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Hybrid resolution approaches for dynamic assignment problem of reusable containers

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Abstract. In this study, we are interested in the reusing activities of reverse logistics. We focus on the dynamic assignment of reusable containers problem (e.g. gas bottles, beverages, pallets, maritime containers, etc.). The objective is to minimize the collect, reloading, storage and redistribution operations costs over a fixed planning horizon taking into account the greenhouse gas emissions. We present a new generic Mixed Integer Programming (MIP) model for the problem. The proposed model was solved using the IBM ILOG CPLEX optimization software; this method yield exact solutions, but it is very time consuming. So we adapted two hybrid approaches using a genetic algorithm to solve the problem at a reduced time (The second hybrid approach is enhanced with a local search procedure based on the Variable Neighborhood Search VNS). The numerical results show that both developed hybrid approaches generate high-quality solutions in a moderate computational time, especially the second hybrid method.

1 Introduction

To meet environmental and economic requirements, supply chain management (SCM) is no longer limited to direct flow management but it includes also the returns flow problems. Reverse logistics is a quite vast field, since the returned products appear in many types of recovery such as remanufacturing, recycling, reusing… (Hanafi et al., [1]). In this study, we are interested in the reusing activity (using a product more than once). The product concerned by our research is the reusable container due to its economic and environmental importance (Bhattacharjya et al. [2]).

The reusable containers require normally certain treatments before they are redistributed, thus reusing containers problem addressed in our research is not limited only to a simple recovery and transportation; it is a logistic system that involves also the cleaning and reloading of containers, as well as their storage and redistribution.

Producers in several countries are facing increasing market pressures to use ecological packaging. Castillo et al. [3] formulate an optimal configuration for the reusable bottle production and distribution activities of a large soft drink manufacturer located in Mexico City. Goudenege et al. [4] propose a generic model for reverse logistics management focused on reusable containers. The authors adapt the model to the specific requirements of companies. Atamer et al. [5] present a study that emphasizes on pricing and production decisions while treating reusable containers with stochastic customer demand. Accorsi et al. [6] propose an original conceptual framework for the integrated design of a food packaging and distribution network. The paper compares a multi-use system to a traditional single-use packaging in order to quantify the economic returns and the environmental impacts of the reusable plastic container (RPC). In the same sense, evaluating the environmental impact is one of the aims of the green supply chain. The signed Kyoto protocol engage many countries and companies as a consequence to a carbon emission quota. Several methodologies are used to calculate carbon emissions (Retel Helmrich et al. [7]). Absi et al. [8] propose four types of carbon emission constraints (Periodic, cumulative, global and rolling) for the multi-sourcing lot-sizing problem, which can be used and adapted to several cases. In this study, we propose a generic mathematical model that helps companies minimizing transportation, storage, containers reloading and investment costs. The model proposes a flow management concerning the reusable containers between the warehouses and the stores. The full delivered containers are consumed and recuperated empty thereafter by the warehouses to be reloaded and redistributed again to the stores on a fixed planning horizon. The mathematical model takes into consideration the carbon emission constraint during the distribution and collection activities.

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2 Mathematical model:

$$\text{TransC}=\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{t=1}^{T}\left(\left(Z_{i,j,t}*pur_{i,j}\right)+\left(Y_{i,j,t}*recov_{i,j}\right)+\begin{pmatrix}(XF_{i,j,t}+XE_{i,j,t})\\ *trans_{i,j}*dist_{i,j}\end{pmatrix}\right)$$

$$\text{HoldC}=\sum_{i=1}^{N}\sum_{t=1}^{T}\left(\left(IFW_{i,t}*h_{f_{w_i}}\right)+\left(IEW_{i,t}*h_{e_{w_i}}\right)\right)+$$
$$\sum_{j=1}^{M}\sum_{t=1}^{T}\left(\left(IFC_{j,t}*h_{f_{c_j}}\right)+\left(IEC_{j,t}*h_{e_{c_j}}\right)\right)+\sum_{i=1}^{N}\begin{pmatrix}\left(IOEW_i*h_{e_{w_i}}\right)+\\ \left(IOFW_i*h_{f_{w_i}}\right)\end{pmatrix}$$

