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G7 Transport Academic Workshop

Navigating Uncertainty: Leveraging AI for Predictive Modeling in Multimodal Transportation and Economic Flows

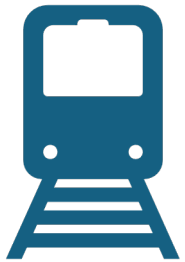
Thierry Warin, PhD
HEC Montréal, Digital, Data and Design (D^3) HBS, CIRANO

Wednesday, 10th April 2024 - Aula Magna "Carassa e Dadda"
Politecnico di Milano, Bovisa Campus, Milan (Italy)

Keywords

Navigating Uncertainty: Leveraging AI for Predictive Modeling in Multimodal Transportation and Economic Flows

Navigating Uncertainty



Multimodal Transportation and Economic Flows

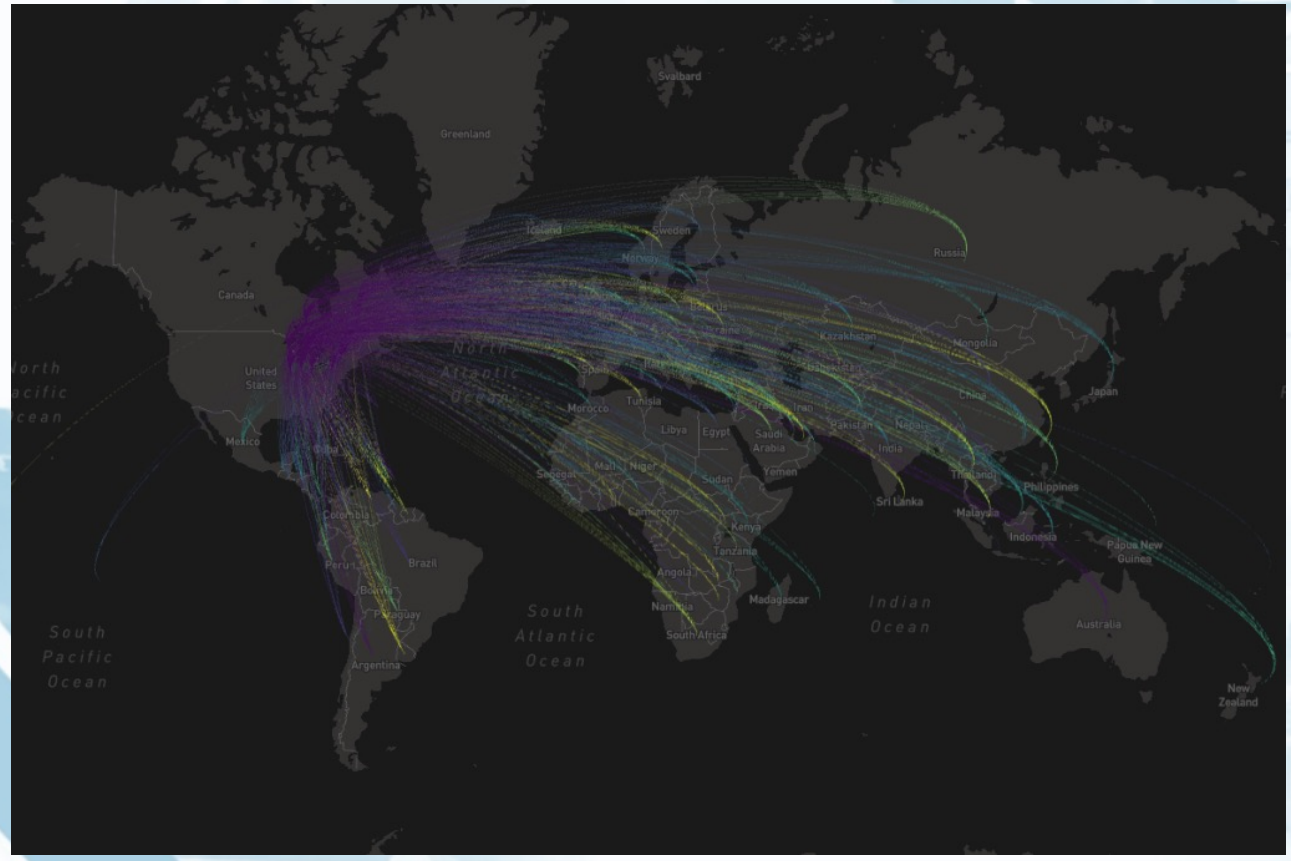
Leveraging AI for Predictive Modeling

Mandate

- The "G7 Transport Academy" to answer two pivotal research questions:
  1. "Are the current decision-making approaches adequate to deal with uncertainty about the future? »
  2. "Are the transportation infrastructure and services prepared to respond to any kind of shocks?"
- The focus would be to:
  - **critically** examine the **adequacy of current decision-making approaches** in planning and designing transport infrastructure, and **handling uncertainties** (such as climate extreme conditions, war, pandemics, and other international crises) on the one hand, and on **expected technological disruptions** such as Artificial Intelligence, big data, digitalization, and others.
  - consider **interdisciplinary approaches** that integrate insights from fields such as data science, risk management, and scenario planning, ensuring a more resilient response to uncertainties.

Contributions of this presentation

- **AI in Practice:**
  - Digital Twin of a region representing economic flows and multimodal transportation
- **AI in Theory:**
  - AI-Based Framework for Trade and Transportation



➔ R&D Lab at CIRANO (Canada) for Transport Canada

"I am not representing the views or policies of any affiliated institution or entity. Only I am responsible for the content and accuracy of this presentation."

