Proceedings of the World Congress on Engineering and Computer Science 2009 Vol II
WCECS 2009, October 20-22, 2009, San Francisco, USA

A Decomposition-based Heuristic Approach to Solve General Delivery Problem

L. Lian[1], and E. Castelain[2]

Abstract—This paper presents a new distribution and route planning problem, General Delivery Problem (GDP). Such problem is more general than well-known Vehicle Routing Problem. To solve GDP, a three-phase framework based on decomposition techniques is introduced. The decomposition techniques are employed to divide an original problem into a set of sub-problems, which can reduce the problem size. A kind of decomposition technique, Capacity Clustering Algorithm (CCA), is embedded into the three-phase framework with Simulated Annealing (SA) to solve a special GDP. The proposed three-phase framework with the above two algorithms is compared with six other decomposition methods in a distribution instance of the Regional Fire and Emergency Center in the north of France.

Index Terms— **Decomposition Technique, General Delivery Problem, Heuristic Method.**

I. INTRODUCTION

The vehicle dispatching and its route planning have a considerable economical impact on a distribution center. In practical aspect, this problem contributes directly to reduce costs of all logistic systems [1] (Alvarenga, Mateus, De Tomi, 2007). In the literature, such a problem is almost researched as a Vehicle Routing Problem (VRP). In general, the VRP can be defined as the problem of designing optimal delivery or collection routes from one or several depots to a number of geographically scattered cities or customers, subject to side constraints[2] (Gilbert Laporte,1992).

This paper focuses on a General Delivery Problem (GDP), which is more general than the well-known VRP and Traveling Salesman Problem (TSP). In GDP, there is no hypothesis on the way that origins and destinations will be linked to organize and to realize the whole set of deliveries. That is to say, when a company confronts a transportation problem and it just knows the locations of the customers and the quantities of the customers' demands, the company needs to decide the strategies to manage the transportation process and to organize the routing sequence. Generally speaking, TSP or VRP is kind of the routing sequence problem. As we know, TSP and VRP are NP-hard combinatorial optimization problems [3](Savelsbergh, 1985). Therefore, GDP is difficult to solve as TSP and VRP are sub-problems of GDP.

1. L. Lian is with LGIL, Ecole Centrale de Lille, Cité Scientifique, 59651 Villeneuve d'Ascq cedex (e-mail: Lian.Lian@ec-lille.fr)

2. E. Castelain is with LGIL, Ecole Centrale de Lille, Cité Scientifique, 59651 Villeneuve d'Ascq cedex (e-mail: Emmanuel.Castelain@ec-lille.fr)

Gilbert Laporte[3](1991) surveyed the main exact and approximate algorithms developed for the VRP, at a level appropriate for a first graduate course in combinatorial optimization. Furthermore, the approximate algorithm mainly includes two kinds of algorithms, constructive heuristic algorithm and meta-heuristic algorithm. Some research efforts were oriented towards the development and analysis of approximate heuristic techniques capable of solving real-size VRP problems. Bowerman et al. (1994)[4] classified the heuristic approaches to the VRP into five classes: (1) cluster-first/route-second (CFRS), (2) route-first/cluster-second (RFCS), (3) savings/insertion, (4) improvement/exchange and (5) simpler mathematical programming representations through relaxing some constraints. For the two clustering procedures, the cluster-first/route-second looks more effective.

Decomposition techniques have been applied to solve VRP. Such decomposition techniques can reduce the problem size and expand the choice of searching strategies. Several authors have previously proposed decomposition technique to solve VRP. Previous works are classified into three types: (1) using optimization model with Lagrangian relaxation as decomposition technique, i.e., Paolo Toth&Daniele Vigo[5], Chi-Bin Cheng&Keng-Pin Wang[6] and Byung-In Kim, Seongbae Kim&Surya Sahoo[7]; (2) heuristic approach to construct the groups. Rodolfo Dondo and Jaime Cerda[8] presented a novel three-phase heuristic/algorithmic approach which embedded a heuristic-based clustering algorithm within a VRPTW optimization framework. In other words, they used a preprocessing method to cluster nodes into groups, and then took the group as node to apply the optimization method; (3) cluster analysis is usually proposed. Sergio Bargio, Carlos Ferreira et al. [9] integrated several hierarchical and non-hierarchical clustering techniques into a sequential heuristic algorithm for the location-routing problem(LRP) model. Byung-In Kim, Seongbae Kim et al.[10] developped a capacitated clustering-based algorithm to deal with the real life waste collection problems. K.Ganesh and T.T.Narendran provided an initial solution with k-means clustering methods and thereby accelerated convergence of the genetic algorithm to solve the vehicle routing problem with deliveries and pickups.

