Development of an Advanced Data Analytics Model to Improve the Energy Efficiency of Haul Trucks in Surface Mines

Research Team:

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Ali Soofastaei

BSc, MSc, PhD, MIEAus, PMP

12 years Work Experience in Mining, Oil and Gas Industry

7 years Work Experience in Academia (Mechanical, Industrial and Mining Engineering)

38 Published Journal Paper

19 Conference Paper

3 Patents

2 Developed Software

More Information :

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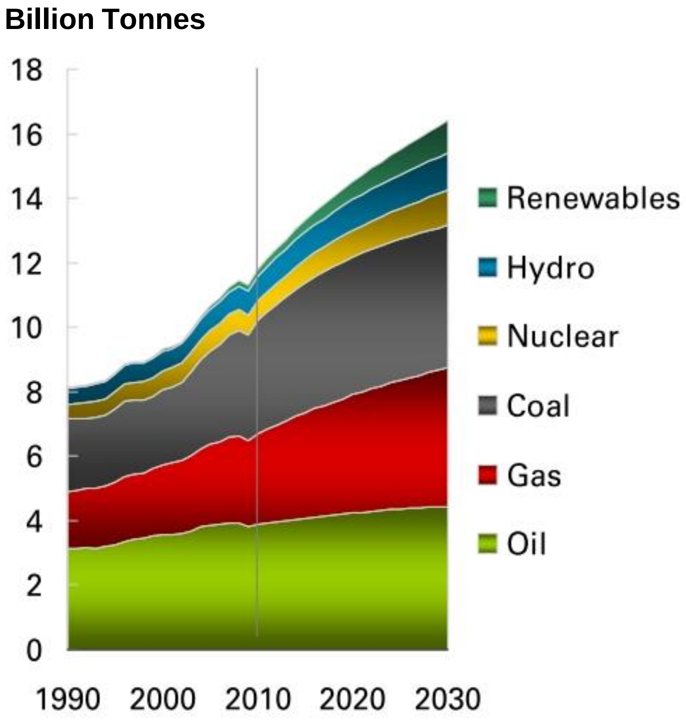
THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

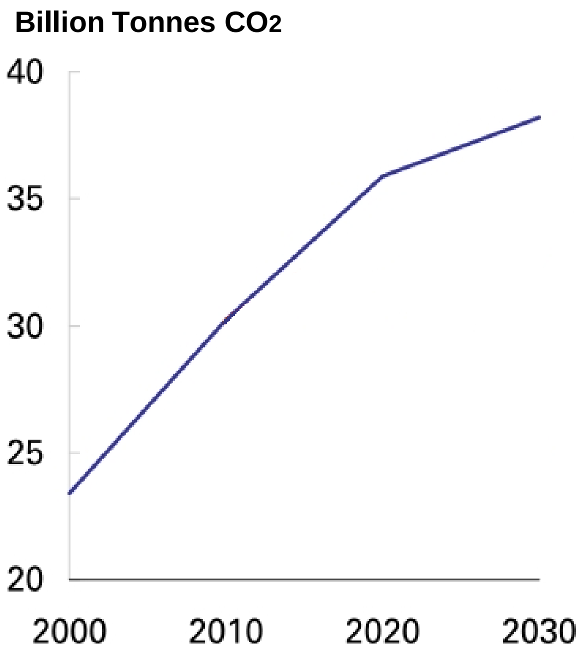
- 103 years old (founded in 1910)
- Over 43,000 students
- 10,500 international students from130 countries
- Ranked 48th in the world by time higher education (2015)

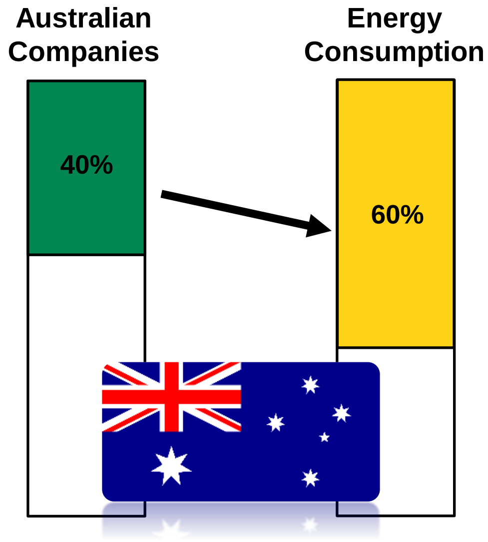
  The best research university in Australia by ERA (2014)
- Over 500 PhDs awarded annually
- Budget of $1.2 billion, research income $500 million

- Home to 1.9 million residents
- Inner-city beach, cultural centres, museums, art galleries, mall and world-class international airport
- Gateway to the gold and sunshine coasts, tropical islands, theme parks, great barrier reef, outback, golden beaches, and endless tourist attractions
- 243 days of sunshine throughout the year
- Multicultural, international city

Introduction







The international energy agency, estimates that by 2030 global energy needs will be **50%** higher than today and this will be **60%** in Australia. **(IEA, 2015)**

It is estimated that **60%** of energy use in Australia is consumed by **40%** of businesses with about **30%** Saving opportunity. **(EEO, 2014)**

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Aim and Objectives

Aim:

To develop an advanced data analytics model for analyzing the complex interactions that influence the energy efficiency of haul trucks in surface mining.

Objectives		Method
Identify key factors driving haul truck energy efficiency;	→	Literature Review
Select the most important controllable parameters;	→	Survey
Quantify the impact of the selected parameters;	→	Data Analysing (Non- linear Regressions)
Simulate the combined interaction of the parameters;	→	Artificial Neural Network (ANN)
Maximise resultant energy efficiency gains; and	→	Genetic Algorithm (GA)
Validate the resultant models.	→	Analysing Mine Site Real Data Sets

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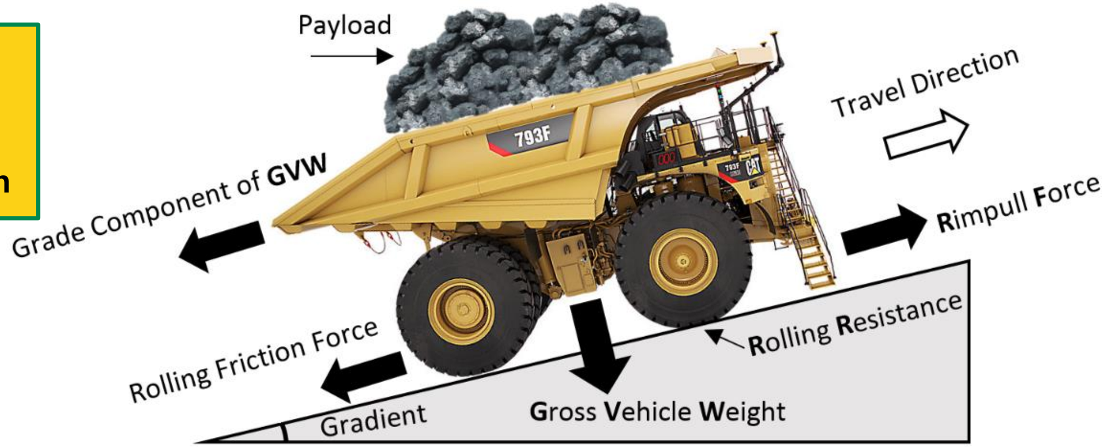
Identify key factors driving haul truck energy efficiency

Key Parameters Affecting Truck Fuel Consumption

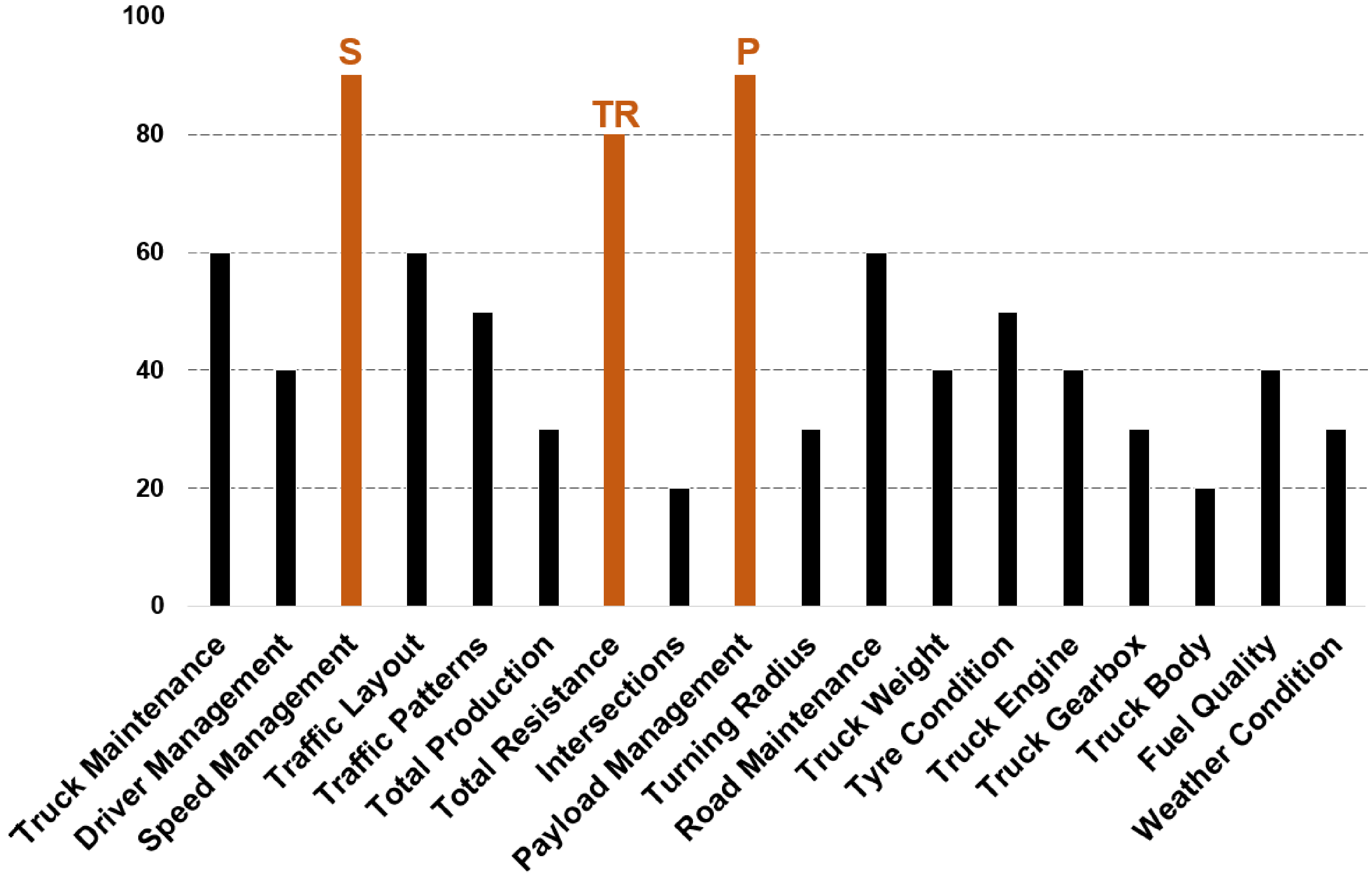
- **Fleet Management**
  - Truck Maintenance
  - Driver Management
  - Truck Speed
- **Mine Planning**
  - Traffic Layout
  - Traffic Patterns
  - Total Production
- **Fuel Quality**
- **Weather Condition**
- **Haul Road**
  - Total Resistance
  - Intersections
  - Turning Radius
  - Road Maintenance
- **Truck Design**
  - Payload
  - Tyre
  - Engine
  - Gearbox
  - Aerodynamic



References:

(Beatty and Arthur, 2009), (Peck and Lee, 2011), (Clark and Cox, 2008), (Masic, et al, 2011), (Li and Liu, 2012), (Bascetin, et al, 2010), (Kesimal, 2004), (Roobin and Wilson, 2008), (Satterthwait, 2013), (Lowery, 2010), (Carter, 2011), (Choi and Nieto, 2012), (E.E.O, 2012), (Wayne and Brus, 2001), (Holman, et al, 2006), (Peake and Septian, 2010), (Redich, 2012), (Wang, et al, 2013), (Caterpillar, 2011), (Anzabi, et al, 2012), (Kecojeric, et al, 2011), (Komatsu, 2012), (Mitsubishi, 2012), (Lee, 2010).

Select the most important controllable parameters



Criteria

Can we collect data?

Are they controllable?

Are they achievable?

Can we model them?

Are they important for industry?

Selected Parameters

Payload

Total Resistance

Truck Speed

Quantify the impact of the selected parameters
(Payload)

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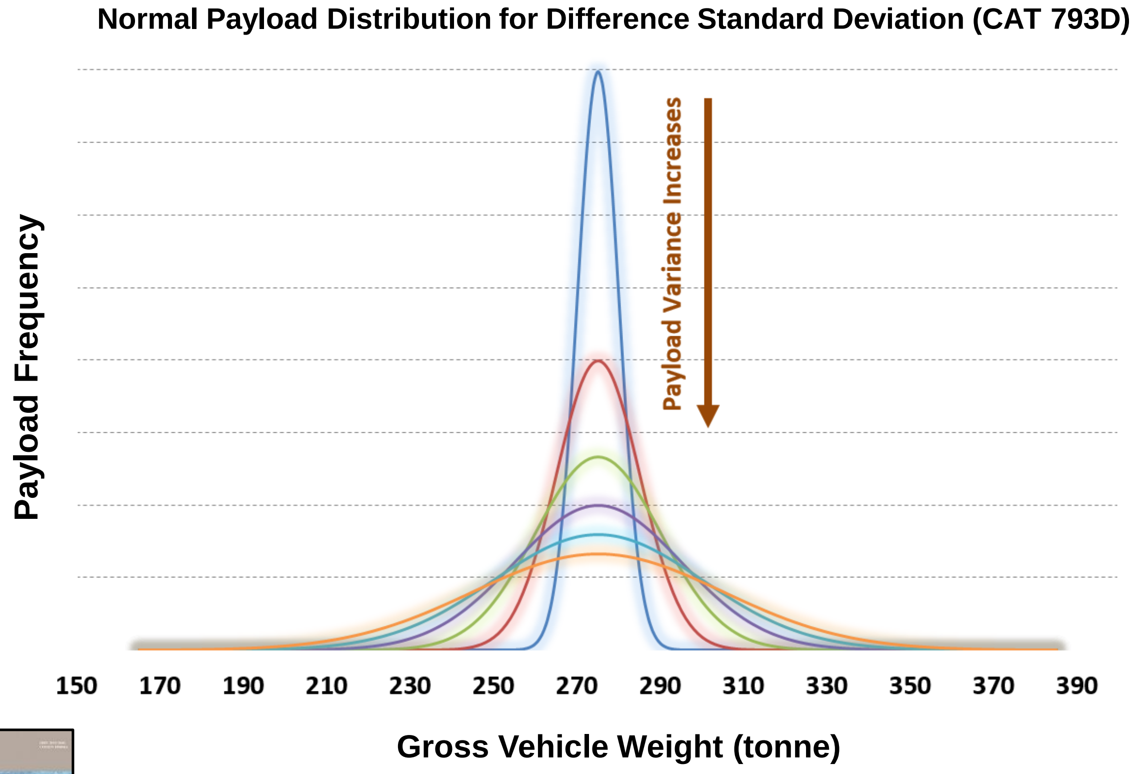
A Comprehensive Investigation of Loading Variance Influence on Fuel Consumption and Gas Emissions in Mine Haulage Operation

Effective Parameters on Loading Variance:

- Material density
- Truck-loader Matching
- Particle size distribution
- Number of shovel passes
- Swell factor



ELSEVIER

Soofastaei, A., Aminossadati, S.M., Kizil, M.S. and Knights, P., **A Investigation of Loading Variance Influence on Fuel Consumption and Gas Emissions in Mine Haulage Operation.** International Journal of Mining Science and Technology, (2016). 22(1): P. 245-258

Quantify the impact of the selected parameters
(Payload)

Calculated Indexes for CAT 793D with average Total Resistance 15% (Sample)

σ	FC_{Index} L/(tonne.hr)	Fuel $Cost_{Index}$ \$/(tonne.hr)	$CO_2\text{-}e_{Index}$ kg/(tonne.hr)	CO_2-e $Cost_{Index}$ \$/(tonne.hr)	Total $Cost_{Index}$ \$/(tonne.hr)
0	0.38	0.37	1.02	0.05	0.42
5	0.45	0.44	1.22	0.07	0.51
10	0.53	0.52	1.44	0.08	0.60
15	0.63	0.61	1.69	0.09	0.70
20	0.73	0.72	1.97	0.11	0.83
25	0.85	0.83	2.29	0.12	0.95
30	0.98	0.96	2.65	0.14	1.10

Data collected from [redacted] company (2015-2016)

Quantify the impact of the selected parameters
(Payload)

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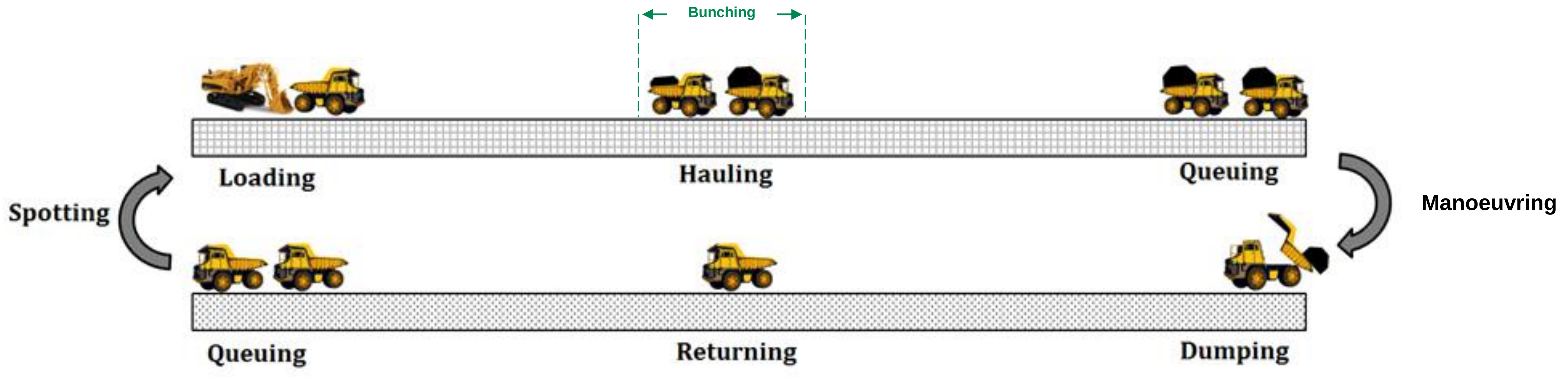
Truck Congestion (Bunching) in Deep Surface Mining Operations



Soofastaei, A., Aminossadati, S.M., Kizil, M.S. and Knights, P.,
A Discrete-Event Model to Simulate the Effect of Payload Variance on Truck Bunching, Cycle Time and Hauled Mine Materials.
International Journal of Mining Technology, (2016). 18(1): P. 161-179

Bunching

Heavily loaded trucks travel slower up ramps than lightly loaded trucks. Faster trucks are slowed by the presence of slower trucks, resulting in ‘bunching’ and production losses.

