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AGILE & RESILIENT MODEL WITH AN IMPROVED DIGITAL TWIN APPROACH: AN OUTLOOK ON SUSTAINABILITY

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ABSTRACT

At the backdrop of the COP-28 summit on Green House Gases (GHG) emissions, the paper explores the supply chain risk and resilience of its supplier-stakeholder logistical node using AHP, FMEA & SERM frameworks. Utilising case-based research on a hypothetical global cluster based on a Canadian Aluminium Corporation with a specific impetus in the Quebec province, the research lays a foundation for normative theories using the Kraljic Matrix and above frameworks. The research establishes factors for strategic sustainable procurement using an improved digital twin approach in the supplier-stakeholder node using linear programming and multi-variate equations. In addition to the widespread interest in addressing GHG emissions, the research also focuses on an empirical carbon management and reporting tool using a strategic data hub to facilitate this process in accordance with the government and UN climate programs.

Keywords: Supply Chain Resilience, IMO, Sustainable Fuel, Sustainable Procurement, Canada

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1. INTRODUCTION

At the backdrop of the COP - 28 Dubai Summit hosting the UNFCCC discussions around the GHG emissions across manufacturing and service industries and logistical partners. Participative partners like the IMO & ICAO have raised concerns surrounding these emissions which have given weightage to recognition of the SERM framework [1] across the global supply chain network to mitigate risk from an ecological point of view. The paper highlights the risk profiling and resilience measures of supplier – stakeholder relationship using the AHP framework [2] by means of case-based research on a global cluster in a Canadian Global Aluminium Corporation (GAC). The paper tests the supply chain across a hypothetical value chain from an LCA perspective with specific impetus to the Canadian Aviation sector in the Quebec province.

The literature throws light on the amalgamation of the Kraljic model on supplier-stakeholder [3] with a SERM framework perspective across supplier-stakeholder partnership in the Canadian GAC region with procurement of raw material imports and back through to the Port of Quebec as finished goods and through the global supply chain networks via air & sea freight channels from the Alu-Quebec clusters via freight consolidators to respective service industries.

A proactive and holistic approach for supply chain resilience that builds the adaptive capacity to handle unforeseeable disruptions. To mitigate the impact of unexpected risk especially on multi-national enterprises, an adoptive supply chain resilience is aimed to achieve flexibility, velocity and visibility and collaboration. In particular, the study highlights the internal risks in sourcing and the delivery, leading to major disruptions of material flow enhancing adaptability and flexibility as a dynamic capability – influencing supply chain resilience and role of risk management strategies through statistical analysis [4].

Rudimentary pro-active tasks in resilience building can be put in place to assess and manage supply chain risks with a resource-based review. These measures lead to process formalization using people, information systems and measurement of key KPI metrics resulting in lower risk management. [5].

Objectives of this study:

- Analysing existing Digital Twins literature particularly from an analytical standpoint.
- Analysing the disruption sources with the supply chain risks through stochastic quantitative approaches to improve supply chain resilience measures over existing capacities for the logistical nodal network as per schematic.

II. LITERATURE REVIEW

Design of an Improved Digital Twin for Carbon Management: The literature in the introduction lacks the theoretical concepts and frameworks of a Carbon Management framework from the UNFCCC (COP – 29) standpoint.

The case-based research lays a foundation for normative theories using the Kraljic portfolio purchasing matrix framework to develop over an iDT model along-with collaborative strategic sourcing partnerships using external and internal risk parameters while assessing the supply chain lead-time and flexibility factors in the logistical nodal network.

Mobility and trade flow [6] across collaborative partners reduces freight bottlenecks and uncertainties in the supply chain network when using the Intelligent Digital Twin Model [7][9][10][11] providing visibility to the supply chain stakeholders making the network easy to respond and adapt to disruption when using digital technologies for continuous monitoring of supply chain functions.

Improved Digital Twin: The Intelligent Digital Twin model is a digital visualisation of a physical supply chain and its elements in a computer model with advanced digital technologies providing data about the physical object (Sensors, Blockchain and Cloud) using descriptive, predictive and prescriptive analytics for decision making support to optimise, simulate and visualise with a human-machine interface [7][9][10][11].

