Natural Resources Canada / Ressources naturelles Canada

CanmetMINING mine electrification research: Goldex Railveyor study ECM

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Canada

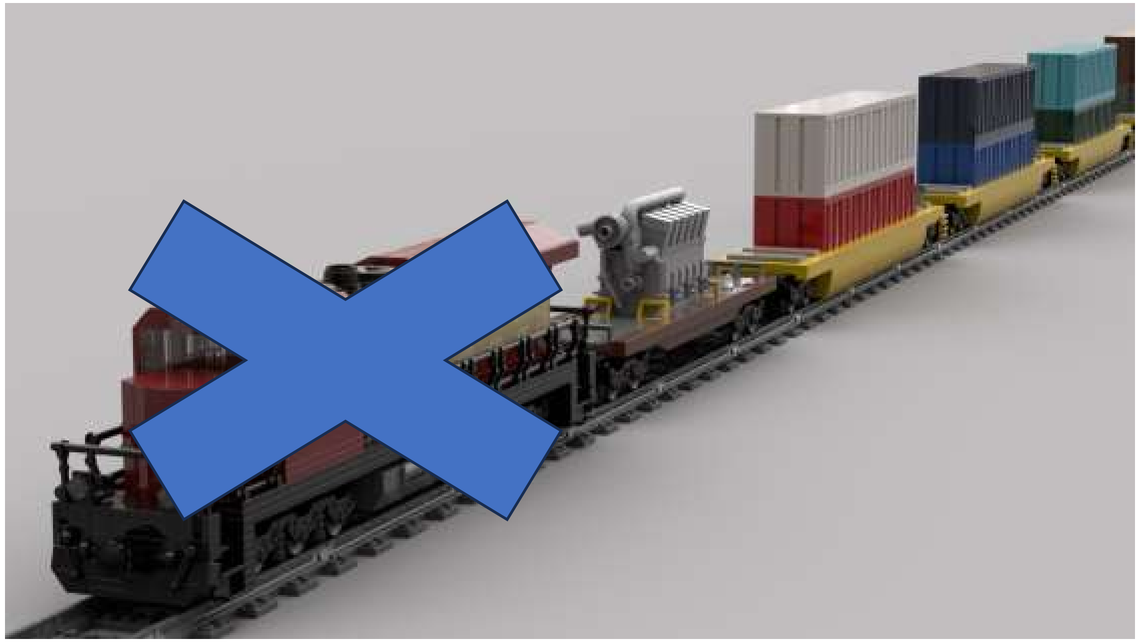
Outline

- What is Railveyor?
- Goldex Mine energy consumption study results for Railveyor application
- How to use the results for other studies
  - Energy Consumption Model (ECM) calibration
  - ‘What if’ ramp scenarios with different grade and tonnages
- Summary

What is the Railveyor?

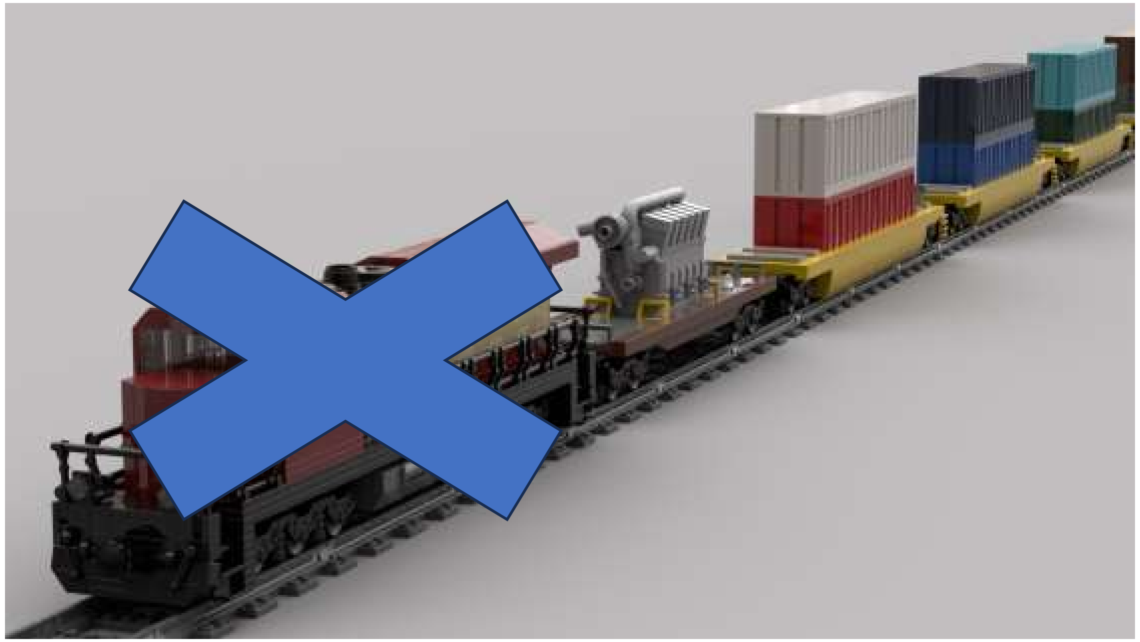
Take a train with rail cars

What is the Railveyor?



