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Optimal Fleet Size of an Integrated Production and Distribution Scheduling Problem for a Single Perishable Product

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OPTIMAL FLEET SIZE OF AN INTEGRATED PRODUCTION AND DISTRIBUTION SCHEDULING PROBLEM FOR A SINGLE PERISHABLE PRODUCT

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ABSTRACT

This dissertation focuses on a practical production problem in which a perishable product must be produced and distributed at minimum cost. The problem has some features of the integrated production and distribution scheduling problem in that we seek to determine the fleet size and their routes subject to a planning horizon constraint but there are significant differences as well. In particular, this research differs because the product has a limited lifetime, the total demand must be satisfied within a planning horizon, multiple trucks can be used, and the production schedule and the distribution sequence are considered. Two mixed integer programming models are formulated to solve the single plant and two-plant problems and, then, heuristics based on evolutionary algorithms are provided to resolve the models in a reasonable time.

DEDICATION

I dedicate this work to my beautiful wife Inoka and to my parents. Without your love and support this work could not have achieved.

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CHAPTER ONE

INTRODUCTION

This research is motivated by a very practical problem in which a production facility with limited capacity is producing a perishable product that requires delivery to a set of geographically dispersed customer sites on or before its effective lifetime expires.

To convert this problem in a quantitative format, we view it in the following way. We consider both single plant and two-plant cases producing a single product that is delivered to a known set of customers. The demand of each customer is known and must be delivered before the end of the planning horizon. For example, suppose we have a chemical plant that produces a product with a lifetime of a few hours when being transported but longer when stored in a special environment at a customer's facility. We assume that customers place orders and require delivery the following day but the time of day does not matter (in which case the planning horizon is one day). The lifetime of the product begins when the production for the order is completed. All customer locations are assumed to be in the 2-D plane with the distance matrix symmetrical and known. The production plants have fixed and identical capacity that is sufficient to satisfy the total demand of customers within the planning horizon. Each plant hires its own fleet independent of the other plant and truck movements from one plant to another are not allowed. Production at each plant is scheduled in such a way that a truck is able to deliver goods to customer sites before expiration; that is, the basic problem is feasible in the sense that we could employ one truck to deliver to each site and demands would be met albeit at a high cost. We assume that distribution is executed under the following assumptions: 1) each customer's demand must be satisfied in one delivery, 2) orders for more than one customer are allowed on one truck, 3) a truck is allowed to carry less than a full truckload, and 4) trucks can return to their respective plants after satisfying demand at one customer to pick up and deliver to another customer until the planning horizon has expired.

The objective is to find the truck fleet size for each plant, their routes, and the production sequence that minimizes the total cost of distribution while total demand is satisfied within the given planning horizon. The cost of distribution includes two components: 1) a fixed cost paid on each truck hired which is a one-time payment for the planning horizon and 2) a variable cost per unit distance traveled. We assume a reasonably higher fixed cost compared to the variable cost which motivates the maximum use of a truck hired during the planning horizon. For example if a set of routes can be found to satisfy the total demand with the multiple use of one truck, that strategy is always less expensive than any other combination of routes that requires hiring two or more trucks. The problem is complicated by our assumption that a product delivered after its lifetime has expired is deteriorated and not useful we do not consider deliveries after the lifetime is expired as being partially useful. This feature impacts several aspects of the supply chain since the lifetime begins when production is completed. For example, production in advance of the delivery truck arrival might be prohibited for some customers who are located a long distance from the plant and partially loading truck for these distant customers might be required.

The single plant integrated production and distribution scheduling problem (IPDSP) and the IPDSP with multi-plants (MPIPDSP) are common and faced by manufacturing companies. This dissertation research considers an integrated production and distribution scheduling problem for a product with a limited lifetime.

CHAPTER TWO

LITERATURE REVIEW

Different integration problems are found in the supply-chain literature, including inventory-distribution (Federgruen (1991), Federgruen and Simchi-Levi (1992), Anily S, Bramel (2002)) and production-distribution (Sarmiento and Nagi (1993), Griffin (1996)). Analysis of integrated supply chain problems is complex in nature; however, successful analysis has contributed to making many organizations more competitive. The literature related to the problem studied in this dissertation can be divided into two broader classes: 1) analysis of classical integrated production-distribution problems, and 2) analysis of integrated production-distribution problem for perishable products. The research on these two classes is discussed in detail in following two sections. On the other hand, the classical vehicle routing problem (VRP) and its various extensions are embedded in both aforementioned classes (excellent surveys are available at Christofides (1985), Solomon (1987), Laporte et al. (2000), and Toth and Vigo (2002), Cordeau et al.(2002), Gendreau et al. (2002), Cordeau and Laporte (2004), and Cordeau et al. (2004, 2005)). The most related extension of VRP to the study of this paper is the fleet size and mix vehicle routing problem (FSMVRP). In FSMVRP, the problem of finding the composition of a fleet and the routing of the fleet is solved to minimize the cost under a given set of problem constraints.

Woods and Harris (1979) analyze the fleet composition for a concrete distribution problem. Their study is restricted to a direct shipping strategy and the solution is obtained through a simulation approach. Etezadi and Beasley (1983) present a mixed-integer program to find the optimal composition of a fleet. They consider the long term decision of what vehicles to own and what vehicles to hire rather than determining what exact routes should be used to deliver and what size of a vehicle visit a particular customer. Golden et al. (1984) adapts the Clarke and Wright's (1964) savings algorithm to solve the FSMVRP. In addition, a two-phase method is also presented where a traveling salesman tour is first developed and then partition into subsets satisfying the problem constraints. Renaud and Boctor (2002) develop a sweep-based heuristic to find the solution to FSMVRP. Initially a large number of routes are generated for subsets of customers that can be served by one or two different sizes of trucks, or of the same size, and then the routes that comply with problem constraints, including a constraint for route length, are selected. A set partitioning procedure is then used to make sure that a customer is allocated to only one truck. The total cost of a delivery consists of a variable cost and a fixed cost, which is paid every time a truck is used.

Taillard et al. (1995) is considered the first study of the FSMVRP with multiple uses of vehicles. The objective of their study is to find a least cost route so that the total demand can be satisfied within a day with a given number of vehicles. Initially a set of good vehicle routing solutions are developed using tabu search ignoring the constraint on number of vehicles available. Then, a packing problem is solved to find out whether the total length can be fit to a given number of vehicles each having the size of the planning horizon which is a day. The feasibility of the packing is ensured using a penalty value corresponding to overtime. Most of these analyses have a constraint on maximum route length, which can be considered as a time window. However, to our knowledge none of the literature on FSMVRP address the fleet sizing problem with multiple use of vehicles where fleet is a decision variable.

Classical Integrated Production-Distribution Problem

A significant amount of research has been done on the classical production-distribution integration problem that does not assume a limited lifetime for the product. The primary objective of almost all of such analysis is to evaluate the effect of considering logistics aspects at the production planning level. Early research (Palekar (1990), Hochbaum (1996), Tuy et al. (1996)) considers generalizations of the transportation problem with a set of supply nodes delivering to a set of demand nodes. These studies do not consider routing and only one order in a truck, sometimes called direct deliveries, is allowed. Most of the research in production-distribution is coupled with the inventory function of an organization. Cohen and Lee (1988), King and Love (1980), Martin et al. (1993) are a few of the works on integrated production, distribution and inventory planning.

The first detailed analysis of an integrated production and distribution systems is found in Chandra and Fisher (1994). The objective of their study is to evaluate the savings from coordination between production scheduling and vehicle routing. They considered a two-echelon system with a plant and stock in the first echelon and a set of geographically-dispersed customers in the second echelon. A detailed computational study is presented showing that the total cost savings from coordination ranging from 3%

to 20%. Our research differs from the production-distribution integration problems because of the inclusion of product lifetime.

Chen and Vairaktarakis (2005) present an integrated analysis of a production and distribution system that is motivated by a make-to-order system with no intermediate inventories. They study the integration analysis under both single machine and the parallel machine configurations at the plant; however, they assume an unlimited number of identical trucks in the fleet to ensure that the fleet size is not a limiting factor. The objective is to minimize the total distribution cost while maintaining a certain service level. They assume that each shipment has a fixed cost and a variable cost proportional to the route length. They analyze many variations of the IPDSP to show how the joint schedule of production and distribution can save money in a make-to-order environment while maintaining a desired service level.

Integrated Production-Distribution Problem for Perishable Products

Most of the literature on integrated production-distribution problem for perishable or time sensitive products was done during the last few years. A recent survey is given in Chen (2006). Among commonly analyzed applications, newspaper distribution, ready-mix concrete distribution, and fashion good distribution have taken researches attention.

Hurter and Buer (1996) analyze a newspaper production/distribution problem treating newspapers as perishable goods. The objective of their study is to find a feasible production and distribution schedules with a minimum number of identical delivery vans so that all newspapers are delivered to drop-off points on or before a given time. They form several zones based on zip codes and, for each zone, a long tour is developed for all demand points. Each tour is then partitioned into trips based on the vehicle capacity constraints. Each trip is checked for the delivery deadline constraint and assigned to a delivery van. A delivery van completes only one delivery per day because the distribution problem is constrained by a tight time window and no multiple uses of delivery vans are considered.

Garcia et al. (2004) analyze the production-distribution problem for a multi-plant problem with parallel machines at each plant. They analyzed a no-wait schedule where products are immediately delivered after production with a given number of trucks. A polynomial time algorithm is given for a special case with non-bottleneck production at plants. Garcia and Lozano (2005) analyze an integrated production and distribution scheduling problem for a ready-mix distribution operation with a finite capacity plant. The objective of their study is to maximize the total customer orders satisfied before the due date with unlimited truck availability. Studies in both Garcia et al. (2004) and Garcia and Lozano (2005) are limited to direct deliveries and no more than one order is allowed to deliver in one truck, so the research in this dissertation is significantly different to both studies.

Chen and Pundoor (2006) analyze the integration of order assignment, production scheduling, and distribution scheduling of a manufacturer that produces a large variety of products with short life cycles and a short selling season. The manufacturer’s supply chain consists of a few overseas plants and a domestic distribution center. The processing times and the cost of an order are assumed to be dependent on the plant in order to account for the variations in productivity and the labor cost across the world. For a given set of orders, they solve the problem of determining: 1) which order to be assigned to which plant 2) a production schedule, and 3) a shipping schedule for completed orders so that a given set of performance measures are maximized. The model considers a direct shipping strategy from plants to the distribution center. The distribution cost from the distribution center to the retailers is assumed to be negligible, implying that retailers are located near the distribution center. They consider different variations of the problem and develop fast heuristics to resolve more complex versions.

In a related study, Geismar et al. (2006) analyzed an extension of Chen and Pundoor (2006). They studied IPDSP with one production plant having a finite capacity with a finite capacity truck with an objective to minimize the total time required to satisfy the demand of all customers. They modeled the system as a two-machine, no-wait flow shop scheduling problem and proposed a two phase heuristic to find a near optimal solution. In the first phase, a locally optimal customer sequence is found using evolutionary heuristics. In the second phase the customer sequence is partitioned into groups and optimally reordered for production using the Gilmore-Gomory (1964) algorithm. The research in this dissertation is an extension of Geismar et al. (2006) and shares the features such as short lifetime of the product, capacitated delivery, and fixed production rate the plant. The most significant differences are that the fleet size is not fixed at one; rather, it is a decision variable, both single plant and multiple plant cases are considered. Having more than one truck in the fleet introduces a new complexity to the problem. If n trucks are used with a single plant, the problem can be modeled as a two machine center no-wait flow shop scheduling problem with n parallel machines at the second machine center. Sriskandarajah and Ladet (1986) proved that the makespan version of that problem is NP-hard. In addition we analyze the multiple plant case with vehicle routing considerations; to date no literature is available on this problem.

CHAPTER THREE

OPTIMAL FLEET SIZE FOR A SINGLE PLANT INTEGRATED PRODUCTION AND DISTRIBUTION SCHEDULING PROBLEM FOR A SINGLE PERISHABLE PRODUCT

Introduction

In this chapter a single plant integrated production-distribution scheduling problem with vehicle routing is analyzed. It is assumed that product must be delivered from a single plant to all the customers before its lifetime is exhausted and the plant has a sufficient capacity to meet the demand of all customers within the given planning horizon. Each truck starts its route from the plant and returns to the plant after delivery to one or more customers. If time permits this truck is allocated to another route. A mixed integer linear programming model is presented while two evolutionary heuristics are used to find approximate solutions. The results of the heuristics are also compared with a lower bound. To provide intuition the following example is used in this chapter.

Example 3.1**:** Consider four customers with demands $q_1 = 20, q_2 = 40, q_3 = 40,$ and $q_4 = 30$ units with distances from the plant to the customers shown in Figure 3.1. Each truck has a capacity of 70 units and the production rate at the plant is 5 units per unit time. The lifetime of the product is 30 time units and each truck has a constant speed of 1 unit distance per unit time.

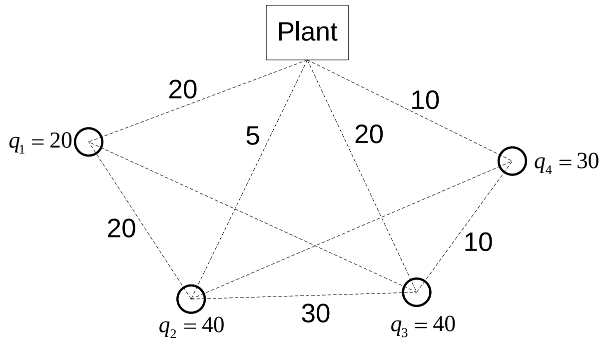

Figure 3.1: A simple example of IPDSP

In one solution to the problem would be to consider an arbitrary sequence of customers, $1 \rightarrow 2 \rightarrow 3 \rightarrow 4$ and partition it into routes along the tour based on both lifetime and capacity constraint. This leads to three routes: $0 \rightarrow 1 \rightarrow 0$, $0 \rightarrow 2 \rightarrow 0$, and $0 \rightarrow 3 \rightarrow 4 \rightarrow 0$ where the plant is denoted by "0" . Assume the production required to satisfy demand along the three routes are scheduled in the same sequence as routes, i.e., the first batch satisfies the demand at customer 1, second batch satisfies demand at customer 2, and the third batch satisfies the demand at customers 3 and 4. Hence the three batches require production time of 4, 8, and 14 units at the plant respectively.

<u>Case 1</u>**:** Planning horizon is 94 time units

If production is scheduled so that the truck is always available to deliver immediately after production of a batch is complete (no-wait) then the total demand cannot be satisfied within the planning horizon of 94 units because as can be seen in Figure 3.2, the total makespan is 98 time units. However if we relax the no-wait requirement the production of batch two can be advanced 4 time units which reduces the plant idle time by 4 time units. This means that not only will the delivery to customer 2 occur before the product lifetime expires but, as a result, the production of batch 3 can also be advanced thereby reducing the makespan to 94 time units as shown in Figure 3.3. Finally the fleet size to complete this is 1 truck.

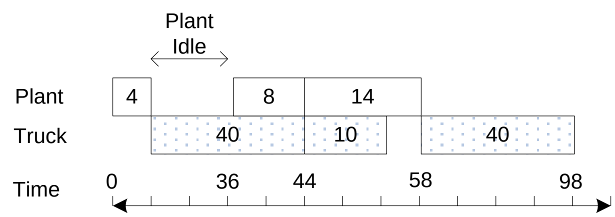

Figure 3.2: No-wait Gantt chart for Case 1

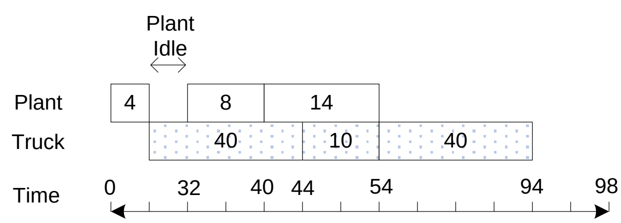

Figure 3.3: Final Gantt chart for Case 1

<u>Case 2</u>: Planning horizon is 93 time units

To satisfy the total demand in 93 time units or less, two trucks must be used and the plant idle time between batches 1 and 2 (Figure 3.4) must be reduced. Note that the delivery to customer 2 starts six time units after production is completed but the products reaches the customer before lifetime expires. Note that in both Case 1 and 2, the solutions depend on the customer sequence used for grouping.