Cluster analysis (Anderberg, 1973[12]) studies the division of entities (as objects or individuals) into groups based on one or several of their characteristics. According to Jain and Dubes (1988): ''Cluster may be described as connected regions of a multi-dimensional space containing a relatively high density of points, separated from other such regions by a region containing a relatively low density of points''. Evidently, it is reasonable to regard cluster analysis as a decomposition technique. However, in all of the above papers, the authors use only one decomposition criterion to divide VRP. Instead, to resolve the large-scale GDP, this paper presents a heuristic framework with multi-decomposition criterions.

Section II describes the framework of the heuristic decomposition procedure and introduces the decomposition criterions. In Section III, a heuristic approach with CCA and SA is embedded into the proposed framework to solve a special GDP. In Section IV, we provide a concrete instance of the decomposition procedure and illustrate the computational results. The paper is concluded in Section V.

II. THE DECOMPOSITION FRAMEWORK

Laporte, Mercure and Nobert (1986) have provided the optimal solution to randomly generated asymmetrical CVRPs involving up to 260 vertices with branch-and-bound-algorithm. So far, it is one of the best solutions to VRP with the most nodes. But the GDP with a huge number of nodes is more difficult to solve. In order to overcome the limitation and to help the distribution centers solve their special vehicle dispatching and routing problem, we introduce a heuristic framework. The proposed heuristic framework includes a three-phase heuristic decomposition procedure which can be used to divide the large-scale GDP into some sub-problems (Transportation Problem, TSP, VRP or basic GDP). Through adding Simulated Annealing (SA) Algorithm into the framework, the delivery routes generated from the proposed framework can be improved, which is explained in Section III.

A. Decomposition procedure

The procedure for the proposed framework consists of three phases as follows:

Phase 1: Divide the huge number of nodes (including original nodes and destination nodes) in GDP into some groups with decomposition techniques.

Phase 2: Determine the distribution route for each group with the existing tools and/or heuristics algorithms.

Phase 3: Improve the routes between groups.

Chi-Bin Cheng and Keng-Pin Wang (2008) have used an iterative interaction between the original problem and many sub-problems to solve VRPTW. The decomposition procedure in this paper is similar to that provided by Chi-Bin Cheng and Keng-Pin Wang and it is illustrated in Fig.1.

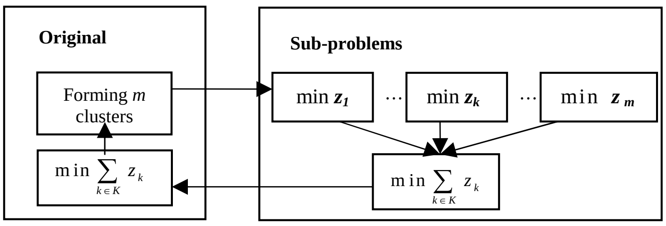


Fig 1. *Interaction between original problem and sub-problem*

In Phase 1, decomposition criterion in strategic view and in operational view should be decided at first. Noticeably, this is fundamental. The different decomposition criterion may lead to different resolution. The description of the division criterions will be presented in the Section II B. The large-scale problem is divided into some sub-problems by a decomposition technique. The decomposition process continues until the problem is divided into the smaller ones, TP, TSP, and VRP, that can be solved successfully.

In Phase 2, the distribution routes in each group are determined. For TP, it's easy to solve since it is a polynomial problem. We use ILOG CPLEX, high-performance optimization software, to generate the solutions. For TSP, we get the optimal solution by well-known and efficient TSP solvers like Concorde[1], which can solve large-scale TSP instance up to the 15,112 cities in Germany in 2001. For other kinds of VRP, genetic algorithm and other meta-heuristic algorithm can be used.

