Designing a Multistage Reverse Logistics Network Problem by Hybrid Genetic Algorithm

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ABSTRACT

We formulate a mathematical model of remanufacturing system as multistage reverse Logistics Network Problem (mrLNP) with minimizing the total costs for reverse logistics. The total costs for reverse logistics include shipping cost, fixed cost of opening the disassembly centers and processing centers and inventory holding cost at these centers over finite planning horizons. In this paper, we formulate the mrLNP model as a three stage logistics network model. For solving this problem, in the 1st and the 2nd stages, we propose a Genetic Algorithm (GA) with priority-based encoding method combined with a new crossover operator called as Weight Mapping Crossover (WMX). Additionally also a heuristic approach is applied in the 3rd stage where parts are transported from some processing centers to one manufacturer.

Categories and Subject Descriptors

G.2.3 [**Mathematics of Computing**]: DISCRETE MATH-EMATICS-*Applications*; G.2.2 [**Mathematics of Computing**]: DISCRETE MATHEMATICS-*Graph Theory*

General Terms

Algorithms, Design.

Keywords

Genetic Algorithm; multistage reverse Logistics Network Problem; priority-based encoding method; Weight Mapping Crossover.

1. INTRODUCTION

Recycling problem can affect not only a cost performance of recycling of a company, but also whole strategy of the company including production strategy and purchase policy. To deal with this problem the government should treat it as a part of industry [1]. In this paper, we consider a complex reverse logistics problem (rLP). This rLP is combined with three reverse processes, *i.e.*, retuning process, disassembly process and processing process. In the practical reverse logistics problems, the different parts should be assigned different processing processes based on the processing competence of the processing center. For this reason, the challenges of our study are both in the mathematical formulation and effective approach construction. Firstly, we

formulate this reverse logistics problem as a multistage network model with considering the practical logistics constraints. Following, for solving this multistage logistics model, we introduced a priority-based GA approach, which was proposed with Gen and Cheng. [2]. Difference with Gen et al.`s priority-based GA, includes the extension of priority-based encoding method to apply multistage logistics model with multi-parts assignment constraint in 1st and 2nd stage, and combine a heuristic approach in the 3rd stage between the processing center to the manufacturer). Lastly, we compare our GA approach with Prüfer number-based GA (pnGA), which is most used approach in logistics models.

2. MAHEMATICAL FORMULATION

In this Section, we consider constituents, variables, and assumptions for formulating a multistage logistics network model.

We make the following assumptions of this mrLNP:
   A1. We consider logistics network for treating single product.
   A2. If one product is disassembled then two parts are obtained.
   A3. The parts that are possible to disassemble are given.
   A4. We consider the inventory factor at disassembly center and processing center over finite planning horizons.
   A5. The demand of parts by manufacturer is known in advanced.
   A6. The maximum capacities about four echelons are known:
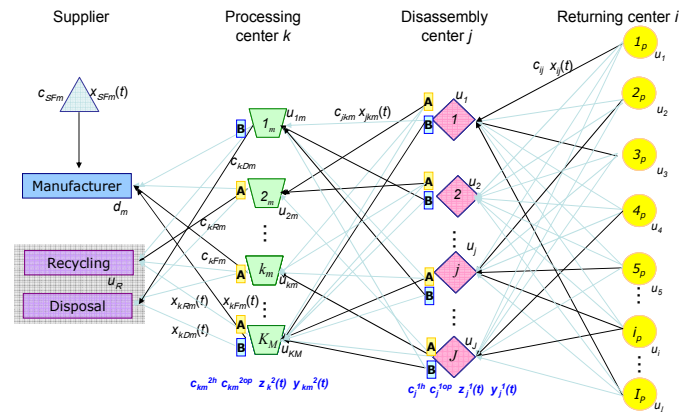   returning centers, disassembly centers, processing centers and manufacturer.

Figure 1. Multistage reverse logistics network model

The mathematical model of the problem is:

$$\min \; z = \sum_{t=0}^{T}\left[\sum_{i=1}^{I}\sum_{j=1}^{J} c_{ij} x_{ij}(t) + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{m=1}^{M} c_{jkm} x_{jkm}(t) + \sum_{k=1}^{K}\sum_{m=1}^{M} c_{kFm} x_{kFm}(t) \right.$$
$$- \sum_{k=1}^{K}\sum_{m=1}^{M} c_{kRm} x_{kRm}(t) + \sum_{k=1}^{K}\sum_{m=1}^{M} c_{kDm} x_{kDm}(t) + \sum_{m=1}^{M} c_{SFm} x_{SFm}(t)$$
$$+ \sum_{j=1}^{J} c_j^{1h} y_j^1(t) + \sum_{k=1}^{K}\sum_{m=1}^{M} c_{km}^{2h} y_{km}^2(t) + \sum_{j=1}^{J} c_j^{1op} z_j^1 + \sum_{k=1}^{K} c_k^{2op} z_k^2 \left. \right] \qquad (1)$$

s. t. $\quad x_{SFm}(t) + \sum_{k=1}^{K} x_{kFm}(t) \ge d_m, \quad \forall m, t \qquad (2)$

$\sum_{j=1}^{J} x_{ij}(t) + y_j^1(t-1) \le u_j z_j^1, \quad \forall j, t \qquad (3)$

