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Improving Charging Infrastructure Requirement Forecasting by Including Elevation Changes in MOSTACHI Software

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Executive Summary

An update to the transport electrification software MOSTACHI incorporating elevation effects was made, where originally, flat terrain was assumed. Energy consumption parameters previously based on general single parameters were updated with values determined with high resolution vehicle power calculations along all points in a small test road network located in eastern Sweden. Results showed that the average overall energy consumption determined as kWh/km changed from 1.435 for flat terrain, to 1.727, an increase of just over 20%. On-going project work is currently porting this simulation to a Canadian context, where topographical variations are of a similar nature to those found in Sweden, and will make a similar difference in energy requirement estimates for long haul trucking, which in turn dictate electrical infrastructure requirements.

Keywords: Heavy Duty electric vehicles and buses; Fast and Megawatt charging infrastructure; Inductive / Wireless Power Transfer; Batteries; Modeling and Simulation

1 Introduction

The the open-source code MOSTACHI (*Model for Optimization and Simulation of Traffic And Charging Infrastructure*) developed by RISE is being used in research on the electrification of truck transport in the Canadian province of Ontario. MOSTACHI is simulation tool designed to study interplay in time and space among logistics patterns, competing charging infrastructure and cost-minimizing vehicle operators [1]. An objective is to compare high current charging to electrified roadways (e-Roads), as well forecasting the economics of various rollout scenarios. Implementation of either transport power modality necessarily entails consideration of accompanying required infrastructure, notably expansions of both equipment and the overall capacity of the provincial electricity distribution network. A preliminary study in press reports on similar objectives applied to the country of Sweden [2]. Here, an is aim to apply expertise and experience with simulations of long haul truck transport and e-Roads modeling to a province-wide Ontario road network context. Previous work considered one vehicle and studied how it performed in various electrification scenarios [3]. In this present project, the intention is to incorporate essential truck-level characteristics of electric transport at a road network level, including introducing elevation effects of the local terrain to impart higher resolution detail to the highway network truck traffic. Any additional energy determined as attributable to elevation effects requires a proportional additional amount of installed electric power infrastructure.

2 Modeling Approach

As originally written, MOSTACHI took a fleet approach to truck traffic modeling, classified and parameterized according to truck types. Energy consumption was estimated with literature values of kWh/km for the trucks. Originally, topographical effects were not considered, with the rationale that Sweden, the test-bed environment for MOSTACHI was not particularly hilly and that driving routes were bidirectional, suggesting elevation related energy requirements in one direction would be compensated somewhat in the opposite direction. The latter claim is less valid with electric vehicles, since net elevation drops allow for energy recovery from regeneration systems. To investigate its effects, elevation was incorporated into the MOSTACHI code. It is understood that greater elevation variations result in larger traversal energy costs. Previous research showed that for driving along the Windsor-Quebec corridor in Canada, with a net elevation change of 160 m over an 811 km distance, energy requirements with topography taken into account varied from -10 to +10% [3] for day to day comparisons to identical duty cycles run with constant elevation.

Thus, the present objectives are to integrate route elevation effects into the original MOSTACHI code. This added a new layer of data to the routes in the network for a MOSTACHI case study. To illustrate, an outline of the route structure follows.

2.1 Modifications to Include Topography in MOSTACHI

MOSTACHI software models highway truck travel in a route-based system, which is the highest level item in a hierarchy. Routes are composed of segments, which are sections of road that are always traversed in their entirety. Junction points offering routing options typically are segment end points. Segments are built up with node pairs, which are pairs of points defined by latitude and longitude values which are normally spaced about 50 m apart, and rarely exceeding 250 m. This allows for uniquely identifiable routes and provides a net travel distance accuracy well within one percent of odometer readings. The routing structure is shown schematically in Fig. 1.

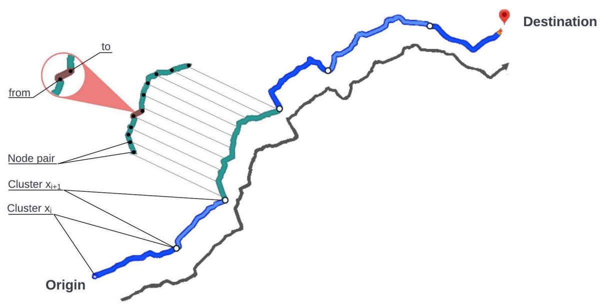

Figure 1: Schematic of Route Network Hierarchy employed in MOSTACHI.

