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Abstract Title: A Multiobjective Approach to Simultaneous Strategic and Tactical Planning For New Products

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Abstract

One of the greatest challenges in highly competitive industries such as electronics and fashionable products is the rapid introduction of new products. New product introduction is imperative for the growth of revenue and to sustain in mature markets for such industries.

In this paper an integrated multiobjective supply chain-planning model is proposed to determine simultaneously capacity and production plan considering uncertain customer demand. The goals of the model are to cover the peculiar characteristics of new products like risk associate with the negative profit, maintenance of desired service level under uncertain demands and maintaining the organization profit goals. The research shows that for new product especially short life cycle products it is significant to cover the design and planning decision in an integrated framework.

Key Words: Supply chain planning, new products, multiobjective optimization, stochastic programming.

1.0 INTRODUCTION: Supply chain planning (SCP) is concerned with the coordination and integration of key business activities undertaken by an enterprise, from the procurement of raw materials to the distribution of the final products to the customer. Given the complexity of supply chain operations and often conflicting objectives of the various business divisions, such as marketing, distribution, planning, manufacturing and purchasing, it is imperative to develop a unified and rigorous framework for capturing the various synergies and trade-offs involved. Effective integration of these various functionalities is one of the objectives of SCP.

The analysis of production-distribution systems has been an active area of research for many years. Previous researchers have addressed a single component of the overall production-distribution system such as purchasing, production and scheduling, inventory warehousing or transportation (Gavish and Graves, 1980; Karmarkar et. al, 1985). In recent years researchers have addressed the integration of such single components into the overall supply chain. This paper has reviewed the development of SCP models in a chronological order and found that there are two types of models, deterministic models and stochastic models.

Arntzen et al (1995) have developed a large mixed integer linear programming model that incorporates a global, multi product bill of materials for supply chain with arbitrary echelon structure. They have also developed an innovative optimizer tool to solve the MIP formulation. Dogan and Goetschalckx (1999) have proposed a MIP model to determine the configuration of production distribution system with the lowest sum of supply, production, transportation, inventory and facility cost such that seasonal customer demands are met. They have proposed a primal decomposition with specialized accelerated technique to obtain optimal solution in reasonable amount of time.

The deterministic optimization models do not capture the truly dynamic behavior of most real-world applications. The main reason is that such applications involve data uncertainties that arise because information that will be needed in subsequent decision stages is not available to the decision maker when the decision must be made (Beamon, 1998). Cohen and Lee (1988) have developed a unified, hierarchical, stochastic model for establishing a material requirements policy for every stage in the supply chain. The key contribution was the integration of entire range of inventory subsystems by tractable stochastic sub models. Gupta and Maranas (2003) have developed a two-stage stochastic programming model for SCP considering demand uncertainty. Production decisions are taken as first stage decisions whereas logistics decisions are taken as second stage decision variables. They have highlighted the significant reduction in computational complexity by adopting distribution-based methodology. The literature analysis clearly shows that the issue of new product has been widely studied in the marketing, operation management and engineering design literature. Very few studies have been reported in the operation management literature addressing issues related to new product planning. The peculiar characteristics for planning of new products are risk associate with the negative profit, maintenance of desired service level under extreme uncertain demands and maintaining the organization profit goals.

In this paper we have presented mathematical programming models for SCP considering demand uncertainty associated with new products. We have developed a multiobjective mixed integer stochastic programming models to determine simultaneously capacity and production plan which maximizes expected profit and maintain the desired service level. The multistage stochastic programming approach is used to model the demand uncertainty. The proposed approach allows revising the production plan as time progress and more information regarding the uncertain parameters becomes available

2.0 MODEL DEVELOPMENT:

In this section, we develop stochastic programming models for SCP under uncertain demand environment. To develop the models we have considered the general supply chain network. We have considered a supply chain network structure consists of different suppliers able to supply different parts, single stage parallel manufacturing facilities having limited production capacities and two stage distribution network. The different manufacturing and distribution facilities are connected geographically by transportation channels. Selection of transportation mode between the facilities is driven by the transportation cost, cycle and pipeline inventory costs.

