Multi-Objective Outsourcing Strategies for Functional and Fast Fashion Products in Textile Supply Chain

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Abstract—**Key factors of outsourcing strategies include cost and capacity flexibility. Cost saving and capacity flexibility depend on the connection between product characteristics and the supply chain network. Functional products involve efficient supply chains. Fashion products should move in the production and distribution system as quickly as possible in which maximum capacity flexibility provides a responsive supply chain. Moreover, complex products with global parts sourcing involve comparatively more risk. This paper evaluates an outsourcing strategies considering functional and fast fashion products in the textile supply chain. There are four categories of production options. Textile manufacturer receives production contracts at in-house facility in home country. Capacity flexibility is measured as the combination of destinations with maximum capacity. Product complexity risk is incorporated as the number of parts/components sourced domestically and internationally at each production destination. A multi-objective model for outsourcing strategiesis proposed based on operational cost, capacity flexibility, and product complexity risk. The model is solved using three variants of goal programming. Based on the results, several insights are proposed for outsourcing decision making.**

Keywords-Textile supply chain, outsourcing strategies, goal programming, functional products, fast fashion products

I. INTRODUCTION

The textile supply chain contains several divisions with a sequence of complicated processes in each division. The garment/fashion production division requires comparatively more labor than capital intensive divisions such as yarn production, fabric production, and fabric processing. In developed markets, labor cost is approximately 50 percent of the final cost of a garment [1], resulting in higher unit production cost. There are three global markets for production outsourcing in the textile industry, the developed, emerging, and developing markets. There is a greater difference of labor cost in the textile industry as shown in Table I. This difference motivates the manufacturers to outsource internationally.

Companies that outsource internationally focus on achieving cost benefits, while companies that outsource domestically focus on achieving capacity flexibility[2]. The garment/fashion manufacturer receives demand for frequent contracts with different varieties. During peak season, level strategy may be unable to meet customer deadlines. In this case, strategic capacity expansion may be considered. However, there is a capacity underutilization risk during slack times. Hence, capacity flexibility tends to decrease beyond the deadlines. This paper estimates the capacity flexibility based on customer deadlines and destination lead time.

The key focus of this paper is to evaluate outsourcing strategies based on two categories of textile products. The first category involves functional textile products which require efficient supply chains. The second category involves fast fashion textile products which require responsive supply chains. A comprehensive evaluation of functional products with efficient supply chains and innovative products with responsive supply chains is provided by Fisher [3].

This paper uses three goal programming (GP) methods to differentiate the functional products from the fast fashion products. GP methods allow the manufacturer to set a priority for an objective based on product requirements (Lexicographic GP). The decision maker may set weights for different objectives based on different requirements (Weighted GP). If the decision maker wants balanced achievement of each objective, Chebyshev GP is applied.

TABLE I. Labor Cost/Hourly Compensation – U.S. $

1. Developed markets				2. Emerging markets		3. Developing markets	
Norway	64.50	France	42.12	Brazil	11.65	Vietnam	0.60
Belgium	54.77	Ireland	39.38	Russia	2.99	Myanmar	0.20
Denmark	51.67	Canada	36.56	India	1.17	Pakistan	0.58
Sweden	49.12	Italy	36.17	China	2.10	Sri Lanka	0.81
Germany	47.38	USA	35.53	Indonesia	1.08	Bangladesh	0.40
Australia	46.29	UK	30.77	Mexico	6.48	Colombia	2.97
Finland	44.14	Spain	28.44	Turkey	4.50		
Austria	43.16	Greece	21.78				
Netherlands	42.26	Portugal	12.91				

Source. Sardar and Lee [4]

Product nature causes the achievement of one objective through compromise on other objectives. This paper considers functional/basic products when operational cost is given first preference and fast fashion products when the capacity flexibility is given first preference. The fast fashion supply chain is a branch of the textile supply chain in which production and distribution lead time is reduced, and new products are manufactured and offered to consumers as fast as possible [5]. Therefore, fast fashion products should be assigned to production destinations which can produce new products as fast as possible. In other words, destinations with maximum capacity flexibility are the first choice for fast fashion products. Therefore, this paper estimates capacity flexibility based on maximum capacity available in the system.

The main contribution of this paper is to evaluate outsourcing strategies for functional and fast fashion products considering operational cost, capacity flexibility, and product complexity risk. Product complexity contributes to the supply chain complexity regardless of the location of the production process across the world. Complex products with complex supply chain networks incur more disruptions. Product complexity risk increases with an increase in number of parts [6]. In the textile industry, parts to be sourced include number of fabric variants, number of trims and accessories, etc. Furthermore, if comparatively more parts are sourced internationally, the probability of missing an item increases. Therefore, this paper incorporates the impact of domestic and international parts sourcing on outsourcing strategies.

II. CONTRIBUTION TO THE LITERATURE

Textile companies face several challenges such as rising costs, reshoring, supply chain globalization, and emerging consumer needs. To deal with such challenges, existing literature needs development of practical decision making tools for managing outsourcing activities. Outsourcing problem incorporates some features of the vendor selection problem. Several studies addressed the vendor selection problem, but few studies addressed the vendor selection in the outsourcing environment [7-8]. Coman and Ronen [9] developed a linear programming model for production outsourcing. They optimized total profit while decisions include which products should be manufactured in-house and which products should be outsourced.

De Almeida [10] proposed a multi-criteria model for outsourcing vendor selection with respect to cost, delivery time, and dependability, using two different approaches. Wadhwa and Ravindran[11] modelled vendor selection in outsourcing as a multi-objective optimization problem assuming price, lead-time, and quality to be the most important objectives.

Liou and Chuang [12] studied a multiple criteria decision-making model for outsourcing provider selection, using the DEMATEL, ANP and VIKOR methods. Their decision making involved cost, quality, risk, and compatibility. Wang et al. [8] presented a linear programming model for outsourcing cost-effectiveness during vendor selection. They use three objectives as total cost, unacceptable material, and lead time.

Bhat and Krishnamurthy [13] modelled a single-stage manufacturing facility with flexible production rate and seasonal demands, and studied the benefits of capacity flexibility. Alp and Tan [14] proposed an integrated capacity and inventory model considering both the in-house permanent capacity and temporary capacity flexibility such as overtime, hiring/firing, or outsourcing. They defined capacity flexibility as "the capability to adopt production capacity with an option of utilizing contingent resources in addition to permanent resources." They concluded that higher demand variability requires more capacity flexibility. Thus, outsourcing helps to save in-house capacity expansion cost in the case of demand variability.

Chen and Kasikitwiwat[15] quantified the capacity flexibility for transport networks. They utilized the concept of total capacity flexibility (based on the ultimate capacity concept) with respect to demand variations.

They defined total capacity flexibility as “the maximum throughput the system can handle subject to relevant constraints.”

In this paper, the concept of maximum capacity flexibility is utilized based on fast fashion products requirements. This concept can be used when demand patterns are uncertain, and production can be allocated to a facility at a destination with maximum capacity flexibility. In contrast, a company may give first preference to operational cost in case of basic/functional products.

This paper develops a multi-objective optimization model with operational cost, capacity flexibility, and product complexity risk as three objectives. Three variants of GP are used as solution methodology. Based on the results, several insights and strategies are proposed. Table II presents the contribution of the multi-objective model to the existing literature.

