UNIVERSITY OF ALBERTA

Department of Civil and Environmental Engineering

School of Mining and Petroleum Engineering

CRANE RENTAL ASSOCIATION OF CANADA
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ASSOCIATION CANADIENNE DE LOCATION DE GRUES

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

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December 2025

Outline

❑ Introduction & Motivation

- Background
- Problem statement
- Research objectives

❑ Methodology & Tasks

- Methodology
- Task 1: **Evaluation of bridge formula and current weight regulations**
- Task 2: **New bridge formula development**
- Task 3: **Standardization of the new bridge formula**

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❑ Applications of mobile cranes

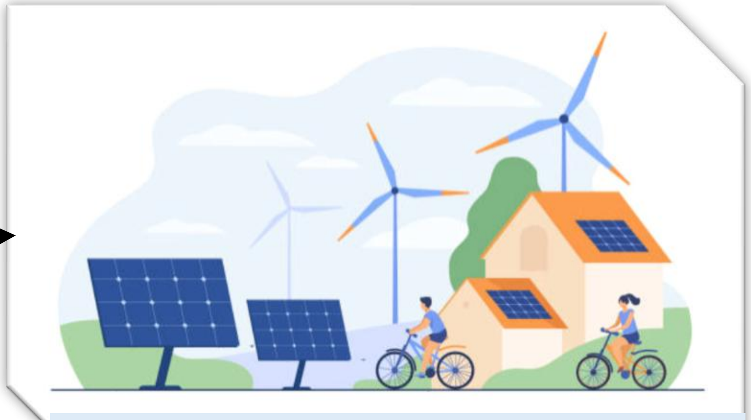

https://www.vecteezy.com/vector-art/7142390

Construction industry

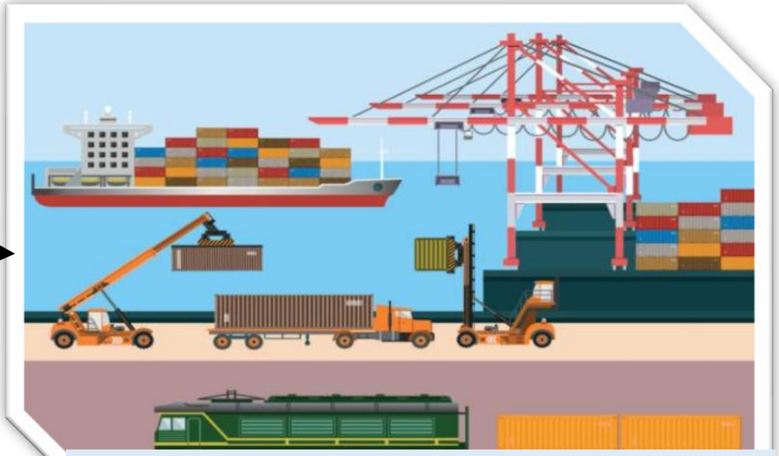

https://www.dreamstime.com/illustration/earthquake.html

Disaster response

Mobile cranes


https://www.istockphoto.com/illustrations/renewable-energy

Power transmission and wind energy


https://www.istockphoto.com/illustrations/ship-to-shore-crane

Shipping industry

❑ Mobile crane evolution: driven by dynamic system updates

*Truck-mounted hydraulic crane – **2 tons***

1946

*First introduction of all-terrain cranes – **25 tons***

1977

*High-capacity 6 axle all-terrain crane – **400 tons***

2013

1955

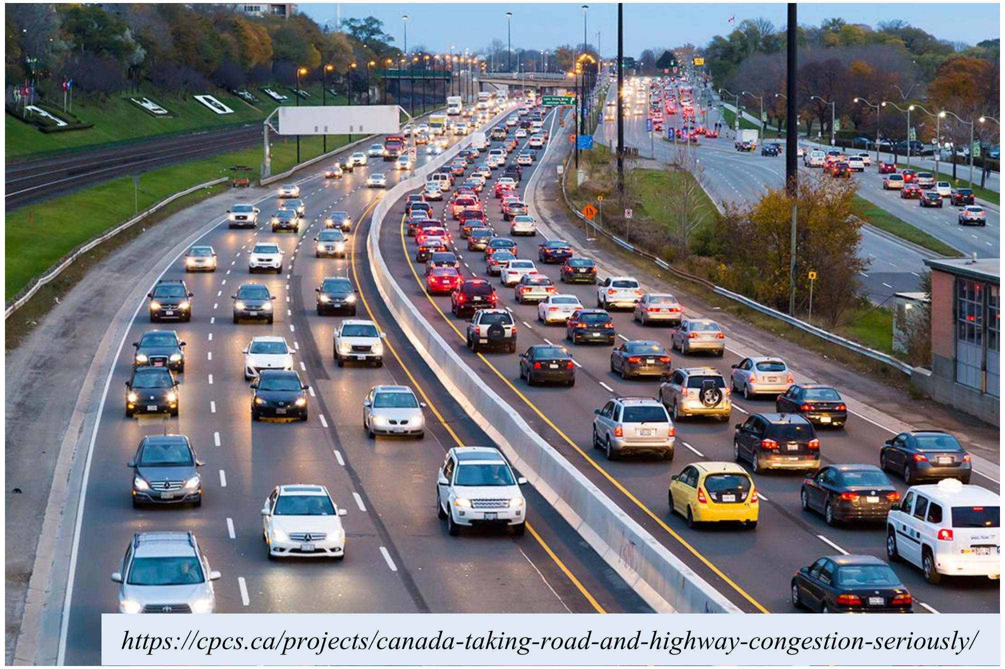
*Early rough-terrain crane – **12 tons***

1998

*Mega-capacity 8 axle all-terrain crane – **550 tons***

❑ Crane supporting infrastructure

Advancements in all-terrain crane technology demand efficient supporting infrastructure



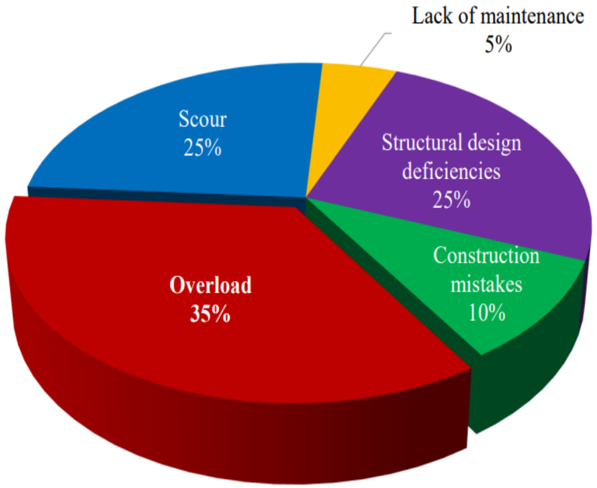
Highway road infrastructure

Highway bridge infrastructure

Critical challenges facing bridge infrastructure

- Growing traffic volume
- Increase the usage of specialized vehicles
- Increasing overweight vehicles

A special heavy-vehicle configuration: All-terrain crane



Bridge collapse causes [4]

Tittle bridge failure in Nova scotia -2020

❑ Problem statement

Are our bridges safe for heavy mobile crane crossings?

Two point of views

Government agencies

- Prohibit some overweight vehicles from using bridges
- Acknowledge the **deteriorating** state of the infrastructure.
- Emphasizes **controlling** highway bridge loads.

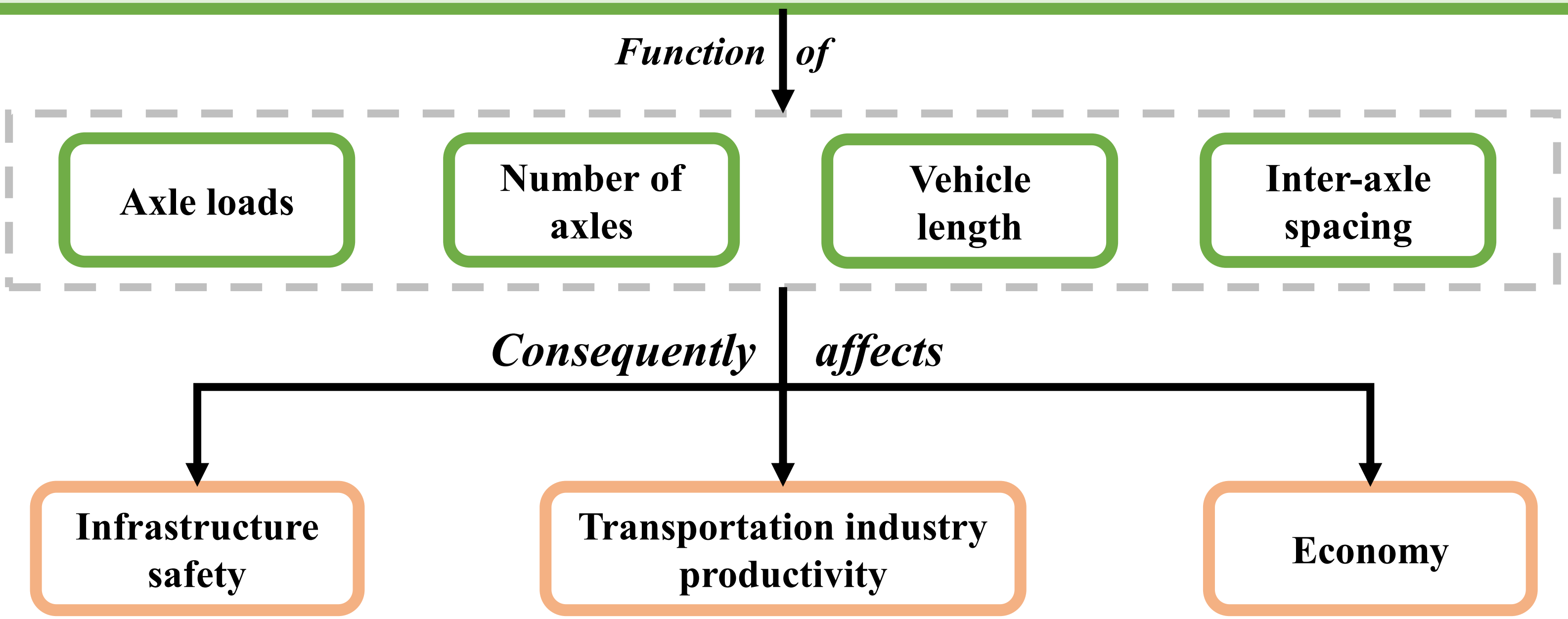
Trucking & crane industry

- Views current weight limits as too **strict**.
- **Blame** governmental conservative policies.

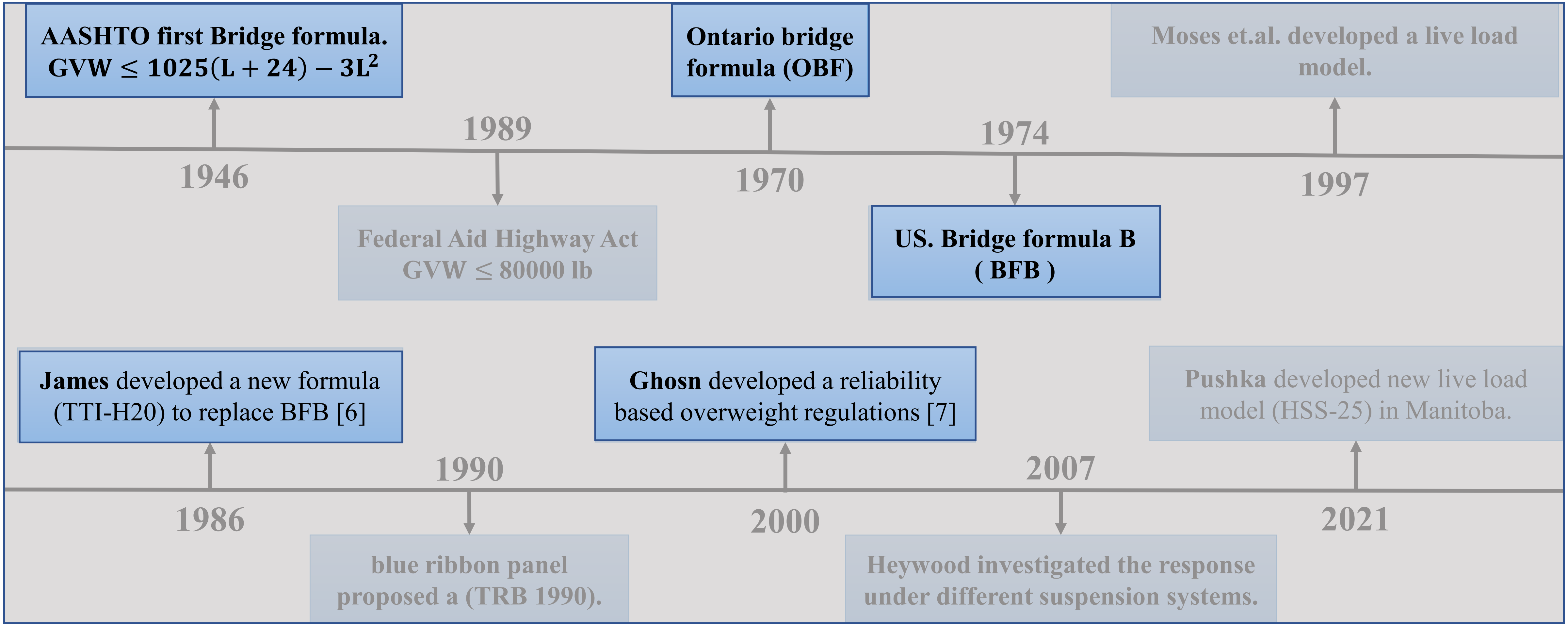
To regulate overloaded vehicles, government agencies use bridge formula.

❑ Bridge formula

A " **bridge formula** " is a performance based equation designed to protect bridges by determining the **maximum weight allowed** on any series of consecutive axles [5].



❑ History of Weight Regulations



US. Bridge formula B (BFB)

$$W = 500\left[\frac{LN}{N-1} + 12N + 36\right]$$

Where:

- **W :** Maximum allowable weight in lbs.
- **L :** Axle Spacing
- **N:** Number of axles in axle group

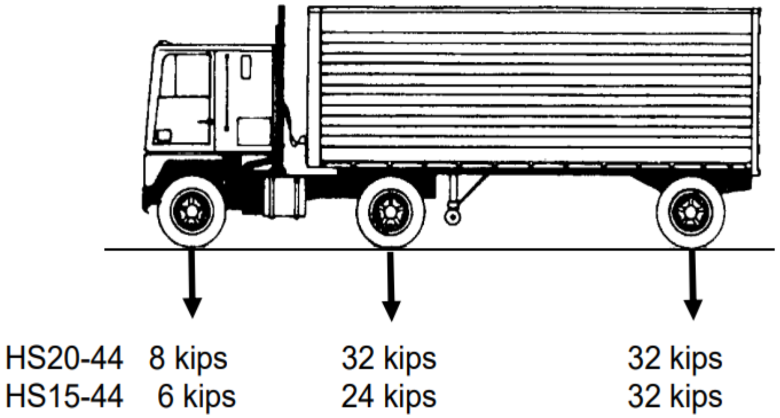
Based on

Weight cap of 80000 lbs (36 tons).

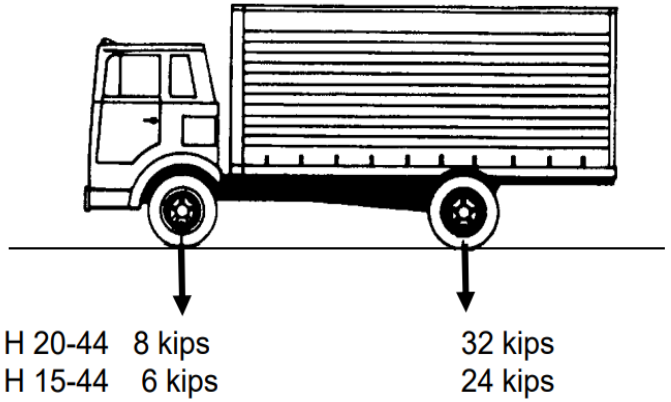
Overstressing of bridges

5% for H-20 bridges

30% for H-15 bridges



AASHTO H-20 Loading Truck



AASHTO H-15 Loading Truck

The justification for these values seems to be rather arbitrary [6][7]

History of Weight Regulations

- **1946** — AASHTO first Bridge formula. $GVW \leq 1025(L + 24) - 3L^2$
- **1989** — Federal Aid Highway Act $GVW \leq 80000$ lb
- **1970** — Ontario bridge formula (OBF)
- **1974** — US. Bridge formula B (BFB)
- **1997** — Moses et.al. developed a live load model.
- **1986** — James developed a new formula (TTI-H20) to replace BFB [5]
- **1990** — blue ribbon panel proposed a (TRB 1990).
- **2000** — **Ghosn** developed a reliability based overweight regulations [6]
- **2007** — Heywood investigated the response under different suspension systems.
- **2021** — **Pushka** developed new live load model (HSS-25) in Manitoba.

