UNIVERSITY OF ALBERTA
Department of Civil and Environmental Engineering
School of Mining and Petroleum Engineering

Advancing Bridge Formula through Integration of All-Terrain Cranes in Canada

A Comprehensive Research Initiative for Efficiency, Safety, and Standardization

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Risk, Reliability, and *Resilience*

Outline

Introduction & Motivation

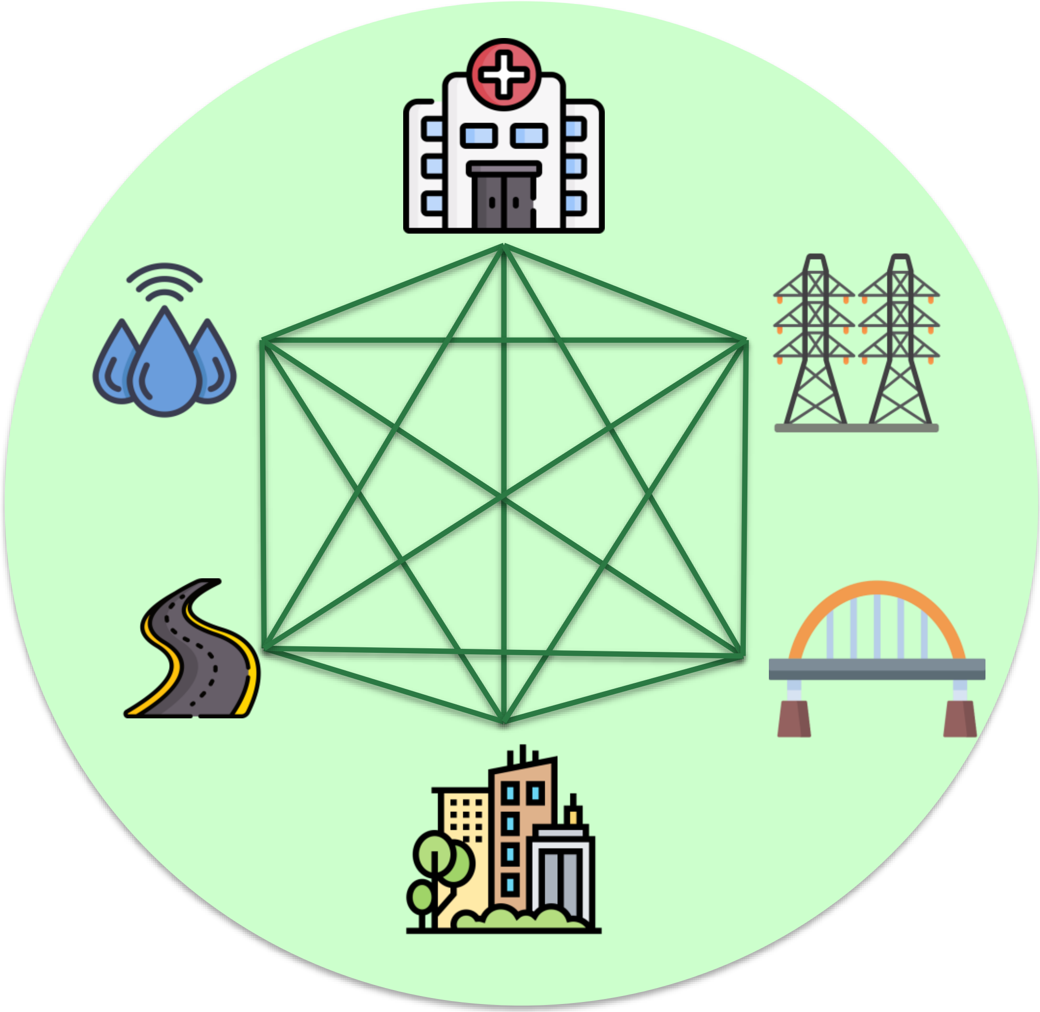
- Background
- Problem statement
- Research objective