Table II. Contribution to the Existing Literature

	Cost	Capacity flexibility	Risk	Lead time	Description
Coman and Ronen [9]	✓	✕	✕	✕	Profit
De Almeida [10]	✓	✕	✕	✕	Total cost + quality + dependability
Wadhwa and Ravindran[11]	✓	✕	✕	✓	Total cost + lead time + quality
Liou and Chuang [12]	✓	✕	✓	✕	Total cost + quality + risk + compatibility
Wang et al. [8]	✓	✕	✕	✓	Total cost + lead time + quality
Bhat and Krishnamurthy [13]	✓	✓	✕	✕	Total expected cost
Alp and Tan [14]	✓	✓	✓	✕	Integrated capacity and inventory model
Chen and Kasikitwiwat[15]	✓	✓	✕	✕	Total capacity flexibility
This paper	✓	✓	✓	✓	Total cost + capacity flexibility + product complexity risk

III. Model Development

Consider a textile manufacturer in the high cost country, which outsources domestically in the same country and outsources internationally to low cost countries. There are four production options, specifically, in-house facility in the home country, domestic suppliers in home country, international subsidiary, and international suppliers. It is supposed that each product, which is outsourced to a destination, is transported back to the in-house facility in home country. Therefore, transportation cost for in-house facility is negligible. Each facility at each destination has its own lead time for each contract. The lead time and deadlines are used to estimate maximum capacity.

Besides cost and capacity flexibility, the manufacturer wants minimum product complexity risk. Maximum loss due to product complexity risk is assumed as quantity assigned at a production facility. Product complexity is measured based on the number of parts which are sourced domestically and internationally at each destination.

Selected facilities should satisfy customer demand. The manufacturer commits minimum production quantity with domestic and international suppliers. Decisions include the selection of production destinations for each contract and production quantity at each destination. Fig. 1 presents schematic of outsourcing problem.

Notations

Sets

I Set of domestic suppliers, $i = 1, 2, ..., I$

J Set of international suppliers, $j = 1, 2, ..., J$

A Set of contracts, $a = 1, 2, ..., A$

Q Set of objective functions, $q = 1, 2, ..., Q$

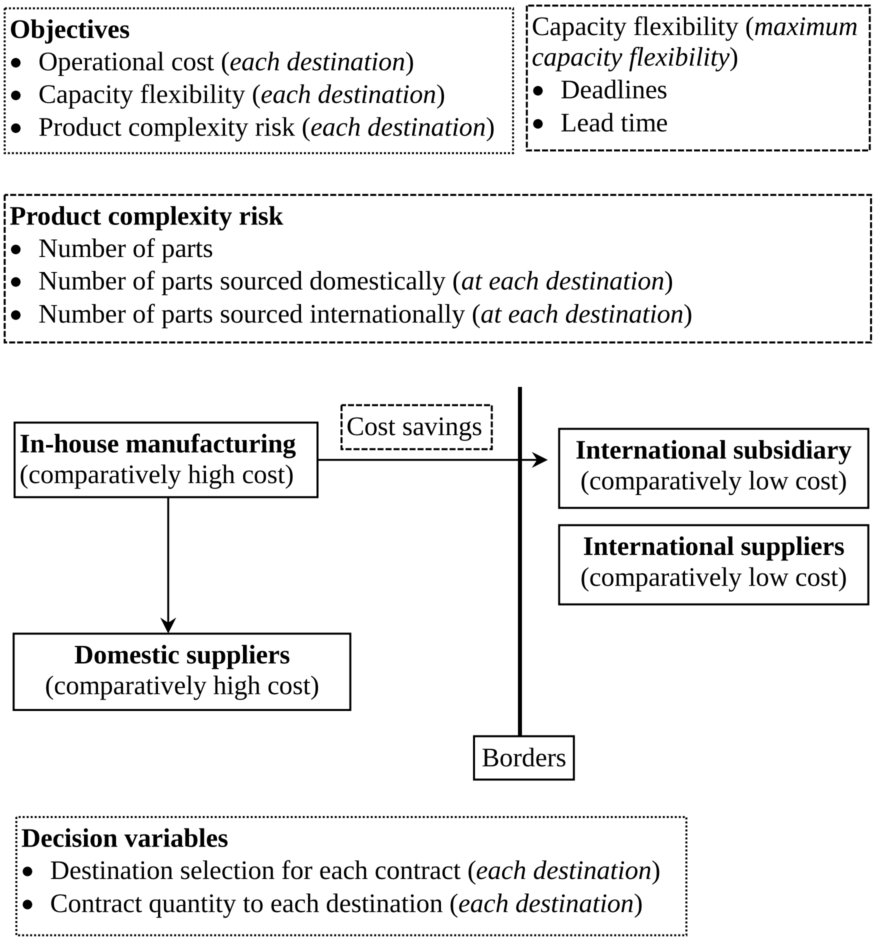

Fig. 1. Problem Environment

Parameters

D_a	Demand for contract a (units/contract)
g_a	Deadline for contract a (days/contract)
LT_a^{in}	Lead time for contract a at local facility/in-house (days/contract)
LT_a^{sb}	Lead time for contract a at subsidiary (days/contract)
LT_{ai}^{ds}	Lead time for contract a at domestic supplier i (days/contract)
LT_{aj}^{is}	Lead time for contract a at international supplier j (days/contract)
C_a^{in}	Unit production cost for contract a at local facility/in-house ($)
C_a^{sb}	Unit production cost for contract a at subsidiary ($)
C_{ai}^{ds}	Unit production cost for contract a at domestic supplier i ($)
C_{aj}^{is}	Unit production cost for contract a at international supplier j ($)
T_a^{sb}	Unit transportation cost for contract a from subsidiary ($)
T_{ai}^{ds}	Unit transportation cost for contract a from domestic supplier i ($)
T_{aj}^{is}	Unit transportation cost for contract a from international supplier j ($)
mq_{ai}^{ds}	Minimum quantity of contract a to be produced at domestic supplier i (units/contract)

mq_{aj}^{is} Minimum quantity of contract a to be produced at international supplier j (units/contract)

E_a Total number of parts in contract a

pr_a^{in} Failure rate for parts sourcing for contract a at in-house facility

BE_a^{in} Number of parts to be sourced internationally for contract a at in-house facility

BE_a^{sb} Number of parts to be sourced internationally for contract a at subsidiary

BE_{ai}^{ds} Number of parts to be sourced internationally for contract a at domestic supplier i

BE_{aj}^{is} Number of parts to be sourced internationally for contract a at international supplier j

dp_a^{in} Failure rate for domestic parts sourcing for contract a at in-house facility

dp_a^{sb} Failure rate for domestic parts sourcing for contract a at subsidiary

dp_{ai}^{ds} Failure rate for domestic parts sourcing for contract a at domestic supplier i

dp_{aj}^{is} Failure rate for domestic parts sourcing for contract a at international supplier j

ip_a^{in} Failure rate for international parts sourcing for contract a at in-house facility

ip_a^{sb} Failure rate for international parts sourcing for contract a at subsidiary

ip_{ai}^{ds} Failure rate for international parts sourcing for contract a at domestic supplier i

ip_{aj}^{is} Failure rate for international parts sourcing for contract a at international supplier j

wt_a^{in} Weight given to international parts sourcing for contract a at in-house facility

wt_a^{sb} Weight given to international parts sourcing for contract a at subsidiary

wt_{ai}^{ds} Weight given to international parts sourcing for contract a at domestic supplier i

wt_{aj}^{is} Weight given to international parts sourcing for contract a at international supplier j

dc_a Total loss as a function of product complexity risk for contract a ($)