For the new product it is extremely difficult to identify probability distribution for demand because there is no historical data. It is proposed to use scenario planning to model uncertainty. Scenario planning is a method in which decision maker captures uncertainty by specifying a no of possible future states. The uncertain parameters could more easily be described as possible scenarios with the help of industry experts and concern managers. Once the scenarios are defined, they need to be assigned a probability of occurrence. From a modeling standpoint, the probabilities can vary or be equally likely. Industry experts can predict the relative likelihood that one event is more likely than another and can assign the appropriate probabilities.

A common modeling approach that uses discrete scenarios is two stage stochastic programming approach. In this approach decision variables of a problem under uncertainty are partitioned into two sets. The first stage variables which are often known as design variables are those that have to be decided before the actual realization of uncertain parameters, subsequently, once the values of the design variables have been decided and the random events have presented themselves, second stage variable also known as control or operating variables are decided. This corrective action after the design phase is also known as recourse. The objective then in two stage modeling approach is to choose the design variables in such a way that the sum of first stage costs and the expected value of the random second stage recourse cost is minimized (Ahmed and Sahinidis, 1998).

The two-stage model does not allow any flexibility in the production plan with respect to the realized state of the world (Ahmed 2002). However in supply chain planning problem random variables like demand is revealed sequentially over time and decision are made over multiple periods. So supply chain planning is a multistage decision process in which resources are committed over time and the goal is to provide a smooth transition into the future, such application lead very naturally to multistage recourse models.

2.1.1 Notations

Following notations are used in the proposed multi stage stochastic programming model for new product SCP:

Sets and Indexes

MP = Set of manufacturing plants, indexed by o.

C = Set of customer groups, indexed by j.

P = Set of finished products, indexed by p.

W = Set of warehouses, indexed by w.

K = Set of suppliers, indexed by k.

S = Set of parts, indexed by s.

L = Set of transportation modes, indexed by l.

Z = Set of scenarios, indexed by z_i

T = Set of time periods, indexed by m.

I= set of production lines, indexed by i

Parameters

FC_{oim} = Fixed costs for using line i at plant o in period m

PI_{oim} = One time fixed cost for installing line i at plant o in period m

PD_{oim} = One time fixed cost for decommission line i at plant o in period m

FWC_{wm} = Fixed cost for using warehouse w in period m

WI_{wm} = One time fixed cost for installing warehouse w in period m

WD_{wm} = One time fixed cost for decommissions warehouse w in period m

P_{z_i} = Probability of scenario z_i

A_{oim} =Time available at line i at plant o in period m

d_{jpmz_i} = Demand at customer group j for product p in period m in scenario z_i

R_{op} = Rate of production for finished product p at plant o

MC_{opm} = Manufacturing cost at plant o for product p in period m

AOT_{oim} = Available overtime at lines i in plant o in period m

OC_{om} = Overtime cost at plant o in period m

WC_{wm} = Warehousing capacity of warehouse w in period m

IC_{wpm} = Unit cost of inventory holding at warehouse w for product p in period m

TC_{owpl} = Transportation cost for shipping product p from plant o to Warehouse w through transportation mode l

$TC1_{wjpl}$ = Transportation cost for shipping product p from Warehouse w to customer group j through transportation mode l

PC_{kols} = Transportation cost for shipping part s from supplier k to plant o through transportation mode l

MC_{ks} = Material cost for part s from supplier k

n_o = Installation time for line I at plant o

n_w = Installation time for warehouse w

PA_{ksm} = Quantity of parts s available with each supplier k in period m.

RM_{sp} = Utilization rate of each part s for one unit of product p.

SP_{ks} = Probability of supplier k for shipping part s on time.

TP_{os} = Target probability to achieve at plant o for part s.

$ETIB_{kol}$ = Expected lead time from supplier k to plant o using transportation mode l

$ETOB_{wjl}$ = Expected lead time from warehouse W to customer group using transportation mode l

$RIIB_{os}$ = Review interval at plant o for part s

CSF= Cycle stock factor

$RIOB_{wp}$ = Review interval at warehouse W for product p

H_o = Holding cost at plant o

$H1_w$ = Holding cost at warehouse w

PZ_{wp} =Inventory value of product p at warehouse w

PP = Planning period

$TTIB_{kols}$ = Total time to calculate inventory costs incurred when supplier k sends raw material s to plant o through transportation mode l