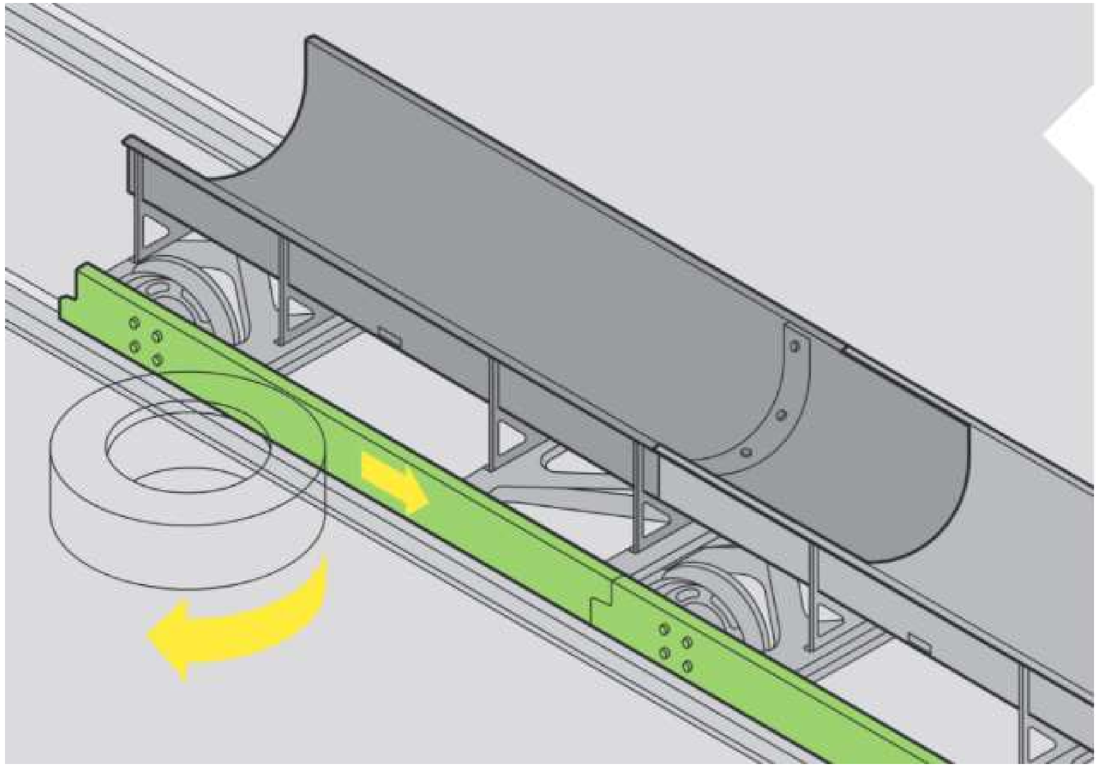
Remove the locomotive

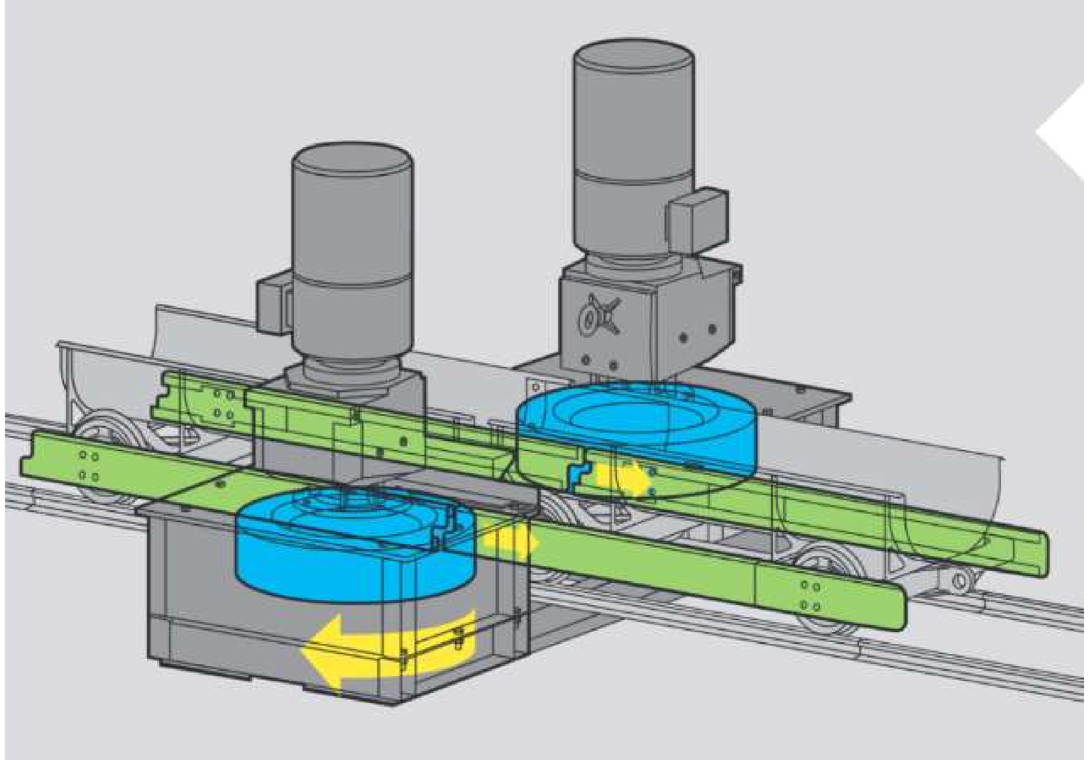
What is the Railveyor?



Instead add driving stations

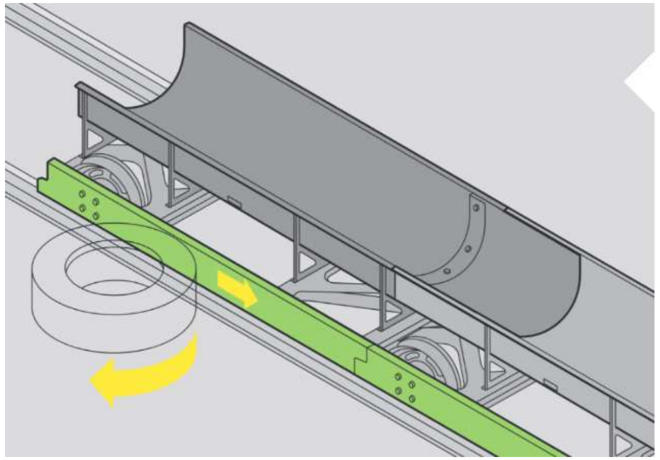