A new c# routine was added to the simulation which tracked each road segment following node pairs, and assigned elevation values to them. A shareware API (https://www.elevation-api.eu/) was inserted into the code which returned an elevation value at mm resolution, and assigned it to a node position in the segment.

2.2 Determinations of vehicle energy requirements

The energy consumption was originally determined using constant kWh/km values multiplied by the route distance, whereas the segment based approach taken here gives a more accurate and detailed determination of energy requirements. At the segment level, different vehicle speeds applied, providing greater accuracy. Significant coding effort was required to sort and organize segment node sequences, since driving is direction dependent, and the OSRM application did not create properly ordered node arrays. As outlined in [3, 5], an instantaneous power requirement for a truck on a highway can be determined with Eq. 1, along with driving condition inputs.

$$P_{\text{truck}} = \frac{(\mu_r + \sin\alpha) M g\, v(t)}{\eta_{\text{eq}}} + \frac{C_d A v(t)^3 \rho}{2\eta_{\text{eq}}} + \frac{\delta M a(t) v(t)}{\eta_{\text{eq}}} + P_{\text{aux}} \tag{1}$$

The terms in Eq. 1 account for rolling resistance, elevation change, form drag and acceleration effects. The power transfer efficiency η_{eff} to the motor was set at 0.84, and when $P_{\text{truck}} < 0$, a regeneration value of 1/0.88 [5] was used. As an example, results from a diagnostic test calculation are shown for *Segment 0* from the sample data set in Fig. 2. This example was set in quite steep terrain, so for a 40 ton truck

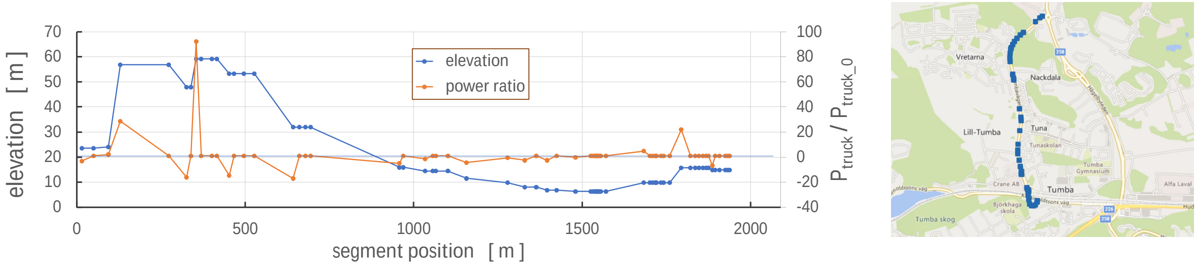

Figure 2: Elevation profile produced for segment 0, along with truck power requirement ratio relative to no elevation effects considered. Inset shows a map of the road segment, a 1.94 km stretch, about 20 km southwest of Stockholm in the direction of Södertälje.

large $P_{\text{truck}}/P_{\text{truck Zero}\Delta\text{Elev}}$ values are seen, compared to values in the 5 to 20% range more typical with gentle elevation variation. The case in Fig. 2 had an averaged elevation power ratio of 1.17, thus 17% extra power is required at the given speed compared to the same distance over flat terrain. In the opposite direction, 127% extra power is required, as the segment is mostly climbing. In this initial study, segment driving speeds were taken as constant, but a future refinement will be to locally adjust speeds according to grade, while retaining the same specified average road segment speed. The present approach thus predicts slightly higher than optimal energy requirements.

3 Results

The initial investigation was to determine to what extent considering elevation affected the energy requirements calculated for use in the MOSTACHI simulations. To demonstrate these effects, a very small demonstration road network consisting of 9 places and 63 routes composed from 579 route segments was used. This test network is shown in Fig. 3, depicting a number of routes mainly in eastern Sweden. For