Decision variables

Qin_a Quantity of contract a produced at local facility/in-house (units/contract)

Qsb_a Quantity of contract a outsourced to international subsidiary(units/contract)

Qds_{ai} Quantity of contract a outsourced to domestic supplier i (units/contract)

Qis_{aj} Quantity of contract a outsourced to international supplier j (units/contract)

z_a Binary variable for assignment of contract a at local facility/in-house

y_a Binary variable for assignment of contract a at subsidiary

w_{ai} Binary variable for assignment of contract a at domestic supplier i

x_{aj} Binary variable for assignment of contract a at international supplier j

$d_{OC}^{\pm}$ Deviational variables for operational cost

$d_{CF}^{\pm}$ Deviational variables for capacity flexibility

$d_{DC}^{\pm}$ Deviational variables for product complexity risk

The operational cost at four production destinations is

$$\sum_{a}\left\{(C_{a}^{in})Qin_{a}z_{a}+(C_{a}^{sb}+T_{a}^{sb})Qsb_{a}y_{a}+\sum_{i}(C_{ai}^{ds}+T_{ai}^{ds})Qds_{ai}w_{ai}+\sum_{j}(C_{aj}^{is}+T_{aj}^{is})Qis_{aj}x_{aj}\right\} \quad (1)$$

The ratio of customer deadlines to the destination lead time can be used to estimate maximum capacity of a production facility at a destination. For all destinations, maximization of the following expression leads to the maximum capacity flexibility available in the system

$$\frac{g_a}{LT_a^{in}}z_a+\frac{g_a}{LT_a^{sb}}y_a+\sum_i\frac{g_a}{LT_{ai}^{ds}}w_{ai}+\sum_j\frac{g_a}{LT_{aj}^{is}}x_{aj},\forall a \quad (2)$$

To include decision variables into objective function, capacity flexibility can be written as the maximization of the following function

$$\frac{Qin_a g_a}{D_a LT_a^{in}}z_a+\frac{Qsb_a g_a}{D_a LT_a^{sb}}y_a+\sum_i\frac{Qds_{ai}g_a}{D_a LT_{ai}^{ds}}w_{ai}+\sum_j\frac{Qis_{aj}g_a}{D_a LT_{aj}^{is}}x_{aj},\forall a \quad (3)$$

Hence, capacity flexibility can be defined as "the maximization of the available capacity amongst different production options." Capacity flexibility per contract can be expressed as follows

$$\sum_a\frac{1}{A}\left(\frac{Qin_a g_a}{D_a LT_a^{in}}z_a+\frac{Qsb_a g_a}{D_a LT_a^{sb}}y_a+\sum_i\frac{Qds_{ai}g_a}{D_a LT_{ai}^{ds}}w_{ai}+\sum_j\frac{Qis_{aj}g_a}{D_a LT_{aj}^{is}}x_{aj}\right) \quad (4)$$

Maximization of the above expression results in the allocation of the production quantity to the combination of destinations with maximum capacity. Measurement unit for the capacity flexibility is illustrated as follows.

Zara, a fast fashion company, increases its responsiveness with 50 percent capacity utilization without extra shifts at most of its production facilities. In this way, Zara intentionally leaves extra capacity for fast response. This extra capacity can be used to fulfil peak or unexpected demand [16]. Fifty percent capacity utilization understands that the Zara could produce double items (2.00 times) using the existing capacity (i.e. capacity flexibility is 2.00).

Suppose that the maximization of capacity flexibility results in 2.00. This can be interpreted as "this combination of destinations has capacity to produce 200% per contract (2.00 times per contract) during deadlines." Hence, capacity flexibility can be measured in terms of times per contract.

Product complexity risk is measured as follows. The probability of disruption as a function of total number of parts in a product at in-house facility can be expressed as follows [6].

$$1-\left(1-pr_a^{in}\right)^{E_a} \quad (5)$$

If the number of parts required for a contract increases, the probability of disruption also increases. Similarly, as the failure rate increases, the probability of disruption also increases. In the above expression, the impact of domestic and international parts sourcing can be included. Hence, the probability of disruption considering domestic and international parts sourcing at in-house facility can be written as

$$wt_a^{in}\left\{1-\left(1-ip_a^{in}\right)^{BE_a^{in}}\right\}+(1-wt_a^{in})\left\{1-\left(1-dp_a^{in}\right)^{E_a-BE_a^{in}}\right\},\forall a \quad (6)$$

The parts that are sourced internationally have more probability of disruption. Therefore, the idea is to assign relatively more weight to international parts sourcing. Moreover, the failure rate for domestic/international sourcing can be estimated considering the factors such as frequency of missing a component from parts suppliers, aggregate quality level of parts suppliers, and manufacturing technology level at domestic or international parts supply markets. In addition to these factors, the failure rate for international parts sourcing also depends on the factors such as uncertain lead times, transportation difficulties, border-crossings, and trade procedures. Hence, two different failure rates are used for parts sourcing at each production destination.

Missing a single part causes additional cost such as premium freight, extra overtime, setups, and downtime cost. In this paper, it is assumed that maximum loss due to product complexity risk is equivalent to the whole quantity assigned to a production facility. Hence, the total loss for contract a at all production destinations is

$$\begin{aligned} dc_a = &\left[\left[wt_a^{in}\left\{1-\left(1-ip_a^{in}\right)^{BE_a^{in}}\right\}+(1-wt_a^{in})\left\{1-\left(1-dp_a^{in}\right)^{E_a-BE_a^{in}}\right\}\right]\right](C_a^{in})Qin_a z_a \\ &+\left[\left[wt_a^{sb}\left\{1-\left(1-ip_a^{sb}\right)^{BE_a^{sb}}\right\}+(1-wt_a^{sb})\left\{1-\left(1-dp_a^{sb}\right)^{E_a-BE_a^{sb}}\right\}\right]\right](C_a^{sb}+T_a^{sb})Qsb_a y_a \\ &+\sum_i\left[\left[wt_{ai}^{ds}\left\{1-\left(1-ip_{ai}^{ds}\right)^{BE_{ai}^{ds}}\right\}+(1-wt_{ai}^{ds})\left\{1-\left(1-dp_{ai}^{ds}\right)^{E_a-BE_{ai}^{ds}}\right\}\right]\right](C_{ai}^{ds}+T_{ai}^{ds})Qds_{ai} w_a \\ &+\sum_j\left[\left[wt_{aj}^{is}\left\{1-\left(1-ip_{aj}^{is}\right)^{BE_{aj}^{is}}\right\}+(1-wt_{aj}^{is})\left\{1-\left(1-dp_{aj}^{is}\right)^{E_a-BE_{aj}^{is}}\right\}\right]\right](C_{aj}^{is}+T_{aj}^{is})Qis_{aj} x_a, \forall a \end{aligned} \tag{7}$$

Total loss as a function of product complexity risk for all contractscan be expressed as

$$\sum_a\left(dc_a\right) \tag{8}$$

Based on above ideas, the multi-objective outsourcing problem is formulated as follows.