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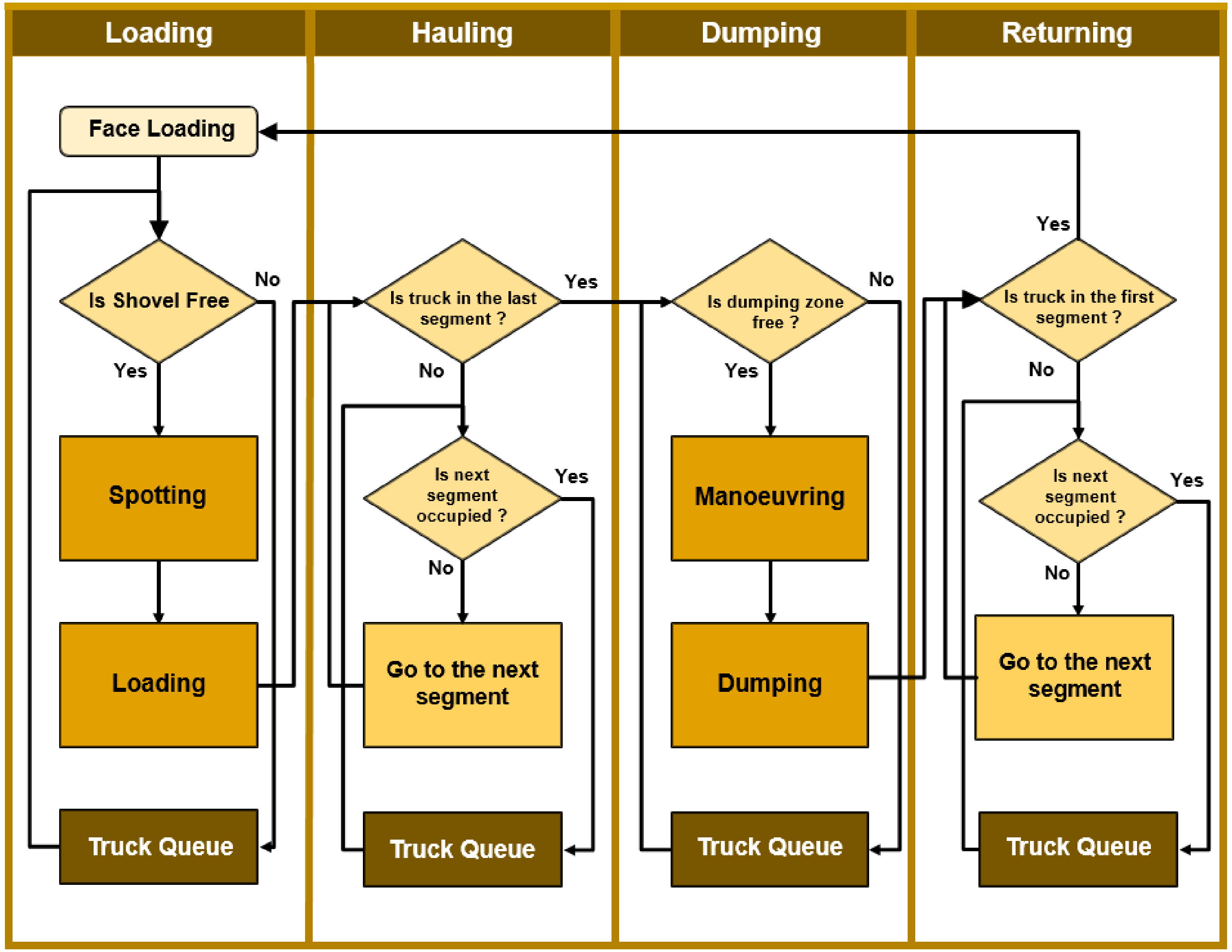
Quantify the impact of the selected parameters
(Payload)

Truck Congestion (Bunching) in Deep Surface Mining Operation



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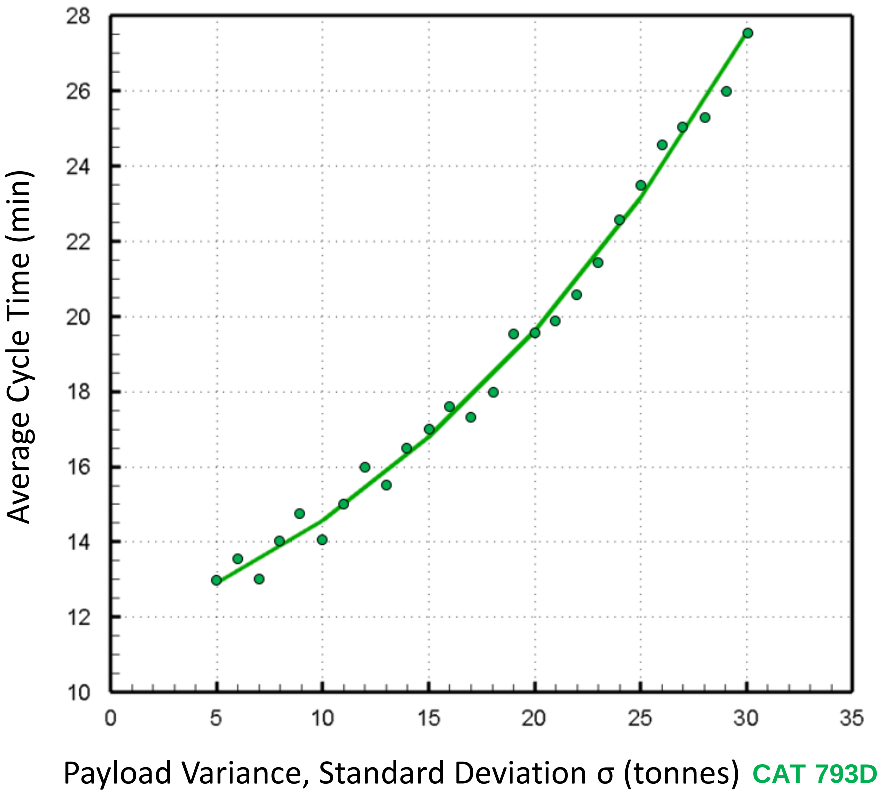
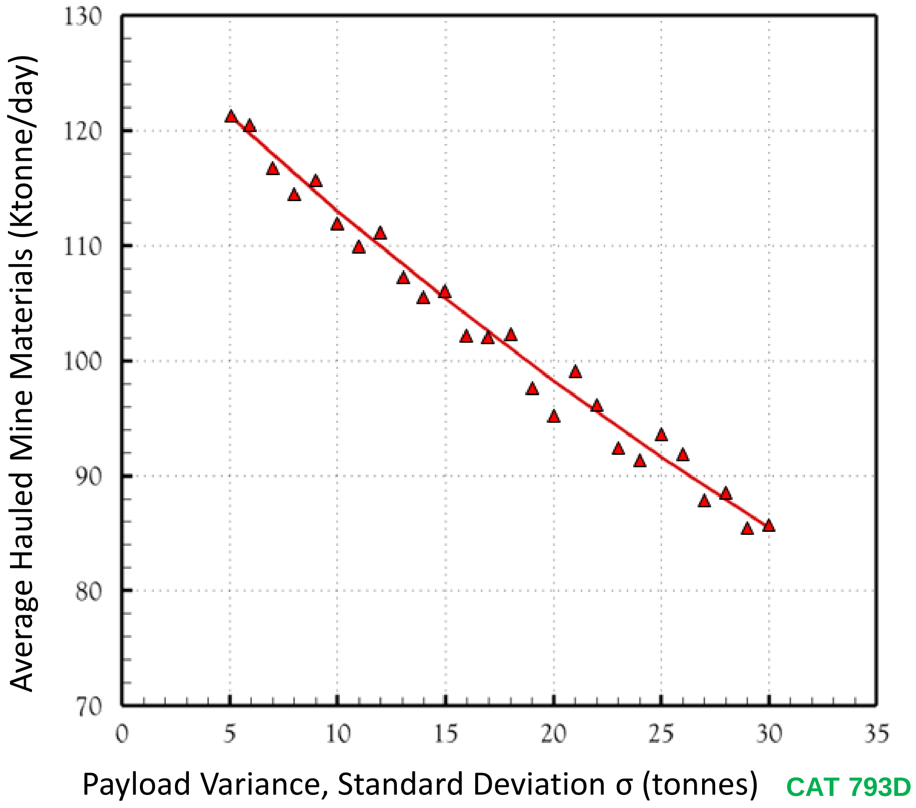
Truck Congestion (Bunching) in Deep Surface Mining Operations





Data collected from [redacted] company (2015-2016)

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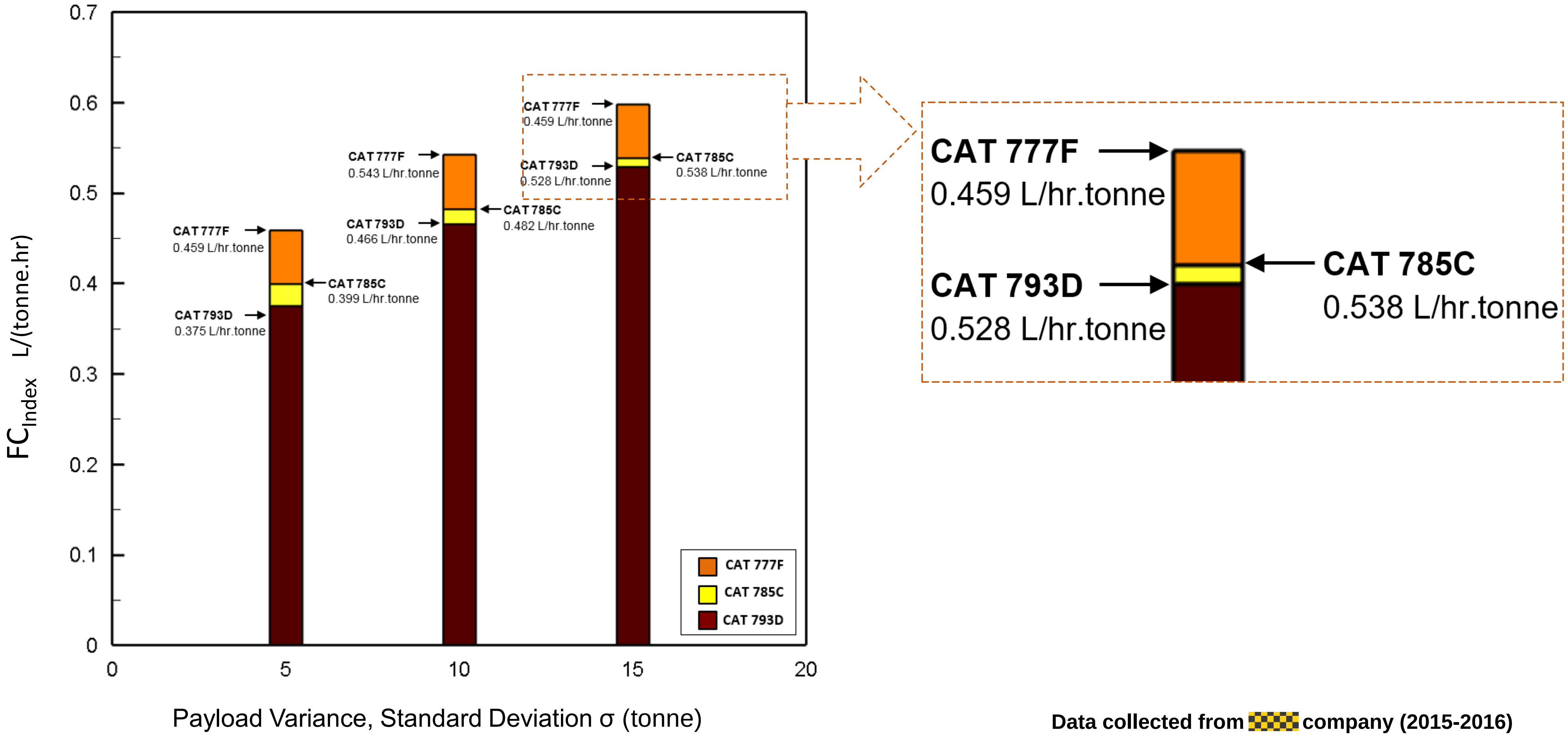
Quantify the impact of the selected parameters
(Payload)

Truck Congestion (Bunching) in Deep Surface Mining Operations



Data collected from [redacted] company (2015-2016)

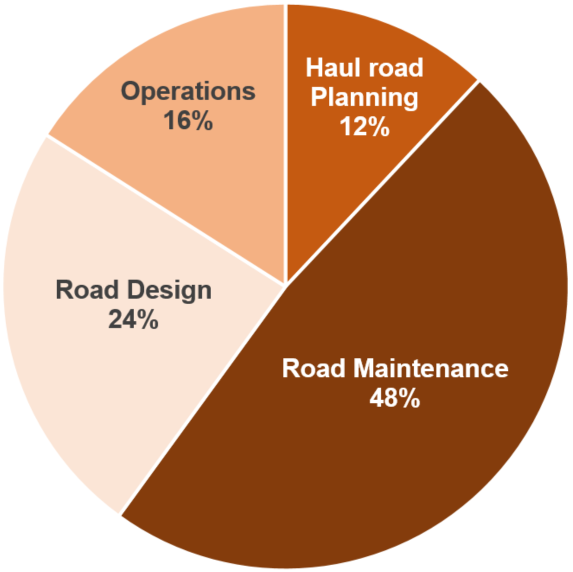
Quantify the impact of the selected parameters
(Total Resistance)

The Influence of Rolling Resistance on Haul Truck Fuel Consumption in Surface Mines

