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An Adaptive Large Neighborhood Search algorithm for sustainable supply chain network design

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Abstract

Supply chain network design is a strategic issue for supply chain management dealing with determining location of facilities and their capacities, suitable technology level and flow of materials. Due to the increasing attention to sustainable development from academia and practical communities, we propose a sustainable supply chain network design model to minimize total logistics cost as well as environmental impact of logistics network.

Getting to optimal or near optimal solutions to large-size problems in reasonable time is a challenging issue. Therefore, we develop a metaheuristic approach based on the Adaptive Large Neighborhoods search.
Mots clés : *Adaptive Large Neighborhood Search, supply chain network design, sustainable development, Facility location.*

1 Introduction

Supply Chain Network Design (SCND) focuses on optimizing the structure of logistics networks. This entails selecting sites for new facilities (e.g. plants and warehouses), deciding on their number and capacity, and identifying distribution channels as well as transportation modes in order to meet customer demands. SCND has been comprehensively investigated from various points of view including basic features (e.g. multi-product and multi-period), advanced features, (e.g. risk management and disruption), and solution methods [1]. Most papers aim at finding out the best configuration of the network regarding an economic goal.

The great majority of SNCDs is classified as NP-hard [2]. General solvers are often able to solve small- or medium-sized SCND instances to optimality. But using heuristic or metaheuristic approaches are inevitable to tackle the high complexity caused by binary variables[1]. Efficient heuristic methods generally exist for solving large-sized instances within reasonable time. The goal of our research is to develop an efficient generic method to be abble to solve large novative SCND model including realistic features and sustainable development goals or constraints.

The concept of sustainable supply chains has given rise to a huge quantity of papers in various scientific domains. In the field of Operations Research (OR), few papers have been integrating sustainable development aspects in supply chain network design and facility location mathematical models. However, this subject has been receiving growing attention in the last five years. We review the various modeling approaches (deterministic or stochastic models, models with single or multiple objectives, linear and nonlinear programmes) in [3].

2 Applying ALNS to supply chain network design problems

The main goal of this research is to propose an Adaptive Large Neighborhood Search (ALNS) method to solve rich SCND problems including complex features. The efficiency of ALNS, proposed by [4], has been proved for Vehicle Routing Problems (VRP) [5]. Hence, ALNS is getting increasing attention and it has been recently employed to solve other combinatorial optimization problems such as scheduling [6] and lot-sizing problems [7].

In view of this fact, we believe that ALNS proposes an efficient framework for exploring the solution space of a large variety of SNCD problems. The underlying principle of the ALNS is to iteratively destroy and repair the current solution in order to improve it. To this end, ALNS uses a collection of ad hoc "destroy" or "rebuild" method. The search is called adaptive because the probability of choosing each “destroy” and “repair” method is re-evaluated periodically depending on their efficiency in the past iterations.

For applying this method to SCND problems, we define several destroy and repair heuristics to create new solutions by changing the value of binary variables associated with location of facilities. Unlike the VRP, supply chain network design problems mixes binary variables (associated with strategic decisions such as opening and closing facilities) and continuous variables (associated with tactical decisions such as products flow between facilities). At each iteration, a complementary algorithm is then required to set continuous variables after having set binary variables.

Our goal is to evaluate the potential of the ALNS algorithm for solving SCND problems. We implemented a preliminary version which only includes 3 simple destroy and 3 repair operators.

3 Brief description of the model considered

Traditionally, SCND has been mostly motivated by economic considerations : minimize total cost or maximize total profit. In contrast, the design of logistics networks that mitigate negative environmental impacts has received very little attention in the literature [8]. Few papers have been dedicated to developing heuristics or meta-heuristics for large scale problems in sustainable supply chain network design. In this research, environmental aspects regarding CO_2 emissions from transportation and facility operations are explicitly incorporated into the logistics design process so as to obtain a sustainable assessment of the supply chain infrastructure performance. To this end, we extend the four-layer model proposed by [9] by integrating environmental factors. Fig. 1 displays the overall view of concerned supply chain network.

