Innovation in Supply Chain Planning: Resilience Quantification

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The aim of this work is to create an approach for supply chain planning that integrates resilience into the better-cheaper-faster supplier evaluation, using a sophisticated yet practical approach.

Motivation

The increasing frequency and severity of global supply chain disruptions require companies to proactively manage risks because the financial consequences are escalating. Additionally, ripple effects cause the impacts of disruptions to cascade upstream and downstream, resulting in operational delays, cost increases, and service level reductions. Several recent examples are shown below:

Rail Worker Strikes in Germany – 2024

Flooding in Dubai and Oman – 2024

Red Sea Piracy by Houthi Rebels – 2024

Political Instability in Venezuela – 2024

Examples of Current Approaches

Methods in Practice

- Score suppliers using an ordinal scale across various performance criteria
- Rely on ISO 9000 or other industry certifications
- Evaluate suppliers based on their past performance
- Conduct audits, risk assessments, and impact analyses

Analytical Methods

- Rank suppliers based on closeness coefficients while handling uncertainty and imprecision using fuzzy logic[1]
- Measure and rank suppliers' resilience with a Bayesian network approach, considering ripple effects[2]
- Quantify the maximum possible loss associated with suppliers' vulnerability to disruptions and ripple effects[3]

Methodology

Expected Value Analyses evaluate the financial impact of each supplier, considering procurement cost, non-conformance rate, late delivery prediction, and disruption probability.

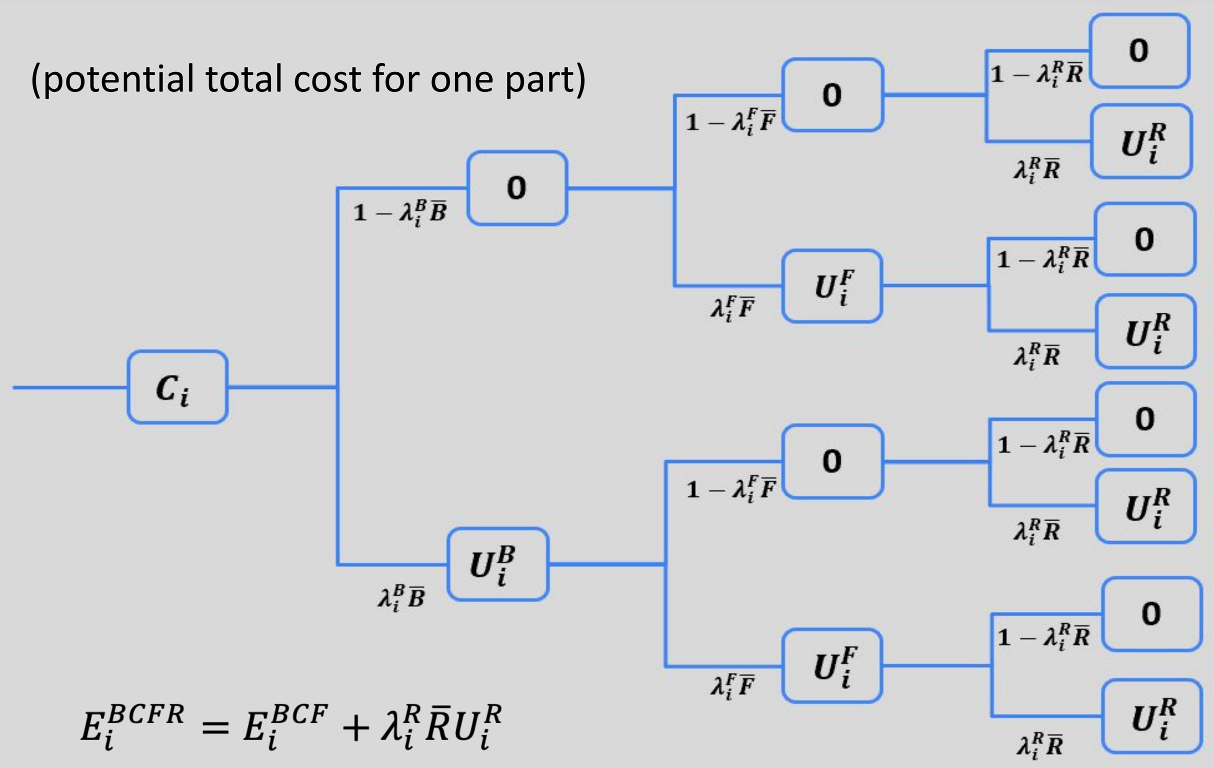
Indifference Probabilities ensure that each criterion is assessed on the same economic scale including direct and ripple effects.

Pairwise Comparisons rank suppliers by comparing them two-at-a-time across each criterion: cost, quality, delivery performance, and resilience.