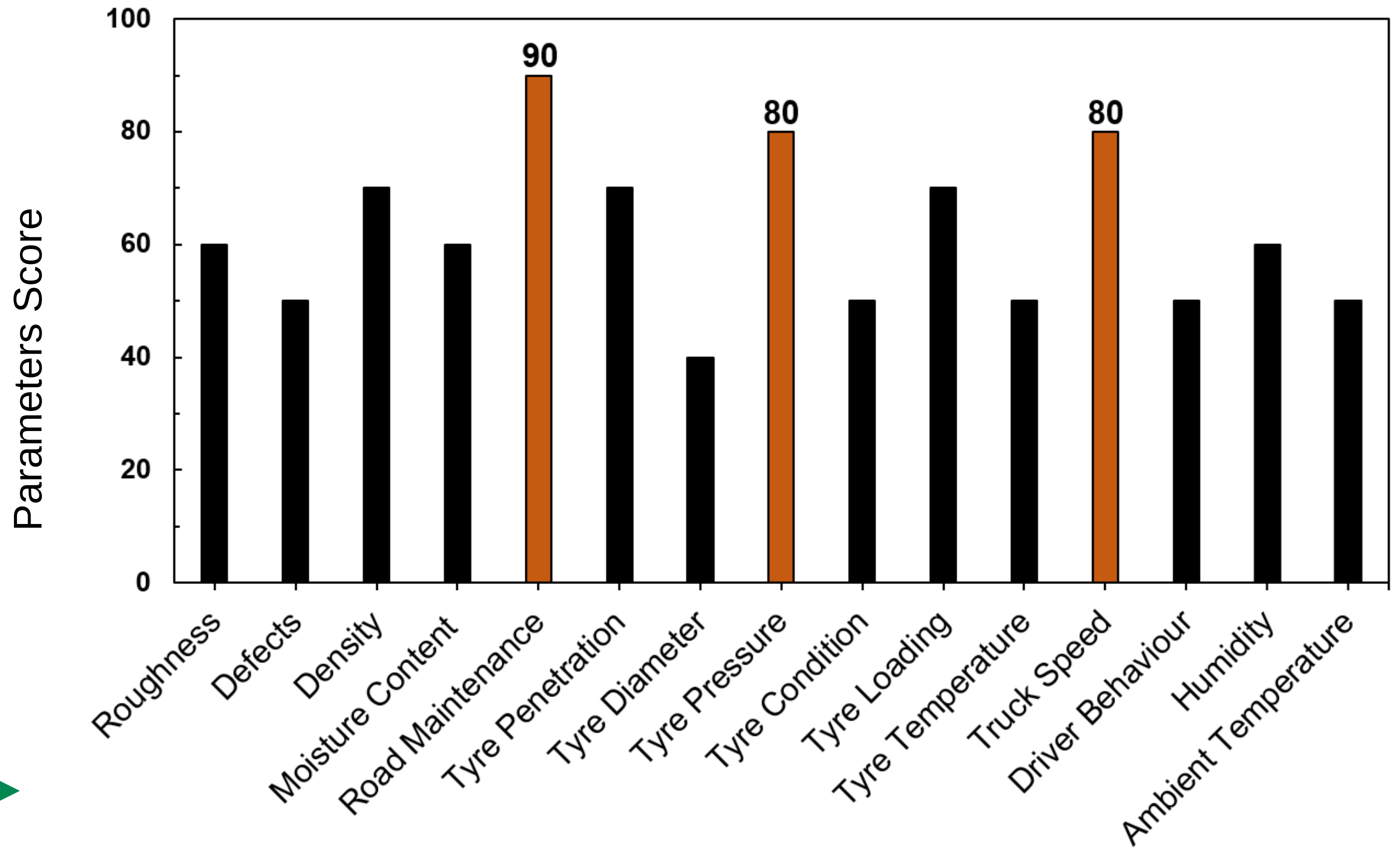
Online Survey

Participants: **50** Industry Personnel

Response Rate: **76%**

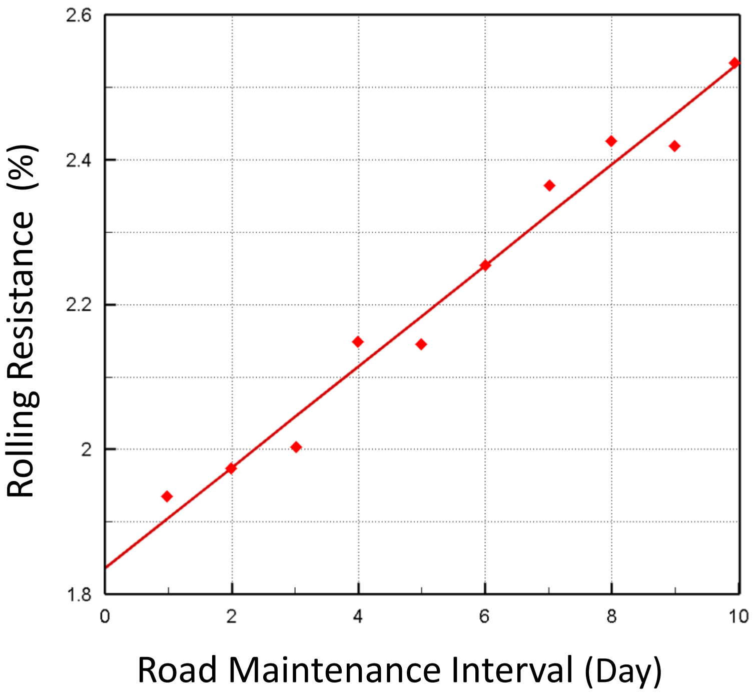


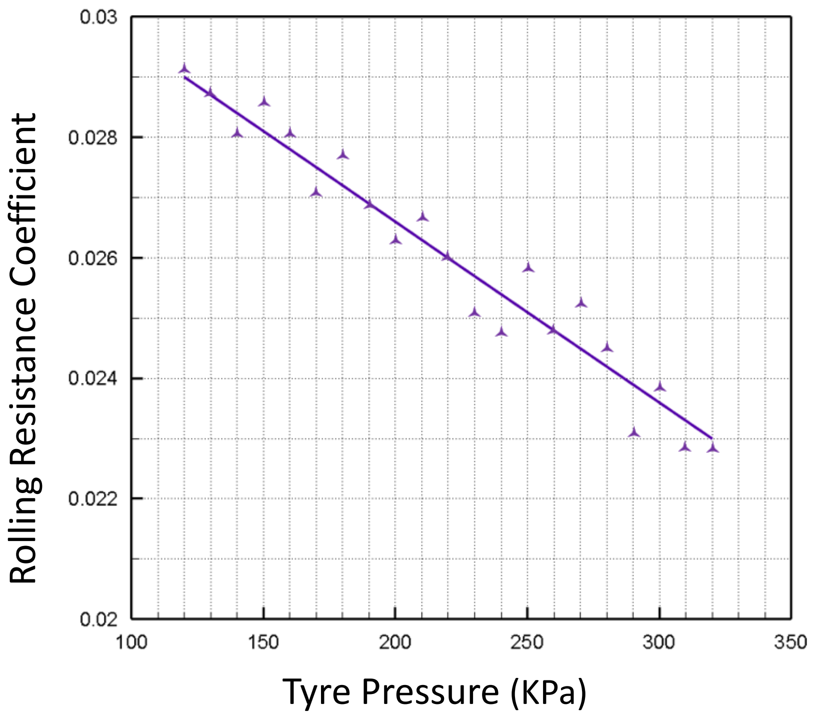
Influential Parameters on Rolling Resistance

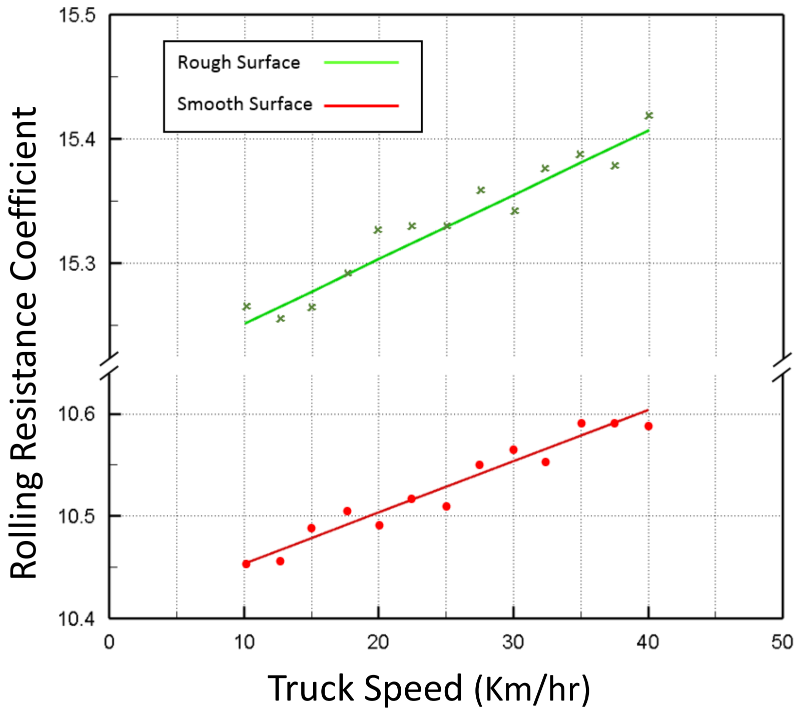


Quantify the impact of the selected parameters
(Total Resistance)

The Influence of Rolling Resistance on Haul Truck Fuel Consumption in Surface Mines







Curtin University

Roger Thompson, Western Australian School of Mines, Curtin University, 2013

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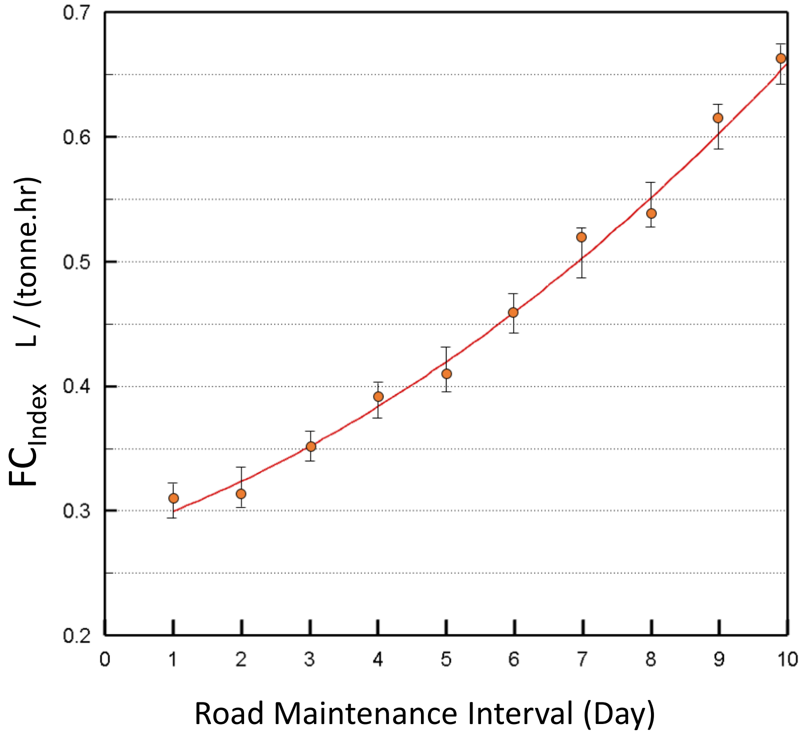
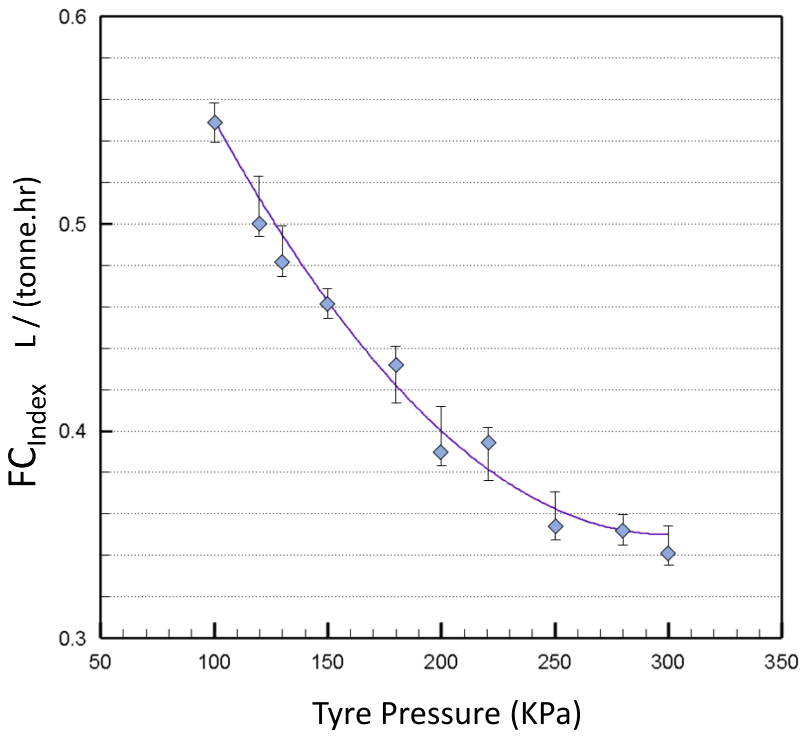
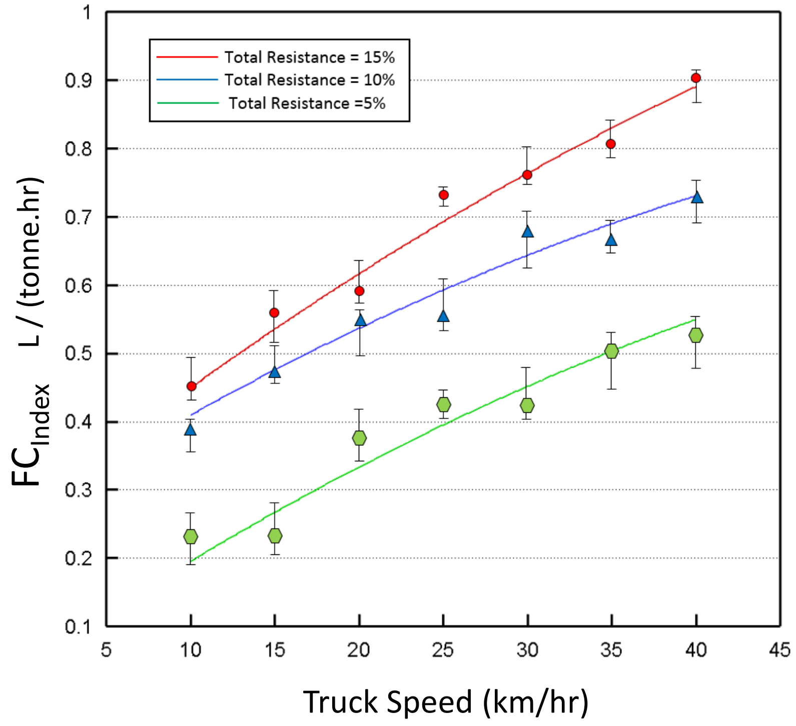
Quantify the impact of the selected parameters
(Total Resistance)

The Influence of Rolling Resistance on Haul Truck Fuel Consumption in Surface Mines







Data collected from [redacted] company (2015-2016)

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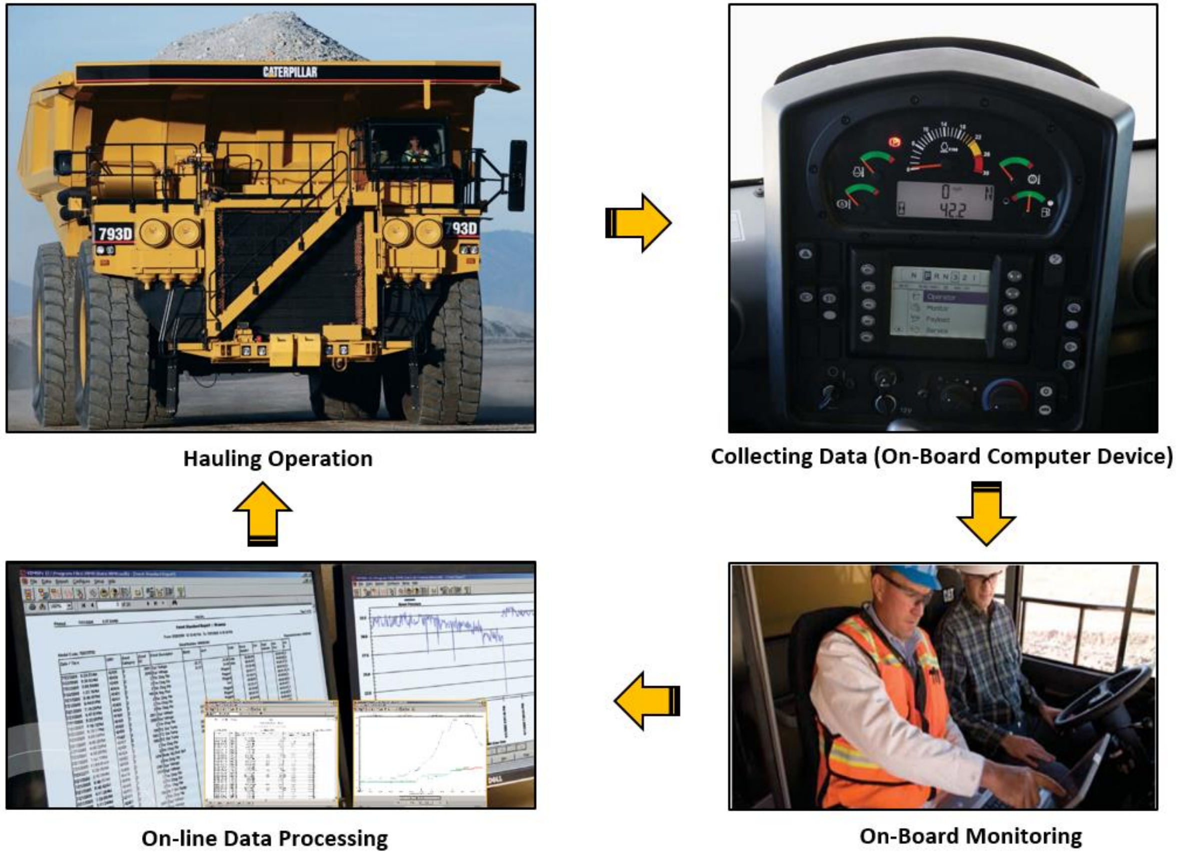
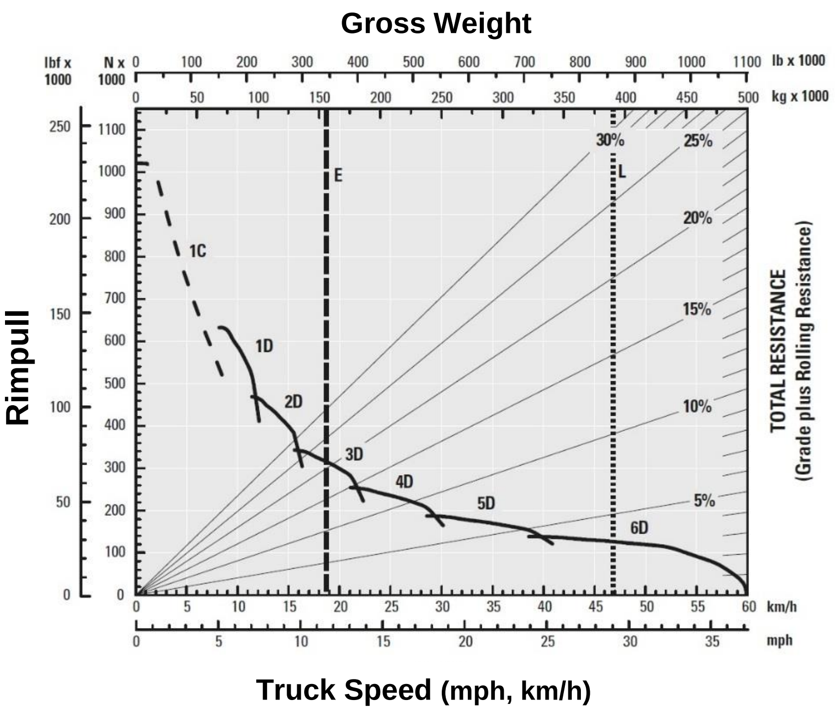
Soofastaei, A., Aminossadati, S.M., Kizil, M.S. and Knights, P.,
The Influence of Rolling Resistance on Haul Truck Fuel Consumption in Surface Mines. Tribology International Journal, (2016). 15(1): P. 185-191

