Visualization of Ripple Effect in Supply Chain under various disruptions

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Introduction & Problem Statement

Supply Chain Vulnerabilities:

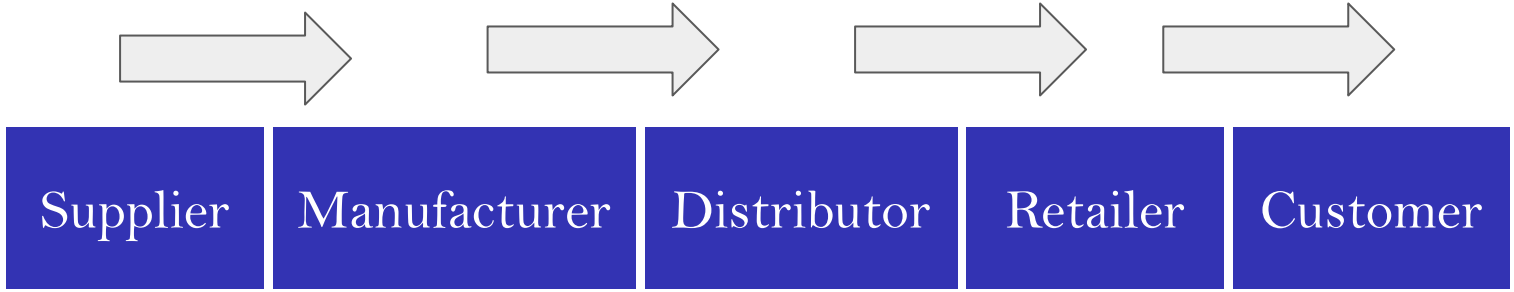
- Exposed to **operational**, **environmental**, and **logistical risks**.
- Risks propagate, causing a **ripple effect** across different stages.

Ripple Effect : The direct aftermath after one solitary action or inaction

Focus of the Study:

- Analyzing ripple effects through **system dynamics modeling**.
- Examining four disruption scenarios:
  - **Supply disruptions**
  - **Demand disruptions**
  - **Logistics disruptions**
  - **Combined simultaneous disruptions**

Components of the supply chain



Risks associated with each entity

MANUFACTURER & RETAILER Risk

Only in Producer and Retailer

INVENTORY Risk

TRANSPORT Risk

- Using these risks, we calculate the risks associated with each entity

Risk Calculation

1. Inventory Risk

Formula:

- If Actual Inventory = Expected Inventory:
  Inventory Risk = 0
- Otherwise:

$$\text{Inventory Risk} = \frac{|\text{Actual Inventory} - \text{Expected Inventory}|}{\text{Expected Inventory}}$$

2. Transport Risk

Formula:

- If Actual Output Quantity ≤ Shipping Capacity:
  Transport risk = 0
- Otherwise :

$$\text{Transport Risk} = \frac{\text{Actual Output Quantity} - \text{Shipping Capacity}}{\text{Actual Output Quantity}}$$

3. Production Risk

Formula:

- If Production Quantity ≥ Planned Production Quantity :
  Production Risk = 0
- Otherwise:

$$\text{Production Risk} = \frac{\text{Planned Production Quantity} - \text{Production Quantity}}{\text{Planned Production Quantity}}$$

4. Sales Risk

Formula:

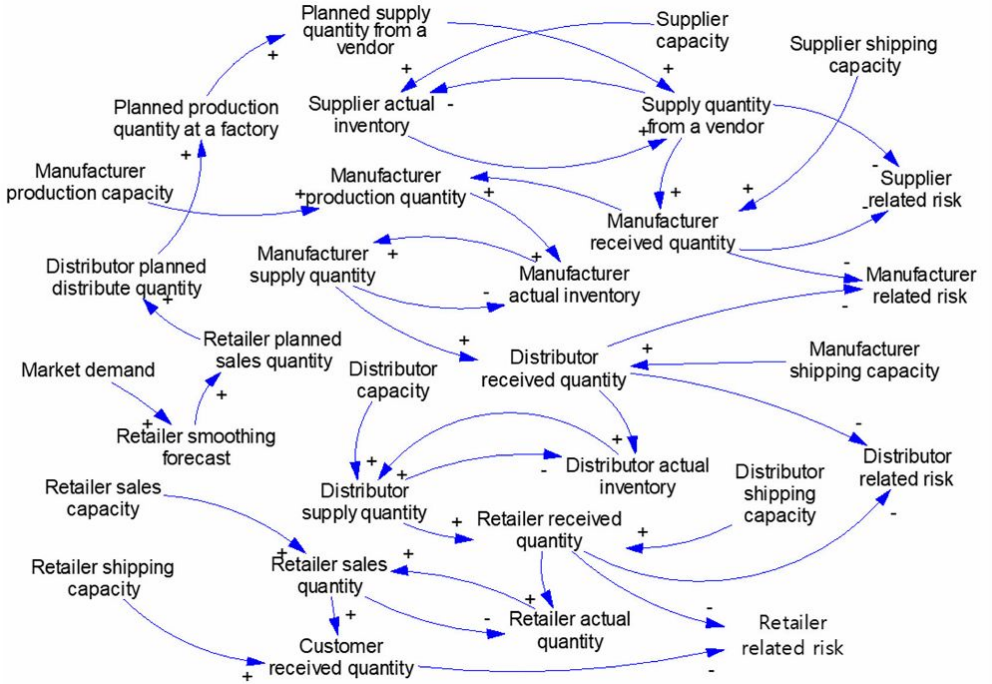
- If Sales Quantity ≥ Planned Sales Quantity:
  Sales Risk = 0
- Otherwise:

$$\text{Sales Risk} = \frac{\text{Planned Sales Quantity} - \text{Sales Quantity}}{\text{Planned Sales Quantity}}$$

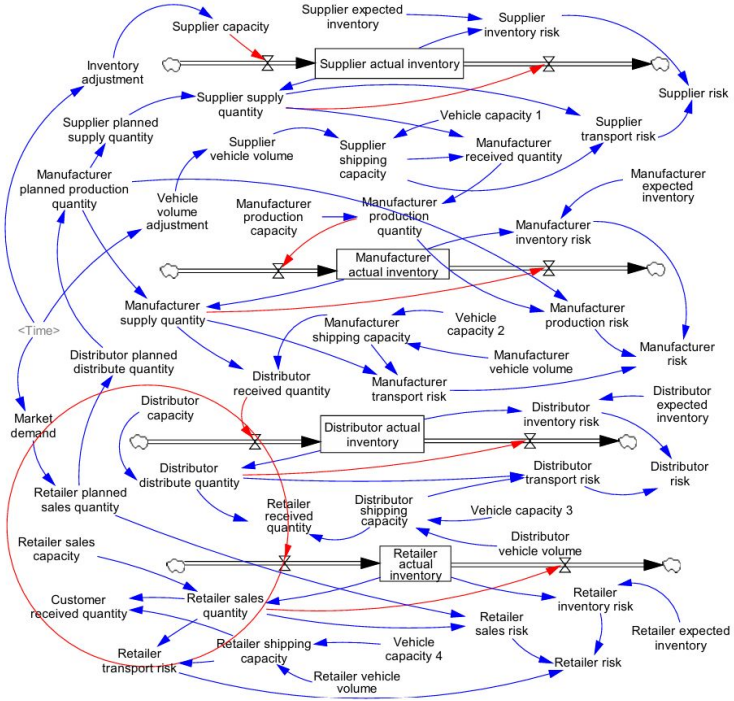
Risk Calculation

- **Supplier Risk:** Inventory Risk (0.6) , Transport Risk (0.4)
- **Manufacturer Risk:** Production Risk (0.5), Inventory Risk (0.3), Transport Risk (0.2)
- **Distributor Risk:** Inventory Risk (0.6), Transport Risk (0.4)
- **Retailer Risk:** Sales Risk (0.5), Inventory Risk (0.3), Transport Risk (0.2)

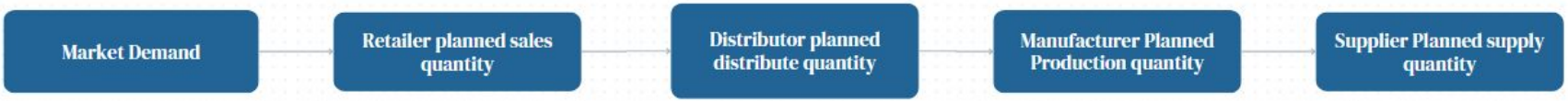
Causal loop diagram



Stock & Flow diagram



Passing of information



- Data from each entity is smoothed before being passed to the next, ensuring robustness.

