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Supply Chain Configuration Model for New Product Development: A Multi-objective Approach

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Abstract

Supply chain configuration involves selection of suppliers, parts, processes and transportation modes at each stage of the supply chain out of several alternatives that vary in cost, lead-time and other measures. Traditionally, the supply chain configuration decision has been done based on costs (inventory, procurement, transportation costs, etc) and other quantitative measures. However, experience has shown that other subjective criteria such as alignment of business practices of partners in the supply chain network also influence the configuration and stability/reliability of the supply chain. This paper presents a multi-objective goal programming approach to supply chain configuration during new product development. In addition to using various production and inventory costs, the model also includes compatibility of firms in configuring the supply chain. The methodology is demonstrated through an illustrative example.

Keywords: Goal programming, supply chain configuration, new product development

1. Introduction

Supply chain configuration involves selection of suppliers, parts, processes and transportation modes at each stage of the supply chain. The selection decisions are made out of several alternatives that vary in cost, lead-time and other measures. Traditionally, the scope of the supply chain configuration problem has been limited to inventory placement decisions at various nodes of a supply network (Ettl et al. 2000). It has been assumed that at each stage planners would already have an option before making inventory placement decisions. However, this severely limits the opportunity to optimize the overall cost of the supply chain (SC) because the option selected at a particular node may not be the best given a firm's business practices. Therefore, the current approach is to simultaneously consider the supplier (or process) selection decision and the inventory (safety stock) placement decision (Graves and Willems 2005, 2008).

Inventory placement decisions are just one part of the global supply chain management equation. In addition to these hard numerical metrics, there are other factors (such as alignment of business culture and management practice of parties in the supply chain network) that equally influence the sustainability of the supply chain but are difficult to quantify.

Therefore in order to meet the challenges of globalized marketplace, manufacturers are currently pursuing strategic partnership with few key suppliers for long term growth. As companies are under tremendous pressure to reduce the product development time and cost and improve the quality and functionality, their supplier selection criteria have changed significantly in recent years. Instead of selecting the lowest cost bidder as that used to be the standard industry practice in the past, companies are now considering total cost of ownership as a new paradigm for supplier selection methodologies (Monczka et al. 2008). Furthermore, as firms have increased their level of outsourcing, they are becoming more dependent on their suppliers. However, the challenge facing most firms is how to build the right alliance in order to improve their overall performance, innovation, competitiveness, and long-term growth. As reported in Trkman and McCormack (2009), Chrysler had to shut down four plants in 2008 because of cash-flow problems of its supplier Plastech.

While the benefits of configuring the supply chain at an early stage of product development (PD) have been well documented in both the PD and supply chain literature (Fine et al. 2005, Zhang et al. 2009), the existing supply chain configuration models are centered around inventory/safety stock placement decisions and focus only on minimization of total supply chain costs (Graves and Willems 2000, 2003, 2005, 2008, Bossert and Willems 2007, Li and Womer 2008). Prior models do not consider soft or intangible variables like the alignment of business practices among supply chain partners. Arguably, such supply chain configurations may not be stable and thus may witness early failures, like the ones at Chrysler in 2008 (Trkman and McCormack 2009).

The objective of this paper is to develop a multi-objective optimization model for supply chain configuration during product development. Unlike the existing literature, the paper includes both hard (supply chain costs) and soft (compatibility of firms) variables in the optimization model. Since the soft variables that determine alignment between supply chain partners are subjective in nature, we use fuzzy logic to quantify those variables. A case study is presented from the existing literature (Graves and Willems 2003) to show the advantages of the proposed multi-objective approach over the single objective approach used in the benchmarked case study.

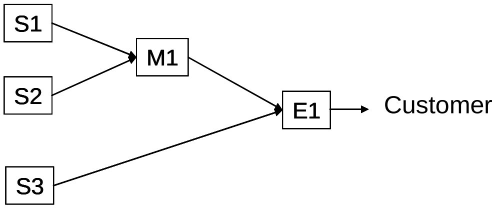
In section 2, we present our multi-objective optimization model for supply chain configuration along with the genetic algorithm for solving the model. Section 3 presents a case study to demonstrate the application of the proposed model. Finally, section 4 provides concluding remarks with some thoughts for further work.

