Redesigning the Wheel
A Multifaceted Approach to Enhanced Mining Wheel and Tire Safety

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Aleksander Tonkovich
M.A.Sc. Candidate

Weldon Li
Ph.D. Candidate

Sante Di Cecco
M.A.Sc. Candidate

William Altenhof
Academic Advisor

University of Windsor
Mechanical, Automotive and Materials Engineering
Presentation Outline

• **Introduction and Motivation**
  - Motivation behind the research

• **Research Purpose and Objectives**
  - Multi-piece wheels and why they are needed
  - Multi-piece wheel failure modes

• **Current Research Endeavours and Goals**
  - Historical Wheel Tracking Database
  - WingFil: A Tire Foam Filler
  - Innovative Wheel Safety Shield
  - Advanced Wheel Redesign

• **Concluding Remarks and References**
Research Motivation

#1 Goal is to make workplaces and heavy vehicles safer to operate and maintain.

- **Safety is the name of the game** – This is the main focus of our research.
- Tragically, failure of wheels tend to lead to **fatalities, not just injuries**.
- Motivation based on incidents and associated reports from **around the world**.

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**SAFETY ALERT**

Queensland Fatality - Prime Mover Rim Assembly Failure

**DOH**

STATE OF NEW YORK DEPARTMENT OF HEALTH

FATALITY ASSESSMENT AND CONTROL EVALUATION

Equipment Operator Killed by a Lock Ring Propelled from a Multi-piece Rim Wheel  
Case Report: 07NY137

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**Alaska FACE**

Fatality Assessment & Control Evaluation

Worker struck by side ring of multi-piece (split) rim during wheel installation

Split ring wheel fatality

Incident

An 18-year-old labourer was killed in April at Toodyay when the split ring from a wheel which he was fitting to a forklift came free and hit him in the chest and head.

General Workplace Inspectorate

Promoting Safety and Health in the Workplace

ACCIDENT/INCIDENT ALERT

Tyre Fitter Killed by Exploding Tyre  3 June 2004

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**NJ FACE**

INVESTIGATION REPORT

Fatality Assessment & Control Evaluation Project

Worker Killed in Compressed Air Explosion at a Tire Retread Plant

Laborer Killed While Inflating a Tire Mounted on a Multi-piece Rim Wheel

Massachusetts Case Report: 03-MA-057-01  Release Date: December 22, 2004

Truck Tire Explosions Claim Two More Lives

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Introduction to Multi-Piece Wheels

• What are multi-piece wheels used for?
• Tires of large sizes (up to 14 feet tall) and sidewall thicknesses (sometimes >8 inches) are necessary for heavy mining vehicles and other off-the-road (OTR) vehicles.
  - **High Payload Requirements** - to ensure high productivity meaning high tire pressures (up to >150 psi) are required.
  - **Harsh Operating Conditions** - requiring high cut and wear resistance is needed for OTR tires.

Operating weight of > 650 tons; 400 ton payload
Introduction to Multi-Piece Wheels, cont’d

• Why are multi-piece wheels required?
Failure Modes of Multi-Piece Wheels

- Most common failure modes result in wheels and tires not performing as they are intended or designed to.
- This results in components not staying properly engaged due to:
  - Tire explosions, fires, or other failures (e.g., “Zipper” Rupture)
  - Tire blowouts due to fatigue failure, wear, corrosion, damage, deformation, or improper assembly [7]
- The danger of multi-piece wheel failures is not limited to the risk associated with the failure of the wheel as a supporting structure of the vehicle, but the explosive loss of pressure that is observed.
- Improving wheel safety is paramount to improving mine safety.
Current Research Endeavours and Goals

- Educate ourselves on mining wheels and vehicles, and the environment they are exposed to:
  - Mine site, supplier, and vehicle repair facility tours

- Quantify aspects of multi-piece wheel loading:
  - Vehicle data acquisition at mine sites