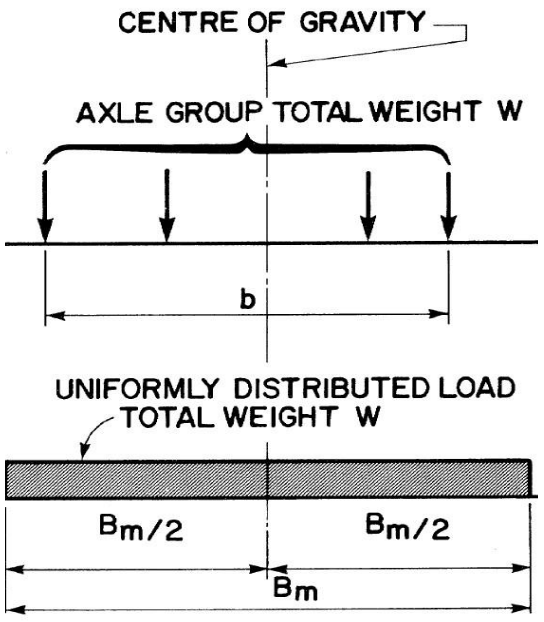
Ontario bridge formula (OBF)

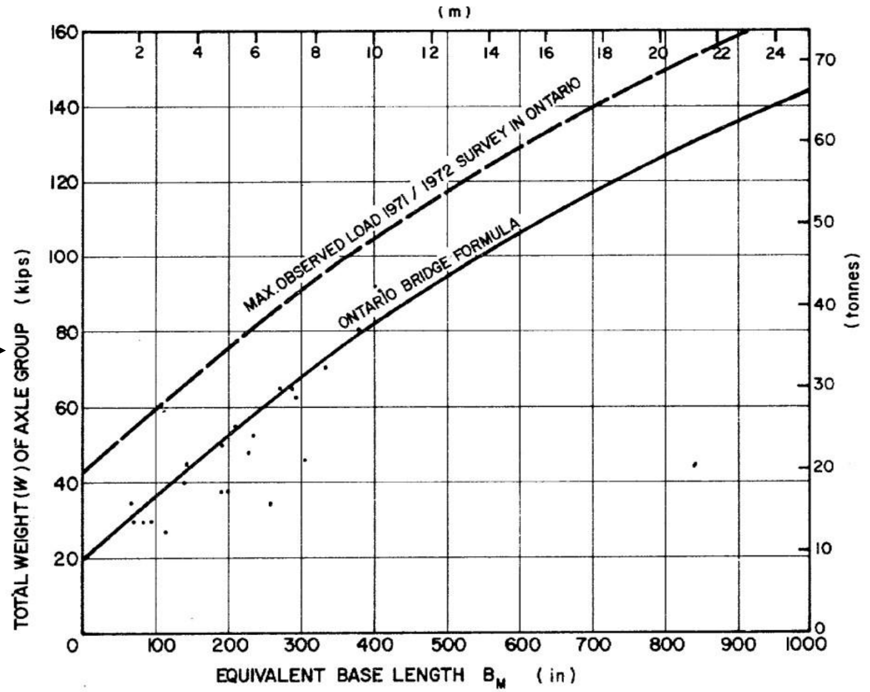
$$W = 10 + 3\,B_M - 0.0325 B_M^2$$

Where:

W : Maximum allowable weight in tons.

B_M : Equivalent base length





Maximum observed traffic load based on Ontario 1972 survey [8]

Requires engineering background [8][9]

Not specifically tailored for special vehicles like mobile cranes [8]

Limitations

Lack of consistency between provinces [8]

Maximum GVW For Canadian Provinces

Table 1. Maximum Allowable Axle Weights per Province

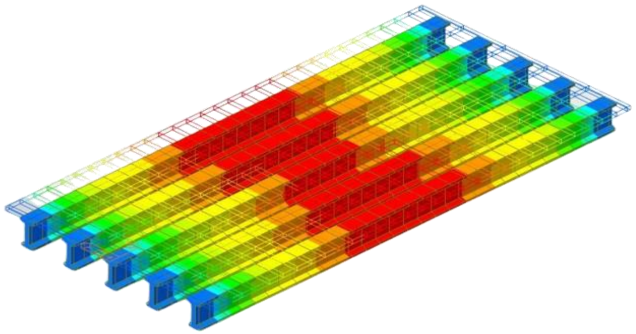
Province	Maximum Allowable Axle Weight (kg)
British Columbia	11,000
Alberta	9,500
Saskatchewan	9,400
Manitoba	5,036
Nova Scotia	6,500
New Brunswick	9,100
Prince Edward Island	9,100

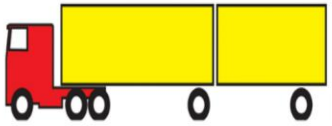
❑ Limitations

Overstress criteria still used in some formulas [6][7]

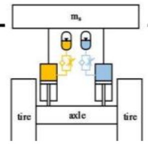
Arbitrary weight caps without clear basis [6][7]

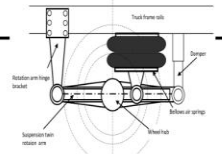
Not tailored to handle specialized crane vehicles [8]





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





Research Questions

1. **Are current weight regulations sufficient for all-terrain cranes?**
2. **How can a bridge formula ensure safe and efficient integration of all-terrain cranes?**
3. **How can we develop an efficient approach to align crane-weight regulations across provinces?**

❑ Research objectives

Main research objective

Developing a standardized weight regulations for all-terrain cranes to enhances safety, efficiency, and regulatory consistency across Canadian provinces

Evaluation of current weight regulations

Task #1

Bridge formula development

Task #2

Standardization

Task #3

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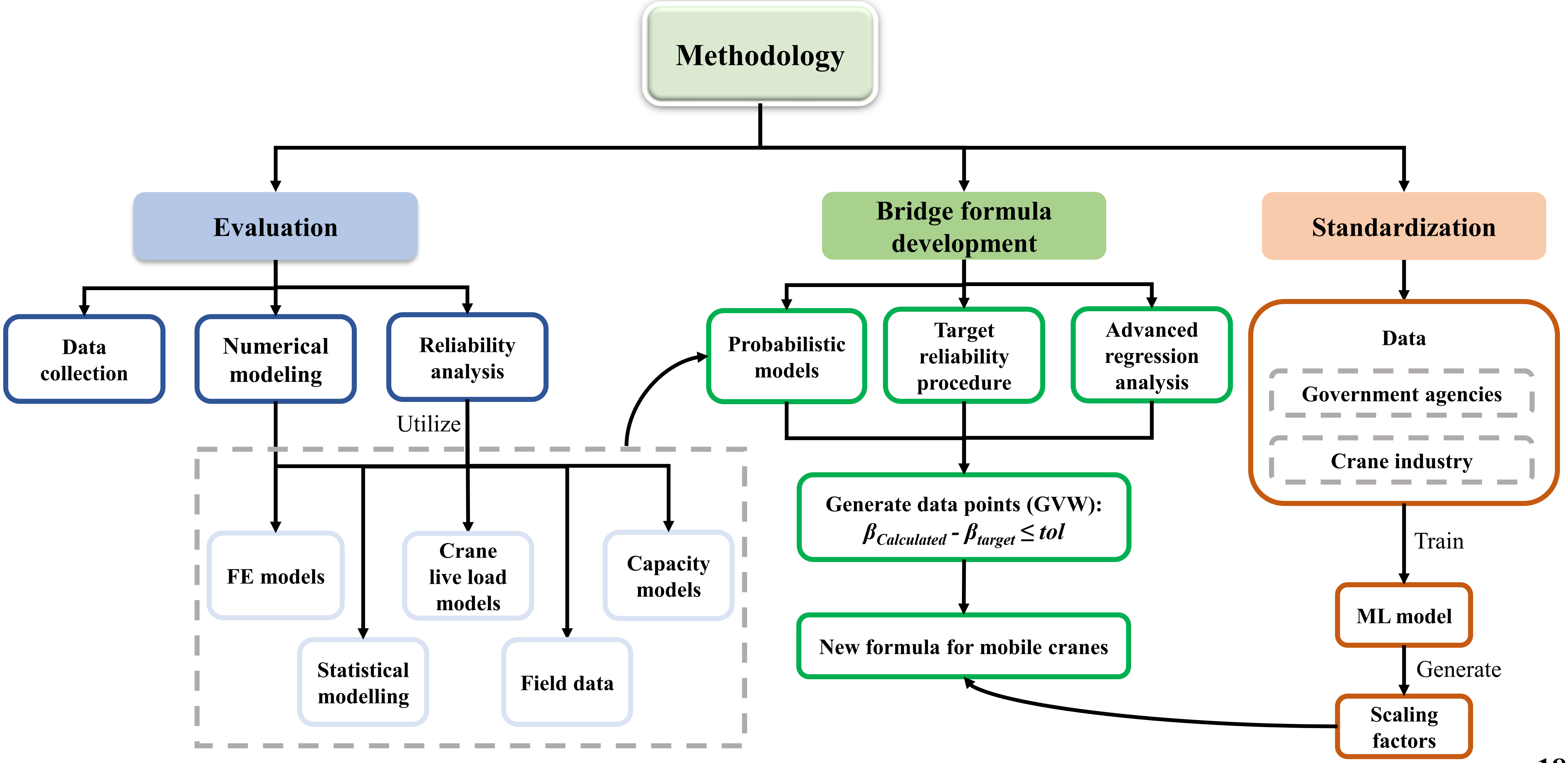
Methodology
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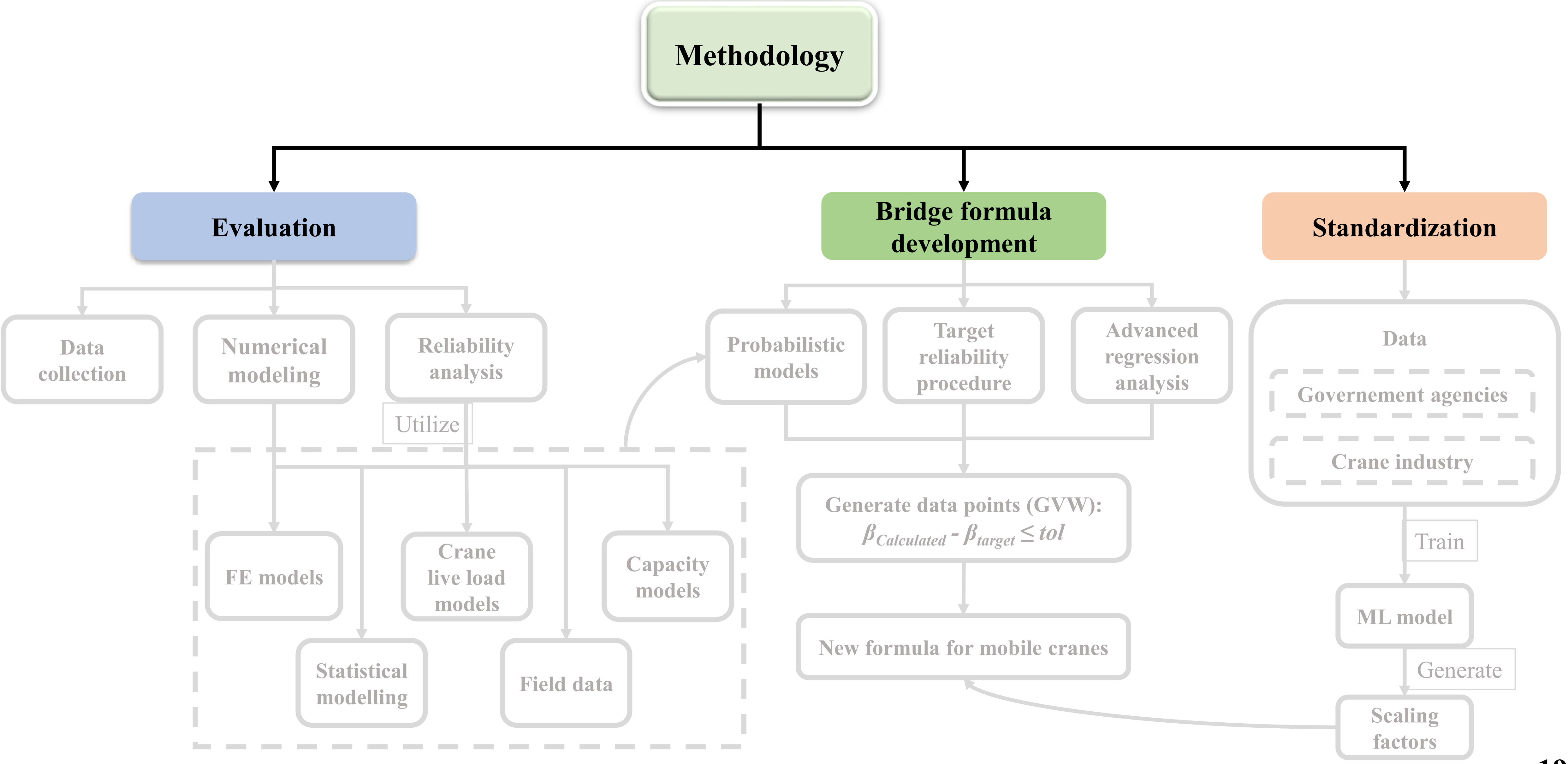
Standardization
Data collection
Numerical modeling
Reliability analysis
Utilize
FE models
Crane live load models
Capacity models
Statistical modelling
Field data
Probabilistic models
Target reliability procedure
Advanced regression analysis
Generate data points (GVW):
$\beta_{Calculated} - \beta_{target} \leq tol$
New formula for mobile cranes
Data
Government agencies
Crane industry
Train
ML model
Generate
Scaling factors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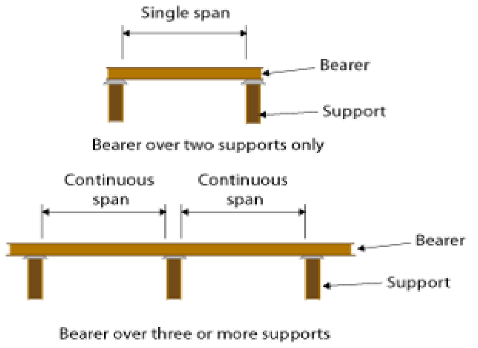
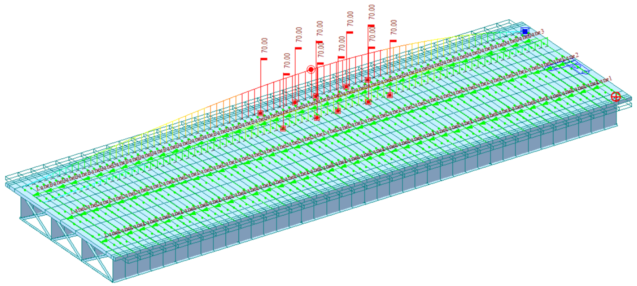
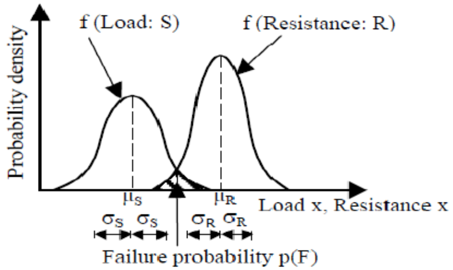
❑ Evaluation of current weight regulations

Evaluation

- **Data collection**
- **Numerical modeling**
- **Reliability analysis module**





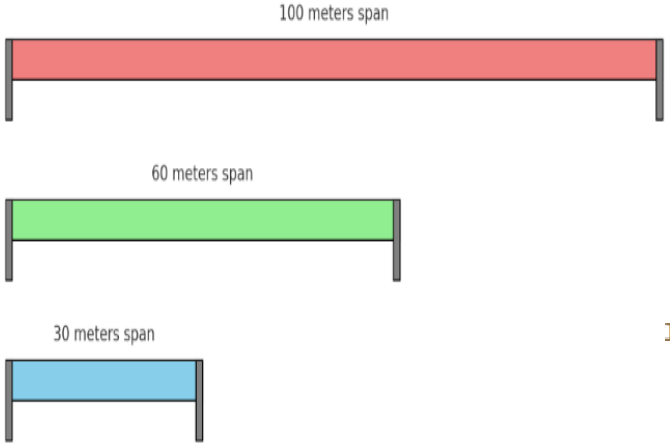


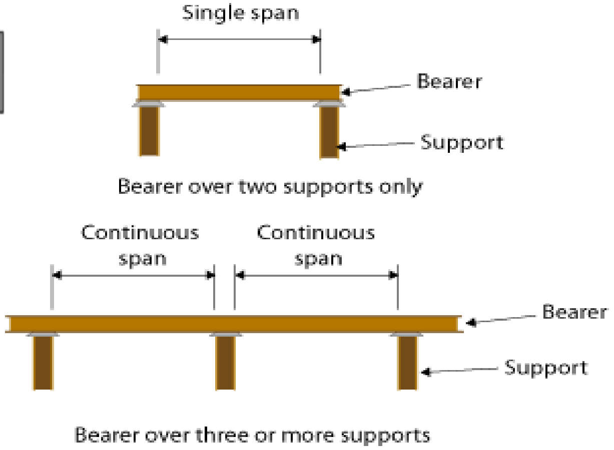
❑ Evaluation of current weight regulations

Bridge representative samples ← **Data collection** → **All terrain cranes representative samples**