$TTOB_{wjpl}$ = Total time to calculate inventory costs incurred when Warehouse W sends finished product p to customer group j using transportation mode l

SP_{jpm} = Selling price of the product p at customer group j in period m

Decision Variables

M_{opmz_i} = Amount of product p to be produce at plant o in period m in scenario z_i

W_{kolsmz_i} = Amount of part s shipped from supplier k to plant o in period m through transportation mode l in scenario z_i

x_{owplmz_i} = Amount of product p shipped from plant o to warehouse w in period m through transportation mode l under scenario z_i

OT_{omz_i} = Overtime at plant O in period m in scenario z_i

I_{wpmz_i} = Amount of end of period inventory at warehouse w for product p in period m in scenarioz_i.

Q_{wjplmz_i} = Amount of product p shipped from warehouse w to destination j in period m through transportation mode l in scenario z_i

V_{kos} =1, if supplier k sends part s to plant o, otherwise it is 0

Y_{oim} = 1 if line i is used in period m at plant o, 0 otherwise

$Y1_{oim}$ = 1 if line i is installed in period m at plant o, 0 otherwise

$Y2_{oim}$ = 1 if line i is decommissioned in period m at plant o, 0 otherwise

R_{wm} = 1 if warehouse w is used in period m, 0 otherwise

$R1_{wm}$ = 1 if warehouse w is installed in period m, 0 otherwise

$R2_{wm}$ = 1 if warehouse w is decommissioned in period m, 0 otherwise

2.1.2 The complete Model:

Objective 1: Maximize Profit=

$$\begin{aligned}
&\sum_{wjplmz_i} Q_{wjplmz_i} SP_{jpm} P_{z_i} - \\
&\sum_{oim} (FC_{oim} Y_{oim} + PI_{oim} Y1_{oim} + PD_{oim} Y2_{oim}) - \\
&\sum_{wm} (FCW_{wm} R_{wm} + WI_{wm} R1_{wm} + WD_{wm} R2_{wm}) - \\
&\sum_{kolsmz_i} W_{kolsmz_i} RC_{ks} P_{z_i} - \sum_{kolsmz_i} PC_{kols} W_{kolsmz_i} P_{z_i} - \sum_{opmz_i} MC_{opm} M_{opmz_i} P_{z_i} - \\
&\sum_{wpmz_i} p_{z_i} IC_{wpm} I_{wpmz_i} - \sum_{owplm} TC_{owpl}\, x_{owplm} - \sum_{wjplmz_i} TC1_{wjpl} Q_{wjplmz_i} P_{z_i} - \\
&\sum_{omz_i} OT_{omz_i} OC_{om} - \\
&\sum_{kolsmz_i} TTIB_{kols} (W_{kolsmz_i} / RIIB_{os}) H_o RC_{ks} P_{z_i} + \\
&\sum_{wjplmz_i} TTOB_{wjl} (Q_{wjplmz_i} / RIOB_{wp}) H1_w PZ_{wp} P_{z_i}
\end{aligned} \tag{1}$$

Objective 2: Service Level

$$\sum_{wjpl} Q_{wjplmz_i} / \sum_{jp} D_{jpmz_i} \ge \varepsilon_1 \qquad m \in T, z_i \in Z \tag{2}$$

Objective 3: Risk

$$\begin{aligned}
&\sum_{wjplm} Q_{wjplmz_i} SP_{jpm} - \\
&\sum_{oim} (FC_{oim} Y_{oim} + PI_{oim} Y1_{oim} + PD_{oim} Y2_{oim}) - \\
&\sum_{wm} (FCW_{wm} R_{wm} + WI_{wm} R1_{wm} + WD_{wm} R2_{wm}) - \\
&\sum_{kolsm} W_{kolsmz_i} RC_{ks} - \sum_{kolsm} PC_{kols} W_{kolsmz_i} - \sum_{opmz} MC_{opm} M_{opmz_i} - \\
&\sum_{wpm} IC_{wpm} I_{wpmz_i} - \sum_{owplm} TC_{owpl} x_{owplm} - \sum_{wjplm} TC1_{wjpl} Q_{wjplmz_i} - \\
&\sum_{om} OT_{omz_i} OC_{om} - \\
&\sum_{kolsm} TTIB_{kols} (W_{kolsmz_i} / RIIB_{os}) H_o RC_{ks} + \\
&\sum_{wjplm} TTOB_{wjl} (Q_{wjplmz_i} / RIOB_{wp}) H1_w PZ_{wp} \qquad \forall z_i \in z
\end{aligned}$$