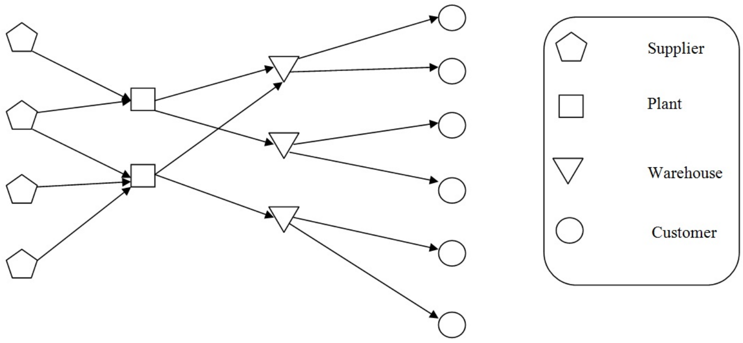

FIGURE 1 – A multi-stage supply chain network

We consider a four-layer model including suppliers, plants, warehouses, and customers. The decision variables select the suitable location of plants and warehouses regarding minimization of cost and CO_2 emissions. The overall problem is formulated as a Mixed Integer Linear Programme (MILP). The objective function incorporates a CO_2 equivalent cost for minimizing environmental impact. We consider three types of constraints : network flow conservation constraints, capacity constraints, and others concerning the upper limit of number of open facilities and non-negativity of variables.

4 Numerical experiments

In order to assess the quality of the ALNS design and implementation for the problems we investigate two mathematical models : a classical SCND model [9], and our extended model including environmental impacts. In both cases, we compare the results of ALNS with the result of a general solver. To this aim, several test problems from small to large scale have been generated. Then, the objective values of ALNS are compared with optimal solutions obtained by IBM Ilog CPLEX 12.4 for small- and medium-sized instances and the best known values found by CPLEX for large instances.

The time needed by CPLEX to solve the model is shown in Fig. 2. As shown in the Fig. 2, the time needed for solving problems is increasing with the size of the instances. It should be mentioned that we stop the solver in largest test problem after 2.5 hours. Table 1 compares the results of ALNS and CPLEX on 10 large-sized instances. The number of suppliers, plants, warehouses, and customers for the first 5 test instances are 25, 20, 40, and 200 and for the test problems from 6 to 10 are 30, 30, 50, and 300. 3000 seconds is the maximum allowed time to get the best solution by proposed ALNS. The results show that there aren't huge gaps between CPLEX and ALNS solutions and it can be improved quickly by adding more operators.

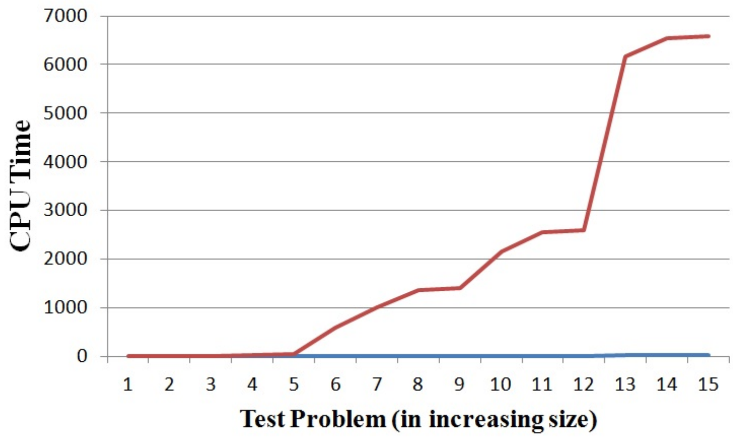

FIGURE 2 – Computational time with CPLEX

TABLE 1 – Test results

Test problems	Solution Quality			CPU Time (in s)
	CPLEX	ALNS	Gap %	CPLEX
1	3941600	3990860	1.25	1010
2	4072910	4137620	1.59	6546
3	3942590	4031460	2.25	1406
4	4127480	4209440	1.99	591
5	3917580	3978070	1.54	1363
6	6068980	6267560	3.27	6173
7	6294460	6535070	3.82	6580
8	6129650	6392450	4.29	2556
9	6287710	6544010	4.08	2586
10	6131270	6284920	2.51	2147

5 Conclusion

We develop a Mixed Integer Linear programming model for a multi-stage supply chain network design regarding minimization of cost and environmental impact. We propose a metaheuristic approach based on the ALNS algorithm to solve the problem in reasonable time.

Current work considers a single aggregated objective function. Future directions include enriching the ALNS algorithm by adding more efficient operators, extending the ALNS to solve the bi-objective problems (economic + environmental) and adapting this algorithm to rich SNCD problem with complex products bill of material and multiple periods.

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