2. Proposed Multi-objective Supply Chain Configuration Model

The supply chain configuration model presented in this paper consists of two objectives: maximization of the total compatibility index in strategic alliance and minimization of the total supply chain costs. We use goal programming model to formulate the given supply chain configuration problem. Following section describes the calculation of total supply chain costs, compatibility index of the partners, and the formulation of the goal programming model.

2.1 Calculation of total supply chain costs (TSCC)

Similar to the approach taken by Huang et al. (2005), a supply chain is modeled as a network where nodes denote members of the supply chain and arcs denote the relationships between the nodes (Figure 1). Generally speaking, there are three types of nodes in a supply chain network: procurement nodes (set P, where raw materials are purchased from outside suppliers), assembly/manufacturing nodes (set R, where raw materials are transformed into subassemblies and end products) and end nodes (set E, where sub-components are finally assembled into the end products and transferred to outside customers). The procurement nodes are those that do not have any incoming arcs (i.e., they represent the purchase of components outside the supply chain). The assembly/manufacturing nodes represent nodes where one or more components are combined together. For arc (i, j), δ_{ij} is used to indicate how many units of upstream component i are required per downstream unit j.



S1, S2, S3 = Procurement nodes; M1 = Intermediate node; E1 = End node

Figure 1. Typical supply chain network

We assume that each node provides 100 percent service time (guaranteed output service time), S_i^{out} to its customer(s) and therefore do not explicitly model a tradeoff between possible shortage costs and inventory costs. This means that a customer order at time t must be filled by time $(t + S_i^{out})$. This assumption is consistent with what is available in today's competitive environment, as most managers desire a 100 percent service level from their suppliers while also striving to provide a 100 percent service level to their own customers.

Furthermore, we also assume that the inventory system for each node of the supply chain network follows a periodically reviewed base-stock policy. At the beginning of each common review period λ, each node reviews its local inventory levels and places orders to their suppliers to bring the inventory position up to a fixed base-stock level.

At each node, there are several alternative suppliers to choose from. Each alternative supplier option O_i at a node has deterministic production lead-time T_{iO_i} and production cost C_{iO_i}. The production lead time is the time it takes a customer to receive the supply for an item from its supplier after placing an order. This includes the processing time at the node plus any transportation time for shipping the item. The production cost of a supplier includes the labor, material, and transportation costs to supply the component.

Apart from performing their respective operations, each stage also serves as a potential inventory location point in the supply chain network. The optimal inventory level for each inventory location is also a decision variable in the model. Therefore, the objective of the model is to select supplier options and their corresponding guaranteed service time at each stage in order to minimize the total supply chain cost, consisting of inventory and production costs.

For this model, it is assumed that external customer demands occur only at the end stage and follow normal distribution, $Z_j \sim N(\mu_j, \sigma_j)$. Since each stage operates a base-stock policy and there is no time delay in ordering so that in each period all stages see the external customers demands, then demands at the upstream stages, also called dependent demands, are derived from the requirements of the bill of material. With δ_{ij} representing the number of component *i* needed at node *j* in order to produce one unit of component *j*, then for the upstream stage *i* the demand is normally distributed with:

$$\mu_i = \sum \delta_{ij} \mu_j \tag{1}$$

$$\sigma_i^2 = \sum \delta_{ij} \sigma_j^2 \tag{2}$$

Just as in Graves and Willems (2003), it is assumed that each stage *i* guarantees an output service time S_i^{out} by which it will satisfy demand from its downstream stages. However, for the end stage, the output service time can be given by the customer or determined by the optimization model. Conversely, each stage *j* is guaranteed an input service time S_j^{in} by its immediate predecessors. This is the time it takes to get supplies from its immediate suppliers after orders have been placed. In practice, stage *j* cannot start production until all inputs are received. Then, the input service time for stage *j* is given as the maximum of the output service time of all its immediate predecessors:

$$S_j^{in} = \max\left\{S_i^{out}\right\} \text{ for all inputs nodes} \tag{3}$$

At each stage, several alternative suppliers are available for selection. Let c_i and T_i denote the production cost and production time at stage *i,* respectively. Then, once a supplier option O_i is selected for stage *i*, its production cost c_i will be set to C_{iO_i} and production time T_i, will be set to T_{iO_i} respectively.