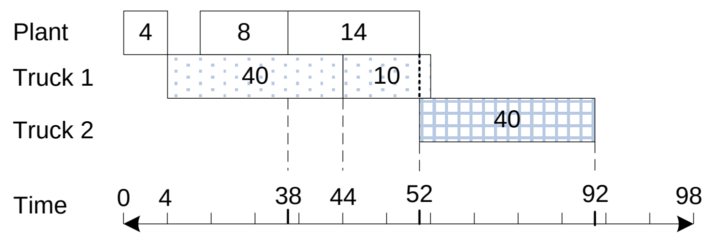

Figure 3.4: Gantt chart for Case 2

The remainder of Chapter 3 is organized as follows. First we propose a mixed integer linear formulation for the IPDSP. As will be illustrated late, this problem cannot be solved with commercial MIP software even for rather small examples, so attention turned to heuristics to obtain approximate solutions. Second, we describe these heuristic solution strategies for this model and examples. Third, we provide two lower bounds to IPDSP and two meta-heuristics for IPDSP. Fourth, we provide a numerical study using a randomly generated data set. Finally, we discuss a few research extensions of IPDSP.

A Mixed-Integer Linear formulation for IPDSP

In this section a mixed-integer formulation is given for the single plant IPDSP. Because the goal is to minimize the total cost for a given planning horizon, the objective function consists of two cost components. A fixed cost F is paid for each truck hired and without loss of generality, the variable cost per unit distance traveled is set to one. Let the given planning horizon be H time units, the production rate at the plant be r units per unit time, and the lifetime of the product be B time units. A production batch's lifetime starts when production is completed. Let $N = \{0, 1, 2, 3, ..., n\}$ be the set that identifies the customers where 0 denotes the plant and $N' = N \setminus \{0\}$ denotes the set of n customers geographically scattered in the 2-D plane. We assume that fleet of identical trucks is used to deliver goods starting from the plant and each customer i has a demand $q_i, i \in N'$ that must be satisfied within H. Each truck has a finite capacity C, where $\max_{i \in N'} q_i \le C \le \sum_{i=1}^{n} q_i$ and each truck starts its route from the plant, visits a sequence of customers and returns to the plant. A truck can be used multiple times within H as needed. Let $T = \{1, ..., H\}$ be the set of time periods in H and τ_{ij} be the travel time from customer i to customer j. Let $e_i \in N'$ be the set of real numbers corresponding to indices used in the sub-tour elimination constraints (Miller 1960). The travel cost between customers i to customer j is given by C_{ij}. The following decision variables and calculated variables are first defined.

$X_{ijkm} = 1$ if m^{th} truck visits j^{th} customer immediately after customer i in its k^{th} trip, 0 otherwise. $i, j \in N$, and $k, m \in N'$

$P_{kmt} = 1$ if the Plant is producing for the k^{th} trip of m^{th} truck at time epoch t, 0 otherwise $t \in T$, and $k, m \in N'$

$y_i = 1$ if the vehicle i is used for delivery, 0 otherwise, $i \in N'$

$Z_{km} = 1$ if the k^{th} trip of the m^{th} truck is used, 0 otherwise, $k, m \in N'$

$t^d_{km} =$ Distribution start time of the k^{th} trip of the m^{th} truck, $k, m \in N'$

$t^{p}_{k\,m} =$ Production start time for the k^{th} trip of the m^{th} truck, $k, m \in N'$

The Model that determines the minimum cost solution is as follows

$$Min \quad \sum_{\substack{i,\,j \in N \\ k,n \in N'}} C_{i\,j}\, X_{i\,j\,k\,m} + F \sum_{m \in N'} y_m$$

Subject to:

$$\sum_{i,\,j \in N} X_{i\,j\,k\,m}\, q_j \le C \qquad \forall\, k, m \in N' \tag{1}$$

$$\sum_{\substack{i \in N \\ k,m \in N'}} X_{i\,j\,k\,m} = 1 \qquad \forall\; j \in N' \tag{2}$$

$$\sum_{\substack{j \in N \\ k,m \in N'}} X_{i\,j\,k\,m} = 1 \qquad \forall\, i \in N' \tag{3}$$

$$\sum_{j,k \in N'} X_{0\,j\,k\,m} = \sum_{k \in N'} Z_{k\,m} \qquad \forall\, m \in N' \tag{4}$$

$$\sum_{j,k \in N'} X_{j\,0\,k\,m} = \sum_{k \in N'} Z_{k\,m} \qquad \forall\, m \in N' \tag{5}$$

$$\sum_{i \in N} X_{i\,j\,k\,m} = \sum_{i \in N} X_{j\,i\,k\,m} \qquad \forall\, m, k,\; j \in N' \tag{6}$$

$$e_i - e_j + 1 \le n \quad 1 - X_{i\,j\,k\,m} \qquad j, k, m \in N' \tag{7}$$

$$X_{i\,j\,k\,m} \le y_m \qquad \forall\, i,\; j \in N, \quad k, m \in N' \tag{8}$$

$$X_{i\,j\,k\,m} \le Z_{k\,m} \qquad \forall\, i,\; j \in N, \quad k, m \in N' \tag{9}$$

$$t^{d}_{k\,m} - \left(t^{p}_{k\,m} + \frac{1}{r} \sum_{i,\,j \in N} X_{i\,j\,k\,m}\, q_j \right) + \sum_{\substack{i \in N \\ j \in N'}} X_{i\,j\,k\,m}\, \tau_{i\,j} \le B \qquad \forall\, k, m \in N' \tag{10}$$

$$t_{k\,m}^{d} + \sum_{i,j \in N} X_{i\,j\,k\,m}\, \tau_{i\,j} \le H \qquad \forall\, k, m \in N' \tag{11}$$

$$t_{k\,m}^{p} + \frac{1}{r} \sum_{i,j \in N} X_{i\,j\,k\,m}\, q_i \le\, t_{k\,m}^{d} \qquad \forall k, m \in N' \tag{12}$$

$$t_{k\,m}^{d} + \sum_{\substack{i \in N \\ j \in N'}} X_{i\,j\,k\,m}\, \tau_{i\,j} \le\, t_{k+1\;m}^{d} \qquad \forall\, k, m \in N' \tag{13}$$

$$t_{k\,m}^{p} + \frac{1}{r} \sum_{\substack{i \in N \\ j \in N'}} X_{i\,j\,k\,m}\, q_j \le\, t_{k+1\;m}^{p} \qquad \forall k, m \in N' \tag{14}$$

$$\sum_{k,m \in N'} P_{k\,m\,t} \le 1 \qquad \forall\, t \in T \tag{15}$$

$$\sum_{t \in T} P_{k\,m\,t} = \frac{1}{r} \sum_{i,j \in N} X_{i\,j\,k\,m}\, q_i \qquad \forall\, k, m \in N' \tag{16}$$

$$t_{k\,m}^{p} \le t\, P_{k\,m\,t} + M \quad 1 - P_{k\,m\,t} \qquad \forall\, k, m \in N', \quad t \in T \tag{17}$$

$$t_{k\,m}^{p} + \frac{1}{r} \sum_{\substack{i \in N \\ j \in N'}} X_{i\,j\,k\,m}\, q_j \ge t\, P_{k\,m\,t} \qquad \forall\, k, m \in N', \quad t \in T \tag{18}$$

$$X_{i\,j\,k\,m},\;\; P_{kmt},\;\; Z_{k\,m},\;\; y_m \in\;\; 0,1 \qquad \forall\, m, k,\; j \in N',\; i \in N$$

$$t_{k\,m}^{d},\; t_{k\,m}^{p},\; e_i \text{ are integers} \qquad \forall\, m, k,\; j \in N',\;\; i \in N$$

Constraints (1) to (7) are typical vehicle routing constraints. Constraint (1) is the truck capacity constraint and constraints (2) and (3) ensure that a customer is visited exactly once. Constraints (4) and (5) ensure the number of times a truck leaves the plant and comes back to the plant is the same as the number of trips for that particular truck.

Constraint (6) is the continuity constraint for each trip. Without this constraint, for example, a truck can reach a customer in its trip k and leave the same customer in its trip $k+2$. The constraints in (7) are the sub-tour elimination constraints from Miller (1960). Constraints (8) and (9) ensure that a customer cannot be visited by given trip of a given truck without hiring that particular truck. Constraint (10) enforces the product lifetime constraint and constraint (11) ensures the planning horizon constraint for all deliveries. Constraint (12) ensures that products cannot be delivered before being produced and constraint (13) ensures that a truck cannot start a new trip before completing the previous job and coming back to the plant. Constraint (14) ensures that the plant cannot start producing for trip $k+1$ before completing the production for trip k. Constraints (15) to (18) together ensure the availability of the single plant at any given time epoch t. Constraint (15) ensures that the plant can produce only for one trip at any given time period. Constraint (16) ensures that the production time of the plant for a batch is the minimum amount of the time required to meet demand of the corresponding route. Constraint (17) and (18) together ensure that when the plant starts producing for a trip it continuously produces until the total demand is produced for that trip. Due to the inherent problem structure, problems having more than 4 customers require a large amount of time to solve to optimality as can be seen in Table 3.1 and Figure 3.5. For all problems $B = 50, C = 60,$ and $F = 200$.

Problem Size	Planning Horizon	Number of Variables	Number of Constraints	% Gap	CPLEX solution	ApproimateTime taken by CPLEX/ (hrs)
4	150	2,921	6,295	0	293	0.01
5	150	4,836	10,551	21.71	910	> 20
6	200	7,429	16,495	22.53	624	> 20
7	200	10,844	24,553	26.19	766	> 20
8	200	15,249	35,223	30.9	728	> 20
9	200	24,886	57,225	42.01	1034	> 20
10	200	32,821	76,801	n/a	no solun	10 days
12	200	54,169	130,953	n/a	no solun	10 days
15	250	104,206	262,551	n/a	no solun	10 days
20	350	319,241	806,751	n/a	no solun	10 days

Table 3.1: Problem size growth with number of customers

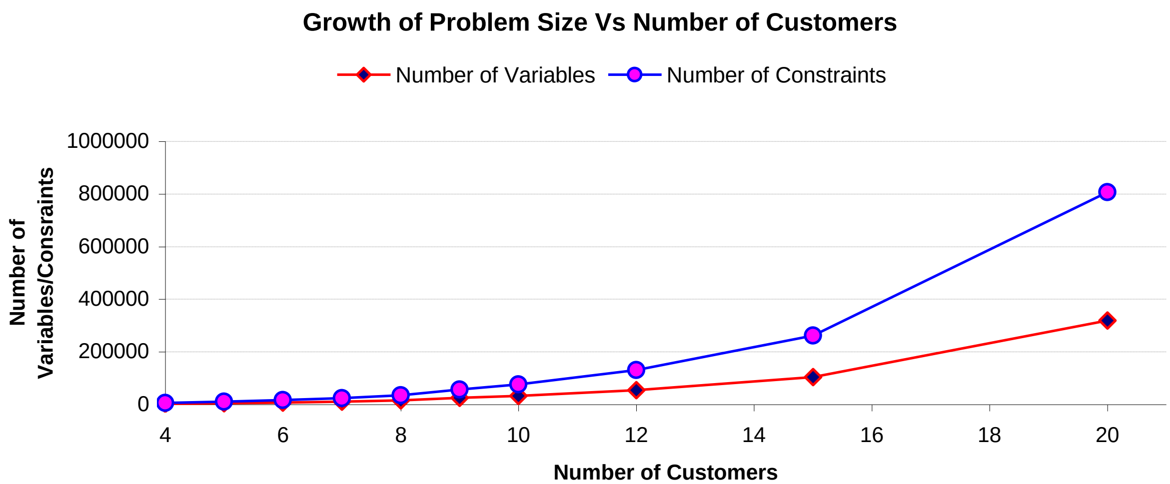

Figure 3.5: Problem size growth with number of customers

CPLEX solved the problem with 4 customers to optimality in less than 0.01 hours; however CPLEX could not solve any problem bigger than 4 customers to optimality within 20 hours. For any problem with more than 9 customers, CPLEX even could not find a feasible solution within 10 days. As shown in Figure 3.5, when the number of customers increases, problem size grows exponentially. As a matter of fact IPDSP is an extension of traveling salesman problem; hence IPDSP is a NP-hard problem. For example consider a simple problem instance of IPDSP where the total demand of customers is less than the truck capacity. The optimal solution to this problem is given by the traveling salesman tour which has been proven to be NP-Hard. Hence, IPDSP is also NP-Hard. We now turn our attention to a heuristic approach to solve the IPDSP using evolutionary algorithms.

Heuristic Solution Approach for IPDSP

The heuristic solution approach used in this paper to solve IPDSP is based on well known “route first cluster second” method from the vehicle routing literature (Beasley 1983). First a route containing all customers that starts and ends at the plant is found. Then the route is partitioned into sub-tours based on truck capacity and lifetime constraints. The production quantities at the plant exactly match the demands of respective sub-tours. For example, if a given route is partitioned into five sub-tours then the plant will produce five batches. The production at the plant is initially scheduled so that a truck is available to deliver at the time of production completion of each batch.

This is the no-wait schedule illustrated in the introduction. Then if plant idle time is available between two consecutive batches, the no-wait schedule is compressed subject to the product lifetime constraint so that overall makespan is maximally compressed. Section 3.2.2 provides additional details of the procedure. This heuristics approach produces a good route leading to a good set of sub-tours with a low cost in other situations.

The following notation is used in the development of the heuristics. A sequence containing all customers is denoted by σ, a sub-tour of σ is σ_j and $\sigma(i_j)$ denotes the i^{th} customer of the j^{th} sub-tour. The sequence σ can be divided into k sub-tours with the j^{th} sub-tour $\sigma_j = \ P, \sigma \ \ i_{j-1}+1 \ , \ \sigma \ \ i_{j-1}+2 \ , ..., \ , \ \sigma \ \ i_j - 1 \ , \sigma \ \ i_j \ \ , P \ \ , \ j = 1, 2, 3, ..., k$. Each sub-tour must consist of at least one customer and for σ_j, $\sigma \ \ i_{j-1}$ is the last customer of the sub-tour σ_{j-1}, $\sigma \ \ i_{j-1}+1$ is the first customer in this sub-tour and P is the plant. It is assumed that each customer belongs to exactly one sub-tour and that each sub-tour is visited once by one truck. For a given σ, if the total demand cannot be satisfied by one truck within H and requires s trucks, $s \geq 2$, then we have the additional problem of assigning s trucks to k sub-tours. To ensure the product is delivered within its effective lifetime the constraint $\tau_{0,i} \leq B$ is imposed $\forall i \in N \setminus \ 0$. Given the Euclidian distance $l_{i,j}$ between any two of the customers and the speed of the truck, the travel time $\tau_{i,j}$ from customer i to customer j is easily calculated. It is assumed that there is no inventory held at any stage of the process and the distances $l_{i,j}$ are symmetric and satisfy the triangle inequality.