This Improved Digital Twin (IDT) model increases the visibility and optimises the logistical resources offering real-time supply chain data facilitating supply chain resilience levels in supply chain at the strategic and operational level leading to a development of resilient supply chain networks. This process incorporates reactive and proactive measures across the entire Canadian GAC supply network lowering GHG emissions in the Alu Quebec cluster from both, the usage of efficient materials and low emission trucking fuel for reducing CO_2e as part of this empirical case-based study from the de-carbonisation perspective – COP-28.

The digital twin is a combination of multiple layers such as network structure, flows, process control algorithms and operational parameters with connectivity with external systems and databases for risk profiling using AHP framework integrating descriptive, predictive and prescriptive analytics [7][9][10][11].

The Digital Twin allows for both numerical outcomes and an extended analysis of bottlenecks, comparison, analyses of resilience investments and digital technologies such as IoT, 5G, Sensors, Blockchain, AI & Data Analytics and Supply Collaborative Partners for real-time decision making among supply chain partners thus enhancing performance, sustainability and resilience analyses, end-end visibility and integration capabilities for digital collaboration. [7][9][10][11].

The development of this Digital Twin based supply chain stress-testing framework is subject to data and model integration. At the pro-active stage, the digital twin uses statistical data in optimisation and simulation models for resilience analysis and stress-testing. To exemplify, an alternate supply design and back up logistics can be analysed to assess the impact of disruption on supply performance [7][9][10][11].

This study, proposes a model with mitigation strategies with comprehensive understanding of potential risks in the network to build an agile and adaptable supply chain. Furthermore, it enhances supply chain resilience capabilities in uncertain supply chain environments that involve different risks. [4]

It needs an incorporation of the Carbon Management System to facilitate virtual reporting of logistical systems in freight transport of physical entities while integrating and managing various existing Business Processes in the Procurement, Supplier Lifecycle Management (SLM) till the delivery of consignments – a hypothetical online portal named e-DTMS (Document & Transportation System) for an ESG & BRSR Standpoint referred here as an Improved Digital Twin.

Table: Supply Network Risk Profile – AHP Framework

Risk Category	Risk Factors	Authors
Procurement Risk (Disruptional)	Sourcing Risks	A. Azaron, K.N.Brown, S.A.Tarim, M.Modarres (2008), Dmitry Ivanov, Alexander Pavlov, Alexandre Dolgui, Dmitry Pavlov, Boris Sokolov (2016), Dmitry Ivanova, Boris Sokolov, Inna Solovyeva, Alexandre Dolgui and Ferry Jie, Jennifer Blackhurst, Kaitlin S. Dunn, Christopher W. Craighead (2016)
	Flexibility Risk	Dmitry Ivanov (2023), Juneho Um, Neungho Han (2021)
	Supplier Relationship	Qualitative Data
	Material Quality Risk	Qualitative Data
Company Holding Risk (Operational)	Kinks in Holding Costs	Qualitative Data
	Product Quality Risk ~ Detoriation	Qualitative Data
	Change in Global Specifications	Qualitative Data
Documentation Risk (Semi-Disruptional)	Forecasting Risk	Manuj and Mentzer (2008a, 2008b), Olson and Wu (2010), Tummala and Schoenherr (2011), Giannakis and Papadopoulos (2016)
	Back-Orders Contracting Risk	Qualitative Data

Sources of Disruptions:

The impact of the sources of disruption on supply chain performance and the scope of changes occurring in the supply chain structures are - structural resilience [back-up suppliers during contingencies] & parametrical resilience [capacity expansion]. These resilience measures make the supply chain network resistant to disruption by tuning critical parameters like lead-time [13] or flexibility to prevent such disruptions.