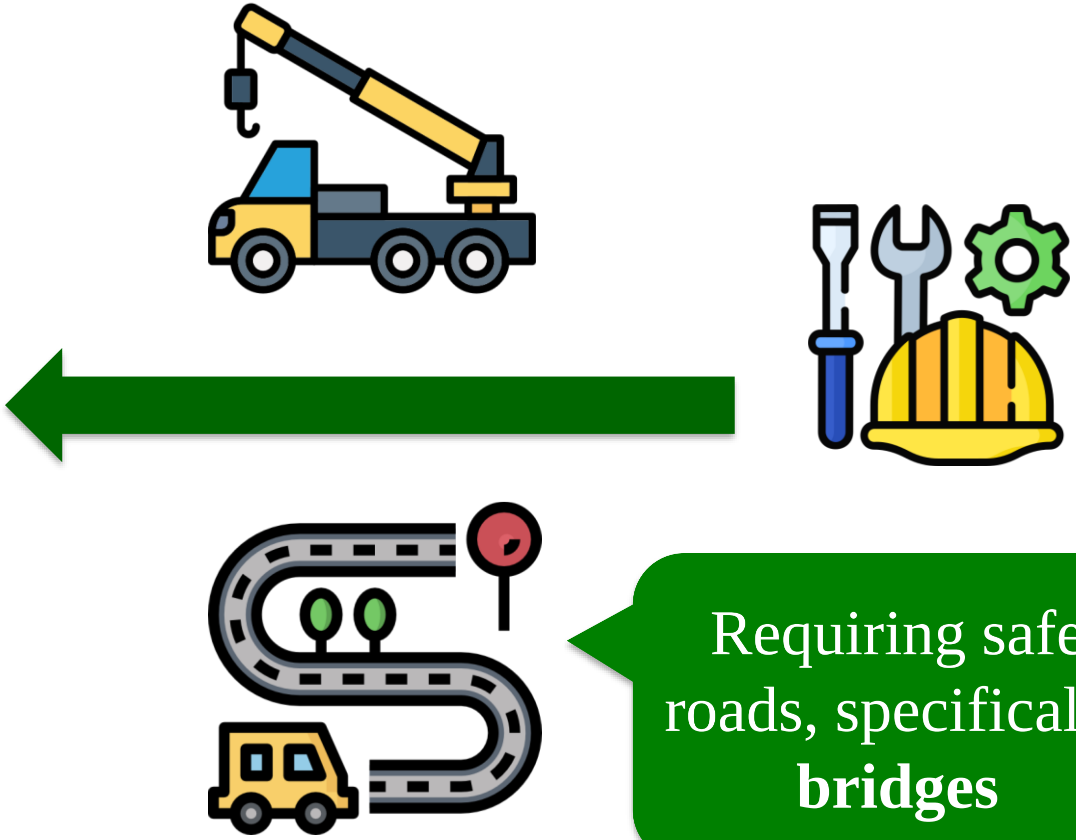
Research Program

- Sub-objectives
- Tasks and research plan
- Research significance

Background

❑Crane Industry





Requiring safe roads, specifically **bridges**

Background

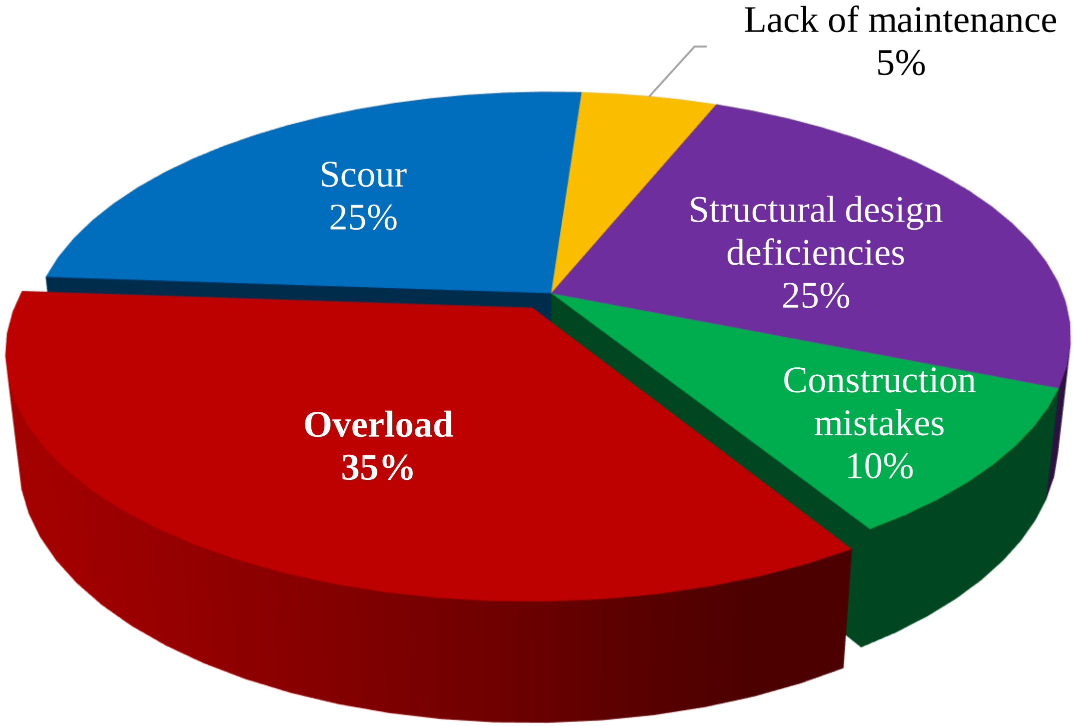
❑Bridges

▪ Causes of failure

Overload

- With the increase in traffic volume, the truckloads exceeded the limitations, resulting in bridge failures, especially for **older** bridges [1].
  - The average service age of failed bridges due to overload reduced to 64 years, while the bridge design life is 75 years [2].

Image courtesy of Yuqiang Liu



Bridge collapse causes [1]

Background

❑Bridges

- **Structural design philosophy**

Limit-State Design

Limit state function: $g = R - D$ → $\begin{cases} g \le 0 & \text{Failed} \\ g > 0 & \text{Safe} \end{cases}$

Capacity (R) — Demand (D)

Uncertainties

In engineering practice

Design equation: $\varphi R_k = \gamma D_k$

Safety coefficient applied to capacity (φ)

Safety coefficient(s) applied to demand (γ)

Nominal demand (D_k)

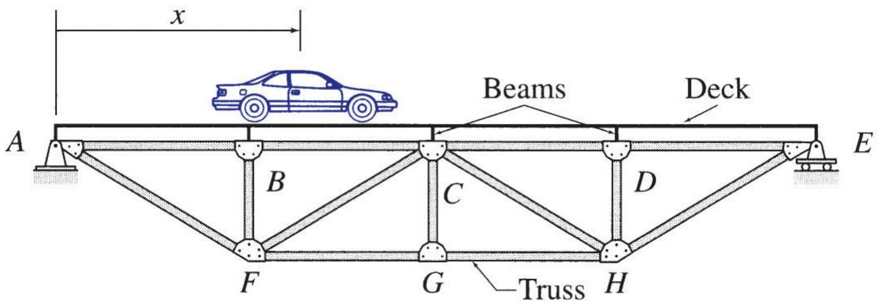
Nominal capacity (R_k)