Minimize operational cost

$$Z_1=\sum_a\left\{(C_a^{in})Qin_a z_a+(C_a^{sb}+T_a^{sb})Qsb_a y_a+\sum_i(C_{ai}^{ds}+T_{ai}^{ds})Qds_{ai}w_{ai}+\sum_j(C_{aj}^{is}+T_{aj}^{is})Qis_{aj}x_{aj}\right\} \tag{9}$$

Maximize capacity flexibility

$$Z_2=\sum_a\frac{1}{A}\left(\frac{Qin_a g_a}{D_a LT_a^{in}}z_a+\frac{Qsb_a g_a}{D_a LT_a^{sb}}y_a+\sum_i\frac{Qds_{ai}g_a}{D_a LT_{ai}^{ds}}w_{ai}+\sum_j\frac{Qis_{aj}g_a}{D_a LT_{aj}^{is}}x_{aj}\right) \tag{10}$$

Minimize product complexity risk

$$Z_3=\sum_a dc_a \tag{11}$$

subject to

$$Qin_a \le z_a\frac{D_a g_a}{LT_a^{in}}, \forall a \tag{12}$$

$$Qsb_a \le y_a\frac{D_a g_a}{LT_a^{sb}}, \forall a \tag{13}$$

$$Qds_{ai} \le w_{ai}\frac{D_a g_a}{LT_{ai}^{ds}}, \forall a,i \tag{14}$$

$$Qis_{aj} \le x_{aj}\frac{D_a g_a}{LT_{aj}^{is}}, \forall a,j \tag{15}$$

$$Qin_a+\sum_i Qds_{ai}+Qsb_a+\sum_j Qis_{aj}=D_a, \forall a \tag{16}$$

$$Qds_{ai} \ge w_{ai}mq_{ai}^{ds}, \forall a,i \tag{17}$$

$$Qis_{aj} \geq x_{aj} mq_{aj}^{is}, \forall a, j \tag{18}$$

$$Qin_a, Qds_{ai}, Qsb_a, Qis_{aj} \geq 0 \tag{19}$$

$$d_{OC}^{\pm}, d_{CF}^{\pm}, d_{DC}^{\pm} \geq 0 \tag{20}$$

$$z_a, y_a, w_{ai}, x_{aj} \in [0,1] \tag{21}$$

Objective function (9) shows minimization of total operational cost. Objective function (10) shows maximization of capacity flexibility. Objective function (11) shows the minimization of total loss as function of product complexity risk. Constraints (12)-(15) represent capacity constraints in terms of lead time and deadlines. Constraint (16) shows demand satisfaction constraint. Constraints (17)-(18) show minimum committed quantity between manufacturer and suppliers. Constraints (19)-(20) are non-negativity constraints. Constraint (21) represents assignment of contracts as binary variable.

IV. GOAL PROGRAMMING FORMULATIONS

This paper uses three variants of GP, Lexicographic GP, Weighted GP, and Chebyshev GP. Optimization software LINGO 15.0 was used to implement GP methods. In GP methods, the target level for each goal is specified, and unwanted deviation from the target level is minimized. Therefore, objective function for minimization of total deviation is

$$Min\ Z = d_{OC}^{+} + d_{CF}^{-} + d_{DC}^{+} \tag{22}$$

In the case of operational cost and product complexity risk, unwanted deviations were specified as positive deviations. In contrast, unwanted deviation for capacity flexibility was specified as negative deviation. Cost and capacity flexibility have different measurement units. To compare deviations in same units, normalization is performed by dividing each objective with a relevant constant [17].In this paper, percentage normalization is used to convert all deviations into percentage value away from target values [17-19]. Thus, the objective (22) becomes

$$Min\ Z = \frac{d_{OC}^{+}}{T_{OC}} + \frac{d_{CF}^{-}}{T_{CF}} + \frac{d_{DC}^{+}}{T_{DC}} \tag{23}$$

where, T_{OC}, T_{CF}, and T_{DC} are normalization constants for operational cost, capacity flexibility, and product complexity risk, respectively. In this paper, normalization constant is the best value achieved through optimization of three objectives separately. These best values are also specified as target values for associated objectives.

A. *Lexicographic GP Formulation*

Lexicographic GP utilizes the priority level for each deviation associated with each objective. It performs a series of optimizations. Higher priority level should be minimized first. The value of minimum deviation in higher priority level should be maintained, and next priority level should be minimized [19].

Suppose the following priority levels are defined by the decision maker, priority 1 (P1) = operational cost, priority 2 (P2) = capacity flexibility, and priority 3 (P3) = product complexity risk. The basic algebraic formulation for priority levels is [19]

$$Min\ a = [P_1, P_2, P_3] \tag{24}$$

This vector restricts the satisfaction of higher priority level first. Therefore, first of all, the objective that has first preference should be minimized [19]. Minimization of first priority level is

$$Min\ z = d_{OC}^{+} \tag{25}$$

subject to

$$\sum_a \left\{ (C_a^{in}) Qin_a z_a + (C_a^{sb} + T_a^{sb}) Qsb_a y_a + \sum_i (C_{ai}^{ds} + T_{ai}^{ds}) Qds_{ai} w_{ai} + \sum_j (C_{aj}^{is} + T_{aj}^{is}) Qis_{aj} x_{aj} \right\} + d_{OC}^{-} - d_{OC}^{+} = T_{OC} \tag{26}$$

$$\sum_a \frac{1}{A} \left(\frac{Qin_a g_a}{D_a LT_a^{in}} z_a + \frac{Qsb_a g_a}{D_a LT_a^{sb}} y_a + \sum_i \frac{Qds_{ai} g_a}{D_a LT_{ai}^{ds}} w_{ai} + \sum_j \frac{Qis_{aj} g_a}{D_a LT_{aj}^{is}} x_{aj} \right) + d_{CF}^{-} - d_{CF}^{+} = T_{CF} \tag{27}$$

$$\sum_a dc_a + d_{DC}^- - d_{DC}^+ = T_{DC} \tag{28}$$

Constraints (12) – (21) are included.

Minimization of the negative deviation for capacity flexibility (second priority) is

$$Min\ z = d_{CF}^- \tag{29}$$

subject to

Optimal value of d_{OC}^+ from Equation (25), Constraints (12)–(21), and Constraints (26)–(28) are included.

The minimization of positive deviation for product complexity risk (third priority) is

$$Min\ z = d_{DC}^+ \tag{30}$$

subject to

Optimal values of d_{OC}^+ and d_{CF}^- from Equations (25) and (29), Constraints (12)–(21), and Constraints (26)–(28) are included. This formulation is the optimal solution for Lexicographic GP.

B. Weighted GP Formulation

Weighted GP allows direct trade-offs between different goals [19]. These direct trade-offs are performed by assigning preferential weights to the goals. Weighted GP can be formulated as

$$Min\ Z = \omega_1 \frac{d_{OC}^+}{T_{OC}} + \omega_2 \frac{d_{CF}^-}{T_{CF}} + \omega_3 \frac{d_{DC}^+}{T_{DC}} \tag{31}$$

where, $\omega_1, \omega_2,$ and ω_3 represent weights for associated objectives.

subject to

$$\sum_{q=1}^{3} \omega_q = 1 \tag{32}$$

Constraints (12)–(21) and Constraints (26)–(28) are included.

C. Chebyshev GP Formulation

Chebyshev GP minimizes the worst (maximum) deviation from any single goal. If decision maker wants a balance between goals achievement, Chebyshev GP is good option [19]. If λ is the maximal deviation from amongst the set of goals, Chebyshev GP formulation is [19]

$$Min\ Z = \lambda \tag{33}$$

subject to

$$\frac{d_{OC}^+}{T_{OC}} \le \lambda \tag{34}$$

$$\frac{d_{CF}^-}{T_{CF}} \le \lambda \tag{35}$$

$$\frac{d_{DC}^+}{T_{DC}} \le \lambda \tag{36}$$

Constraints (12) – (21) and Constraints (26) – (28) are included.