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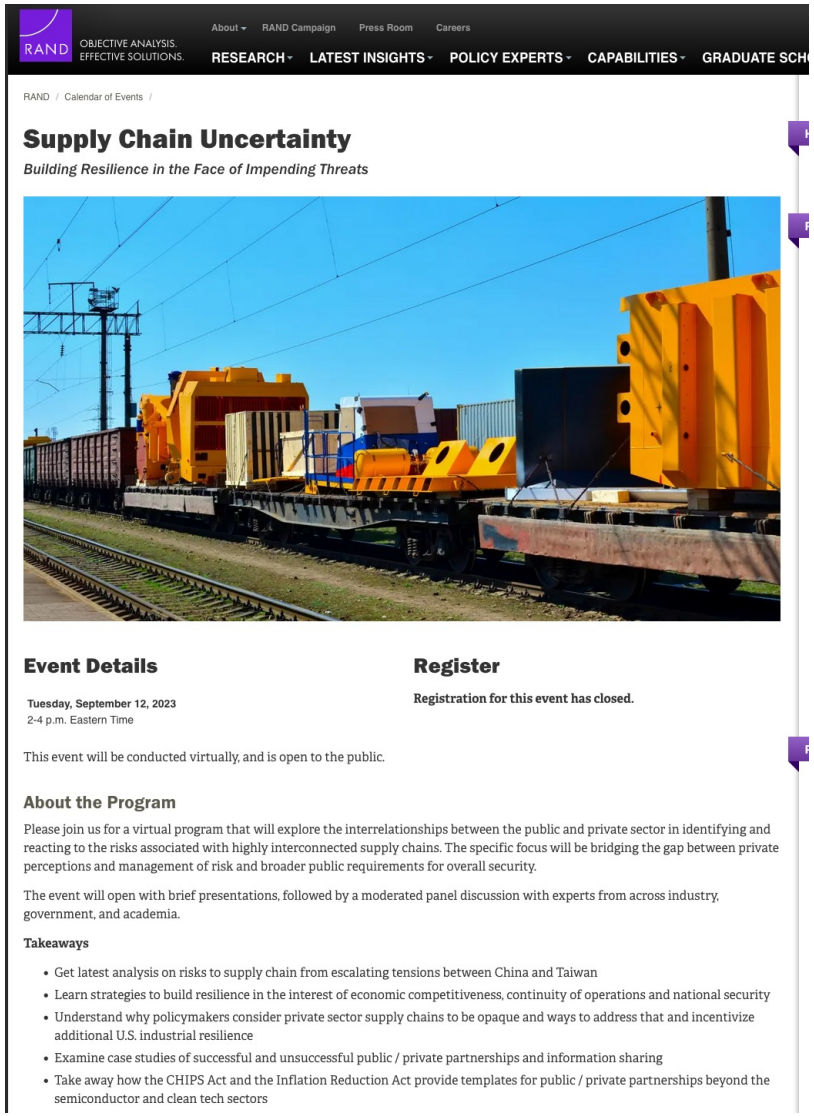
Agenda

- 1. Research Context
- 2. Theoretical Approach: Our AI-Based Framework for Trade and Transportation
- 3. Empowering Transport Solutions through AI and Data Science

1. Introduction

Supply Chain Uncertainty

- Geopolitical Risks
- Continuity of Operations
- National Security



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Supply Chain Uncertainty

Building Resilience in the Face of Impending Threats

Event Details

Tuesday, September 12, 2023
2-4 p.m. Eastern Time

This event will be conducted virtually, and is open to the public.

Register

Registration for this event has closed.

About the Program

Please join us for a virtual program that will explore the interrelationships between the public and private sector in identifying and reacting to the risks associated with highly interconnected supply chains. The specific focus will be bridging the gap between private perceptions and management of risk and broader public requirements for overall security.

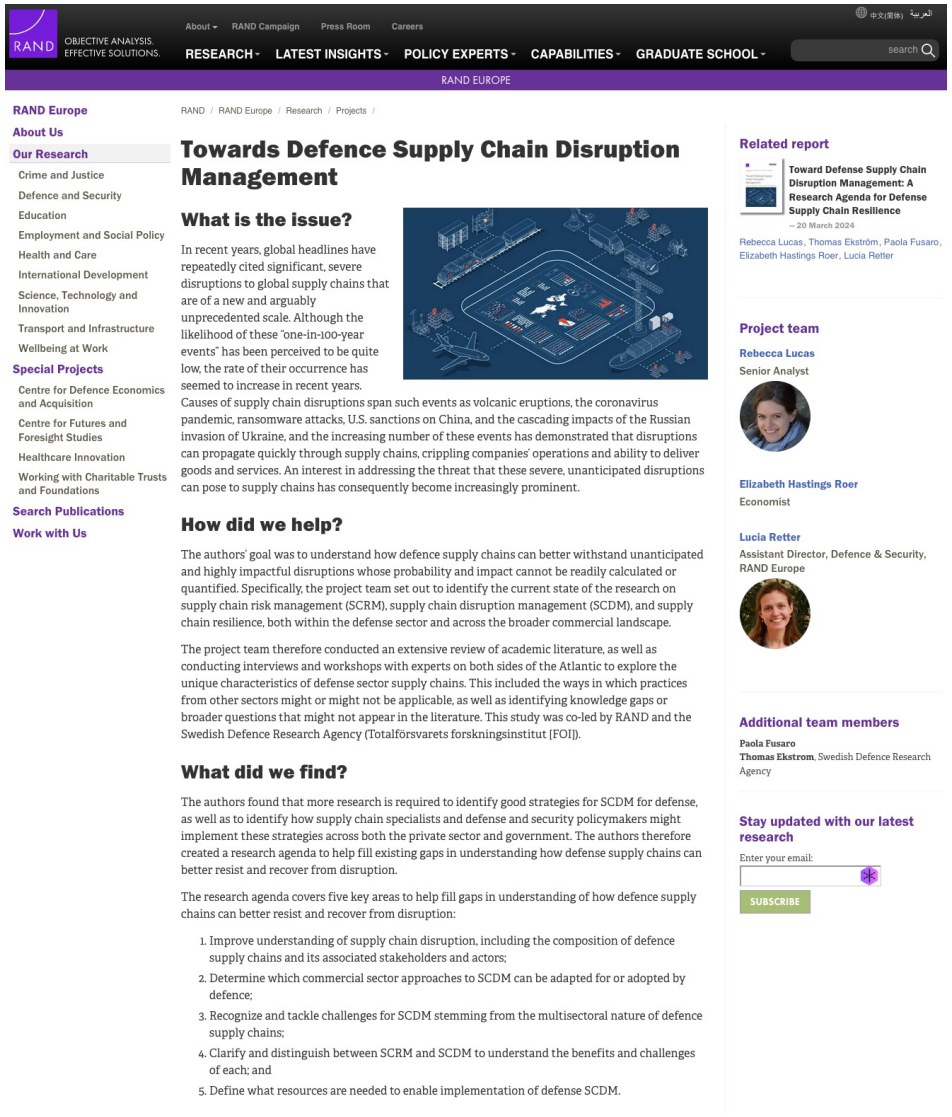
The event will open with brief presentations, followed by a moderated panel discussion with experts from across industry, government, and academia.