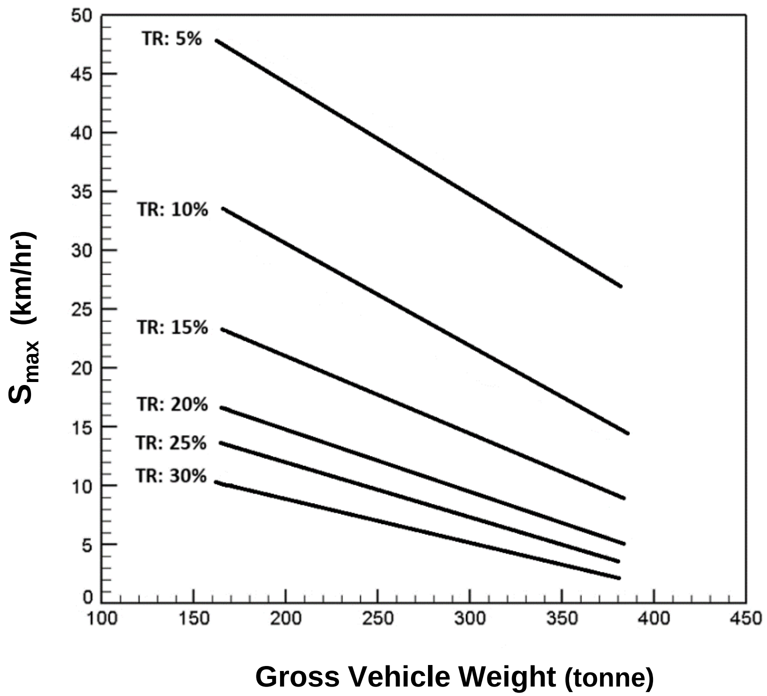
Quantify the impact of the selected parameters
(Truck Speed)

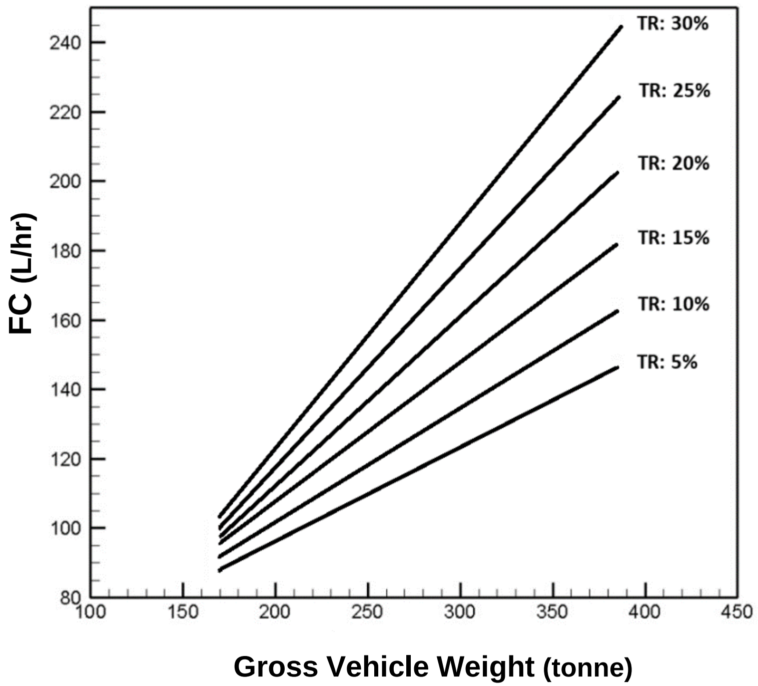


Quantify the impact of the selected parameters
(Truck Speed)

The Effect of Average Truck Speed on Fuel Consumption in Surface Mines







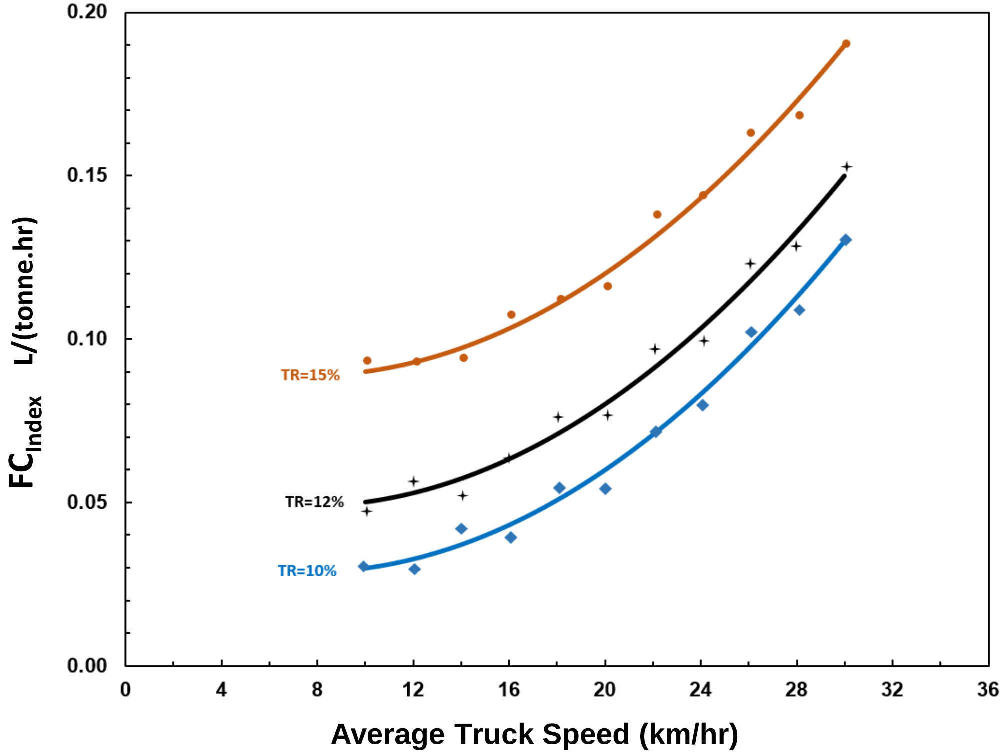
Completed based on the Caterpillar Performance Handbook (2015)

Quantify the impact of the selected parameters
(Truck Speed)

The Effect of Average Truck Speed on Fuel Consumption in Surface Mines

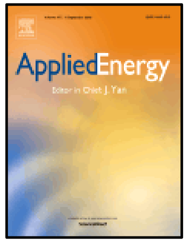
The [redacted] **mine** is a large iron mine located in western Australia in [redacted]. [redacted] represents one of the largest iron ore reserves in Australia and in the world having estimated reserves of **2** billion tonnes of ore grading **35.5%** iron metal.

Data collected from [redacted] company (2015-2016)



ELSEVIER

Soofastaei, A., Aminossadati, S.M., Kizil, M.S. and Knights, P.,
The Influence of Truck Speed on Energy Consumption.
Tribology International Journal, (2016). 12(2): P. 352-231



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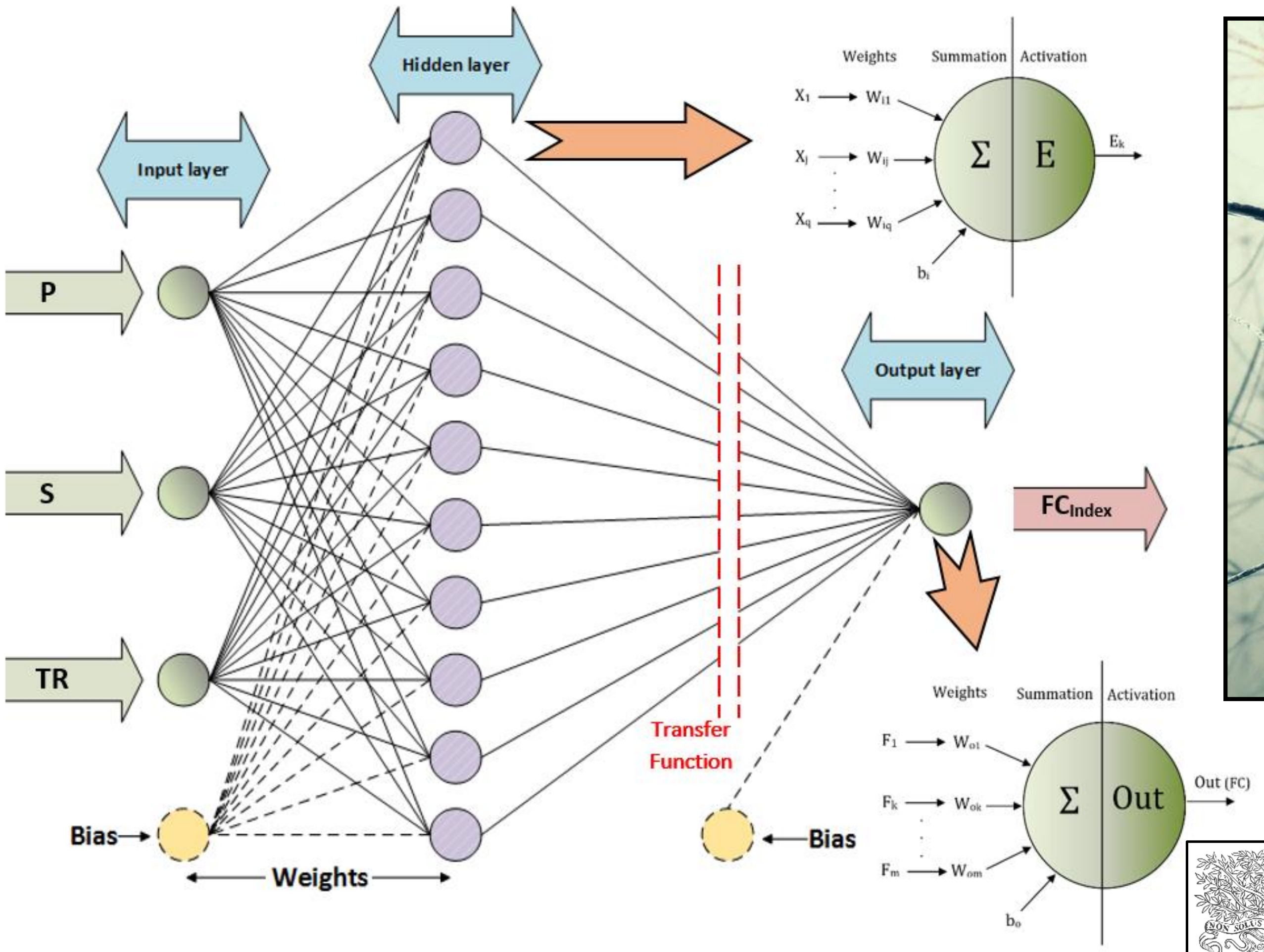
Simulate the combined interaction of the parameters

Artificial Neural Network (ANN)



P: Payload (tonne), **S:** Truck Speed (Km/hr), **TR:** Total Resistance (%)

FC_{Index} : Fuel Consumption (L/(tonne.hr))

ELSEVIER

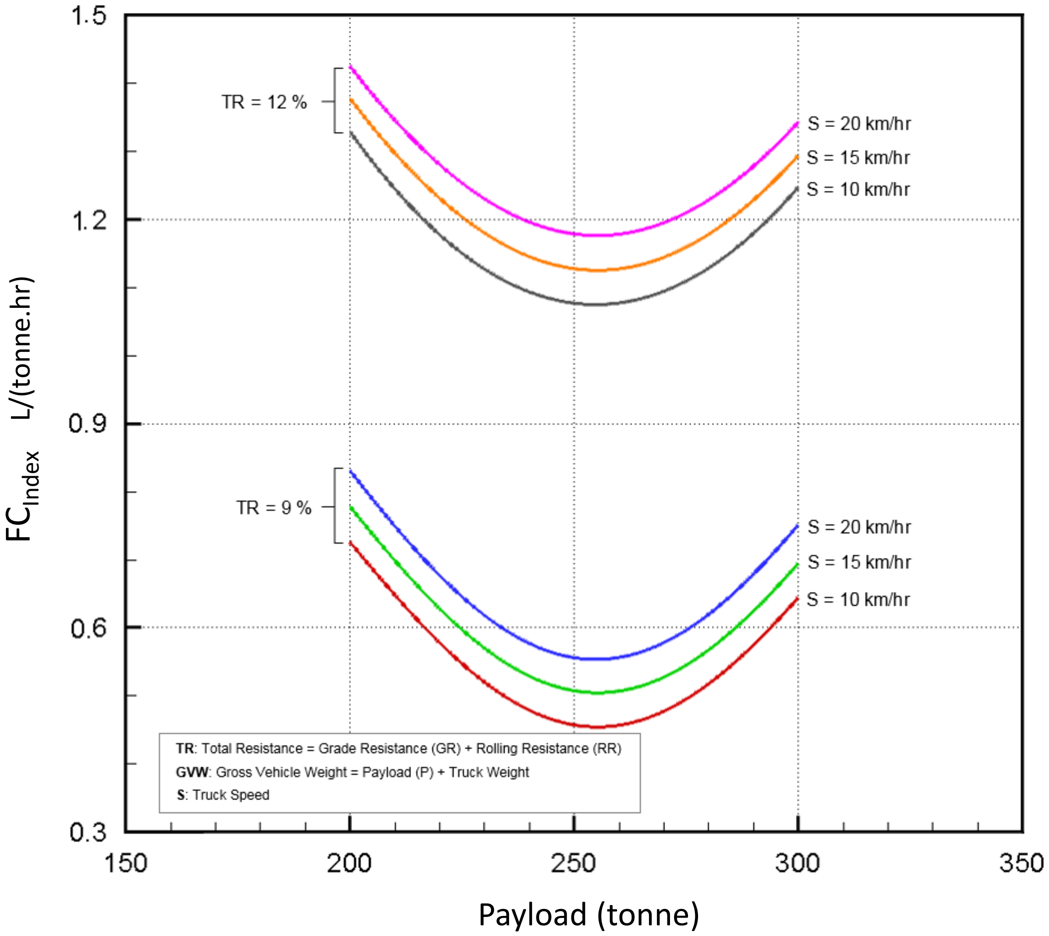
Soofastaei, A., Aminossadati, S.M., Arefi, M.M. and Kizil, M.S., **Development of a multi-layer perceptron artificial neural network model to determine haul trucks energy consumption.** International Journal of Mining Science and Technology, (2016). 26(2): P. 285-293

Simulate the combined interaction of the parameters

Artificial Neural Network (ANN)

[redacted] Mine

[redacted] mine is a coal mine located in the Central Queensland south of the town of [redacted]. The mine has coal reserves amounting to 877 million tonnes of coking coal, one of the largest coal reserves in Asia and the world. It has an annual production capacity of 13 million tonnes of coal.



Correlation between P, S, TR and FC_{Index} based on the developed ANN model for CAT 793D.