V. NUMERICAL EXAMPLE

In this section, effectiveness of multi-objective GP model is tested. Table III presents numerical data for the multi-objective model. For three contracts, demand is 3636 units, 5547 units, 4960 units, respectively, customer deadlines are 5 days, 15 days, and 5 days, respectively, and number of parts is 20, 95, and 186, respectively.

Optimization of individual objective provides the following results.

- In the case of only operational cost, most of the quantity is outsourced to low cost destinations. Operational cost, capacity flexibility, and product complexity risk are \$1372190, 0.60 times per contract, and \$62058, respectively.

- In the case of only capacity flexibility, most production is outsourced to the domestic suppliers. Operational cost, capacity flexibility, and product complexity risk are $2662291, 2.08 times per contract, and $86300, respectively.
- In the case of only product complexity risk, production is allocated based on minimum loss. Operational cost, capacity flexibility, and product complexity risk result in $1732738, 1.26 times per contract, and $58576, respectively.

Now, six cases are evaluated based on changing priority levels in Lexicographic GP, and preferential weights in Weighted GP. In each case, preferential weights for first, second, and third preferences are specified as 0.65, 0.25, and 0.10, respectively. Chebyshev GP has same results in each case. Following abbreviations are used, operational cost = OC, capacity flexibility = CF, and product complexity risk = DC.

To compare all objectives in the same units, normalization was performed using the Value Path Approach (VPA). This approach is the most efficient technique to illustrate the comparisons between objectives. In this approach, achieved value for each objective is divided by the best solution for associated objective. The VPA technique is applied in several papers [11, 20].

In the case of operational cost and product complexity risk, normalized values are greater than or equal to one. In this case, performance of an objective decreases as the value increases from one. In the case of capacity flexibility, normalized values are less than or equal to one. In this case, performance of an objective decreases as the value decreases from one. For each objective the best value is 1. For the six cases, a summary of results and normalized values are given in Table IV.

Table III. Input data for outsourcing problem

Contract no.	**In-house**	**Domestic suppliers**		**Subsidiary**	**International suppliers**	
		1	**2**		**1**	**2**
Unit production cost ($)						
1	177	186	189	89	93	95
2	272	286	291	136	143	146
3	70	74	75	35	37	37
Lead time of each facility at each destination (days/contract)						
1	8	4	7	17	15	18
2	10	7	6	15	14	12
3	5	2	4	23	19	25
Number of parts that are sourced internationally						
1	18	19	12	15	12	18
2	53	68	16	54	73	50
3	118	15	145	76	40	146
Failure rate for international parts sourcing						
1	0.02	0.02	0.03	0.04	0.05	0.04
2	0.02	0.03	0.02	0.05	0.06	0.04
3	0.01	0.03	0.02	0.06	0.05	0.05
Failure rate for domestic parts sourcing						
1	0.01	0.01	0.02	0.02	0.02	0.02
2	0.01	0.02	0.01	0.02	0.02	0.03
3	0.01	0.01	0.02	0.02	0.02	0.03
Weight given to international parts sourcing						
1	0.60	0.60	0.65	0.75	0.75	0.70
2	0.55	0.60	0.55	0.70	0.80	0.75
3	0.65	0.65	0.75	0.75	0.75	0.80
Transportation cost per unit ($)						
Contract 1 to 3		0.33	0.35	1.38	1.46	2.48
Minimum production quantity committed with suppliers (units/contract)						
Contract 1 to 3		100	100		200	200

VI. RESULTS AND DISCUSSION

GP methods can be compared using normalized values in Table IV. For instance, consider Case 1. For capacity flexibility, Lexicographic GP performs 86% worse than Weighted GP. This outcome can be calculated as follows.

$$\frac{Greater\ value - Lesser\ value}{Lesser\ value} = \frac{0.54 - 0.29}{0.29} = 0.86\ times\ worse = 86\%\ worse$$

In the following, key results are summarized based on approximate observations. Graphical representations are shown in Fig. 2 to Fig. 6. In Case 1, for operational cost and product complexity risk, Lexicographic GP and Weighted GP perform better than Chebyshev GP. For capacity flexibility, Chebyshev GP performs better than other two variants, and Weighted GP performs better than Lexicographic GP (Fig. 2). In Case 2, for operational cost and product complexity risk, Lexicographic GP and Weighted GP perform better than Chebyshev GP. For capacity flexibility, Chebyshev GP performs better than other two variants (Fig. 3). In Case 3, for operational cost and product complexity risk, Lexicographic GP performs worse than other two variants. For capacity flexibility, Lexicographic GP performs better than other two variants (Fig. 4). Case 4 behaves same as Case 3. In Case 5, for product complexity risk, Lexicographic GP performs better than the other two variants. For operational cost, Weighted GP performs better than the other two variants (Fig. 5). In Case 6, for product complexity risk, Chebyshev GP performs worse than the other two variants (Fig. 6).

Table IV. GP solution and normalized comparison for alternative cases

	Operational cost ($)	**Capacity flexibility (times per contract)**	**Product complexity risk ($)**
Ideal value for each objective	1372190 (minimum)	2.08 (maximum)	58576 (minimum)
Case 1. OC—CF—DC Sequence			
Lexicographic GP	1372190	0.60	62058
Weighted or non-preemptive GP	1463654	1.13	60914
Chebyshev or Minmax GP	1738381	1.52	74203
Normalized Comparison			
Lexicographic GP	1.00	0.29	1.06
Weighted or non-preemptive GP	1.07	0.54	1.04
Chebyshev or Minmax GP	1.27	0.73	1.27
Case 2. OC—DC—CF Sequence			
Lexicographic GP	1372190	0.60	62058
Weighted or non-preemptive GP	1379054	0.76	61445
Chebyshev or Minmax GP	1738381	1.52	74203
Normalized Comparison			
Lexicographic GP	1.00	0.29	1.06
Weighted or non-preemptive GP	1.01	0.37	1.05
Chebyshev or Minmax GP	1.27	0.73	1.27
Case 3. CF—OC—DC Sequence			
Lexicographic GP	2656652	2.08	86138
Weighted or non-preemptive GP	1808220	1.58	61284
Chebyshev or Minmax GP	1738381	1.52	74203
Normalized Comparison			
Lexicographic GP	1.94	1.00	1.47
Weighted or non-preemptive GP	1.32	0.76	1.05
Chebyshev or Minmax GP	1.27	0.73	1.27

Case 4. CF—DC—OC Sequence			
Lexicographic GP	2656652	2.08	86138
Weighted or non-preemptive GP	1808220	1.58	61284
Chebyshev or Minmax GP	1738381	1.52	74203
Normalized Comparison			
Lexicographic GP	1.94	1.00	1.47
Weighted or non-preemptive GP	1.32	0.76	1.05
Chebyshev or Minmax GP	1.27	0.73	1.27
Case 5. DC—OC—CF Sequence			
Lexicographic GP	1732738	1.26	58576
Weighted or non-preemptive GP	1429083	0.98	60276
Chebyshev or Minmax GP	1738381	1.52	74203
Normalized Comparison			
Lexicographic GP	1.26	0.61	1.00
Weighted or non-preemptive GP	1.04	0.47	1.03
Chebyshev or Minmax GP	1.27	0.73	1.27
Case 6. DC—CF—OC Sequence			
Lexicographic GP	1732738	1.26	58576
Weighted or non-preemptive GP	1767309	1.42	59214
Chebyshev or Minmax GP	1738381	1.52	74203
Normalized Comparison			
Lexicographic GP	1.26	0.61	1.00
Weighted or non-preemptive GP	1.29	0.68	1.01
Chebyshev or Minmax GP	1.27	0.73	1.27

