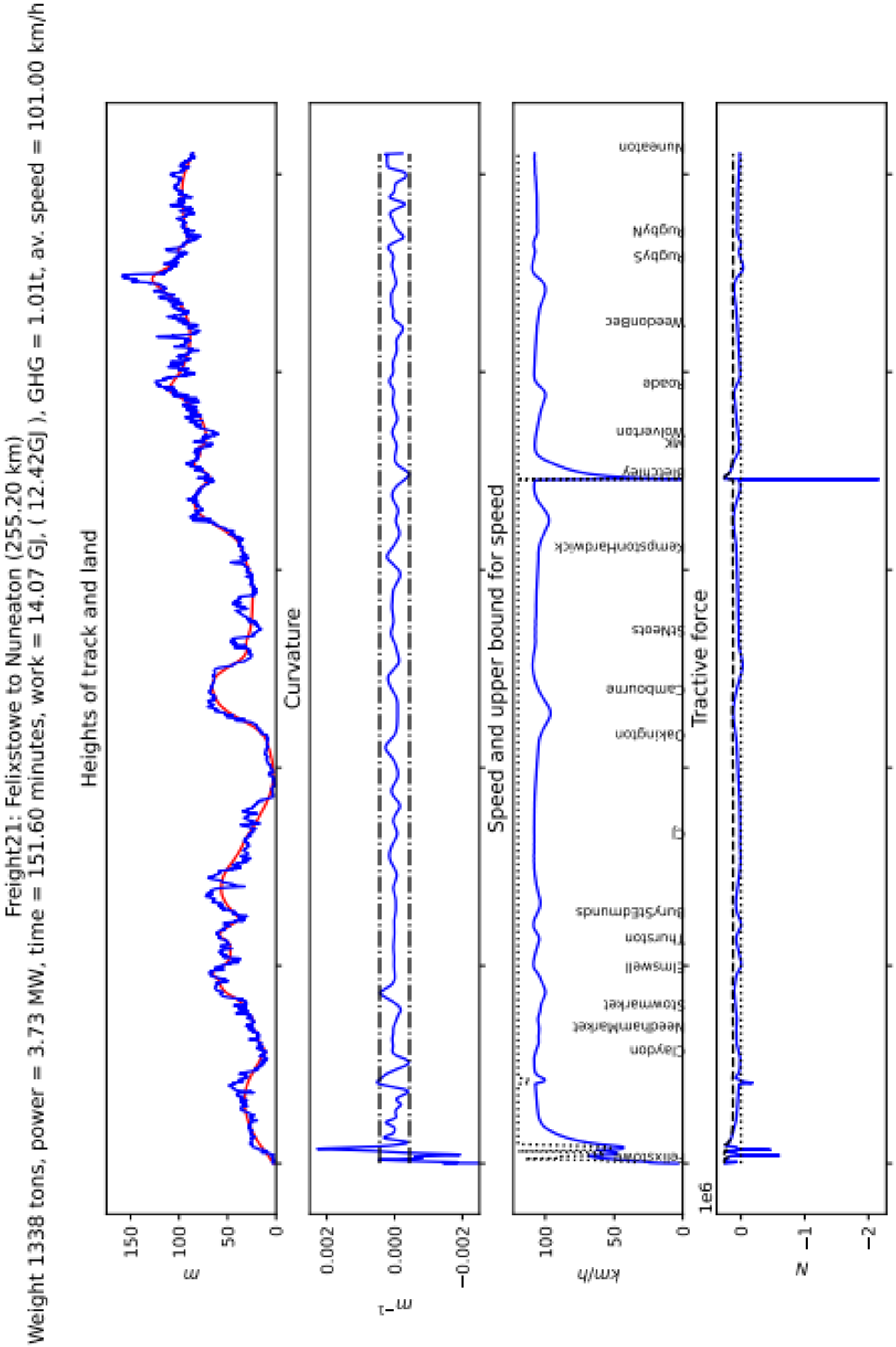

Figure 5: Freight21 route, Class 90, 1 stop, 66 TEU

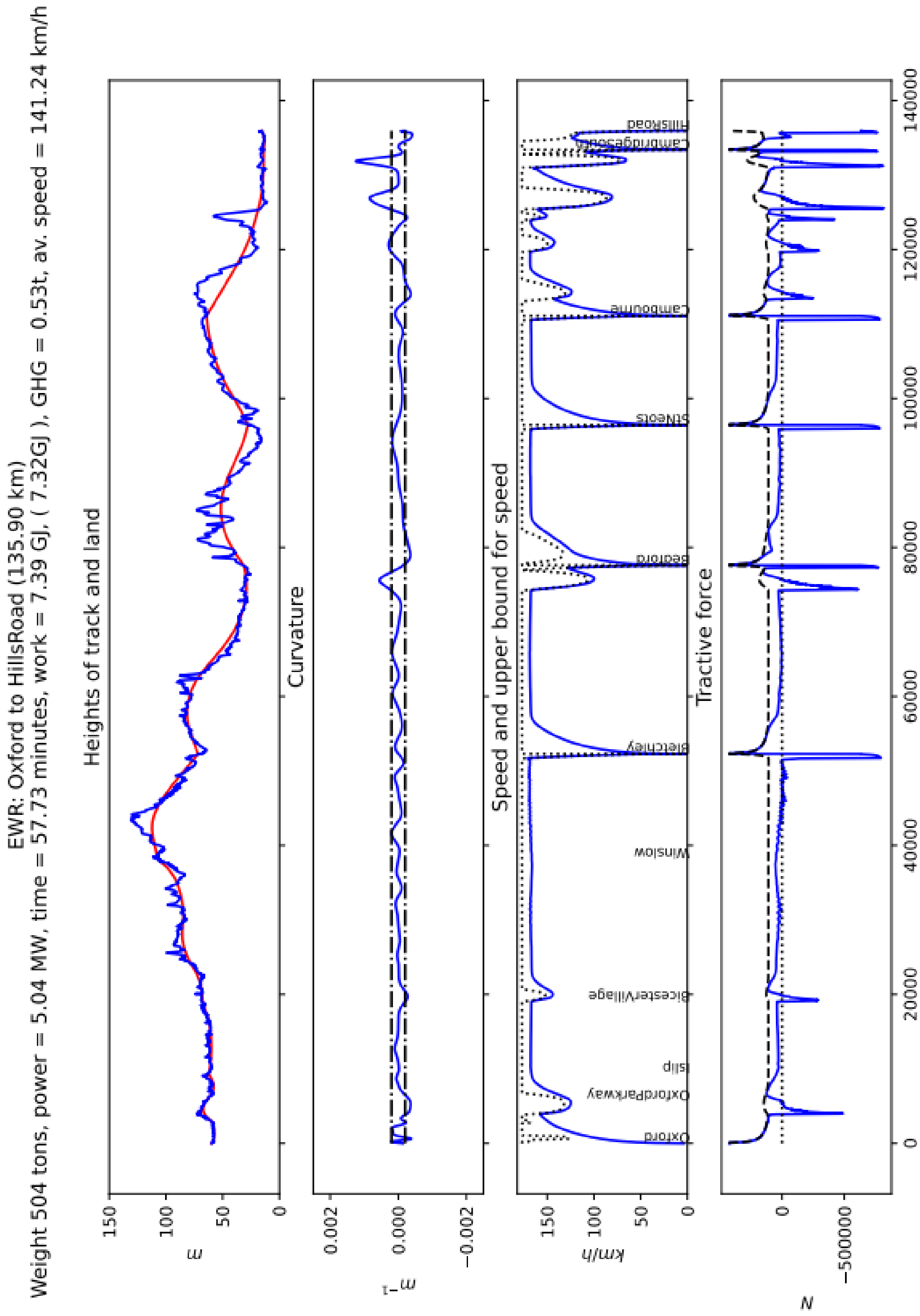

Figure 6: Passenger Train Oxford to Cambridge stopping, EWR route

