A GENETIC ALGORITHM BASED OPTIMIZATION APPROACH FOR PRODUCTION-DISTRIBUTION PROBLEM

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Abstract - Production-Distribution planning (PDP) is a tactical decision problem for Supply Chain Systems (SCS). It aims to optimize supply, production and distribution systems of a chain. In this study, a PDP for a multi-echelon SCS which has suppliers, plants, warehouses, retailers has been considered. A, 0 – 1 mix integer programming model has been developed for the PDP. The mathematical model can be solved global optimal for small size problems. However, it is not possible to solve PDP when the numbers of suppliers, plants, products, warehouses, retailers and transportation paths increase. In this study, a Genetic Algorithm based optimization (GA) has been developed to solve large size PDP. The proposed GA algorithm has been tested for small size PDPs. The results showed that the proposed GA algorithm is successful in finding solutions within of 4 % of known optimal solutions. Then, it has been tested on a randomly generated large size PDP which cannot be solved by optimization software.

Keywords: Production Distribution, Supply Chain System, Genetic Algorithm.

I. INTRODUCTION

Production-Distribution Planning is a critic decision-making process for aggregate production planning and distribution planning. Therefore, there is a significant literature on PDP. The researchers have studied on a different type of PDP. [1, 2] focused on deterministic PDP, [3, 4] considered stochastic PDP and [5, 6] handled fuzzy PDP. The number of echelons in the SCS directly affects the hardiness of the problem. The PDP model can be divided several categories from one echelon to four echelons with single or multi products, single or multi transportation path and single or multi-time periods [7 - 14]. Those PDP have been solved by using different techniques such as mathematical programming [15], simulation [16] and heuristic [17].

In this paper, we proposed a GA based solution approach for multi-suppliers, multi-product, multi-plant, multi-warehouse, multi-retailers, multi-transport paths and multi-time periods PDP which is an NP-hard problem for big size SCS.

II. 0-1 MIX INTEGER MODEL FOR PDP

The mathematical model considered in this paper given as follows:

Parameters

RUP_{ist} : Unit price of raw material I in supplier s at period t
RC_{ist} : total amount of raw material i on hand in supplier s at period t
$TCSP_{spkt}$:total capacity of transport path k from supplier s to plant p at period t
$FTCS_{spkt}$:fixed cost of using path k from supplier s to plant p at period t
$VTCS_{ispkt}$: unit transportation cost of raw material I from supplier s to plant p by using path k at period t
RRC_i : required capacity to transport a unit raw material i
RRM_{ij} : required amount of raw material I for unit product j
IRC_i : required capacity to store a unit raw material i
TSC_p : inventory capacity in plan p for raw for raw materials
SRC_{ipt} : unit holding cost of raw material I in plant p at period t
UPT_{jpt} : unit production time of product j in plant p at period t
RPC_{jpt} : unit production cost of product j in regular time in plant p at period t
ARC_{pt} : available regular capacity (time) in plant p at period t
OPC_{jpt} : unit production cost of product j in overtime in plant p at period t
AOC_{pt} : available overtime capacity (time) in plant p at period t
PHC_{jpt} : unit holding cost of product j in plant p at period t
$TCPW_{pwkt}$: transportation capacity of path k from plant p to warehouse w at period t
$FTCP_{pwkt}$: fixed cost of using path k from plant p to warehouse w at period t
$VTCP_{jpwkt}$: unit transportation cost of product j from plant p to warehouse w by using path k at period t
RTC_j : required capacity to transport a unit product j
$TCWR_{wrkt}$: transportation capacity of path k from warehouse w to retailer r at period t
$FTCW_{wrkt}$: fixed cost of using path k from warehouse w to retailer r at period t
$VTCW_{jwrkt}$: unit transportation cost of product j from warehouse w to retailer r by using path k at period t
WHC_{jwt}: unit holding cost of product j in warehouse w at period t
WIC_w: inventory capacity in warehouse w

HCR_{jrt} : unit holding cost of product j in retailer r at period t
RIC_{r}: inventory capacity in retailer r
BCR_{jrt} : backorder cost of product j in retailer r at period t
CDP_{jrt}: total demand of customer c for product j from retailer r at period t
POP_{jt}: price of product j at period t