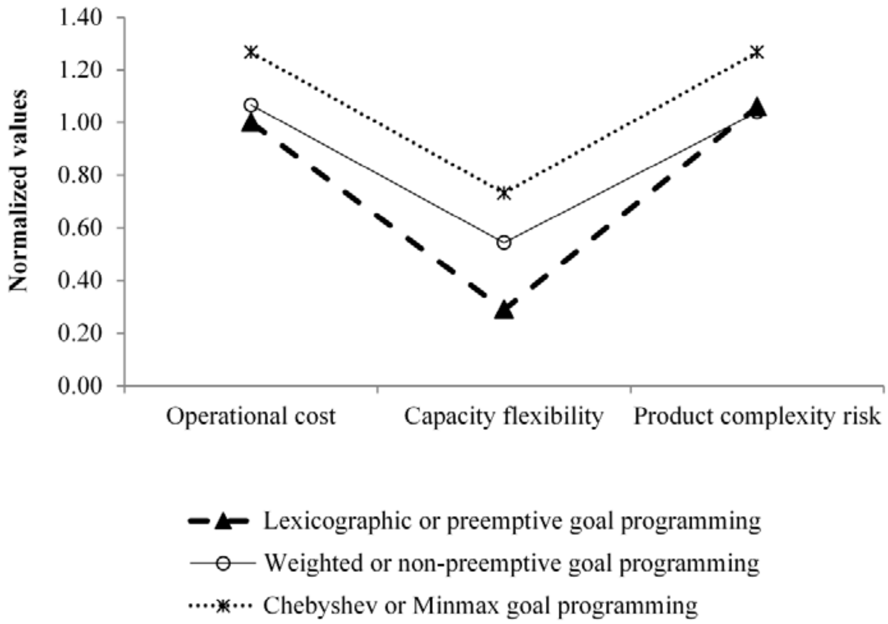

Fig. 2. Case 1, OC—CF—DC sequence

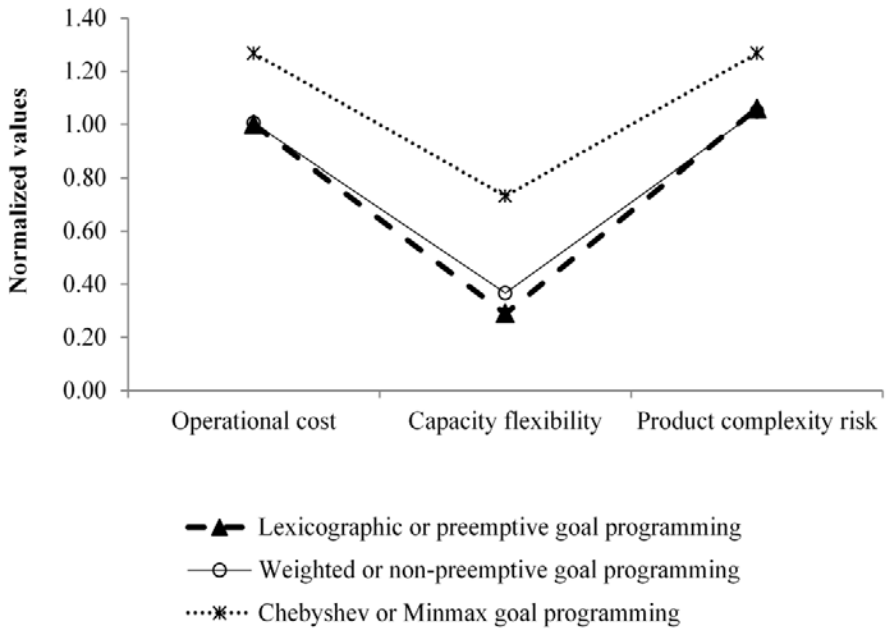

Fig. 3. Case 2, OC—DC—CF sequence

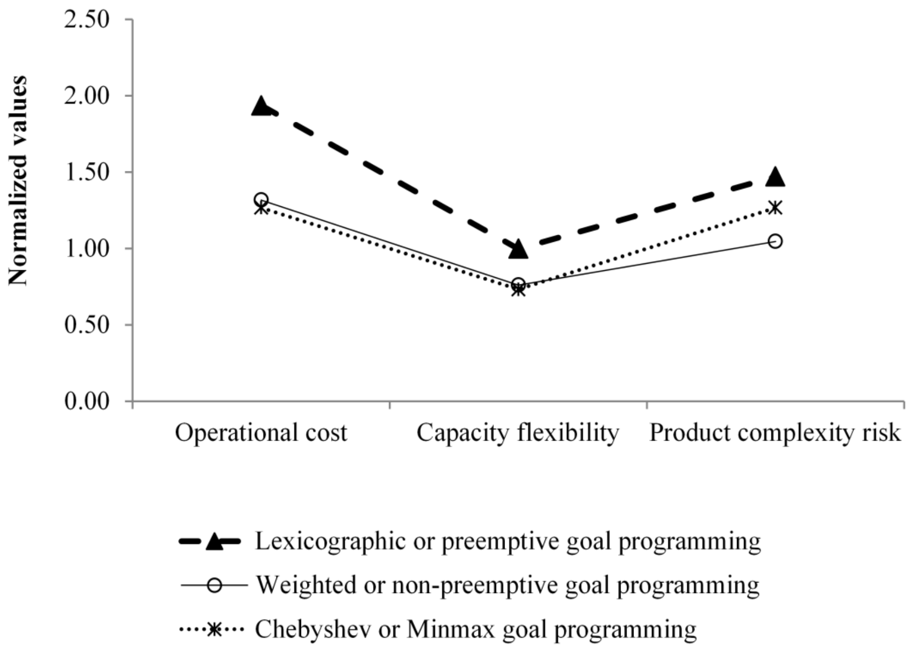

Fig. 4. Case 3, CF—OC—DC sequence

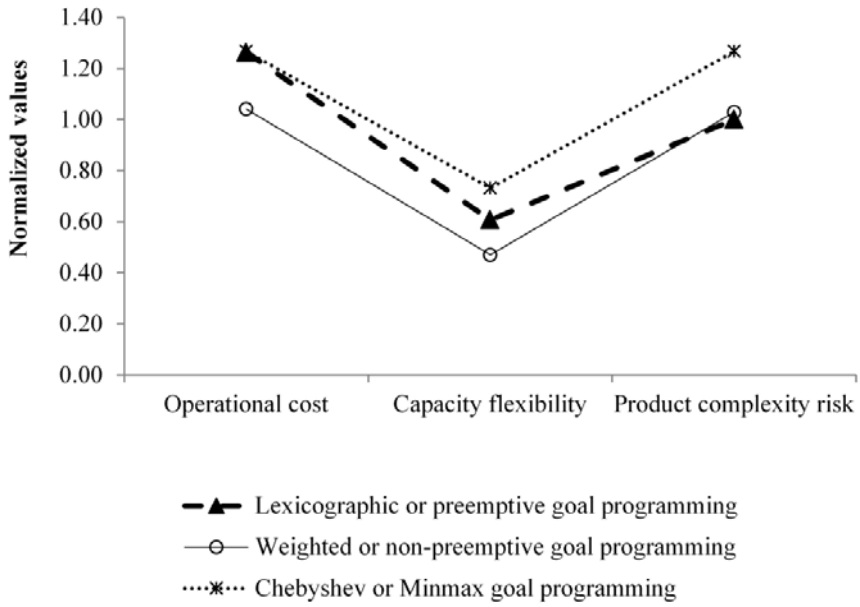

Fig. 5. Case 5, DC—OC—CF sequence

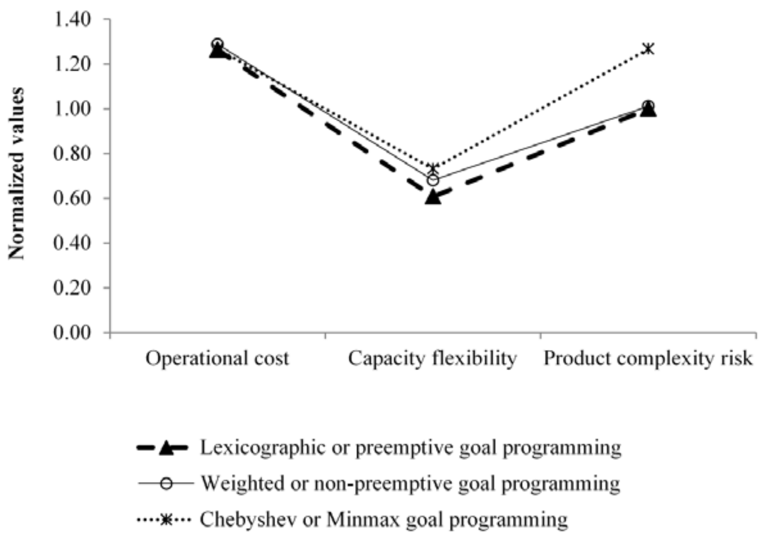

Fig. 6. Case 6, DC—CF—OC sequence

In Lexicographic GP, if more preference is given to operational cost, most of the production is outsourced to low cost international destinations. In this case, capacity flexibility cannot be achieved. Moreover, changing the sequence for capacity flexibility and product complexity risk (CO-CF-DC or CO-DC-CF) does not change the results. In both orders, capacity flexibility results in the worst value. However, product complexity risk objective shows moderate achievement in both orders. Hence, these two sequences seem appropriate for the functional products with moderate product complexity. Product complexity risk depends on the characteristics of the domestic and international parts sourcing at a production destination.

In Lexicographic GP, if high preference is given to capacity flexibility, then operational cost and product complexity risk objectives become worse due to the allocation of more quantity to the high cost domestic destinations with more capacity flexibility. In this case, changing the sequence for operational cost and product complexity risk (CF-CO-DC or CF-DC-CO) shows similar results. This is due to the fact that after achievement of capacity flexibility goal, it becomes difficult to achieve other two goals. As a result, more production moves towards high cost domestic destinations. Hence, these two sequences seem appropriate for the fast fashion products with moderate product complexity.

In Lexicographic GP, if more preference is given to product complexity risk, both domestic and international destinations are selected based on the least impact of the product complexity. In this case, operational cost and capacity flexibility depend on the destinations with least product complexity risk. Furthermore, order change of operational cost and capacity flexibility (DC-CO-CF or DC-CF-CO) shows same results. Hence, these two sequences seem appropriate for significantly complex products with lower preferences of operational cost and capacity flexibility. Hence, if the decision maker has a clear priority in mind, Lexicographic GP seems best.

