Models for estimating energy consumption and CO$_2$ emissions due to rolling resistance

Session 325: Road Infrastructure Reduction in CO2 emission by reducing pavement rolling resistance

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Overview

1) Introduction and motivation

2) Modeling approaches

3) Simulation results
   a) AIT simulations
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4) Conclusions and outlook
Introduction and motivation

• CO₂ emissions from road transport contribute to climate change

• Overall objective: Optimization of road infrastructure characteristics to reduce fuel consumption and greenhouse gas emission

• Rolling resistance due to tire-road interaction is a key parameter which can be influenced by pavement design and management

• MIRIAM topics:
  • Measurement models and simulation capabilities for rolling resistance
  • Integration of rolling resistance expertise into pavement management
Introduction and motivation

Activities in MIRIAM first phase:

• Investigation of the influence of pavement characteristics on energy efficiency
• Evaluation of existing expertise
• Evaluation of available modeling capabilities
• Identification and analysis of influencing parameters
Modeling approaches

Objective:

- Model energy efficiency and rolling resistance (RR) as a function of road surface characteristics
- First approach:
  - Characterize road surface by unevenness (IRI) and macrotexture (MPD)
  - Derive target RR function based mainly on IRI, MPD, speed
  - Integrate this function into a larger model (e.g. VETO)
- Second approach:
  - Use direct model of unevenness and texture
  - Use vehicle dynamic model to model the reaction of the vehicle
  - Integrate into larger model
VTI modeling approach

- Follows first approach for macrotexture (MPD) and unevenness (IRI), alternative approach concerning IRI possible
- Uses VETO model based on experience from IERD and ECRPD projects
- General rolling resistance model based on literature, coast-down measurements and drum measurements:
  \[ Cr = Cr_0 + Cr_1 \cdot IRI \cdot v + Cr_2 \cdot MPD \]
- \( Cr_i \) parameters for Passenger cars, trucks and tires

Source: Hammarström, VTI
VTI modeling approach

Driving resistance influences torque and energy consumption

*Figure 4.1 Engine map (g/kWh) for petrol engine. Engine specification: petrol, year model 1996-2003; PMrat=100 kW, displacement=1.95 dm³.*

Source: Hammarström, VTI
VTI modelling approach

- Fuel consumption model on a link level - parameters
  - rolling resistance (based on IRI, MPD)
  - road curvature
  - road alignment
  - air resistance
  - speed
  - vehicle type: passenger car (PC), truck, truck with trailer
Simulation results - VTI

Influence of macrotexture (MPD) variation on fuel consumption for a PC at different speeds

Figure 6.4 Fcs as a function of the road surface condition (mpd) and speed for a car. Scl 1.

Source: Hammarström, VTI
Simulation results - VTI

Influence of macrotexture (MPD) variation on fuel consumption for a truck at different speeds

Figure 6.5 Fcs as a function of the road surface condition (mpd) and speed for a heavy truck. ScI 1.

Source: Hammarström, VTI
Simulation results - VTI

Influence of macrotexture (MPD) variation on fuel consumption for a truck and trailer at different speeds

*Figure 6.6 Fcs as a function of the road surface condition (mpd) and speed for a truck+trailer. Scl 1.*

Source: Hammarström, VTI
Simulation results VTI

At an average speed of 90 km/h (alignment standard scl 1) the simulated fuel consumption $F_{cs}$ increases per unit increase of MPD by:

- car: 2.8 %
- heavy truck: 3.4 %
- truck+trailer: 5.3 %.

The importance of MPD increases with increasing vehicle weight. Road alignment and IRI influence speed, which can reduce the values given above.
Simulation results - VTI

Influence of unevenness (IRI) variation on fuel consumption for a PC at different speeds

Figure 6.7  Fcs as a function of the road surface condition (iri) and speed for a car  Scl 1.
Source: Hammarström, VTI
Simulation results - VTI

Influence of unevenness (IRI) variation on fuel consumption for a truck at different speeds

Figure 6.8 Fcs as a function of the road surface condition (iri) and speed for a heavy truck. Source: Hammarström, VTI
Simulation results - VTI

Influence of unevenness (IRI) variation on fuel consumption for a truck and trailer at different speeds

Figure 6.9 Fcs as a function of the road surface condition (iri) and speed for a truck+trailer. Sc1 1.

Source: Hammarström, VTI
Simulation results VTI

At an average speed of 90 km/h (alignment standard scl 1) the simulated fuel consumption \( F_{cs} \) increases per unit increase of IRI by:

- car: 0.8 %
- heavy truck: 1.3 %
- truck+trailer: 1.7 %.

The importance of IRI increases with increasing vehicle weight.

Road alignment and IRI influence speed, which in turn can reduce the values given above.

Source: Hammarström, VTI
Simulation results VTI

- Fuel consumption functions showing the influence of road surface parameters were derived
- Road surface parameters were assumed to be constant along a link
- Further simplifications for integration into pavement management systems may be needed
- More different tyre models needed
- There is still a lack of useful data for validation of the models

Source: Hammarström, VTI
AIT modeling approach

Modeling strategy:
• Follows second approach
• 3D modeling of the road surface based on direct measurements of real road surfaces
• Simulation of interaction of the 3D road surface model with a tire model (FTire)
• Derivation of road surface influence on driving resistance
• Integration into a vehicle dynamics model (Dymola/Modelica)
AIT modelling approach

Road profile database interacts with tire model

- IRI,
- MPD,
- WLP,
- etc.

Measurement of RR

Image source: cosin scientific software
AIT modelling approach

Tire model -> Vehicle model -> Driving resistance -> Energy consumption

Driver Models

3D Road Graph

Probe Vehicle (validation)

FTire

Image source: Modelica
AIT modeling approach

Combined modeling of the influence of infrastructure parameters on energy efficiency:

- Curvature
- Crossfall
- Slope
- Longitudinal Profile
- Lateral Evenness
- Texture
Simulation results - AIT

- Simulation of tire/road interaction for 3D models of 24 real road surfaces
- Combined effects of all road surface effects
Simulation results - AIT

- Longitudinal resolution of 0.05 m
- Identification of very localized effects
- Analysis of unevenness wavelengths possible

![Simulation results graph](image-url)
Simulation results - AIT

- Estimation of effect on fuel consumption based on driving resistance effect
- Up to 3.5% predicted increase in fuel consumption
Conclusions and Outlook

- Two modeling approaches with different focus were developed, further integration needed
- Estimation of fuel consumption effects possible
- Many direct and indirect effects involved
- Road surface properties influence both rolling resistance and speed
- Road surface condition influence increases with increasing vehicle weight and with increasing road alignment standard
- Better connection to measurement methods needed
- Data basis needs to be widened and improved
Thank you for your attention!