Table: Performance Metrics for Supply Chain Resilience Factoring across:

Vulnerability	Supply Chain Resilience Capability
Turbulence – Transportation failure leading to production stoppages.	Flexibility in sourcing of suppliers
Deliberate threats	Flexibility in order fulfilment
Sensitivity to external pressures	Tracking and visible collaboration across partners and cyber-security measures
Resource limitation at supplier production line	Proactive agile measures

Research Design/Methodology:

Case Study Approach - Schematic Diagram of Supply Chain Network – AHP Framework

Figure – Schematic Diagram

Above schematic depicts the Supplier-Enterprise framework design using Supplier - OEM supply network in Alu-Quebec cluster from the Smelter Processing Units, structural parts and avionics to the OEM in the Quebec Province [14].

As per schematic diagram, the level of disruptions in Supplier – OEM supply network depends basis characteristics of the supply chain network. The resilience of a supply chain and the recovery time from a disruption should be inversely related. [5][15].

Supply Chain Risk Management

The supply chain becomes vulnerable, if the Canadian GAC supply chain ignores resilience measures pushing for lower costs and higher efficiency thus emphasising the need for resilience measures ie. strategic stock, maintain low-capacity utilisation & multiple suppliers' information sharing – supply chain integration and flexibility [16].

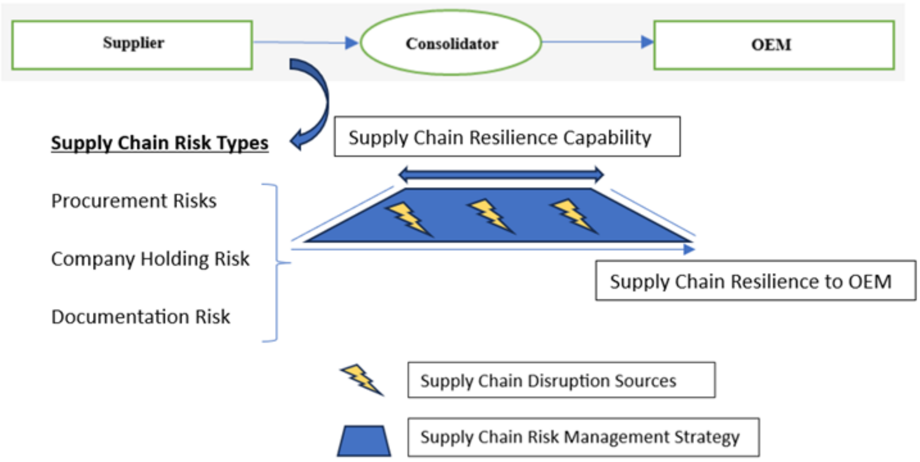
Table: Risk Profiling – AHP Framework

Risk Profiles	Description	Description	Description
Risk Assessment	Analysis & Evaluation	ESG – Alu-Quebec Cluster	CO_2e; SDG Goals; Governance (GAC)
Risk Reporting	IDT - e-DTMS	Digital Technologies	5G, IoT, Sensors, Cloud ERP & Remote Digital Hub
Risk Treatment	Resilience Measures	Drivers of Resilience Supply Chain	Supply Chain Agility & Responsiveness
Risk Monitoring	Improved Digital Twin	e-DTMS	Supplier-Stakeholder Collaboration
Risk Mitigation & Control	Risk Mitigation Strategies	De-Carbonomics	Carbon-Free Aluminium & Renewable Trucking Fuel, UN Offset Program

Mainly procurement, company inventory and documentation sources of risk upon the onset of disruptive activities are countered by resilience measures through resource re-configuration. To ideally manage risk management across such supply chain infrastructure to managing resilience in order to develop capabilities to mitigate the impact of a certain risk under disruption. [17]

The ability to quickly stabilize after a shock and strengthen the immunity of supply chain which makes the supply network agile and capable of protecting itself with human-AI tool (e-DTMS ~ Improved Digital Twin) in real-time saving time.

Risk Models [Supplier – OEM Supply Network]:



Mathematical Frameworks:

Disruption Quotient in the supply logistical nodal network is calculated using a dependent variable i.e.