Next, inventory coverage period is calculated from the replenishment lead-time L_i, review period λ_i and the guaranteed output service time S_i^{out} of the stage. The replenishment lead time includes the waiting time for inputs and the processing time at that stage. Therefore, the L_i is given as:

$$L_i = S_i^{in} + T_i \quad (4)$$

By using the above mentioned relations (Van Ryzin, 2001) and assumptions, we calculate the total costs of inventory as follows:

First, the cost of average on-hand inventory(AOH) at each node *i* is given as:

$$\text{(Cost of AOH}_\text{i}\text{)} = C_i \times AOH_i \quad (5)$$

Second, the cost of the working inventory (WIP) at each node *i* is given as:

$$\text{(Cost of WIP}_\text{i}\text{)} = W_i \times WIP_i \quad (6)$$

And finally, Then the total cost of inventory at each node i is given as:

$$\text{(Total inventory cost)}_\text{i} = h_i \{(C_i \times AOH_i) + (W_i \times WIP_i)\} \quad (7)$$

Where h_i denotes the per-unit holding cost for inventory at stage *i*. Similarly, let H denote the time interval of interest to the decision maker, then the production/procurement cost (i.e., COGS) at each node is given as:

$$\text{(Production/procurement cost)}_\text{i} = (H \times c_i \times \mu_i)$$

Therefore, the total cost at each node is given as:

$$\text{(Total cost)}_\text{i} = h_i \{(C_i \times AOH_i) + (W_i \times WIP_i)\} + (H \times c_i \times \mu_i) \quad (8)$$

For the entire supply chain network, the total supply chain cost is given as the sum of the total cost at each node. That is:

$$\text{Total supply chain cost} = \sum_{i \in N} [h_i \{(C_i \times AOH_i) + (W_i \times WIP_i)\} + (H \times c_i \times \mu_i)] \quad (9)$$

2.2 Calculation of supply chain compatibility index (SCCI)

Every supply chain network consists of different players, with each player acting for its own self-interest. Therefore the selection of compatible players in the supply chain network becomes important in order to increase the stability of the supply chain. In this research, we consider three key qualitative factors in determining the compatibility index of SC partners at the early stages of product development. The factors are *structural* (cultural alignment, communication and information sharing, and coordination and cooperation); *managerial* (managerial trust and commitment, compatibility in strategic goals, conflict management techniques); and *financial* (profit margin, return on investment, bond rating). These measurements are subjective in nature because it is difficult to quantify those variables during the early stage of product development. Therefore, we use fuzzy logic to compute the compatibility index for each node. For a detailed fuzzy logic framework for calculation of compatibility index, readers are encouraged to see Famuyiwa et al. (2008). Thus, each supplier alternative O_i at a node i will have a compatibility index factor β_{iO_i} . Where, β_i represents the compatibility index of each node, *i*, of the supply chain. Thus and the total compatibility index of the supply chain is given as

$$\text{Total SCCI} = \left\{ \sum_{i \in N} \beta_i \right\} \tag{10}$$

2.3 Formulation of Goal Programming (GP) model

In this section, we present the weighted goal programming model for supply chain configuration. Let λ_{TSCC} denote target value for total supply chain cost, λ_{CI} denote the target value for total compatibility index, w_{TSCC} and Δ_{TSCC} denote the weight and deviation of the total supply chain cost from its target value, and w_{CI} and Δ_{CI} denote the weight and deviation compatibility index from its target value. Then the weighted goal programming formulation of the multi-objective problem is given as:

Minimize $\{\, w_{TSCC}\left(\dfrac{\Delta_{TSCC}}{\lambda_{TSCC}}\right)+w_{CI}\left(\dfrac{\Delta_{CI}}{\lambda_{CI}}\right)\}$

