Causal Framework for Supply Chain Analysis

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Background

Supply chain is an intricate network of organizations or individuals that are integrally involved in the direct flows of products, services or information from the point of origin to the end-user. [3]

Significance:

Robust and Resilient supply chains are vital for economic health as it directly impacts a country's GDP by stimulating trade and investments, optimizing resources, creating jobs and helping with innovation and investment.

Motivating Example:

In March 2020, a South Korean semiconductor supplier to Apple and LG experienced disruptions on the supplier side, due to pandemic. This caused factory lockdown in manufacturing in China, causing increased operational costs and contributed to delays in the production of iPhones.

Objective:

Define model and quantify *ripple effect* and *bullwhip effect* and leverage them to build resilient supply chains.

Temporal Causal Model: (Figure 1)

A Temporal Causal Model (TCM) is an extension of the causal model that includes temporal dynamics, defined by a triple $M = < U_t, V_t, F_t >$ where

- U_t is a set of background(exogenous) variables at time t, each U_i^t represents external influences relevant to the specific time
- V_t is a set of endogenous variables denoted by $\{V_1^t, V_2^t, ..., V_n^t\}$
- F_t comprises a set of functions $\{ f_1^t, f_2^t, .., f_n^t \}$ [2]

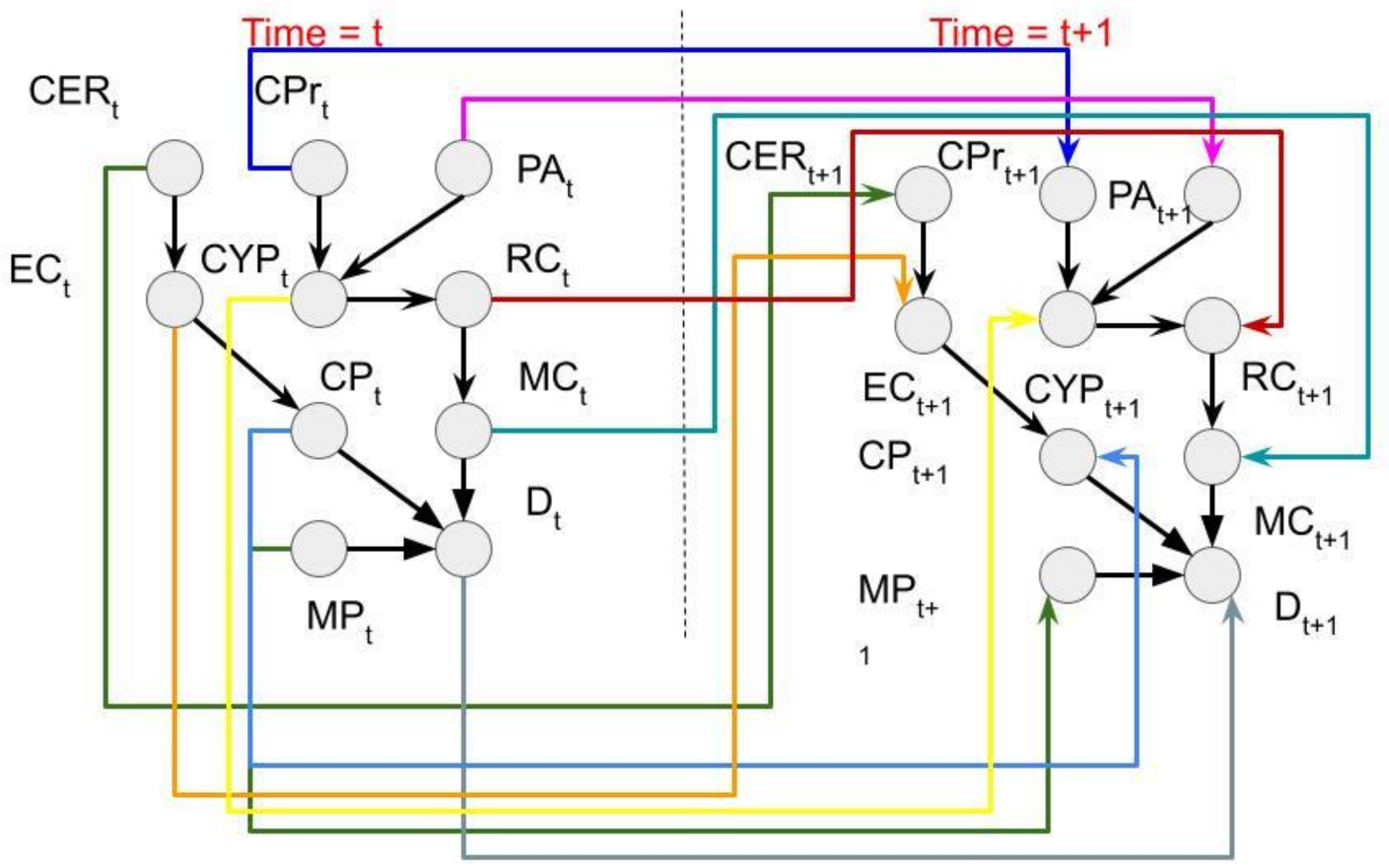
Ripple Effect

Ripple effect in supply chains refers to the propagating impact effect of a disruption as it moves downstream, altering demand fulfillment, structural design and planning parameters throughout the network. [3]

Example:

Due to the pandemic, a South Korean company faced disruptions on its supplier side. This effect propagated downstream to its distributor, Apple, resulting in increased operational costs for Apple phones. [4]

Source:
[4]https://www.weforum.org/agenda/2020/03/coronavirus-south-koreanvietnam-business-economics-coronavirus-covid19/.
[5]https://cnr.ncsu.edu/news/2020/05/coronavirus-toilet-paper-shortage/



Adapted from : The Design and Development of a Causal Bayesian Networks Model for the Explanation of Agricultural Supply Chains, Mallika Kliangkhlao, Limsiroratana Somchai, Bukhoree Sahoh