Optimal Tour Partitioning

Partitioning a given sequence σ into sub-tours is constrained by both the truck's capacity and the product's lifetime. The optimal tour partitioning procedure given in Beasley (1983) and later called algorithm Split by Prins (2004) is used in this research to partition σ. Given a sequence with n customers, algorithm Split works on a directed graph G with $n+1$ nodes and a set of arcs. Each arc corresponds to a feasible sub-tour in the given sequence and arc weights correspond to the distance of each sub-tour. The node 0 represents the plant and the other n nodes represent customers in the sequence, while the last node represents the last customer in the sequence. The graph G contains an arc between nodes i and j if the sub-tour visiting customers represented by nodes $i+1$ through j along the selected sequence are feasible, both in terms of the truck capacity and the lifetime of the product. The arcs in the shortest path of G from node 0 to the last node optimally partition the sequence into sub-tours minimizing the distance required to visit all customers. The example given below demonstrates how a given sequence of customers is partitioned into sub-tours using the Split algorithm.

Example 3.2: Suppose $n = 6, C = 500, B = 70, \sigma = \ 2, 5, 3, 6, 4, 1$, and a unit travel cost per unit distance. Customer demands are as follows. $q_1 = 350,$ $q_2 = 100,$ $q_3 = 150,$ $q_4 = 100,$ $q_5 = 250$, and $q_6 = 300$. The symmetric travel times are given in Table 3.2, and Figure 3.5 is a graphical representation of the data. In Figure 3.6, we have omitted drawing arcs which cannot constitute a sub-tour for clarity. For example, it is not possible to include customers 2, 5, and 3 in one sub-tour since the life time constraint is violated; hence we have not drawn an arc from node 2 to node 5. Note that the first customer in the sequence is represented by $\sigma\ 1 = 2$. Similarly, $\sigma\ 2 = 5,$ $\sigma\ 3 = 3,$ $\sigma\ 4 = 6,$ $\sigma\ 5 = 4,$ and $\sigma\ 6 = 1$.

	0	1	2	3	4	5	6
0	-	10	20	20	30	20	40
1		-	20	30	30	20	50
2			-	30	40	20	30
3				-	30	40	30
4					-	30	10
5						-	20
6							-

Table 3.2: Travel Time Matrix of Example 3.2

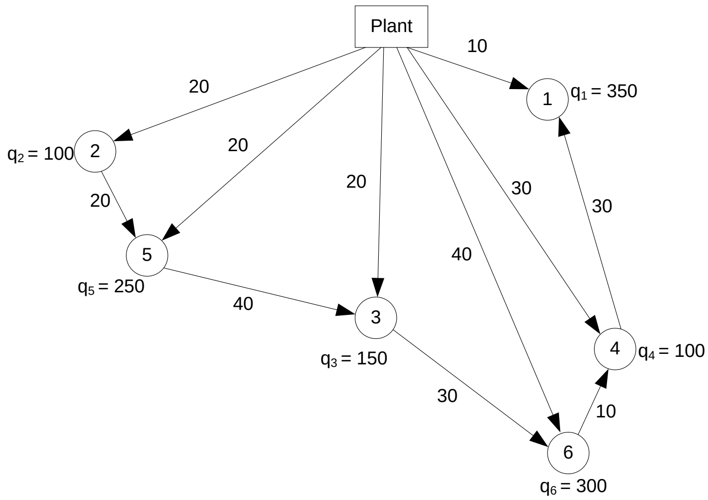

Figure 3.6: Schematic representation of Example 3.2.

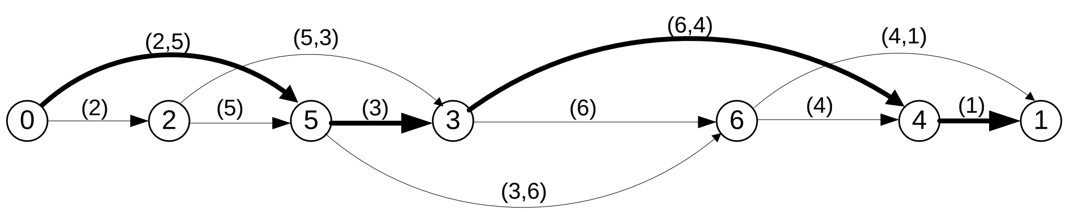

Figure 3.7: Partitioning with Split algorithm for Example 3.2.

In Figure 3.6, the arc $0, 2$ represents the sub-tour $0, 2, 0$ containing only customer 2. The number(s) written within parentheses on the arc represent the customers included in the sub tour represented by the arc. The graph also contains an arc between $0, 5$ representing the feasible sub-tour $0, 2, 5, 0$ because customer 5 can also be included into the same sub-tour with customer 2. Note that customer 3 cannot be included in a sub-tour with customers 2 and 5 since the lifetime constraint is violated; hence there exists no arc $0, 3$. All other arcs are similarly constructed. The arcs in the graph represent all feasible sub-tours that can be formed along the sequence $\sigma = \ 2, 5, 3, 6, 4, 1$ without violating the problem constraints. According to the Split algorithm, the shortest path (Dijkstra 1959) between node 0 and the last node contains 4 arcs that optimally partition the sequence $\sigma = \ 2, 5, 3, 6, 4, 1$ into 4 sub-tours $\sigma_1, \sigma_2, \sigma_3,$ and σ_4 as explained. Note that $i_0 = 0$ represents the plant.

$$\sigma_1 = \ 0, \sigma \ \ i_0 + 1 \ , \sigma \ \ i_1 \ \ , 0 \ = \sigma_1 = \ 0, \sigma \ \ 1 \ , \sigma \ \ 2 \ \ , 0 \ = \ 0, 2, 5, 0 \ \text{, where } i_1 = 2.$$

$$\sigma_2 = \ 0, \sigma \ \ i_1 + 1 = i_2 \ \ , 0 \ = \sigma_2 = \ 0, \sigma \ \ 3 \ \ , 0 \ = \ 0, 3, 0 \ \text{, where } i_2 = 3.$$

$$\sigma_3 = \ 0, \sigma \ \ i_2 + 1 \ , \sigma \ \ i_3 \ \ , 0 \ = \sigma_3 = \ 0, \sigma \ \ 4 \ , \sigma \ \ 5 \ \ , 0 \ = \ 0, 6, 4, 0 \ \text{, where } i_3 = 5.$$

$$\sigma_4 = \ 0, \sigma \ \ i_3 + 1 = i_4 \ \ , 0 \ = \sigma_3 = \ 0, \sigma \ \ 6 \ \ , 0 \ = \ 0, 1, 0 \ \text{, where } i_4 = 6.$$

The total distance of the shortest path is 200. It should also be noted that optimal tour partitioning does not necessarily minimize the number of sub-tours but it does minimize the total distance travel to serve all customers. The total demand in this example can also be satisfied with 3 sub-tours, $2, 5$, $3, 6$, and $4, 1$, but at the higher cost of 220. The optimal tour partitioning is algorithmically explained below for a problem with n customers.

Algorithm Optimal Tour partition

Step 1: Select a sequence σ of customers. Go to *Step 2.*

Step 2: Generate graph G with $n+1$ nodes where first node corresponds to plant and the last node corresponds to the last customer in the selected sequence. Create directed arcs from each node $i \rightarrow i+1$ for $i=0$ to n. Set $i=1$. Go to *Step 3.*

Step 3: Generate all feasible sub-tours starting from i along σ and create arcs from node i to node j where j is the last customer in a sub-tour. Go to *Step 4.*

Step 4: If $i=n$ stop, Go to *Step 5.* Else set $i=i+1$ and Go to *Step 3.*

Step 4: Calculate the shortest path in Graph *G*.

Every arc in the shortest path of G corresponds to a sub-tour with one or more customers. For example, the arc from node $i \rightarrow i+3$ corresponds to a sub-tour with customers represented by nodes $i+1, i+2,$ and $i+3$ in that order. The worst case complexity of optimal tour partitioning algorithm is $O(n^2)$ where algorithm Split has a complexity of $O(n^2)$ and Dijkstra's shortest path algorithm has a complexity of $O(n^2)$.

The Makespan Compression of IPDSP

This section describes how a no-wait schedule is calculated and compressed using a polynomial time algorithm for a given sequence and a given set of sub-tours when more than one truck is required to satisfy the demand within H. During some or all of the time that a truck is delivering sub-tour σ_j, the plant is producing products for sub-tour σ_{j+1}. Note that the time required to produce the required amount of product for sub-tour σ_{j+1} is p_{j+1} and the total travel time of sub-tour j is T_{σ_j}. Then,

$$p_{j+1} = \frac{1}{r}\sum_{k=i_j+1}^{i_{j+1}} q_{\sigma\ k} \quad \text{and,}$$

$$T_{\sigma_j} = \tau_{0,\sigma\ i_{j-1}+1} + \sum_{k=i_{j-1}+1}^{i_j-1} \tau_{\sigma\ k\ ,\sigma\ k+1} + \tau_{\sigma\ i_j\ ,0} \qquad (19)$$

From equation (19), the delivery time from the plant to the last customer in sub-tour j is given by $T_{\sigma_j} - \tau_{\sigma\ i_j\ ,0}$, where $\tau_{\sigma\ i_j\ ,0}$ is the travel time between the last customer in sub-tour j and the plant.

Unlike the one truck case, the delivery finish times of all sub-tours in progress should be monitored in order to obtain the potential delivery start time for the next sub-tour in a no-wait schedule. For example, assume an IPDSP with two trucks and eight sub-tours and the no-wait delivery start time of the fifth sub-tour has to be determined. Since there are only two trucks, delivery start time of the fifth sub-tour depends on the delivery of sub-tours currently being delivered by the two trucks. These two sub-tours can be any combination of two sub-tour subsets from the set $1, 2, 3, 4$ and, depending on the distance; one truck could complete many sub-tours before the other truck completes one. The theorem given below establishes this concept and calculates a no-wait schedule for a given sequence of IPDSP.

Theorem 3.1: Let s trucks be in use and let the delivery finish time of the s sub-tours in progress at a particular time epoch be F_g, where $g \in 1,2,...,s$. Further, let v_j be the delivery start time of sub-tour σ_j in a no-wait schedule. The delivery of sub-tour σ_{j+1} is started at time v_{j+1} where

$$v_{j+1} = \max\left[\min_{1\le g\le s} F_g, \quad \left\{ v_j + \frac{1}{r}\sum_{k=i_j+1}^{i_{j+1}} q_{\sigma\ k} \right\} \right] \qquad (20)$$

Proof: Since no inventory is held at the plant, production for sub-tour $j+1$ cannot begin before time epoch v_j. Given v_j, delivery of sub-tour σ_{j+1} cannot be started earlier than V_{j+1}, where $V_{j+1} = \left(v_j + \frac{1}{r}\sum_{k=i_j+1}^{i_{j+1}} q_{\sigma\ k} \right)$. However, in order to start the routing on sub-tour $j+1$, at least one truck should be available at the plant when the production for sub-tour $j+1$ is completed. The earliest delivery finish time of the last s sub-tours is $\min_{1\le g\le s} F_g$. So in order to obtain a no-wait schedule, v_{j+1} should be scheduled at $\max \min_{1\le g\le s} F_g, \quad V_{j+1}$ ■

Example 3.3**:** Table 3.3 contains data for a given sequence of customers. The sequence has been grouped into seven sub-tours based on both capacity and lifetime constraints. Let the fleet size be 3 trucks.

Sub-tour	Production Time p_j	Distribution Time T_{σ_j}
σ_1	2	13
σ_2	4	5
σ_3	3	12
σ_4	4	13
σ_5	5	5
σ_6	2	4
σ_7	4	3

Table 3.3: Data for example 3.3

Figures 3.7 through 3.9 show how to calculate the no-wait delivery start times v_6 and v_7 of two consecutive sub-tours. Figure 3.8 shows the no-wait schedule calculated using Theorem 3.1, up to the fifth sub-tour. From Theorem 3.1, the delivery start time of the sixth sub tour $v_6 = \max\{\min\{F_3, F_4, F_5\}, V_6\}$ which is equal to the $\max\{\min\{21, 26, 23\}, 20\} = 21$. So the updated no-wait schedule is given in Figure 3.9. Similarly, the delivery start time of the seventh sub-tour can be calculated as $v_7 = \max\{\min\{F_4, F_5, F_6\}, V_7\} = 25$, where $V_7 = 21 + 4 = 25$. Figure 3.10 displays the no-wait schedule for a delivery containing seven sub-tours.

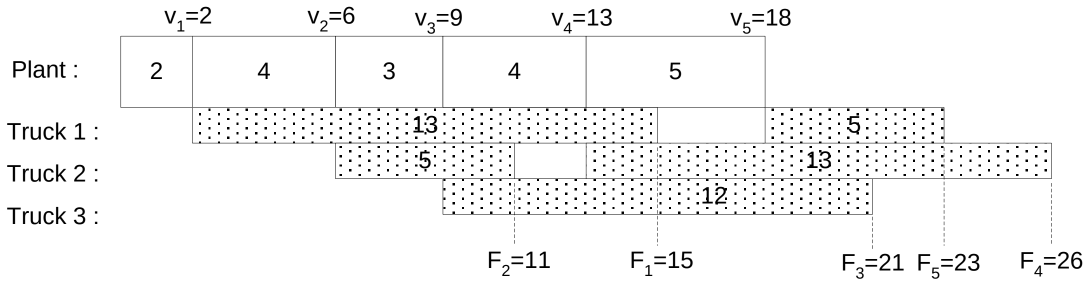

Figure 3.8: No-wait schedule for the first 5 sub-tours in Example 3.3

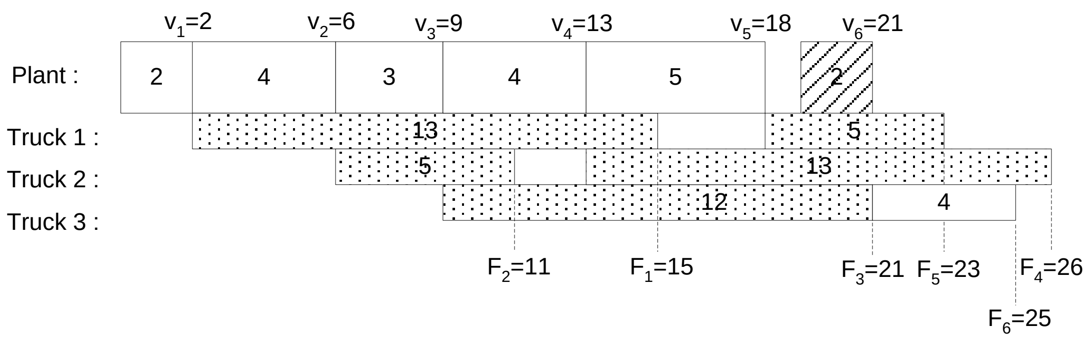

Figure 3.9: No-wait schedule for the first 6 sub-tours in Example 3.3

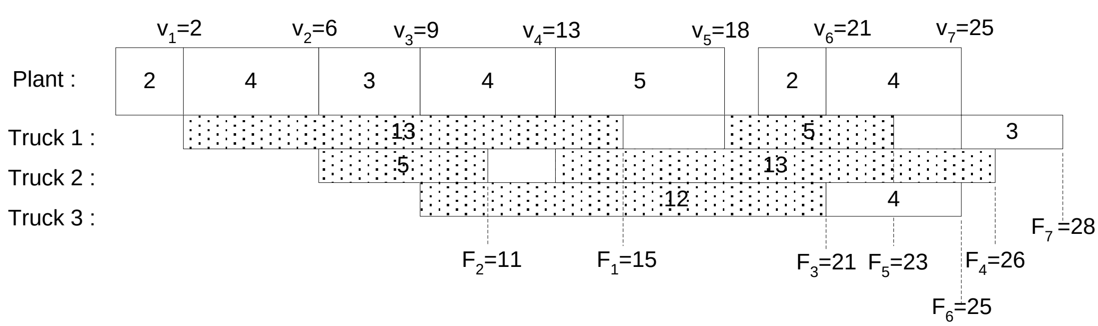

Figure 3.10: No-wait schedule for the first 7 sub-tours in Example 3.3.