Concrete bridges


Steel girder bridges





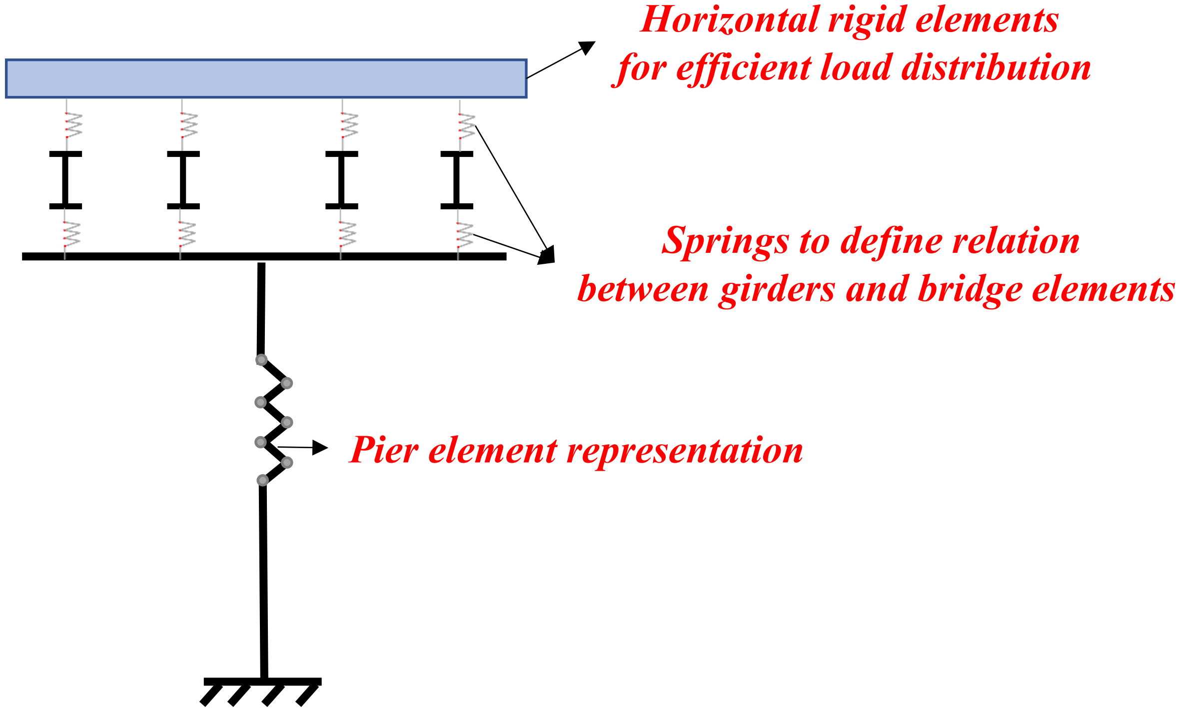

5 - Axle mobile crane


6 - Axle mobile crane

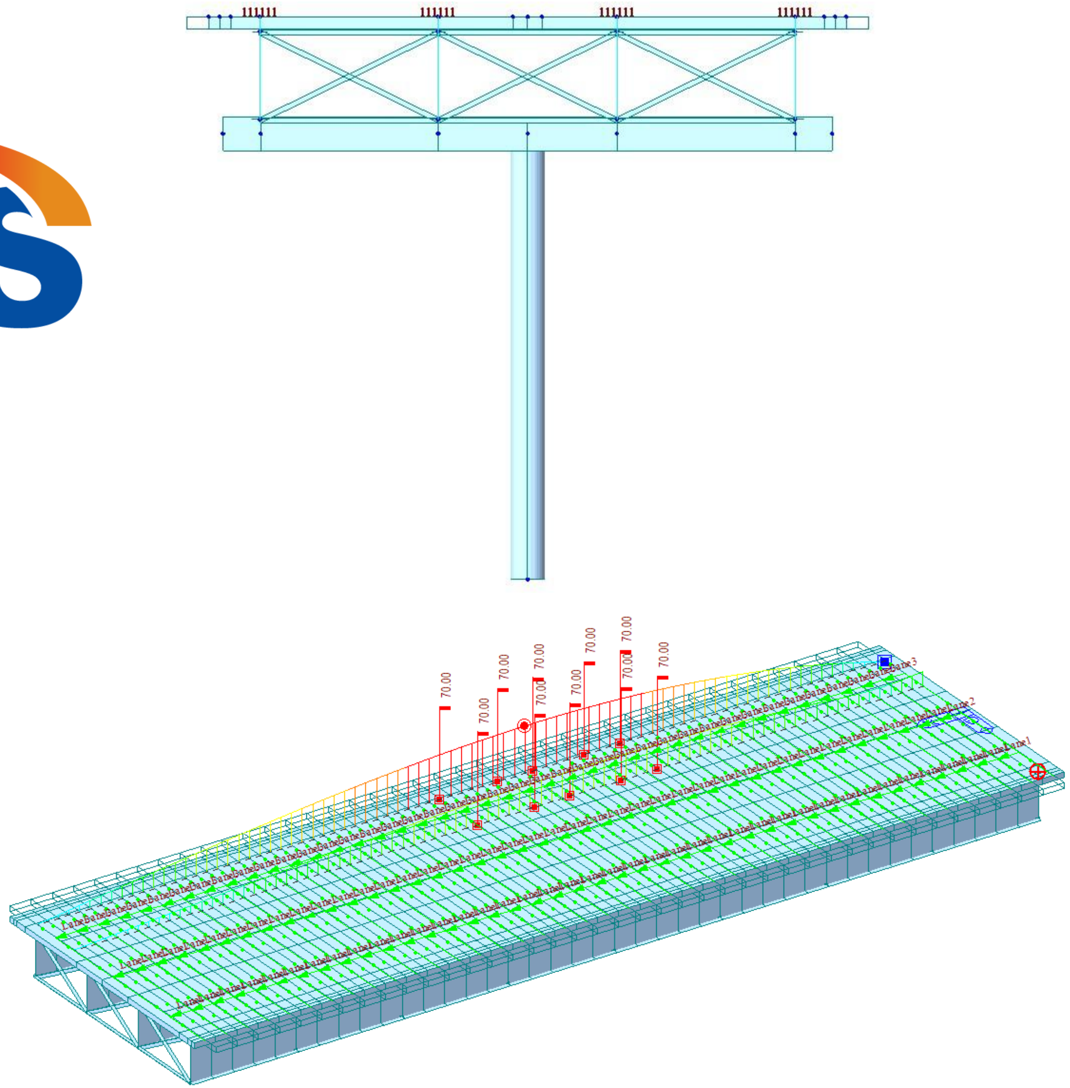

7 - Axle mobile crane

❑ Finite element modelling

The primary bridge model was developed with the **MIDAS Civil finite-element solver.**

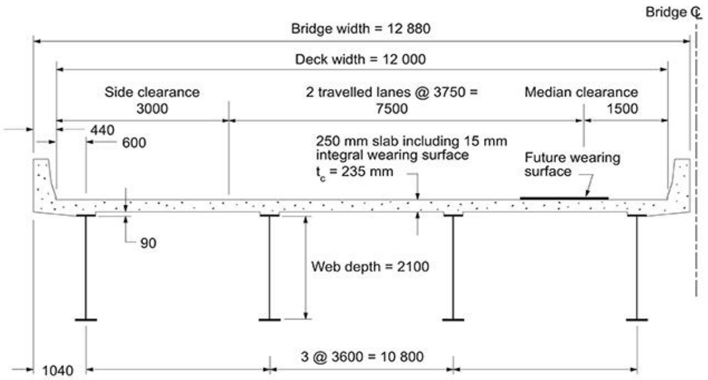


Bridge FE schematic representation



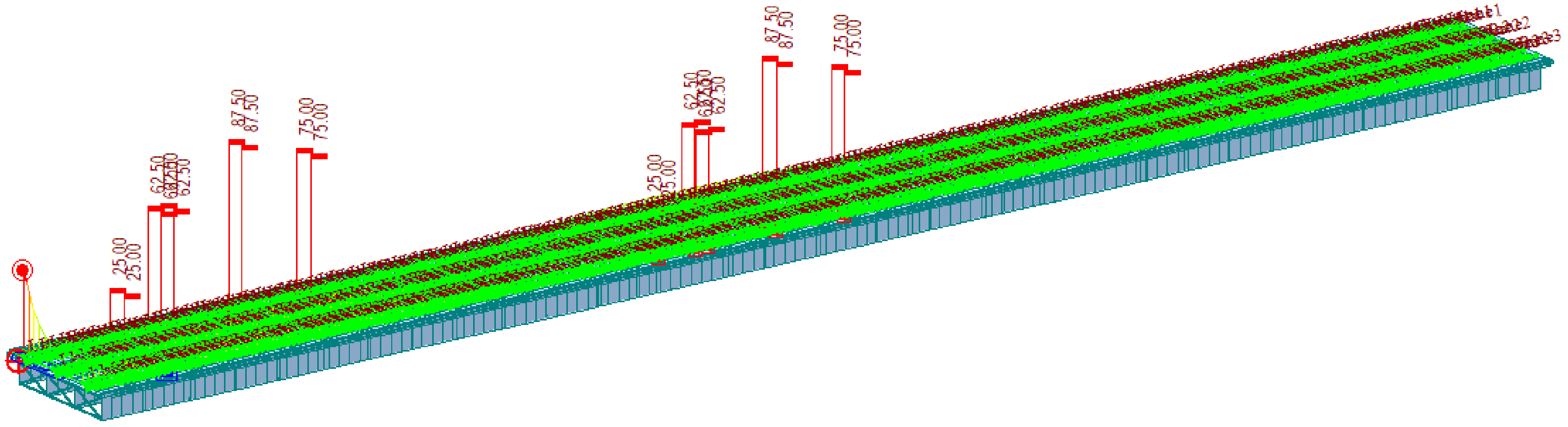
Midas Civil steel girder bridge model

❑ FE model verification



CISC bridge cross section

CISC bridge span details

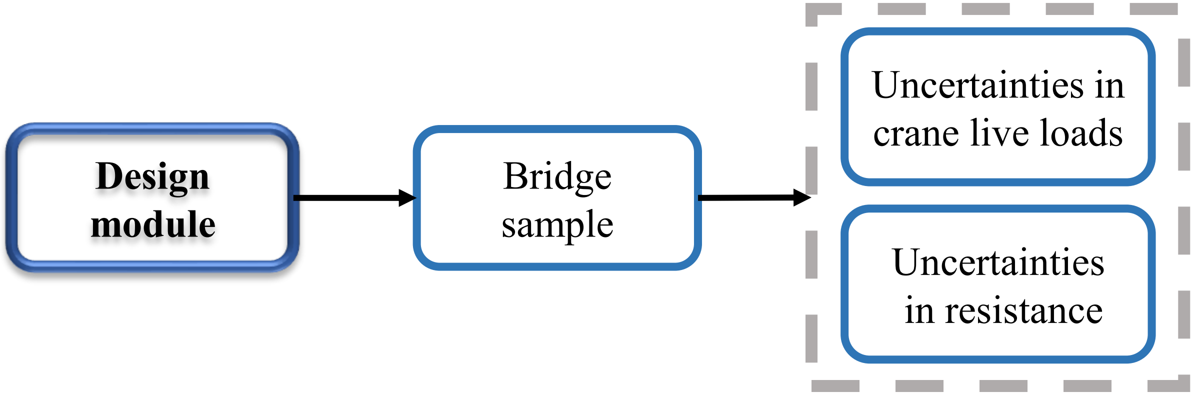


Midas Civil model

Table 2. Verification results

Case	CHBDC Live-Load Case		CHBDC ULS Case		Discrepancy (%)	
	CISC FE model	**MIDAS Civil model**	**CISC FE model**	**MIDAS Civil model**	**Live-load case**	**ULS-case**
Back-span moment (kN·m)	6007	5877	10510	10252	2.16 %	2.45 %
Support moment (kN·m)	5614	5511	14224	14044	1.83 %	1.27 %

❑ Reliability analysis procedure



Reliability analysis procedure

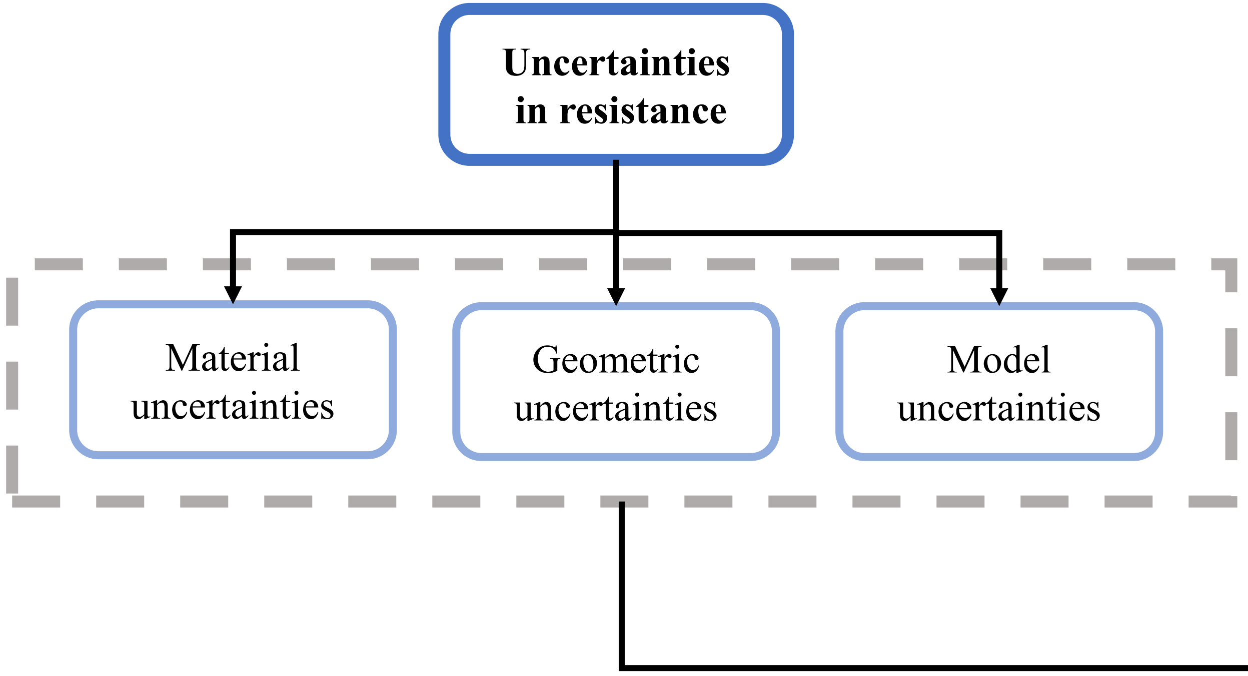
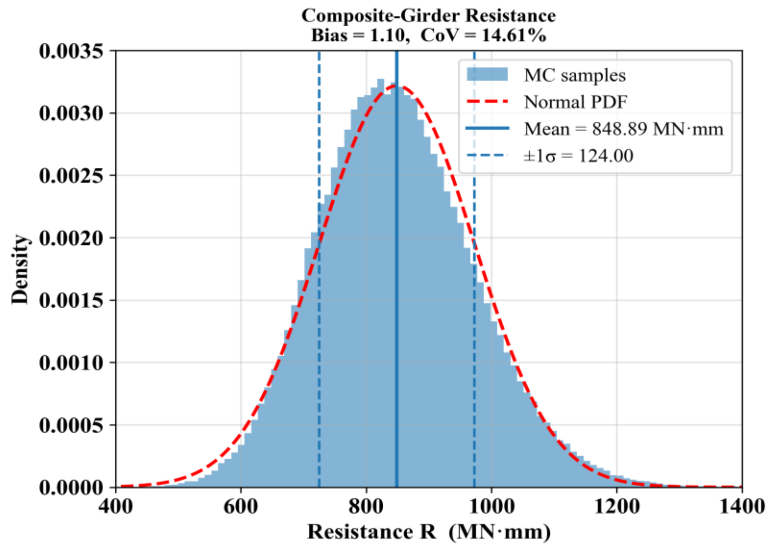


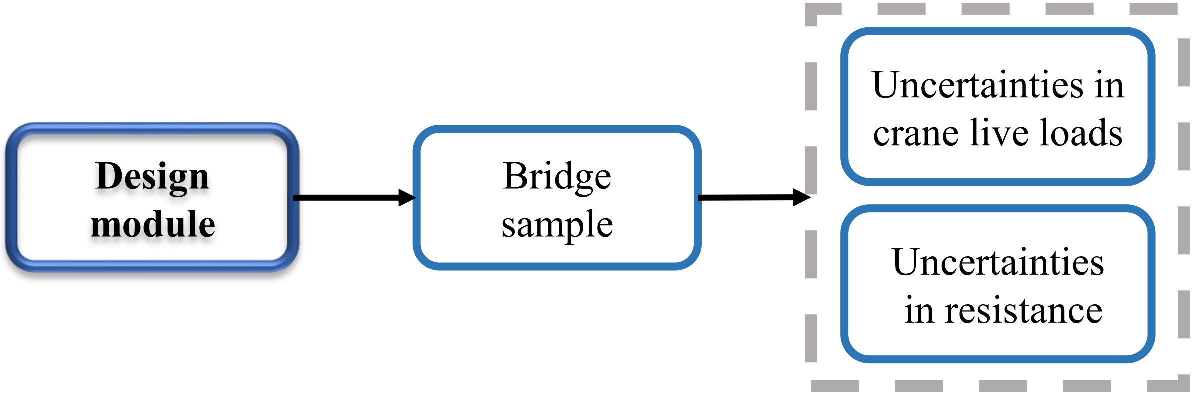
Table 4. Statistical parameters for bridge girder resistance [10]