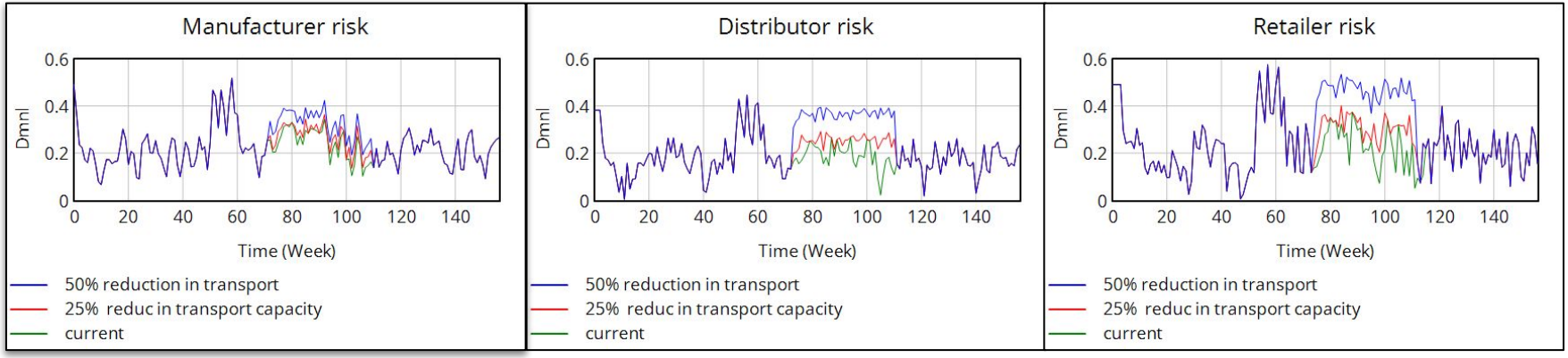
  i.e Time to form demand expectations at each SC entity = 3 weeks

Simulation Setup

- **Start week** = 0 , **final week** = 156, **time interval** = 1 week (Units : week)
- **Average market demand** = 50 thousand units/week, changing with 70–130% variation, which starts from week 4.
- **Initial inventory level** for each SC entity= 20 thousand units.
- **Expected inventory level** at each SC entity= 55 thousand units.
- **Vehicle capacity** (same for all SC entities) = 2.5 thousand units/car
- **Vehicle volume** at each SC entity : Range [15,25] (unit: car)
- **Inventory** & **vehicle volume adjustment** : On week 50 with 35% volume is decreased.

Experiments

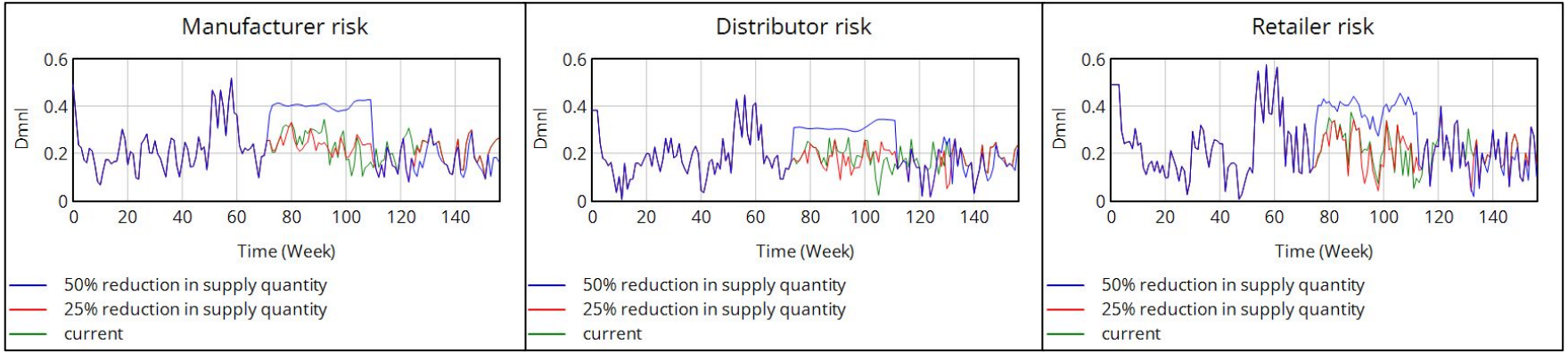
Scenario 1 (Shipping capacity)



- 25% & 50% reduction in manufacturer shipping capacity between weeks 72 & 110
- Impacted the retailer to the highest extent, with delay or shortages in stock for meeting end customers' demands