[Supply Chain Performance [Zij] = Cost [Cij] * Risk [Rij]] ------- Linear Programming Model.

The notation i-j are denoted as node i and node j where the risk occurs and the supply chain (SC) performance is being evaluated for resilience to the interventions in the logistical nodal network.

The supply chain performance quantifies the disruption quotient in the logistical node i-j.

SC Performance [Zij] = a * Xij + b * Yij + c ------------------- Multi-Variate Equation

Where the supply chain performance is factored by Z, X – lead-time and Y – supplier flexibility while a, b and c are lead-time uncertainty, flexibility uncertainty and other unknown uncertainty respectively.

To assess the multi-variate equation using two-way ANOVA, three null hypotheses and three alternate hypotheses is being used.

Null Hypotheses H0 -

1) There is no significant difference in the mean between the groups (factor levels) of the first factor.
2) There is no significant difference in the mean between the groups (factor levels) of the second factor.
3) One factor has no effect on the effect of the other factor.

Alternate Hypotheses H1

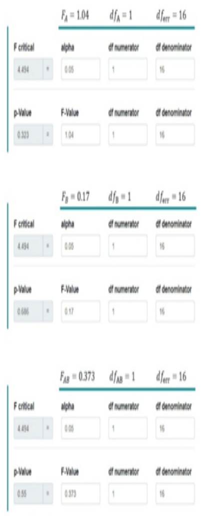
1) There is a significant difference in the mean between the groups (factor levels) of the first factor.
2) There is a significant difference in the mean between the groups (factor levels) of the second factor.
3) One factor has an effect on the effect of the other factor.

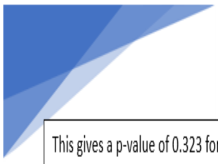
Assumptions: -

1) The scale level of the dependent variable should be a metric and that of independent variable (factors) nominal.
2) The data within the groups is normally distributed.

Calculating Two-Way ANOVA

Calculating two-way ANOVA using Sum of Squares, Degree of Freedom, Variances and F-Value, to evaluate p-value basis the above measure. The disruption quotient evaluates the supply chain performance in the logistical nodal network as a dependent variable basis independent variable – lead-time and flexibility. The p-value is derived from a mathematical-software tool using the above measures and is discussed in the box below.





This gives a p-value of 0.323 for Factor A, a p-value of 0.686 for Factor B and a p-value of 0.55 for the interaction. None of these p-values is less than 0.05 and thus we retain the respective null hypotheses.

Parameter	Dependent Variable	SC Performance	
Factor A	Independent Variable	Lead-Time	
Factor B	Independent Variable	Flexibility	

Likert Scale [1-10]	High Lead-time	Low Lead-time	
	6	4	
	4	5	
High Flexibility	7	6	
	9	7	
	3	5	
Mean	5.8	5.4	5.6
	8	3	
Low Flexibility	3	5	
	5	9	
	8	2	
	6	3	
Mean	6	4.4	5.2
	5.9	4.9	5.4

Table – Supply Chain Risk Types and Disruptive Sources Pre-Disruption

	Disruption Magnitude = Cost [C_{ij}] * Risk Rating [R_{ij}]						
Supply Chain Risk Types	**Material Mis-Handling** (Y_1)	**PESTLE** (Y_2)	**Transportation Failure** (Y_3)	**Thermal PCM Failure** (Y_4)	**Back Order Mis-Management** (Y_5)	**Kinks - Holding Costs** (Y_6)	**Cyber Attacks** (Y_7)
Procurement Risk	74388360 * 4 = **297553440**	74388360 * 3.8 = **282675768**	74388360 * 3.4 = **252920424**	74388360 * 3.8 = **282675768**	74388360 * 3.5 = **260359260**	74388360 * 4 = **297553440**	74388360 * 3.66 = **272261397.6**
Warehouse Inventory Risk	37162880 * 4 = **148651520**	37162880 * 3.8 = **141218944**	37162880 * 3.4 = **126353792**	37162880 * 3.8 = **141218944**	37162880 * 3.5 = **130070080**	37162880 * 4 = **148651520**	37162880 * 3.66 = **136016140.8**
Documentation Risk ~ [Back-Ordering]	18590940 * 4 = **74363760**	18590940 * 3.8 = **70645572**	18590940 * 3.4 = **63209196**	18590940 * 3.8 = **70645572**	18590940 * 3.5 = **65068290**	18590940 * 4 = **74363760**	18590940 * 3.66 = **68042840.4**