Takeaways

- Get latest analysis on risks to supply chain from escalating tensions between China and Taiwan
- Learn strategies to build resilience in the interest of economic competitiveness, continuity of operations and national security
- Understand why policymakers consider private sector supply chains to be opaque and ways to address that and incentivize additional U.S. industrial resilience
- Examine case studies of successful and unsuccessful public / private partnerships and information sharing
- Take away how the CHIPS Act and the Inflation Reduction Act provide templates for public / private partnerships beyond the semiconductor and clean tech sectors

Disruption Management

- Strategic Planning
- Scenario Planning



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Towards Defence Supply Chain Disruption Management

What is the issue?

In recent years, global headlines have repeatedly cited significant, severe disruptions to global supply chains that are of a new and arguably unprecedented scale. Although the likelihood of these "one-in-100-year events" has been perceived to be quite low, the rate of their occurrence has seemed to increase in recent years. Causes of supply chain disruptions span such events as volcanic eruptions, the coronavirus pandemic, ransomware attacks, U.S. sanctions on China, and the cascading impacts of the Russian invasion of Ukraine, and the increasing number of these events has demonstrated that disruptions can propagate quickly through supply chains, crippling companies' operations and ability to deliver goods and services. An interest in addressing the threat that these severe, unanticipated disruptions can pose to supply chains has consequently become increasingly prominent.

How did we help?

The authors' goal was to understand how defence supply chains can better withstand unanticipated and highly impactful disruptions whose probability and impact cannot be readily calculated or quantified. Specifically, the project team set out to identify the current state of the research on supply chain risk management (SCRM), supply chain disruption management (SCDM), and supply chain resilience, both within the defense sector and across the broader commercial landscape.

The project team therefore conducted an extensive review of academic literature, as well as conducting interviews and workshops with experts on both sides of the Atlantic to explore the unique characteristics of defense sector supply chains. This included the ways in which practices from other sectors might or might not be applicable, as well as identifying knowledge gaps or broader questions that might not appear in the literature. This study was co-led by RAND and the Swedish Defence Research Agency (Totalförsvarets forskningsinstitut (FOI)).

What did we find?

The authors found that more research is required to identify good strategies for SCDM for defense, as well as to identify how supply chain specialists and defense and security policymakers might implement these strategies across both the private sector and government. The authors therefore created a research agenda to help fill existing gaps in understanding how defense supply chains can better resist and recover from disruption.

The research agenda covers five key areas to help fill gaps in understanding of how defence supply chains can better resist and recover from disruption:

1. Improve understanding of supply chain disruption, including the composition of defence supply chains and its associated stakeholders and actors;
2. Determine which commercial sector approaches to SCDM can be adapted for or adopted by defence;
3. Recognize and tackle challenges for SCDM stemming from the multisectoral nature of defence supply chains;
4. Clarify and distinguish between SCRM and SCDM to understand the benefits and challenges of each; and
5. Define what resources are needed to enable implementation of defense SCDM.

Risk versus Uncertainty

- Risk refers to situations where the probabilities of various outcomes are known, allowing individuals or organizations to calculate and manage potential losses.
- Uncertainty, as defined by Frank Knight in 1921, occurs when these probabilities are unknown, making it impossible to calculate risks in a mathematical sense.
- Knight's distinction highlights the difference between calculable challenges, which can be insured against or hedged, and those that are incalculable, requiring a different strategic approach due to their unpredictability.

Risk versus Uncertainty

- In mathematical terms:
- **Risk**: where outcomes have known probabilities, mathematically represented as

$$E(X) = \sum p_i x_i \quad (1)$$

  - where $E(X)$ is the expected value of outcome X, p_i is the probability of each outcome, and x_i is the value of each outcome.
  - **Specific**, **systemic** and **systematic risks** (Prasch, 2016).

- **Uncertainty**: Situations where the probabilities (p_i) of outcomes are not known, making it impossible to calculate an expected value in the traditional sense.

Decision-Making under Uncertainty

- Probabilities are inestimable
- Traditional Decision-Making Approaches are less useful

SUPPLY CHAIN MANAGEMENT REVIEW

Supply Chain Disruption:
Supply Chains brace for economic impact as governor declares state of emergency over Francis Scott Key bridge collapse Read more.