Reduction in supply quantity

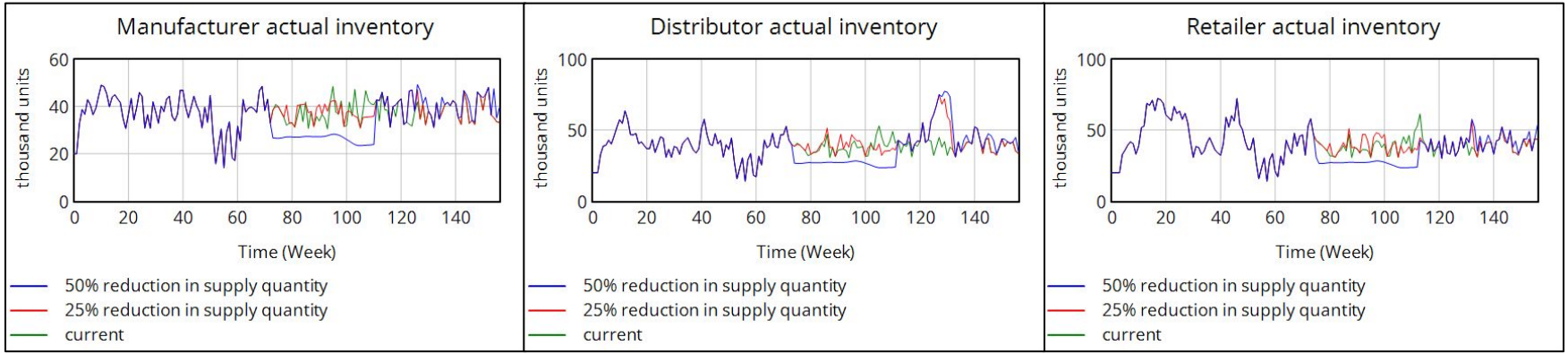
Scenario 2



- Simulated a scenario with 25 and 50% reduction in supply quantity between weeks 72 and 110

Observation on Scenario 2

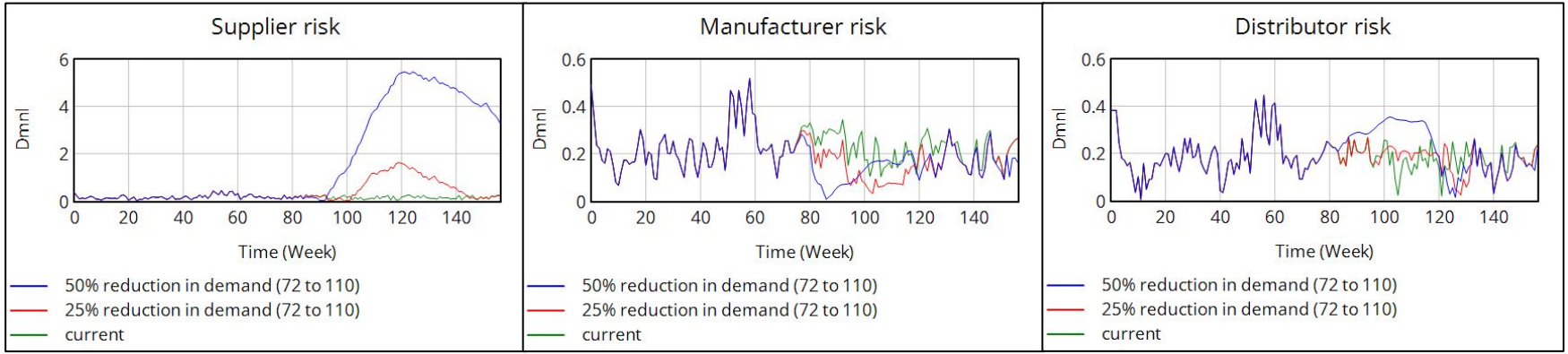
Inventory levels



- Here disruption in the supply quantity primarily impacts the manufacturer with inventory shortage which further affects the downstream nodes .