The decomposition procedure of GDP in Phase 1 and Phase 2 is an interaction between the original problem and its sub-problems. The original problem can be transformed into several sub-problems by dividing all nodes of original problems into several groups in terms of decomposition criterions. And then each sub-problem optimizes its own routing sequence. During the improvement of the routes (Phase 3), an improvement heuristics, i.e., 2-opt, 3-opt, Lin-Kernighan can be used to reform the current sequence. The sum of the objective values of all new sub-problems is returned to the original problem as a performance indicator for evaluating the current decomposition result. Fig.2 shows the two phases of the proposed framework.

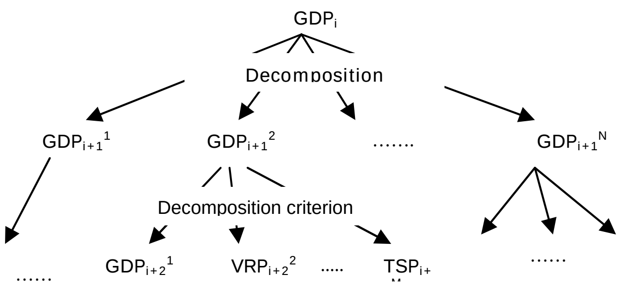


Fig. 2 *Two Phases of Proposed Framework*

B. Decomposition Criterion

In Phase 1, origin nodes and destination nodes are sorted and divided into several groups according to decomposition criterions. In this section, we describe these decomposition criterions in two aspects.

B.1 Decomposition Criterion in Strategic View

In the strategic view, the company locates several distribution centers between the supplier nodes and the destination nodes. In this situation, the number and the locations of the distribution centers should be decided. The transportation process of GDP is divided into two parts, transportation problem between suppliers and distribution centers, and transportation problem between distribution centers and customers. Moreover, each customer is assigned to a certain distribution center. Fig 3 shows a simple example of the decomposition criterion in strategic view. In the Fig.3, the ring represents the origin and the other points are customers. Firstly, the four other distribution centers are located, and then the origin delivers products to the four distribution centers. At last, the decomposition of the original problem has resulted in four sub-problems (TSP or VRP) from each of the 4 depots. In the real world, this approach can help the companies to improve the management of their transportation process. Hence, we propose the strategic criterion to locate the platforms to optimize the distribution systems.

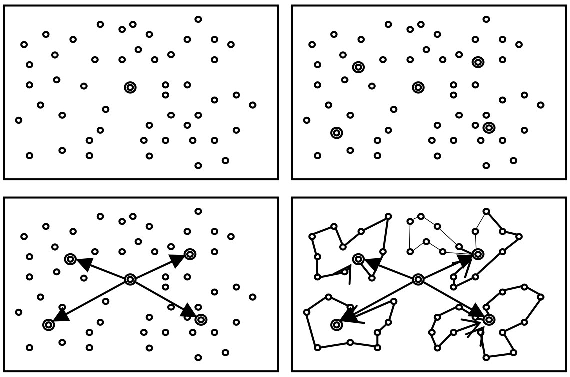


Fig. 3 *An example of the division criterion in Strategic view*

B.2 Decomposition criterion in operational view

Space criterion is to choose the adjacent nodes as the same group. There are several approaches to divide the large-scale problem with space criterions. Heung Suk Hwang[13] has developed a sector-clustering algorithm to convert a multi-supply centre problem into single supply center problems. Clarisse Dhaenens-Flipo[14] has investigated a spatial decomposition to divide a multi-facility production and distribution problem into some sub-problems and then developed a branch-and-bound algorithm to obtain the exact solutions of the sub-problems. Fig 4 illustrates an example of the space criterion. First of all, the nodes are divided into 4 groups with space criterion, and then we decide the itinerary for each group.

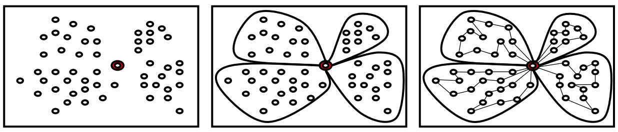


Fig. 4 *An example of space criterion*

Time criterion is used to divide the destination nodes into several priority-ranked groups according to customers' urgencies of the requirement deadline. Fig.5 presents an example of the time criterion. According to time criterion, the delivery destinations are divided into three subsets distinguished by different colors. In other words, the destinations with the same color must be served in the same day. The routing sequence for each day is finally presented.