(3)

<u>Subject to :</u>

$$Y_{oim} - Y_{oim-1} \le Y1_{oim-n_0} \qquad \forall o \in mp,\ m \in T, i \in I \tag{1}$$

$$Y_{oim-1} - Y_{oim} \le Y2_{oim} \qquad \forall o \in mp,\ m \in T, i \in I \tag{2}$$

$$R_{wm} - R_{wm-1} \le R1_{wm-n_w} \qquad \forall w \in W,\ m \in T \tag{3}$$

$$R_{wm-1} - R_{wm} \le R2_{wm} \qquad \forall w \in W,\ m \in T \tag{4}$$

$$\sum_p r_{op} M_{opmz_i} \le \sum_i (A_{oim} + AOT_{oim})\ Y_{oim} \qquad o \in MP, m \in T, Z_i \in Z \tag{5}$$

$$\sum_{ol} W_{kolsmz_i} \le PA_{ksm} V_{kos} \qquad k \in K, o \in MP, s \in S, m \in T, z_i \in z \tag{6}$$

$$\sum_{owpl} X_{owplmz_i} \le R_{wm} WC_{wm} \qquad \forall w \in W,\ m \in T, z_i \in z \tag{7}$$

$$M_{opmz_i} = \sum_{wl} X_{owplmz_i} \qquad o \in O, p \in P, m \in T, z_i \in z \tag{8}$$

$$\sum_{ol} x_{owplmz_i} + I_{wpm-1z_i} - I_{wpmz_i} = \sum_{jl} Q_{wjplmz_i} \qquad w \in W, p \in P, m \in T, z_i \in Z \tag{9}$$

$$\sum_{wj} Q_{wjplmz_i} <= d_{jpmz_i} \qquad j \in C, p \in P, l \in L, m \in T, z_i \in Z \tag{10}$$

$$\sum_{p} RM_{sp} M_{opmz_i} \leq \sum_{kl} W_{kolsmz_i} \qquad o \in MP, s \in S, m \in T, z_i \in z \tag{11}$$

$$\begin{aligned}
Q_{wjplmz_i} &= Q_{wjplmz_q} && i \neq q, \forall z_i, z_q \subset B_{n,} n \in N_m, m = 2..T-1, o \in MP, p \in P \\
I_{opmz_i} &= I_{opmz_q} && i \neq q, \forall z_i, z_q \subset B_{n,} n \in N_m, m = 2..T-1, o \in MP, p \in P \\
x_{owjplmz_i} &= x_{owjplmz_q} && i \neq q, \forall z_i, z_q \subset B_{n,} n \in N_m, m = 2..T-1, o \in MP, w \in W, j \in C, p \in P \\
M_{opmz_i} &= M_{opmz_q} && i \neq q, \forall z_i, z_q \subset B_{n,} n \in N_{m-1}, m \in 2.T, o \in MP, p \in P \\
W_{kolsmz_i} &= W_{kolsmz_q} && i \neq q, \forall z_i, z_q \subset B_{n,} n \in N_{m-1}, m \in 2.T, k \in K, o \in MP, s \in S
\end{aligned} \tag{12}$$

$$\sum_{k} V_{kos} \, |\log(SP_{ks})| \leq |\log(TP_{os})| \qquad o \in MP, s \in S \tag{13}$$

$$TTIB_{kols} = ETIB_{kol} + RIIB_{os} CSF \qquad k \in K, o \in MP, l \in L, s \in S \tag{14}$$

$$TTOB_{wjl} = ETOB_{wjl} + RIOB_{wp} CSF \qquad w \in W, j \in C, l \in L, p \in P \tag{15}$$

$$M_{opmz_i}, I_{wpmz_i}, x_{owplmz_i}, Q_{wjplmz_i}, W_{kolsmz_i} \; OT_{omz_i} >= 0 \tag{16}$$

$$v_{KOS,}, Y_{OIM}, Y1_{OIM,} Y2_{OIM}, R_{WM}, R1_{WM}, R2_{WM}, V_{kos} \qquad \in \{0,1\} \tag{17}$$