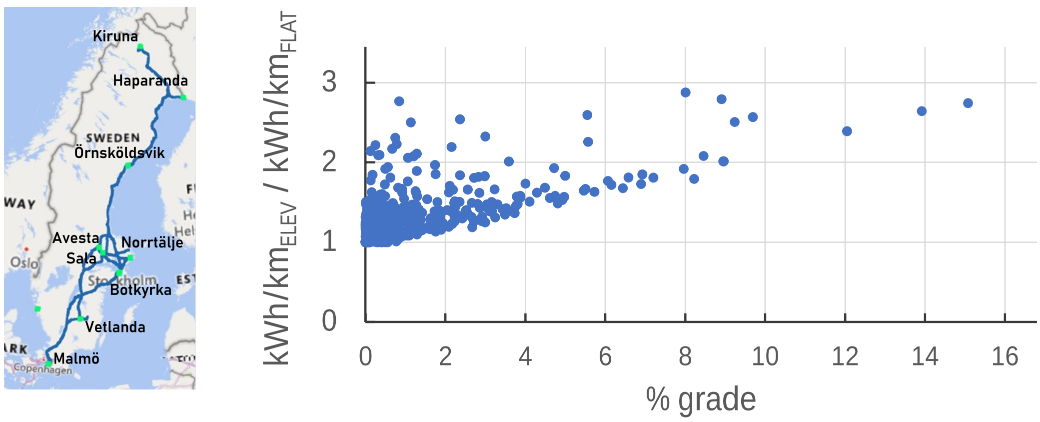

Figure 3: Test road network for code development work (left), and energy use elevation factors determined for each route segment in the network plotted against average segment incline grade (right).

the entire road network, the plot in Fig. 3 shows points for each road segment with the ratio of kWh/km for cases considering elevation to cases assuming flat terrain. For segments with slope grades below 2%, the effect is minor, but there are enough segments with significant grades to make the overall effect appreciable.

At this point, with on-going efforts to port the MOSTACHI software to a Canadian context, where current efforts are preparing route and traffic data, Table 1 summarizes the present study which considered a small test road network that had previously been prepared for Sweden. It can be noted that the flat terrain kWh/km value of 1.435 for the network is almost identical to the parameter value of 1.46 given for 40 tonne class trucks in the MOSTACHI source download. In Table 1, the *+5% Elevation* heading indicates a scenario where the elevation differences on the road network between node pairs was increased by 5%, and the Ontario transform was to show the planned Canadian context, where a latitude and longitude transform was applied to the API call to place the road network in Ontario to the north of Lake Ontario. It is understood that this transform will exaggerate the elevation effects, since the node positions were unlikely to be along roadways, where extreme elevation changes are avoided or mitigated, but may better reflect conditions on smaller rural roads.

Table 1: Energy consumption values in kWh/km for 40 tonne class long haul trucks for various topography contexts averaged over the entire test road network.

Flat terrain	**Elevation**	**+5% Elevation**	**+10% Elevation**	**Ontario transform**
1.435	1.727	1.746	1.764	1.809

4 Preparing Ontario Road Network Data Set

Data has been made available by the iCorridor service of the Ontario Ministry of Transport (MTO) for the purposes of this project [6]. There are three data sets that require some treatment to adapt these data to input formats required by MOSTACHI. Fig. 4 shows a map of the road network covered by iCorridor. The present study will restrict itself to locations south and east of the city of Sudbury.