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Exclusive

Decision making under uncertainty: A primer

The probabilities of uncertain futures are inestimable. Hence, one can't use traditional decision making (DM)

This is an excerpt of the original article. It was written for the May-June 2022 edition of *Supply Chain Management Review*. The full article is available to current subscribers.

May-June 2022

I recently returned from three days in Atlanta at the Modex trade show. Although advertised as a supply chain event, it's really a materials handling automation show with a handful of logistics providers thrown in for good measure. Heading out the door to the airport, I had no idea what to expect. The two-year absence from the trade show and conference scene had me, and many of the individuals I spoke to before the show opened, wondering what's next—not just for the show but for operations in general. If the turnout and the enthusiasm is any indication, I think supply chain is in pretty good shape these days, despite the disruptions we've...

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- Transforming Supply Chain Management with Intelligent Software
- Address Supply Chain Risk with Strong Risk Councils

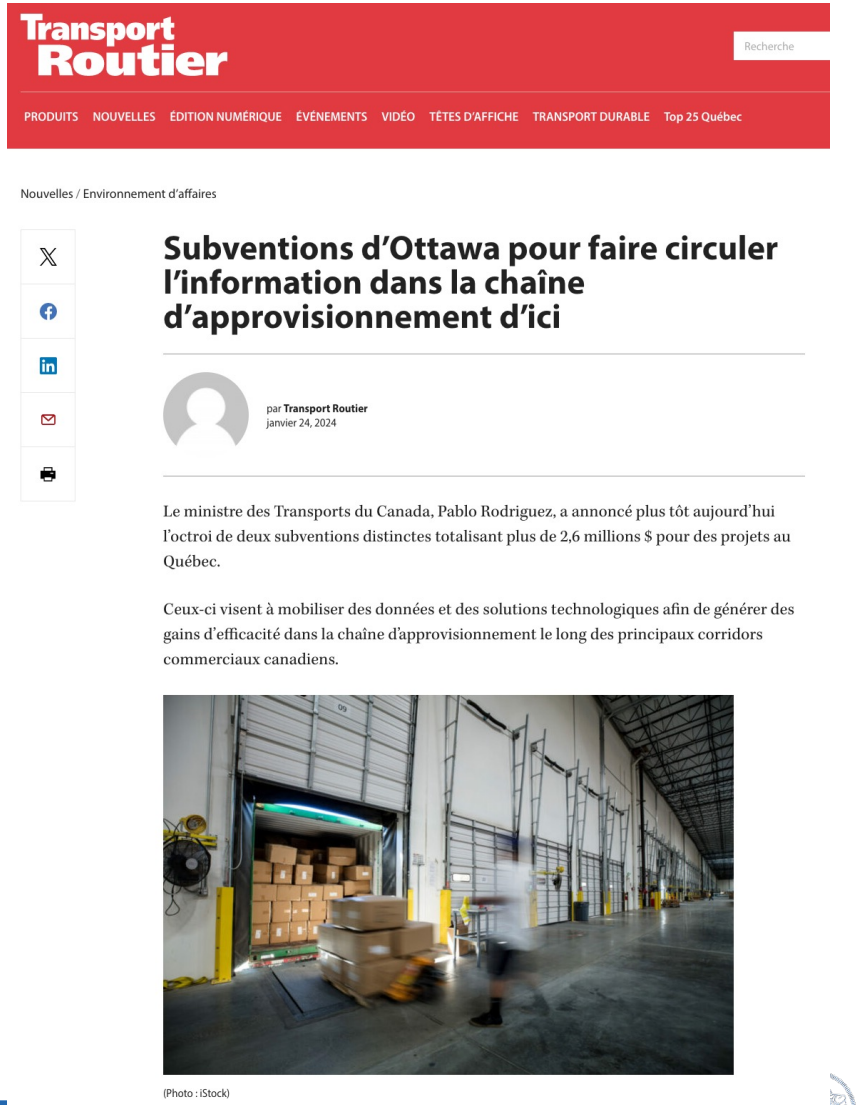
More Risk Management

Larry Lapide · May 2, 2022 ·

In my last Insights column, I advised that when a portion of a supply chain becomes froth with uncertainties, it's best to sever that portion and let supply-demand operational planning for it be handled by an ad hoc quick response (QR) team, one that is adept at making decisions under uncertainty vis a vis under risk2. Why did I believe so? Basically, because the probabilities of uncertain futures are inestimable. Hence, one can't use traditional decision making (DM) under risk methods that are predicated upon assuming a stable probability distribution exists.

Public Policies

- Heavy Subsidies to **Reduce Information Asymmetries**
- System Optimization **with Better Information**



Transport Routier

Recherche

PRODUITS NOUVELLES ÉDITION NUMÉRIQUE ÉVÉNEMENTS VIDÉO TÊTES D'AFFICHE TRANSPORT DURABLE Top 25 Québec

Nouvelles / Environnement d'affaires

Subventions d'Ottawa pour faire circuler l'information dans la chaîne d'approvisionnement d'ici

par **Transport Routier**
janvier 24, 2024

Le ministre des Transports du Canada, Pablo Rodriguez, a annoncé plus tôt aujourd'hui l'octroi de deux subventions distinctes totalisant plus de 2,6 millions $ pour des projets au Québec.

Ceux-ci visent à mobiliser des données et des solutions technologiques afin de générer des gains d'efficacité dans la chaîne d'approvisionnement le long des principaux corridors commerciaux canadiens.