Subject to:

i. $\left\{\sum_{i\in N}\left[h_i\left((C_i\times AOH_i)+(W_i\times WIP_i)\right]+(H\times c_i\times \mu_i)\right)\right\}$ - $\Delta_{TSCC}\leq \lambda_{TSCC}$ (TSCC Goal)

ii. $\left\{\sum_{i,j\in A}\beta_{ij}\right\}$ + Δ_{CI} $\geq \lambda_{CI}$ (Total SCCI Goal)

iii. $\left\{\sum_{O_i\in S(i)}T_{iO_i}y_{iO_i}\right\}-T_i=0$, i $\in N$

iv. $\left\{\sum_{O_i\in S(i)}C_{iO_i}y_{iO_i}\right\}-c_i=0$, i $\in N$

v. $S_i^{in}+T_i-S_i^{out}\geq 0$, i $\in N$

vi. $\left\{\sum_{i\in N}y_{iO_i}\beta_{iO_j}\right\}-\beta_i=0$, i $\in$ N

vii. $\sum_{O_i\in S(i)}y_{iO_i}=1$, i $\in$ N

viii. $S_i^{out}, O_i, \beta_{ij}\geq 0$ i $\in$ N

ix. y_{iO_i} is binary for i $\in$ N and O_i

where Δ_{TSCC}, Δ_{CI}, S_i^{out} and y_{iO_i} are decision variables. Constraints (*i*) and (*ii*), referred to as soft constraints, ensure that the deviations of both total supply chain cost and compatibility are not greater than their target values. Constraints (iii) and (iv) apply to production time and production cost corresponding to the option selected at each node. Once a supplier option is selected, the production lead time and production cost of the node are set to the corresponding production lead time and production cost of the option selected. Constraint (v) ensures that the inventory coverage time is non-negative since back ordering is not allowed. Constraint (vi) ensures that once a supplier option is selected, the compatibility index of the node is set to the corresponding value of the compatibility index of the supplier selected. Constraint (vii) ensures that only one supplier is selected at each node (single sourcing). Lastly, constraints (viii and ix) represent non-negativity and binary constraints.

3. Configuration of a Bulldozer Supply Chain - An Example

Here we demonstrate the multi-objective supply chain configuration model by applying it to a bulldozer supply chain as given in Graves and Willems (2003) (referred to as GW). The GW case study is used as a benchmark to show the improvements in results due to the proposed multi-objective optimization model. The bulldozer supply chain is an example of a heavy industry supply chain. The components of a bulldozer can be broadly combined into 14 major groups: (1) frame assembly, (2) case, (3) brake, (4) drive, (5) plant carrier, (6) platform, (7) fender, (8) roll-over, (9) transmission, (10) engine, (11) fan, (12) bogie assembly, (13) pin assembly, and (14) track-roller frame.

Since our objective is to compare the performance of the multi-objective optimization model with that of GW's single objective approach, the supply chain setting in this paper is the same as that in GW. In other words, for the supply chain configuration, the average daily demand is set at 5 and the daily standard deviation is 3. Furthermore, the demand bound is equal to the 95th percentile of demand, so that the safety factor is equal to 1.645. The following assumptions are made for the purpose of analysis: the bulldozer manufacturing company uses annual demand for configuring the supply chain, there are 260 days per year, and the company applies an annual holding cost rate of 30 percent when calculating the inventory costs. Figure 2 shows the supply chain network diagram for the bulldozer case study.