The next issue to be addressed is how to compress a no-wait schedule to reduce the makespan. Assume a sequence σ generates k sub-tours. Let u_j and v_j be the production and delivery start times of sub-tour serving customers $\sigma(i_{j-1}+1), \sigma(i_{j-1}+2), ..., \sigma(i_j)$. If plant idle time exists between the production start times corresponding to sub-tours $j-1$ and j, then it may be possible to start the production for sub-tour j earlier resulting an earlier delivery start time. Let u'_j, v'_j be the respective compressed production and delivery start times for the sub-tour j where $j = 1, 2, 3, ..., k$. Let f_j be the delivery finish time of sub-tour j. At time f_j, the truck assigned to sub-tour j returns to the plant after delivery. Example 3.4 shows the steps of compressing a no-wait schedule.

Example 3.4: Table 3.4 contains data for a given sequence of customers. The selected sequence has been grouped into six sub-tours based on both capacity and lifetime constraints as illustrated in section 3.3.1 Note that $n = 10, s = 2, B = 17$.

Sub-tour	Production Time p_j	Delivery Time $T_{\sigma_j} - \tau_{\sigma\ i_j\ ,0}$	Return Time $\tau_{\sigma\ i_j\ ,0}$
σ_1	2	17	2
σ_2	3	4	1
σ_3	3	2	1
σ_4	6	4	2
σ_5	3	5	1
σ_6	1	5	3

Table 3.4: Data for Example 3.4

First, the no-wait schedule is calculated according to Theorem 3.1. It has a makespan of 30 time units. As shown in Figure 3.11, before starting the production for the third sub-tour, the plant has an idle time of 2 time units. Since the delivery time of sub-tour 3 is 2 time units, the production start time of sub-tour 3 can be advanced by a maximum of $B-2=15$ time units. On the other hand, the available plant idle time is only 2 time units, so, u_3 is compressed by 2 time units and $u_3'=5$. With u_3' now defined, a new no-wait schedule can be calculated for u_j, $j=4, 5, 6$ as shown in Figure 3.12. This can have a dramatic impact for example; notice how sub-tours σ_5 and σ_6 switch trucks with a makespan reduced to 29 time units.

The second compression is on u_5; it does not reduce the makespan, although it advances production as illustrated in Figure 3.13. Note that T_j in this figure represents T_{σ_j}.

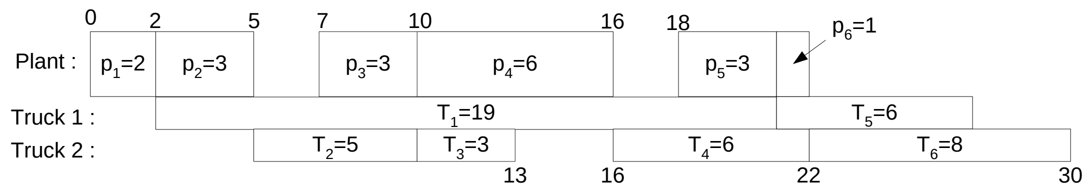

Figure 3.11: No-wait schedule for Example 3.4

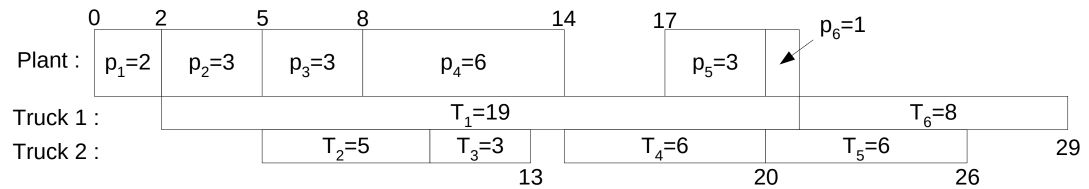

Figure 3.12: After the first compression of no-wait schedule for Example 3.

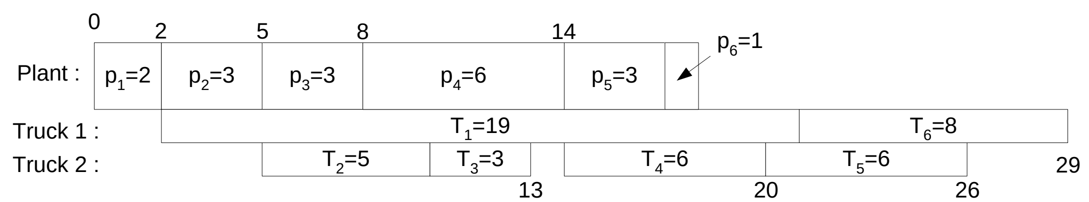

Figure 3.13: After the second compression of no-wait schedule for Example 3.4

Algorithm-Compress operates on a no-wait schedule to compress the makespan obtained in a no-wait schedule as illustrated by the Example 3.4 Given below is the Algorithm-Compress procedure when $s \geq 1$ trucks are used in a no-wait schedule having k sub-tours.

Algorithm—Compress

Step 1: Obtain a no-wait schedule for the selected route using equation (2). Set $v'_1 = v_1$, $v'_2 = v_2, ..., v_s = v_s$, and $u'_1 = u_1, u'_2 = u_2, ..., u'_s = u_s$.

Step 2: Start compression at $j = s+1$. If $u_{s+1} - v_s > 0$, compress u_{s+1} by x_{s+1}, where $x_{s+1} = \min\left[B - \left(T_{\sigma_j} - \tau_{\sigma\left(i_{s+1}\right),0}\right), \left(u_{s+1} - v_s\right)\right]$. Set $u'_{s+1} = u_{s+1} - x_{s+1}$ and $v'_{s+1} = v_{s+1}$. Calculate the no-wait schedule for sub-tours $j = s+2, s+3, ..., k$, using the new values of u'_{s+1} and v'_{s+1}.

Step 3: Set $j = s+2$ and repeat the procedure in *Step 2*.

Step 4: Increase the value of j sequentially and apply *Step 2*. Stop when $j = k+1$. Set the makespan f, for the selected route to $\max_{1 \le j \le k}\left(v'_j + T_{\sigma_j}\right)$.

If s trucks are used in IPDSP, calculating the no-wait production start time of the j^{th} sub-tour requires that all s sub-tours in progress be monitored. If there are $k \le n$ sub-tours, then calculation of the no-wait schedule has a time complexity of $O(sk)$. In the worst case, there can be n sub-tours and n trucks for a given sequence; thus, calculation of a no-wait schedule has a complexity of $O(n^2)$. In Algorithm-Compress, $(n-s)$ no-wait schedules have to be calculated. Therefore, Algorithm-Compress has a worst case complexity of $O(n^3)$.

Lower Bounds on the Total Cost of the IPDSP

The evaluation of heuristic results for large problems is done using a lower bound on the minimum cost. In this section two lower bounds are established for the total cost TC of the IPDSP. A lower bound to IPDSP can be written as the sum of two terms; 1) the lower bound on the fixed hiring cost of trucks 2) the lower bound on the transportation cost. In section 3.6, the maximum of the two lower bounds is used to evaluate the results obtained from the proposed heuristics for IPDSP.

Theorem 3.2: Assume the following are known: 1) an IPDSP with n customers, each with demand $q_i \quad i = 1, 2, 3, ..., n$, 2) a matrix of travel times between customers i and j of $\tau_{i,j}$, $0 \le i, j \le n,$ where 0 denotes the plant, 3) a fixed production rate r , 4) a fixed cost of hiring a truck F, and 5) the truck's capacity $C.$ Let

$$g = \left\lfloor \frac{\sum_{i=1}^{n} q_i}{C} \right\rfloor + 1 \ ,$$

and G be the set of $g-1$ customers who are closest to the plant and H be the given planning horizon. If each truck travels at a constant speed 1 then the lower bound LB_1 on TC of IPDSP is

$$TC \ge 2 \max_{1 \le i \le n} \tau_{0,i} + 2 \sum_{i \in G} \tau_{0,i} + F \left\lceil \frac{\frac{1}{r} \min_{1 \le i \le n} q_i + \left\{ 2 \max_{1 \le i \le n} \tau_{0,i} + 2 \sum_{i \in G} \tau_{0,i} \right\}}{H} \right\rceil$$

Proof: A lower bound on the number of sub-tours required to satisfy the total demand is g. One sub-tour delivers to the farthest customer, possibly including some others, so it requires at least $2\max_{1\le i\le n} \tau_{0,i}$ time units. The other $g-1$ sub-tours satisfy the demand of all other customers at least in $2\sum_{i\in G}\tau_{0,i}$. The term $\frac{1}{r}\min_{1\le i\le n} q_i$ determines minimum truck waiting time at the plant to start the first sub-tour. The minimum truck wait time is equivalent to the production time required to satisfy the smallest customer demand. Thus, the term within the ceilings gives the lower bound on the number of trucks required to hire in order to satisfy the total demand within the planning horizon H. The lower bound on the hiring cost is obtained by multiplying the number of trucks by the fixed cost F. The sum of two terms $2\max_{1\le i\le n} \tau_{0,i} + 2\sum_{i\in G}\tau_{0,i}$ gives a lower bound on the travel cost ■

The second lower bound to IPDSP is based on a lower bound on the classical bin packing problem given in Bourjolly and Rebettez (2005). They observed that no two customers whose demand is greater than half of the truck's capacity C can be served in one sub-tour and, at most, two customers whose demand is between $C/2$ and $C/3$ can be served in one sub-tour. More formally, when q_i is the demand of customer i, let $A=\left\{i:\ q_i>\frac{C}{2}\right\}$, $G=\left\{j:\ \frac{C}{2}\ge q_j>\frac{C}{3}\right\}$ and $K=\left\{k:\ q_k\le\frac{C}{3}\right\}$: then, only one customer in A can be served in one sub-tour, no more than two customers in G can be served in one sub-tour and at least three customers in K can be served in one sub-tour.

The perishable constraint of IPDSP is incorporated into the lower bound as explained below.

To begin, the number of sub-tours must be greater than or equal to $|A|$. A customer $i \in G$ can be served on the same sub-tour with a customer $j \in A$, if $q_i + q_j \leq C$ and $\tau_{0,i} + \tau_{i,j} \leq B$ or $\tau_{0,j} + \tau_{j,i} \leq B$. Let $\bar{h}$ be the number of customers in G that are not included in a sub-tour with a customer in A. Then $\left\lceil \frac{\bar{h}}{2} \right\rceil$ is the smallest number of additional sub-tours that must be made assuming no perishable constraint. The number of sub-tours obtained ignoring the perishable constraint is always less than or equal to that obtained considering the perishable constraint. Let $G^{\bar{A}}$ be the set of customers that cannot be included in a sub-tour with a customer in A and $g(q_i)$ be the contribution to the lower bound from customers in K. Using the notation in Bourjolly and Rebettez [2005], let $W(a,b) = \{i \in N : a < q_i \leq b\}$ be the set of customers having demand larger than *a* but smaller than or equal to *b*, and $\bar{W}(a,b) = \{i \in N : a \leq q_i \leq b\}$ be the set of customers having demand larger than or equal to *a* but smaller than or equal to *b*. Then, the minimum number of sub-tours, $T_{\min}$, required to satisfy the total demand is given by $|A| + \left\lceil \frac{\bar{h}}{2} \right\rceil + g(q_i)$, where

$$g(q_i) = \max_{0 \leq q_i \leq C/3} \left\{ \max\left(0, \left\lceil \frac{\sum_{i \in \bar{W}(q_i,\, C-q_i)} q_i}{C} - |A| - \left\lceil \frac{\bar{h}}{2} \right\rceil \right\rceil \right) \right\}$$

Theorem 3.3: Given an IPDSP with n customers having demand q_i, $i = 1, 2, 3, ..., n$ and a matrix of travel times $\tau_{i,j}$, $0 \le i, j \le n$, where 0 denotes the plant, and a fixed production rate r, a fixed cost of hiring F, and the truck capacity C. Let H be the given planning horizon, each truck travels at a constant speed of 1 unit distance per unit time, and there is a unit travel cost per unit distance. Then, the lower bound, LB_2 on TC of IPDSP is

$$TC \ge 2\left(\sum_{f \in A} \tau_{0,f} + \sum_{i=1}^{\lceil \bar{h}/2 \rceil} \tau_{0,g_{2i}} + \sum_{i=1}^{g\ q_i} \tau_{0,k_{3i}} \right) + F \left\lceil \frac{\frac{1}{r} \min\limits_{1 \le i \le n} q_i + 2\left(\sum_{f \in A} \tau_{0,f} + \sum_{i=1}^{\lceil \bar{h}/2 \rceil} \tau_{0,g_{2i}} + \sum_{i=1}^{g\ q_i} \tau_{0,k_{3i}} \right)}{H} \right\rceil$$

Proof: Using the same notation as in the proof of LB1, the first term is the lower bound on the transportation cost of the IPDSP. The second term is the lower bound on the fixed cost of the minimum number of trucks required to meet the total demand within the planning horizon. In order to form LB_2, distances are first calculated and since no two customers in A can be served in the same sub-tour, a distance of at least $2\sum_{f \in A} \tau_{0,f}$ has to be traveled. Next, the elements of $G^{\bar{A}}$ are sorted in ascending order of the distance from the plant. Let the distance of the i^{th} element in the sorted list $G^{\bar{A}}$ be g_i. Because at most two customers in $G^{\bar{A}}$ can be served in one sub-tour, a distance of at least $2\sum_{i=1}^{\lceil \bar{h}/2 \rceil} \tau_{0,g_{2i}}$, $i \in G^{\bar{A}}$, should be traveled in $\left\lceil \frac{\bar{h}}{2} \right\rceil$ sub-tours. Then, the elements of K are sorted in ascending order with the i^{th} element in K denoted by k_i. Since at least three customers in K can be served in one sub-tour, a distance of at least $2\sum_{i=1}^{g\ q_i}\tau_{0,k_{3i}}$, $i \in K$, should be traveled in $g\ q_i$ sub-tours. Hence, $2\left(\sum_{f\in A}\tau_{0,f} + \sum_{i=1}^{\left\lceil \bar{h}/2 \right\rceil}\tau_{0,g_{2i}} + \sum_{i=1}^{g\ q_i}\tau_{0,k_{3i}}\right)$ gives a lower bound on the travel cost in IPDSP. A lower bound on the travel time is obtained by adding the minimum truck wait time at the plant to start the first sub-tour, $\frac{1}{r}\min_{1\le i\le n} q_i$, and the lower bound on the total travel time obtained above ■

Meta-heuristics for IPDSP

Two algorithms given in this paper for IPDSP are based on a commonly used meta-heuristic in the optimization literature developed by Holland (1975) called genetic algorithms (GA). GA's have been successfully used in complex optimization problems to obtain near optimal solutions within a short computational time. GAs are global search procedures that imitate Darwinian natural evolution processes. GA evolves candidate solutions, which are known as chromosomes, over generations to obtain good solutions. In literature methods analogous to many biological evolution concepts are used to enhance the performance of GAs.

Genetic Algorithms

GAs operates on a population that consists of a predetermined number of chromosomes (e.g., solutions). Each of these solutions has a measurable quality that assesses its value that is called the “fitness” and is analogous to the objective function value for a given solution to a mathematical programming problem. In IPDSP, a chromosome is a sequence of customers σ . The sequence σ defines k sub-tours using the optimal tour partition algorithm The fitness value associated with each chromosome is the total cost of a solution: hence the smaller values are better.

The fitness of a chromosome is generated by a fitness function. In IPDSP, this is accomplished through a process that takes advantage of theories previously developed in this dissertation. First, a given chromosome is partitioned into feasible sub-tours using the optimal tour partitioning algorithm so that total distance traveled is minimized. Then a no-wait schedule is calculated using Theorem 3.1 to find the makespan with a fleet of one truck and the makespan is improved by Algorithm-compress if possible. If the makespan is smaller than the planning horizon, the total cost is calculated with one truck. Otherwise, the fleet size is increased by one truck and the above procedure is repeated. The fleet size is increased incrementally until a feasible solution is obtained and the total cost is recorded as the fitness of that chromosome.