Background

❑Bridges

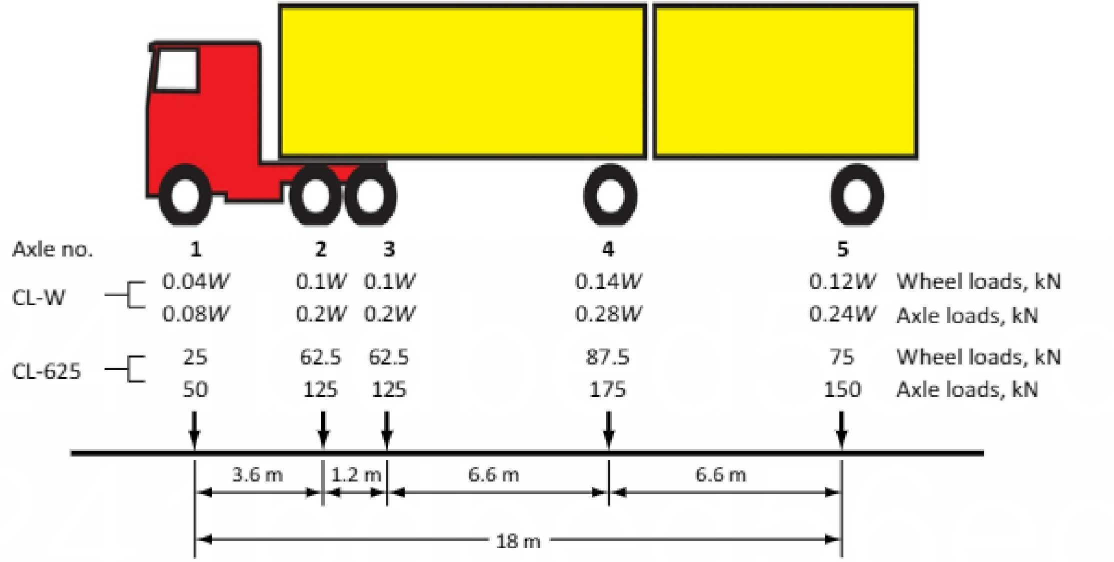
▪ Structural loads

- Loads with *position fixed* on the structure (e.g., dead loads due to the weights)
- Loads with *position varying* on the structure (e.g., moving vehicle on the bridge)
  - The most unfavorable position for the response of interest
  - The maximum value of the response of interest



Design Truck

- Specified in each design code
- A representative moving vehicle, but may not exist
- Load carrying capacity for vehicle trains
- Multiple (e.g., three) design trucks are moved simultaneously along longitudinal lines (one truck in each traffic lane) to maximize the live load effect [3].



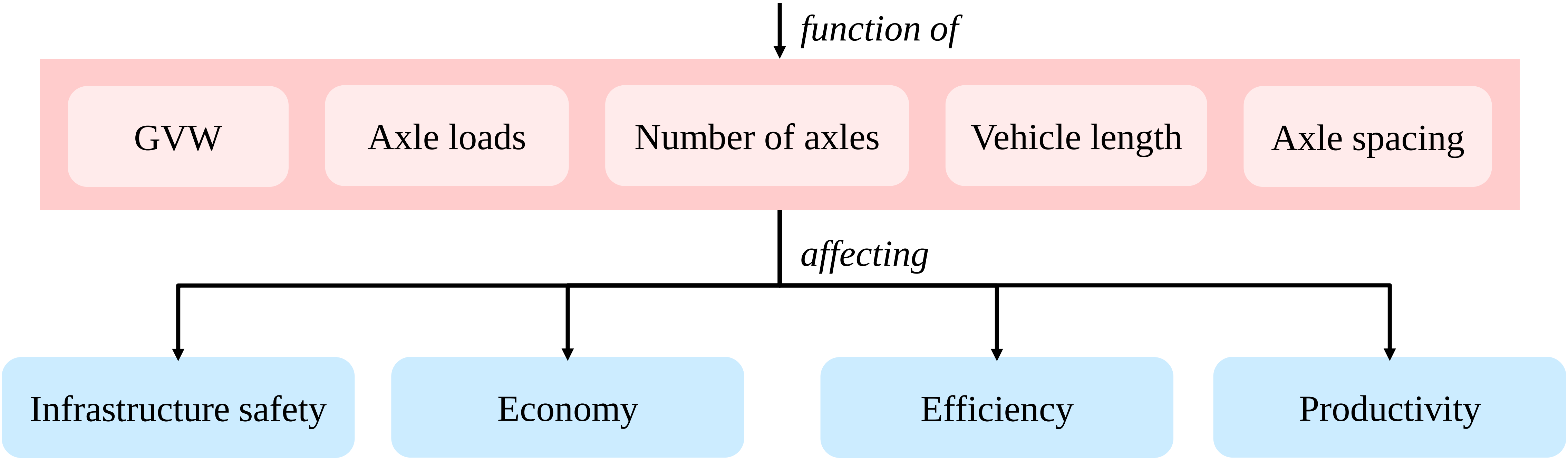
CSA S6 standard design truck

Background

❑Bridge Formula

A "bridge formula" is a performance-based standard, which regulates the parameters related to the performance of the vehicle in terms of the load effect imposed on bridges and pavement.

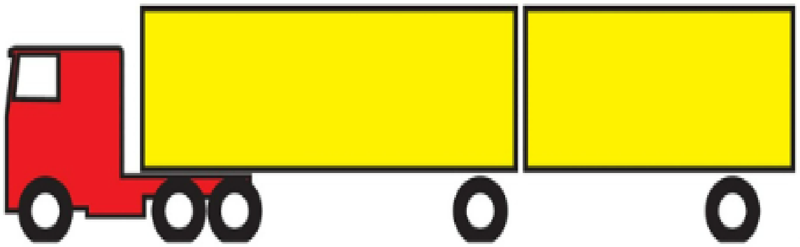
- To protect bridges by determining the **maximum weight** allowed on any series of consecutive axles
  - Function of axle spacing and the number of axles



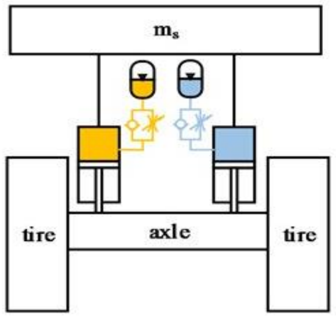
Background

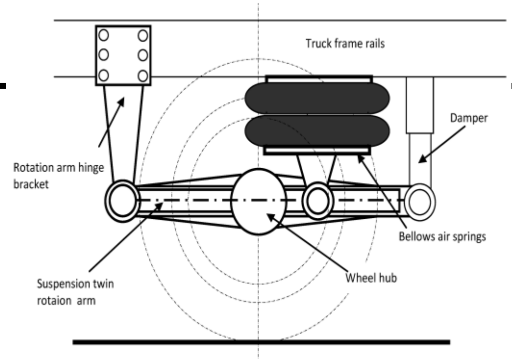
❑Bridge Formula

All-Terrain Crane vs Design Truck



Known weight	Load variation due to different supplies
Bigger wheels and thicker tires	Normal truck wheels and standard tire thickness
Hydro-pneumatic suspension → less dynamic impact	Air suspension system