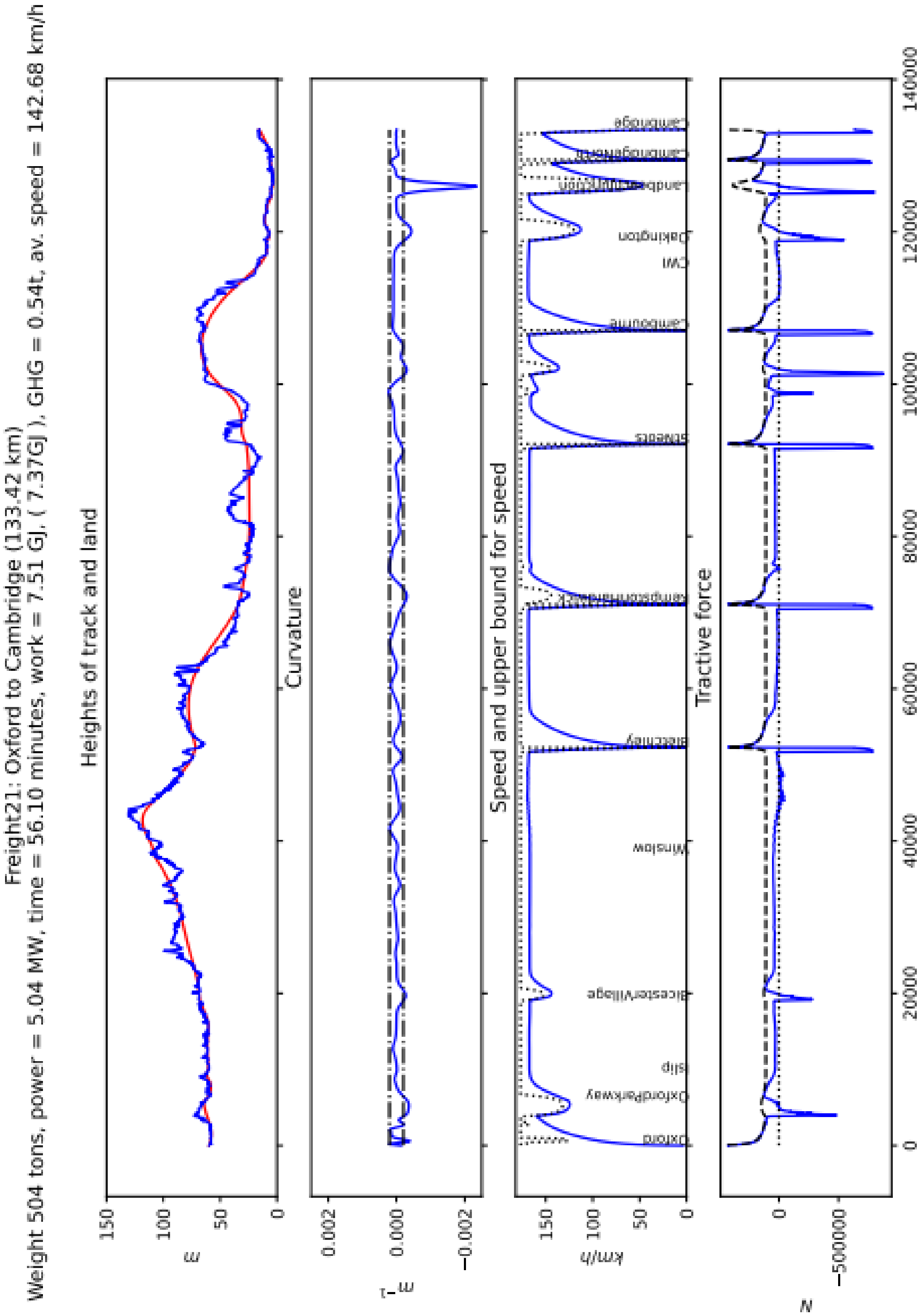

Figure 7: Passenger Train Oxford to Cambridge stopping, Freight21 route

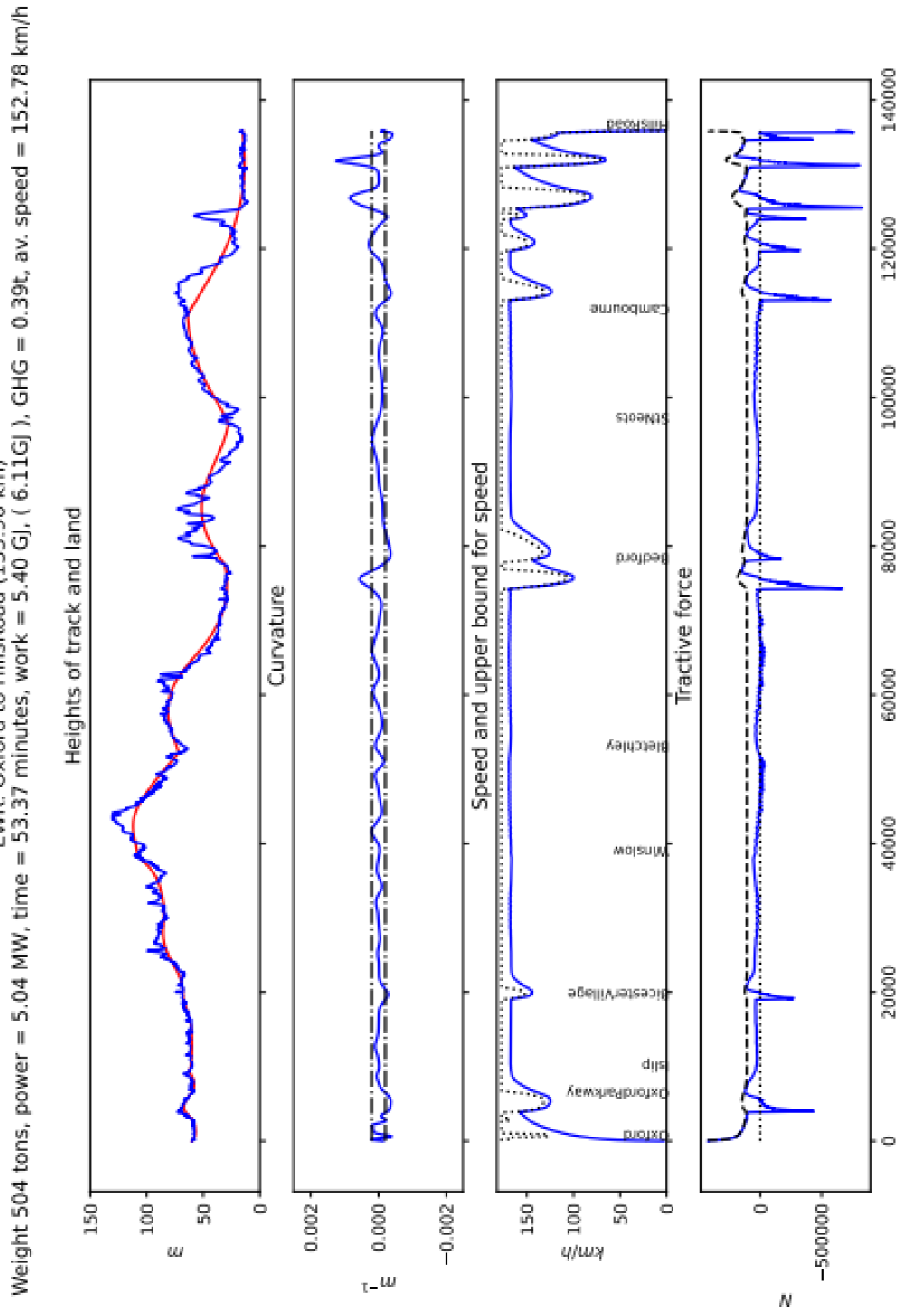

Figure 8: Passenger Train Oxford to Cambridge non-stop, EWR route