Market demand disruption

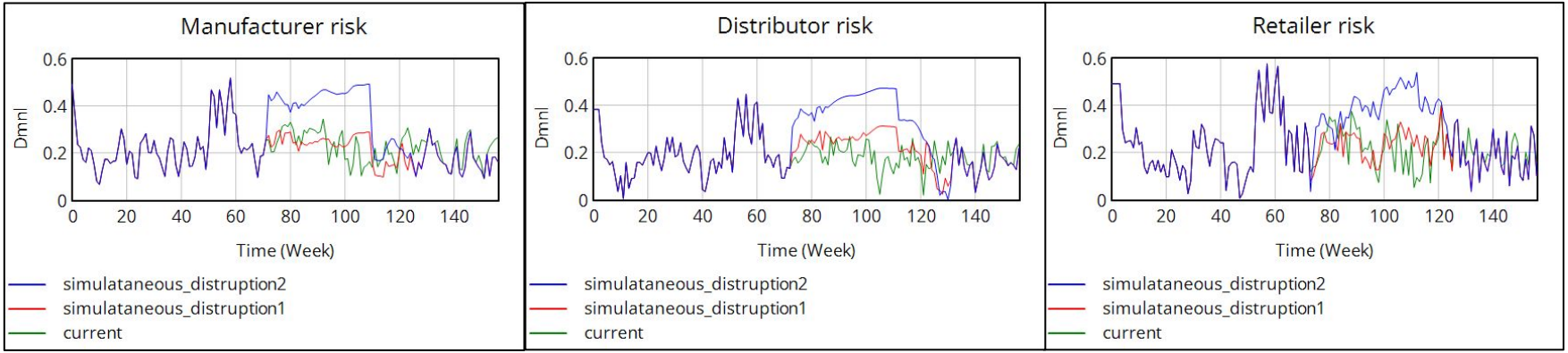
Scenario *3*



- Here it can be seen that disruption due to market demand primarily impacts the supplier and the distributor with inventory shortage.

Simultaneous disruption

Scenario 4



- Simultaneous disruption with 25% & 50% reduction in manufacturer shipping capacity, market demand & supplier capacity between weeks 72 and 110

Observations

Manufacturer Shipping Capacity Reduction

- A 25–50% reduction between weeks 72 and 110 caused **severe delays and stock shortages** at the retailer level, affecting the ability to meet customer demand.

Supply Disruption

- **Concurrent Impact**: Distributor and retailer **simultaneously face inventory shortages**, leading to **lost sales** and **decreased customer satisfaction**.

Market Demand Disruption

- **Retailer**: Minimal impact on vulnerability index due to rapid demand adaptation (~3 weeks).
- **Distributor**: Higher vulnerability due to **excess or backlogged inventory**, caused by decreased average network demand.

Simultaneous Disruption

- Retailers and manufacturers are **most fragile** due to their involvement in multiple SC activities, compared to distributors.

Conclusion

Ripple Effect Dynamics

- Disruptions propagate across the supply chain (SC) in both **upstream** and **downstream directions**, with impacts varying based on **risk type**, **combination of risks**, and **impacting nodes**.

Risk-Specific Findings

- **Demand Disruptions**: Begin downstream and propagate upstream, creating cascading effects.
- **Logistics Disruptions**: Originate from manufacturers, exposing retailers to the highest inventory risk.

Simultaneous Disruptions

- Multiple, concurrent disruptions lead to **larger ripple effects** compared to individual disruptions, with manufacturers and retailers being the most vulnerable nodes.

Duration and Accumulation of Risks

- Disruptions of longer duration amplify their impact across the SC, where recovery depends on factors like risk type, resilience, and mitigation actions.

References

1. Ghadge, A., Er, M., Ivanov, D., & Chaudhuri, A. (n.d.). Visualization of ripple effect in supply chains under long-term, simultaneous disruptions: A system dynamics approach.
2. Wagner, S. M., & Neshat, N. (n.d.). Assessing the vulnerability of supply chains using graph theory. *Chair of Logistics Management, Swiss Federal Institute of Technology Zurich.*
3. *Sokolov, B., Ivanov, D., Dolgui, A., & Pavlov, A. (n.d.). Structural quantification of the ripple effect in the supply chain.*
4. *Li, Y., Chen, K., Collignon, S., Ivanov, D. (n.d.). Ripple effect in the supply chain network: Forward and backward disruption propagation, network health and firm vulnerability.*
5. Kinra, A., Ivanov, D., Das, A., & Dolgui, A. (2020). Ripple effect quantification by supplier risk exposure assessment. *International Journal of Production Research, 58*(19), 5559–5578.
6. Llaguno, A., Mula, J., & Campuzano-Bolarin, F. (2021). State of the art, conceptual framework, and simulation analysis of the ripple effect on supply chains. *International Journal of Production Research.*
7. Olivares-Aguila, J., & ElMaraghy, W. (2020). System dynamics modelling for supply chain disruptions. *International Journal of Production Research*
8. Paul, S. K., & Chowdhury, P. (2020). A production recovery plan in manufacturing supply chains for a high-demand item during COVID-19. *International Journal of Physical Distribution & Logistics Management.*