The first generation chromosomes are randomly generated. Each of them is evaluated by the fitness function, and the fitness is recorded along with the number of trucks required. If a sequence is infeasible with respect to the specified planning horizon, the number of trucks is set to a very large value that results in an undesirable fitness. This ensures that all infeasible sequences are assigned fitness that makes it very likely that they will be eliminated in the next generation.

The genetic algorithm evolves from one generation to the next using evolutionary operators. There are a number of these operators used in the literature but the two used here are crossover and mutation. Crossover begins by forming a mating pool with existing chromosomes with a higher fitness value of the current population. The chromosomes that are selected to form the mating pool are called parents since the next generation chromosomes (children) are made by mating them. The chromosomes are qualified to be transferred to the mating pool based on their fitness values. Roulette-wheel selection is used to copy parents to the mating pool to ensure that parents with better fitness values are preferred. This research uses the procedure that follows. All chromosomes are sorted in decreasing order of their fitness values (increasing order of the total cost), denoted by f_i, $i = 1, 2, 3, ..., M$, where M is the size of the population. The IPDSP is a cost minimization problem and it is converted into a maximization problem by defining a value $k_i = \frac{1}{f_i \Big/ \sum_{i=1}^{M} f_i}$ for each sequence. Then, roulette wheel probabilities p_i for each sequence is given by $p_i = \frac{k_i}{\sum_{i=1}^{M} k_i}$. The roulette wheel partitions are defined by $\sum_{j \le i} p_j$, where $j = 1, 2, 3, ..., M$. Two parents in the mating pool are randomly selected and assigned to be a couple that may or may not give birth to a child. Whether a couple mates is randomly decided, weighted by the crossover probability. Non-mating couples are moved to the next generation without making any changes in their genetic sequence. This enables unaltered beneficial features of chromosomes to carry through the generations. Since two chromosomes are randomly selected from the mating pool to crossover, the same chromosome can possibly be selected more than once. A two point crossover demonstrated in Figure 3.14 is used for mating in this research. The crossover occurs at two randomly selected fields (c_1 and c_2) in each parent. The genetic sequence of child 1 is formed using genes 1 through c_1 and c_2 through the last gene from parent 1 and the rest is copied exactly as in the order of the second parent. This is illustrated in Figure 3.14. Child 2 is similarly created with parent 2 and parent 1 reversed.

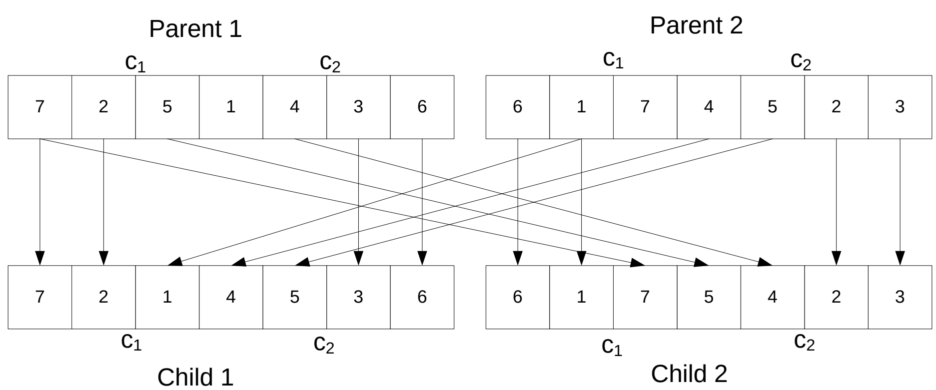

Figure 3.14: The two point crossover

The GA analog of mutations consists of randomly changing a gene in chromosome. This is done only in a predetermined percentage of children and helps the GA in avoiding local minima by diversifying population. In this research a swap of two genes is used to mutate a child chromosome as shown in Figure 3.14. The fitness of each child is then evaluated.

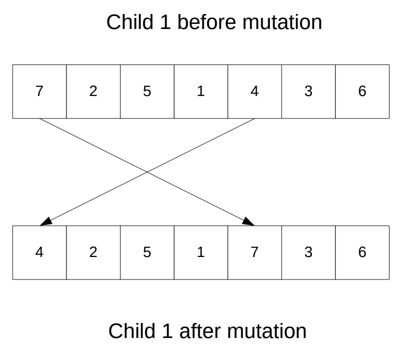

Figure3.15: A pairwise exchange mutation.

The next generation is populated using both the child generation chromosomes and parent chromosomes (elite reproduction). In the genetic algorithm literature (Potvin 1996) higher cross over rates have been used successfully to find good solutions. The minimum cost of each generation is recorded with the corresponding sequence and number of trucks. A stopping criterion is frequently defined by a predetermined percentage in the fitness value between successful generations or this procedure is continued for a fixed number of generations. In this research we decided to use the later approach that ensures each problem instance and each replication is given an equal length of evolution. The minimum cost solution is generated by the best sequence over all generations. A step by step procedure is for the GA-based heuristic is now described.

Heuristic IPDSP-GA

Step 1: *Initial parent generation:* Select a predefined number of random sequences connecting the plant and all customers. Go to *Step 2*.

Step 2: Divide each sequence into sub-tours using algorithm Split. Set $s = 1$.

Step 3: Select a sequence. Obtain the no-wait schedule. Compress the no-wait schedule using Algorithm-Compress and find the compressed makespan. If the compressed makespan is less than or equal to H, calculate the fitness with s trucks and go to *Step 4*. If not, and $s = n$ sequence is infeasible, assign a very high cost. If not, and $s < n$ set $s = s + 1$ and repeat S*tep 3.*

Step 4: Have all sequences been considered in the current generation? If not, go to *Step 3*. If so, go to *Step 5.*

Step 5: Form a child generation through crossover and mutation. Evaluate the fitness of each child using *Step 2* and *Step 3*. Have all generations been considered? If not, do elite reproduction to create the next generation. Go to *Step 2.* If yes, go to *Step 6.*

Step 6: Select the sequence corresponding to the minimum cost i.e., the highest fitness, of all generations.

A 3^2 Full Factorial Design to Select Best IPDSP-GA Parameters

Generally, GA parameters and operators are chosen by the user depending on the problem and it is rather an art than a science. However, selecting a population size so that a GA can converge to a good solution in a short computational time depends on the population size. For example, let's consider solving a traveling salesman problem with 20 cities that consist of $20!$ feasible solutions. In that case, a population size of 20 chromosomes is too low while 1000 can be too high requiring higher computational time yet converging to the same solution with a population size of 100 or 200. Thus, there is no optimal size of the population as such. Users can pick the population size at their discretion and computational expertise.

In this research, an experimental design was conducted with 150 chromosomes per generation to fine tune the IPDSP-GA parameters. The two factors tested are the mutation probability (MP) and the crossover probability (COP). For each factor three levels are tested as shown in Table 3.5. Heuristic IPDSP-GA was tested for a 30 customer problem with a planning horizon of 550 time units, a production rate of 5 units per unit time, a fixed cost of hiring a truck of $200, a speed of travel 1 unit per unit time, and a travel cost of 1 unit per unit distance. The capacity and the lifetime of the product are set at 60 units and 50 units respectively. Each factor combination is replicated 30 times using IPDSP with random starts. The results obtain at show in Table 3.6. A Kruskal-Wallis test is conducted to test whether the median of cost obtained with each factor level is the same or at least one is different using the classic hypothesis test.

$H_1:$ All medians are similar

$H_1:$ At least one median is different

Factor	Probability (%)

	Low	Med	High
MP	20	30	40
COP	70	80	90

Table 3.5: Factor levels of IPDSP-GA parameters

Run	Design[MP, COP]								
	[20,70]	[20,80]	[20,90]	[30,70]	[30,80]	[30,90]	[40,70]	[40,80]	[40,90]
R1	1825	1819	1785	1778	1790	1773	1808	1808	1798
R2	1817	1785	1788	1808	1817	1817	1794	1821	1825
R3	1843	1816	1804	1778	1803	1785	1808	1806	1825
R4	1808	1832	1792	1781	1776	1847	1813	1808	1815
R5	1808	1808	1817	1776	1824	1813	1808	1809	1773
R6	1833	1808	1776	1773	1831	1776	1808	1808	1776
R7	1773	1799	1808	1819	1813	1776	1821	1792	1820
R8	1783	1776	1825	1808	1862	1773	1808	1815	1813
R9	1836	1813	1811	1785	1812	1776	1776	1813	1817
R10	1824	1809	1788	1776	1792	1815	1776	1813	1783
R11	1838	1794	1808	1808	1825	1814	1776	1817	1776
R12	1785	1808	1773	1808	1808	1813	1776	1808	1776
R13	1776	1827	1843	1785	1808	1773	1800	1792	1843
R14	1781	1822	1798	1808	1815	1781	1788	1825	1809
R15	1815	1781	1832	1783	1813	1813	1813	1818	1816
R16	1808	1805	1822	1822	1822	1815	1808	1795	1817
R17	1831	1799	1808	1816	1809	1815	1773	1815	1799
R18	1785	1783	1831	1781	1776	1773	1776	1797	1815
R19	1785	1773	1776	1776	1831	1816	1813	1817	1778
R20	1792	1773	1781	1776	1781	1820	1808	1808	1838
R21	1825	1817	1809	1849	1792	1817	1808	1812	1827
R22	1776	1776	1808	1808	1812	1783	1808	1776	1825
R23	1773	1778	1791	1785	1815	1800	1776	1819	1815
R24	1813	1843	1813	1787	1808	1812	1821	1813	1817
R25	1829	1825	1811	1817	1800	1822	1817	1822	1811
R26	1808	1792	1808	1814	1781	1776	1816	1792	1837
R27	1808	1822	1817	1813	1826	1813	1825	1812	1818
R28	1776	1778	1799	1773	1817	1831	1785	1818	1791
R29	1823	1773	1778	1809	1806	1820	1855	1773	1808
R30	1825	1838	1790	1818	1843	1823	1792	1781	1783
Mean	1807	1802	1803	1797	1810	1803	1802	1807	1808
Std. Dev	22	21	18	20	19	21	19	14	20
Median	1808	1807	1808	1798	1812	1813	1808	1811	1815

Table 3.6: Results of the full factorial design IPDSP-GA parameters

Treatment	N	Median	Ave Rank	Z
(20, 70)	30	1808	147.1	0.86
(20, 80)	30	1807	128.6	-0.51
(20, 90)	30	1808	127.5	-0.60
(30, 70)	30	1798	108.0	-2.05
(30, 80)	30	1812	155.3	1.47
(30, 90)	30	1813	133.2	-0.17
(40, 70)	30	1808	119.9	-1.16
(40, 80)	30	1811	144.7	0.68
(40, 90)	30	1815	155.3	1.47
Overall	270		135.5	

H = 10.41 DF = 8 P = 0.237
H = 10.46 DF = 8 P = 0.234 (adjusted for ties)

Table 3.7: MINITAB output Kruskal-Wallis test

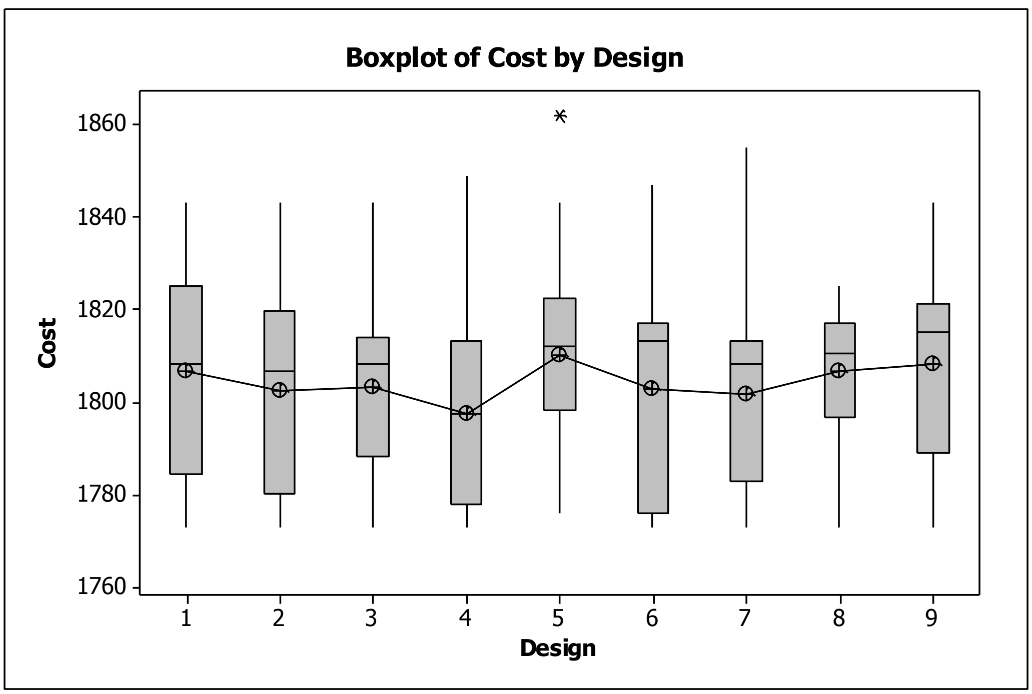

Figure 3.16: Box Plots for Cost; MINITAB output

From Table 3.7, it can be seen that the *p*-value of the Kruskal-Wallis test is 0.237 meaning that there is insufficient evidence to reject the null hypothesis of medians are being similar. The smallest median cost is reported in treatment 4 (see Table 3.6) with a mutation probability of 30% and a crossover probability of 70%. In addition, the box plot in Figure 3.15 shows that the smallest median is also reported with a lower range of values at the same design. Therefore, although the medians are not statistically different, a mutation probability of 30% and a crossover probability of 70% are selected as the parameter levels for the IPDSP-GA.

Improving the Solution of IPDSP-GA by Local Search (IPDSP-MA1)

To further enhance the performance of the GA, researches often add local search and we do as well. The GAs with local search is also known as Memetic Algorithms which is explained in detail in Section 3.5.2. The local search takes the best chromosome at the end of IPDSP-GA and scans all *possible* pairs of fields of the solution chromosome using the following six moves. Let a, b be any pair of genes in the genetic sequence of the chromosome and x , y be the preceding genes of a and b respectively.

1). Remove a and insert it after b.

2). Remove a, x and insert them after b.

3). Insert x, a after b.

4). Swap a and b.

5). Swap a, x and b.

6). Swap a, x and b, y.

For a selected pair of genes a,b , these moves are repeated until either an improved solution is found or moves are exhausted. Moves resulting higher costs are ignored and the processing simply continued. The local search on any selected pair of genes a,b is discontinued after the first move that improves the current solution and the search continues with the next pair of genes. Every time an improvement is found the solution gene is updated and recorded as the current solution.

Memetic Algorithms (IPDSP-MA2)

An intuitive definition of a memetic algorithm (MA) is that it is a traditional GA hybridized with a local search operator (Moscato 1989). The fitness value of a child chromosome generated by a GA is improved by a local search rather than by a traditional mutation operator. MAs have recently been applied to determine approximate solutions to NP-hard problems. Prins (2004) applied an MA to a classical vehicle routing problem. In this paper an MA is applied to the IPDSP and results are compared to the results obtained from a traditional GA.

In the heuristic IPDSP-MA2, the 150 chromosomes in the initial population are again randomly generated. After a chromosome is generated it is compared with those of other chromosomes to minimize the chances that the current chromosome is a clone of another. In this research a clone of a chromosome is a chromosome having the same fitness value irrespective of the genetic sequence. If the fitness values are not equal, the chromosome is added to the population. If they are, the chromosome is rejected and a new chromosome is generated. The fitness function for each chromosome in the generation is same to that used in the genetic algorithm. Searching for clones ensures that the initial population is well spaced (i.e., each chromosome is different from all others in terms of the fitness function value).