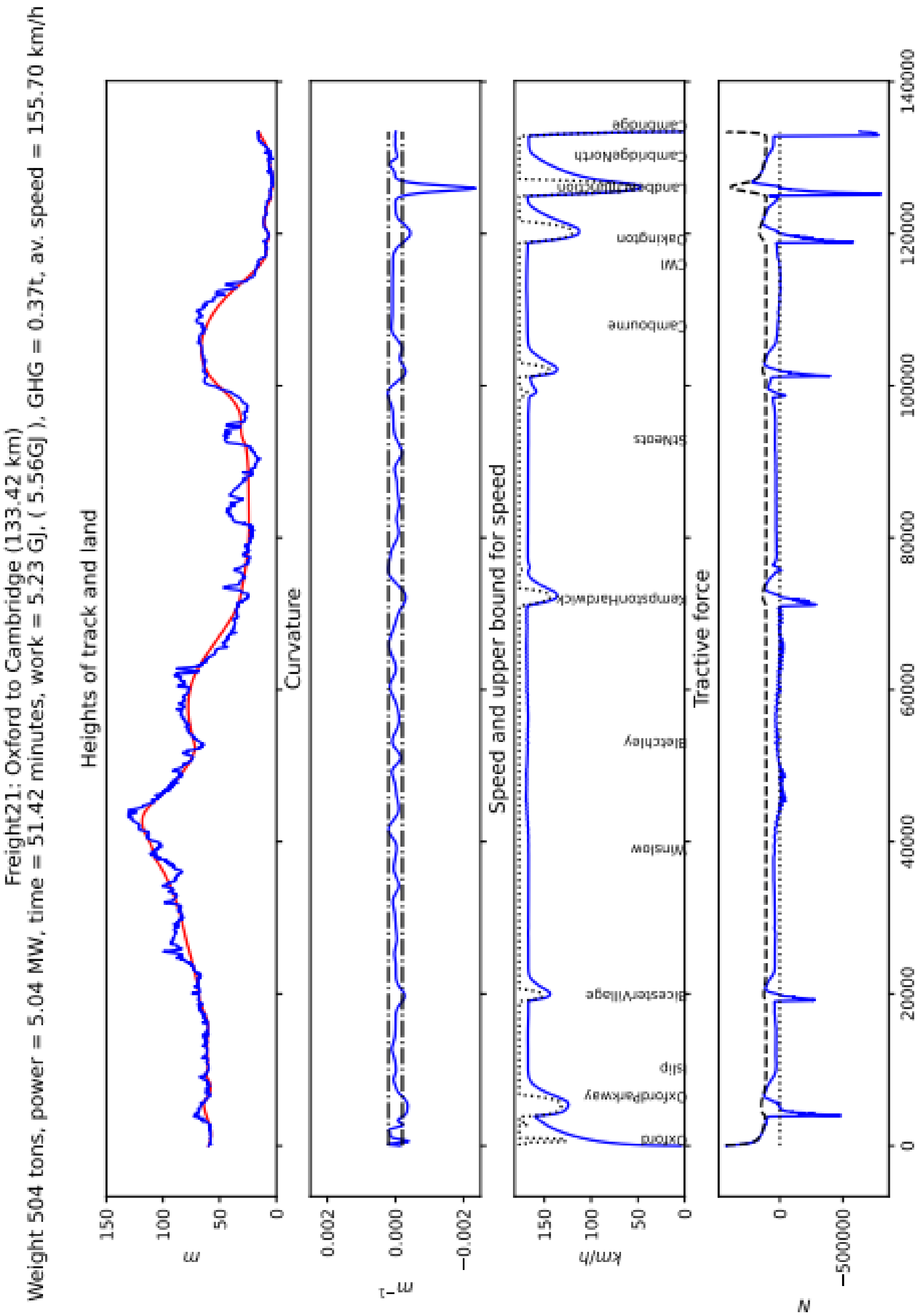

Figure 9: Passenger Train Oxford to Cambridge non-stop, Freight21 route

References

[1] Elena Agenjos, Antonio Gabaldon, Francisco G Franco, Roque Molina, Sergio Valero, Mario Ortiz, and Rafael J Gabaldon. Energy efficiency in railways: Energy storage and electric generation in diesel electric locomotives. In CIRED 2009-20th International Conference and Exhibition on Electricity Distribution-Part 1, pages 1–7. IET, 2009.

[2] Faithful & Gould. East West Rail central section options. Technical report, SNC-Lavalin Group, 2019. 1