- Educate the mining industry to increase knowledge of multi-piece wheel potential dangers:
  - Attend WSN Technical Advisory Committee meetings
  - Present research at:
    - Canadian Institute of Mining, Metallurgy, and Petroleum's (CIM) Maintenance Engineering/Mining Operators' (MEMO) Conference
    - Health and Safety Ontario's (HSO) Partners in Prevention Conference

Bucket was raised up and lowered down to excite the tire in order to get large, measurable deflections.
Current Research Endeavours and Goals

• Understand the failure modes and life cycle of wheels and tires
  – Extensive historical wheel failure database development
  – Examine wheel handling regulations and improve where possible.

• Increase safety of multi-piece wheels and improve their design
  – Use innovative engineering techniques to examine and improve wheel designs through the development of virtual tire and wheel models

  – Safety shield design, model development, and prototype implementation

  – Determine feasibility of foam filling tires and develop new materials and inflation processes

  – Develop an innovative wheel concept that mitigates safety risks through improved design
The Power of Finite Element Analysis

- Finite Element Analysis (FEA) is a powerful tool implemented in the study of wheels and tires.
- Tires pose great challenges in virtual modeling due to their complicated and complex structures.

Virtual models are validated with real world data, and then allow for a wide range of versatile virtual testing that may otherwise be impractical or impossible.
The virtual tire/wheel model was built using finite element (FE) method for tire 29.5-29 used in R2900G underground loader.

The FE model was validated in the following steps:
1. The model was built to meet the tire engineering data – static load vs. deflection, provided by tire manufacturer.
2. The tire was tested under static loading condition at mine site and simulations were conducted under identical conditions with the tests and the tire deflections were compared.
3. Quasi-static experiments were conducted and the measured wheel axle displacements were used in the FE model as driving forces and tire lateral and in-plane deflections (longitudinal - y and vertical - z direction) were compared.

<table>
<thead>
<tr>
<th>Virtual Model Development and Validation</th>
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<tbody>
<tr>
<td>N - numerical data</td>
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<td>E - engineering data</td>
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Vertical displacement: 80 mm
Lateral deflection: 36.5 mm

Bucket raised up and pushes against the rear bumper of a CAT 990
Tire moves down

91 psi
23,400 kG
Purpose

- To identify the most frequent damage to wheels that requires repair
- Use as a tool to determine the average life of wheels – something that has never been done previously.
- Understanding what causes wheel damage and scrapping is the first step to preventing failure, increasing safety, and decreasing downtime.

Accomplishments to Date

- An extensive new statistical wheel tracking database was created based on scrap wheel info with an easy and simple to use interface
- Organizes information based on available wheel information using numerous criteria of interest
- It is recommended to actively track all currently in-use wheels to provide usage statistics faster and to enable heightened awareness of necessary maintenance prior to failure

Wheel Tracking Database

Selected Wheel Scrap Reasons by Valid Scrap Code (26.5 x 25)
Safety Shield Design

Safety Shield Goals

• **Fail-safe device** that can be applied to currently in-use wheel designs

• **Protects the wheel in two different ways:**
  • Physical barrier between operators and maintenance personnel and the wheel should failure occur
  • Protects the wheel from impact and abrasion

• As **simple and financially viable** as possible
Safety Shield Future Development

- A **finite element model of the shield** has been developed and is being used for simulation purposes and design validation.

- Major industrial supporter, North Shore Industrial Wheel Mfg., will potentially **build prototypes** to test once a final design is determined.
Foam Filled Tires

• A promising means to improve wheel safety and vehicle operation
  - **Potential Advantages**: Elimination or reduction of air pressurization; reduced vehicle downtime
  - **Potential Challenges**: Ride quality; heat build up; extra mass

• An initial investigation of tire foam filling was conducted to determine its mechanical performance, and to experimentally and numerically characterize the material properties

• WingFil was selected for the initial study based on its use in small tire foam filled applications