The mating pool for crossover is selected using the roulette wheel selection as explained earlier in this chapter. However, unlike in the IPDSP-GA, the mating pool of IPDSP-MA2 consists of a small number of parent chromosomes with new children are added to the existing population given that they are not clones of existing chromosomes. The *2-point order crossover* used to do this is illustrated in the mating process as shown in Figure 3.17.

The crossover occurs at two randomly selected fields (c_1 and c_2) in each parent. Unlike in traditional 2-point crossover, genes from c_1 to c_2 from parent 1 are directly copied to the same fields of child 1.

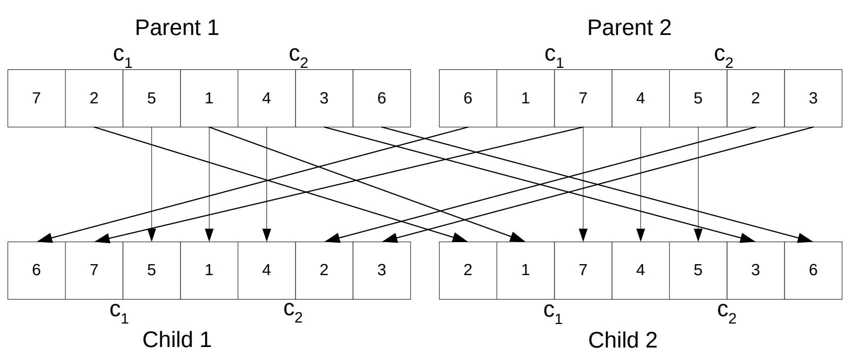

Figure 3.17: Two-point order crossover

The genes of child 1 starting from gene c_2+1 until last gene, and genes from first gene to gene c_1 are copied from parent 2 as follows. The copying process starts at gene c_2+1 of child 1. The genes between c_2+1 and last gene of parent 2 are copied in the same order to child 1, given that those genes have not already been copied from Parent 1 to Child 1. If some of those genes of parent 2 has already been copied to the child 1 from parent 1 (genes between c_1 and c_2 of child 1), then the genes of parent 2 starting from the first gene onwards are copied to child 1 until all fields of the child 1 is filled as shown in Figure 3.17. Child 2 is similarly created with parent 2 and parent 1. Each child's fitness is then evaluated. If a child is not a clone of any of the existing parents, a randomly selected parent whose fitness is below the median is replaced.

In each generation the best child chromosome is selected for the local search. The all six moves applied in IPDSP-MA1 are used for the local search. As in the IPDSP-GA, IPDSP-MA2 runs for a predetermined number of generations.

A Statistical Test to Select the Best Parameters of the IPDSP-MA2

In IPDSP-MA2 the population management in is important so that no clones are created. The use of local search replaces the necessity of maintaining a large population and creating a large number of children saving the computational time spent on evaluating them. It is important to determine the number of child chromosomes created at each evolution such that IPDSP-MA2 converges to a good solution within a reasonable computational time. A Kruskal-Wallis test with multiple comparisons is conducted to find out the effect of the size of child population created. A random problem is created with 30 customers having a planning horizon of 550 time units, a production rate of 5 units per unit time, a fixed cost of hiring a truck of $200, a speed of travel 1 unit per unit time, and a travel cost of 1 unit per unit distance is tested. The capacity and the lifetime of the product are set at 60 units and 50 units. The number of children is varied from 2 to 18 in intervals of two and all the experimental results are tabulated in Appendix A, Table A.1. The low *p*-value of 0.000 (Appendix A.2) means that there exists evidence to conclude the medians are statistically different. The test statistic of Fisher's least significant difference between samples i and j LSD_{ij} is compared to the difference of ranked means between samples i and j denoted by $\bar{R}_i$ and $\bar{R}_j$ respectively. Given the total sample size N, sample sizes n_i and n_j, and a level of significance α, the least significant difference between samples i and j is calculated by $LSD_{ij} = Z_{\alpha/2}\sqrt{\left(\frac{N\ N+1}{12}\right)\left(\frac{1}{n_i}+\frac{1}{n_j}\right)}$. Two treatments i and j are declared different if $\left|\bar{R}_i - \bar{R}_j\right| > LSD_{ij}$. The total sample size is 270, each treatment having a sample size of 30 resulting $LSD_{ij} = 40$ for each treatment combination. The rank means of each treatment is shown in Table 3.8. The difference between rank means of treatments corresponding to 2, 4, and 6 children and any other treatment is greater than $LSD_{ij} = 40$, hence are significantly different from all other treatments. In addition, treatments corresponding to 8 children through 18 children are not statistically significantly different from each other.

Based on the above experiment, we select 8 to be the computationally efficient number of children to create in each generation of the IPDSP-MA2.

Number of Children	2	4	6	8	10	12	14	16	18
Rank Means	279	239	177	151	104	108	106	148	111

Table 3.8 Rank means for multiple comparison

Computational Study

The aforementioned heuristics are tested on three problems with different sizes 0f 20, 30, and 40 customers. Results are evaluated by comparing to the lower bounds. In addition a few smaller problems are solved using the aforementioned heuristics and the solutions are compared to the optimal solution, when it could be obtained by CPLEX. The location and demand of each customer are determined by a random problem generator (RPG). When the number of customers is given, the RPG selects random locations in the XY plane and assigns demands randomly between 1 and the truck capacity. The RPG has been designed so that it selects a location for every customer to give a direct travel time from the plant not exceeding the effective lifetime.

Table 3.9 shows the comparison of optimal solution obtained by CPLEX and heuristics for small to moderate size problems (see Appendix G for details). It should be noted that small size problems are not tested with IPDSP-MA due to the difficulty arising from population management. The heuristic IPDSP-MA maintains a well spaced population searching for clones. When the problem size becomes small, there aren't many different solutions for IPDSP-MA to create a well spaced population. The IPDSP-GA is run for 30 random starts for each problem and average values are given in Table 3.9. For four customer problems IPDSP-GA finds the optimal solution. However, when problem size becomes larger, CPLEX needs longer computational times to determine the optimal solution. For example problems with 6 and 7 customers, both IPDSP-GA and CPLEX finds the same solution. However, we cannot theoretically conclude that the solution is optimal since CPLEX cannot stop the branch-and –bound method because of the % gap between the current best node (best lower bound) and the current best integer solution. For problems with 10 customers or more CPLEX cannot find even a feasible solution within a reasonable time. Thus for large problems heuristic results are compared to the lower bounds explained earlier in this chapter

Number of Customers	Number of Variables	Number of Constraints	% Gap	Approimate Time taken by CPLEX	CPLEX solution	IPDSP-GA	IPDSP-MA
4	2921	6295	0	0.01 hrs	293	293	N/A
5	4836	10551	21.71	> 20 hrs	910	710	N/A
6	7429	16495	22.53	> 20 hrs	624	624	N/A
7	10844	24553	26.19	> 20 hrs	766	766	N/A
8	15249	35223	30.9	> 20 hrs	728	703	N/A
9	24886	57225	42.01	> 20 hrs	1034	878	N/A
10	32821	76801	n/a	10 days	no solun	1144	N/A
12	54169	130,953	n/a	10 days	no solun	1399	1410
15	104206	262,551	n/a	10 days	no solun	1182	1189
20	319241	806,751	n/a	10 days	no solun	1842	1855

Table 3.9: Comparison of optimal solution and heuristic solution

For each larger problem size, 30 problem instances are created for testing. First, heuristic IPDSP-GA is run for 250 generations and the solution is improved by the local search. For the same set of problems IPDSP-MA is run for a higher number of generations (350) with a smaller number of child chromosomes added each time. For each problem of each problem size, both heuristics are run for 300 replications and the results shown below are the average fitness value over 300 runs. Tables 3.10 Table 3.11 and Table 3.12 show the comparisons of heuristic results for IPDSP-GA and IPDSP-MA with the highest lower bound on the total cost of the IPDSP for each problem. Graphs shown in Figure 3.18, Figure 3.19 and 3.20 also show comparison of three heuristics. The deviation of heuristic results from the lower bound is calculated as (Heuristic result-Lower bound) /Lower bound.

Problem	Lower Bound	IPDSP-GA		IPDSP-MA1		IPDSP-MA2	
		Solution	% Gap above the lower bound	Solution	% Gap above the lower bound	Solution	% Gap above the lower bound
1	742	1191	60.47	1190	60.44	1200	61.71
2	706	1110	57.28	1108	56.99	1119	58.55
3	1020	1267	24.18	1266	24.14	1281	25.61
4	1024	1169	14.19	1169	14.17	1191	16.33
5	446	876	96.49	821	84.04	868	94.51
6	640	1064	66.33	1064	66.23	1071	67.39
7	952	1130	18.70	1130	18.70	1145	20.25
8	630	1026	62.89	1023	62.31	1033	63.95
9	1162	1293	11.27	1293	11.27	1294	11.39
10	1142	1187	3.96	1187	3.95	1199	4.97
11	1166	1282	9.97	1282	9.96	1288	10.49
12	1160	1214	4.69	1214	4.69	1223	5.43
13	1068	1451	35.89	1450	35.75	1566	46.63
14	1146	1254	9.42	1254	9.42	1272	11.03
15	1248	1420	13.78	1420	13.76	1419	13.71
16	720	1156	60.56	1153	60.08	1173	62.97
17	980	1140	16.35	1139	16.20	1144	16.76
18	714	1234	72.81	1233	72.72	1248	74.83
19	660	1150	74.21	1146	73.68	1166	76.61
20	746	1093	46.47	1089	45.95	1098	47.20
21	1090	1254	15.05	1254	15.05	1256	15.26
22	1072	1211	12.94	1211	12.93	1215	13.31
23	722	1016	40.66	1015	40.61	1018	40.96
24	1130	1849	63.63	1849	63.63	1849	63.65
25	1228	1344	9.45	1344	9.45	1351	10.01
26	1136	1312	15.54	1307	15.02	1326	16.72
27	1150	1347	17.15	1347	17.14	1361	18.36
28	1058	1392	31.58	1384	30.79	1422	34.41
29	734	1118	52.29	1117	52.17	1133	54.32
30	1028	1138	10.71	1138	10.70	1151	11.92

Table 3.10: Problem Set 1, n = 20, H = 550, B = 50, C = 60

Problem	Lower Bound	IPDSP-GA		IPDSP-MA1		IPDSP-MA2	
		Solution	% Gap above the lower bound	Solution	% Gap above the lower bound	Solution	% Gap above the lower bound
1	1052	1800	71.12	1790	70.12	1784	69.61
2	1428	1760	23.22	1758	23.09	1754	22.85
3	1086	1301	19.82	1294	19.14	1288	18.57
4	1866	2048	9.74	2046	9.65	2052	9.97
5	1398	1664	19.02	1651	18.07	1678	20.04
6	1768	1964	11.08	1961	10.91	1964	11.07
7	1262	1773	40.46	1769	40.19	1771	40.32
8	1260	1777	41.03	1772	40.64	1772	40.61
9	1220	1350	10.69	1349	10.56	1350	10.67
10	1168	1385	18.55	1381	18.20	1378	17.96
11	1262	1794	42.18	1792	42.03	1796	42.33
12	1338	1766	32.01	1765	31.89	1766	32.01
13	1270	1705	34.22	1702	34.03	1701	33.91
14	1150	1714	49.05	1710	48.67	1704	48.20
15	1790	1957	9.32	1956	9.25	1956	9.30
16	1126	1300	15.43	1294	14.88	1291	14.66
17	1334	1829	37.11	1826	36.89	1826	36.88
18	976	1413	44.82	1403	43.77	1399	43.34
19	1446	1782	23.26	1779	22.99	1776	22.79
20	1296	1734	33.81	1730	33.45	1731	33.54
21	1248	1717	37.60	1712	37.21	1716	37.50
22	970	1341	38.24	1334	37.54	1334	37.56
23	1172	1698	44.90	1691	44.28	1688	44.02
24	1462	1856	26.97	1855	26.89	1857	27.03
25	1154	1376	19.28	1374	19.08	1370	18.73
26	1090	1638	50.30	1573	44.31	1579	44.84
27	966	1283	32.84	1277	32.17	1268	31.23
28	1280	1786	39.55	1778	38.92	1773	38.48
29	1200	1678	39.87	1672	39.37	1683	40.25
30	1314	1451	10.40	1445	9.95	1444	9.92

Table 3.11: Problem Set 2, n = 30, H = 550, B = 50, C = 60

Problem	Lower Bound	IPDSP-GA		IPDSP-MA1		IPDSP-MA2	
		Solution	% Gap above the lower bound	Solution	% Gap above the lower bound	Solution	% Gap above the lower bound
1	2032	2497	22.87	2495	22.80	2500	23.03
2	1738	2368	36.25	2327	33.92	2353	35.39
3	1424	1983	39.27	1979	38.95	1975	38.67
4	1480	1963	32.64	1955	32.06	1947	31.55
5	1188	1801	51.61	1782	50.01	1770	49.03
6	1468	1919	30.71	1911	30.18	1903	29.63
7	1834	2024	10.34	2020	10.15	2016	9.93
8	2034	2199	8.13	2175	6.91	2165	6.43
9	1712	1996	16.58	1994	16.48	1989	16.19
10	1718	2040	18.77	2033	18.36	2032	18.30
11	1924	2078	8.02	2072	7.68	2071	7.64
12	1754	2095	19.44	2088	19.05	2087	18.98
13	1916	2566	33.94	2565	33.87	2564	33.80
14	1262	1968	55.91	1943	53.97	1935	53.35
15	1456	2180	49.72	2144	47.27	2128	46.18
16	1842	2117	14.93	2106	14.35	2105	14.27
17	1368	1981	44.84	1967	43.82	1952	42.67
18	1108	1859	67.76	1842	66.20	1833	65.40
19	1328	1832	37.98	1828	37.63	1825	37.42
20	1346	1830	35.99	1827	35.74	1819	35.12
21	1390	2039	46.71	2019	45.22	2010	44.58
22	1910	2490	30.36	2484	30.03	2475	29.56
23	2158	2576	19.39	2572	19.18	2570	19.08
24	1756	2029	15.56	2027	15.43	2018	14.93
25	1390	2074	49.19	2060	48.22	2042	46.93
26	1244	1908	53.34	1889	51.88	1873	50.59
27	2056	2485	20.87	2473	20.30	2473	20.30
28	1742	2000	14.81	1987	14.05	1978	13.57
29	1880	2355	25.25	2301	22.41	2251	19.76
30	1484	2061	38.85	2050	38.15	2030	36.83

