Sustainable Supply Chain Optimisation

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IIT Indore

PROPOSAL

OVERVIEW

Supply Chain Management (**SCM**) is the management of the flow of goods and services, including all processes that transform raw materials into final products between businesses and locations. However, to effectively manage a supply chain, it must be sustainable not only in terms of cost but also in terms of environmental and social impacts. Thus, the sustainability of a supply chain is calculated using three indicators, i.e. the **total cost, GHG emissions** and **lead time**. Therefore, it turns out to be a multi-objective problem with equality as well as inequality constraints.

PROBLEM STATEMENT

A supply chain network consists of raw material suppliers, production plants and customers. The production plants purchase raw materials from suppliers and deliver the finished product to the customers. Each production plant can have a different number of stages and units. Thus, for the given data consisting of raw material suppliers, production plants, customer locations, transportation routes, customer demands, production and transportation capacities, processing times, transportation distances and times, fixed and variable costs and environmental impact factors, the goal is to optimize the sustainability of the supply chain network for a single period, while satisfying all customer demands.

MATHEMATICAL FORMULATION

$$SUP_{i,m,p} + \sum_{q \in P_m} \overline{PRO}_{i,m,q,p} + PTP^{in}_{i,m,p} = \sum_{k \in K_{m,p}} FED_{i,m,p,k} \quad \forall m, p \in P_m,\ i \in I^{FED}_{m,p} \tag{1a}$$

$$FED_{i,m,p,k} = \sum_{j \in I^{PRO}_{m,p}} CF_{i,j,m,p,k} PRO_{j,m,p,k} \quad \forall m,\ p \in P_m,\ k \in K_{m,p},\ i \in I^{FED}_{m,p} \tag{1b}$$

$$\sum_{k \in K_{m,p}} PRO_{i,m,p,k} = \sum_{q \in P_m} \overline{PRO}_{i,m,p,q} + PTP^{out}_{i,m,p} + SAL_{i,m,p} \quad \forall m,\ p \in P_m,\ i \in I^{PRO}_{m,p} \tag{1c}$$

The inflow of a unit in a stage in a production process should be equal to its outflow, and this property gives us the following equality constraints.

$$\sum_s \overline{SUP}_{i,s,m} = \sum_{p \in P_m} SUP_{i,m,p} \qquad \forall m, i \tag{2a}$$

$$\overline{SUP}_{i,s,m} = 0 \qquad \forall s, m, i \notin I^{SUP}_{s,m} \tag{2b}$$

$$\sum_n \overline{PTP}_{i,n,m} = \sum_{p \in P_m} PTP^{in}_{i,m,p} \qquad \forall m, i \tag{3a}$$

$$\overline{PTP}_{i,m,n} = 0 \qquad \forall m, n, i \notin I^{PTP}_{m,n} \tag{3b}$$

$$\sum_{p \in P_m} PTP^{out}_{i,m,p} = \sum_n \overline{PTP}_{i,m,n} \qquad \forall m, i \tag{3c}$$

$$\sum_{p \in P_m} SAL_{i,m,p} = \sum_c \overline{SAL}_{i,m,c} \qquad \forall m, i \tag{4a}$$

$$\overline{SAL}_{i,m,c} = 0 \qquad \forall m, c, i \notin I^{SAL}_{m,c} \tag{4b}$$

$$\sum_m \overline{SAL}_{i,m,c} = D_{i,c} \qquad \forall i, c \tag{4c}$$

Capacity constraints on the production and transportation operations give us the following inequality constraints.

$$CLO_{i,m,p,k}\,Y_{i,m,p,k} \leqslant PRO_{i,m,p,k} \leqslant CUP_{i,m,p,k}\,Y_{i,m,p,k} \quad \forall m, p \in P_m, k \in K_{m,p}, i \in I^{PRO}_{m,p} \tag{5a}$$

$$\sum_{p\in P_m}\sum_{k\in K_{m,p}}\sum_{i\in I^{PRO}_{m,p}} PRO_{i,m,p,k} \leqslant \overline{CUP}_m \qquad \forall m \tag{5b}$$

$$\sum_{i\in I^{PRO}_{m,p}} \frac{PRO_{i,m,p,k}}{R_{i,m,p,k}} \leqslant CUP^{T}_{m,p,k} \qquad \forall m, p \in P_m, k \in K_{m,p} \tag{5c}$$