Problem Statement

❑Industry Challenges

Access conditions are inconsistent and not easily accessible

Access responses can be ambiguous or inconsistent

Lack of certainty and visibility of access and mass limits

Permit approval process slow cumbersome inconsistent

Want maximum productivity benefits and a level playing field

Problem Statement

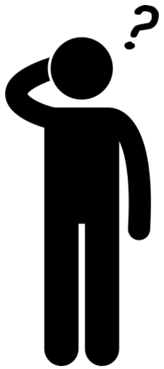
❑Industry Challenges

Variation of Weight Regulations among Canadian Provinces

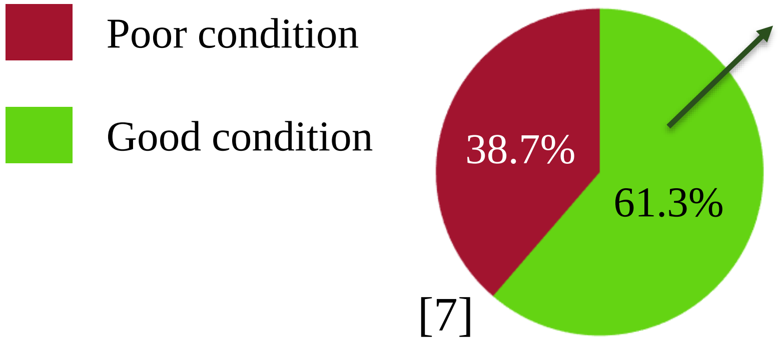
Province	Maximum Axle Weight Kips		Maximum Gross Weight Kips	Maximum Length of Combination Ft.
	Single	Tandem		
Newfoundland	18.0 (8 165 kg)	32.0 (14 515 kg)	112.0 (50 802 kg)	65 (19.8 m)
Nova Scotia	20.0 (9 072 kg)	35.0 (15 876 kg)	80.0 (36 287 kg)	65 (19.8 m)
New Brunswick	20.0 (9 072 kg)	40.0 (18 144 kg)	125.0 (56 699 kg)	65 (19.8 m)
Prince Edward Island	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	65 (19.8 m)
Quebec	22.0 (9 979 kg)	38.0 (17 237 kg)	126.0 (57 153 kg)	65 (19.8 m)
Ontario	20.0 (9 072 kg)	40.0 (18 144 kg)	140.0 (63 503 kg)	65 (19.8 m)
Manitoba	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	65 (19.8 m)
Saskatchewan	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	70 (21.3 m)
Alberta	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	70 (21.3 m)
British Columbia	20.0 (9 072 kg)	35.0 (15 876 kg)	110.0 (49 895 kg)	72 (21.9 m)
Yukon Territory	20.0 (9 072 kg)	40.0 (18 144 kg)	132.0 (59 874 kg)	70 (21.3 m)

Problem Statement

❑Concerns and Challenges



- **Overly restrictive** regulations lead to increased energy demand, higher carbon emissions, and greater stress on transportation infrastructure [4]
- Current bridge formulas result in conservative and non-economical outcomes
  - **Not specific for all-terrain cranes** with no consideration of new developments [3]
- **Variability** of bridge formula among provincial codes
  - Diverse carrying capacities of bridges, originally designed to varying strength levels [3, 5]
- **Aging** effects on the performance of bridges under service loads [6]
  - All existing studies and regulations are based on new bridges



[7]

Risk of rapid deterioration

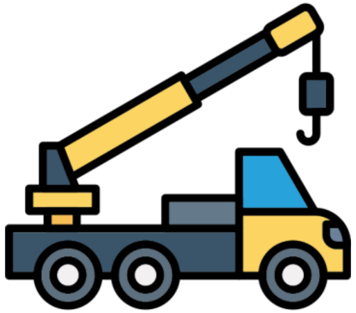
For example, **corrosion and freeze-thaw cycles** accelerated by climate change [8]:
- Temperature rise
- Use of de-icing salts in extreme cold

Problem Statement

❑Research Question

Recognize the need to control highway bridge loads

Acknowledge the deteriorating state of the infrastructure



Views current weight limits as too strict

Blame bridge owners' conservative policies

Research question:

How to develop a standardized bridge formula, specifically designed for all-terrain cranes, that enhances **safety** and **efficiency**?

Research Objective

Developing a Standardized Bridge Formula for All-terrain Cranes to Enhances Safety, Efficiency, and Regulatory Consistency across Canadian Provinces, while Comprehensively Accounting for Structural Demands and Aging Effects

Research Program

❑Sub-Objectives

Developing a Standardized Bridge Formula for All-terrain Cranes to Enhances Safety, Efficiency, and Regulatory Consistency across Canadian Provinces, while Comprehensively Accounting for Structural Demands and Aging Effects

1. Standardization of Bridge Formula for All-Terrain Crane
2. Advanced Considerations in Bridge Dynamics and Reliability
3. Impact of Aging-Related Deteriorations

Research Program

❑1. Standardization of Bridge Formula for All-Terrain Crane

- Tasks

1.1. Evaluation of current bridge formula

1.2. Unifying provincial considerations for bridge formulas

1.3. Develop new/modified bridge formula

Introduction & Motivation: Background | Problem statement | Objective
Research Program: Sub-objectives | Tasks | Research significance

Research Program

❑1. Standardization of Bridge Formula for All-Terrain Crane

- **Tasks**

1.1. Evaluation of current bridge formula

- Considerations in the current bridge formula
  - Stress levels caused by practical vehicles
  - Maximum allowable response (e.g., maximum bending moment along the deck)
  - Fatigue considerations
  - Pavement considerations
- **Reliability evaluation** of existing bridge formulas
  - For bridges with 75-year design life CSA uses target reliability index of 3.50

Limit state function: $g = R - D$ → $\begin{cases} g \le 0 & \text{Failed} \\ g > 0 & \text{Safe} \end{cases}$

Probability of failure in the design life: 10^{-4} = Reliability index of 3.5

Research Program

❑1. Standardization of Bridge Formula for All-Terrain Crane

- **Tasks**

1.1. Evaluation of current bridge formula

- **Reliability evaluation** of existing bridge formulas
  - Wide range of design scenarios