Supplier i Decision Tree Model

Notation:
C_i = Procurement Cost for Supplier i
$\bar{B}$ = Suppliers' Mean Non-Conformance %
$\bar{F}$ = Suppliers' Mean Late Delivery %
$\bar{R}$ = Suppliers' Mean Disruption %
$\lambda_i^B \bar{B}$ = Non-Conformance % for Supplier i
$\lambda_i^F \bar{F}$ = Late Delivery % for Supplier i
$\lambda_i^R \bar{R}$ = Disruption % for Supplier i
U_i^B = Non-Conformance Cost for Supplier i
U_i^F = Late Delivery Part Cost for Supplier i
U_i^R = Disruption Part Cost for Supplier i

(potential total cost for one part)

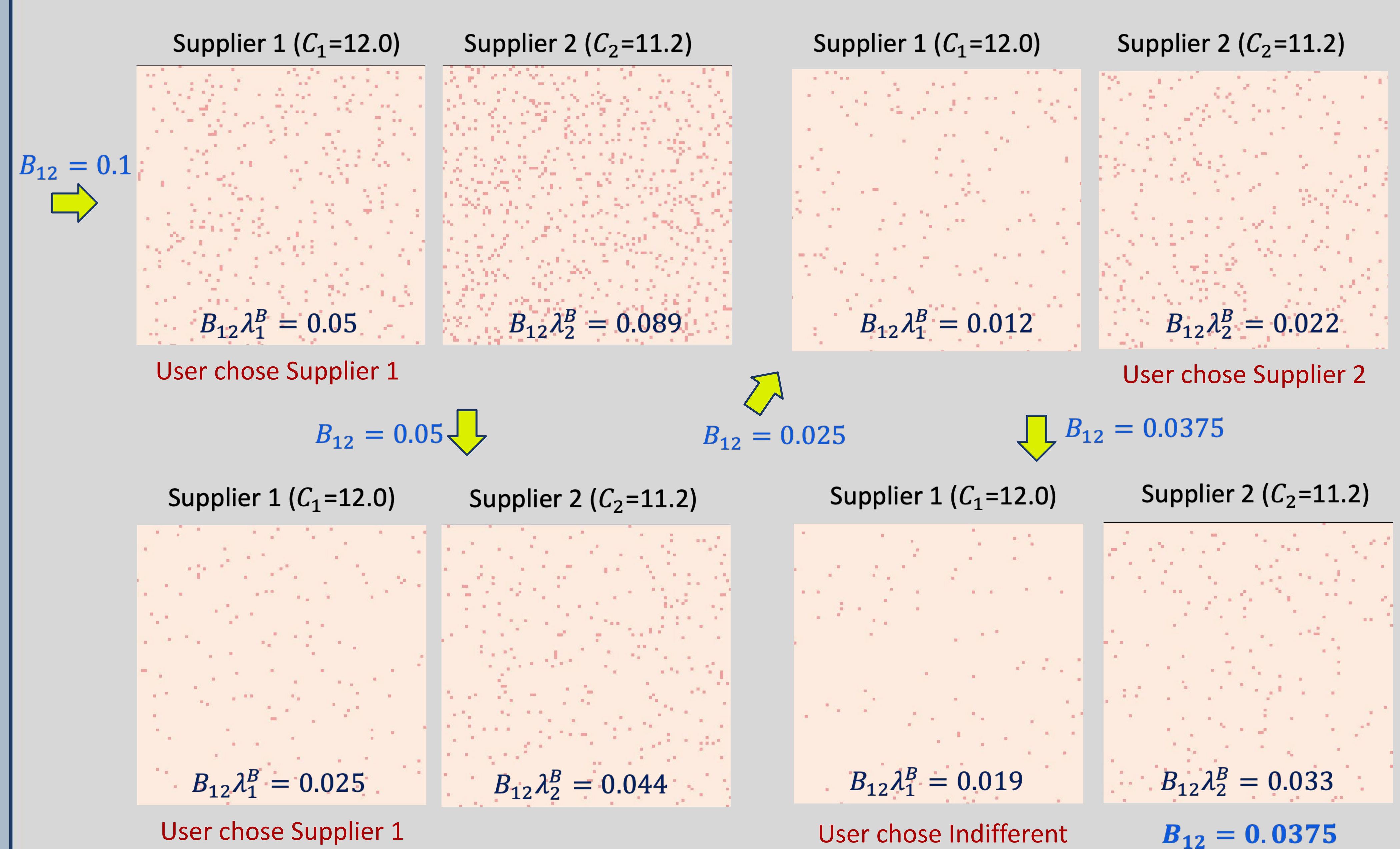


$E_i^{BC} = C_i + \lambda_i^B \bar{B} U_i^B$ $\quad E_i^{BCF} = E_i^{BC} + \lambda_i^F \bar{F} U_i^F$ $\quad E_i^{BCFR} = E_i^{BCF} + \lambda_i^R \bar{R} U_i^R$

Indifference Analysis – BC (Example)

The impacts represented by U_i^B, U_i^F, and U_i^R are known to the decision maker but not in financial terms because of their ripple effects. Indifference probabilities are used to estimate the differences in these values for each pair of suppliers using a binary search. Color-coded matrices are employed where the darker color indicates an undesirable event.