What is the Railveyor?

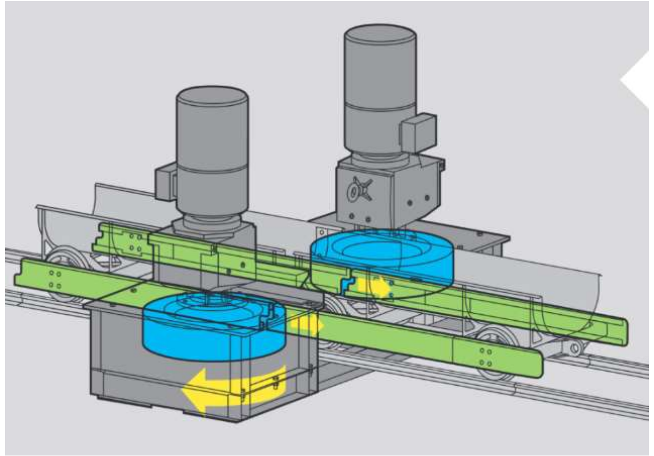


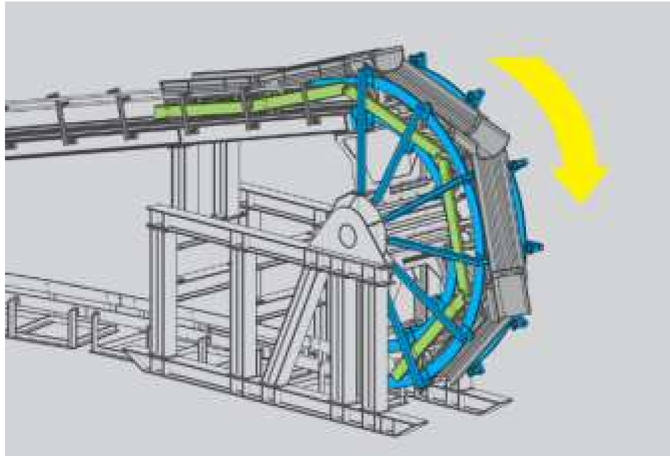


Adapt the design for mining environments

What is the Railveyor?