2.1.3 Constraints:

The supply chain planning problem is modeled as a multiobjective problem. The first objective function is maximization of expected profit considering different cost components like one time installation cost for different plant lines, warehouses, fixed cost for operating the production lines in each period and other variables cost like raw material procurement cost, inbound and outbound transportation cost, inventory cost and production cost. The second objective is to control the service level in each period and in each scenario. The risk objective is modeled as controlling the profit to be remains above the threshold level specified by the management under all adverse scenarios. This objective is very crucial especially for new product to see that product is profitable in all adverse demand scenarios. The problem is formulated as maximization problem which governs the maximization of expected profit and controls the two other objectives by ε constraint method, which allows flexibility to obtain a Pareto solution. Such Pareto solutions are very helpful to top management to set the service level and minimum profit level.

The Constraints (1-4) are the design constraints governing the opening and closing of supply chain facilities like production lines, warehouses in different periods. As these decisions are costly and time intense, are modeled as fixed for different scenarios. The constraints (5-7) represent the capacity constraints for manufacturing of different products, supplier capacity for different parts and warehouse capacity for different product handling. Constraints (8-10) are the demand satisfaction constraints. The production quantity and quantity transferred to warehouses are also taken as scenario dependent and can be revised as per scenario realization.

The Constraint 11 calculates which raw materials are required for each of the finished product and how much quantity are required of each raw material. The constraint 12 is the nonanticipative constraint required to be define for all decision variables which are scenario dependent (Sen and Hingle (1999)). The constraint 13 is governing the Supplier reliability, it select only those supplier combinations which meet the plant required reliability. Constraints (14-15) are the inventory constraints calculating the both pipeline inventory cost and cycle inventory cost. Constraint 16 represents the non-negativity of variables and constraint 17 imposes integer requirements on the variables.

3. The computational experience:

Here, we present our computational experience for SCP problem under uncertain demand, applied to representative supply chain network. The supply chain consists of two plants producing single product and procuring single raw material from two different raw material sources. The final products can be distributed through two distribution centers to final customer groups. Eight scenarios over seven time periods are considered for new product demand. The computational complexity of the model depends on the number of time periods and the number of scenarios considered. The resulting mathematical formulation has 1615 constrains, 2192 continuous variables and 130 binary variables. The model is implemented in Lingo and solved using CPLEX solver. The time required to obtain solution with 0% integrality gap ranges from 9 to 66 seconds depending on the different target imposed to the solution. Results from the optimization exercise are presented in the following section.

Analysis over Multiobjective Function

In traditional SCP problems single objective like minimizing cost or maximizing profit are considered. For new product it's more important to consider the service level and analyze the different trade off exist for different service levels. The ε constraint method is selected, as no specific conditions are required to achieve the solutions and allows the analyst the ability to specify bounds on the objective in sequential manner.

There exist always a tradeoff between service level and profit. This would become more important in case of new product where the management wants to meet certain minimum service level and simultaneously control the profit.