Weighted GP achieves target levels for one objective on the expense of worse value of the other objective. If direct trade-offs are desired between operational cost, capacity flexibility, and product complexity risk, Weighted GP seems good. This variant of GP seems appropriate for the products for which the manufacturer is not fully confident about the priorities for operational cost, capacity flexibility, and product complexity risk. In this variant, direct trade-offs between goals are performed based on increasing or decreasing weights.

In Chebyshev GP, none of the objectives is fully achieved, but production is allocated to each selected destination based on balanced optimization of each objective. Hence, this variant of GP seems suitable for the products which require balanced achievement of operational cost, capacity flexibility, and product complexity risk. These products fall between basic/functional products and fast fashion products.

GP methods were also compared in terms of the solution times. Considering the weights and priorities in Case 1 (i.e. OC—CF—DC sequence), the problem size was gradually increased as follows.

Problem size A: Contracts = 2, domestic suppliers = 2, international suppliers = 2.

Problem size B: Contracts = 3, domestic suppliers = 2, international suppliers = 2.

Problem size C: Contracts = 3, domestic suppliers = 3, international suppliers = 3.

The solution times for each problem size are shown in Fig. 7. In the problem size B, only one contract is added. Thus, there is not much difference of the solution times between problem sizes A and B. However, remarkable difference of solution times can be observed between problem sizes A and C, for each GP variant.

This comparison was performed only for the small problem sizes. The large size problem would take considerable solution times. Therefore, future work may develop an improved algorithm to increase the overall effectiveness of the solution.

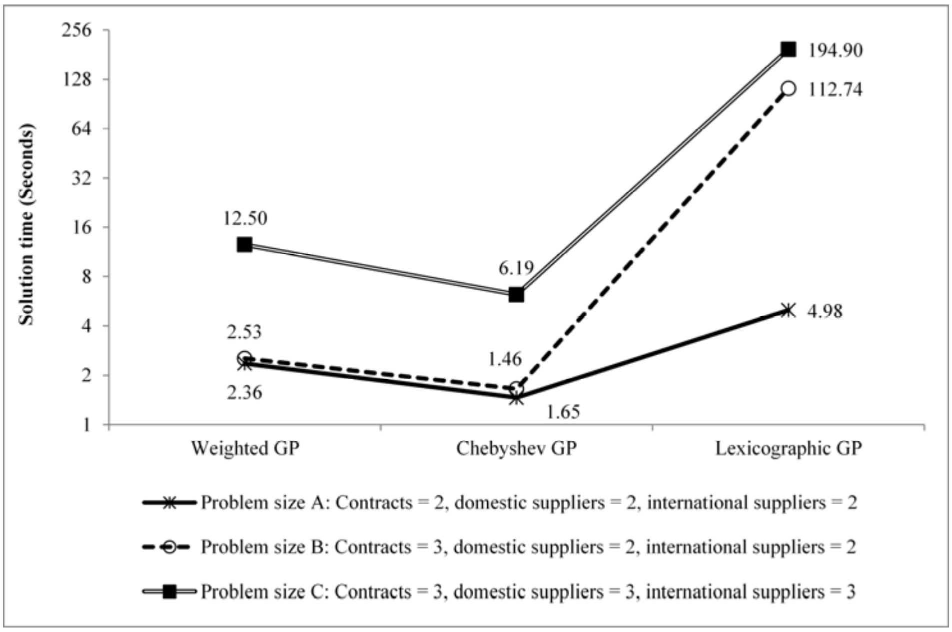

Fig. 7.Solution times for different problem sizes for three GP variants

VII. INSIGHTS FOR PRACTITIONERS

Three variants of GP were used to evaluate the outsourcing strategies. Based on Lexicographic GP, some of the key observations may be summarized as follows.