Table – Supply Chain Risk Types and Disruptive Sources Post-Disruption

	Disruption Magnitude = Cost [C_{ij}] * Risk Rating [R_{ij}]						
Supply Chain Risk Types	**Material Mis - Handling** (Y_1)	**PESTLE** (Y_2)	**Transportation Failure** (Y_3)	**Thermal PCM Failure** (Y_4)	**Back Order Mis-Management** (Y_5)	**Kinks - Holding Costs** (Y_6)	**Cyber Attacks** (Y_7)
Procurement Risk	91351960 * 4 = **365407840**	91351960 * 3.8 = **347137448**	91351960 * 3.4 = **310596664**	91351960 * 3.8 = **347137448**	91351960 * 3.5 = **319731860**	91351960 * 4 = **365407840**	91351960 * 3.66 = **334348173.6**
Warehouse Inventory Risk	22831740 * 4 = **91326960**	22831740 * 3.8 = **86760612**	22831740 * 3.4 = **77627916**	22831740 * 3.8 = **86760612**	22831740 * 3.5 = **79911090**	22831740 * 4 = **91326960**	22831740 * 3.66 = **83564168.4**
Documentation Risk ~ [Back-Ordering]	45644480 * 4 = **182577920**	45644480 * 3.8 = **173449024**	45644480 * 3.4 = **155191232**	45644480 * 3.8 = **173449024**	45644480 * 3.5 = **159755680**	45644480 * 4 = **182577920**	45644480 * 3.66 = **167058796.8**

Table - Disruption Reduction for Optimal Supply Chain Performance = [Cost (Cij)] * [Reduction in Risk (Resilience) (Rij)] - Resilience Factor – Appendix 1

T0 - Time Phase — Disruption Reduction (Resilience) of Failure Causes / Risk Sources

	Material Mis-Handling	PESTLE	Transportation Failure	Thermal-PCM Failure	Back-Order Contract Mismanagement	Kink - Holding Cost	Cyber Attacks
Risk Types = ? (Supplier 1 - Supplier 6) / Failure Modes	y1 * Resilience Factor	y2 * Resilience Factor	y3 * Resilience Factor	y4 * Resilience Factor	y5 * Resilience Factor	y6 * Resilience Factor	y7 * Resilience Factor
Procurement Risk	297553440 * 0.4	282675768 * 0.55	252920424 * 0.6	282675768 * 0.3	260359260 * 0.2	0	272261397.6 * 0.47
Company Inventory Holding Risk	0	0	0	141218944 * 0.2	130070080 * 0.5	148651520 * 0.4	0
Documentation Risk	0	0	0	0	65068290 * 0.5	0	68042840.4 * 0.5

T1 - Time Phase — Disruption Reduction (Resilience) of Failure Causes / Risk Sources

	Material Mis-Handling	PESTLE	Transportation Failure	Thermal-PCM Failure	Back-Order Contract Mismanagement	Kink - Holding Cost	Cyber Attacks
Risk Types = ? (Supplier 1 - Supplier 6) / Failure Modes	y1 * Resilience Factor	y2 * Resilience Factor	y3 * Resilience Factor	y4 * Resilience Factor	y5 * Resilience Factor	y6 * Resilience Factor	y7 * Resilience Factor
Procurement Risk	297553440 * 0.2	282675768 * 0.15	252920424 * 0.2	282675768 * 0.05	260359260 * 0.2	0	272261397.6 * 0.2
Company Inventory Holding Risk	0	0	0	141218944 * 0.05	130070080 * 0.2	148651520 * 0.3	0
Documentation Risk	0	0	0	0	65068290 * 0.2	0	68042840.4 * 0.3