CER: Currency Exchange Rate; EC: Exchange Costs; CP: Customer Preference; MP: Market Price; CPr: Climatic Problems; PA: Plantation Area; CYP: Crop Yield Production; RC: Raw Material Costs; MC: Manufacturing Capacity; D: Distribution

Figure 1: Temporal Causal Graph: Supply Chain for Agricultural Commodity

Graphical Representation of Ripple Effects

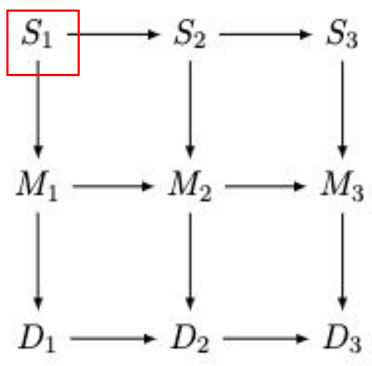


Figure 2: Ripple Effect in South Korean Company

where, at time i,
S_i :Supplier
M_i:Manufacturer
D_i:Distributor

From figure(2), disruption (intervention) occurred at S_1, which affects distributor D_3, so the ripple effect of supplier S_1 on distributor D_3 is $P(D_3 \mid do(S_1 = s))$ [1]

Bullwhip Effect

Bullwhip effect describes how a small fluctuation in consumer demand at initial level cause progressively larger swings in demand at upstream stages, leading to excessive inventories.

Example

During the COVID-19 pandemic, due to consumers fearing shortages of toilet paper, they began panic buying, leading to a spike in demand. In response, distributors urgently increased their orders to satisfy this sudden surge. This spike in distributor orders prompted manufacturers to ramp up production significantly.

So, the market experienced bullwhip effect, where temporary consumer behavior led to excessive goods accumulation throughout the supply chain once the initial panic subsided. [5]

Graphical Representation of Bullwhip Effects

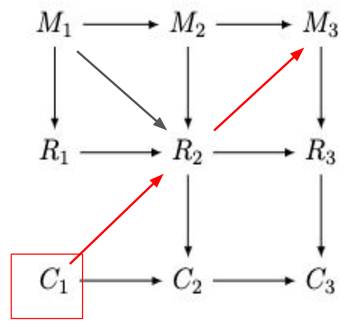


Figure 3: Bullwhip Effect due to intervention in C_1

where,
M_i : Manufacturer at time i; R_i : Retailer at time i; C_i : Customer at time i
Here, the bullwhip effect of customer demand C_1 on manufacturer M_3 is
$P(M3 \mid do(C_1 = c_1))$

Future Directions:

Further, we aim to use these ideas to build methods and strategies for supply chain resilience - the ability of a system to revert back to the desirable state after any kind of disruption.

References:

1. Pearl, J. 2020, On the Interpretation of do(x), *Journal of Causal Inference*
2. Pearl, J. 2000. Causality: Models, Reasoning, and Inference. *Cambridge University Press.*
3. Ivanov, D. , Dolgui, A., Sokolov, B. Handbook of Ripple Effects in the Supply Chain, *International Series in Operational Research & Management Science*