Girder Type	Mean-to-Nominal Ratio	COV
Non-composite steel	1.11	0.115
Composite steel	1.10	0.12
Reinforced concrete	1.14	0.13
Prestressed concrete	1.05	0.075

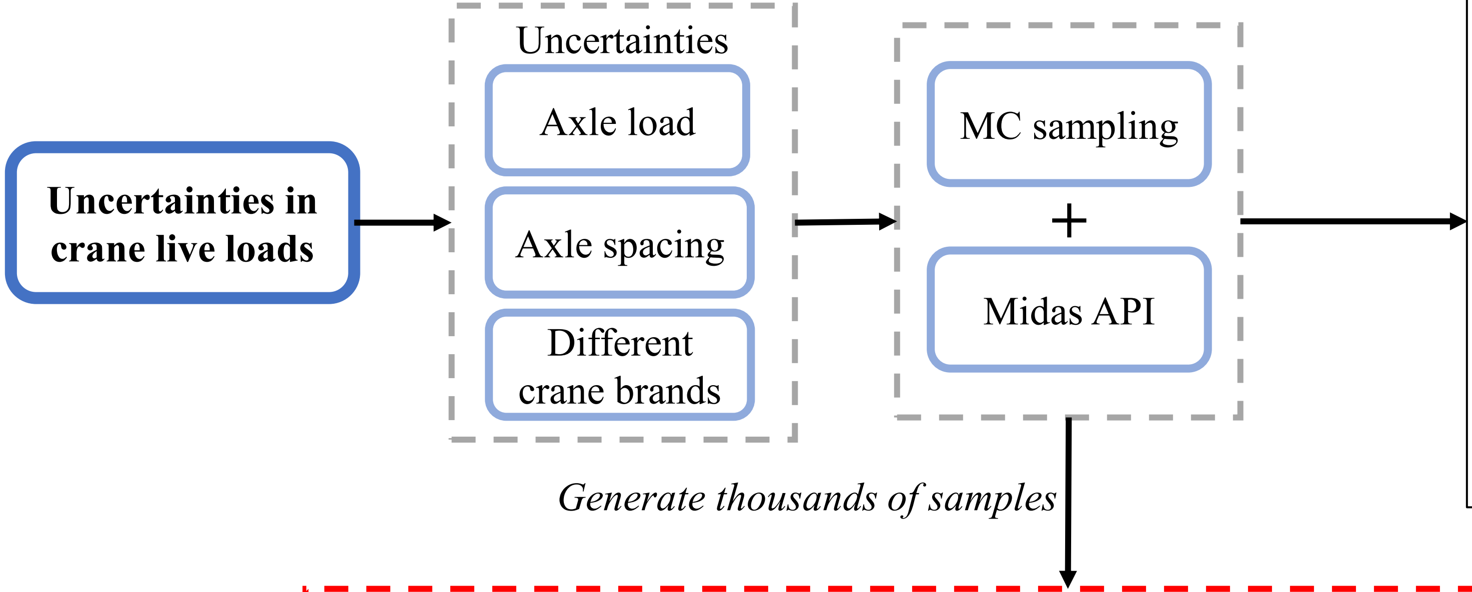


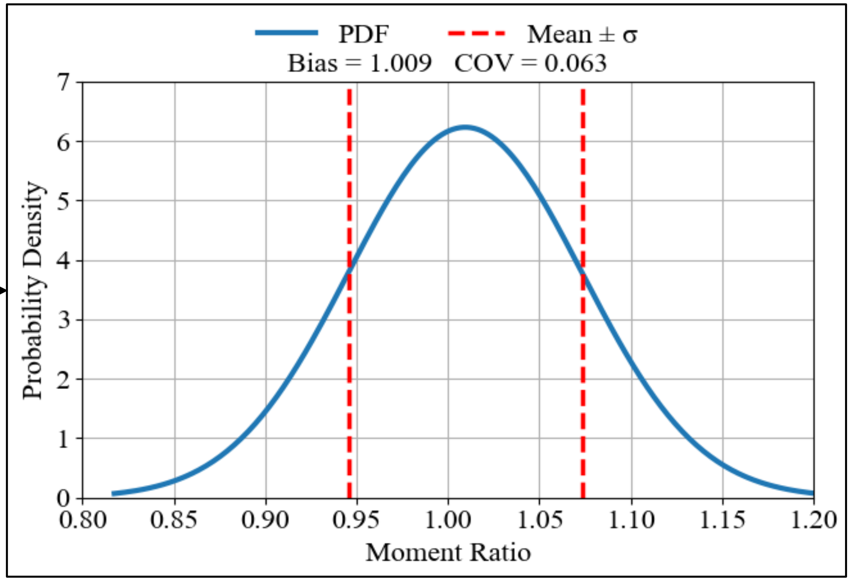
Uncertainties in composite girder resistance

❑ Reliability analysis procedure

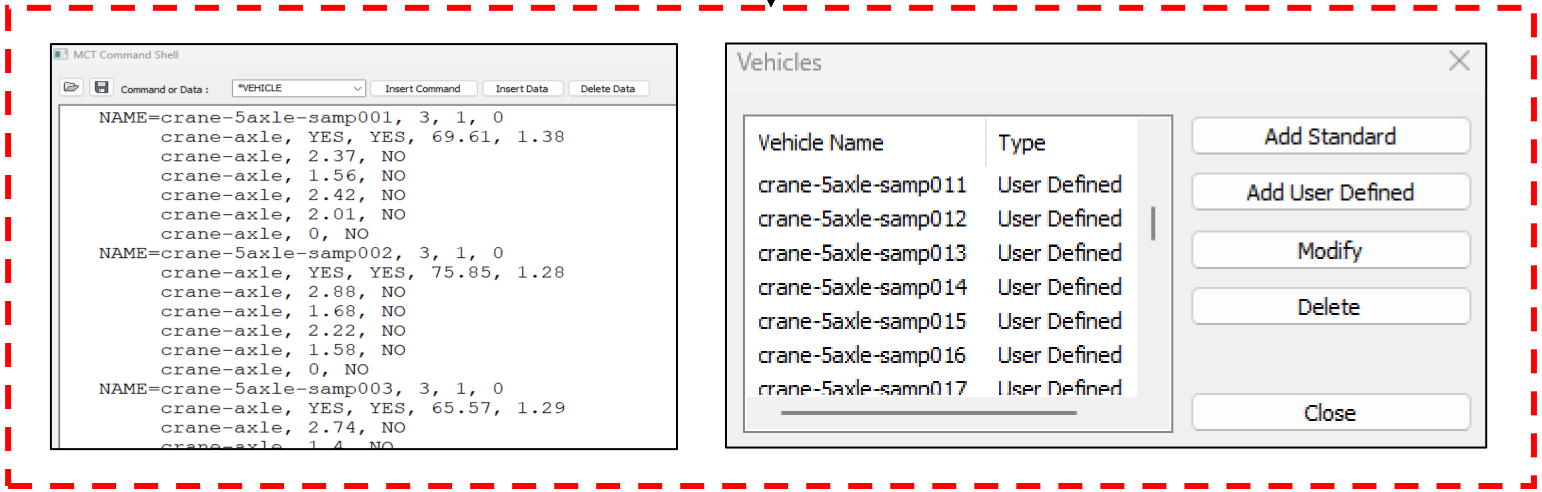


❑ Reliability analysis procedure



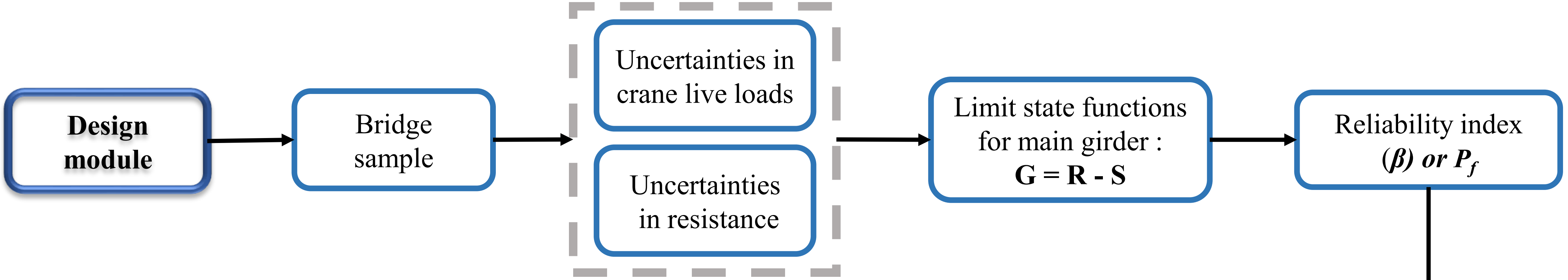


Uncertainties in crane live load response



Midas API

❑ Reliability analysis procedure



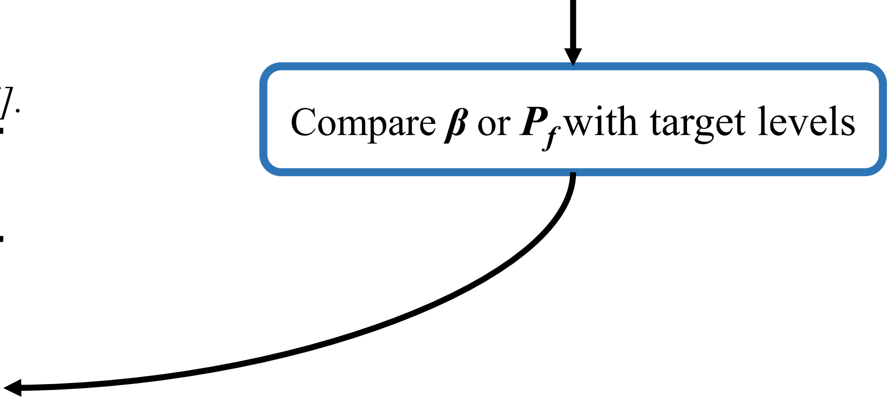


Table 3. Target Reliability Levels in accordance with CSA and AISC Standards [1][7].

Case	Reference	Design Life	Target Reliability Index (β_T)
New bridges	AASHTO	75 years	3.5
New bridges	CSA S6	75 years	3.75
Permit Vehicle Loading (Overload evaluation)	CSA S6	-	2.5 – 2.75
Existing bridges (Operating level)	AASHTO	-	2.5
Existing bridges	M. Ghosn	-	2.5

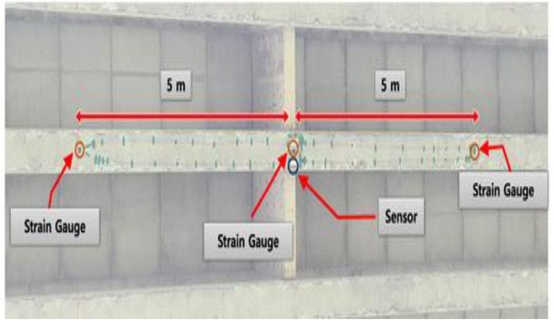
❑ Field testing

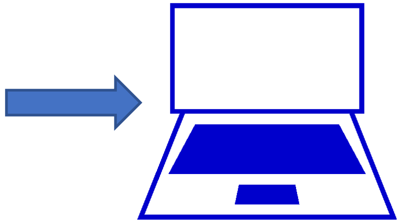
Bridge field load testing

Setup sensors and use SHM techniques

Apply crane loading

Data collection and processing



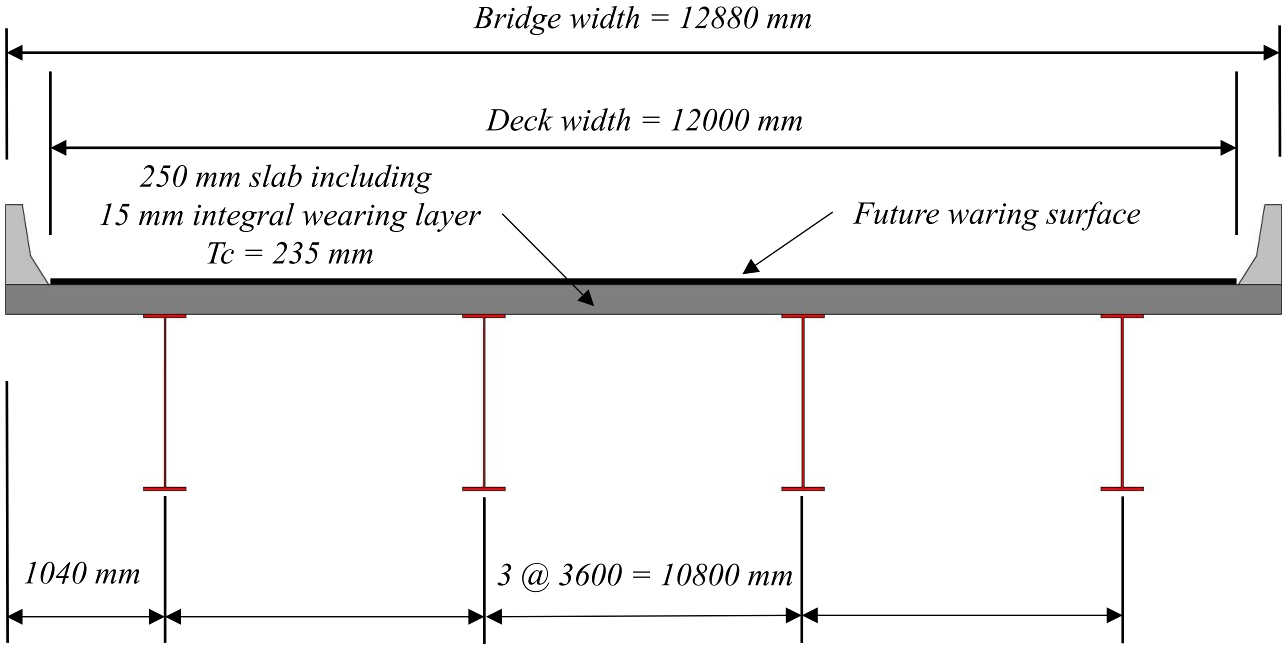


Test data

- FE model validation
- Study the dynamic effect of All-terrain cranes (work on developing DLA for all-terrain cranes)
- Reliability analysis for crane loading effect

- Crane loading evaluation
- Formula development

❑ Reliability evaluation: Case studies for steel girder bridge



Typical bridge section for 3 lane bridge

Table 5. Material properties

Material	Value (Mpa)
Concrete compressive strength	30
Steel yield stress	350
Rebar yield stress	400

Table 6. Loading data

Load	Value
Concrete slab	23.5 kN/m^3
Steel weight	77 kN/m^3
Formwork	0.72 kN/m^2
Barrier	2.96 kN/m
Wearing surface	1.20 kN/m^2

Table 7. Steel girder bridge parameters considered in the study

Parameter	Values Considered
Span (m)	10, 20, 30, 40, 50
Number of lanes	3, 4, 5 lanes
Bridge system	Single-span, Double-span, Continuous

❑ Reliability evaluation: bridge data

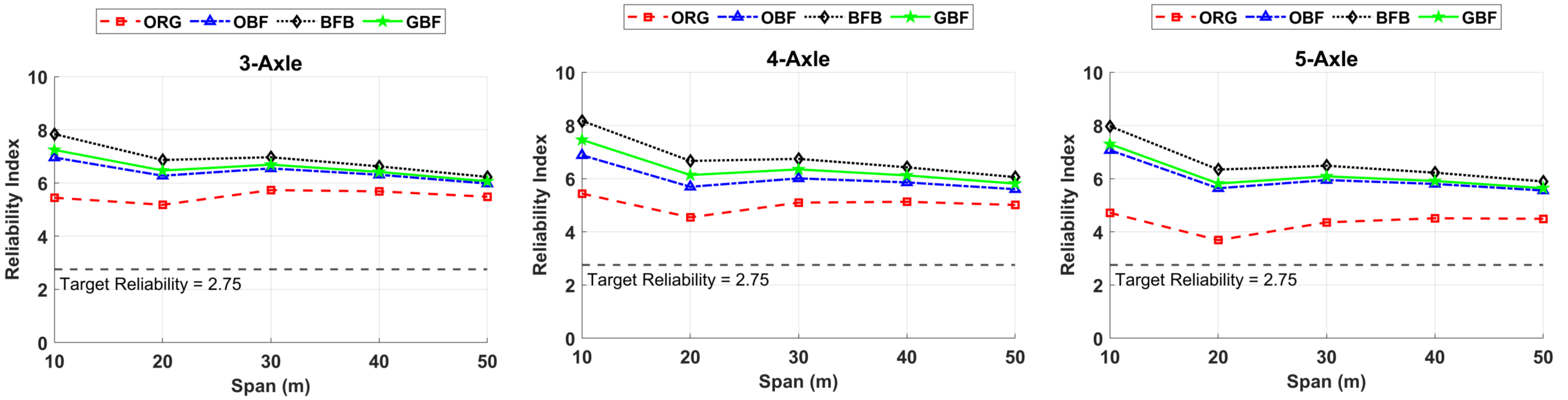
Table 8. All-terrain crane configurations considered in the study.