Data collected from [redacted] company (2015-2016)

Simulate the combined interaction of the parameters

Artificial Neural Network (ANN)

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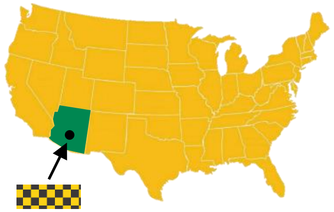
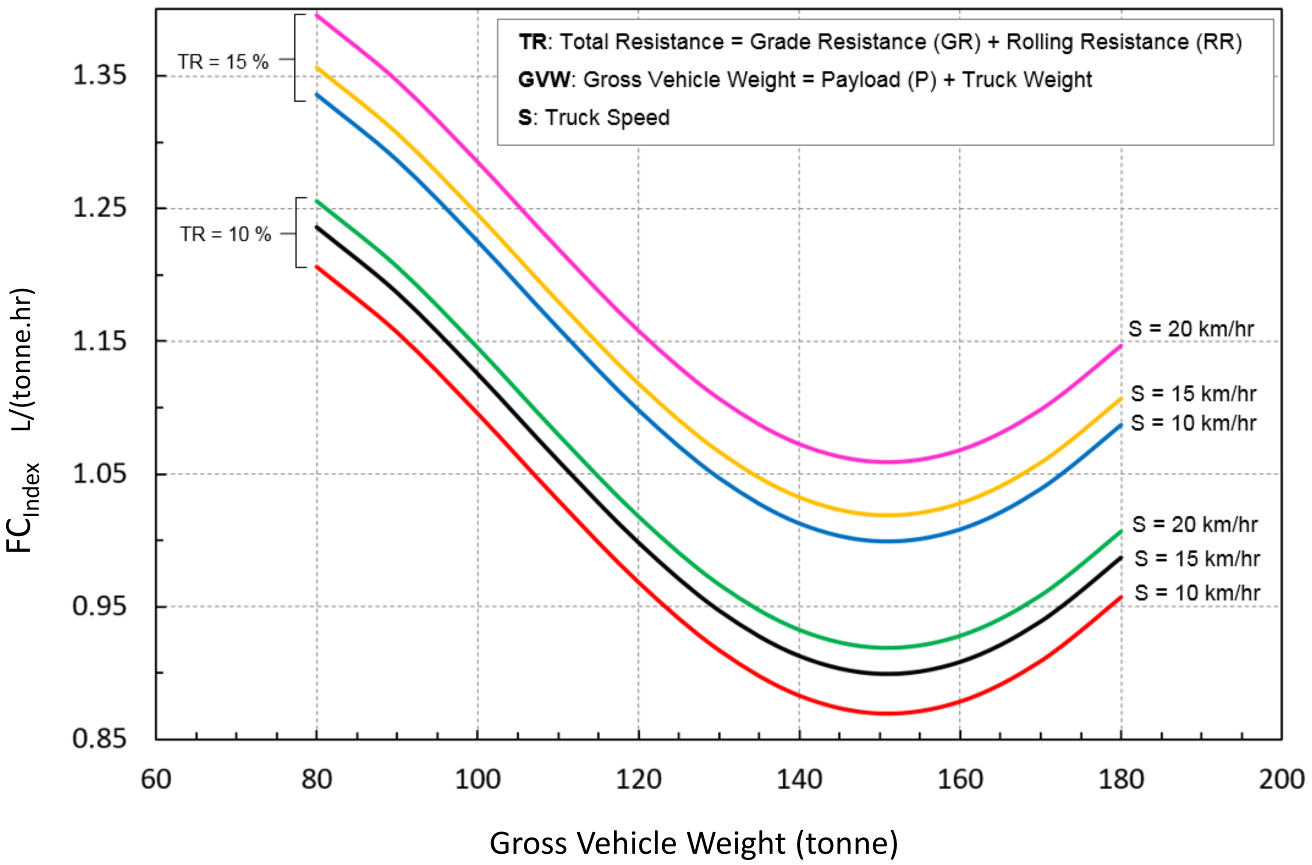


[redacted] Mine

The [redacted] mine is a large copper mine located in Arizona. [redacted] represents one of the largest copper reserves in the United States and in the world, having estimated reserves of 3.2 billion tonnes of ore grading 0.16% copper.

Data collected from [redacted] company (2015-2016)



Correlation between P, S, TR and FC_{Index} based on the developed ANN model for CAT 777D.

Simulate the combined interaction of the parameters

Artificial Neural Network (ANN)

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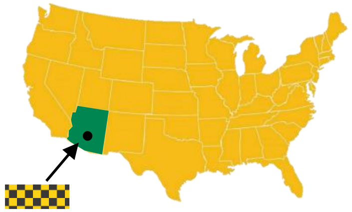
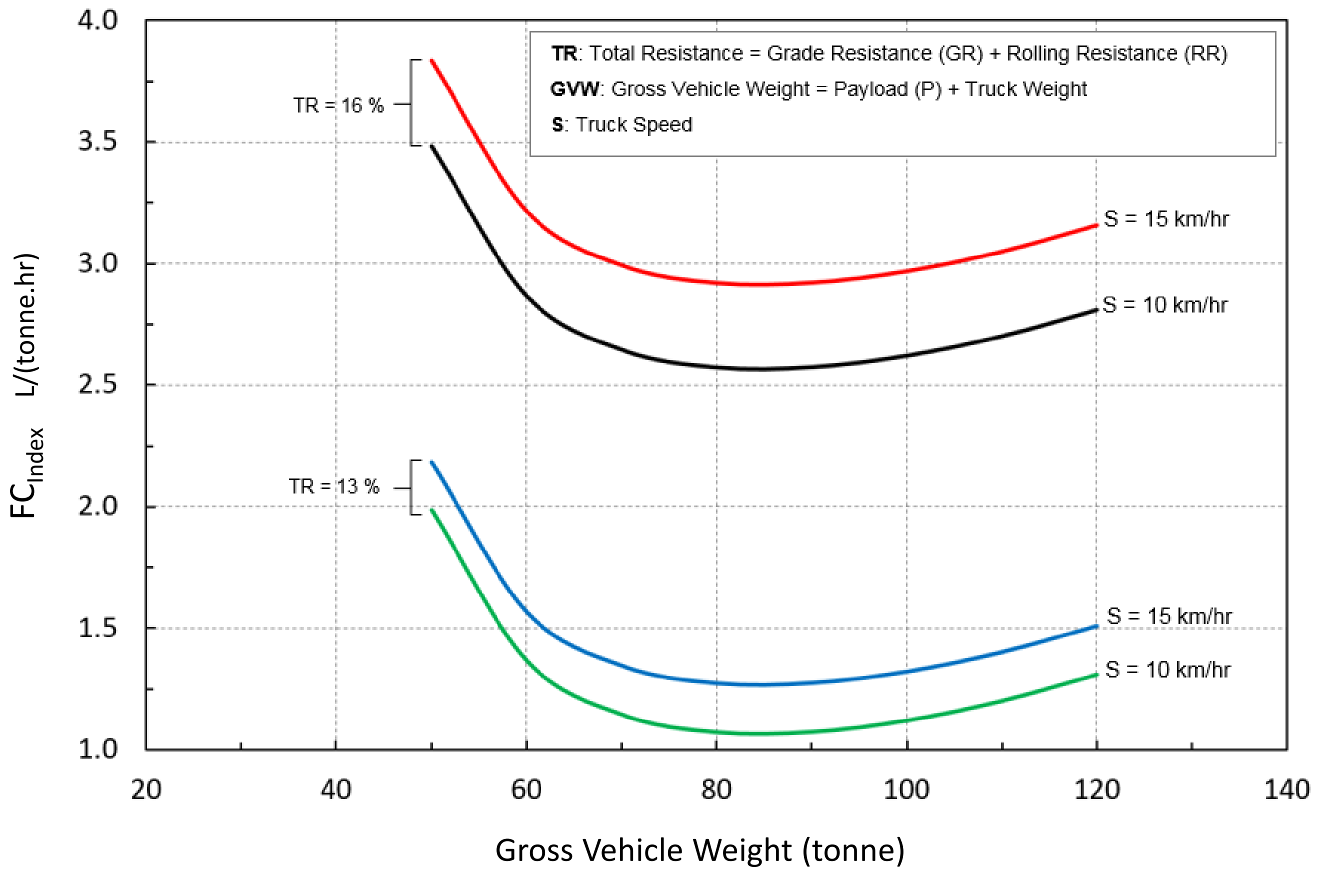


[redacted] Mine

The [redacted] Mine is a large copper mine located in the [redacted] Mountains of Arizona. The deposit had estimated reserves (in 2013) of 907 million tonnes of ore grading 0.26% copper and 0.03% molybdenum. The mine is located in southern Pima County, southwest of Tucson.

Data collected from [redacted] company (2015-2016)



Correlation between P, S, TR and FC_{Index} based on the developed ANN model for CAT 775G.

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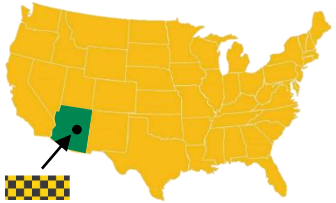
Simulate the combined interaction of the parameters

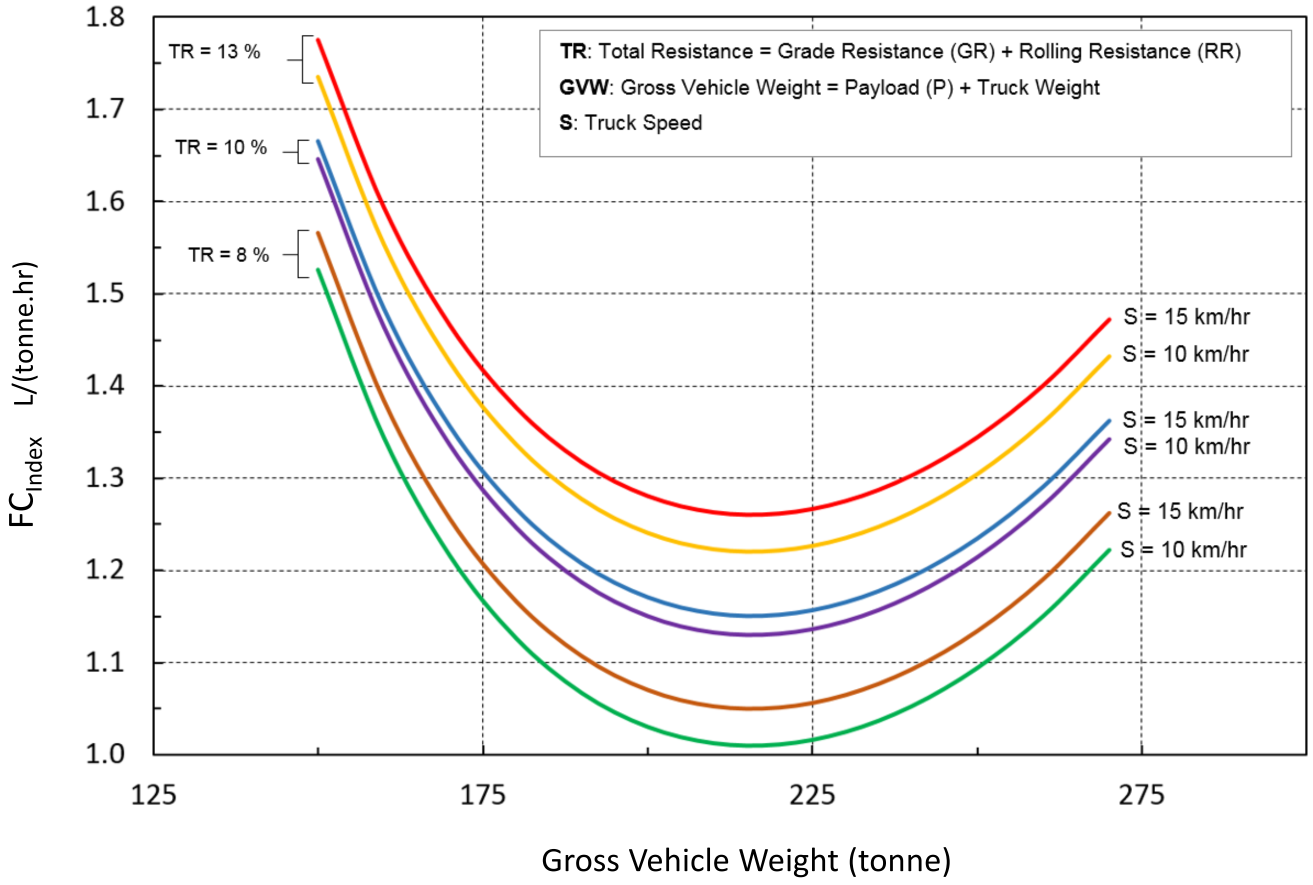
Artificial Neural Network (ANN)



[redacted] Mine

The [redacted] mine is a surface coal mine operated by [redacted] Energy on the Navajo Indian Reservation in northern Arizona. About 400 acres are mined and reclaimed each year, providing about 8 million tonnes of coal annually.

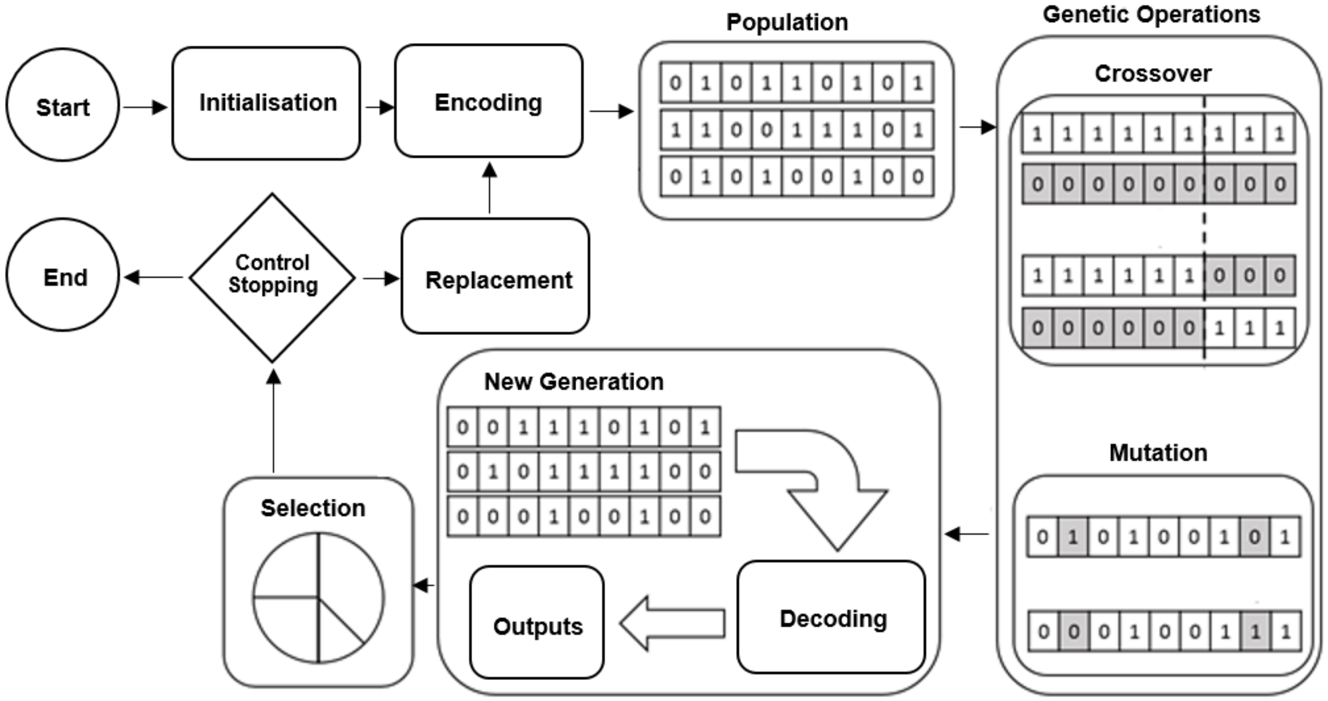
Data collected from [redacted] company (2015-2016)

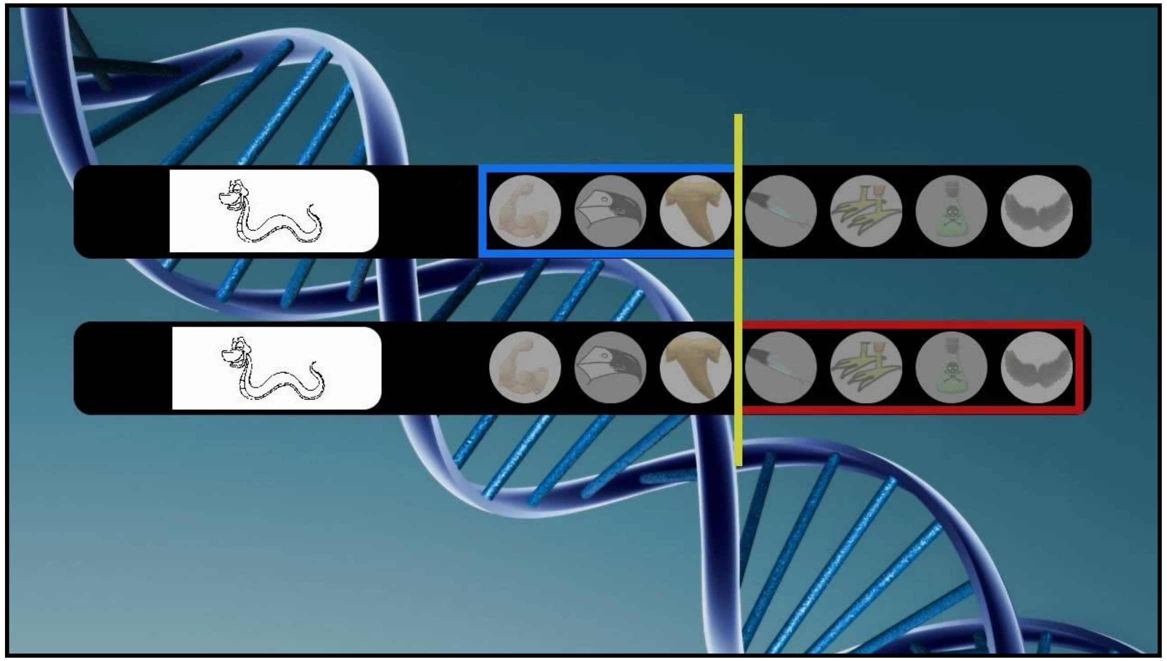


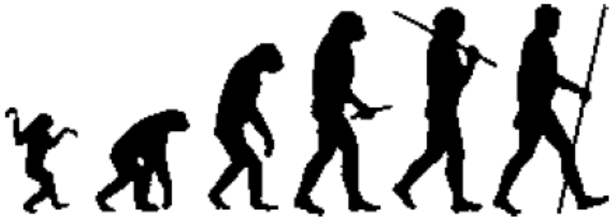
Correlation between P, S, TR and FC_{Index} based on the developed ANN model for **CAT 785D.**

Maximize resultant energy efficiency gains

Genetic Algorithm (GA)