$$\text{ProdC} = \sum_{i=1}^{N}\sum_{t=1}^{T}\left(Q_{i,t}*Prod\_cost_i\right)$$

The integrated planning model is shown in the following:

$$\text{Min (TransC+HoldC + ProdC)} \tag{1}$$

Subject to:

$$IFW_{i,1} = IOFW_i + Q_{i,1-Delay} - \sum_{j=1}^{M}\left(XF_{i,j,1}\right)\ \forall i, (\forall Delay < 1 \mathit{if\ not}\ Q = 0) \tag{2}$$

$$IFW_{i,t} = IFW_{i,t-1} + Q_{i,t-Delay} - \sum_{j=1}^{M}\left(XF_{i,j,t}\right)\ \forall i, (\forall t > Delay, \text{if not } Q = 0) \tag{3}$$

$$IEW_{i,1} = IOEW_i - Q_{i,1} + \sum_{j=1}^{M}\left(XE_{i,j,1}\right)\ \forall i \tag{4}$$

$$IEW_{i,t} = IEW_{i,t-1} - Q_{i,t} + \sum_{j=1}^{M}\left(XE_{i,j,t}\right)\ \forall i \tag{5}$$

$$IFC_{j,1} = IOFC_j - dem_{j,1} + \sum_{i=1}^{N}\left(XF_{i,j,1-d_{j,i}}\right)\ \forall j, (\forall d_{j,i} < 1\ \mathit{ifnot}\ XF = 0) \tag{6}$$

$$IFC_{j,t} = IFC_{j,t-1} + \sum_{i=1}^{N}\left(XF_{i,j,t-d_{j,i}}\right) - dem_{j,t}\ \ \forall j, \forall t > 1, (\forall d_{j,i} < t \text{ else } XF = 0) \tag{7}$$

$$IEC_{j,1} = IOEC_j - \sum_{i=1}^{N}\left(XE_{i,j,1+d_{j,i}}\right)\ \forall j, (\forall d_{j,i} < T \text{else } XE = 0) \tag{8}$$

$$IEC_{j,t} = IEC_{j,t-1} - \sum_{i=1}^{N}\left(XE_{i,j,t+d_{j,i}}\right) + dem_{j,t-1}\ \ \forall j,\ \forall t > 1, \left(\forall d_{j,i} \le T - t \text{ else } XE = 0\right) \tag{9}$$

$$\sum_{i=1}^{N}\sum_{j=1}^{M}\sum_{t=1}^{T}\left(\left(XF_{ijt} + XE_{i,j,t}\right) * CO2 * dist_{i,j}\right) \le Emax * \sum_{j=1}^{M}\sum_{t=1}^{T} dem_{j,t} \tag{10}$$

$$XF_{ijt} \le H * Z_{i,j,t}\ \ \forall i, \forall j,\ \forall t \tag{11}$$

$$XE_{ijt} \le H * Y_{i,j,t}\ \forall i, \forall j, \forall t \tag{12}$$

$$IFW_{it} + IEW_{it} \le s\_c\_w_i\ \forall i,\ \forall t \tag{13}$$

$$IFC_{jt} + IEC_{jt} \le s\_c\_c_j\ \forall j,\ \forall t \tag{14}$$

$$XE_{ijt}, XF_{ijt}, IFW_{it}, IEW_{it}, IFC_{jt}, IEC_{jt}, IOFW_i, IOEW_i, Q_{i,t} \ge 0 \tag{15}$$

The objective function (1) calculate the solution fitness. It minimizes the transportation, reloading, investment and holding cost of reusable containers between warehouses and stores. Constraints (2& 3) and (4 & 5) are respectively the inventory flow conservation equations for full and empty reusable containers in the warehouses. Constraints (6 & 7) and (8 & 9) are respectively the inventory flow conservation equations for full and empty reusable containers in the stores. Constraint (10) presents the unitary carbon emission over the whole horizon that cannot be larger than the maximum unitary environmental impact allowed. Constraints (11) and (12) guarantee respectively the cancellation of full and empty reusable containers deliveries when no delivery is programmed. Constraints (13) and (14) guarantee respectively the respect of the inventory capacity of the warehouses and stores.