(Photo : iStock)

New Data Era

- New technological tools
  to monitor trade disruptions
- Data driven analysis and measures

2. Theoretical Approach: Our AI-Based Framework for Trade and Transportation

A Tale of Two Disciplines

2.1 International Economics

2.2 Logistics / Transportation

2.1 International Economics

- **Newton's Universal Law of Gravitation**: relationship between masses and distance
  - Newton's Law of Gravitation mathematically expresses the force of attraction between two masses as

$$F = G\frac{m_1 m_2}{r^2} \tag{2}$$

  - where F is the gravitational force, G is the gravitational constant, m_1 and m_2 are the masses, and r is the distance between their centers.

2.1 International Economics

- Over fifty years ago, Jan Tinbergen (1962) drew a parallel to Newton's universal law of gravitation to explain bilateral aggregate trade flows between two countries, A and B. He suggested these flows are "directly proportional to their gross national products and inversely proportional to the distance between them," represented as:

$$T_{A,B} \propto (GDP_A)^{\alpha}(GDP_B)^{\beta} \div (Dist_{AB})^{\zeta} \quad (3)$$

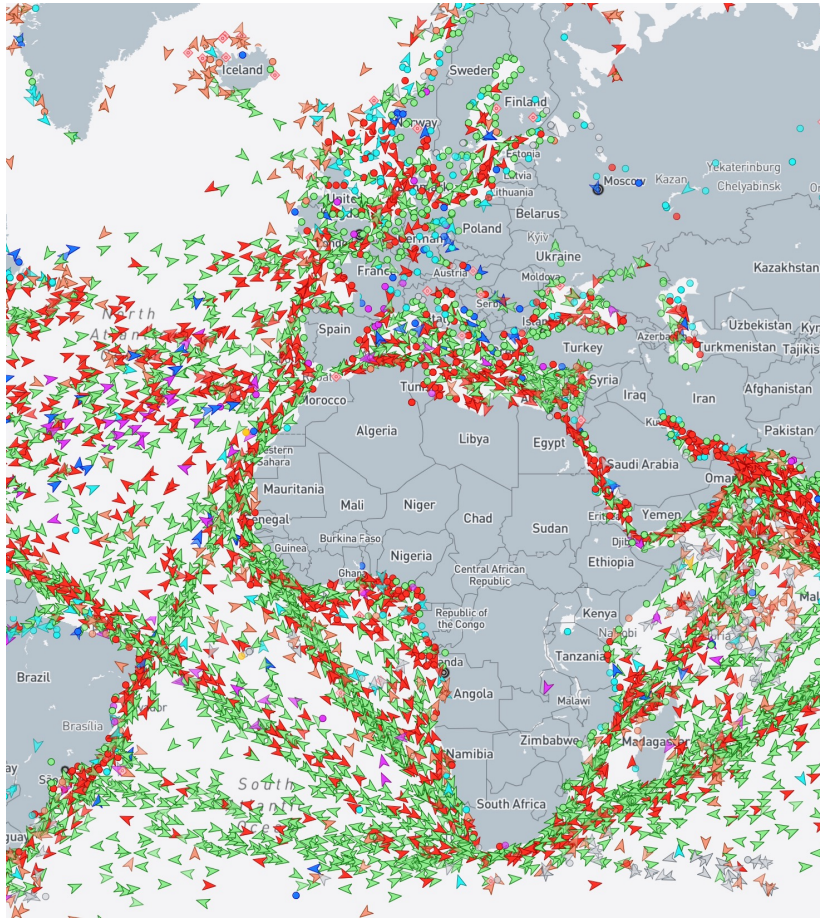
  - where α, β, and ζ are all approximately equal to 1. This "gravity equation" in international trade has remained remarkably consistent over time, showcasing its stability and robustness as one of the empirical regularities in economics.

2.1 International Economics

- **Gravity Equation in Economics**:
  - Typically used to predict trade flows between countries based on their economic mass (GDP) and distance,
  - this equation can be adapted to understand the **flow of goods and passengers in multimodal transportation networks, considering 'economic mass' and 'distance' as critical variables**.

2.1 International Economics

$$T_{A,B} \propto (GDP_A)^{\alpha}(GDP_B)^{\beta} \div (Dist_{AB})^{\zeta}$$



2.2 Logistics / Transportation

- Search Keywords: Supply Chain Resilience
  - *International Journal of Production Economics*
  - 314 articles
  - From 2015 to 2023
  - The focus areas include:
    - the impact of digitalization
    - the role of government
    - organizational strategies
    - technology's influence on supply chain resilience,

    ➢ highlighting a robust interdisciplinary approach to addressing supply chain challenges in the current dynamic global environment.

2.2 Logistics / Transportation

Authors	Year	Title	Category	Main Contribution
Zhao, Hong, Lau	2023	Impact of supply chain digitalization on supply chain resilience and performance	Digitalization	Explored the mediating role of digitalization in enhancing supply chain resilience and performance
Dubey, Bryde, Papadopoulos	2023	Dynamic digital capabilities and supply chain resilience: The role of government effectiveness	Government and Resilience	Investigated how government effectiveness influences the relationship between digital capabilities and supply chain resilience
Parast	2022	Toward a contingency perspective of organizational and supply chain resilience	Organizational Strategy	Developed a contingency framework to understand the variables influencing organizational and supply chain resilience
Ali, Arslan, Mainela	2023	Supply chain resilience to climate change inflicted extreme events in agri-food industry	Climate Change Adaptation	Assessed the role of social capital and network complexity in fortifying agri-food supply chains against climate change