Table 3.12: Problem Set 3, n = 40, H = 550, B = 50, C = 60

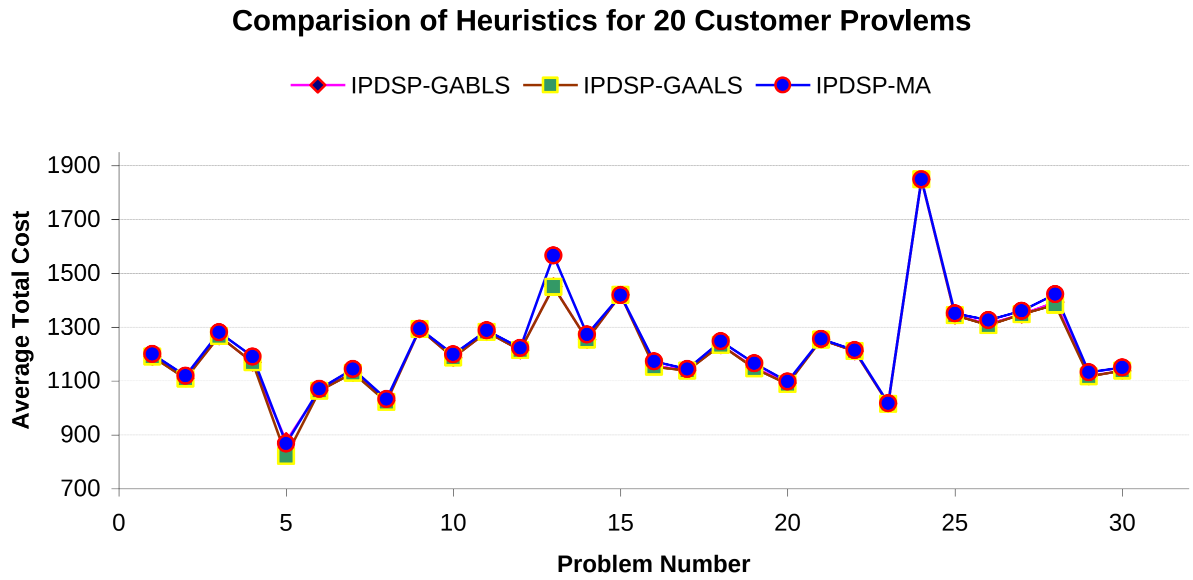

Figure 3.18: Comparison of heuristics for 20 customer problems

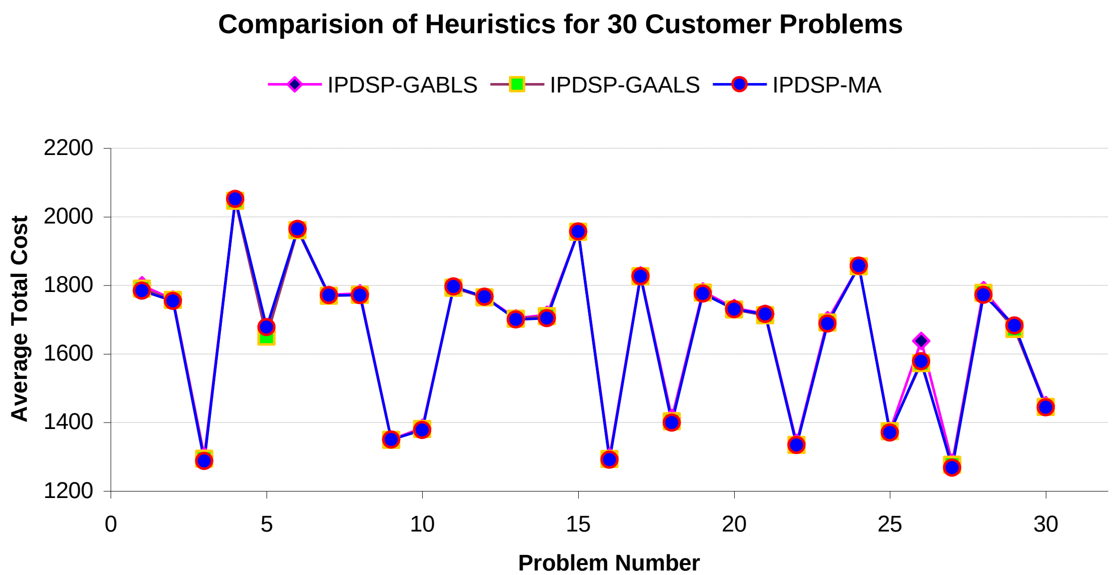

Figure 3.19: Comparison of Heuristics for 30 customer problems

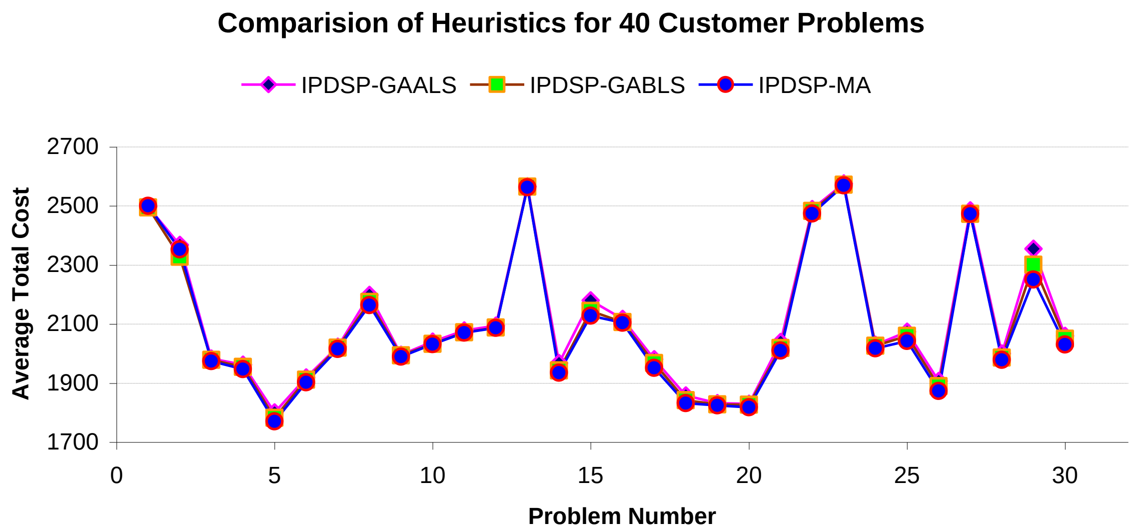

Figure 3.20: Comparison of Heuristics for 40 customer problems

In order to compare the performance of the IPDSP-GA (both before and after local search) and IPDSP-MA a Kruskal-Wallis test is conducted for the median of the percentage gap above the lower bound given by each heuristic for each problem. Recall each problem size has 30 randomly generated problems and each problem is tested with 300 random starts creating 9000 fitness values for each heuristic. Even though each of the 30 problems of any given size are randomly generated with the same parameter values, including product lifetime, truck capacity, plant production rate and truck speed, the demands and customer locations are different from one problem to another. Therefore, statistical analysis is conducted on the percentage gap above lower bound values of all problems of a given size. Initially, an Anderson-Darling tests was conducted to check the normality of each population with 27000 data points with mean of 34.56%, standard deviation 25.79% and concluded that the data does not follow a normal distribution with a p-value < .005 (This suggests that ANOVA normality assumption is not satisfied and non parametric tests are required to compare the heuristics used in this research). The Kruskal-Wallis test is conducted for all problem sizes and the results are shown in Appendix C, Tables C.1-C.3. Treatment 1, 2, and 3 corresponds to the total cost of heuristics IPDSP-GA before local search, IPDSP-GA after local search, and IPDSP-MA respectively. The lower p-value of 0.000 indicates that there is enough statistical evidence to reject the null hypothesis that all medians are same. In order to find out which medians are different multiple comparison tests are conducted on ranked means for each problem size. The test statistic of Fisher's least significant difference between samples i and j $LSD_{i\,j}$ is compared to the difference of ranked means between samples i and j denoted by $\bar{R}_i$ and $\bar{R}_j$ respectively. For all 3 problem sizes sample size is selected to be 27000, each treatment having a sample size of 9000 (30 problems each having 300 replications) resulting $LSD_{i\,j} = 228$ for each 3 populations. Table 3.13 shows the all pairwise differences of ranked means.

Problem size	20	30	40
$\bar{R}_1$	13304	13771	13920
$\bar{R}_2$	13199	13330	13433
$\bar{R}_3$	13998	13401	13148
$\bar{R}_1 - \bar{R}_2$	105	441	486
$\bar{R}_1 - \bar{R}_3$	694	370	771
$\bar{R}_2 - \bar{R}_3$	799	71	285

Table 3.13: Multiple comparisons of Kruskal-Wallis test

As shown in Table 3.13, for problem size 20, since $\bar{R}_1 - \bar{R}_2$ =105 which is lower than 228 treatments 1 and 2 were not statistically different. However, treatment 1 and treatment 3 are significantly different from each other since $\bar{R}_1 - \bar{R}_3 >$ 228. Similarly, treatments 2 and 3 are also significantly different. As shown in Appendix C, Table C.1 the highest median is reported under treatment 3. Even though medians of treatment 1 and 2 are the same, treatment 2 always has a similar or better solution than treatment 1. Thus treatment 2, IPDSP-MA1 after local search is selected as the best heuristic for 20 customer problems. A similar analysis for 30 customer problems shows that treatment 1 is significantly different from both treatment 2 and 3 while treatment 2 and 3 are not significantly different. Treatment 2 has a median of .3315 which higher than the treatment 3 median of .3276 Thus treatments 3, IPDSP-MA2 is selected as the best heuristic for 30 customer problems. As shown in Table 3.13, for 40 customer problems, all i and j pairs of multiple comparisons of ranked means are greater than $LSD_{i\,j} = 228$. We conclude that each treatment is significantly different from other and the treatment with minimum median IPDSP-MA2 is selected as the best for 40 customer problems.

Conclusions and Future Research

A common cost minimization problem faced by a logistic manager of a production and distribution company is solved in Chapter 3. The IPDSP is a NP-hard problem; the existence of an algorithm to find the optimal solution of IPDSP in polynomial time is not possible as problem size grows beyond 5 customers. The lower bound calculated using Theorem 2 was the highest, hence the best for all problems. Statistical testing revealed that IPDSP-GA is superior for 20 customer problems and IPDSP-MA1 is superior for 30 customer problems while IPDSP-MA2 is superior for 40 customer problems.

For future research there are a number of variations of IPDSP that could be insightful. One is to extend IPDSP to non-identical trucks because in the real world, the fixed and the variable cost of using a truck depend on the size of the truck. When a truck's capacity is not fully or nearly fully utilized, replacing it by a smaller truck saves money.

This research assumed that the fixed cost of hiring does not depend on the number of days a truck is hired for. Another extension of IPDSP would be to include the dependence of hiring cost on the number of days that a company keeps the truck. For example, renting two vehicles for a whole week is more expensive than renting one vehicle for the whole week and the second vehicle for two days.

A practical extension of IPDP, but that is likely very complex, is to consider a product mix. Having more than one product changes the delivery characteristics. In this research we assume that a truck can visit a customer at most once. If the product mix consists with two products, a truck can visit a customer at most two times. This not only require a different model and heuristics but the solution representation of genetic algorithm and the memetic algorithm must also be changed to consider the product mix. Production scheduling at the plant is also changed because production can be done at the same plant or two different plants located at the same place.   Finally, an improved lower bound on IPDSP would help a better comparison of both heuristic performances.

Another extension of IPDSP is the analysis of multiple plant case. The requirement of multiple plants is explicit and it is mainly due to the perishable nature of the product. Some of the customers can be located at a distance where even the direct shipping from the plant is impossible before the expiration of the product. Hence multiple plants are needed to satisfy the demand of all customers. Solving the IPDSP with multiple plants is considered in Chapter 4

CHAPTER FOUR

OPTIMAL FLEET SIZE FOR A MULTI PLANT INTEGRATED PRODUCTION AND DISTRIBUTION SCHEDULING PROBLEM FOR A SINGLE PERISHABLE PRODUCT

Introduction

This chapter focuses on an integrated scheduling of a production-distribution problem with multiple plants (MPIPDSP). Initially the analysis is for two-plants. The perishable product is produced in one or both of the plants and distributed to customers. The goal is to determine the fleet size associated with each plant and their routes subject to a planning horizon constraint to minimize the total cost. This research differs significantly from the literature on IPDSP with multi-plants given in Section 2.2 and 2.3 as explained below. Chen and Vairaktarakis (2005) analyze a classical IPDSP with parallel machines. In their study the objective of having parallel machines is similar to a classical production scheduling problem with parallel machines and they do not consider the perishable nature of the product. Chen and Pundoor (2006) as well as Garcia et al. (2004) analyze a multiple plant IPDSP for a time sensitive product without vehicle routing considerations. Moreover none of the above studies are fleet selection problems and Garcia et al. (2004) assumes the availability of trucks at all times.

The MPIPDSP is also related to p-median problem in facility location research which has been extensively studied in the literature. The p-median problem consists of locating p facilities and assigning a set of customers to them such that the sum of the weighted demand distance from the plant is minimized. In MPIDSP, the location of two plants is given and in addition it assumes a truck capacity constraint, a lifetime constraint, and a fixed cost for each truck used. A simple example can show that allocating customers to plants by solving the *p*-median problem is not optimal for MPIDSP. For example consider the problem shown in Figure 4.1. According to the *p*-median problem customer 2 should be allocated to plant 1 that results a higher cost than allocating to plant 2.

To our knowledge this is the first time a fleet selection problem is solved for multi-plant integrated production and distribution scheduling problem with vehicle routing considerations for a perishable product. A mixed integer linear program is formulated to solve the problem to optimality. Two heuristic solution approaches are also given to find a near optimal solution.

This problem is an extension of the optimal fleet selection for a single plant integrated production-distribution problem for a perishable product given in Chapter 3; hence the same notation is used as provided in Section 3.3. Here two plants having identical capacities produce a perishable product and trucks are used to deliver the product to customers that are geographically dispersed in the 2-D plane before the limited lifetime of the product expires. It is assumed that the location of all customers is known and two plants are located such that each customer can receive a delivery from at least one plant before the product lifetime expires. The motivation for having multiple plants is to serve the customers because of the limited lifetime of the product. The production in two plants is simultaneous and each plant hires its own fleet of trucks. The existence of two plants allows customers to be classified in one of three set of customers:

1) customers that can be delivered only from plant 1, 2) customers that can be delivered only from plant 2, and 3) customers that can be delivered from either plants (overlapping customers).

In this research the problem is solved using two approaches. In the first approach each overlapping customer is initially and permanently assigned to one of the plants and the problem is solved as two single plant problems using IPDSP-MA1 given in Chapter 3. We selected IPDSP-MA1 since it is computationally faster than IPDSP-MA2 which was proved superior in Chapter 3 for 40 customer problems. The shortcoming of this approach is that if the initial assignment of overlapping customers is not optimal, then the final solution to the whole problem will not be optimal. On the other hand this would be a quick and easy method. So it is pursued with some energy. In particular four assignment methods are used for the initial customer assignment and the results are compared. In the second approach each overlapping customer is dynamically assigned during the evolution of the genetic algorithm. For example, different candidate solutions of the genetic algorithm might have the same overlapping customer assigned to different plants. The following example illustrates the problem solved in this chapter.

Example 4.1: Consider three customers with demand $q_1 = 20, q_2 = 30,$ and $q_3 = 10,$ units. While customer 1 and customer 3 can only be served from plant 1 and 2 respectively, customer 2 can be served from either plant. The distance from each plant to each customer is as shown in Figure 4.1. Each truck has a capacity of 40 units and the production rate at the plant is 10 units per unit time. The lifetime of the product is 30 time units and each truck has a constant speed of 1 unit distance per unit time.

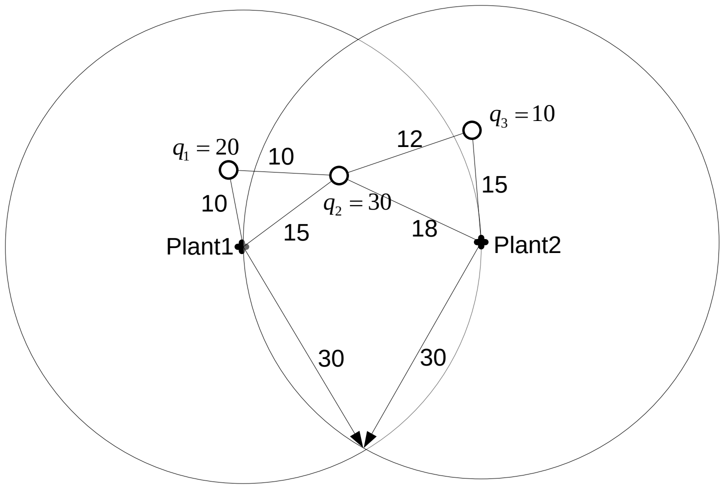

Figure 4.1: Data for Example 4.1

Case 1: If customer 2 is assigned to plant 1

Customer 2 in the overlapping region but is closer to plant 1. So it is assigned as if the shortest distance is the role. Because total demand of customer 1 and 2 is greater than truck capacity, two trips are required. Figure 4.2 shows the production-distribution schedule that illustrates the details of satisfying the total demand within the planning horizon of 50 time units re quires plant 1 to use two trucks and plant 2 to use one truck.