Configuration	Original GVW (tons)	BFB GVW (tons)	OBF GVW (tons)	GBF GVW (tons)	Vehicle length (m)
3-Axle	36	21	26	24.3	4.40
4-Axle	48	25	35	30.7	7.00
5-Axle	60	29	36.4	34.5	8.55
6-Axle	72	33	42	39.2	10.50
7-Axle	84	35	44	41.5	11.45

- **OBF**: Ontario Bridge Formula
- **BFB**: Bridge Formula B
- **GBF**: Ghosn Bridge Formula
- **GVW**: Gross vehicle weight

Original configuration of 7 Axle Mobile Crane [11]

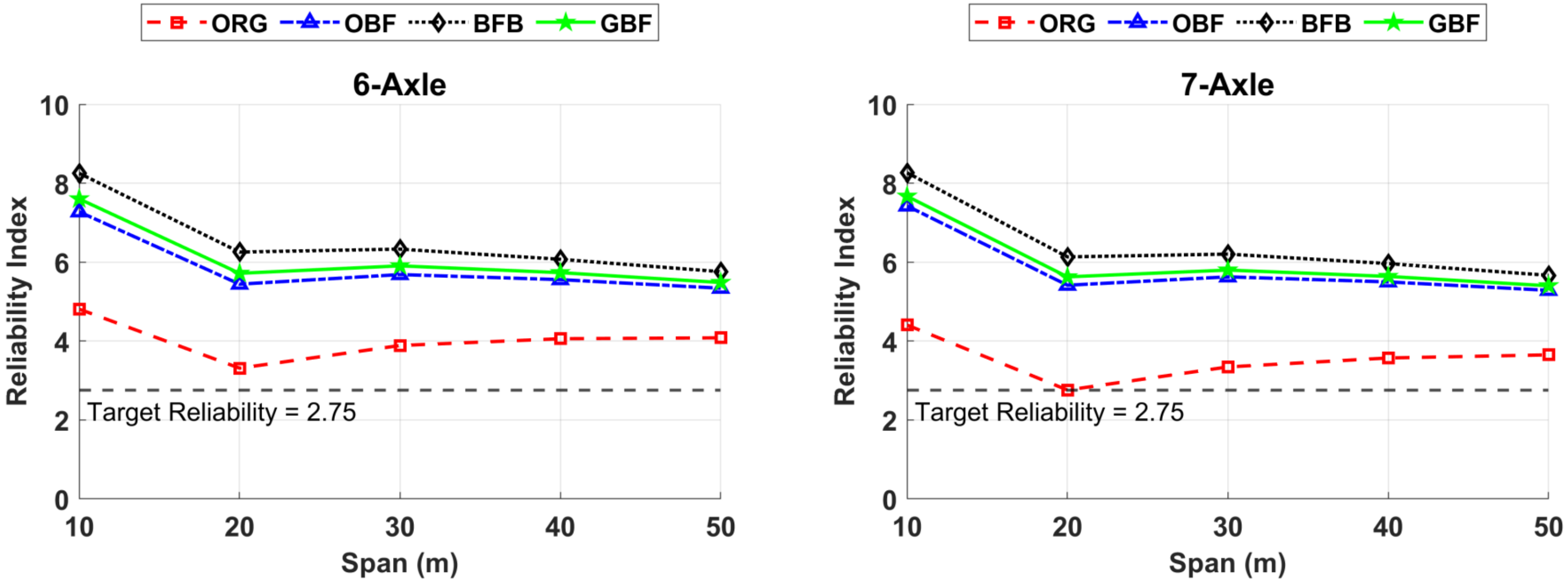
Results: flexural limit state



Reliability evaluation of single-span steel girder highway bridge under flexural limit state

- **ORG:** Original crane configuration with 120 kN axle load
- **OBF**: Ontario Bridge Formula maximum crane configuration
- **BFB**: Bridge Formula B maximum crane configuration
- **GBF**: Ghosn Bridge Formula

❑ Results: flexural limit state



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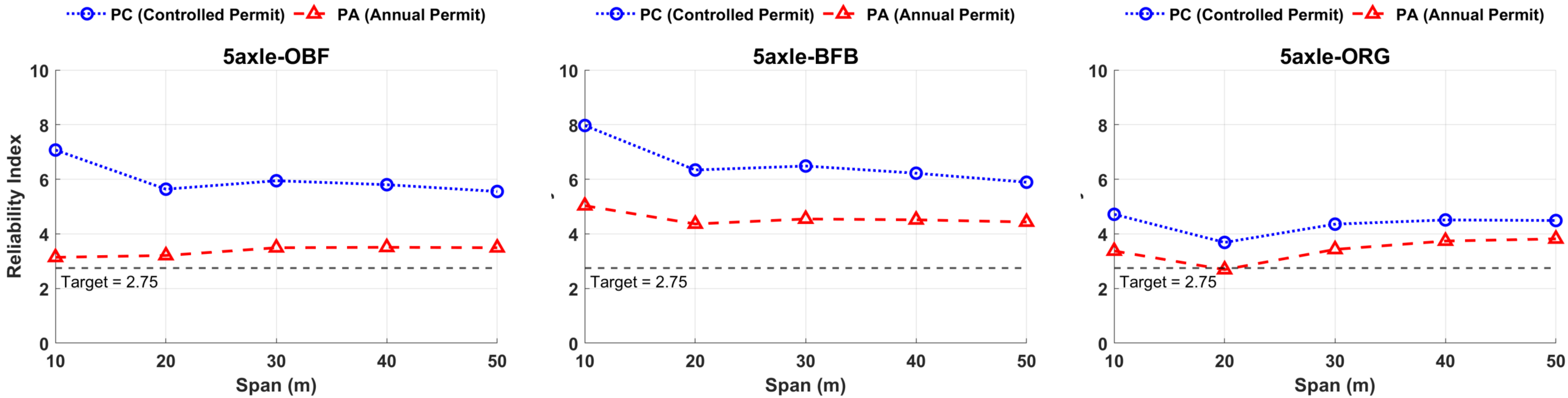
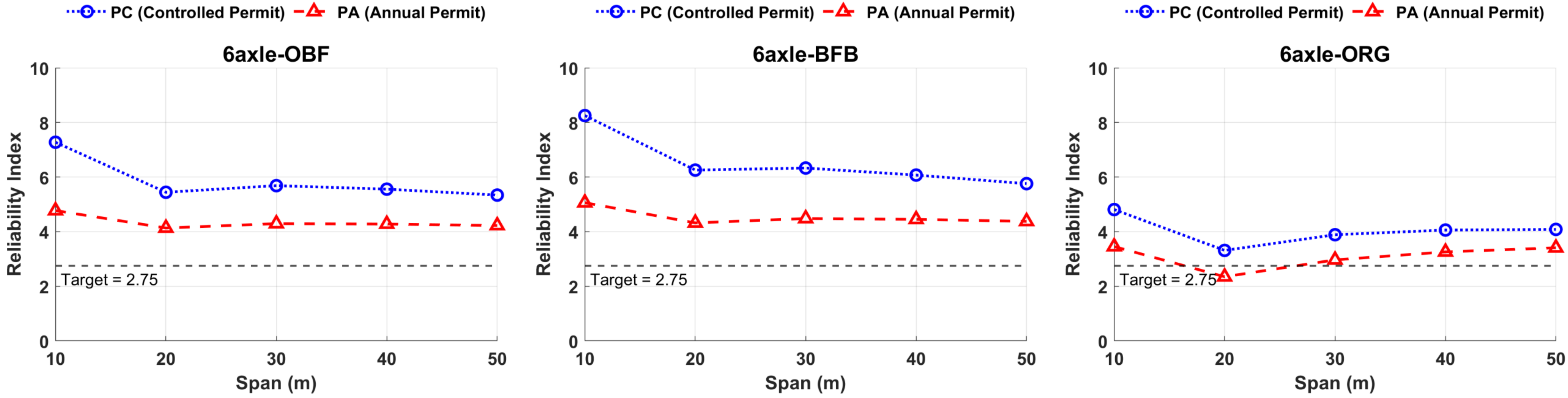
❑ Results: flexural limit state (controlled and annual permits)



Reliability evaluation of single-span steel girder highway bridge under flexural limit state (5-axle crane)

- **ORG:** Original crane configuration with 120 kN axle load
- **OBF**: Ontario Bridge Formula maximum crane configuration
- **BFB**: Bridge Formula B maximum crane configuration

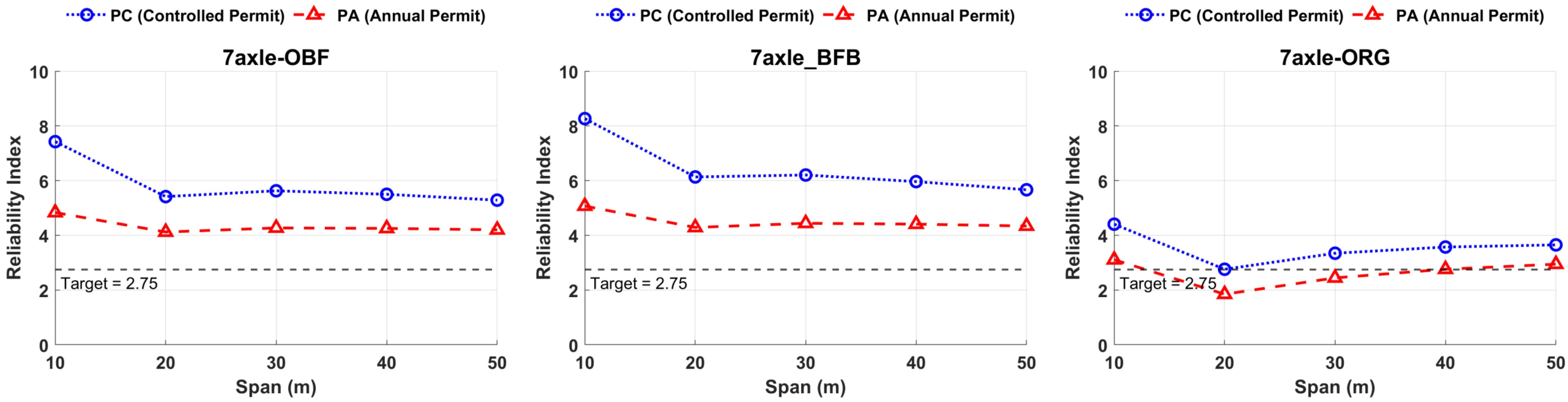
Results: flexural limit state (controlled and annual permits)



Reliability evaluation of single-span steel girder highway bridge under flexural limit state (6-axle crane)

- **ORG:** Original crane configuration with 120 kN axle load
- **OBF**: Ontario Bridge Formula maximum crane configuration
- **BFB**: Bridge Formula B maximum crane configuration

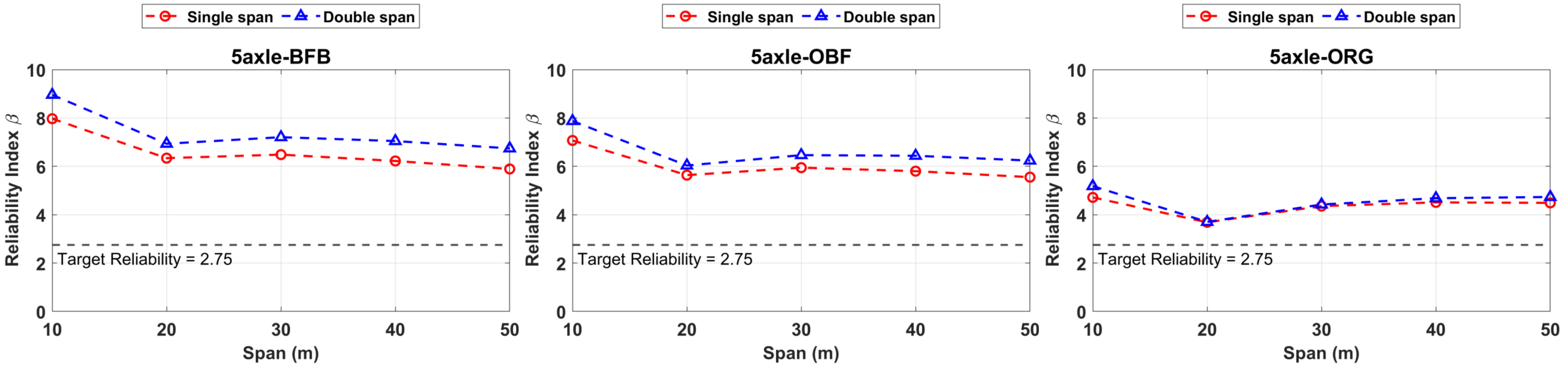
❑ Results: flexural limit state (controlled and annual permits)



Reliability evaluation of single-span steel girder highway bridge under flexural limit state (7-axle crane)

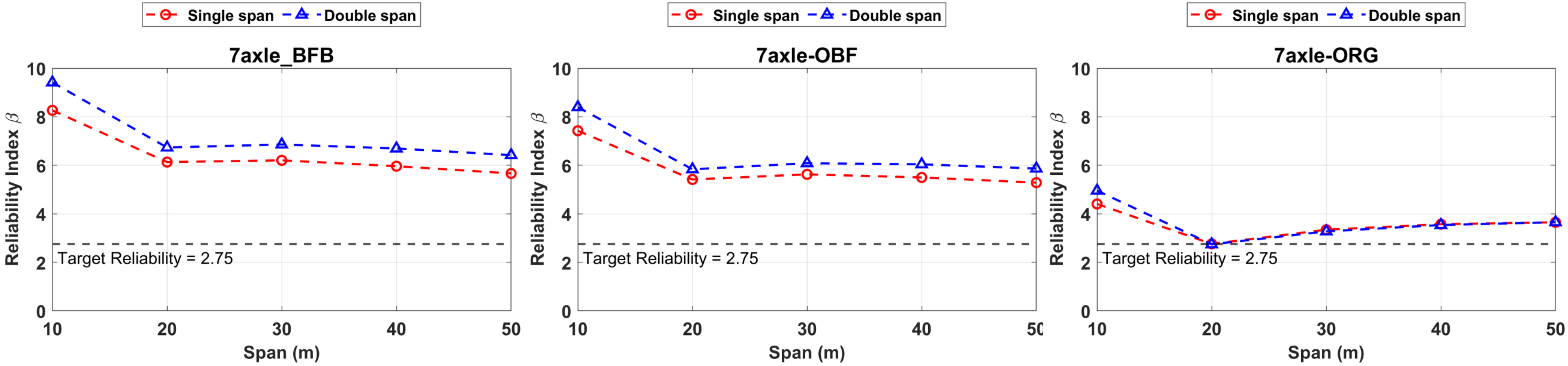
- **ORG:** Original crane configuration with 120 kN axle load
- **OBF**: Ontario Bridge Formula maximum crane configuration
- **BFB**: Bridge Formula B maximum crane configuration

❑ Results: flexural limit state (Continuity effect)



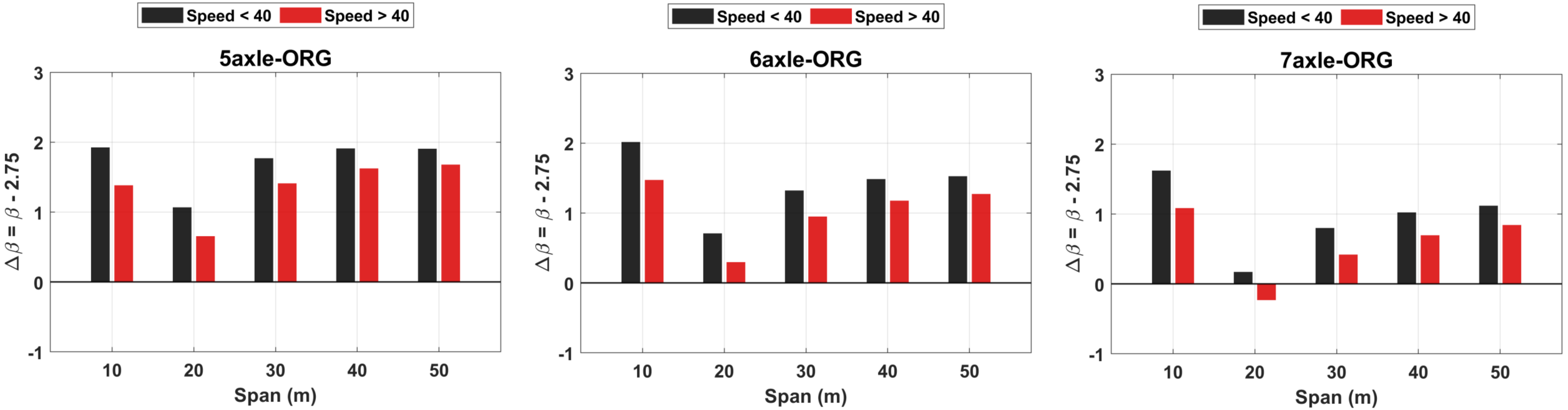
Reliability evaluation of girder highway bridge under flexural limit state

❑ Results: flexural limit state (Continuity effect)