[1] http://www.tsp.gatech.edu/concorde.html

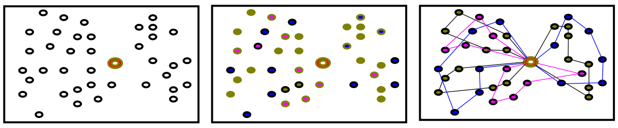


Fig. 5 *An example of time criterion*

III. Heuristic Method to Capacitated Vehicle Routing Problem (CVRP) Based on the Proposed Framework

A framework to decompose the large-scale problem and improve the solution has been designed in the section II. This paper aims to design a framework to assist the company to solve their GDP. Here, this study is applied to a special case, CVRP, of GDP.

In this case, we take the CCA as decomposition technique, apply Concorde as the solver, and then improve the solution with SA. The method is described in Section III A.

A. Heuristic approach based on CCA and SA

Heuristic approach based on CCA and SA

Phase 0: Estimate the number of vehicles, N, based on the total workload. Construct the distance matrix.

Phase 1: Decompose the large-scale problem into several TSPs with CCA.

Phase 2: Use Concorde to determine the routing sequence for each TSP.

Phase 3: Modify the routes between each TSP with SA.

Phase 4: Finish the heuristic approach.

The number of required vehicles (phase 0) is estimated by the total distribution workload divided by the daily workload capacity of each vehicle. Note that we assume that the vehicles are of the same type. The explanations of the other phases will be done in Section III B.

B. Capacitated clustering algorithm

In phase 1, we decompose the original problem into several TSPs by CCA. In standard k-means algorithm, nodes are clustered according to the distances between the nodes and the centroids, i.e., a node is assigned to the cluster whose centroid is the closest to the node. But in the CCA, the centroid of the centroids is also considered, which would be called "the grand centroid. Additionally, in order to minimize the number of vehicles, we begin the algorithm with the number abtained in Phase 0 of the method in Section III A.

Capacitated clustering algorithm

Step 1: N initial centroid seed nodes are selected according to k-means cluster algorithm, the remaining nodes are assigned to the clusters.

Step 2: Let the cycle index m=0, a new centroid of each cluster and the grand centroid are calculated.

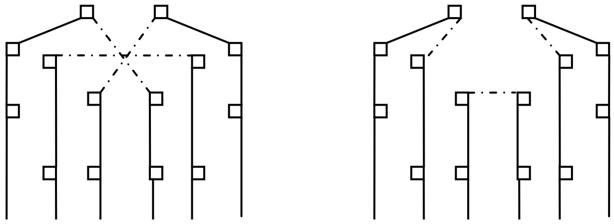
Step 3: Sort the nodes and assign nodes to new clusters with the grand centroid are repeated until there is no change

Step 4: If the capacity of any cluster is not satisfied the workload capacity of vehicle, the cycle index m=m+1, return to step 3; If m passes cycle index m_{max}, N=N+1, return to step 2;

Step 5: Finish the algorithm until the groups of nodes are found.

C. *Simulated Annealing Improvement Heuristic*

The optimal solution to each group is produced by Concorde in Phase 2. In Phase 3, we modify the routing sequence between the routings to approach the global optimal solution. SA with 3-opt improvement heuristic algorithm has been developed for this problem. In the basic iteration of SA, the neighbors of each state are obtained by 3-opt improvement heuristics. The basic idea of 3-opt local search algorithm is to start from the routing sequence, to choose three edges from the routing sequence, to remove them, and to combine the six parts to a routing sequence in the cheapest way. The idea is shown in the Fig. 6.



(a) *Routing before 3-opt* (b) *Routing after 3-opt*

Fig. 6 *Idea of 3-opt Algorithm*

3-opt improvement heuristic algorithm

Step 0 (Initialization) Let cycle index =1; Let the solution *S* from Phase 3 as the best solution *S**, the objective f corresponding to *S** as the best objective *f**.

Step 1(Edges choosing) Apply 3-opt algorithm to three edges r_1, r_2, r_3, randomly choosing from edge set W. Then, at most, 15 new solutions S_1, S_2, …, S_{15} can be produced.

Step 2(Exchange evaluation) Evaluate all the candidates of 3-opt exchanges. Calculate the objective (the total distance) $f_1, f_2, \ldots, f_{15}$. Index *f'*=min {f_1, f_2 , …, f_{15}}, and S' corresponded to f'.