3 Solving approaches

3.1 Hybrid algorithm 1 (HA1)

In this section, we propose an approach made of hybridization between an evolutionary algorithm (the genetic algorithm) and an exact resolution (the mixed integer programming) to solve the problem in a moderate computational time. Some interesting applications of GA are presented by Supithak et al. [9], Rezaei et al. [10], and Zouadi et al. [11].

3.1.1 Solution encoding

The proposed binary encoding in Figure 1 presents 3-dimensional vectors which are the period of the planning horizon (T), the warehouses number (N) and the double of the stores number (2×M), which constitutes the collect and the distribution parts. In the first part of the vector, we find the reusable containers deliveries binary decision variables between the warehouses and the stores over the planning horizon. While in the second part of the vector, we have the reusable containers collection binary decision variables.

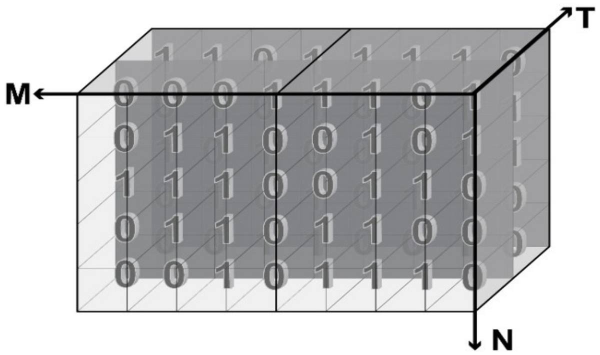

Fig. 1. Solution presentation

3.1.2 Crossover

Following the nature of the solutions encoding, we proposes a new crossover operator to cross the two different 3-dimensional offsprings. The proposed crossover is presented in the Figure 2.

The proposed crossover operator consists of splitting the 3-dimensional vectors into T matrix (2-dimensional vectors), in a way that each matrix presents the full reusable containers deliveries and the empty reusable containers collection binary decisions over a period *t*. The crossover operator consists of crossing randomly two matrixes issued from two parents using one of the crossing operators proposed by Toledo et al. [12].

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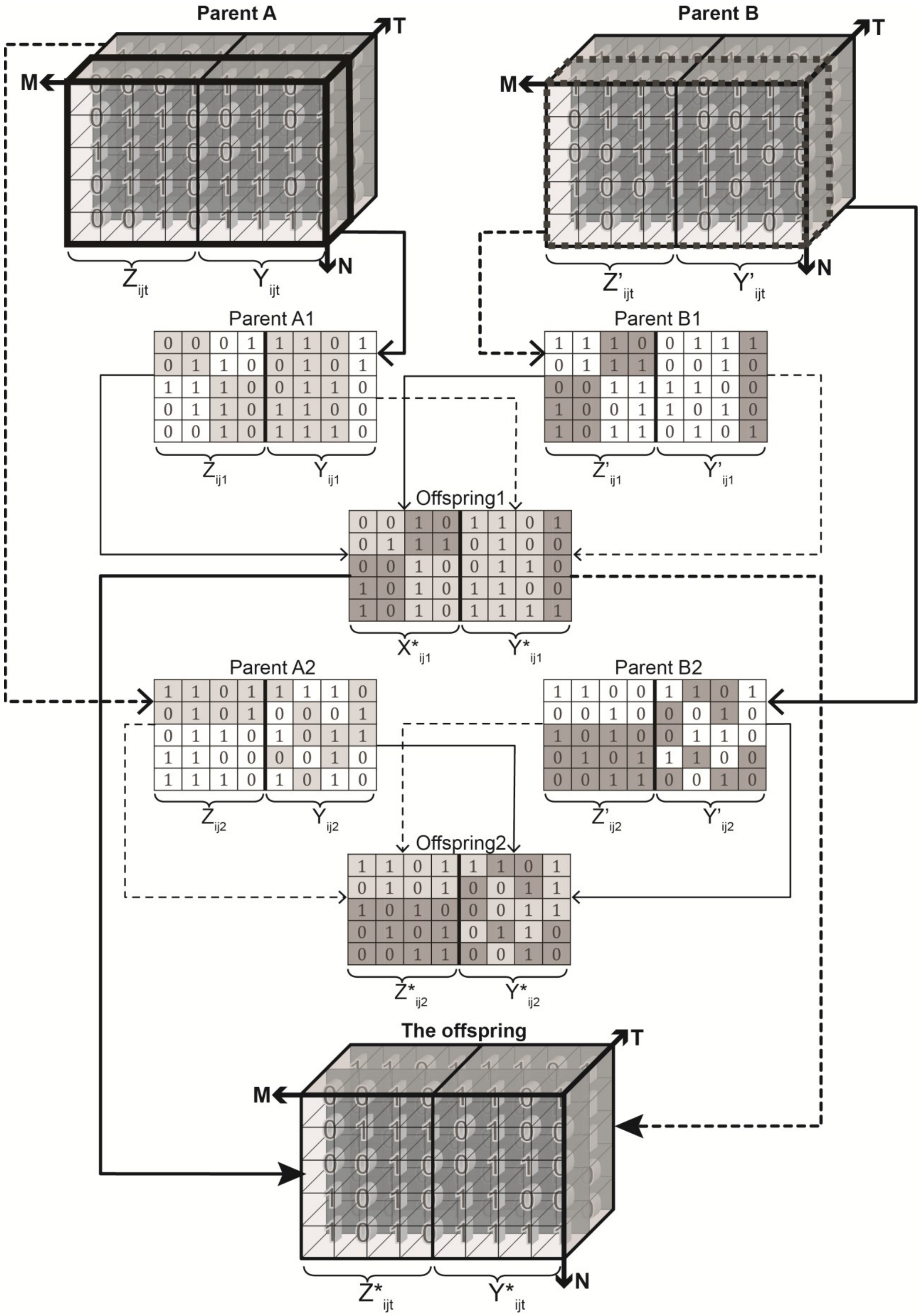