$\sum_{k=1}^{K} x_{jkm}(t) + y_{km}^2(t-1) \le u_{km} z_k^2, \quad \forall k, m, t \qquad (4)$

$x_{kRm}(t) \le u_R, \quad \forall k, m, t \qquad (5)$

$\sum_{j=1}^{J} z_j^1(t) \le J, \quad \forall t \qquad (6)$

$\sum_{k=1}^{K} z_k^2(t) \le K, \quad \forall m, t \qquad (7)$

$x_{ij}(t), \; x_{jkm}(t), \; x_{kFm}(t), \; x_{kRm}(t), \; x_{kDm}(t), \; x_{SFm}(t) \ge 0 \quad (8)$

$z_j^1, z_k^2 \in \{0,1\} \qquad (9)$

3. HYBRID GENETIC ALGORITHM

We here adopt the priority-based encoding method developed Gen, Altiparmak and Lin [3]. Although this encoding had been successfully applied on shortest path problem and project scheduling problem, the difference of our approach comes from the facts that of special decoding and encoding procedures for transportation trees. The priority-based encoding method is an indirect approach. In this method, a gene in chromosome contains two kinds of information: the locus, the position of the gene within the structure of a chromosome, and the allele, the value the gene takes. The position of a gene is used to represent a node (source depot), and the value is used to represent the priority of the node for constructing a tree among candidates.

For a transportation problem, a chromosome consists of priorities of sources and depots to obtain transportation tree and its length is equal to total number of sources m and depots n, *i.e.* m+n. The transportation tree corresponding with a given chromosome is generated by sequential arc appending between sources and depots. At each step, only one arc is added to tree selecting a source (depot) with the highest priority and connecting it to a repot (source) considering minimum cost.

For mrLNP, we use two priority-based encodings to represent the transportation trees on stages. This means that each chromosome in the population consists of two parts. While the first part (i.e. the first priority-based encoding) represents transportation tree between return centers and disassembly centers, the second part (i.e. the second priority-based encoding) represents transportation tree between disassembly centers and processing centers. The detailed encoding and decoding process of a chromosome consists of three main phase:

Phase 1: Coding process on 1st stage
Step 1.1: Priority-based encoding from returning center to
disassembly center
Step 1.2: Decoding from returning center to disassembly center
Phase 2: Coding process on 2nd stage
Step 2.1: Priority-based encoding from disassembly center to
processing center
Step 2.2: Decoding from disassembly center to processing
center

Phase 3: A heuristic approach in the 3rd stage
1) **Crossover Operator:** We proposed a new crossover operator, weight mapping crossover (WMX). WMX is same as that of the conventional one-cut point crossover can generate two new paths that exchanged sub-route from two parents.
2) **Mutation Operator:** In this study, insertion mutation has been adopted. Insertion mutation selects a gene at random and inserts it in a random position.

4. EXPERIMENT AND DISCUSSION

We used using pnGA (Prüfer number-based GA) proposed by Syarif and Gen [4], to study the effectiveness of the developed GA with new encoding method (priGA). The number of returning centers changes between 4 and 30, number of disassembly centers and number of processing centers changed between 3-15, and 3-20, respectively. The transportation costs, demand of parts, capacitates of returning centers, disassembly processes, processing processes, recycles and manufacturer are randomly generated to provide realistic scenarios.

Numerical experiments demonstrated the efficiency and effectiveness of the hybrid GA approach for solving the mrLNP problems. Although memory requirement for new representation was greater than pnGA, i.e., Prüfer number-based GA, only 2 digits for each stage in transportation problem, this representation got very important two advantages in the real world applications. One of them was that its implementation was very easy. Another one was that after genetic operators, always feasible solutions were obtained. Based on this study, it was seen that the hybrid priGA with WMX demonstrated the best performance according to solution quality.

Table. 1 Computational results with pnGA and priGA

Problems No.	stage	no. of constraints	no. of shipping variables	pnGA			priGA		
				Best	Average	ACT	Best	Average	ACT
1	stage 1	1275	975	35650	35650	0.65	35650	35650	0.65
	stage 2			43200	43200	0.60	43200	43200	0.65
	stage 3			50100	50100	-	50100	50100	-
	total			**128950**	**128950**	**1.25**	**128950**	**128950**	**1.30**
2	stage 1	2505	2055	53795	54710	0.90	53490	54250	1.00
	stage 2			48270	50180	0.95	47370	49800	0.95
	stage 3			75500	75500	-	75500	75500	-
	total			**177565**	**180390**	**1.85**	**176360**	**179550**	**1.95**
3	stage 1	8745	7800	86300	88006	6.10	82920	85273	6.05
	stage 2			81480	81661	6.80	80730	83223	6.00
	stage 3			110050	110050	-	110050	110050	-
	total			**277830**	**279717**	**12.90**	**273700**	**278546**	**12.05**
4	stage 1	20430	18930	195895	199381	13.05	189765	193995	12.30
	stage 2			198915	205788	9.40	192900	199822.5	10.75
	stage 3			237675	237675	-	237675	237675	-
	total			**632485**	**642844**	**22.45**	**620340**	**631492.5**	**23.05**

5. REFERENCES

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