Finish by adding a dumping station
(assume the loading station exists)

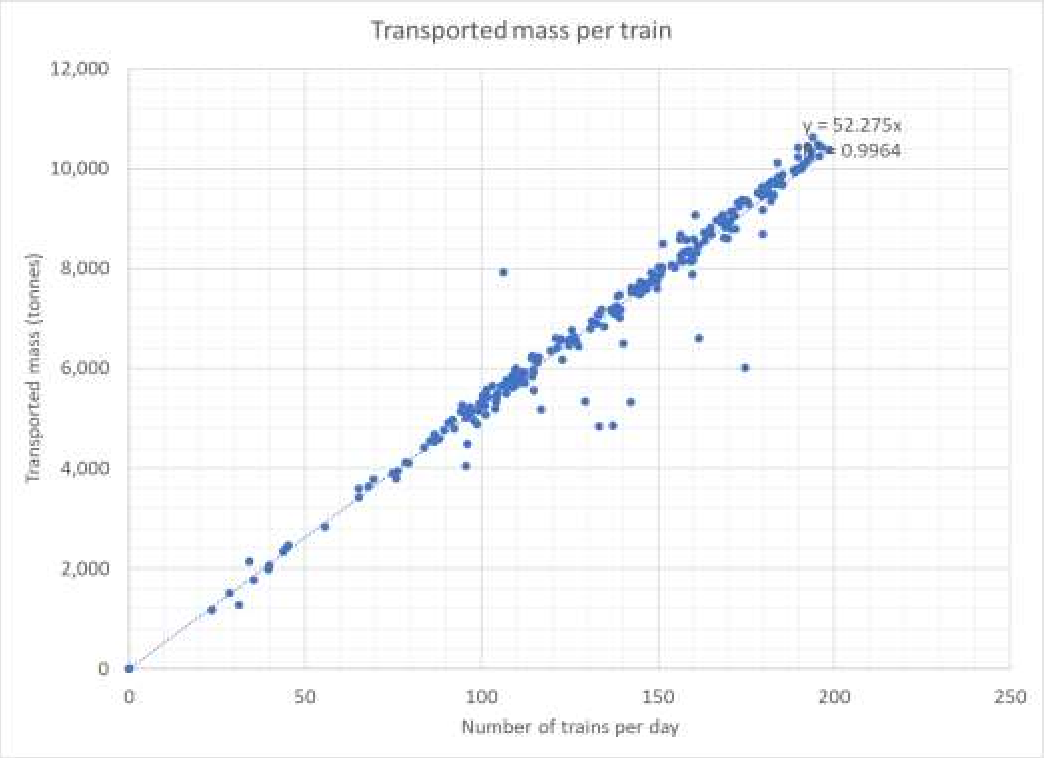
What is the Railveyor?

+

That is the Railveyor EV technology

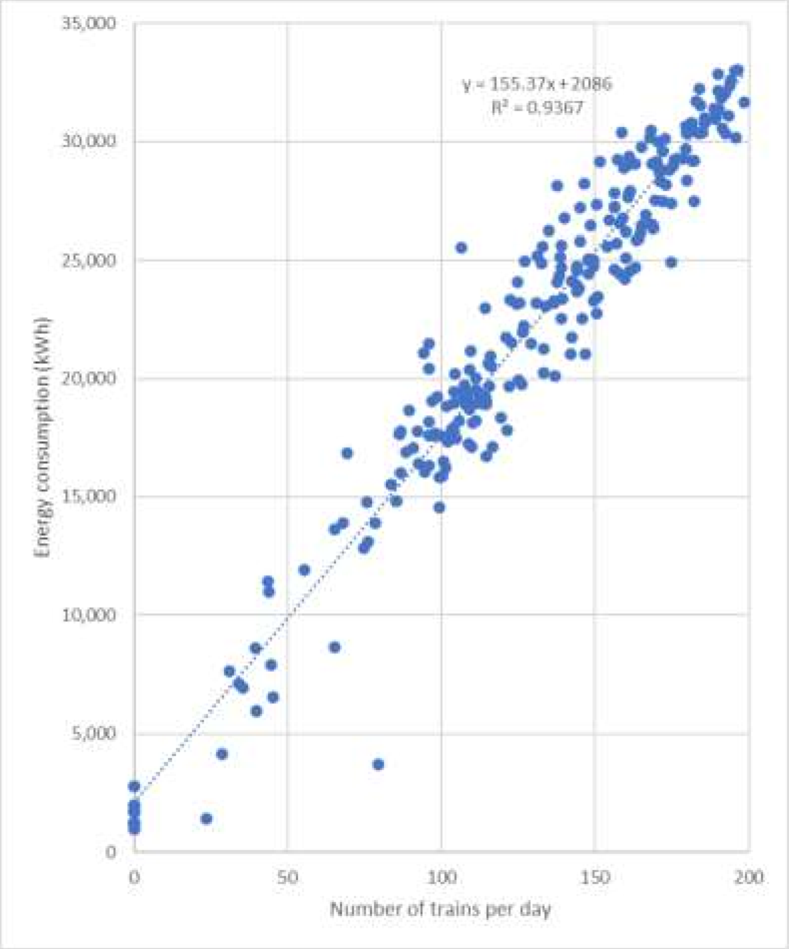
Goldex Mine - Railveyor application results