T2 - Time Phase — Disruption Reduction (Resilience) of Failure Causes / Risk Sources

	Material Mis-Handling	PESTLE	Transportation Failure	Thermal-PCM Failure	Back-Order Contract Mismanagement	Kink - Holding Cost	Cyber Attacks
Risk Types = ? (Supplier 1 - Supplier 6) / Failure Modes	y1 * Resilience Factor	y2 * Resilience Factor	y3 * Resilience Factor	y4 * Resilience Factor	y5 * Resilience Factor	y6 * Resilience Factor	y7 * Resilience Factor
Procurement Risk	297553440 * 0.2	282675768 * 0.15	252920424 * 0.2	282675768 * 0.05	260359260 * 0.3	0	272261397.6 * 0.2
Company Inventory Holding Risk	0	0	0	141218944 * 0.1	130070080 * 0.2	148651520 * 0.3	0
Documentation Risk	0	0	0	0	65068290 * 0.2	0	68042840.4 * 0.2

Calculating with paired T-test.

Compare the before and after disruption quotient with the intervention of indicators by comparing if there is significant difference in disruption or supply chain performance before and after intervention.

Null Hypothesis – H0 – There is no significant difference between disruption quotient before and after intervention.

Alternate Hypothesis – H1 – There is significant difference between disruption quotient before and after intervention.

Alpha – 5%; degree of freedom df – 4. As per Resilient tables and T-tests t-value is greater than t-critical from T distribution chart, hence reject null hypothesis.

e-DTMS - Improved Digital Twin

The e-DTMS digital supply chain twin – an improved digital twin over existing digital twins, is a supply chain simulation and optimisation tool for which describes a hypothetical online portal for all entities in the described supply chain in fragments. (Procurement, Trucking; Import/Export; Warehousing; Supplier-Stakeholder & Freight Transport Tracking and Visibility) using –

Table: e-DTMS – Tool Features

Supplier Lifecycle Management	Data Management	Global Supply Chain – Canadian Global Aluminium Corporation
Procurement Planning & Implementation	Database	With 4PL Consolidators at Port-of-Quebec Transhipment Hub
Contracting & Vendor Management	Forecasting	Freight Consolidator

Inventory & Warehouse Management	Inventory Planning	Freight Consolidator
Sustainable Logistics	Replenishment Planning	Freight Consolidator