2.2 Logistics / Transportation

Authors	Year	Title	Category	Main Contribution
Ivanov	2023	Intelligent digital twin (iDT) for supply chain stress-testing, resilience, and viability	Advanced Technologies	Introduced the concept of intelligent digital twins for stress-testing supply chain resilience
Huang, Wang, Yeung	2023	The impact of industry 4.0 on supply chain capability and supply chain resilience	Industry 4.0	Examined the influence of Industry 4.0 on supply chain capabilities and resilience from a dynamic resource-based view
El Baz, Ruel, Jebli	2023	Harnessing supply chain resilience and social performance through safety and health practices	Health and Safety	Investigated how safety and health practices during COVID-19 impact supply chain resilience and social performance
Queiroz, Wamba, Machado	2022	Supply chain resilience in the UK during the coronavirus pandemic	Pandemic Response	Offered a resource orchestration perspective on supply chain resilience during the coronavirus pandemic
Belhadi, Kamble, Benkhati	2022	Building supply chain resilience and efficiency through additive manufacturing	Additive Manufacturing	Provided an ambidextrous perspective on enhancing supply chain resilience and efficiency via additive manufacturing

First lessons

- **A Tale of Two Disciplines:**
  - International Economics:
    - Distance -> Time
  - Logistics / Transportation:
    - Volume -> Value
- **For our AI-based framework to build our digital twin about trade and transportation:**
  - **Interdisciplinary**
  - **Data driven (real-time and geolocated)**

3. Empowering Transport Solutions through AI and Data Science

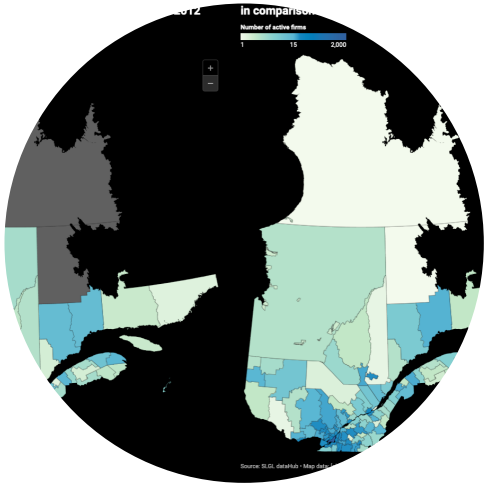
Empowering Transport Solutions through AI and Data Science

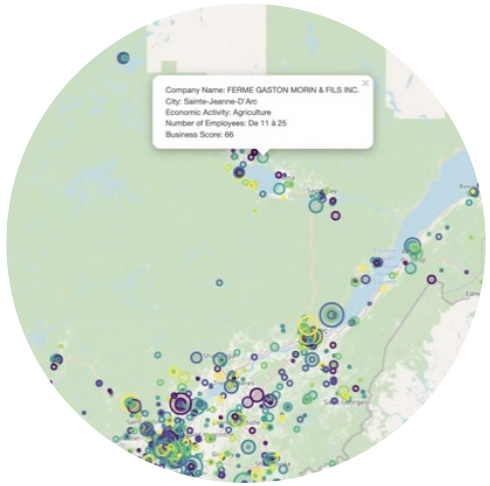
- Supervised and self-supervised machine learning techniques
  - Deep learning involves neural networks, which are layers of neurons with weights and biases. The output y from a neuron is computed as

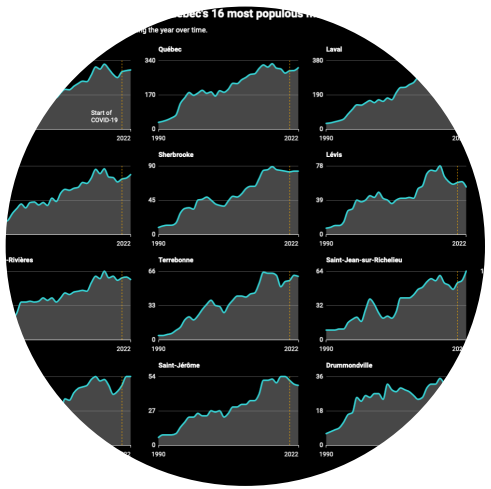
$$y = f(\sum(w_i \cdot x_i) + b) \tag{5}$$

    - where x_i are inputs, w_i are weights, b is the bias, and f is an activation function like ReLU or Sigmoid. Deep learning models learn by adjusting w_i and b to minimize the difference between predicted and actual outcomes, often using backpropagation and gradient descent.
  - Classification and regression methods

Use Case







Digital Twin of the Third Economy in the World

- St. Lawrence Great Lakes Region
- Bi-national

2
Canadian Provinces

8
US States

4
modes of transportation

$7.9T
current-dollar GDP in 2022

109M
estimated population in 2022

The St. Lawrence – Great Lakes region is a bi-national macro region between Canada and the United States

Source: U.S. Bureau of Economic Analysis, U.S. Census Bureau, Statistics Canada • Created with Datawrapper