Short Span Bridges
(up to 20 meters)

https://steelconstruction.info/Bridges

Medium Span Bridges
(20 to 60 meters)

https://www.mdpi.com/1996-1944/13/2/405/

Long Span Bridges
(over 60 meters)

https://blog.enerpac.com/7-types-of-bridges-every-engineer-should-know-about/

Research Program

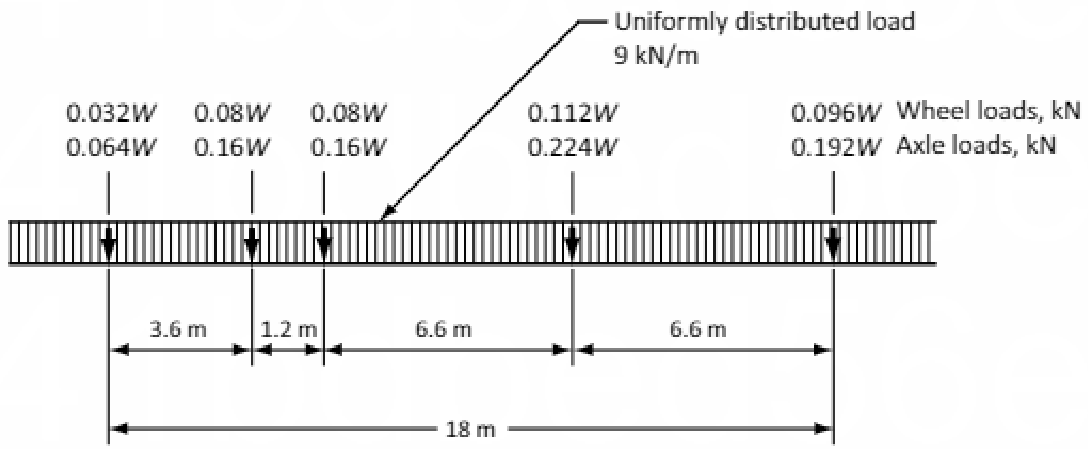
❑1. Standardization of Bridge Formula for All-Terrain Crane

▪ **Tasks**

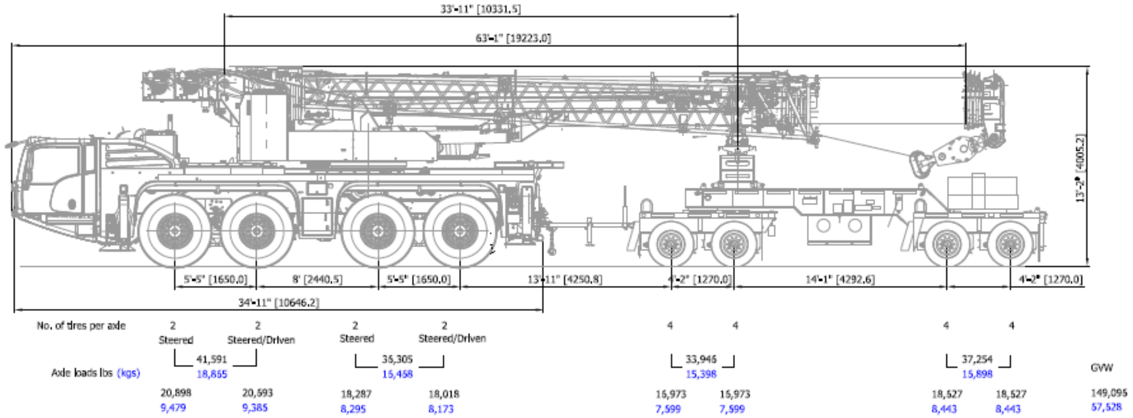
1.1. Evaluation of current bridge formula

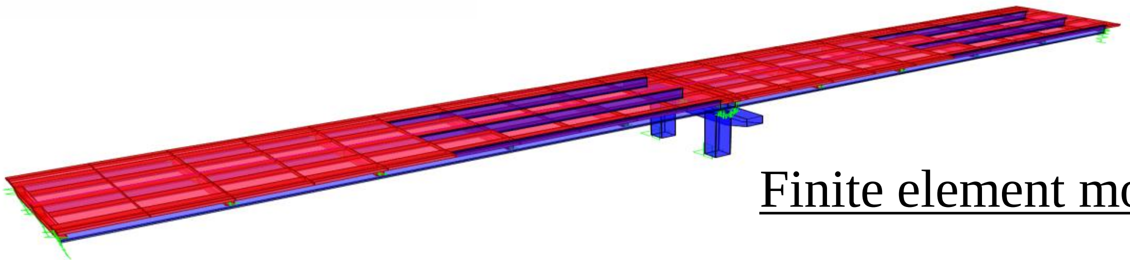
- **Preliminary case study:** Evaluating the live load effect of mobile cranes in comparison to the CSA S6 standard design truck.

CSA S6 standard design truck: CL-W lane load



4-axle all-terrain crane (57 tons)