- Data from the 1st January to the 31st September 2022 (243 days).
- Ramp distance 3 km, vertical elevation 553 m.
- The average transported tonnage per train was 52.3 tonnes (± 6.6 tonnes)



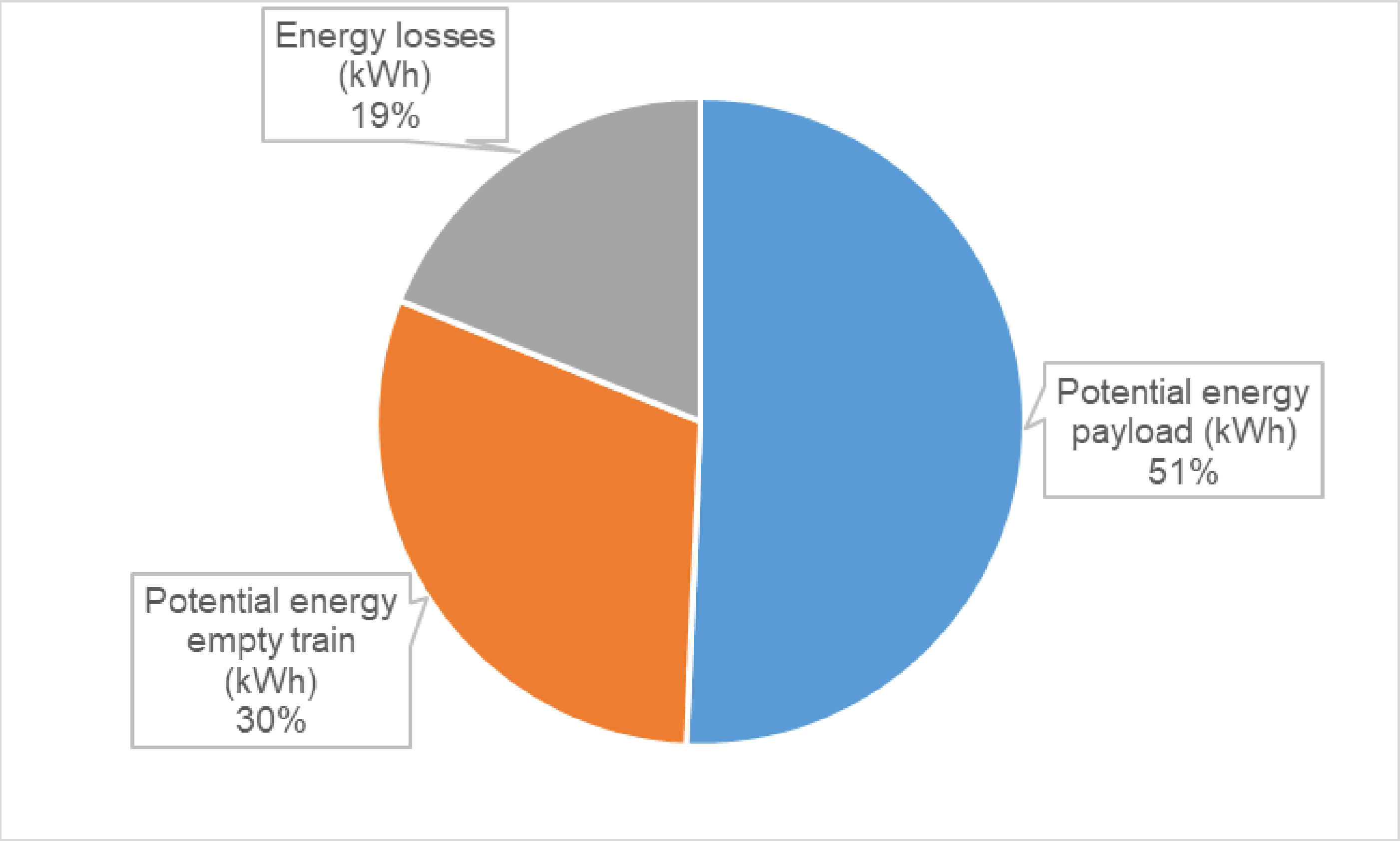
Goldex Mine - Railveyor application results

- Average energy per train is 155.4 kWh.