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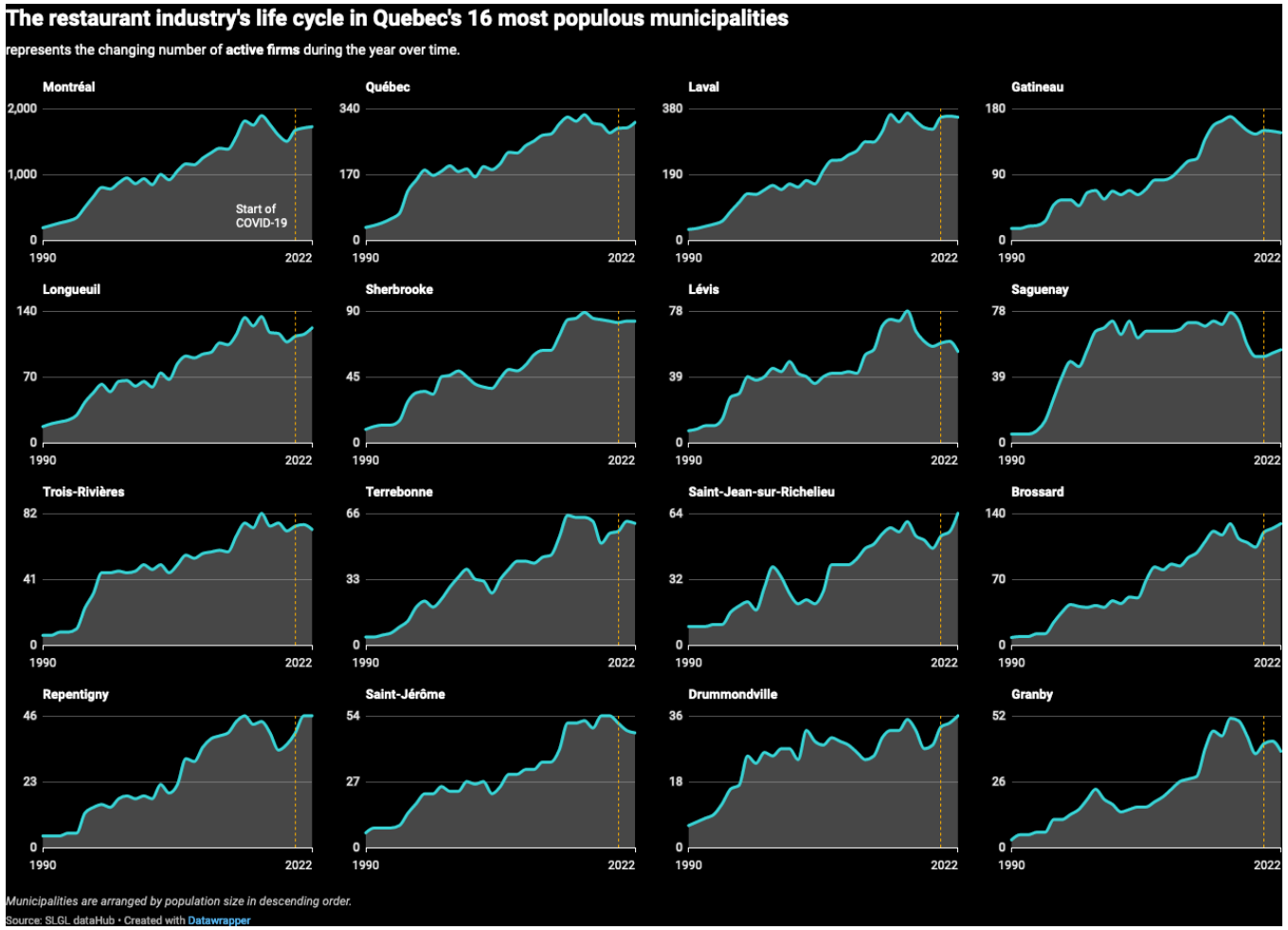
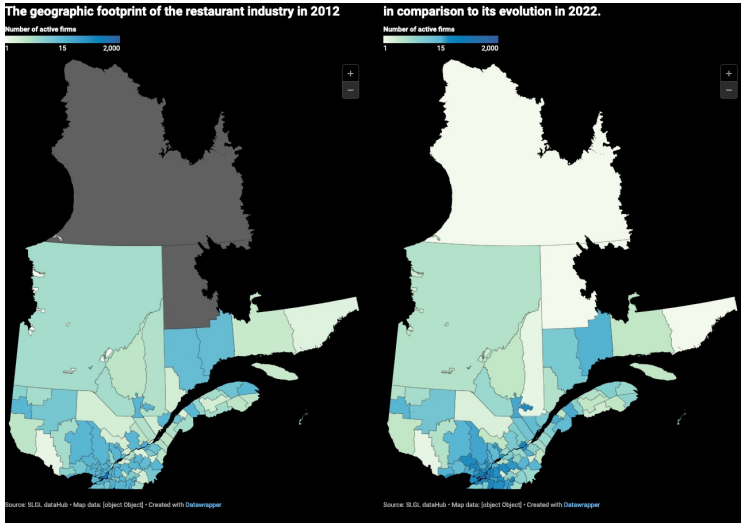
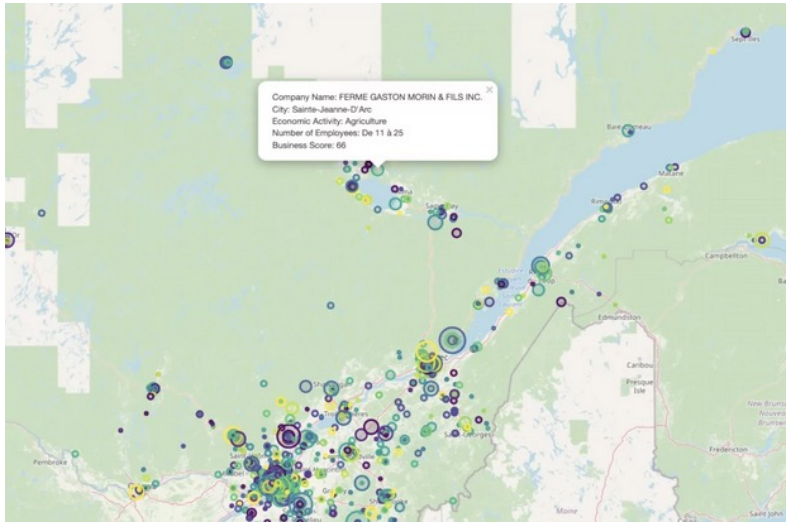