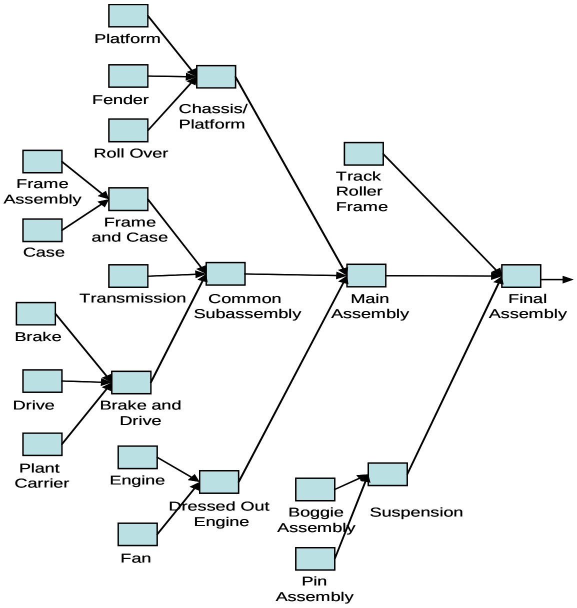


Figure 2. Supply chain network of a bulldozer (adopted from Graves and Willems 2003)

Having figured out the bill of materials and corresponding SC network nodes and arcs, the next step is to identify alternatives at each node of the supply chain and collect information on their costs, lead times, and corresponding compatibility indexes. There are two types of nodes in the given bulldozer supply chain: procurement and assembly nodes. The procurement nodes represent the procurement of components from outside the supply chain, while the assembly nodes represent where one or more components are combined together in the process. Table 1 shows the production costs and lead time data for the bulldozer supply chain. It may be noted that each node present in the supply chain has two potential supply alternatives. If the node is a procurement stage, the first alternative represents the standard supply option (that is, the existing procurement arrangement). However, the second option represents a consignment option where the supplier is responsible for providing immediate delivery to the bulldozer line.

Table 1. Lead-times and costs for bulldozer assembly (source: Graves & Willems 2003)

	Alternative	**Lead-time (Days)**	**Cost ($)**
Frame Assembly	Standard	19	605
	Consignment	0	622
Case	Standard	15	2200
	Consignment	0	2250
Brake Group	Standard	8	3850
	Consignment	0	3896
Drive Group	Standard	9	1550
	Consignment	0	1571
Plant Carrier	Standard	9	155
	Consignment	0	157
Platform Group	Standard	6	725
	Consignment	0	732
Fender Group	Standard	9	900
	Consignment	0	912
Roll Over Group	Standard	8	1150
	Consignment	0	1164
Case & Frame	Standard	16	1500
	Expedite	4	1575
Transmission	Standard	15	7450
	Consignment	0	7618
Final Drive & Brake	Standard	6	3680
	Expedite	2	3755
Engine	Standard	7	4500
	Consignment	0	4547
Fans	Standard	12	650
	Consignment	0	662
Chassis/Platform	Standard	7	4320
	Expedite	2	4395
Common Subassembly	Standard	5	8000
	Expedite	2	8075
Dressed-Out Engine	Standard	10	4100
	Expedite	3	4175
Boggie Assembly	Standard	11	575
	Consignment	0	584
Pin Assembly	Standard	35	90
	Consignment	0	95
Track Roller Frame	Standard	10	3000
	Consignment	0	3045
Main Assembly	Standard	8	12000
	Expedite	2	12150
Suspension Group	Standard	7	3600
	Expedite	2	3675
Final Assembly	Standard	4	8000
	Expedite	1	83000

For the assembly node, the first option represents the standard manufacturing method while the second option represents an expedited alternative that corresponds to a supplier who has invested in process improvement efforts in order to decrease its supply lead-time. As mentioned earlier, the production costs and lead times are obtained from GW. As for the data on the compatibility drivers for each alternative at each node, it is assumed that the ratings of the compatibility drivers for the low-cost alternative range uniformly in [1–8] and that of high-cost alternative ranges uniformly in [3–10]. Therefore, for the low-cost supply alternative, the value of the rating for each compatibility driver is randomly selected from U(1 – 8), while that of the high-cost supply alternative is randomly selected from U(3 – 10), where U(a, b) is a discrete uniform distribution in the range of [a, b]. Although the data on compatibility drivers are not based on actual data, they are indicative of the kinds of data seen in the real world as low-cost suppliers usually exhibit lower compatibility than high-cost suppliers. Once the evaluation ratings for the compatibility drivers are obtained, the next step is to input them into the fuzzy logic-based framework to compute the compatibility index for each alternative. Table 2 gives the ratings for the compatibility drivers and the corresponding compatibility index for each alternative.