Goldex Mine - Railveyor application results

- The 155.4 kWh per train can be separated by category:
  - 126.0 kWh are consumed by the potential energy of the transported loaded train. Including 78.8 kWh for the material or payload and 47.2 kWh for the empty train mass.
  - 29.4 kWh are consumed by losses per train which includes rolling resistance and system efficiency.



How to use the results for other studies?

- Other mine applications could have different duty cycles:
  - speeds
  - loads
  - grades
  - distances
- Making use of these results for other analysis is not a straightforward ‘rule of thumb’ process, but it can still be done

How to use the results for other studies?

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  - This includes the power needed to move the vehicle

$$P_m = v(mgsin\theta + mgC_r cos\theta + \frac{1}{2}\rho v^2 A_{front} C_d + ma)$$

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - This includes the power needed to move the vehicle, which has five components:
    - vertical (gravitational potential)

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    - rolling resistance

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    - rolling resistance
    - drag

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  - This includes the power needed to move the vehicle, which has five components:
    - vertical (gravitational potential)
    - rolling resistance
    - drag
    - acceleration
    - and speed

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - This includes the power needed to move the vehicle
  - Power for auxiliary consumption (lights and controls)

$$P_m = v(mgsin\theta + mgC_r cos\theta + \frac{1}{2}\rho v^2 A_{front} C_d + ma)$$

$$P_{aux} = P_{others}$$

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - This includes the power needed to move the vehicle
  - Power for auxiliary consumption (lights and controls)
  - Energy required for moving and auxiliary consumption

$$P_m = v(mgsin\theta + mgC_r cos\theta + \frac{1}{2}\rho v^2 A_{front} C_d + ma)$$

$$P_{aux} = P_{others}$$

$$E_{duty\ cycle} = \sum_{i=0}^{n} \left(\frac{P_{m\,i}}{\eta_{EVcons}}, P_{m\,i} \cdot \eta_{EVcapt} + \frac{P_{aux\,i}}{\eta_{EVcons}}\right) \Delta t_i$$

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - The duty cycle provides speeds

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How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - The duty cycle provides speeds, loads

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How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - The duty cycle provides speeds, loads, grades

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How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - The duty cycle provides speeds, loads, grades and distances (or time at a certain speed)

$$P_m = v(mg\sin\theta + mgC_r\cos\theta + \frac{1}{2}\rho v^2 A_{front} C_d + ma)$$

$$P_{aux} = P_{others}$$

$$E_{duty\ cycle} = \sum_{i=0}^{n} \left(\frac{P_{m\,i}}{\eta_{EVcons}}, P_{m\,i} \cdot \eta_{EVcapt} + \frac{P_{aux\,i}}{\eta_{EVcons}}\right)\Delta t_i$$

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - Drag and acceleration are considered negligeable for the speed considered.

$$P_m = v(mg\sin\theta + mgC_r\cos\theta + \tfrac{1}{2}\rho v^2 \ldots_{nt} C_d + \ldots)$$

$$P_{aux} = P_{others}$$

$$E_{duty\ cycle} = \sum_{i=0}^{n} \left(\frac{P_{m\,i}}{\eta_{EVcons}}, P_{m\,i} \cdot \eta_{EVcapt} + \frac{P_{aux\,i}}{\eta_{EVcons}}\right) \Delta t_i$$

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - Due to nature of data, it was assumed that the auxiliary power consumption was 0 kW
  - Energy was dissipated in the form of heat while returning downhill (power captured was 0 kW)

$$P_m = v(mgsin\theta + mgC_r cos\theta + \frac{1}{2}\rho v^2 A_{front} C_d + ma)$$

$$= P_{others}$$

$$E_{duty\ cycle} = \sum_{i=0}^{n} \left(\frac{P_{m\,i}}{\eta_{EVcons}}, P_{m} \ldots_{EVcapt} + \frac{\ldots_{i}}{\eta_{EVcons}} \right) \Delta t_i$$