Step 3(Improvement) If *f'*< *f**, let *S**= *S'*, t =1; Else, t = t+1, go to Step 4.

Step 4(End standard) If *f** doesn't change within n_{max} loops, end; else, go back to Step 1.

IV. COMPUTATIONAL RESULTS

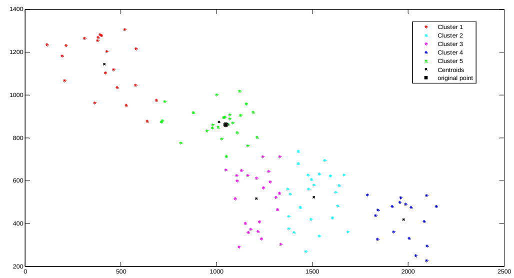
To evaluate the performance of the proposed approach, our approach with the decomposition technique is compared with the other five approaches and the old strategy used by a distribution instance of the Regional Fire and Emergency Center in the north of France.

The regional service centre needs to delivery the medicine to its firefighter centers in five regions each week. Before, the regional service center firstly distributed the medicine to five distribution centers in each administrative region. Each distribution center organized the transportation sequence in the form of the round-trip vehicles between the distribution center and the firefighter centers in its region. Here, we regard the transportation strategy as Old Strategy.

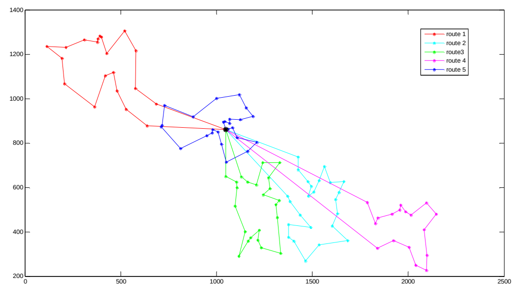
In the case of the Regional Fire and Emergency Center in the north of France, the distribution process is not associated with the time windows. From the performance point of view, the center just aims to minimize the number of the vehicles and the traveling distance. The centre has 10 vehicles with the same capacity of 500. There are 110 firefighter centers in five different regions.

A. *Performance of the proposed heuristic approach*

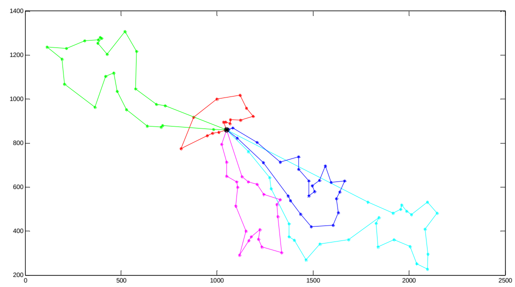
Fig.7 shows the results of each phase in the heuristic approach based on CCA and SA when the approach is used to solve the problem instance. Fig.7 (a) indicates the groups of firefighter centers produced by Phase 1. After Phase 2, routing sequence for each group of the firefighter centers is shown in Fig. 7(b). At last, Fig. 7(c) shows the routing sequence improved by SA in Phase 3.



(a) *Groups Produced by Capacitated Clustering*



(b) *Routing Sequence after Clustering the Destination Nodes*



(c) *Routing Sequence Improved by SA*

Fig. 7 *Performance of the Proposed Heuristic Approach*

B. *Performance comparison between different approaches*

Our proposed heuristic approach is compared with other six approaches: the Old Strategy, Routing First and Cluster Second (RFCS) without the improvement technique, RFCS with 3-opt improvement heuristics, RFCS with SA, Cluster First and Routing Second (CFRS) without the improvement technique and CFRS with 3-opt improvement heuristics.

Computational results by different approaches are shown in Fig. 8 respectively. We can see that our proposed approach outperforms the other six approaches in terms of the total distance (in kilometer).

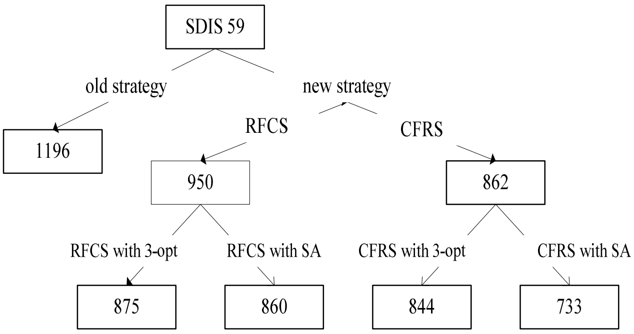


Fig. 8 *Performance comparison between different approaches*

V. Conclusion

The decomposition technique divides the original problem into some sub-problems. In this way, the size of the problem is reduced and it is simpler to solve sub-problems with fewer nodes than to solve the original problem. Due to its advantages, a heuristic approach based on the decomposition technique is a promising way to find a good solution for large problem.