Finally, the objective functions take into account the whole life cycle of the production process, and the three parameters, i.e. **total cost, GHG emissions** and **lead time,** are formulated as follows:

$$\begin{aligned} TCO = & \sum_{s}\sum_{m}\sum_{i\in I^{SUP}_{s,m}} UCO^{SUP}_{i,s}\,\overline{SUP}_{i,s,m} \\ & + \sum_{m}\sum_{p\in P_m}\sum_{k\in K_{m,p}}\sum_{i\in I^{PRO}_{m,p}} \Big(FCO^{PRO}_{i,m,p,k}\,Y_{i,m,p,k} + UCO^{PRO}_{i,m,p,k}\,PRO_{i,m,p,k} \\ & + FCO^{WT}_{i,m,p,k}\,Y_{i,m,p,k} + UCO^{WT}_{i,m,p,k}\,PRO_{i,m,p,k} \Big) \\ & + \sum_{m}\sum_{p\in P_m}\sum_{k\in K_{m,p}}\sum_{i\in I^{SU}_{m,p,k}} FCO^{SU}_{i,m,p,k}\,Y_{i,m,p,k} \\ & + \sum_{s}\sum_{m}\sum_{i\in I^{SUP}_{s,m}} UCO^{TRSUP}_{i,s,m}\,\overline{SUP}_{i,s,m} \\ & + \sum_{m}\sum_{n}\sum_{i\in I^{PTP}_{m,n}} UCO^{TRPTP}_{i,m,n}\,\overline{PTP}_{i,m,n} \\ & + \sum_{m}\sum_{c}\sum_{i\in I^{SAL}_{m,c}} UCO^{TRSAL}_{i,m,c}\,\overline{SAL}_{i,m,c} \end{aligned} \tag{7}$$

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\begin{aligned}
TGHG = & \sum_{s}\sum_{m}\sum_{i\in I_{s,m}^{SUP}} EF_{i,s}^{SUP}\,\overline{SUP}_{i,s,m} + \sum_{m}\sum_{p\in P_m}\sum_{k\in K_{m,p}}\sum_{i\in I_{m,p}^{PRO}} \Big(EF_{i,m,p,k}^{PRO} \\
& + EF_{i,m,p,k}^{WT} + EF_{m}^{EC}\,UEC_{i,m,p,k}\Big)\,PRO_{i,m,p,k} \\
& + \sum_{s}\sum_{m} DIS_{s,m}^{SUP} \sum_{i\in I_{s,m}^{SUP}} EF_{i,s,m}^{TRSUP}\,\overline{SUP}_{i,s,m} \\
& + \sum_{m}\sum_{n} DIS_{m,n}^{PTP} \sum_{i\in I_{m,n}^{PTP}} EF_{i,m,n}^{TRPTP}\,\overline{PTP}_{i,m,n} \\
& + \sum_{m}\sum_{c} DIS_{m,c}^{SAL} \sum_{i\in I_{m,c}^{SAL}} EF_{i,m,c}^{TRSAL}\,\overline{SAL}_{i,m,c}
\end{aligned} \tag{8}
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\begin{aligned}
TLT = & \sum_{m}\sum_{p\in P_m}\sum_{k\in K_{m,p}}\sum_{i\in I_{m,p}^{PRO}} \frac{PRO_{i,m,p,k}}{R_{i,m,p,k}} + \sum_{s}\sum_{m}\sum_{i\in I_{s,m}^{SUP}} TT_{i,s,m}^{SUP}\,Y_{i,s,m}^{SUP} \\
& + \sum_{m}\sum_{n}\sum_{i\in I_{m,n}^{PTP}} TT_{i,m,n}^{PTP}\,Y_{i,m,n}^{PTP} + \sum_{m}\sum_{c}\sum_{i\in I_{m,c}^{SAL}} TT_{i,m,c}^{SAL}\,Y_{i,m,c}^{SAL}
\end{aligned} \tag{9}
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GOALS

1. To gather data for a supply chain network to optimize its sustainability or to create a dummy dataset.
2. To understand the supply chain network and quantify the environmental performance of a process using GHG emissions and formulate the problem along with its constraints.
3. To find a Pareto-optimal frontier for the given problem using different techniques available.