Table 2. Compatibility index ratings for alternatives at each node of the given bulldozer supply chain

	Alternative	Cultural Alignment	Communication & Information sharing	Coordination & Co-operation	Managerial trust & commitment	Compatibility in strategic goals	Conflicts management techniques	Profit Margin	Return on assets	Bond rating	**Compatibility Index**
Frame Assembly	Standard	1	4	5	4	5	6	1	3	6	**0.3750**
	Consignment	5	6	4	10	10	9	7	10	8	**0.7568**
Case	Standard	2	5	5	2	6	2	3	1	6	**0.3000**
	Consignment	6	8	6	5	8	10	5	6	10	**0.7000**
Brake Group	Standard	2	6	4	1	1	2	4	5	4	**0.3682**
	Consignment	9	6	4	6	8	6	4	4	4	**0.5500**
Drive Group	Standard	3	1	1	4	5	6	3	3	5	**0.2872**
	Consignment	7	5	5	9	4	6	8	7	6	**0.7000**
Plant Carrier	Standard	3	1	6	1	2	3	6	6	5	**0.3749**
	Consignment	8	4	9	6	8	9	7	9	7	**0.7500**
Platform Group	Standard	4	3	1	2	4	6	1	5	6	**0.3249**
	Consignment	5	9	10	7	9	8	10	5	5	**0.7500**
Fender Group	Standard	5	5	3	4	4	6	1	1	3	**0.2804**
	Consignment	9	6	6	9	6	9	10	10	10	**0.8517**
Roll Over Group	Standard	2	5	1	6	6	5	3	2	1	**0.3249**
	Consignment	8	6	6	10	7	10	10	4	6	**0.7596**
Case & Frame	Standard	2	4	6	6	1	6	3	4	4	**0.4250**
	Expedite	6	6	10	8	8	10	7	7	10	**0.7500**
Transmission	Standard	3	4	6	4	6	4	2	6	2	**0.3750**
	Consignment	8	5	4	4	6	6	5	7	10	**0.6250**
Final Drive & Brake	Standard	3	6	2	2	3	3	6	3	1	**0.2499**
	Expedite	5	8	4	9	6	4	8	4	9	**0.7000**
Engine	Standard	4	5	4	4	4	6	5	5	1	**0.3750**
	Consignment	9	8	7	4	9	4	9	6	6	**0.7500**
Fans	Standard	5	6	5	2	2	4	4	3	1	**0.3000**
	Consignment	4	10	7	6	10	5	6	7	10	**0.7500**
Chassis/Platform	Standard	2	3	6	2	3	5	1	2	3	**0.2499**
	Expedite	9	4	8	8	8	9	9	10	7	**0.8446**
Common Subassembly	Standard	4	4	1	3	5	2	5	2	4	**0.3749**
	Expedite	7	4	5	8	8	10	4	4	8	**0.5750**
Dressed-Out Engine	Standard	2	6	1	1	4	2	4	6	4	**0.3749**
	Expedite	4	6	9	4	6	6	9	6	10	**0.6750**
Boggie Assembly	Standard	4	1	5	5	4	3	2	4	5	**0.4499**
	Consignment	5	8	6	10	8	8	6	5	9	**0.7000**
Pin Assembly	Standard	4	1	4	6	6	3	3	5	2	**0.3249**
	Consignment	9	6	7	8	10	7	5	7	7	**0.7500**
Track Roller Frame	Standard	4	2	4	1	3	3	5	4	4	**0.4250**
	Consignment	9	6	9	10	8	8	5	10	9	**0.7500**
Main Assembly	Standard	1	3	5	2	5	1	6	5	2	**0.3749**
	Expedite	4	5	9	7	5	5	10	6	5	**0.6750**
Suspension Group	Standard	1	4	1	5	5	7	3	1	2	**0.3249**
	Expedite	9	3	4	9	6	5	4	9	4	**0.7000**
Final Assembly	Standard	2	5	5	6	6	3	3	2	4	**0.3750**
	Expedite	8	6	9	7	10	8	8	10	7	**0.7500**

These data are then incorporated into the multi-objective optimization to determine the supply chain configuration. Genetic algorithm is used to solve the given multi-objective optimization model. Figure 3 illustrates the optimal supply chain network diagram for the given bulldozer manufacturing case study.