$E_j^{BC} - E_i^{BC} = 0 = (C_j - C_i) + B_{ij}(\lambda_j^B U_j^B - \lambda_i^B U_i^B)$ $\quad B_{ij}$ is the BC indifference probability, supplier i vs j



Indifference Analysis – BCF

$E_j^{BCF} - E_i^{BCF} = 0 = (E_j^{BC} - E_i^{BC}) + F_{ij}(\lambda_j^F U_j^F - \lambda_i^F U_i^F)$ $\quad F_{ij}$ is the BCF indifference probability, supplier i vs j

Indifference Analysis – BCFR

$E_j^{BCFR} - E_i^{BCFR} = 0 = (E_j^{BCF} - E_i^{BCF}) + R_{ij}(\lambda_j^R U_j^R - \lambda_i^R U_i^R)$ $\quad R_{ij}$ is the BCFR indifference probability, supplier i vs j

Four Stage Procedure

1. **BC Analysis**: Perform expected value analysis on procurement cost & non-conformance % by determining indifference probabilities for B (better) and C (cheaper).
2. **BCF Analysis**: Incorporate late delivery % into the expected value analysis by determining indifference probabilities for BC and F (faster).
3. **BCFR Analysis**: Incorporate disruption % into the expected value analysis by determining indifference probabilities for BCF and R (resilience).
4. **AHP Ranking**: Use the Analytical Hierarchy Process to convert the pairwise comparisons to supplier rankings.

Example

Four suppliers are evaluated. The table below shows their locations and procurement cost (annual total cost in $millions). An evaluation predicts the following non-conformance probabilities, late delivery frequencies, and disruption likelihoods over a one-year period.

	Location				
1	Venezuela	12.0	0.042	0.072	0.093
2	Germany	11.2	0.075	0.038	0.076
3	Dubai	11.7	0.093	0.059	0.035
4	Vietnam	9.8	0.128	0.083	0.110

$\bar{C} = 11.175$
$\bar{B} = 0.0845$
$\bar{F} = 0.0630$
$\bar{R} = 0.0785$

Each supplier has its advantage: Supplier 1 has the best quality, Supplier 2 has the fastest delivery, Supplier 3 has strongest resilience, and Supplier 4 has the lowest price.

The following table compares suppliers to one another, resulting in the expected values and indifference probabilities for each of the four analysis stages.

1,2	-$0.80	$1.44	-$0.21	-$0.30	$0.13
1,3	-$0.30	$0.27	-$0.07	-$0.34	-$0.44
1,4	-$2.20	$1.98	$0.37	$0.69	$0.84
2,3	$0.50	$0.21	$0.10	-$0.63	$0.19
2,4	-$1.40	$0.56	$0.63	$0.44	$0.23
3,4	-$1.90	$1.28	$0.96	$0.80	$1.14

The BCFR expected value differences are converted to AHP scale (matrix **A**) as follows:

	1	2	3	4
1	1	1.93	0.25	6.93
2	0.52	1	2.30	2.60
3	4.08	0.43	1	9.00
4	0.14	0.38	0.11	1

Where a_{ij} is the preference of supplier i over supplier j (9 indicates strongest preference, and $a_{ji} = 1/a_{ij}$).

The ranking for each supplier ($r_i, i = 1,2,3,4$) is calculated using the AHP methodology, resulting in these supplier rankings: $r_1 = 0.278$, $r_2 = 0.280$, $r_3 = 0.390$ and $r_4 = 0.052$.

Supplier 3 is the preferred supplier. This supplier is best in resiliency, which was given highest priority by the decision maker when they chose their indifference probabilities.

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1. Hasan et al (2020). Resilient supplier selection in Logistics 4.0 with heterogeneous information. *Expert Systems with Applications*, *139*, 112799.
2. Hosseini & Ivanov (2019). A new resilience measure for supply networks with the ripple effect considerations. *Annals of Operations Research*, *319*(1), 581–607.
3. Kinra et al (2019). Ripple effect quantification by supplier risk exposure assessment. *International Journal of Production Research*, *58*(18), 5559–5578.

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