With a proper investigation of the foam materials and the filling process, it is believed the potential challenges can be overcome
WingFil Experimental Testing

- Material testing of WingFil tire foam filler has determined its stress-strain behaviour for 50% compaction

- Observations:
  - Cyclic loading of the foam reveals hysteretic behaviour
    - Likely caused by microvoids closing over time
    - Appears to stabilize after the first 50 cycles
  - The peak stress of the foam decreases marginally with cycles
    - Attributable to foam damage over time
Wingfil Material Model Development

A material model emulating Wingfil foam has been developed using FEA large deformation code, LS-DYNA. The model is based on a Simplified Rubber material model, which utilizes many of the rubber foam's material properties as input.

The material model was validated against experimental test observations using three different criteria:

- Downwards Deformation: 1.83% Error
- Side-bulge Deformation: 8.97% Error
- Compaction force: 14.0% Error

Graphs showing force-time and force-displacement comparisons for both experimental and numerical results.
• After foam material model development and validation, the foam was simulated within a tire model previously validated by the research group.

• The numerical foam filled tire was simulated under static loading conditions typical of vehicle operation.

• Stiffness of the foam tire was extracted from the simulation and compared against that of a pneumatic tire.
Tire Foam Filling Future Development

- Based on initial results from foam filled tire simulations, the following changes are being investigated:
  - Ensure foam remains in contact with tire sidewalls during simulation
  - Use inflated tire dimensions (recommendation based on supplier information)

- Experimental testing of a Wingfil filled tire is required to validate the current model
  - Possible with current industrial partners’ support

- Once the current foam filled tire model is validated, consider:
  - Investigating suitable replacement foams to improve ride quality
  - Developing a hybrid partially pressurized/partially foam filled tire for mining operation
Innovative Wheel Design - Concepts

New design focuses on removing the lock ring since this is the key part to cause wheel failures due to wear, cracks and incorrect assembly.

Thread connection for safety

- Material added for the proposed design
- Threaded-connection design
- Lock ring design
- Fatigue cracks or breaks
- Rim base
- Worn out
- Lock ring groove
Innovative Wheel Design – Simulation Results
Mechanical Performance of the Threaded-Connection Design

1. BS band pull-out tests - assess the engagement capability of rim components

Conclusion: Threaded-connection design is almost twice as strong as conventional design to maintain proper engagement of rim components.

2. Stress level assessments

Maximum Von Mises stress on rim base front region:

- Conventional lock ring design: 136 MPa
- Proposed threaded-connection design: 96 MPa

29% reduction

3. Fatigue life estimates

Steel_UML_200 ($S_y = 146$ Mpa, $S_{ut} = 200$ Mpa) was used to assess fatigue life

Estimated minimum fatigue life on rim base front region:

- Conventional lock ring design: $1.240 \times 10^7$
- Proposed threaded-connection design: $2.896 \times 10^7$

Fatigue life was doubled.
Conclusions

• Using **innovative engineering techniques** to increase wheel safety
• The most significant benefit of our research to date is simply bringing to light the **potential dangers of multi-piece wheels**
• Building relationships with industrial partners has made our research group part of their incident review process and provides us with information on any wheel related incidents
Acknowledgements

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- Xstrata’s Nickel Rim and Copper Kidd Mines
- Royal Tire
- Fountain Tire
- McDowell-Driftech
- The Ontario Graduate Student Program
- The Natural Sciences and Engineering Research Council of Canada
References


15. “Serve multi-piece and single piece rim wheels”, Standard Number 1910.177. Occupational Safety & Health Administration, Department of Labor, USA.

Thank you!
May we answer any questions?

University of Windsor

Weldon Li
li12c@uwindsor.ca

Aleksander Tonkovich
tonkovi@uwindsor.ca

Sante DiCecco
dicecco@uwindsor.ca

William Altenhof
altenh1@uwindsor.ca

Richard Banting
RickBanting@workplacesafetynorth.ca
Workplace Safety North