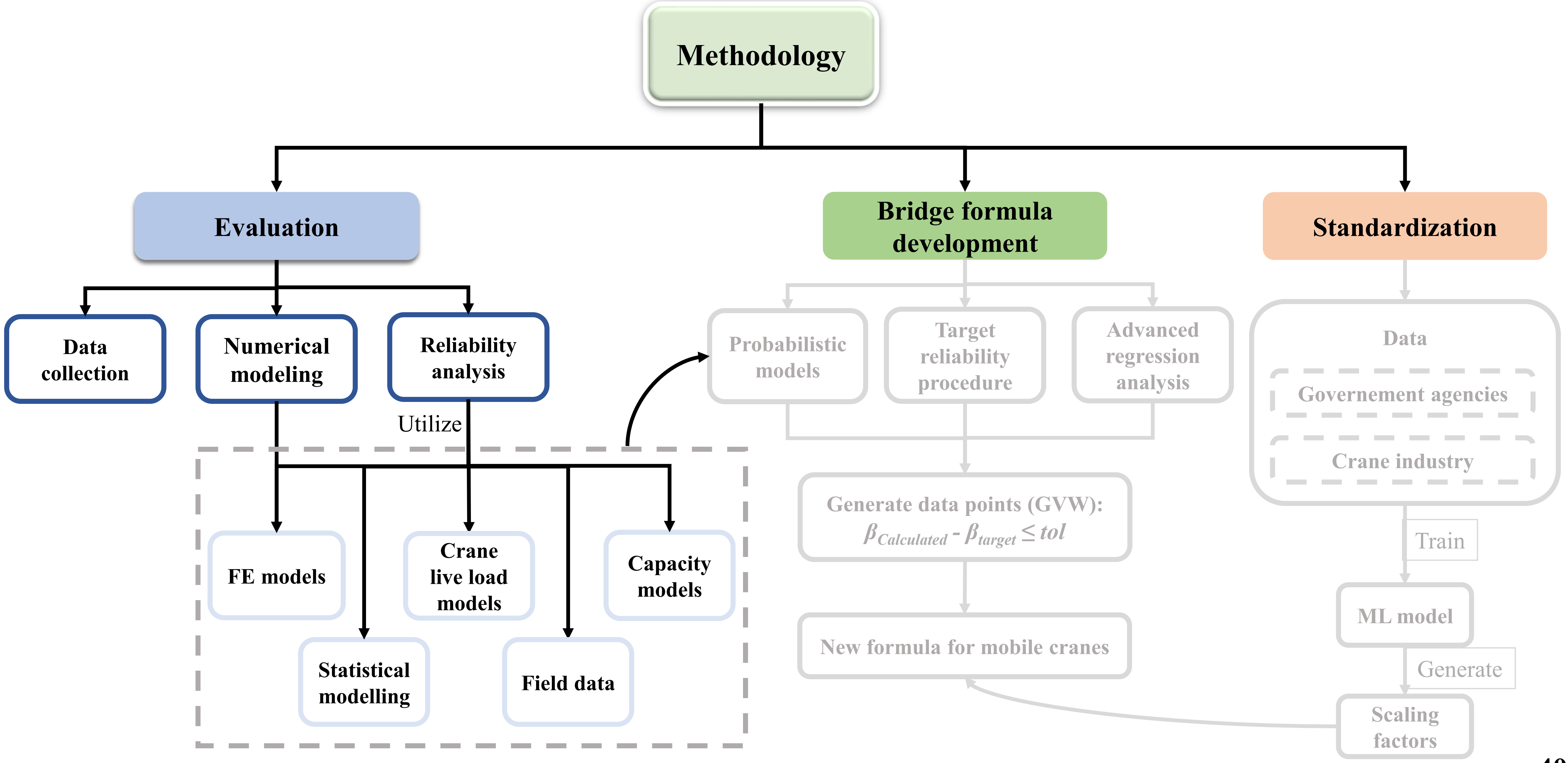
Reliability evaluation of steel girder highway bridge under flexural limit state

❑ Results: flexural limit state (Crane speed effect)



Reliability evaluation of single-span steel girder highway bridge under flexural limit state

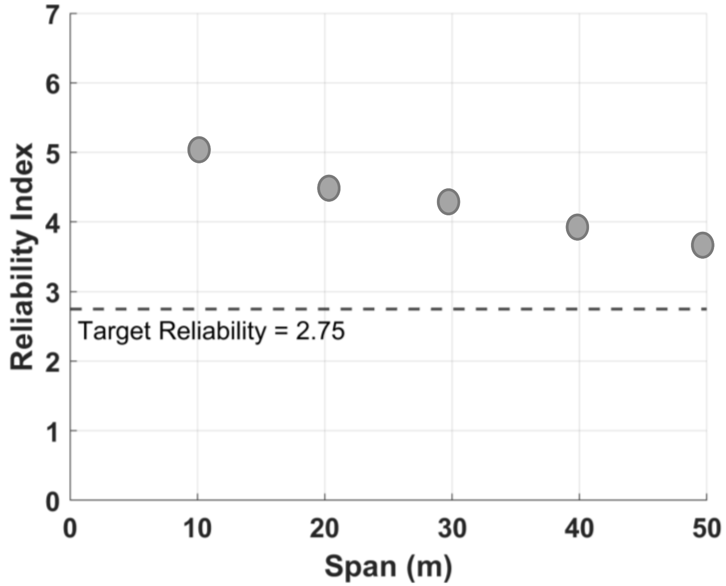
- **ORG:** Original crane configuration with 120 kN axle load
- **OBF**: Ontario Bridge Formula maximum crane configuration
- **BFB**: Bridge Formula B maximum crane configuration


Methodology
Evaluation
Bridge formula development
Standardization
Data collection
Numerical modeling
Reliability analysis
Utilize
FE models
Crane live load models
Capacity models
Statistical modelling
Field data
Probabilistic models
Target reliability procedure
Advanced regression analysis
Generate data points (GVW):
$\beta_{Calculated} - \beta_{target} \leq tol$
New formula for mobile cranes
Data
Governement agencies
Crane industry
Train
ML model
Generate
Scaling factors

❑ Bridge formula Development

Bridge formula development

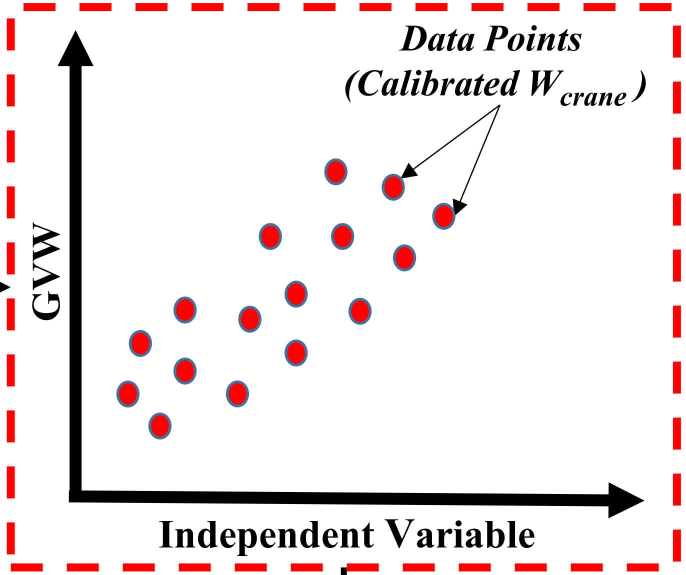
Data generation



Old configuration

New configuration
calibrated *axle load*

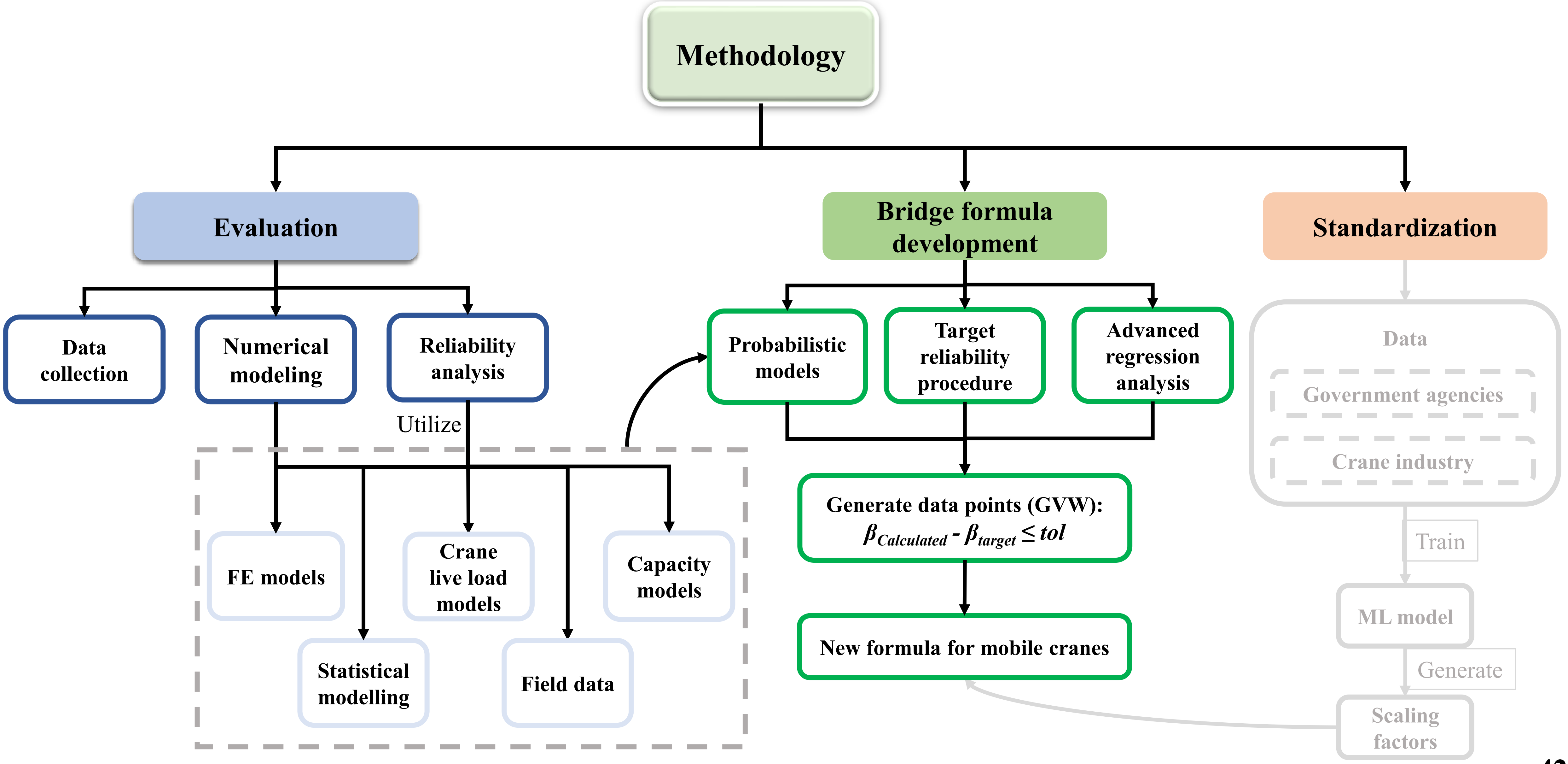
Regression analysis



New bridge formula

Advantages

- Complies with established reliability targets in current design standards
- Specifically calibrated for all-terrain crane configurations
- Designed for ease of application by non-engineering professionals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❑ Standardization

Provincial data → **Automated crane reliability evaluation modules** → **Dataset of maximum permissible crane gross weights** → **ML model** → **Modification factor For proposed equation**

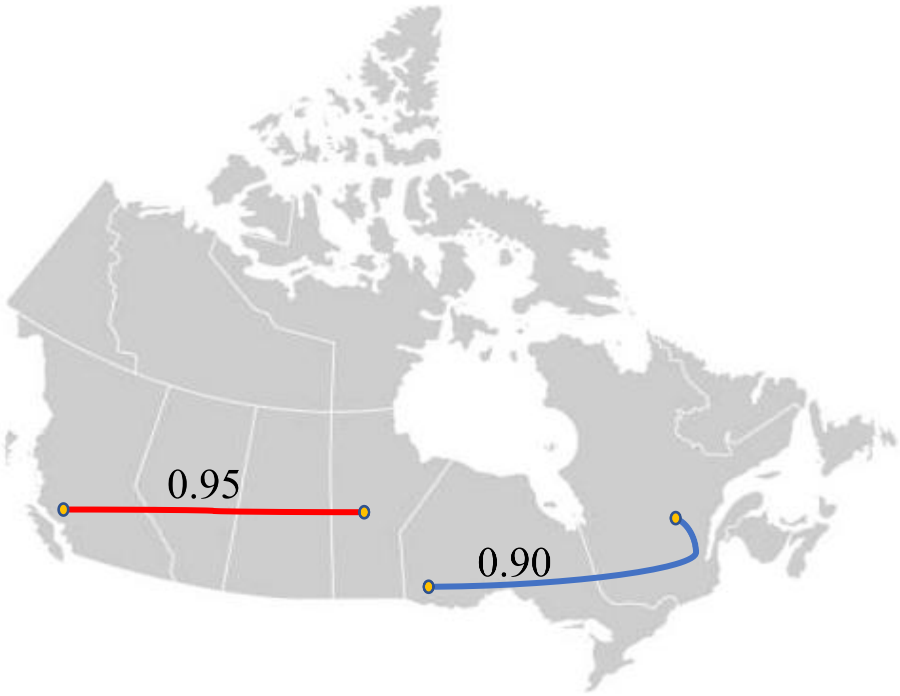
Modification factor For proposed equation → Bridge condition reports; Crane route usage

Bridge condition

Bridge type

Structural system

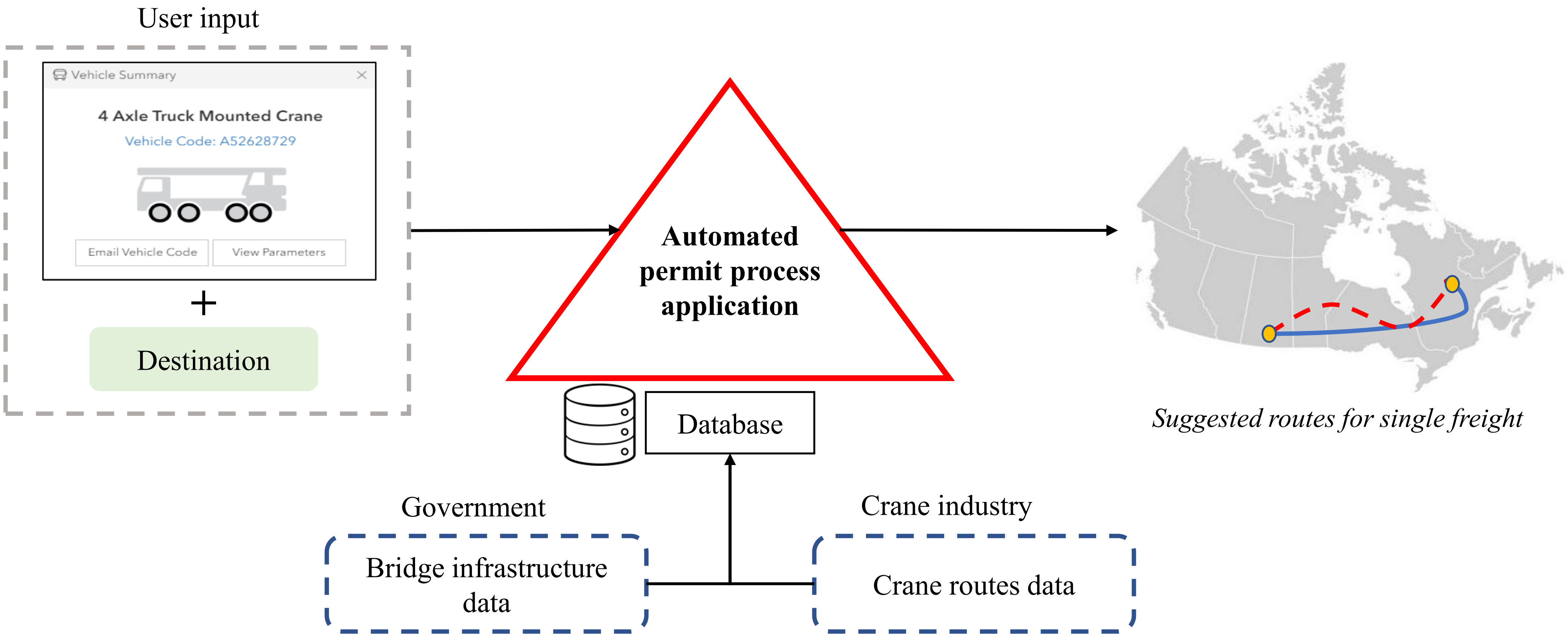
Seasonal loads



Proposed bridge-formula scaling factor based on freight route

❑ Research Significance

This research will serve as a backend foundation for a platform that streamlines the permit process for specialized all-terrain crane vehicles.



❑ Limitations

Limited access to reliable, up-to-date bridge-condition data.

Fragmented, hard-to-obtain weight-regulation and permit information across provinces.

Limited allowance for conducting field tests on bridges restricts the ability to capture sufficient data on crane movements and structural response.