Decision Variables

TRQ_{ispkt} : quantity of raw material I transported from supplier s to plant p by using path k at period t
SRP_{ipt} : inventory level of raw material I stored in plant p at the end of the period t
RPQ_{jpt} : quantity of product j manufactured at regular time in plant p at period t
OPQ_{jpt} : quantity of product j manufactured at overtime in plant p at period t
$TPQP_{jpwkt}$: quantity of product j transported from plant p to warehouse w by using path k at period t
SLP_{jpt} : inventory level for product j in plant in plant p at the end of the period t
SLW_{jwt} : inventory level for product j in warehouse w at the end of the period t
$TPQW_{jwrkt}$: quantity of product j transported from warehouse w to retaier r by using path k at period t
SLP_{jrt} : inventory level for product j in retailer r at the end of the period t
BLR_{jrtc} : backorder level for product j in retailer r for customer c at the end of the period t
SPQ_{jrtc} : quantity of product j sold from retailer r to customer c at period t
UKS_{spkt} : 1 if path k is used between supplier s and plant p at period t, 0 otherwise
UKP_{pwkt} : 1 if path k is used between plant p and warehouse w at period t, 0 otherwise
UKW_{wrkt} : 1 if path k is used between warehouse w and retailer r at period t, 0 otherwise

$$\begin{aligned} Max\ Z = & \left[\sum_{t=1}^{T}\sum_{j=1}^{J}\left(POP_{jt} * \sum_{c=1}^{C}\sum_{r=1}^{R} SPQ_{jrtc}\right)\right] - \left[\sum_{t=1}^{T}\sum_{s=1}^{S}\sum_{i=1}^{I}\left(RUP_{ist} * \sum_{p=1}^{P}\sum_{k=1}^{K} TRQ_{ispkt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{s=1}^{S}\left(FTCS_{spkt} * UKS_{spkt}\right)\right] \\ & - \left[\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{p=1}^{P}\sum_{s=1}^{S}\sum_{i=1}^{I}\left(VTCS_{ispkt} * TRQ_{ispkt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{i=1}^{I}\left(SRC_{ipt} * SRP_{ipt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{j=1}^{J}\left(RPC_{jpt} * RPQ_{jpt}\right)\right] \\ & - \left[\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{j=1}^{J}\left(OPC_{jpt} * OPQ_{jpt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{p=1}^{P}\sum_{j=1}^{J}\left(PHC_{jpt} * SLP_{jpt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{w=1}^{W}\sum_{p=1}^{P}\left(FTCP_{pwkt} * UKP_{pwkt}\right)\right] \\ & - \left[\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{w=1}^{W}\sum_{p=1}^{P}\sum_{j=1}^{J}\left(VTCP_{jpwkt} * TPQP_{jpwkt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{w=1}^{W}\sum_{j=1}^{J}\left(WHC_{jwt} * SLW_{jwt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{w=1}^{W}\left(VTCW_{wrkt} * UKW_{wrkt}\right)\right] \\ & - \left[\sum_{t=1}^{T}\sum_{k=1}^{K}\sum_{r=1}^{R}\sum_{w=1}^{W}\sum_{j=1}^{J}\left(VTCW_{jwrkt} * TPQW_{jwrkt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{j=1}^{J}\left(HCR_{jrt} * SLR_{jrt}\right)\right] - \left[\sum_{t=1}^{T}\sum_{r=1}^{R}\sum_{j=1}^{J}\left(BCR_{jrt} * \left(\sum_{c=1}^{C} BLR_{jrtc}\right)\right)\right] \end{aligned} \quad (1)$$

s.t.