- For functional/basic products with lower/moderate complexity, operational cost may be given first priority. In this case, capacity flexibility cannot be achieved. However, product complexity risk depends upon the nature of the connection between product complexity and supply chain network.
- For fast fashion products with lower/moderate complexity, capacity flexibility may be given first priority. Consequently, more capacity flexibility provides resilience to deal with product complexity risk or uncertain situations.
- For functional/basic products with higher product complexity, both the operational cost and product complexity risk may be given the same preference (first priority). In this case, Lexicographic GP may be used. The sum of unwanted deviations for operational cost and product complexity risk should be minimized first. Capacity flexibility may be given second priority.

- For fast fashion products with higher product complexity, both capacity flexibility and product complexity risk may be given the same preference (first priority). In this case, Lexicographic GP may be used. The sum of deviations for capacity flexibility and product complexity risk should be minimized first. Operational cost may be given second priority.

If the decision maker wants a balanced achievement between goals, Chebyshev GP seems appropriate. Weighted GP may be used if the decision maker wants to perform direct trade-offs between goals using appropriate weights. Thus, the application of appropriate GP variant depends on product nature and existing situation. Selecting appropriate solution techniques has a greater impact on outsourcing strategies.

Domestic outsourcing provides more capacity flexibility than international outsourcing, because capacity flexibility tends to become ineffective beyond the deadlines. Domestic outsourcing would save capacity expansion cost. Furthermore, if the low cost subsidiary confronts capacity shortage problems, domestic suppliers in the same country, in which subsidiary is located, provide similar capacity benefits as the capacity expansion at this subsidiary.

There is a greater difference of labour cost in the developed, emerging, and developing markets. From emerging to developing markets, further cost savings may be achieved. Contracts with relaxed deadlines and constant rate demand may be shifted from increasing cost emerging markets towards the low cost developing markets. The risk sharing strategy may be adopted with suitable combination of global destinations.

Product complexity risk results in disruption cost. However, relatively high operational cost markets incur additional over time, setups, and downtime cost due to the labour cost difference across the globe. Manufacturers do not realize disruption cost due to the fact that this cost is offset by lower cost at international destinations. Furthermore, product complexity along with extended supply chain networks increases disruption risk regardless of the manufacturing location across the globe.

VIII. Conclusions And Future Work

In this paper, an outsourcing problem is proposed based on operational cost, capacity flexibility, and product complexity risk. The key focus of the outsourcing problem was to evaluate the outsourcing strategies considering functional/basic and fast fashion products. Product complexity risk affects both the functional and fast fashion products.

The key reason for international outsourcing is cost saving, and the key reason for domestic outsourcing is capacity flexibility. Product complexity affects the outsourcing decision making regardless of the domestic/international outsourcing. Hence, this paper captures realistic aspects of the outsourcing problem. Three variants of GP were used to evaluate the outsourcing strategies. Multi-objective outsourcing problem provides useful insights for outsourcing and offshoring decision making.

Optimization software Lingo 15.0 was used to solve outsourcing problem. The solution time considerably increases with an increase in problem size. Future work may develop an improved algorithm to solve large size problem. Furthermore, this model studies capacity flexibility based on maximum capacity available in the system. Future work may consider other conditions in which capacity flexibility should match specific demand situations. For example, capacity expansion/contraction seems more practical than outsourcing in certain situations. In this case, evaluation of outsourcing strategies for offshoring/reshoring phenomenon can be modelled. The risk related to globalization may be incorporated in different ways. More rigorous models will facilitate offshoring and reshoring practices.

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References

[1] Yu, Y., and V. Lindsay. 2011. “Operational Effects and Firms' Responses: Perspectives of New Zealand Apparel Firms on International Outsourcing.” International Journal of Logistics Management 22 (3): 306-323.

[2] Grobler, A., B. T. Laugen, R. Arkader, and A. Fleury. 2013. “Differences in Outsourcing Strategies between Firms in Emerging and in Developed Markets.” International Journal of Operations and Production Management 33 (3): 296-321.

[3] Fisher, M. L. 1997. “What is the Right Supply Chain for Your Product?” Harvard Business Review 75 (2): 105-117.

[4] Sardar, S. and Y. H. Lee. 2013. “Analysis of Outsourcing Strategies for Cost and Capacity Flexibility in Textile Supply Chain Management.” Proceedings of the 17th International Conference on Industrial Engineering Theory, Applications and Practice, Pusan National University, Busan, South Korea, October 6-9: 218-225.

[5] Choi, T. M. 2013. “Fast Fashion Systems: Theories and Applications.” CRC Press.

[6] Inman, R. R., and D. E. Blumenfeld. 2014. “Product Complexity and Supply Chain Design.” International Journal of Production Research 52 (7): 1956-1969.

[7] Wang, J. J., R. Gu, and X. J. Diao. 2008. “Using a Hybrid Multi-Criteria Decision Aid Method for Outsourcing Vendor Selection.” Proceedings of the 4th International Conference on Wireless Communications, Networking and Mobile Computing, WiCOM'08, Dalian, October 12-14: 1-4.

[8] Wang, E. J., Y. C. Chen, W. S. Wang, and T. S. Su. 2010. "Analysis of Outsourcing Cost-Effectiveness Using A Linear Programming Model with Fuzzy Multiple Goals." International Journal of Production Research 48 (2): 501-523.

[9] Coman, A., and B. Ronen. 2000. "Production Outsourcing: A Linear Programming Model for the Theory-of-Constraints." International Journal of Production Research 38 (7): 1631-1639.

[10] De Almeida, A. T. 2007. "Multi-Criteria Decision Model for Outsourcing Contracts Selection based on Utility Function and ELECTRE Method." Computers & Operations Research 34 (12): 3569-3574.

[11] Wadhwa, V., and A. R. Ravindran. 2007. "Vendor Selection in Outsourcing." Computers & Operations Research 34 (12): 3725-3737.

[12] Liou, J. J., Y. T. Chuang. 2010. "Developing a Hybrid Multi-Criteria Model for Selection of Outsourcing Providers." Expert Systems with Applications 37 (5): 3755-3761.

[13] Bhat, S., and A. Krishnamurthy. 2015. "Value of Capacity Flexibility in Manufacturing Systems with Seasonal Demands." IIE Transactions 47 (7): 693-714.

[14] Alp, O., and T. Tan. 2008. "Tactical Capacity Management under Capacity Flexibility." IIE Transactions 40 (3): 221-237.

[15] Chen, A., and P. Kasikitwiwat. 2011. "Modeling Capacity Flexibility of Transportation Networks." Transportation Research Part A: Policy and Practice 45 (2): 105-117.

[16] Ferdows, K., M. A. Lewis, and J. A. Machuca. 2004. "Rapid-fire fulfillment." Harvard Business Review 82 (11): 104-117.

[17] Tamiz, M., D. Jones, and C. Romero. 1998. "Goal Programming for Decision Making: An Overview of the Current State-of-the-art." European Journal of Operational Research 111 (3): 569-581.

[18] Romero C. 1991. "Handbook of Critical Issues in Goal Programming, Pergamon Press, Oxford.

[19] Jones, D., and M. Tamiz. 2010. "Practical Goal Programming." New York: Springer Vol. 141.

[20] Ravindran, A. R., R. UfukBilsel, V. Wadhwa, and T. Yang. 2010. "Risk Adjusted Multi-Criteria Supplier Selection Models with Applications." International Journal of Production Research 48 (2): 405-424.

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