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8. Ontario Ministry of Transportation (1978). *Vehicle Weights Regulations Across Canada: A Technical Review with Respect to the Capacity of Highway Systems*
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10. A. S. Nowak, "Calibration of LRFD bridge design code," *Journal of Structural Engineering*, vol. 118, no. 8, pp. 2076–2089, Aug. 1992, doi:10.1061/(ASCE)0733-9445(1992)118:8(2076).
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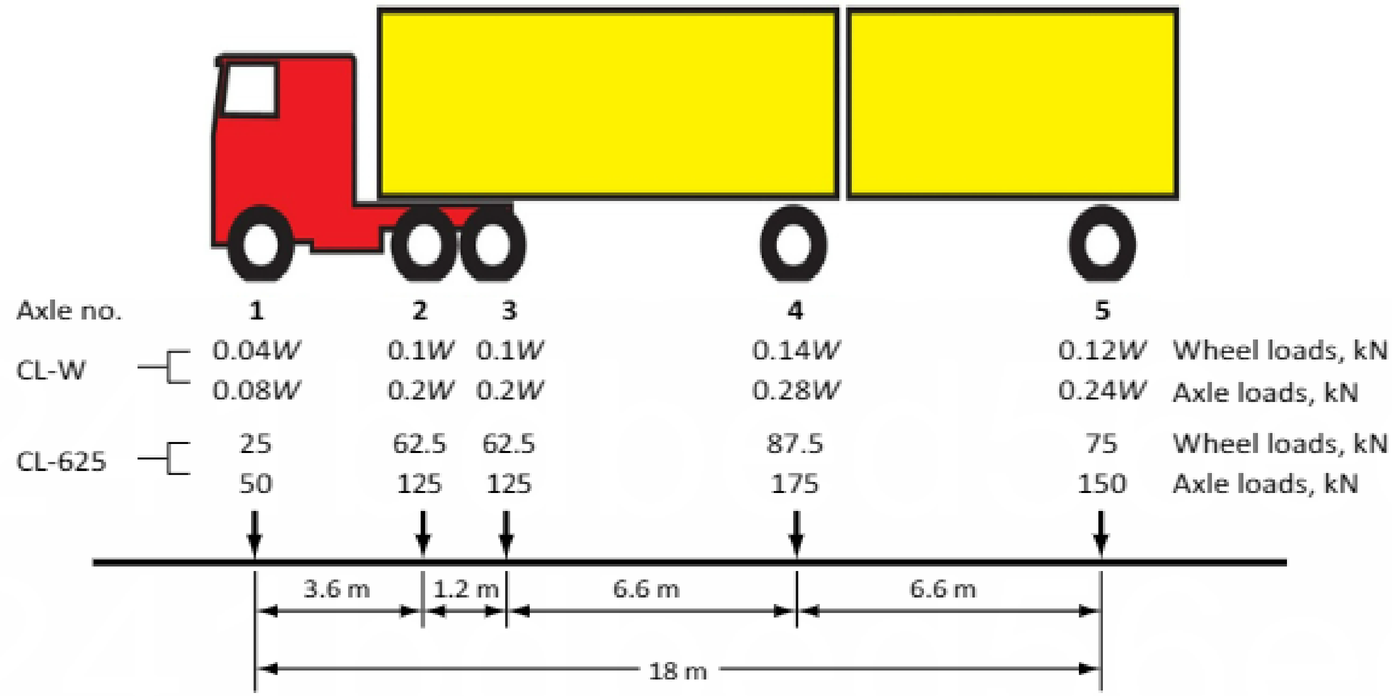
Thank You

- ***We extend our sincere appreciation for the collaboration between the Canadian Crane Rental Association for providing the essential data and support that continue to advance this research and knowledge exchange***

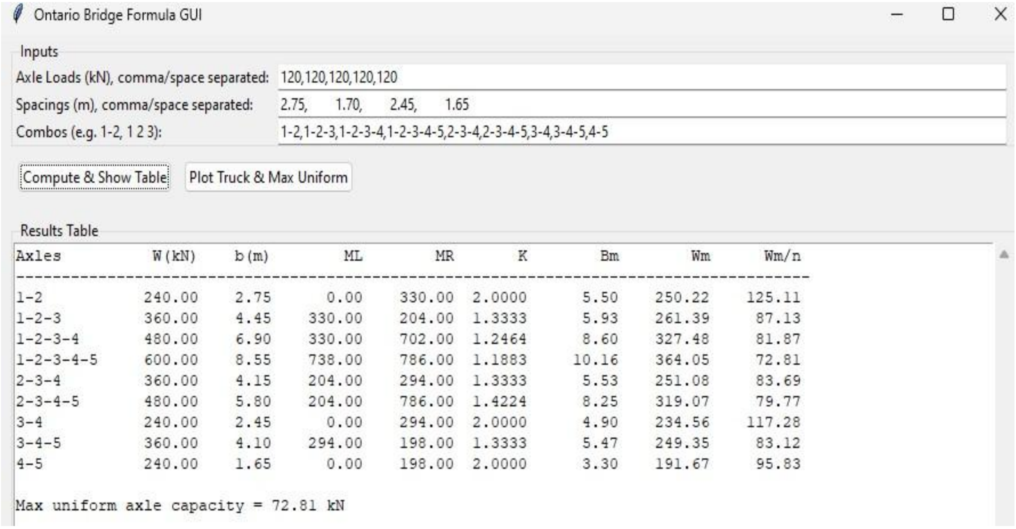


CSA S6 standard design truck

Calculating a vehicle's maximum gross weight is an inverse problem!

Suggested configuration

Feed into



Ontario Bridge Formula GUI

Inputs

Axle Loads (kN), comma/space separated: 120,120,120,120,120

Spacings (m), comma/space separated: 2.75, 1.70, 2.45, 1.65

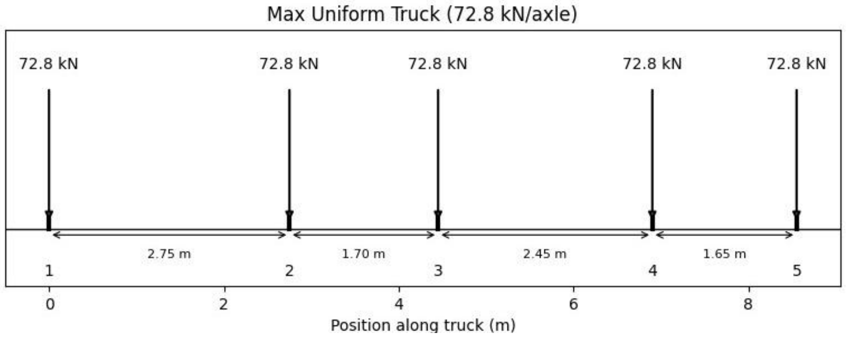
Combos (e.g. 1-2, 1 2 3): 1-2,1-2-3,1-2-3-4,1-2-3-4-5,2-3-4,2-3-4-5,3-4,3-4-5,4-5

Compute & Show Table | Plot Truck & Max Uniform

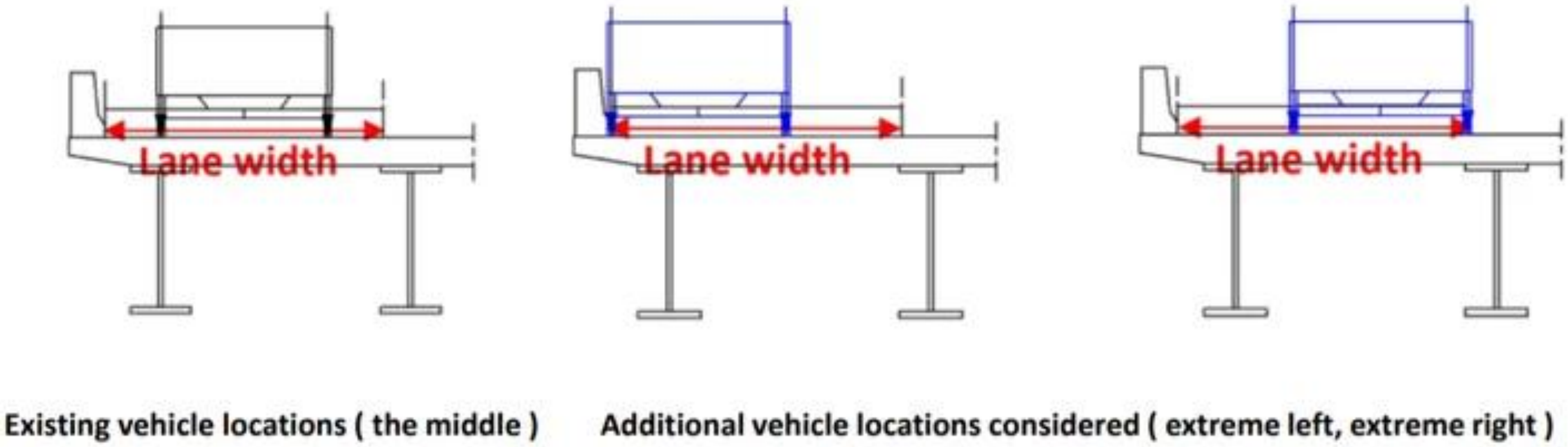
Results Table

Axles	W (kN)	b (m)	ML	MR	K	Bm	Wm	Wm/n
1-2	240.00	2.75	0.00	330.00	2.0000	5.50	250.22	125.11
1-2-3	360.00	4.45	330.00	204.00	1.3333	5.93	261.39	87.13
1-2-3-4	480.00	6.90	330.00	702.00	1.2464	8.60	327.48	81.87
1-2-3-4-5	600.00	8.55	738.00	786.00	1.1883	10.16	364.05	72.81
2-3-4	360.00	4.15	204.00	294.00	1.3333	5.53	251.08	83.69
2-3-4-5	480.00	5.80	204.00	786.00	1.4224	8.25	319.07	79.77
3-4	240.00	2.45	0.00	294.00	2.0000	4.90	234.56	117.28
3-4-5	360.00	4.10	294.00	198.00	1.3333	5.47	249.35	83.12
4-5	240.00	1.65	0.00	198.00	2.0000	3.30	191.67	95.83

Max uniform axle capacity = 72.81 kN

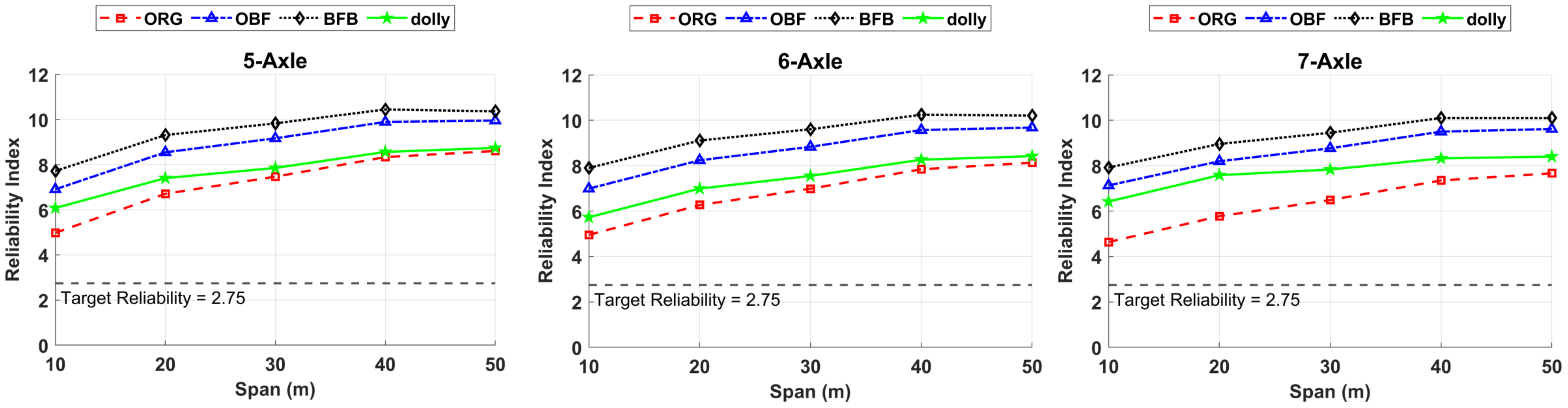


Ontario bridge formula maximum GVW module



Lane optimization

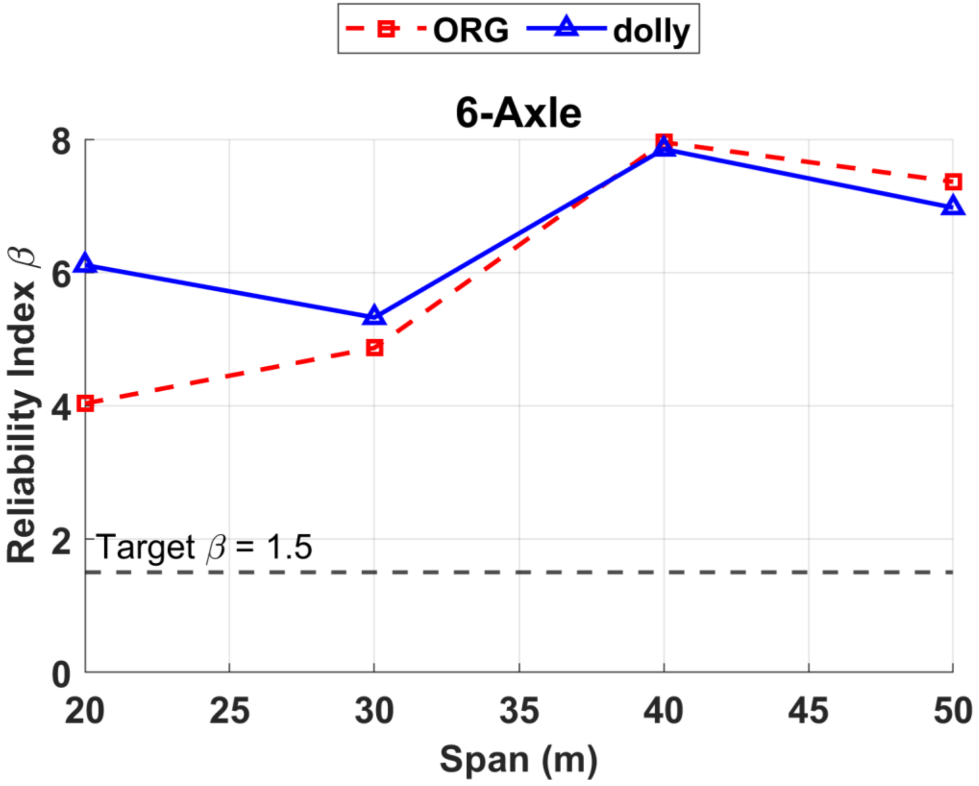
❑ Results: shear limit state

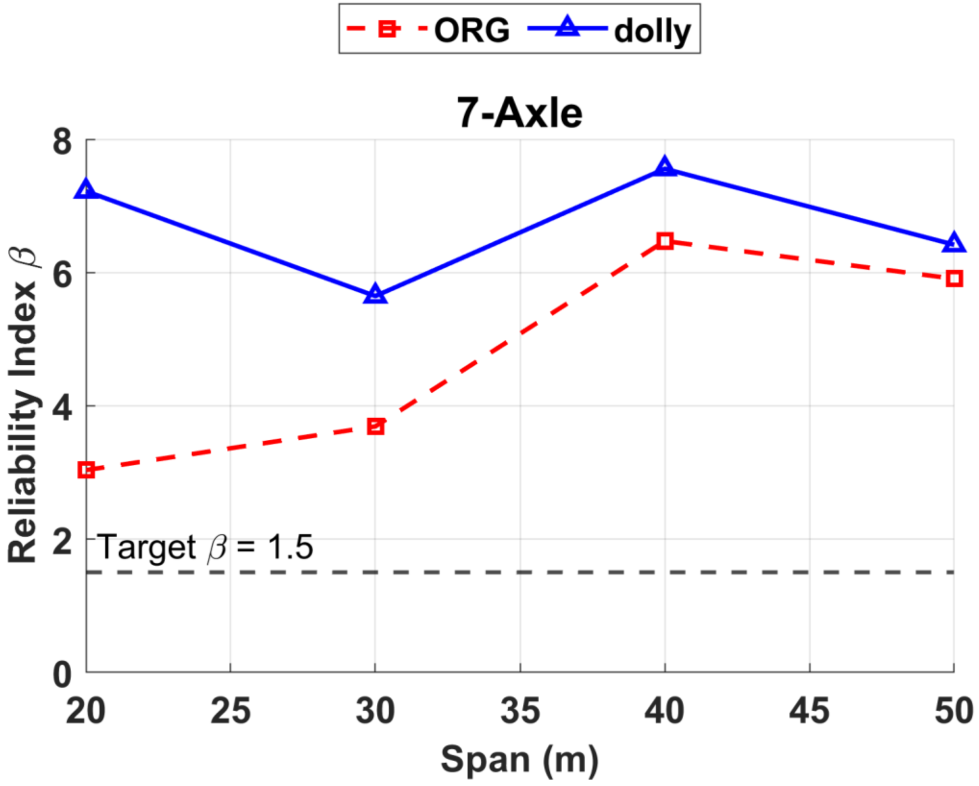


Reliability evaluation of single-span steel girder highway bridge under shear limit state (5 lane case)

- **ORG:** Original crane configuration with 120 kN axle load
- **OBF**: Ontario Bridge Formula maximum crane configuration
- **BFB**: Bridge Formula B maximum crane configuration
- **Dolly**: Crane configuration with additional dolly unit

❑ Results: service limit state





Reliability evaluation of single-span steel girder highway bridge under service limit state (5 lane case)

- **ORG:** Original crane configuration with 120 kN axle load
- **Dolly**: Crane configuration with additional dolly unit

Standardization

Province infrastructure condition
- Good
- Fair
- Poor

Climate variability / Special loads (e.g. Wind)

Bridge type
- Steel girder
- Concrete
- Precast

Structural system

Advancements of crane technology

Affect the allowable crane load to pass through the bridge

Differ from province to another

Is it feasible to capture all these factors in a single, efficient equation?