Fig. 2. Crossover operator

In the example presented in the Figure 2, all of the two 3-dimensional vectors (Parent A, Parent B) are divided into two matrixes {(PA1, PA2) ;(PB1, PB2)} representing the deliveries and collection decision variables of the two period of the planning horizon (T). The crossover operator consists of crossing the first half of the matrix PA1 (presenting the deliveries decision variables) with the first half of the matrix PB1, and the second half of the PA1 (presenting the collection decision variables) with the second half of the PB1 to get the offspring1 presenting the first period matrix decision crossing. The same procedure is launched to cross the PA2 and PB2 to get the second offspring. The two offspring 1 and 2 are assembled in a 3-dimensional vector presenting the resulted offspring.

3.1.3 Mutation

In this paper, we use the implementation of four mutation operators proposed by Teledo et al. [12]. The first operator resides on changing the value of a randomly chosen variable. In the second operator, two variables are randomly chosen from the same column and their values are exchanged. In the third operator, two variables are randomly chosen from the same column and their values are exchanged. The last operator consists of applying the first mutation operator twice. We select randomly one of these four mutations.

3.1.4 Exact resolution to determine collected and delivered quantities

At each iteration of the Hybrid algorithm, the generated offspring determine the solution for only the binary decision variables of full and empty reusable containers deliveries or collects. These propositions generated by the offspring are integrated in the mathematical model which is solved by IBM ILOG CPLEX platform. The solution returned by CPLEX defines optimal reusable containers quantities to deliver and to collect according to the binary decisions proposed by the offspring structure resulting from the crossover and mutation operators.

3.2 Hybrid algorithm 2 (HA2)

In the second hybrid structure (HA2), we consider the same hybridization architecture with the use of a memetic algorithm instead of the genetic used in the (HA1).