$$\sum_{k=1}^{K}\sum_{p=1}^{P} TRQ_{ispkt} \le RC_{ist} \qquad \forall i, \forall s, \forall t \quad (2)$$

$$\sum_{i=1}^{I}\left(RRC_{i} * TRQ_{ispkt}\right) \le \overline{TCSP}_{spkt} + \left(1 - UKS_{spkt}\right) * M \qquad \forall s, \forall p, \forall k, \forall t \quad (3)$$

$$\sum_{i=1}^{I}\left(RRC_{i} * TRQ_{ispkt}\right) \le UKS_{spkt} * M \qquad \forall s, \forall p, \forall k, \forall t \quad (4)$$

$$\left(\sum_{k=1}^{K}\sum_{s=1}^{S} TRQ_{ispkt} + SRP_{ip(t-1)}\right) - \sum_{j=1}^{J}\left(RRM_{ij} * \left(RPQ_{jpt} + OPQ_{jpt}\right)\right) = SRP_{ipt} \qquad \forall i, \forall p, \forall t \quad (5)$$

$$\sum_{j=1}^{J}\left(UPT_{jpt} * RPQ_{jpt}\right) \le ARC_{pt} \qquad \forall p, \forall t \quad (6)$$

$$\sum_{j=1}^{J}\left(UPT_{jpt} * OPQ_{jpt}\right) \le AOC_{pt} \qquad \forall p, \forall t \quad (7)$$

$$\sum_{j=1}^{J}\left(RHC_{j} * SLP_{jpt}\right) \le PIC_{p} \qquad \forall p, \forall t \quad (8)$$

$$RPQ_{jpt} + OPQ_{jpt} + SLP_{jp(t-1)} - \sum_{k=1}^{K}\sum_{w=1}^{W} TPQP_{jpwkt} = SLP_{jpt} \qquad \forall j, \forall p, \forall t \quad (9)$$

$$\sum_{j=1}^{J}\left(RTC_{j} * TPQP_{jpwkt}\right) \le \overline{TCPW}_{pwkt} + \left(1 - UKP_{pwkt}\right) * M \qquad \forall p, \forall w, \forall k, \forall t \quad (10)$$

$$\sum_{j=1}^{J}\left(RTC_j * TPQP_{jpwkt}\right) \le UKP_{pwkt} * M \qquad \forall p, \forall w, \forall k, \forall t \tag{11}$$

$$\sum_{k=1}^{K}\sum_{p=1}^{P} TPQP_{jpwkt} + SLW_{jw(t-1)} - \sum_{k=1}^{K}\sum_{r=1}^{R} TPQW_{jwrkt} = SLW_{jwt} \qquad \forall j, \forall w, \forall t \tag{12}$$

$$\sum_{j=1}^{J}\left(RHC_j * SLW_{jwt}\right) \le WIC_w \qquad \forall w, \forall t \tag{13}$$

$$\sum_{j=1}^{J}\left(RTC_j * TPQW_{jwrkt}\right) \le \overline{TCWR}_{wrkt} + \left(1 - UKW_{wrkt}\right) * M \qquad \forall w, \forall r, \forall k, \forall t \tag{14}$$

$$\sum_{j=1}^{J}\left(RTC_j * TPQW_{jwrkt}\right) \le UKW_{wrkt} * M \qquad \forall w, \forall r, \forall k, \forall t \tag{15}$$

$$\sum_{k=1}^{K}\sum_{w=1}^{W} TPQW_{jwrkt} + SLR_{jr(t-1)} - \sum_{c=1}^{C} SPQ_{jrtc} = SLR_{jrt} - \sum_{c=1}^{C} BLR_{jrtc} \qquad \forall j, \forall r, \forall t \tag{16}$$

$$\sum_{j=1}^{J}\left(RHC_j * SLR_{jrt}\right) \le RIC_r \qquad \forall r, \forall t \tag{17}$$

$$SPQ_{jrtc} \le \overline{\overline{CDP}}_{jrtc} \qquad \forall j, \forall r, \forall t, \forall c \tag{18}$$

$$\begin{aligned} &TRQ_{ispkt}, SRP_{ipt}, RPQ_{jpt}, OPQ_{jpt}, SLP_{jpt}, TPQP_{jpwkt} \ge 0 \\ &SLR_{jrt}, BLR_{jrtc}, SPQ_{jrtc}, SLW_{jwt}, TPQW_{jwrkt} \ge 0 \\ &UKS_{spkt}, UKP_{pwkt}, UKW_{wrkt} = 0, 1 \end{aligned} \tag{19}$$