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - Rolling resistance coefficient

$$P_m = v(mgsin\theta + mgC_r cos\theta + \frac{1}{2}\rho v^2 A_{front} C_d + ma)$$

$$P_{aux} = P_{others}$$

$$E_{duty\ cycle} = \sum_{i=0}^{n} (\frac{P_{m\,i}}{\eta_{EVcons}}, P_{m\,i} \cdot \eta_{EVcapt} + \frac{P_{aux\,i}}{\eta_{EVcons}})\Delta t_i$$

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
  - Rolling resistance coefficient and the vehicle efficiency remain to be determined

$$P_m = v(mg\sin\theta + mgC_r\cos\theta + \frac{1}{2}\rho v^2 A_{front}C_d + ma)$$

$$P_{aux} = P_{others}$$

$$E_{duty\ cycle} = \sum_{i=0}^{n} \left(\frac{P_{m\,i}}{\eta_{EVcons}}, P_{m\,i} \cdot \eta_{EVcapt} + \frac{P_{aux\,i}}{\eta_{EVcons}}\right)\Delta t_i$$

How to use the results for other studies?

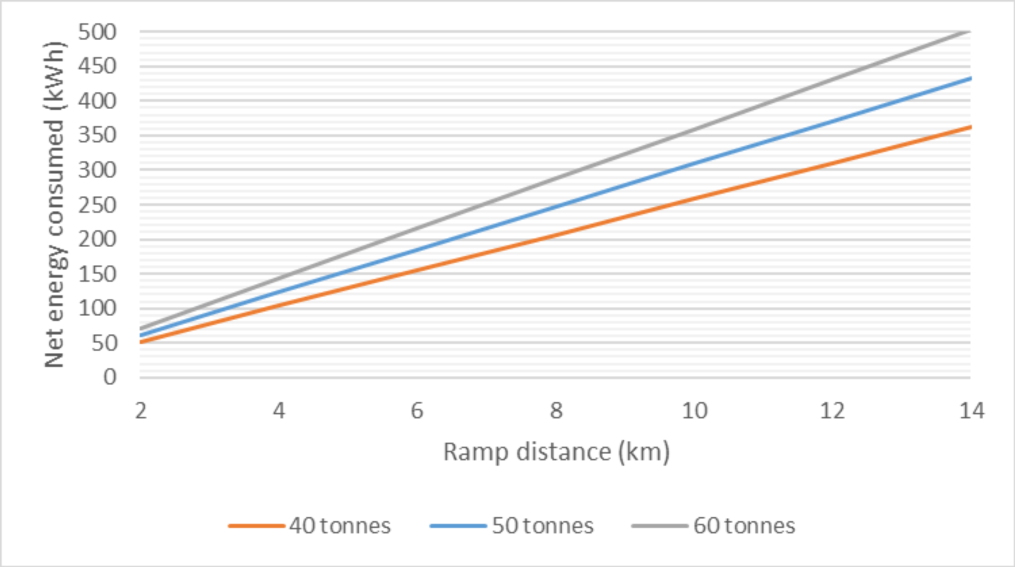
- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
- Then calibrate the ECM with the field data from Goldex study
  - Calibrate means finding the values of the rolling resistance coefficient and the vehicle efficiency that minimize the difference between the model prediction and the field test results (P_{aux} = 0 kW)

$$Minimize \sum_{i=0}^{n} (Etest_i - Emodel_i)^2$$

$$Subject\ to\ C_r, P_{aux}, \eta_{EVcons} \geq 0$$

How to use the results for other studies?

- A model can be derived from first principles to assess energy consumed Energy Consumption Model (ECM)
- Then calibrate the ECM with the field data from Goldex study
- Finally, the calibrated ECM can be used to predict energy consumption under different duty cycles, which for example could include different grades and tonnages.



Energy Consumption Model (ECM) calibration

- ECM calibration results:

Case	Initial
Cr (%)	0.5
Paux (kW)	0
ηEVcons (%)	83.3
Energy (kWh)	155.4

- Were parameters in the expected range?
  - Rolling resistance coefficient for rails is within predicted range by literature (0.2 to 0.8%). Reference: GROTE, K-H and ANTONSSON, E K (editors) (2009), Springer handbook of mechanical engineering, Springer, see p1023.
  - Electric system efficiency was within range as per previous CanmetMINING research.

Energy Consumption Model (ECM) calibration

- ECM calibration results:
  - with 88% system efficiency

Case	Initial	88% Eff
Cr (%)	0.5	1.6
Paux (kW)	0	0
ηEVcons (%)	83.3	88.0
Energy (kWh)	155.4	155.4

- Where parameters in the expected range?
  - The new obtained rolling resistance coefficient value reflects the wheel/rail and the tire/cart contacts.
  - Electric system efficiency was within range as per previous CanmetMINING research.