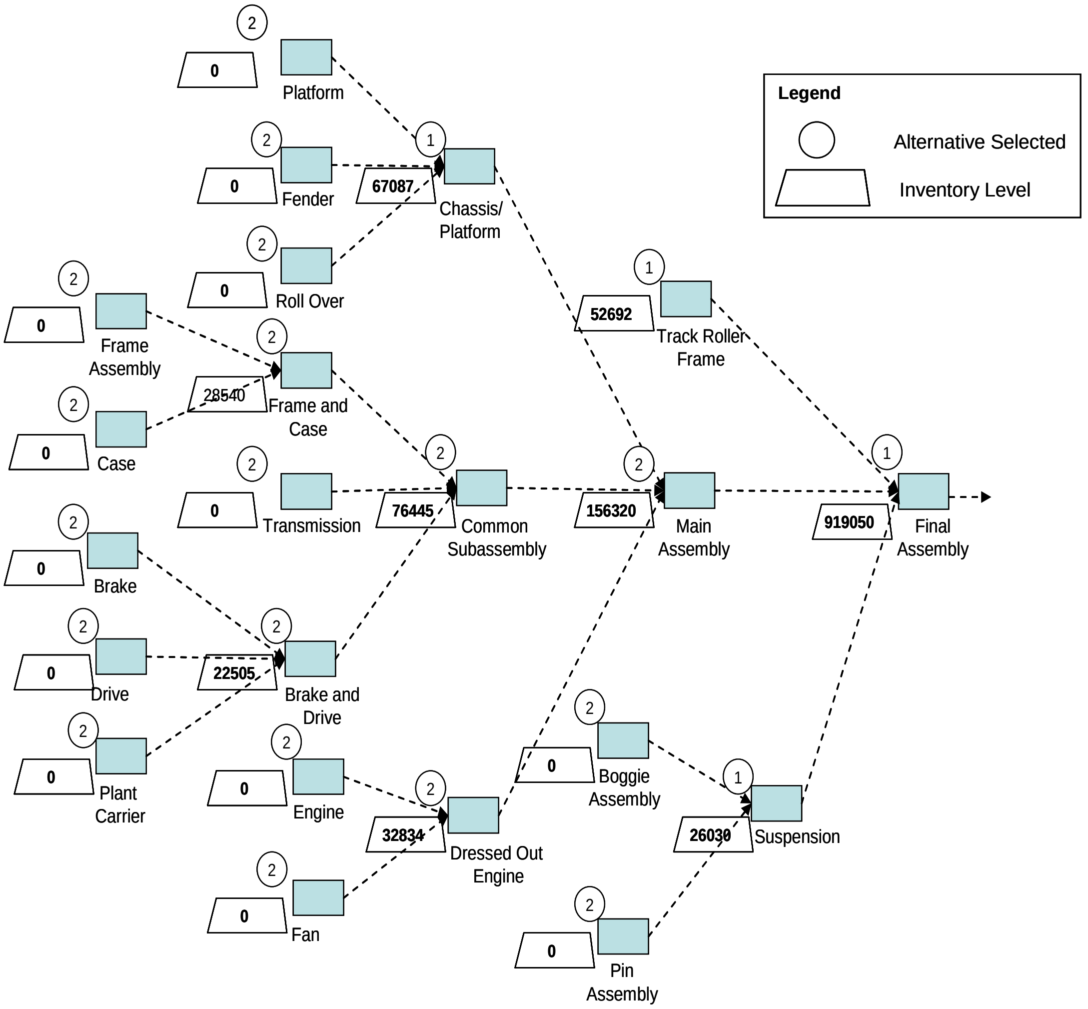


Figure 3. Optimal supply chain configuration for bulldozer manufacturing

In addition to the location and actual inventory level, it shows what option has been selected at various nodes of the supply chain. For example, at *Pin Assembly* node, *Consignment* (option 2) has been selected and the guaranteed service time is 0 day, hence there is no inventory held at that node (*Inventory level = 0*). On the other hand, at *Suspension* node, existing *Standard* procurement (option 1) is selected and the guaranteed service time is days, therefore there are 26020 units of inventory paced at that node.