❑ Infrastructure condition

Infrastructure state

USA

Overall, U.S. bridges are rated **D** (poor) to **C** (mediocre) [2].

42% of all bridges are over **50 years old** [2].

Canada

60% of Canadian bridges are classified in **good and very-good condition** (40% **fair and poor**) [3]

CIRC reported a **doubling** of poor/very poor bridges between 2016 and 2020 [3]

❑ Reliability analysis procedure

Limit state functions for main girder :
G = R - S

Flexural Limit state	Shear limit state	Deflection limit state	Fatigue limit state	System limit state

Image courtesy of Jamie Farris

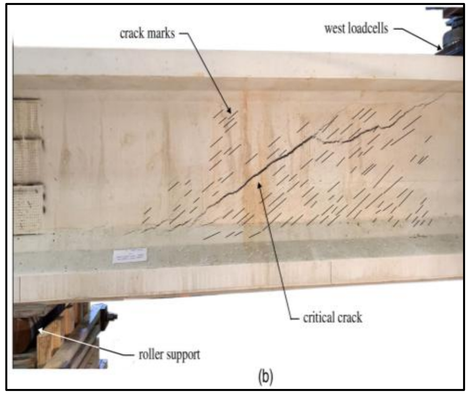


Image courtesy of Rafic G. El-Helou

Image courtesy of Ala'a M. Darwish et.al.

Image courtesy of Wiss, Janney, Elstner Associates

Image courtesy of Mohamed Magdi Abdelaziz

$G = M_r - M_{DL} - M_{Crane}$

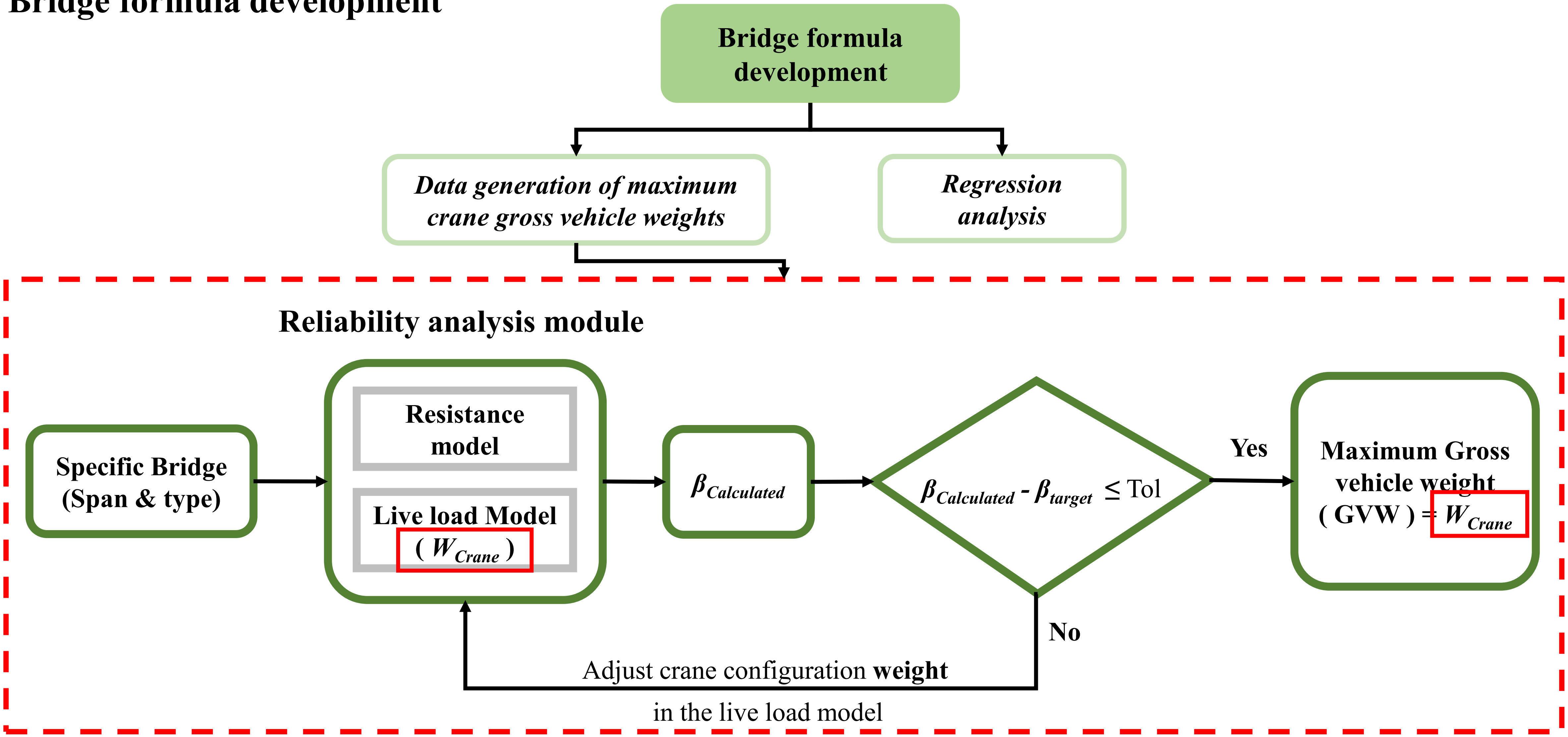
$G = V_r - V_{DL} - V_{Crane}$

$G = \Delta_{limit} - \Delta_{Crane}$

$G = N_{maximum} - N_{traffic} - N_{crane}$

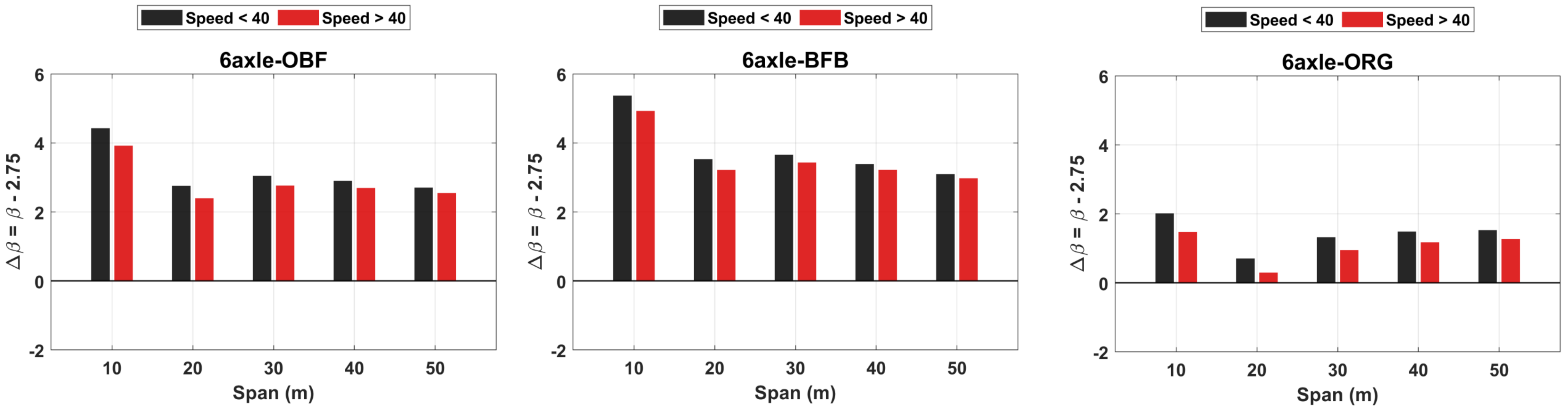
$G = R_{system} - S_{crane}$

❑ Bridge formula development



Adjust the crane weight iteratively until the reliability index $\beta = 2.75$ is achieved

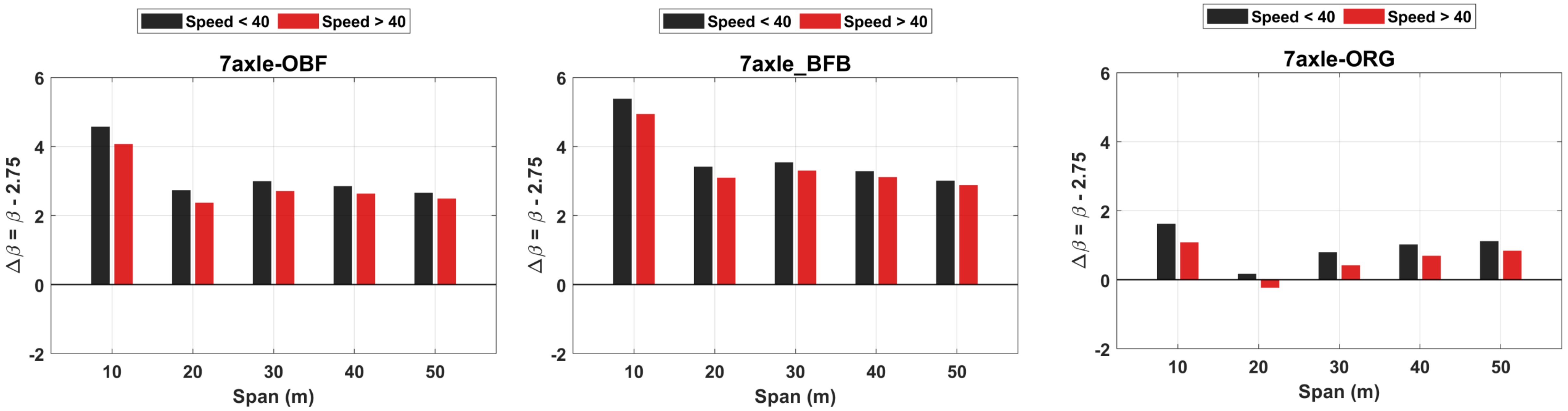
❑ Results: flexural limit state (Crane speed effect)



Reliability evaluation of single-span steel girder highway bridge under flexural limit state (6-axle crane)

- **ORG:** Original crane configuration with 120 kN axle load
- **OBF**: Ontario Bridge Formula maximum crane configuration
- **BFB**: Bridge Formula B maximum crane configuration

❑ Results: flexural limit state (Crane speed effect)



Reliability evaluation of single-span steel girder highway bridge under flexural limit state (7-axle crane)

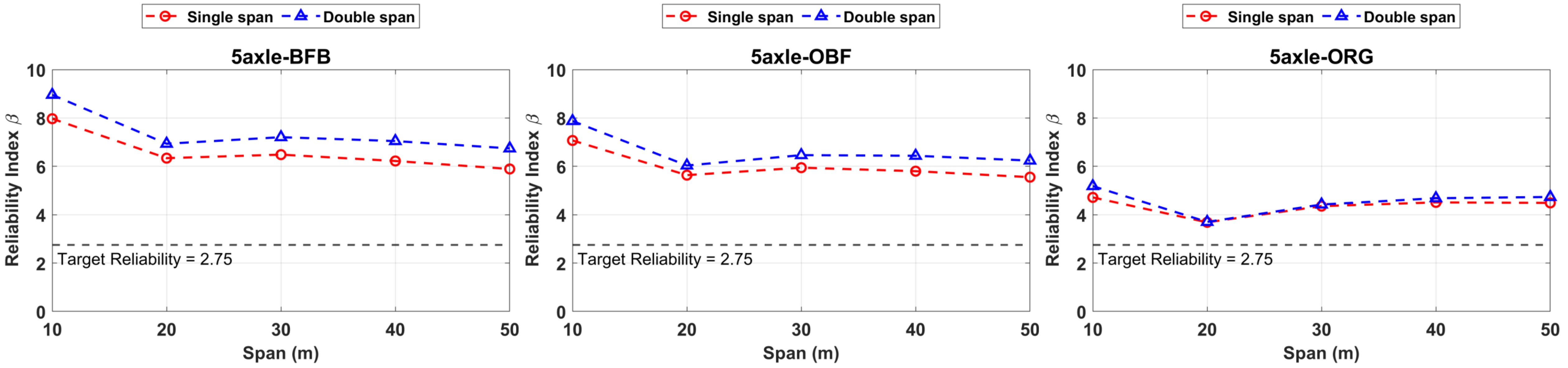
- **ORG:** Original crane configuration with 120 kN axle load
- **OBF**: Ontario Bridge Formula maximum crane configuration
- **BFB**: Bridge Formula B maximum crane configuration

$$R_n = (\gamma_1\, DL_1 + \gamma_2\, DL_2 + \gamma_w\, DL_w + \gamma_L\, LL + \gamma_I\, I\,)\,/\,\phi$$

Table 1. Length and weight requirements for commercial vehicles [8]

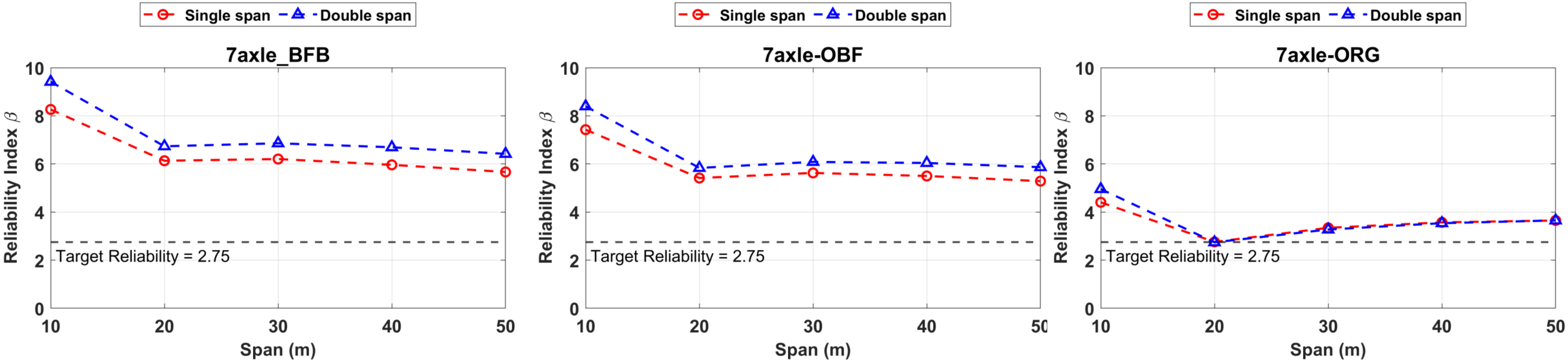
Province	Single Axle (kg)	Tandem Axle (kg)	Max Gross Weight (kg)	Max Length (m)
Newfoundland	8,165	14,515	50,802	19.8
Nova Scotia	9,072	15,876	36,287	19.8
New Brunswick	9,072	18,144	56,699	19.8
Prince Edward Island	9,072	15,876	49,895	19.8
Quebec	9,979	17,237	57,153	19.8
Ontario	9,072	18,144	63,503	19.8
Manitoba	9,072	15,876	49,895	19.8
Saskatchewan	9,072	15,876	49,895	21.3
Alberta	9,072	15,876	49,895	21.3
British Columbia	9,072	15,876	49,895	21.9
Yukon Territory	9,072	18,144	59,874	21.3

❑ Results: flexural limit state (Continuity effect)

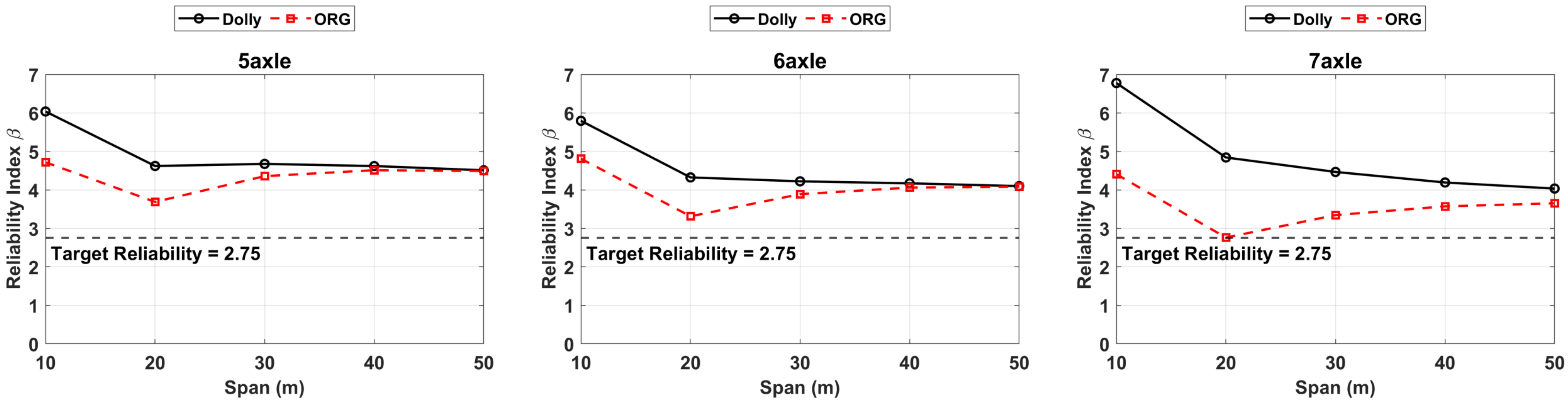


Reliability evaluation of girder highway bridge under flexural limit state

❑ Results: flexural limit state (Continuity effect)



Reliability evaluation of steel girder highway bridge under flexural limit state


Dolly
ORG
5axle
6axle
7axle
Reliability Index β
Target Reliability = 2.75
Span (m)
10
20
30
40
50
0
1
2
3
4
5
6
7