The restaurant industry's life cycle in Quebec's 16 most populous municipalities
represents the changing number of active firms during the year over time.
Montréal
2,000
1,000
0
Start of COVID-19
1990
2022
Québec
340
170
0
Laval
380
190
Gatineau
180
90
Longueuil
140
70
Sherbrooke
90
45
Lévis
78
39
Saguenay
Trois-Rivières
82
41
Terrebonne
66
33
Saint-Jean-sur-Richelieu
64
32
Brossard
140
70
Repentigny
46
23
Saint-Jérôme
54
27
Drummondville
36
18
Granby
52
26
Municipalities are arranged by population size in descending order.
Source: SLGL dataHub • Created with Datawrapper


The geographic footprint of the restaurant industry in 2012
in comparison to its evolution in 2022.
Number of active firms
1
15
2,000

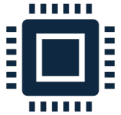

Company Name: FERME GASTON MORIN & FILS INC.
City: Sainte-Jeanne-D'Arc
Economic Activity: Agriculture
Number of Employees: De 11 à 25
Business Score: 66

Empowering Transport Solutions through AI and Data Science

- **What have we learned in this research for our AI-based framework to build our digital twin about trade and transportation?**
  - **Interdisciplinary**
  - **Data driven**
    - **real-time and geolocated**
    - **Unique training datasets (***)**
  - **Model-driven (***)**
    - **Real-time**
    - **Self-supervised models: real-time (live) feature selection**

      -> Accuracy for predictive modeling

What have we learned?



Digital Twins as a Predictive Tool

The role of digital twins in simulating transport systems and economic flows, emphasizing their potential as a predictive and diagnostic tool in the face of disruptions.

Policy Implications of AI-Driven Transport Models

How AI-driven transport models can inform policy, particularly in optimizing infrastructure investment and maintenance in anticipation of future shocks.

Cross-Disciplinary Methodologies for Transport Analytics

Advocate for a cross-disciplinary methodological approach, combining insights from data science, economics, and urban planning to create robust transport analytics.

Ethical Considerations in AI Deployment for Transportation

Address the ethical considerations and societal impacts of deploying AI in transportation planning, including issues of privacy, data security, and algorithmic bias.

Toward a Holistic Transport System Framework

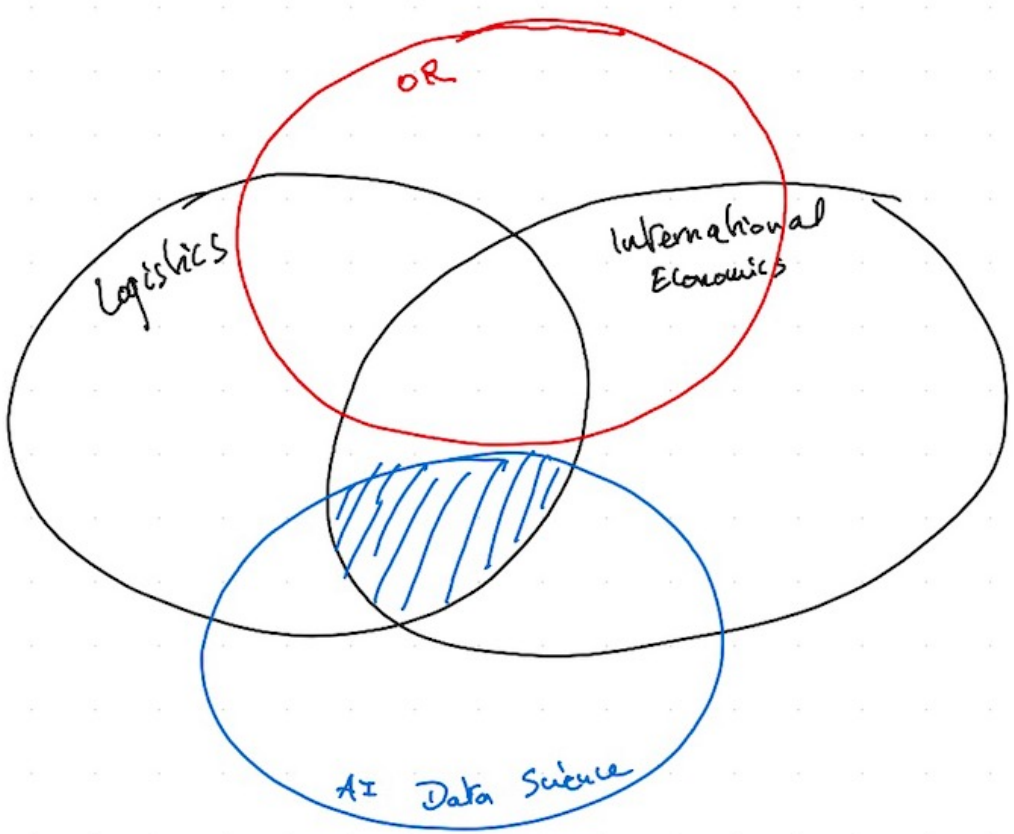
Propose a holistic framework for transportation systems that integrates physical infrastructures with digital innovations, emphasizing the importance of sustainability and adaptability.

Conclusion

Mandate

- The "G7 Transport Academy" to answer two pivotal research questions:
  1. "Are the current decision-making approaches adequate to deal with uncertainty about the future? »
  2. "Are the transportation infrastructure and services prepared to respond to any kind of shocks?"
- The focus would be to:
  - **critically** examine the **adequacy of current decision-making approaches** in planning and designing transport infrastructure, and **handling uncertainties** (such as climate extreme conditions, war, pandemics, and other international crises) on the one hand, and on **expected technological disruptions** such as Artificial Intelligence, big data, digitalization, and others.
  - consider **interdisciplinary approaches** that integrate insights from fields such as data science, risk management, and scenario planning, ensuring a more resilient response to uncertainties.

Navigating Uncertainty: Leveraging AI for Predictive Modeling in Multimodal Transportation and Economic Flows



Conclusion

- Grazie!

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