Finite element model of bridge

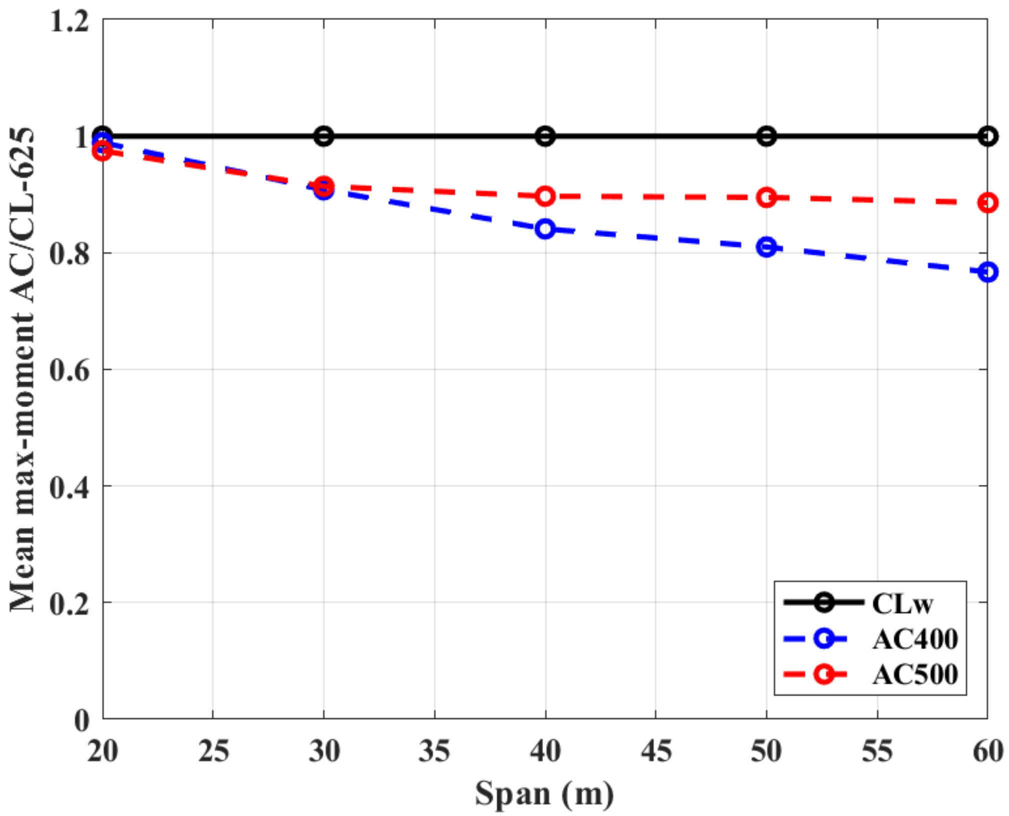
Research Program

❑1. Standardization of Bridge Formula for All-Terrain Crane

▪ **Tasks**

1.1. Evaluation of current bridge formula

- **Preliminary case study:**
  - Mean max-moment caused by all-terrain crane over the corresponding value caused by standard design truck
  - Initial observations confirms that the all-terrain cranes have significantly lower impacts on bridges than expected.



Research Program

❑1. Standardization of Bridge Formula for All-Terrain Crane

▪ Tasks

1.1. Evaluation of current bridge formula

1.2. Unifying provincial considerations for bridge formulas

- Design considerations of each province
  - Design scenarios for bridges
- Standardization of requirements for bridge formula development

Research Program

❑1. Standardization of Bridge Formula for All-Terrain Crane

- **Tasks**

1.1. Evaluation of current bridge formula

1.2. Unifying provincial considerations for bridge formulas

1.3. Develop new/modified bridge formula

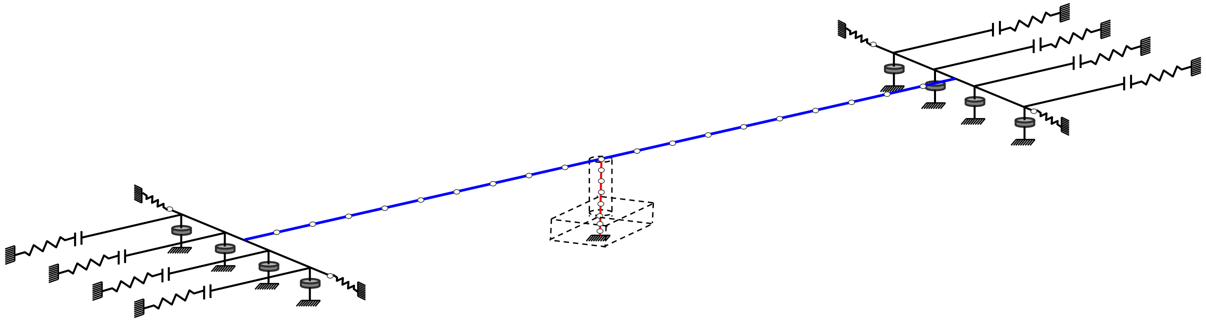
- Goal: Uniform set of bridge formula depending on route classification and specifically for all-terrain cranes

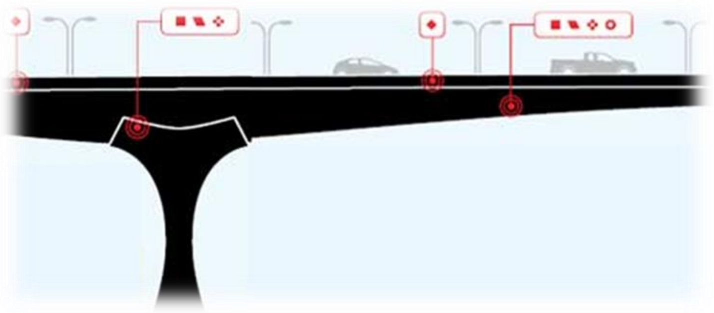
Research Program

❑1. Standardization of Bridge Formula for All-Terrain Crane

- Tasks

1.3. Develop new/modified bridge formula





Numerical Simulation	Field experiment
Modeling bridges subjected to the equivalent loading	Measuring of stress levels in bridges through instrumentation, when all-terrain crane passes
Validating the model based on field experiment	Comparison with the stress level considered in the current bridge formulas

Data generation based on unified design scenarios + Incorporating uncertainties

Developing new bridge formula

Research Program

❑2. Advanced Considerations in Bridge Dynamics and Reliability

- **Tasks**

2.1. Impact of advanced suspension systems on bridge dynamic load factors bridge formula

- All-Terrain Cranes, with hydro-pneumatic suspension systems, introduce nuanced factors influencing bridge dynamic load factors.
- Goal: Adjustments in axle capacity limits within the bridge formula
- Methodology:
  - Incorporating existing models into the numerical model of the bridge
  - Proposing modifications based on data generated by the new simulations

