A Two-Phase Genetic Algorithm for Incorporating Environmental Considerations with Production, Inventory and Routing Decisions in Supply Chain Networks

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ABSTRACT
In this paper, we study an integrated production-inventory-routing planning (PIRP) problem which addresses important decisions in the supply chains and it is classified as an NP-hard problem. Studies shows that companies solving their production, inventory and routing decisions simultaneously, can reduce their total costs significantly and respond to the customers' needs efficiently. Nowadays due to strict regulations, companies must take into account environmental considerations as well as cost minimization in their processes. Therefore, in this paper we develop a mixed-integer linear programming model to formulate the green PIRP (GPIRP) problem which optimizes the economic and social dimensions of the supply chains. Also, we propose a two-phase genetic algorithm (GA) in which the inventory and production decisions are solved in the first phase and the vehicle routing and transportation decisions are solved in the second phase. In the computational experiments we conduct sensitivity analysis to investigate the efficiency of our proposed solution algorithm for the large-sized instances

KEYWORDS
Production-routing-inventory problem; Vehicle routing; Green supply chain; Genetic algorithm.

1 INTRODUCTION AND CONTRIBUTIONS
Nowadays, due to the increasing of the competition, all the activities of the supply chain including the extraction of raw materials, production and delivering goods and services to the customers require an efficient decisions making. On the other hand, supply chains prefer to integrate important decisions in the system to maximize the possible profit and in particular, coordinate more efficiently different parties in the network.

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One of the different types of coordination between supply chain parties is the coordination between inventory and routing in the distribution systems. In this problem, both inventory and vehicle routing decision are optimized simultaneously. The common objective of these problems is to determine the distribution strategy to minimize the distribution and inventory costs in the long term. One of the main challenges of the transportation sector of the petroleum industry is its hazardous pollutions which can seriously harm global health [1]. In recent years, the global warming problem has become more serious and therefore, decreasing the production of carbon is the first priority for many governments [2]. Green transportation is among the appropriate policies for reducing carbon emission [2]. As a result, the investigation of the mentioned issues in the domain of green supply chain has become important.

This paper contributes to the literature papers in different ways. The first contribution is to study the environmental considerations in the inventory-routing problem by taking into account the maximum allowable limit for the green gas emissions. The second one is the development of an integrated model for the production-inventory-routing planning in a bi-echelon green supply chain including the factories and DCs of a manufacturing company. The developed model which considers all the aspects of production, inventory, and routing decisions complicates the solution approach. According to the literature, these problems are classified as the NP-hard problems [3]. Therefore, the third contribution of this paper is to develop a two-phase genetic algorithm (GA). We decompose the main problem into two sub-problems which makes the solution approach highly efficient, especially for large-sized instances. Although the developed solution algorithm does not provide an exact solution, it proposes very quickly a solution with a very small error compared to the optimal solution. This algorithm can be very effective for the managers as they need to find a good quality solution in a short time. Finally, we validate the efficiency of our model by applying a real case of a sugar refinery company.

2 A TWO-PHASE GENETIC ALGORITHM
As the developed GPIRP problem is a complex model, standard commercial solvers such as CPLEX can be used to solve only the

small-size instances. For large-size instances we need to develop an efficient solution method. In this paper, we focus on genetic algorithm (GA) which was first discussed by John Holland [4]. GA dates back to the 1960s when several independent studies were conducted in order to use evolution theory in the optimization of engineering problems. The basic idea in all these systems was the growth of a population of primary solutions to a problem towards the optimal solution, inspired by natural genetic selection and mutation operators.

We use a two-phase approach in the GA for solving the GPIRP as the problem is too complicated to solve in one stage. It should be noted that the two-phase approach has been widely used in the literature [6] [7]. In the first phase, production and inventory planning is carried out. Here, the optimum quantity of producing each product in the factory, as well as the quantity of inventory in the factory and DCs are determined for each period. In the second phase, taking into account the output of the first phase, transportation planning is accomplished. In summary, "Phase I is production and inventory planning", and "Phase II is vehicle routing for transportation of products".

Phase I of the problem can be solved using linear programing (LP) solver such as CPLEX solver because all of its variables are continuous and proposed model is linear. But, as mentioned above, in the Phase II a VRP should be solved. The VRP is NP-hard combinatorial optimization problem that can be exactly solved only in small-sized instances. Although the heuristic approach does not guarantee optimality, it yields a best result in practice. In the last twenty years, the meta-heuristics has emerged as the most promising direction of research for the VRP family of problems. Due to the specific structure of solution representation in the VRP, GA is a common solver for the VRP and Green VRP [8]. In this research, similar to the paper of Mirzapour Al-e-hashem and Rekik [2], the GA is applied to solve VRP in the Phase II. Figure 1 shows the flowchart of the proposed two phases solution approach which will be further explained in later sections.

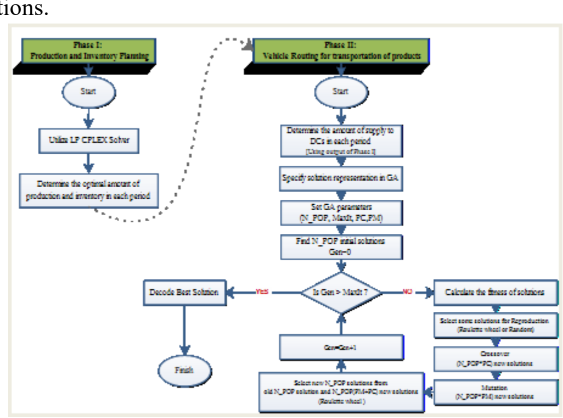

Figure 1: Steps of the two phase GA

3 EFFECIENCY OF GENETIC ALGORITHM

In this section, we evaluate the performance of the developed GA and model in different sizes of the problem. For this purpose, we compare our GA with CPLEX commercial solver. Also in order to evaluate a wide range of problem sizes, we use the sizes introduced in Mirzapour Al-e-hashem and Rekik (2014) [2]. Each instance is solved by both CPLEX commercial solver and the developed GA. After solving the instances, the average gap from optimal solution for all instances is about 4% for the GA. On the other hand, by using the proposed GA the optimal solution time improves by average 78% in all instances over CPLEX. Therefore, by using the GA we can reach a good and efficient solution in a reasonable amount of time. It should be noted that based on the results for the similar problems in the literature (e.g., Mirzapour Al-e-hashem and Rekik [2]) 4% gap from optimal solution time is a reasonable and good gap and also 78% improvement in optimal solution time is completely significant (please see similar result, Mirzapour Al-e-hashem and Rekik [2])

4 CONCLUSIONS

In this study, we developed a model in the area of PIRP which aims to minimize the total production, transportation and inventory costs. In addition to the economical dimension of the supply chains, companies nowadays must take into account environmental considerations in all the processes, from production to supply. Considering an efficient transportation planning, companies can decrease both cost and environmental pollutions. In this paper, we proposed a green supply chain problem known as GPIRP by applying environmental constraints to the PIRP problem. This problem simultaneously controls both the economic and social dimensions of production and supply activities in the companies. We formulated the problem as a mixed-integer linear programming model and developed a GA to solve. As observed in the literature, although meta-heuristic algorithms do not guarantee a global optimization solution, they can provide acceptable solutions to complex problems in a short time. Consequently, we proposed a two-phase GA and decomposed the main problem into two sub-problems. Our results showed that the proposed algorithm results a good quality solution with a small error at a short time.

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