3.1 Comparison of results with the benchmark case study

Here we compare the supply chain configuration results for the given bulldozer design using the single objective presented in GW and the multi-objective configuration proposed in this paper. The GW approach uses total supply chain costs as the single objective for configuring the supply chain. Results indicate that the multi-objective model selects higher production costs and shorter production lead-time options for only six of the twenty-two stages. The procurement stages with the higher production cost and shorter production lead-time option are the brake group, fender group, and plant carrier. Similarly, the assembly stages with the higher production cost and shorter production lead-time option are common subassembly, dressed-out engine, and main assembly.

Table 3. Comparison of results of single-objective and multi-objective supply chain configuration

Cost Category	Results from single-objective (total supply chain cost) supply chain configuration model (Graves & Willems, 2003)	Results from multi-objective (total supply chain cost and compatibility) supply chain configuration model	Numerical difference
Cost of goods sold	$94,807,700	$95,498,000	$690,300
Total Inventory stock cost	$1,720,300	$1,381,503	-$338,797
Total supply chain cost	$96,528,000	$96,879,503	$351,503

Table 3 summarizes the results from optimizing the supply chain configuration based on a single objective (total supply chain cost) and compares the results to those for the multiple objectives (total supply chain cost and supply chain compatibility indexes) model as presented in this paper. Although the multi-objective supply chain configuration model increases the cost of goods sold by $690,300 relative to the single-objective model, the higher production cost options have lower production lead times; there is a reduction of $338,797 in the total inventory cost in the supply chain network as a result. Obviously, it still leads to an overall increase in supply chain cost of \$351,503, but it comes with a benefit of more stability in the supply chain relationship due to the selection of more compatible and efficient suppliers with shorter replenishment lead times. This benefit can be a critical factor, particularly if a company is trying to launch a new product ahead of its competition in order to capture the niche market. Conversely, there may be greater risks in making an investment in a supplier whose business practices and financial objectives do not match with the OEM, such as the Chrysler-Plastech example reported by Trkman and McCormack (2009). More importantly, this tool gives the decision maker an ability to quantify the tradeoffs involved in achieving compatibility of supply options selected in the supply chain.

Furthermore, although the current problem assumed a guaranteed service time, the benefits of incorporating a compatibility index can be a crucial decision-making factor if the service times are stochastic. Although we did not test this claim in our paper, it is fair to say that the level of uncertainty increases if the partners are not compatible.

4. Conclusions and Future Work

This paper has presented a multi-objective optimization model for supply chain configuration considering total supply chain costs and compatibility index of the supply chain partners. The proposed model was applied to a bulldozer supply chain and the results compared with that of the single-objective optimization approach given in GW, the benchmark case study. The GW approach considered only supply chain costs. Although the total inventory holding costs are less in the case of a multi-objective solution, the COGS sold are higher than that of GW. This is because the former method chooses the more expensive options at six nodes due to their better compatibility ratings. Even though it can be argued which option is better for a company (minimum costs or reliable supply chain), it is no secret that reliability and shorter lead times come with premiums.

The proposed model can be a strategic tool to aid supply chain practitioners in selecting more compatible members for their supply chain, thereby enhancing the stability of the supply chain network. Integrating the suppliers early on during product design and development provides more opportunities for improving the product at lower costs (Nepal and Monplaisir, 2009). On the other hand, although the proposed multi-objective optimization methodology provides a necessary decision support tool for design engineers and supply chain managers, the model has been simplified with some key assumptions, such as unlimited capacity and guaranteed service time in the supply chain. Relaxation of such assumptions would be a natural extension of this work in the future.

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