Energy Consumption Model (ECM) calibration

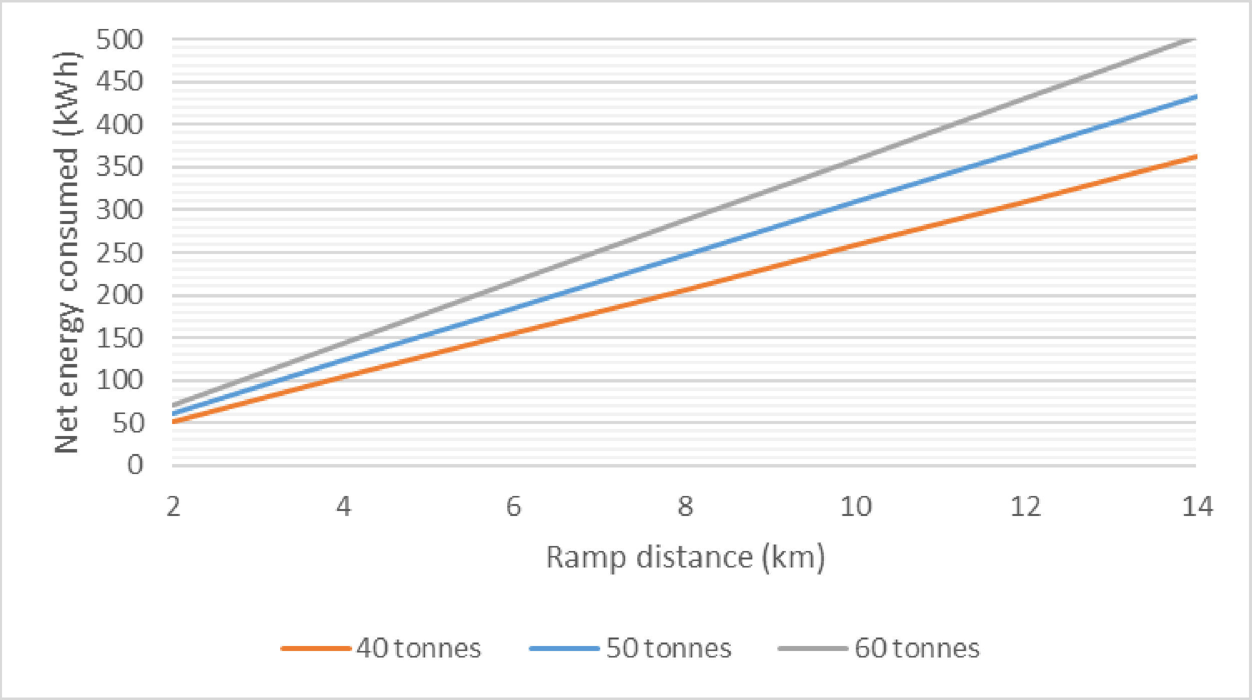
- ECM calibration results:
  - Middle
  - Mass 83.6 tonnes (52.3 load + 31.3 train).
  - Speed 10.8 km/h (3 m/s).
  - Grade 18.8%.

Case	Initial	88% Eff	Middle
Cr (%)	0.50	1.6	1.00
Paux (kW)	0	0	0
ηEVcons (%)	83.3	88.0	85.4
Energy (kWh)	155.4	155.4	155.4

- Calibrated ECM results were 155.4 kWh for one train trip, same as average from study results, with all parameter sets.
- Middle parameter set selected to account for inputs of literature, original equipment manufacturer and time of operation.

‘What if’ ramp scenarios with different grade and tonnages including regeneration

- Different loads were considered: 40, 50 and 60 tonnes. Railveyor design limit was 60 tonnes.
- For a ramp distance ranging from 2 to 14 km, with a grade of 15%.
- ECM calculated with (155.4 kWh):
  - C_r = 1.0%
  - P_{aux} = 0 kW
  - η_{EVcons} = 85.4%



Summary

- The results of the field study performed to the operational Railveyor EV technology setup implemented at Goldex Mine, Agnico Eagle, were presented.
- An energy consumption model (ECM) based on first principles was presented and calibrated with the study field data for the Goldex application. The calibrated ECM results matched the study data.
- The calibrated ECM was used to predict energy consumed under different grade, tonnage and ramp length conditions.
- More studies will be required to determine the potential for capturing energy while the train travels downhill.

Thank you!
Questions?

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