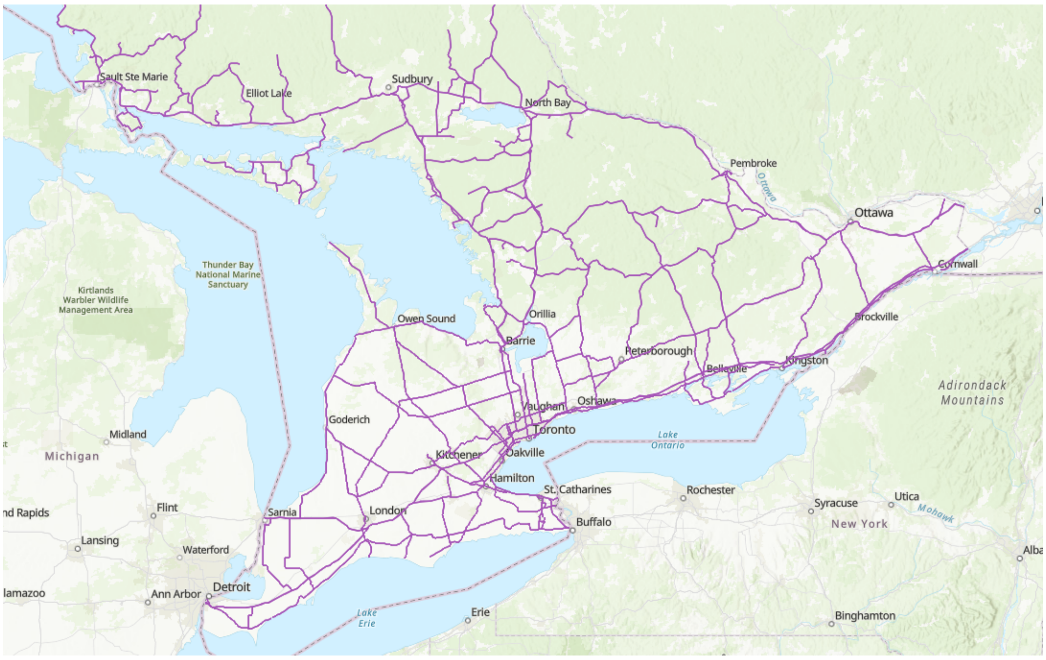

Figure 4: Map of Ontario Highway network where AADTT iCorridor data are provided .

Traffic volume data for the provincial highway network were made obtained for the year 2021. The data set covered highways designated as King's, Secondary, Tertiary Roads, and 7000 Series Highways. These are data known as annual average daily truck traffic (AADTT), reported as vehicle counts. Ontario truck traffic origin-destination data is also available online from the MTO iCorridor project. The origin-destination data is provided in two sections; one on trip volumes, the other on cargo weights. These data, along with data giving percentages of the truck fleet by weight class have to be combined and scaled to 2021 traffic levels (2021 is the most recent AADTT survey, other data are slightly older) to provide the data inputs required by MOSTACHI. A numerical approach is currently being developed to make use of these MTO data which adheres to both the origin-destination data which prescribes routing, as well as the AADTT data which specifies traffic level along the routing, such that a coherent data set is produced which determines traffic levels over the entire road network with the least amount of total summed difference from the AADTT data values.

5 Conclusions

A significant modification to the open-source transport electrification software MOSTACHI was made which incorporated the effects of variable topography into the simulation. This adaptation necessitated slight overhauls in how energy usage information was stored and handled inside MOSTACHI, but did not fundamentally change it, nor predict different outcomes if the elevation changes were set to zero. Results from considering a small test road network showed that the average overall energy consumption determined as kWh/km changed from 1.435 to 1.727, an increase of just over 20%, requiring a commensurate increase in electrification infrastructure. On-going project work is currently porting this simulation to a Canadian context, where topographical variations are of a similar nature, and the incorporation of elevation effects will provide more accurate energy requirement estimates. These preliminary results afford an opportunity to assess their general coherence with field data to identify areas which could benefit from further refinement.

Acknowledgments

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References

[1] JakobRogstadius/MOSTACHI, [online] https://github.com/JakobRogstadius/MOSTACHI [accessed 26 Feb., 2024]

[2] Rogstadius J, Alfredsson H, Sällberg H, Faxén KF. Electric Road Systems: A No-Regret Investment with Policy Support. in press, (2024) Nature Communications.

[3] Darcovich K, Ribberink H, Qiu K, Soufflet E, Battery Pack Prospects for Long-Haul Transport Trucks Considering Electrified Highways and Megawatt Charging. World Electric Vehicle Journal, 14 [3] (2023) 60.

[4] Luxen D, Vetter C, Real-time routing with OpenStreetMap data. In Proceedings of the 19th ACM SIGSPATIAL international conference on advances in geographic information systems 2011 Nov 1 (pp. 513-516).

[5] Foote A, Onar OC, Debnath S, Chinthavali M, Ozpineci B, Smith DE, Optimal sizing of a dynamic wireless power transfer system for highway applications. In 2018 IEEE Transportation Electrification Conference and Expo, (ITEC) 2018 Jun 13 pp. 1-6.

[6] Ontario, [online] https://icorridor-mto-on-ca.hub.arcgis.com/ [accessed 27 January, 2025]

Presenter Biography

Hajo Ribberink has a M.A.Sc. degree in Applied Physics from Delft University in the Netherlands. He has over 30 years of experience in using modelling and simulation to assess new and innovative technologies in the energy field. At Natural Resources Canada, he leads CanmetENERGY's research on transportation electrification and advanced transportation technologies.