The objective function, given in Eq. 1, maximizes the total profit. Eq. 2 is a capacity constraint for the supplier that ensures the total transported quantity from supplier s for material i at each period will be less than or equal to total capacity. Eq. 3 and 4 are constructed to select the transportation path from supplier to plant and not to exceed its capacity where M is a big number. Eq. 5 is an inventory balance constraint for the raw material in a plant. Eq. 6, 7 and 8 are capacity constraints for regular production, overtime production and inventory level in plants respectively. Eq. 9 is an inventory balance constraint for the product in a plant. Eq. 10 and 11 are designed to select the transportation path from a plant to the warehouse and not to exceed its capacity. Eq. 12 is an inventory balance constraint in a warehouse. Eq. 13 is an inventory capacity constraint for a warehouse. Eq. 14 and 15 are designed to select the transportation path from a warehouse to the retailer and not to exceed its capacity. Eq. 16 is a balance constraint for inventory and backorder level. Eq. 17 is an inventory capacity constraint for a retailer. Eq. 18 ensures to meet customer demand. Eq. 19 is the definitions of the decisions variables.

III. PROPOSED SOLUTION APPROACH

Genetic Algorithms (GAs) are nature-inspired evolutionary search algorithms based on natural selection and genetics [65]. GA process for maximization problem is given in Table 1.

The proposed GA based optimization algorithm has been testedon problem that includes forty suppliers (s=40) twelve raw materials (i=12), three plants (p=3), three products (j=3), twelve warehouses (w=12), forty retailers (r=40) and four transportation paths between each of echelons (supplier-plant, plant-warehouse, warehouse-retailer). The solutions are given in Fig. 1 where the iteration process is limited to 1000. According to this solution, total profit will be 68855275 Turkish liras.