This study, firstly, presented the General Delivery Problem which is more general than the well-known delivery problem, VRP and TSP and a framework of a heuristic approach based on decomposition technique to solve GDP was proposed in order to assist the delivery management of the distribution centre. Then a heuristic approach with CCA and SA was designed to delivery problem instance in the north of France. The proposed approach was evaluated by comparing with the other six approaches. Computational results showed that our approach outperformed these six approaches.

Despite of these encouraging results, there are also many opportunities. For instance, further research includes in the following aspects. Firstly, summarize the existing approaches to solve GDP and improve the proposed framework in the paper. Secondly, test the proposed heuristic approach to solve GDP in more instances to demonstrate the performance of the proposed approaches. Meanwhile, apply the proposed framework to the other types of distribution problems. Moreover, in the aspect of decomposition technique, it is possible to introduce other better techniques and compare with the capacity clustering algorithm to improve the computational results. We attempt to improve the solution concerning delivery distance; nevertheless, the choice of the final solution doesn't only depend on the delivery distance in practical perspective. So in the future, removing the overlaps of the routing, reinforcing the workload balance and other practical aspects will be considered.

References

[1] GB Alvarenga, GR Mateus and G de Tomim, A genetic and set partitioning two-phase approach for the vehicle routing problem with time windows, Computers & Operations Research 34(2007) pp. 1561–1584.

[2] M. W. P. Savelsbergh, Local search in routing problems with time windows. Annals of Operations Research 4(1985) pp. 285-305.

[3] Gilbert Laporte, The vehicle routing problem an overview of exact and approximate algorithms, European Journal of Operational Research 59(1992) pp. 345~358.

[4] RL Bowerman, PH Calamai, GB Hall, The spacefilling curve with optimal partitioning heuristic for the vehicle routing problem, European Journal of Operational Research 76(1994) pp. 128–142.

[5] Paolo Toth, Daniele Vigo, A heuristic algorithm for the symmetric and asymmetric vehicle routing problems with backhauls, European Journal of Operational Research 113(1993) pp. 528-543.

[6] Doris Sáez, Cristián E. Cortés, Alfredo Núñez, Hybrid adaptive predictive control for the multi-vehicle dynamic pick-up and delivery problem based on genetic algorithms and fuzzy clustering Computers & Operations Research 35(2008) pp. 3412-3438.

[7] Rodolfo Dondo, Jaime Cerdá, A cluster-based optimization approach for the multi-depot heterogeneous fleet vehicle routing problem with time windows, European Journal of Operational Research 176(2007) pp. 1478-1507.

[8] Rodolfo Dondo, Jaime Cerdá, A cluster-based optimization approach for the multi-depot heterogeneous fleet vehicle routing problem with time windows, European Journal of Operational Research 176(2007) pp. 1478-1507.

[9] Sérgio Barreto, Carlos Ferreira, José Paixão, Beatriz Sousa Santos, Using clustering analysis in a capacitated location-routing problem European Journal of Operational Research 179(2007) pp. 968-977.

[10] Byung-In Kim, Seongbae Kim, Surya Sahoo, Waste collection vehicle routing problem with time windows, Computers & Operations Research 33(2006): 3624-3642.

[11] K Ganesh, TT Narendran, CLOVES: A cluster-and-search heuristic to solve the vehicle routing problem with delivery and pick-up, European Journal of Operational Research 178(2007) pp. 699-717.

[12] Anderberg, R Michael, Cluster Analysis for Applications, Probability and Mathematical Statistics, New York: Academic Press, 1973.

[13] HS Hwang, Design of supply-chain logistics system considering service level, Computer &Industrial engineering 43(2002) pp. 283~297.

[14] Clarisse Dhaenens-Flipo, Spatial decomposition for a multi-facility production and distribution problem, Production Economics 64(2000) pp. 177-186.