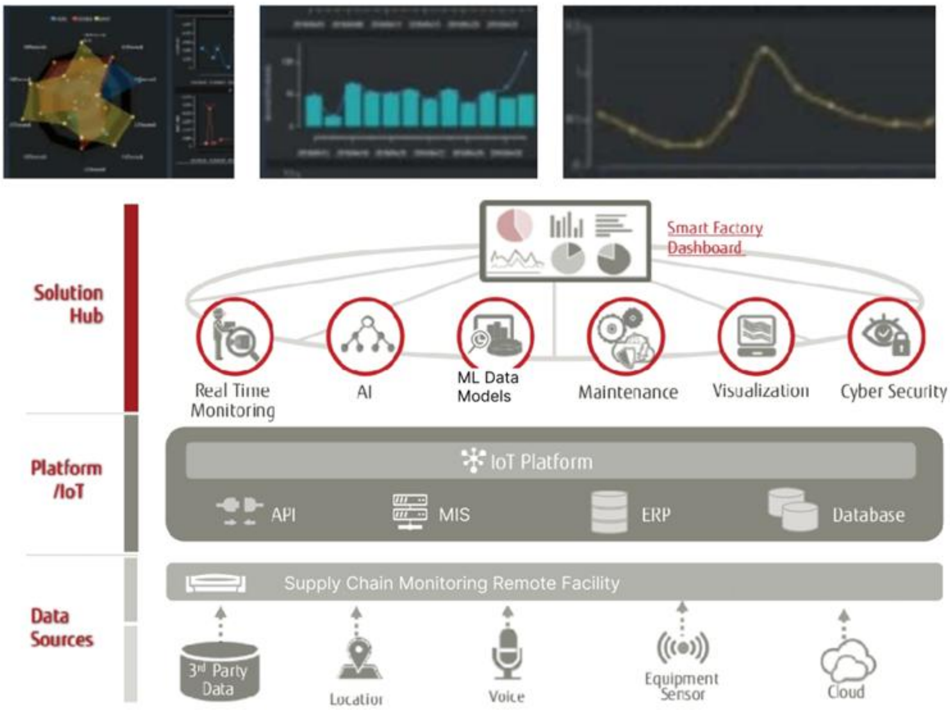


Fig. – Improved Digital Twin [e-DTMS] – Supply Chain Risk & Resilience with Carbon Management Interface [18]

In this figure, the e-DTMS allows risk profiling for Supply Chain Resilience analysis and stress-testing integrating supply chain entities using data analytic techniques for data-driven decision making through a digital tool. Such a digital twin model develops several management capabilities including visibility; real-time decision making; data visualization; data accuracy and traceability with KPI dashboard to enhance demand, supply and process knowledge.

Table: Qualitative Inputs:

Position in Supply Chain	Data Source Methodology	Data Content
Supplier – OEM	Semi-structured interviews with Aerospace Manufacturing Corporation Consultant – Expert 1	Supply chain impact upon disruption from risk sources and subsequent mitigation strategies
Supplier – OEM	Qualitative Method using stochastic analysis – own understanding with logical view evaluating applicability with respective response time basis a	Supply chain impact upon disruption from risk sources and subsequent mitigation strategies

	certification course. *** [Due to Qualitative Data In-availability from Industry Experts]**	

Findings:

Supply Chain Mapping in Supplier – OEM

- Modelling Framework - Risk Propagation Index – Model I [T-Test Statistics and control using resilience strategies and verify using two-way Anova statistically]
- Two-Way Anova requires two or more independent variables – Lead-time and flexibility on a dependent variable – SC Performance
- Impact Assessment – Tables with Disruption Reduction
- Visualisation – Proposed IDT Model

  assessing resilience factor in the Supplier – OEM logistical nodal network basis disruption / failure sources.
- Reduce Risk Propagation Index [RPI]
- Assessing SC fragility between Supplier – OEM node (with Statistics)
- Resilience Index – Scorecard
- Adaptive Learning (GenAI SC) for disruption scenarios in the logistical node.

Scorecard Table:

Failure Modes	**Failure Causes / Disruptional Sources [Σ(Yn)] across 7 stated Risks**			
[Across 6 Aerospace Suppliers]	**Probability of Risk [P_R**	**Impact of Risk [I_R]**	**Response Time [T_R] (week)**	**Score = [PR] * [IR] * [TR]**
Disruptional Risk	0.7	1.8	3	3.78
Operational Risk	0.2	2	10	4
Semi-Disruptional Risk	0.2	4	3	2.4

Results:

This model highlights the supply chain visibility, risk profiling and the resilience management from operational perspective leading to identification and primary detection of the risk from a strategic point of view. Thus preventing the risk from recurring while fostering sustainability and innovation using the disruption framework to define the problem, investigate and resolve with course corrective measures. Hence by changing the systems and processes in the supply network leading to a smoother supply chain.

The multi-variate model equation to factor for supply chain flexibility and lead-time which indirectly evaluate supply chain performance as a dependent variable. Since data pointers of experimental data was below 200 entries; statistical Two-Way Anova tool was used to validate the multi-variate equation in the supplier-stakeholder logistical node.

Hence, with the T-test, I conclude that the resilient strategies are effective to keep the single logistical node resilient with the rejection of H0 – null hypothesis i.e. post intervention caused via the Linear Programming model.

Assumptions of Study:

- Certain strategies are null in timeframes during movement of flow units.
- Assumption on constant uncertainty in the logistical nodal network.
- Pre-Disruption risk is unknown, hence high/medium risk might happen due to a possibility of a global health risk/natural disaster.
- Disruption magnitude increases as per risk rating and then as per resilient strategies it keeps reducing.