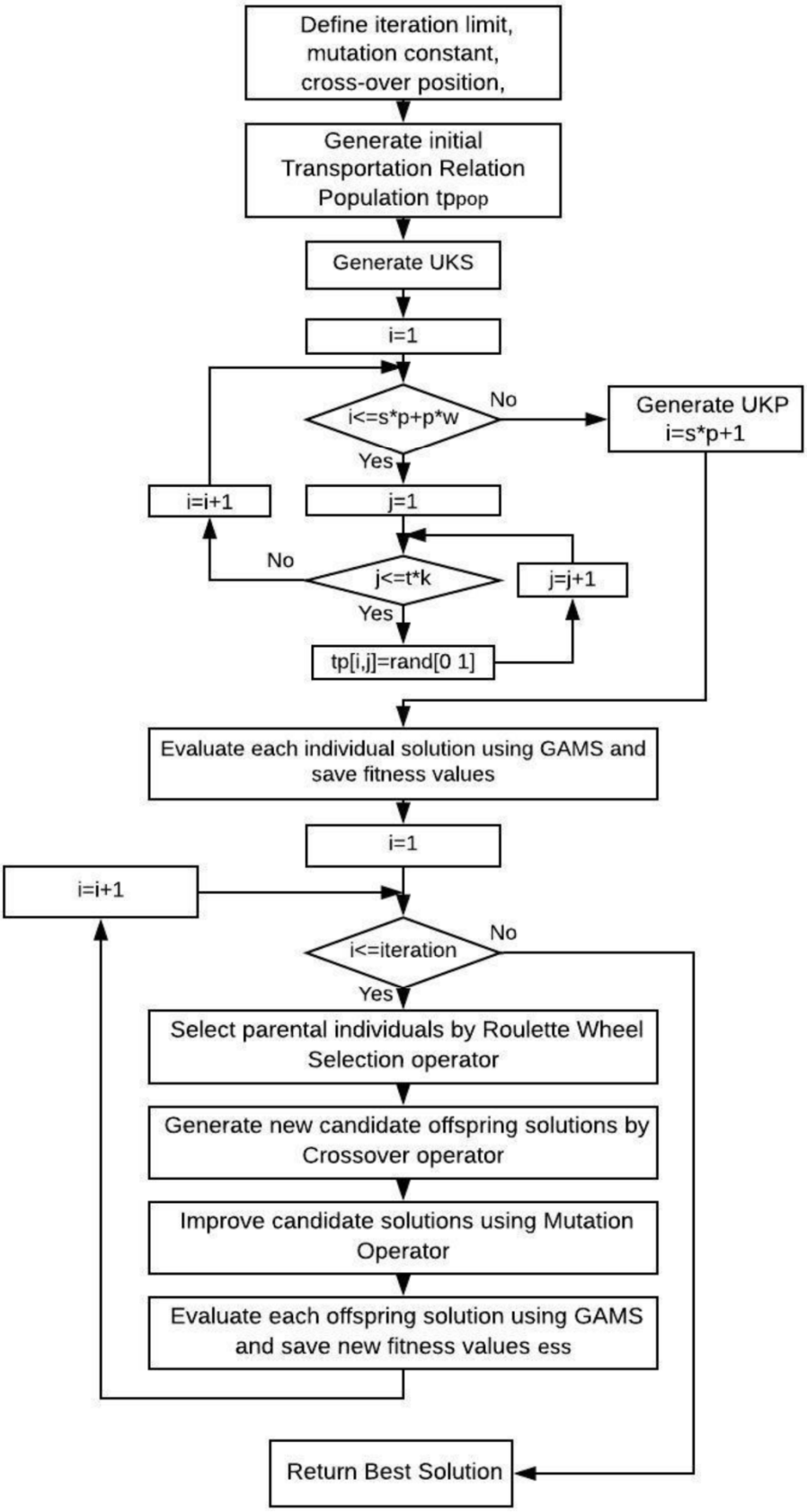


Table 1. The flowchart of the proposed GA

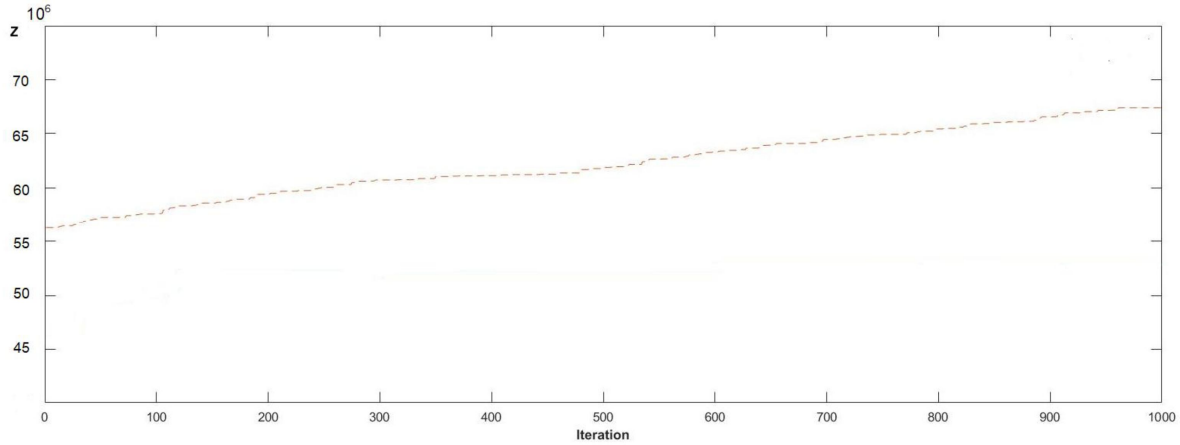


Fig.1. Maximization process of the Z

CONCLUSION

In this study, the solution approach for PDP which has four echelons (suppliers, plants, warehouses,and retailers) with multi-products, multi transportation paths and multi-time periodsis researched. The selection of transportation paths is modeled as binary variables. When the numbers of echelons in SCS increase, the number of binary variables exponentiallyincrease. Therefore, the problem converts into an NP-hardoptimization problem which is a challenge for big size SCS.

A Genetic Algorithm based optimization approaches have been developed has been implemented on a test problem which is a large size. The solutions show that the proposed solution approaches produce a robust solution for PDP in large size SCS.

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