The proposed memetic algorithm keeps the same genetic algorithm architecture (The same solution presentation, crossover and mutation operators, and the exact resolution). In addition to genetic features, the memetic algorithm uses a local search to enhance the solutions quality. We use the Variable Neighborhood Search (VNS) approach; The VNS concept is to exploit systematically the idea of neighborhood change (intensification). (Hansen et al. [13])

The VNS in this configuration exploits three different local searches. The metaheuristic logic is to explore distant neighborhoods of the current solution (offspring) until a stopping criterion, and moves from solution to another and from a local search procedure to another only if an improvement was made. In the case where no improvement is made, the metaheuristic pass to the second local search exploitation with the best-found solution found until a stopping criterion. If no improvement is made, the same strategy is followed by launching the third local search. In the case of finding a better solution in the second or in the third local search, the VNS starts from the beginning by exploring the first local search using the best solution found. We propose three local searches. The first local search consists of permuting the matrixes presenting the full and empty reusable containers deliveries and collets decisions on each period T_i. The move A in Figure 3 shows an example of the used local search. The second local search consists of permuting the lines of the matrix T_i presenting the full and empty reusable containers deliveries and collets decisions of the period *i*. The move B in Figure 3 shows an example of the used local search. The third local search consists on inverting the bit's value, one by one of each line in the matrix T_i until a stopping criterion. The move C in Figure 3 shows an example of the used local search.

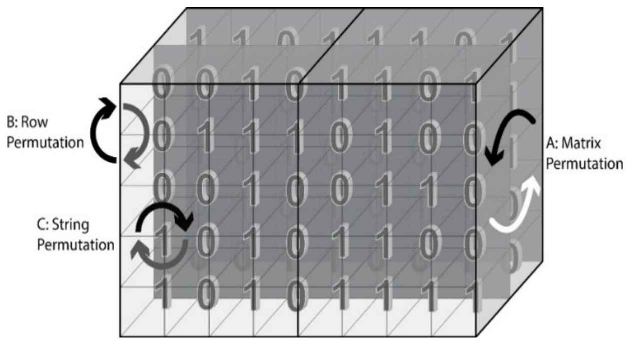

Fig. 3. The used local search procedures

4 Result and discussion

To prove the proposed algorithms performance, we summarize in this section the numerical experiments performed on these approaches. The obtained results by the first Hybrid method 1 (HA1), and the second Hybrid method (HA2) are compared with those obtained by CPLEX. The instances are derived from the article of Teunter et al. [14], Zouadi et al. [11] and Absi et al. [8]. Five different types of demand and return patterns (stationary, linearly increasing, linearly decreasing, seasonal peak in the middle and seasonal valley in the middle, 6 horizon lengths, 4 set of warehouses, and 8 sets of clients are considered.

Table 1. The results obtained according to the number of periods.

Periods	**Cplex**		**HA1**				**HA2**			
	AS	**AT(s)**	**AS**	**GHA1C**	**AT(s)**	**MaxG**	**AS**	**GHA2C**	**AT(s)**	**MaxG**
5	80889,34	66	81989,44	1,36%	73	7,00%	81876,19	1,22%	75	3,45%
10	193663,88	332	198931,54	2,72%	211	17,27%	198428,01	2,46%	233	5,76%
15	315144,58	3425	324977,09	3,12%	396	8,10%	321857,16	2,13%	424	8,10%
20	433879,89	8409	447156,61	3,06%	501	13,38%	443078,14	2,12%	779	11,91%
25	577111,09	13353	592923,93	2,74%	779	9,10%	586864,27	1,69%	1054	9,10%
30	747121,18	24438	764529,10	2,33%	968	11,80%	757431,45	1,38%	1634	9,80%

Compared to the results obtained by CPLEX, HA2 gives solutions that are close by 1.83% to the optimal solutions while the HA1 is less efficient, it gives solutions that are close by 2,56 % to the optimal solutions. The computational time of the HA2 is greater than the HA1 due to the used local search.

The quality of solutions depends on the length of the planning horizon. For small horizons (5 periods), both methods give solutions that are close to the optimal solutions, especially HA2, and in particular when the number of client and warehouses is small. While for long horizons, the solutions are pretty far from being close to optimal. Regarding the computational time, CPLEX is rather efficient to prove optimality for small size instances, but on larger ones, the computational time becomes more important and exceeds half an hour on many instances without finding an optimal solution.

5 Conclusion

This contribution proposes a new generic mixed integer programming model of dynamic assignment of reusable containers, and two hybrid approaches to solve the problem in a moderate computational time. The two developed hybrid approaches generate high-quality solutions. This addition is a base to develop more integrated models by considering several constraints such as the number of products, multi-level structures and cooperation between different actors.

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