Dual Carbon Management:

- Freight GHG Accounting
- Regulatory Compliance (Carbon-Free Aluminium)
- Operational Fuel Efficiency via Capacity Utilisation framework

Table: Supply Network and CO2e of Canadian-Global Aluminium Corporation:

Supply Network	**Process Description**	**tCO_2e**
Guinea Port to Quebec Port	Raw Material Sourcing (Bauxite)	-
Refinery – Smelter (Scope 1 & Scope 2)	Bayer Process	**$3080.710 * 10^6$**
Refinery – Smelter (Scope 3)	Bayer Process	-
Smelters - Casting Processing Units (Scope 1 & Scope 2)	Hall-Heroult Process	**$94.562 * 10^6$**
Smelters - Casting Processing Units (Scope 3) – 2023	Hall-Heroult Process	**16411302.183**
Casting Processing Units to OEMs	Logistical transportation of Casted Products	-
Manufacturers/OEMs to Transhipment Port Consolidators (Scope 3)	Logistical transportation of Finished Products – Boeing & Air Bus (OEMs) & Bombardier	-
Transhipment Port Consolidators to Global Supply Chain.	Logistical transportation via Air Freight or Sea Freight	**8298720**

Conclusions:

With the considerations of parameters discussed, I provide the model for explaining the cost model in disruptive scenarios for a resilient supply chain approach using resilient strategies as per multi-variate equation. The produced model is an initiative for SEM – AMOS and it may get further refined with the consideration of other relevant parameters. [more consolidators to a single OEM – i.e. larger data entries].

Data Availability Statement

The paper has been singly authored by the author mentioned in the abstract, hence there is supposedly no conflict of interest to anyone pertaining to this paper. The paper solely belongs to the author mentioned in the abstract itself.

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<u>Appendix:</u>

<u>Questionnaire for Consolidator – OEM Supply Network</u>

- Rate any kind of Material Mis-Handling Risk in supply network on Scale of 1-10

  …………….

- Rate any kind of PESTLE associated Risk in supply network on Scale of 1-10

…………….

- Rate any kind of Transportation Failure Risk [LCL] in supply network on Scale of 1-10

………………

- Rate any kind of Thermal Phase Changer Risk in supply network on scale of 1-10

………………

- Rate any kind of Back-Order Mismanagement Risk at OEM on scale of 1-10

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- Rate any kind of Kink in Holding Costs at OEM on Scale of 1-10

……………..

- Rate any kind of Sourcing Challenges to Primary Supplier in supply network on Scale of 1-10

…………….

- Rate any kind of Improper Collaborative Risk Developing at OEM on Scale of 1-10

…………….

- Rate any kind of Export/Import Restrictions Risk on Scale of 1-10

…………….

- Rate any kind of Product Recall Risk on Scale of 1-10

…………….

Action Recommended Strategies basis Risk Types:

Risk Types	Material Mis-Handling (y1)	Summation of Strat.	Resilient Factor [0-1]	Response Time
Sourcing Risk ~ (Procurement)	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx	xxxxxxxxxxx		xxxx
	Strategy 1 - Transport Insurance ~ Safety	$\Sigma(S1 + S2 + S3 + S4 + S5 + S6 + S7) =$	0.4	30 mins
	Strategy 2 - Reduced Outsourcing			
	Strategy 3 - Increased Budget Allocation			
	Strategy 4 - Contingency Shipment			
	Strategy 5 - Building Resilience by (n+1) Approach - **GenAI**			
	Strategy 6 - Reserve Suppliers			
	Strategy 7 - Agile Lean Practices			
	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx			
Company Inventory Holding Risk	xxxxxxxxxxxxxxxxxxxxxx			
	xxxxxxxxxxxxxxxxxxxxxx			
	xxxxxxxxxxxxxxxxxxxxxx			
Documentation Risk	xxxxxxxxxxxxxxxxxxxxxx			
	xxxxxxxxxxxxxxxxxxxxxx			

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