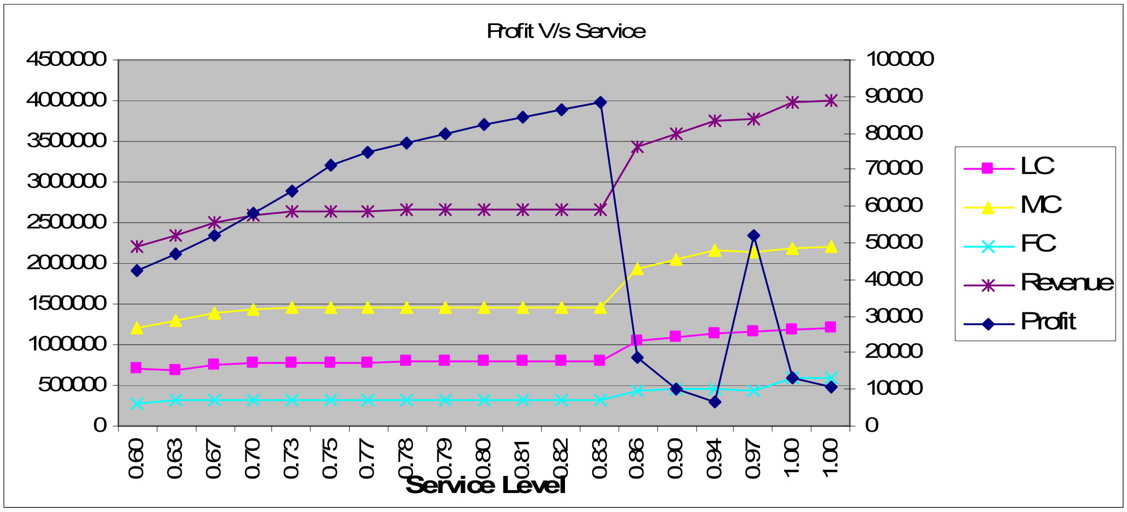

Figure 1: Profit V/s Service

The curve is obtained by maximizing the net profit and progressively constraining the service levels. Figure 1 shows the expected profit under different service level decided by the analyst. The satisfying demand is most profitable until a level of 83.3%, further constraining the service level results into lower profit. The drop in profit is justify by setting up of an additional production line, results into higher fixed cost and lower economics of scale. This analysis can be very helpful to top management to decide a service level objectives and doing the capacity planning accordingly. The analysis also shows the contribution of different components like logistics cost (LC), Manufacturing cost (MC) and Fixed cost (FC) on the revenues and profit from the supply chain.

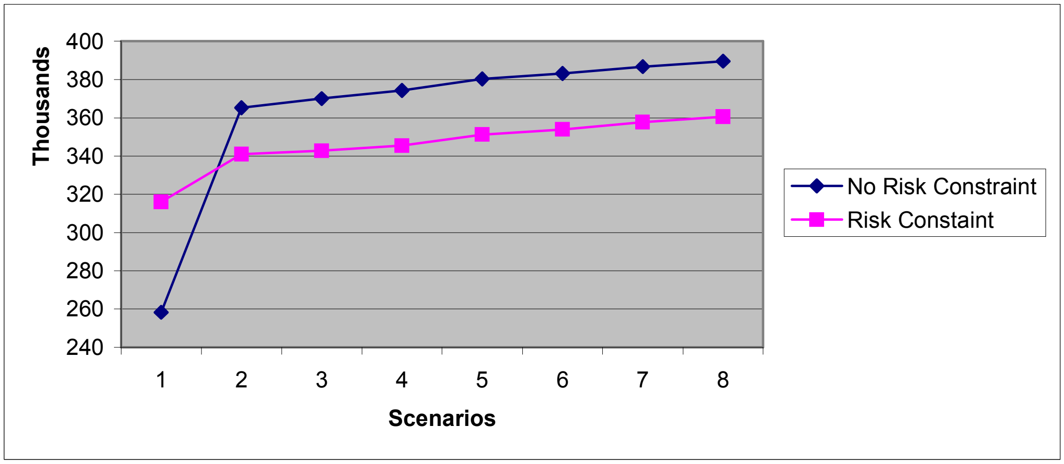

Figure 2: Profit over Scenarios

In situations involving large amounts of capital investments, the associated downside risk must be controlled. The risk is defined as to control the situations where the profit cannot recede below a threshold. The graph shows the profit under two approaches, first with risk constraint and second without risk constraint. The no risk constraint yields an expected profit of \$3, 67,665 and with the risk constraint the expected profit went down to \$3,45,108. This lower in profit is justified by reduction in the variability in profit as shown in Figure 2. The risk constraint also ensures a minimum level of profit in any realized scenario.

4.0 CONCLUSIONS

We have developed a multi period SCP model for new product launches under uncertain demand for supply chain network structure. Our model allows simultaneous determination of optimum supply chain design, optimum procurement quantity, production quantity across the different plants, transportation routes under different service level imposed. The proposed multi-stage model is compared with the standard two-stage model by examining the difference between the objective values of two solutions. On an average for four data sets the value of multistage stochastic programming is found to be good (of the order of 7%) as compare to two-stage programming model. Generally supply chain costs are in millions of dollars and a saving of 7% is significant. This clearly shows the importance of multistage model as compared to two-stage programming model.

Three different sets of objectives were evaluated to see the effect of different drivers on total expected revenue and profit from the supply chain. These trade off helps the management to explore the different potential solutions and depending on his experience and other practical factors the decision makers can choose the best solution from the efficient set of solutions.

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