FURTHER SCOPE

The problem can be extended to solve the expansion of supply chain networks, i.e. either through setting up additional production plants or by increasing the capacity of existing plants.

To increase the capacities of existing production plants, we will have to change the constraints by the following constraints and consider the additional costs for the same.

$$CLO_{i,m,p,k}\,Y_{i,m,p,k} \leqslant PRO_{i,m,p,k} \leqslant CUP_{i,m,p,k}\,Y_{i,m,p,k} + CI_{i,m,p,k} \quad \forall m, p \in P_m, k \in K_{m,p}, i \in I_{m,p}^{PRO} \tag{16a}$$

$$\sum_{p \in P_m} \sum_{k \in K_{m,p}} \sum_{i \in I_{m,p}^{PRO}} PRO_{i,m,p,k} \leqslant \overline{CUP}_m + \overline{CI}_m \quad \forall m \tag{16b}$$

$$\sum_{i \in I_{m,p}^{PRO}} \frac{PRO_{i,m,p,k}}{R_{i,m,p,k}} \leqslant CUP_{m,p,k}^{T} + CI_{m,p,k}^{T} \quad \forall m, p \in P_m, k \in K_{m,p} \tag{16c}$$

$$CI_{i,m,p,k} \leqslant CIUP_{i,m,p,k}\,Y_{i,m,p,k}^{CI} \quad \forall m, p \in P_m, k \in K_{m,p}, i \in I_{m,p}^{PRO} \tag{16d}$$

$$\overline{CI}_m \leqslant \overline{CIUP}_m\,\overline{Y}_m^{CI} \quad \forall m \tag{16e}$$

$$CI_{m,p,k}^{T} \leqslant CIUP_{m,p,k}^{T}\,Y_{m,p,k}^{CIT} \quad \forall m, p \in P_m, k \in K_{m,p} \tag{16f}$$

$$\begin{aligned} &\sum_m \sum_{p \in P_m} \sum_{k \in K_{m,p}} \sum_{i \in I_{m,p}^{PRO}} \left(FCO_{i,m,p,k}^{CI}\,Y_{i,m,p,k}^{CI} + UCO_{i,m,p,k}^{CI}\,CI_{i,m,p,k} \right) \\ &+ \sum_m \left(\overline{FCO}_m^{CI}\,\overline{Y}_m^{CI} + \overline{UCO}_m^{CI}\,\overline{CI}_m \right) \\ &+ \sum_m \sum_{p \in P_m} \sum_{k \in K_{m,p}} \left(FCO_{m,p,k}^{CIT}\,Y_{m,mp,k}^{CIT} + UCO_{m,p,k}^{CIT}\,CI_{m,p,k}^{T} \right) \end{aligned} \tag{17}$$

Otherwise, to add an additional production plant, we will have to incorporate its costs and GHG emissions into account and introduce a binary variable Y_m in the set of plants. Y_m is 1 if the plant is built and 0 otherwise.

$$Y_{i,m,p,k} \leqslant \overline{Y}_m \quad \forall m \in M^{new}, p \in P_m, k \in K_{m,p}, i \in I^{PRO}_{m,p} \tag{18}$$

$$\sum_{m \in M^{new}} FCO^{INV}_m \overline{Y}_m \tag{19}$$

$$\sum_{m \in M^{new}} GHG^{CON}_m \overline{Y}_m \tag{20}$$

This paper employs the ε-constraints method to solve the multi-objective optimization problem. Other multi-objective optimization techniques, such as Multi-Objective Simplex or Weighted Sum, can be used to compare and achieve a better solution.

REFERENCES

1. Supply chain management. (2022, October 28). In *Wikipedia*. https://en.wikipedia.org/wiki/Supply_chain_management
2. Zhang, Q., Shah, N., Wassick, J., Helling, R., & van Egerschot, P. (2014). Sustainable supply chain optimisation: An industrial case study. *Computers & Industrial Engineering*, *74*, 68-83. https://doi.org/10.1016/j.cie.2014.05.002

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