Research Program

❑3. Impact of Aging-Related Deteriorations

- **Tasks**

3.1. Performance assessment of bridge formula for aged bridges

3.2. Developing aging related modifications

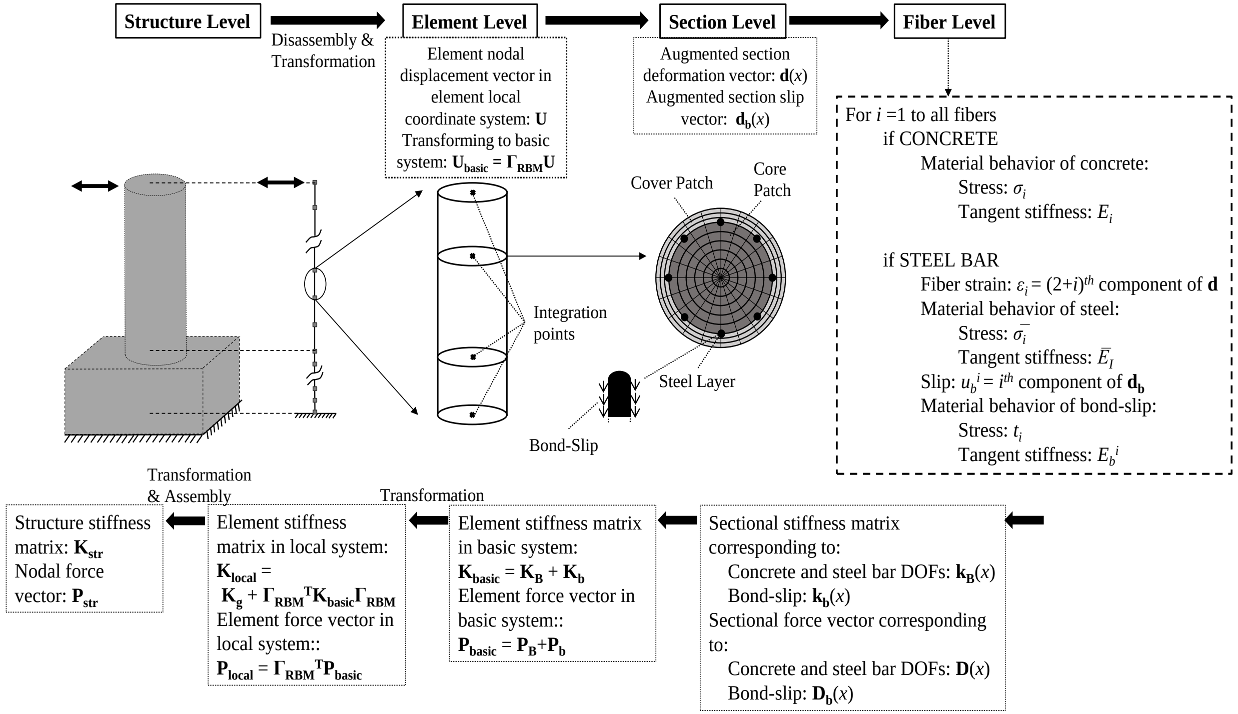
Research Program

❑3. Impact of Aging-Related Deteriorations

- Tasks

3.1. Performance assessment of bridge formula for aged bridges

- Modeling aged bridges using previously developed tool by PI



OpenSees

Required elements and materials developed in OpenSees for finite element modeling of bridges (steel and reinforced-concrete) [6, 8, 9]

Research Program

❑3. Impact of Aging-Related Deteriorations

▪ **Tasks**

3.1. Performance assessment of bridge formula for aged bridges

- Modeling aged bridges using previously developed tool by PI
- Experimental evaluation of aged bridge deck under the equivalent loading
  - Small-scale testing in I. F. Morrison Structures Lab, University of Alberta
    - Similar test done in 2018, but with different loading setup [10]:

Research Program

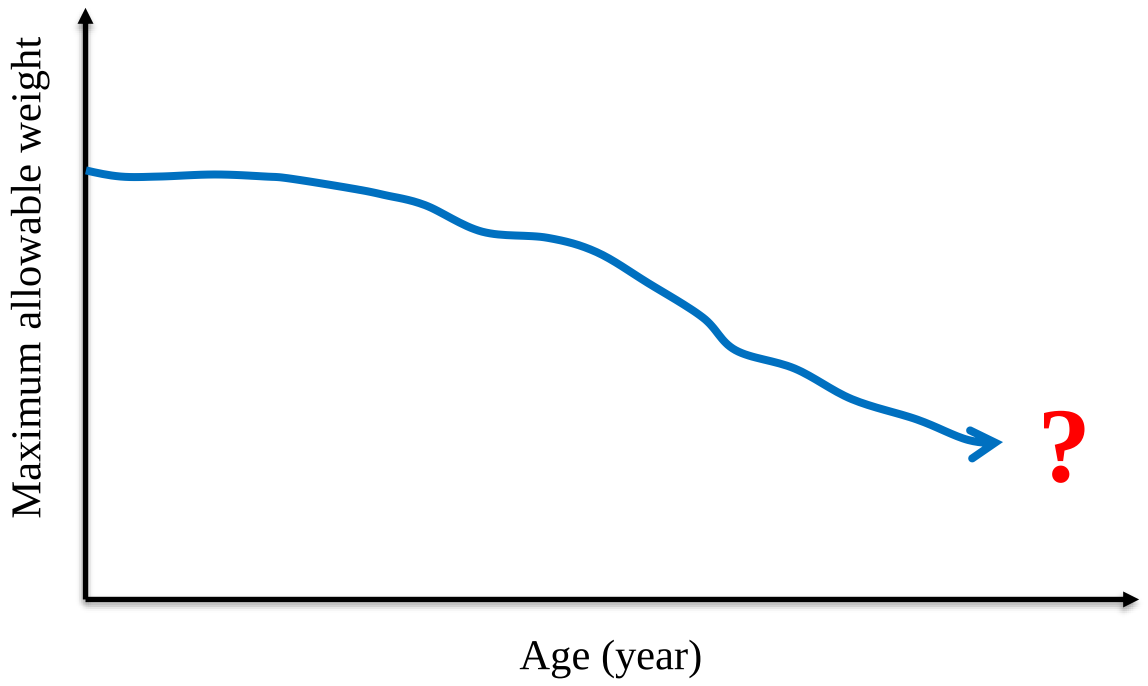
❑3. Impact of Aging-Related Deteriorations