Soofastaei, A., Aminossadati, S.M., Kizil, M.S. and Knights, P., **Reducing Fuel Consumption of Haul Trucks in Surface Mines Using Genetic Algorithm.** Applied Soft Computing, (2016). 38(2): P. 264-298

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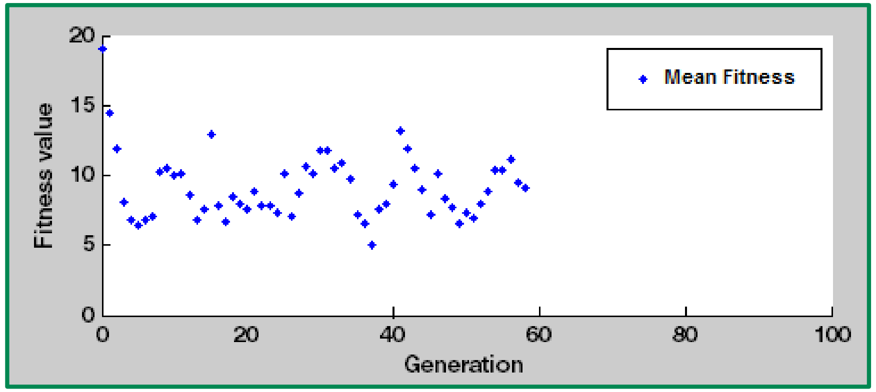
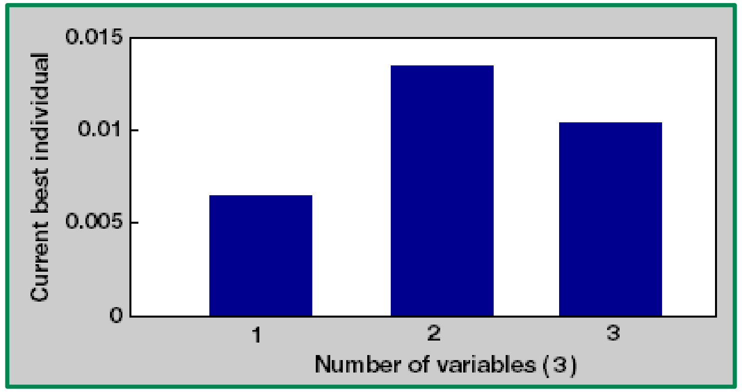
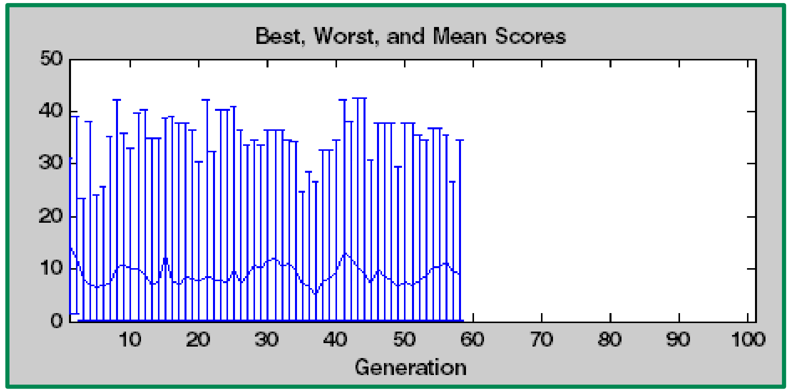
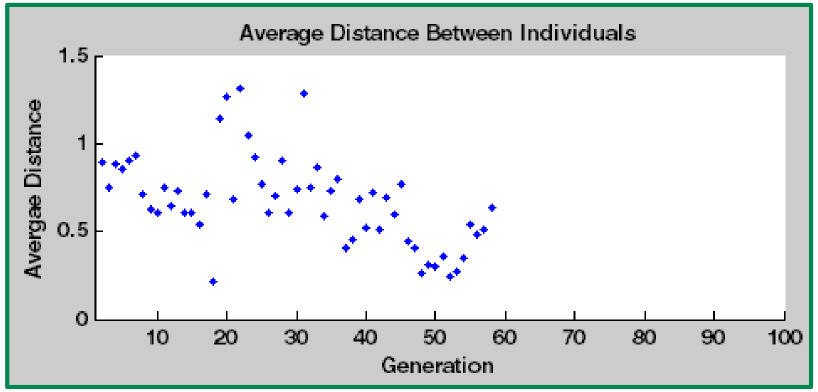
Maximize resultant energy efficiency gains

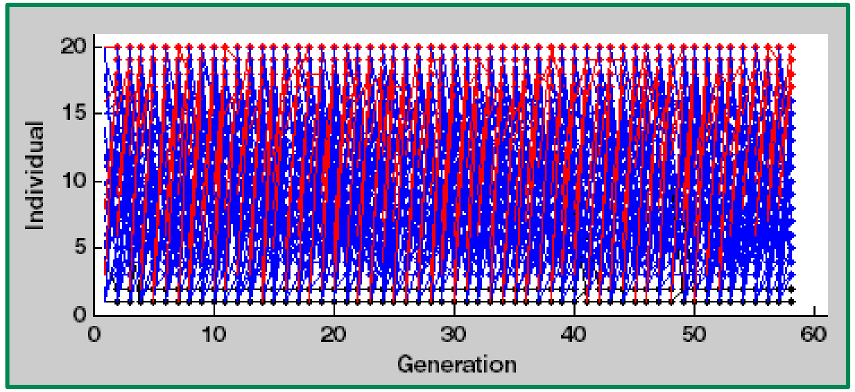
Genetic Algorithm (GA)

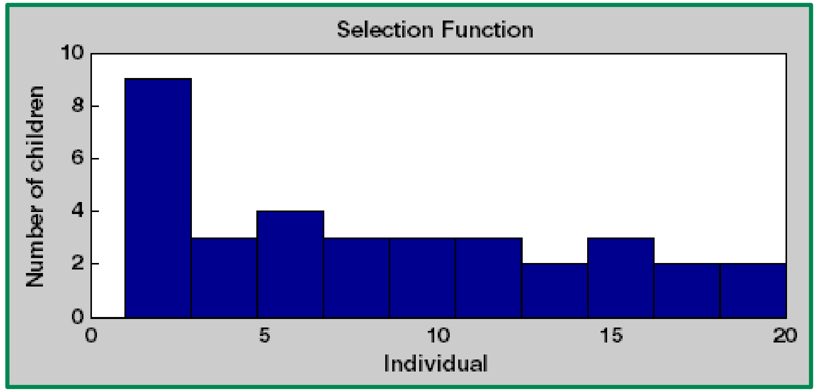






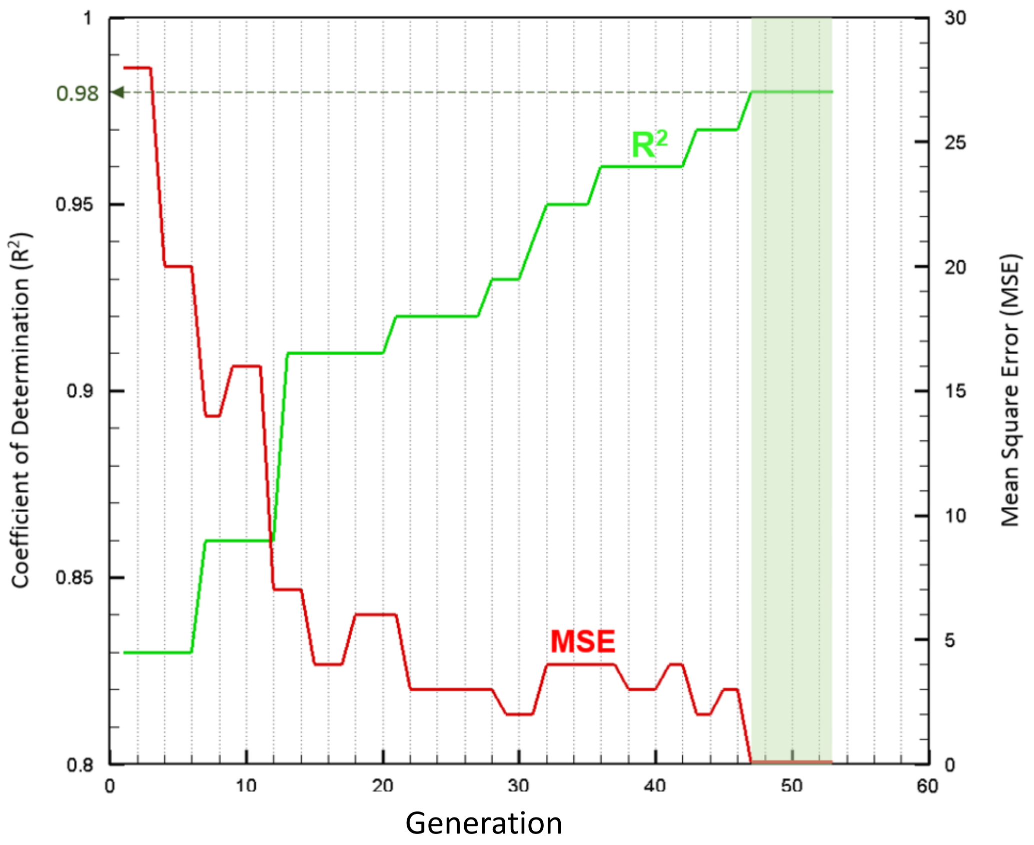




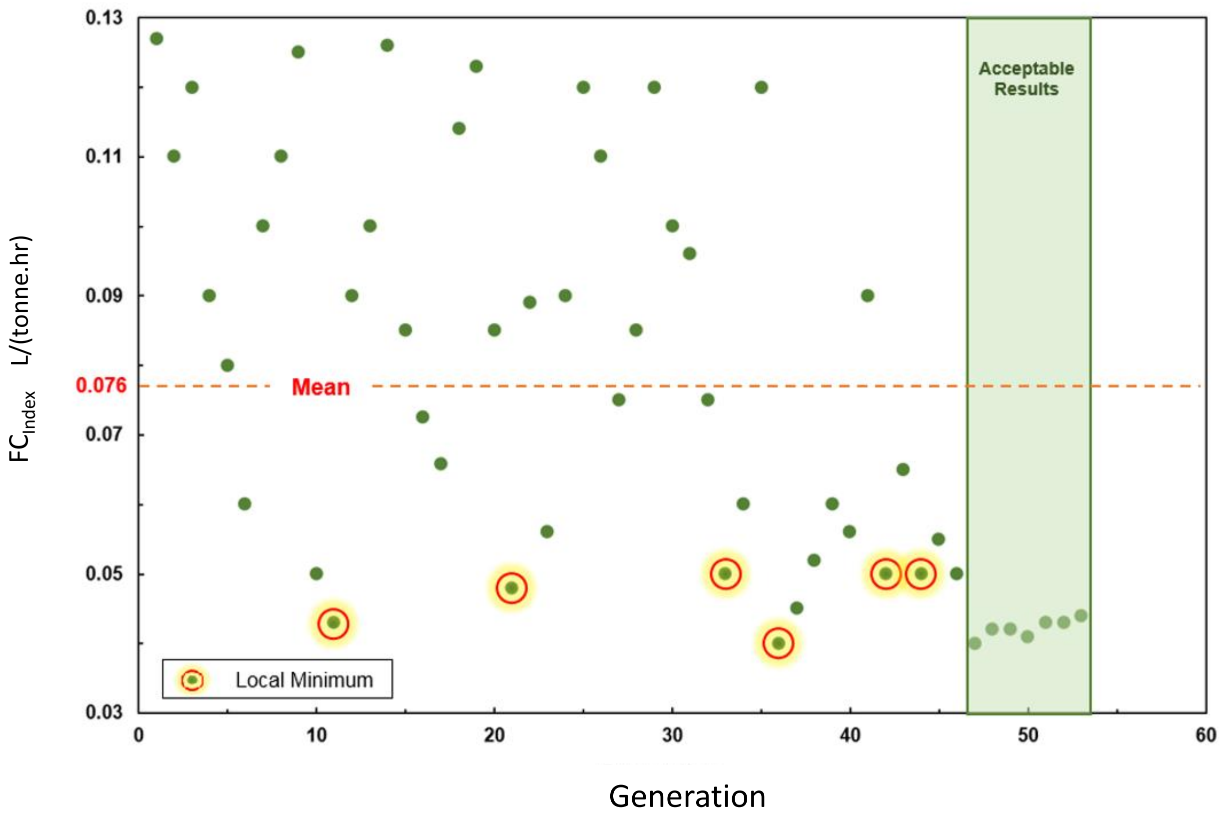


Maximize resultant energy efficiency gains

Genetic Algorithm (GA)



The coefficient of determination and mean square error for all generation



Fuel consumption (Fitness Value) in all generations

Maximize resultant energy efficiency gains

Genetic Algorithm (GA)

The range of normal values for variables in developed model

Optimum range of variables to minimise fuel consumption by haul trucks finalised by GA Model

Mine CAT 793D

Variables	Minimum	Maximum
Gross Vehicle Weight **(tonne)**	150	380
Total Resistance **(%)**	8	20
Truck Speed **(Km/hr)**	5	25

Variables	Minimum	Maximum
Gross Vehicle Weight (tonne)	330	370
Total Resistance (%)	8	9
Truck Speed (Km/hr)	10	15

Mine CAT 777D

Variables	Minimum	Maximum
Gross Vehicle Weight **(tonne)**	65	150
Total Resistance **(%)**	9	25
Truck Speed **(Km/hr)**	10	45

Variables	Minimum	Maximum
Gross Vehicle Weight (tonne)	145	155
Total Resistance (%)	9	11
Truck Speed (Km/hr)	10	12

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Maximize resultant energy efficiency gains

Genetic Algorithm (GA)

The range of normal values for variables in developed model

Optimum range of variables to minimise fuel consumption by haul trucks finalised by GA Model

Mine CAT 775G

Variables	Minimum	Maximum
Gross Vehicle Weight **(tonne)**	45	85
Total Resistance **(%)**	13	20
Truck Speed **(Km/hr)**	5	55

Variables	Minimum	Maximum
Gross Vehicle Weight (tonne)	75	90
Total Resistance (%)	13	14
Truck Speed (Km/hr)	9	13

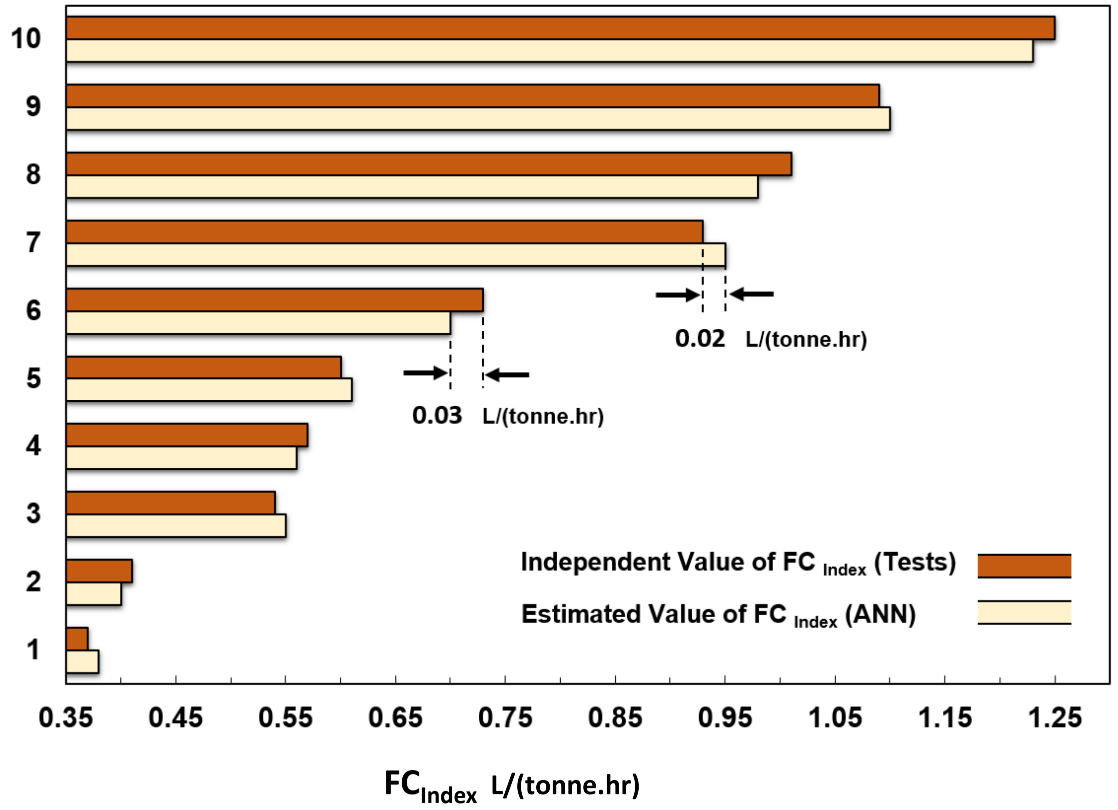
Mine CAT 785D

Variables	Minimum	Maximum
Gross Vehicle Weight **(tonne)**	125	215
Total Resistance **(%)**	8	15
Truck Speed **(Km/hr)**	5	45