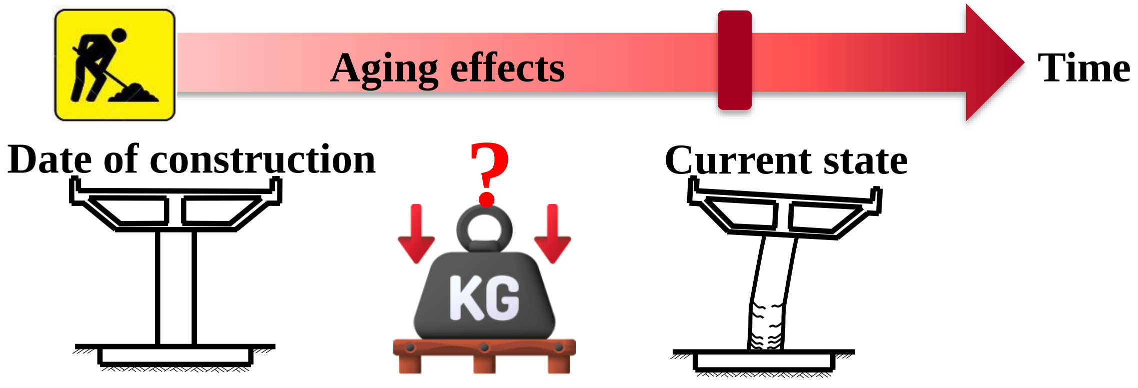
▪ Tasks

3.1. Performance assessment of bridge formula for aged bridges

3.2. Developing aging related modifications

- Using validated model for data generation and model development





Ensuring safety for aged bridges
Improving efficiency
Avoiding over conservatism

Research Program

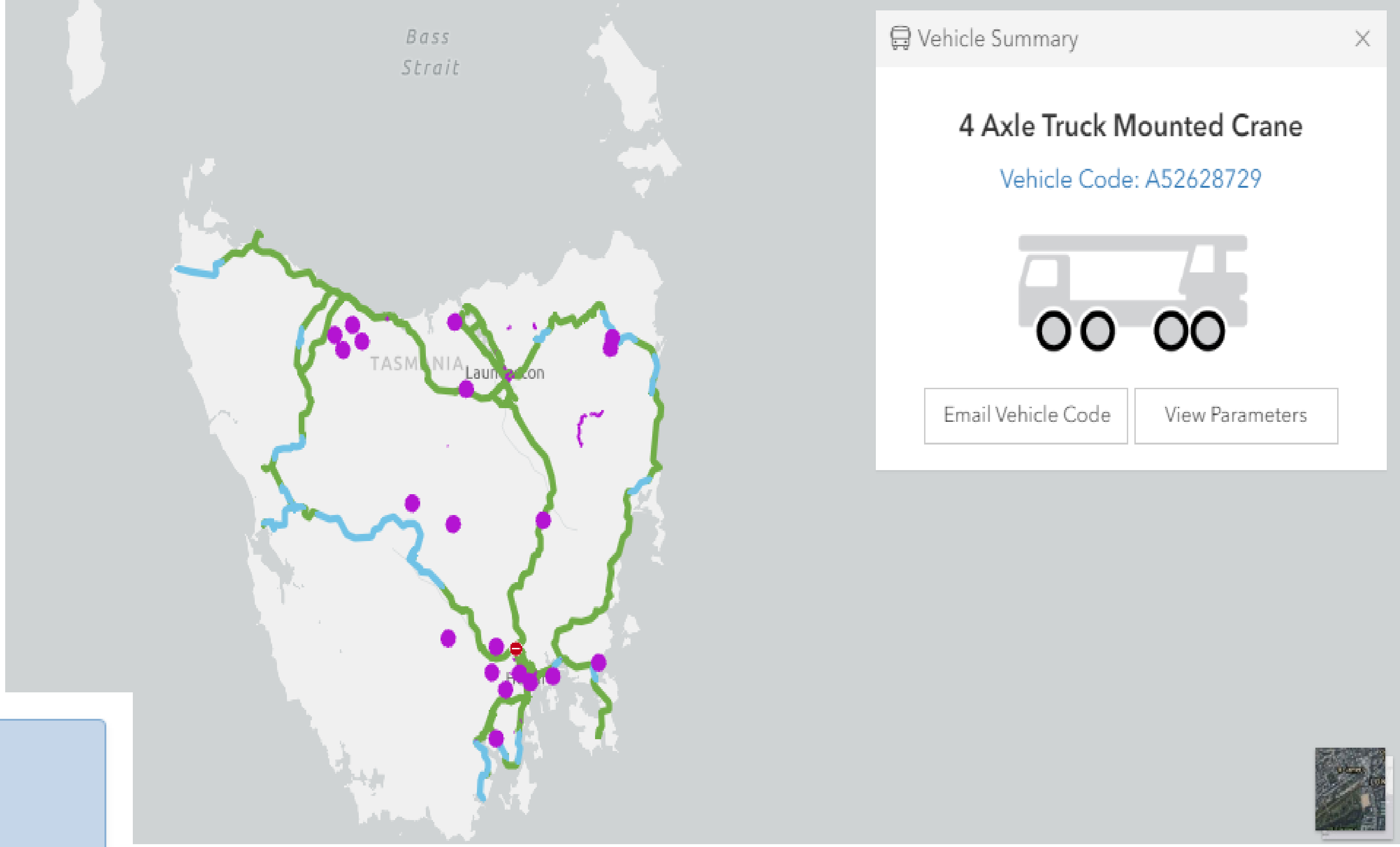
❑Creating a Digital Platform to Optimize Routing

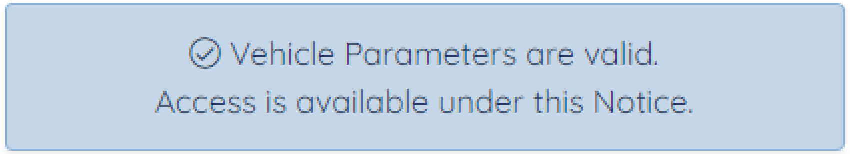
Goals:

- To accommodate and mitigate road manager challenges
- To delivers on industry priorities

Similar platforms in other countries:

- Heavy Vehicle Access Management System (HVAMS) in Australia





Research Program

❑Research Significance

Developing a Standardized Bridge Formula for All-terrain Cranes to Enhances Safety, Efficiency, and Regulatory Consistency across Canadian Provinces, while Comprehensively Accounting for Structural Demands and Aging Effects

Enhancing the efficiency and safety of crane operations nationwide

Enhancing project efficiency economically

Facilitating smoother inter-provincial travels for all-terrain cranes

Reduction of greenhouse gas emissions, aligning with environmental sustainability goals

Thank you for your attention!

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