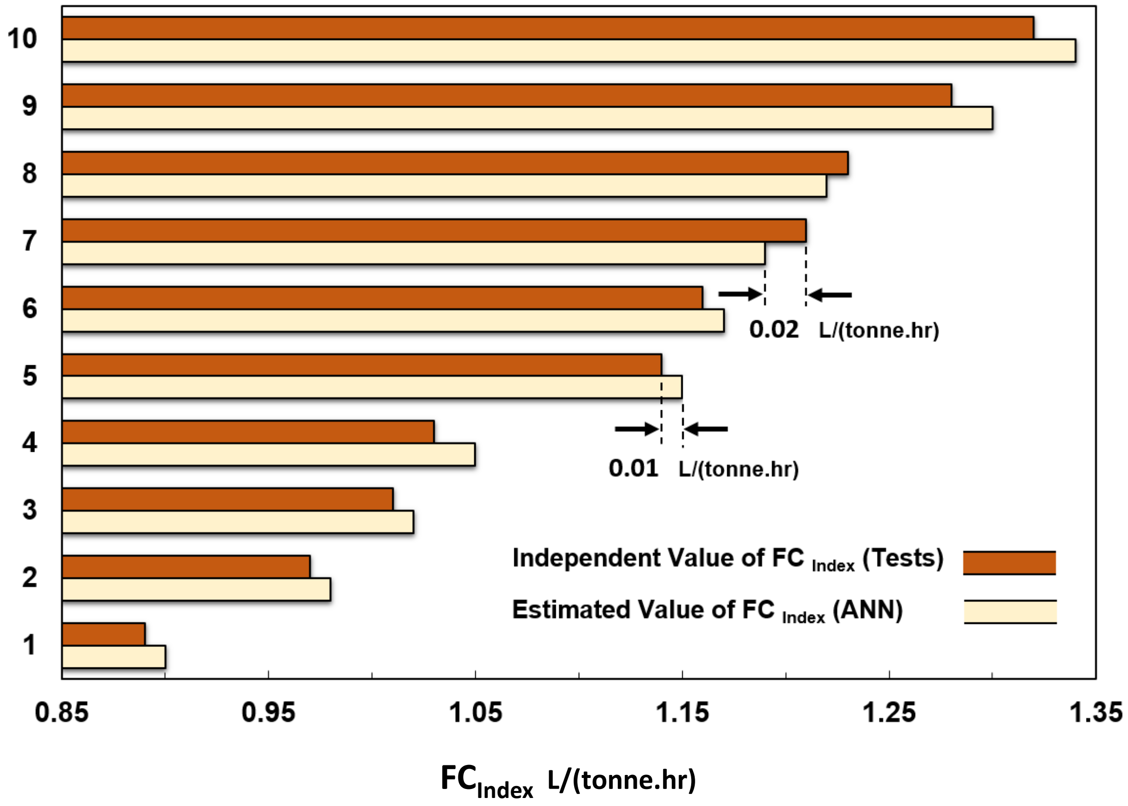
Variables	Minimum	Maximum
Gross Vehicle Weight (tonne)	200	225
Total Resistance (%)	8	9
Truck Speed (Km/hr)	10	15

Validate the developed ANN computer model

Sample values for estimated (ANN) and independent (Tests) fuel consumption



Data collected from [redacted] company, CAT 793D (2015-2016)



Data collected from [redacted] Company, CAT 777D (2015-2016)

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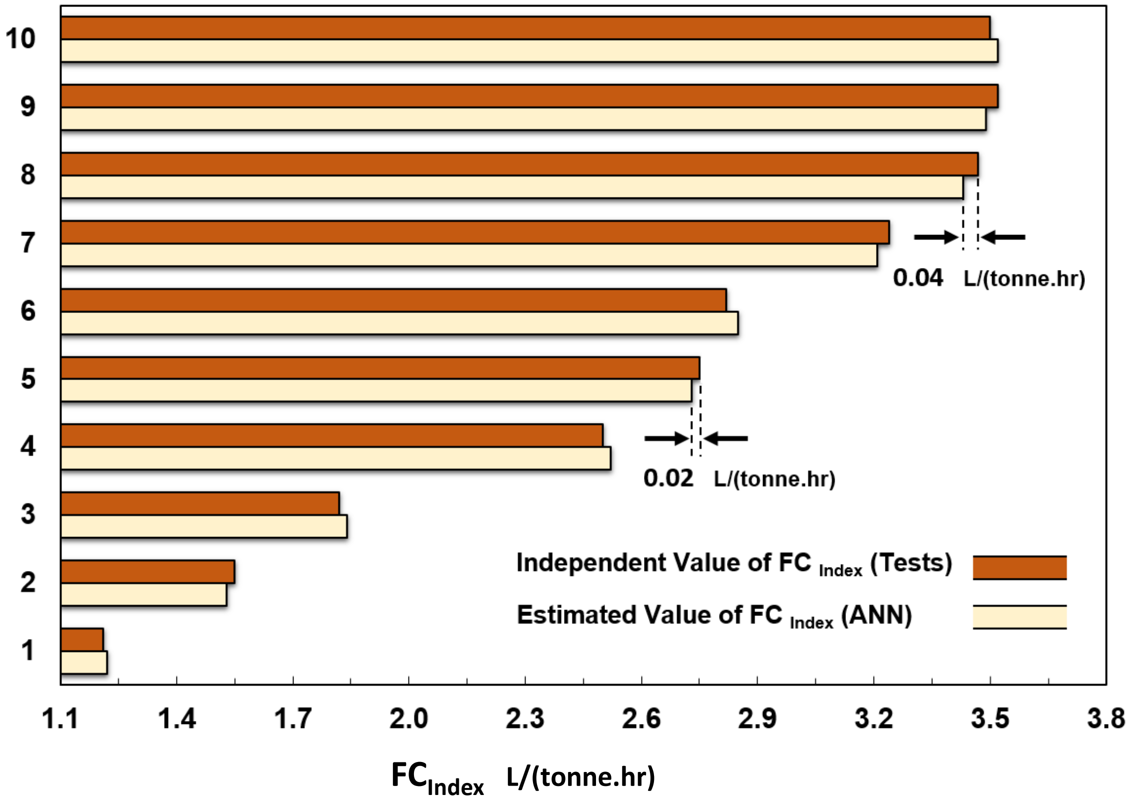
Validate the developed ANN computer model

Sample values for estimated (ANN) and independent (Tests) fuel consumption



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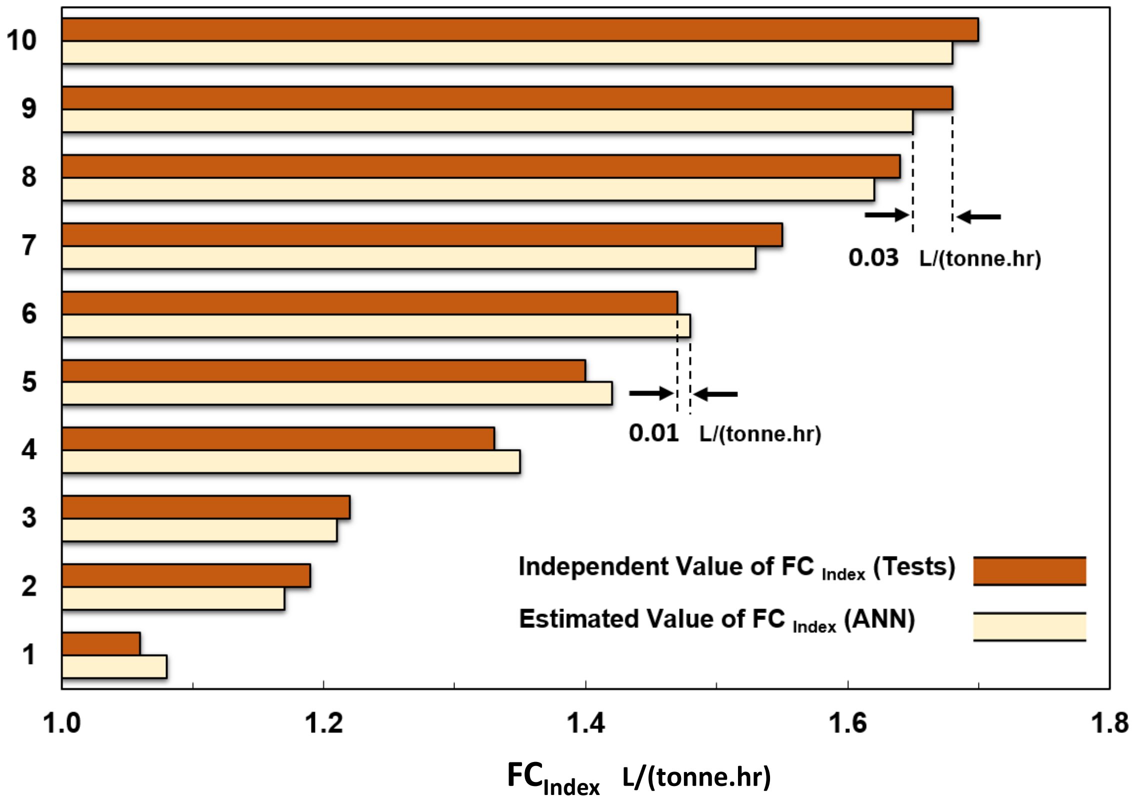
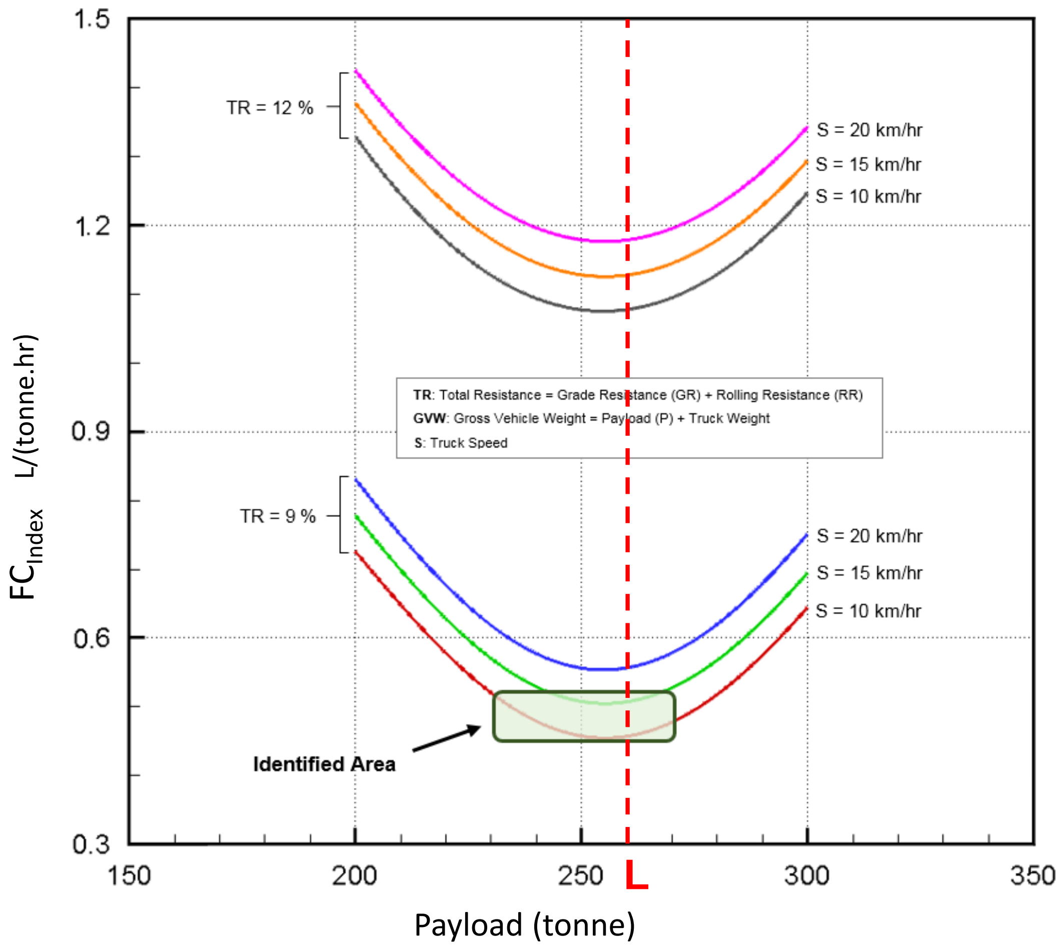


Data collected from [redacted] Company, CAT 785D (2015-2016)

Validate the developed GA computer model



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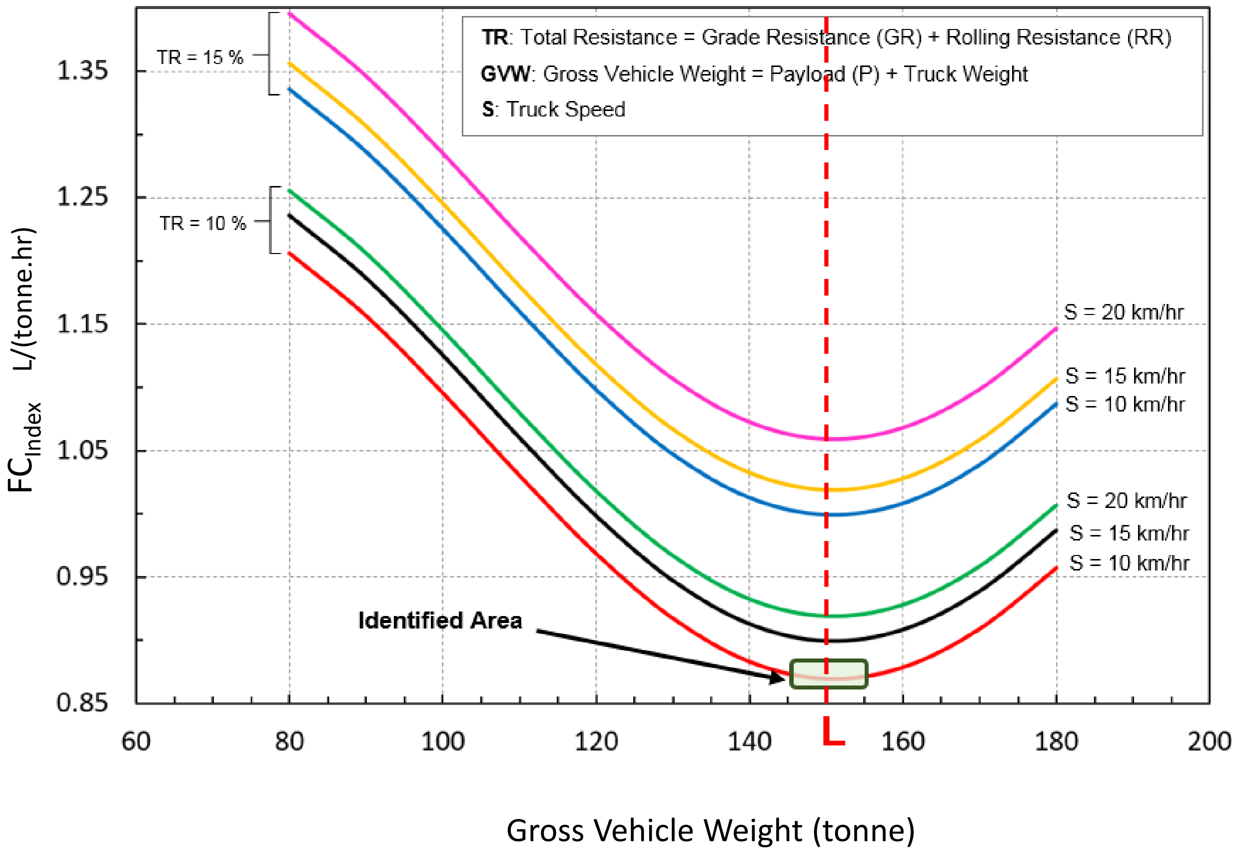
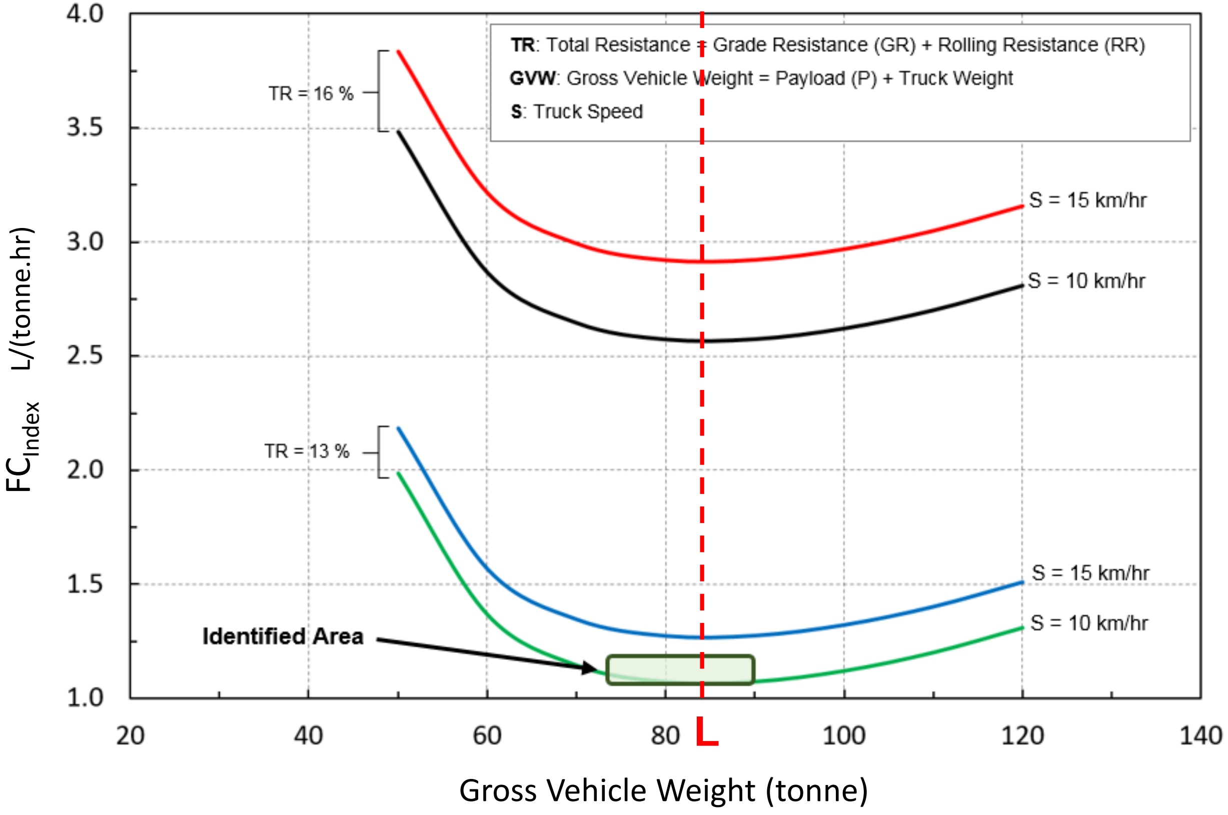
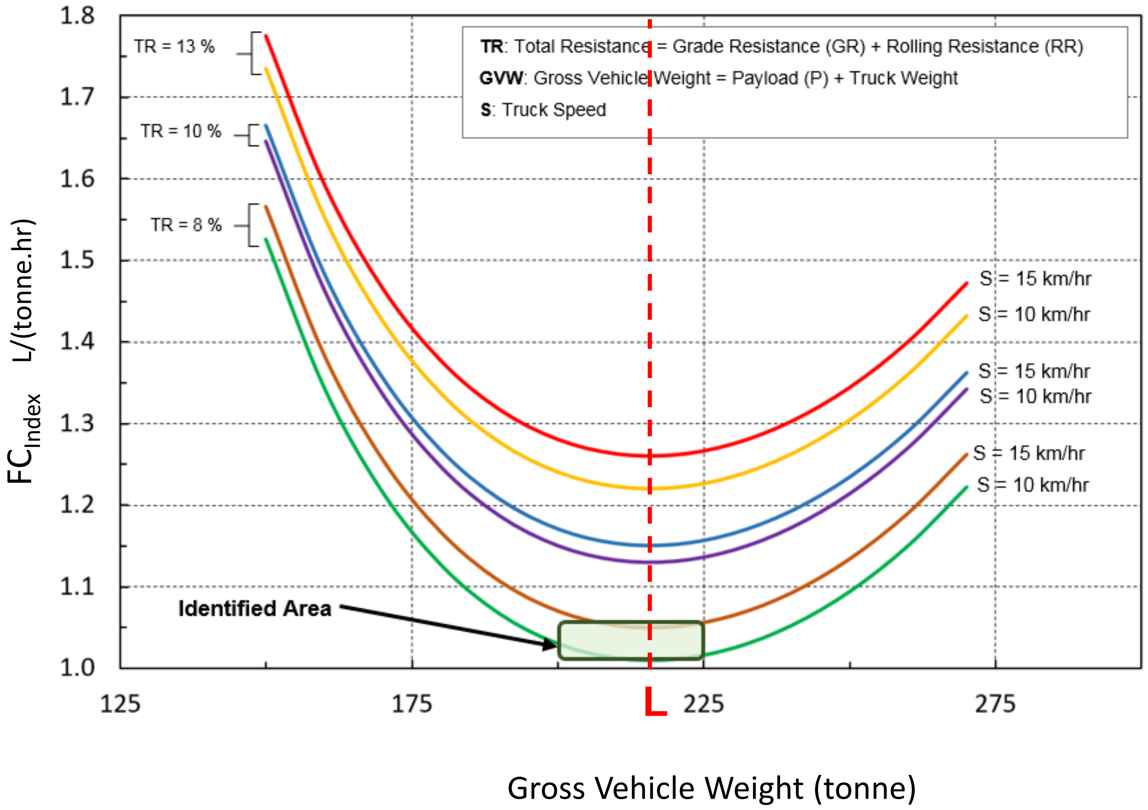


Data collected from [redacted] Company, CAT 777D (2015-2016)

Validate the developed GA computer model



Data collected from [redacted] company, CAT 775G (2015-2016)



Data collected from [redacted] Company, CAT 785D (2015-2016)

Conclusions

- ✓ This study has advanced a structured methodology involving ANNs and GAs to predict fuel consumption of mining haul trucks and to optimise set points for key controllable parameters.
- ✓ In this application, the results of the ANN and GA algorithms applied to coal and coper mine case studies demonstrate that control parameters (payload, speed and total resistance) should be maintained between tight control limits.
- ✓ This methodology is applicable to a range of data analytics problem.

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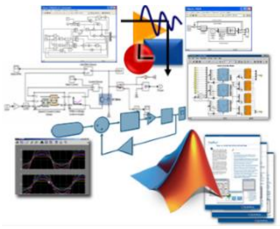
Current research projects

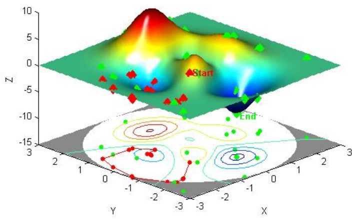
Data Collection

Data Cleaning

Data Analytics

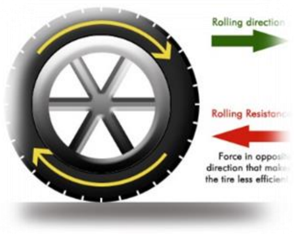


Simulation



Optimisation

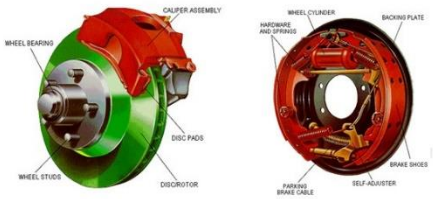
Truck Speed



Rolling Resistance

Payload

Maintenance



Breaking System

Air filtering system

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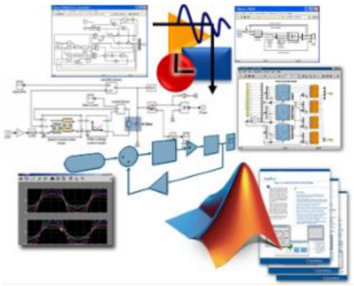
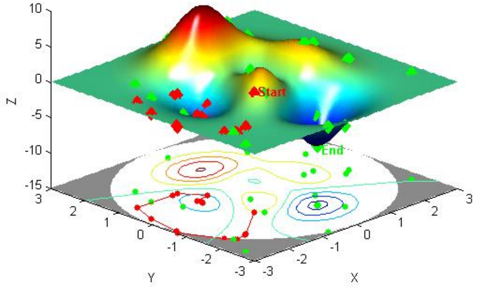
Current research projects

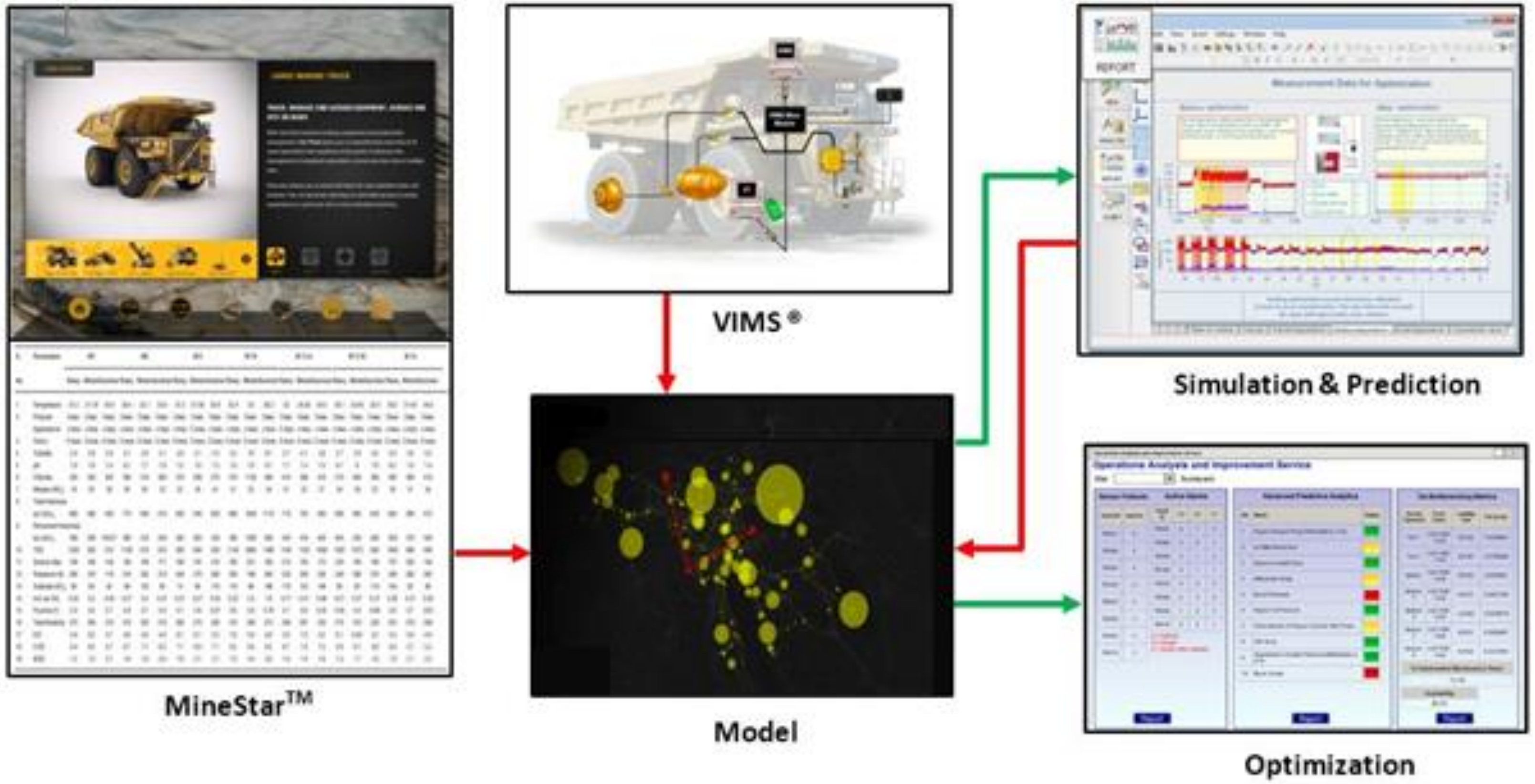


Simulation



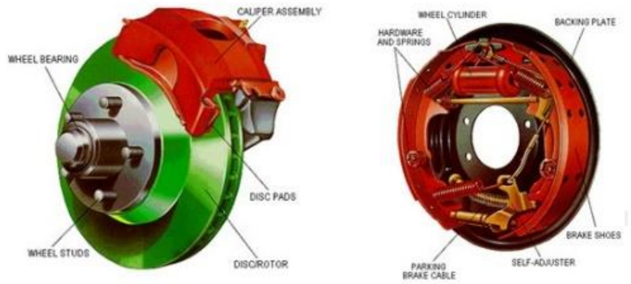
Optimisation

Haul Truck Advanced Data Analytics Model



Current research projects

Maintenance

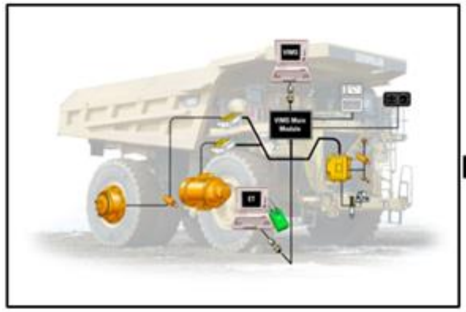


Breaking System

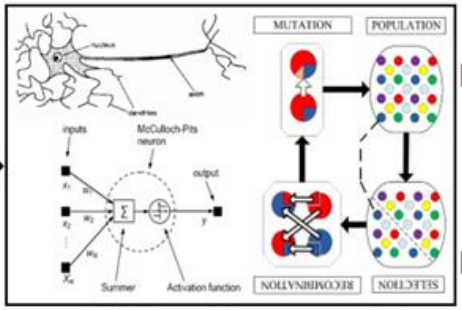
ACARP
Australian Coal Association Research Program

ACARP Accepted Proposal

Project Title : Advanced Predictive Analytics for Haul Trucks Braking System

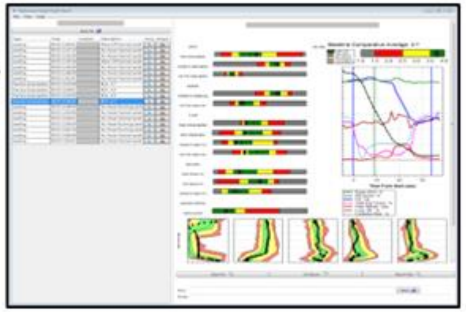


Data Collection Systems



Artificial Intelligence Models

Data Visualization/Story Telling



Advanced Predictive Analytics

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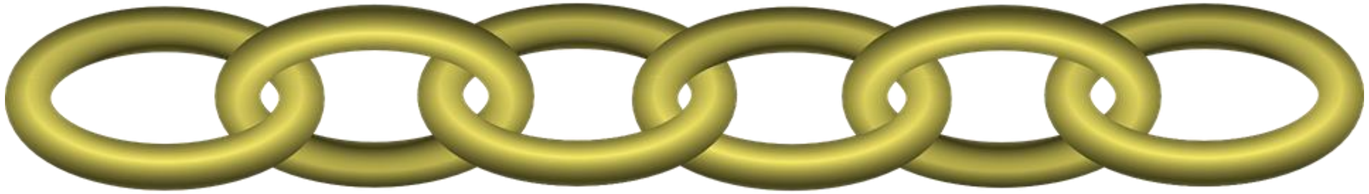
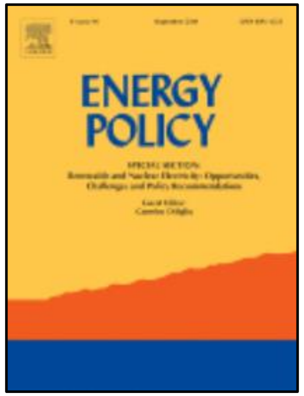
Future research plan

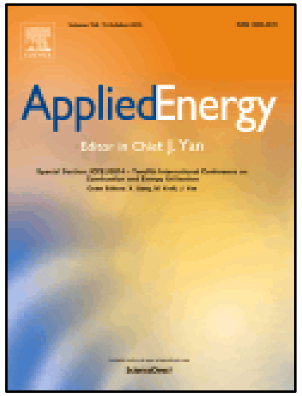
Development of a Comprehensive Advanced Data Analytics Model to Improve Energy Efficiency and Productivity through the Mining Value Chain

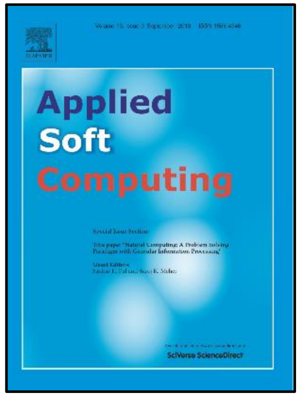


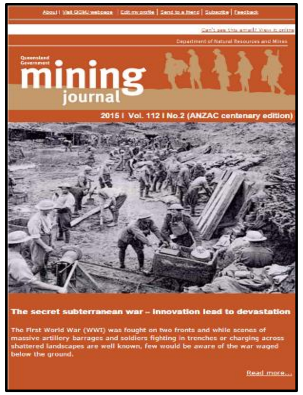
Locate → Valuate → Establish → Mine → Transport

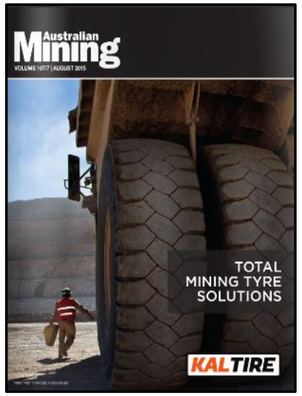
Publications

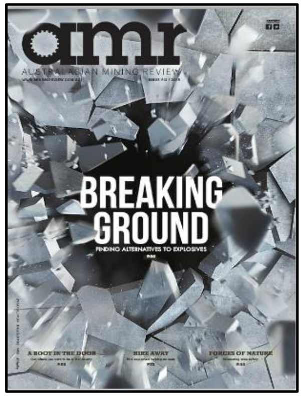












Collaborations

Academia

The University of Arizona – Tucson

West Virginia University

The Pennsylvania State University

The University of California Berkeley

The University of California Los Angeles

The Massachusetts Institute of Technology – Cambridge

Harvard University – Boston

Columbia University – New York

Microsoft Research Centre – Washington DC

Collaborations

Academia

The University of Western Australia – Perth

The University of Queensland

Mining Education Australia

The University of Adelaide

University of Wollongong

The University of New South Wales

Collaborations

Industry

Downer EDI Mining Company – Brisbane Office

BHP Billiton Mitsubishi Alliance Company

Fortescue Mining Company – Perth Office

Leighton Mining Company

Rio Tinto Mining Company

Caterpillar

Freeport-McMoRan, Peabody Energy

CONSOL Energy – Pittsburgh, Pennsylvania Office

Computer Science Corporation

Australia Mining Cooperative Research Centre

Mining 3 Australia

Thank You