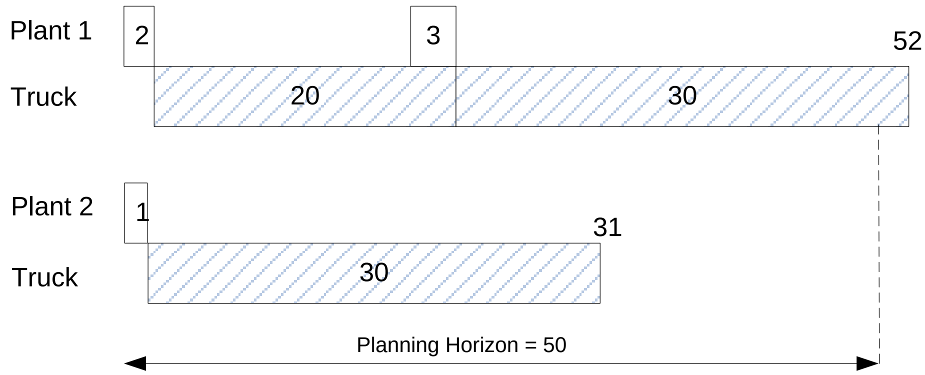

Figure 4.2: Gantt chart for Case 1, Example 4.1

Case 2: If customer 2 is assigned to plant 2

Customer 2 is not as close to plant 2 as close as to plant 1; however, as shown in Figure 4.3, assigning customer 2 to plant 2 results in only two trips because the demand of customers 2 and 3 can be consolidated and served in one trip from plant 2. Hence, each plants requires one truck to satisfy the total demand within the planning horizon 50 time units.

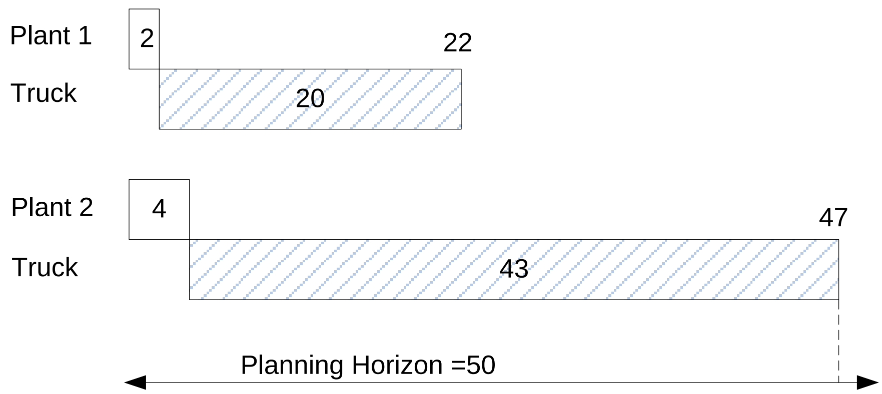

Figure 4.3: Gantt chart for Case 2, Example 4.1

Example 4.1 illustrates the impact that the assignment of customers in the overlapping region has on the final solution. It also shows that assigning a customer to the closest plant may not be necessarily optimal. The remainder of the Chapter 4 is organized as follows. First we provide a mixed-integer linear formulation for MPIPDSP. Second we provide a heuristic solution approach for MPIPDSP. Third we provide a detailed computational analysis of MPIPDSP for a randomly generated data set. Finally we provide some ideas for research extensions.

A Mixed-Integer Linear Formulation for MPIPDSP

A mixed-integer linear formulation is given in this section to solve MPIPDSP. In addition to the notation given in Section 3.3 the following additional notation is defined.

First we define the decision variables and calculated variables. Let $v = \{0,1\}$ be the set that denotes two plants, Plant 0 and plant 1. $N = \{0,1,2,3,...,n\}$ be the set of customers including plant 1 and plant 2, and let $N' = N \setminus \{0,1\}$. A truck speed of unit distance per unit time is assumed.

X^{u}_{ijkm} = 1 if m^{th} truck of plant u visits customer j immediately after customer i in its k^{th} trip, 0 otherwise. $i, j \in N$, $k, m \in N'$, and $u \in v$

P^{u}_{kmt} = 1 if the Plant u is producing for the trip k of truck m at time epoch t, 0 otherwise, $t \in T$, $k, m \in N'$

$y^{u}_{i} = 1$ if the truck i of plant u is used for delivery, 0 otherwise, $i \in N'$

$Z^{u}_{km} = 1$ if the trip k of the truck m of plant u is used, 0 otherwise, $k, m \in N'$

d^{u}_{km} = distribution start time of the trip k of the truck m of plant u, $k, m \in N'$

p^{u}_{km} = production start time for the trip k of the truck m of plant u, $k, m \in N'$

$$Min \sum_{\substack{i,j \in N \\ k,m \in N' \\ u \in v}} C_{ij} X^{u}_{ijkm} + F \sum_{\substack{m \in N' \\ u \in v}} y^{u}_{m}$$

Subject to:

$$\sum_{\substack{i,j \in N \\ u \in v}} X^{u}_{ijkm} q_j \le C \qquad \forall\, k, m \in N', \quad u \in v \tag{21}$$

$$\sum_{\substack{i \in N \\ k,m \in N'}} X^{u}_{ijkm} = 1 \quad \forall\, j \in N', \quad u \in v \tag{22}$$

$$\sum_{\substack{j \in N \\ k,m \in N' \\ u \in v}} X^{u}_{ijkm} = 1 \qquad \forall\, i \in N', \quad u \in v \tag{23}$$

$$\sum_{j,k \in N'} X^{u}_{0jkm} = \sum_{k \in N'} Z^{u}_{km} \qquad \forall\, m \in N', \quad u \in v \tag{24}$$

$$\sum_{j,k \in N'} X^{u}_{j0km} = \sum_{k \in N'} Z^{u}_{km} \qquad \forall\, m \in N', \quad u \in v \tag{25}$$

$$\sum_{i \in N} X^{u}_{i\,j\,k\,m} = \sum_{i \in N} X^{u}_{j\,i\,k\,m} \qquad \forall\, m, k,\; j \in N', \quad u \in v \tag{26}$$

$$e^{u}_{i} - e^{u}_{j} + 1 \le n \quad 1 - X^{u}_{i\,j\,k\,m} \qquad \forall\, i \in N, \quad j, k, m \in N', \quad u \in v \tag{27}$$

$$X^{u}_{i\,j\,k\,m} \le y^{u}_{m} \qquad \forall\, i,\; j \in N, \quad k, m \in N', \quad u \in v \tag{28}$$

$$X^{u}_{i\,j\,k\,m} \le Z^{u}_{k\,m} \qquad \forall\, i,\; j \in N, \quad k, m \in N', \quad u \in v \tag{29}$$

$$d^{u}_{k\,m} - \left(p^{u}_{k\,m} + \frac{1}{r} \sum_{i, j \in N} X^{u}_{i\,j\,k\,m}\; q_{j} \right) + \sum_{\substack{i \in N \\ j \in N'}} X^{u}_{i\,j\,k\,m}\; \tau_{i\,j} \le B \qquad \forall\, k, m \in N', \quad u \in v \tag{30}$$

$$d^{u}_{k\,m} + \sum_{\substack{i \in N \\ j \in N'}} X^{u}_{i\,j\,k\,m}\; \tau_{i\,j} \le H \qquad \forall\, k, m \in N', \quad u \in v \tag{31}$$

$$p^{u}_{k\,m} + \frac{1}{r} \sum_{\substack{i \in N \\ j \in N'}} X^{u}_{i\,j\,k\,m}\; q_{i} \le\; d^{u}_{k\,m} \qquad \forall k, m \in N', \quad u \in v \tag{32}$$

$$d^{u}_{k\,m} + \sum_{\substack{i \in N \\ j \in N'}} X^{u}_{i\,j\,k\,m}\; \tau_{i\,j} \le\; d^{u}_{k+1\;\,m} \qquad \forall\, k, m \in N', \quad u \in v \tag{33}$$

$$p^{u}_{k\,m} + \frac{1}{r} \sum_{\substack{i \in N \\ j \in N'}} X^{u}_{i\,j\,k\,m}\; q_{j} \le\; p^{u}_{k+1\;\,m} \qquad \forall k, m \in N', \quad u \in v \tag{34}$$

$$\sum_{\substack{k, m \in N' \\ u \in v}} P^{u}_{k\,m\,t} \le\; 1 \qquad \forall\, t \in T \tag{35}$$

$$\sum_{t \in T} P^{u}_{k\,m\,t} = \frac{1}{r} \sum_{\substack{i \in N \\ j \in N'}} X^{u}_{i\,j\,k\,m}\; q_{i} \qquad \forall\, k, m \in N' \tag{36}$$

$$p^{u}_{k\,m} \le t\; P^{u}_{k\,m\,t} + M \quad 1 - P^{u}_{k\,m\,t} \qquad \forall\, k, m \in N', \quad t \in T \quad u \in v \tag{37}$$

$$p^{u}_{k\,m} + \frac{1}{r} \sum_{\substack{i \in N \\ j \in N'}} X^{u}_{i\,j\,k\,m}\; q_{j} \ge t\; P^{u}_{k\,m\,t} \qquad \forall\, k, m \in N \setminus 0, \quad t \in T, \quad u \in v \tag{38}$$

$X^u_{ijkm},\ P^u_{kmt},\ Z^u_{km},\ y^u_m \in \ 0,1 \qquad \forall\ m, k,\ j \in N',\ i \in N,\ \ u \in v$

$d^u_{km},\ p^u_{km},\ e_i$ are integers $\qquad \forall\ m, k,\ \ i \in N,\ \ u \in v$

The objective function has two cost components: 1) the variable transportation cost relevant to both plants, and 2) the fixed hiring cost of both plants. Constraints (21) to (27) are typical vehicle routing constraints for both plants. Constraint (21) is the truck capacity constraint and constraints (22) and (23) ensure if a customer is visited and left exactly once by only one plant. Constraint (24) and (25) ensures the number of times a truck leaves the plant and comes back to the respective plant is the same as the number of trips for that particular truck of the particular plant. Constraint (26) is the trip continuity constraint for each trip. Without this constraint a truck can reach a customer in trip k and leave the same customer in i trip $k+2$. Constraint (27) is the sub-tour elimination constraints Miller (1960). Two sets of sub-tour elimination constraints are required for two plants. Constraints (28) and (29) ensure that a customer cannot be visited by given trip of a given truck without hiring that particular truck. Constraint (30) ensures the product lifetime constraint and constraint (31) ensures the planning horizon constraint for all deliveries. Constraint (32) ensures that products cannot be delivered before being produced and constraint (33) ensures that a truck cannot start a new trip before completing the previous job and coming back to the respective plant. Constraint (34) ensures that the plant cannot start producing for the trip $k+1$ before completing the production for trip k. Constraints (35) to (38) together ensures the availability of two plants at any given time epoch t. Constraint (35) ensures that a plant can produce only for one trip at any given time period. Constraint (36) ensures that a plant is allocated for any given trip only for the production time required to satisfy the demand of that trip. Constraint (37) and (38) together ensures that when a plant starts producing for a trip it continuously produces until the total demand is produce for that trip. Due to the large number of constraints problems having more than 6 customers require a large amount of time even to find a feasible solution. The rest of the paper presents a heuristic approach to solve the MPIPDSP using evolutionary algorithms.

Table 4.1 and Figure 4.4 show how the problem size grows with the number of customers for six problems with increasing size from 6 customers to 16 customers. The % Gap refers to the gap between the current best solution and the best integer solution reported in CPLEX at the time the readings were taken. The Dynamic Allocation Solution procedure is explained later and mentioned here for completeness.

Problem Number	Number of Customers	Number of Variables	Number of Constraints	% Gap	Approimate Time taken by CPLEX	CPLEX solution	Dynamic Allocation Solution
1	6	14857	33482	0	0.85 sec	926	926
2	8	30497	71582	32.1	10 days	1224	1098
3	10	65641	155782	25.39	10 days	1075	1075
4	12	108337	265626	n/a	10 days	n/a	1062
5	14	169401	427262	n/a	10 days	n/a	1553
6	16	254017	656242	n/a	10 days	n/a	1797

Table 4.1: Growth of problem size with number of customers in MPIPDSP

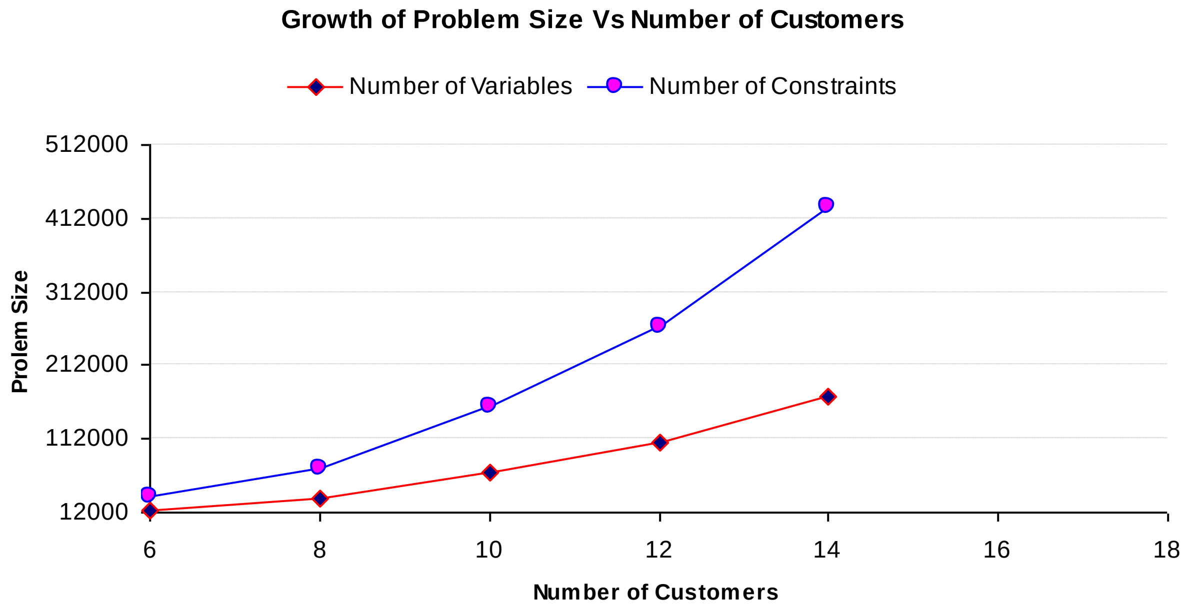

Figure 4.4: Growth of problem size of MPIPDSP with number of customers

Heuristic Solution Approach for MPIPDSP

MPIPDSP is also a NP-Hard problem because it consists of two IPDSP's that can be proved NP-Hard by reducing to a traveling salesman problem. With the assignment problem of overlapping customers, solving the MPIPDSP becomes harder than the IPDSP. Note that each overlapping customer is a candidate to be allocated to either plant. In this section two heuristic approaches: static allocation heuristics and dynamic allocation heuristics, are given to solve MPIPDSP. In the first approach each overlapping customer is assign to one of the two plants first. Then, as discussed in Chapter 3, two single plant IPDSP problems are solved using the heuristic IPDPP-MA1. As shown in

Example 4.1, assignment of customers to plants is critical to the solution quality. If the assignment of customers is not optimal the final solution cannot be optimal. In the second approach overlapping customers are dynamically assign to plants during the evolution of the IPDSP-MA1 and solve the two plant problem.

Static Allocation Methods for MPIPDSP

In this section four methods are discussed to allocate overlapping customers to a plant. Allocations are static in the sense that an overlapping customer is allocated to a plant permanently and only once. Methods 1 and 4 are simple and in Method 1 each overlapping customer is randomly allocated to a plant such that both plants have an equal number of customers. In Method 4 each overlapping customer is allocated to the closest plant using the direct distance from each plant to the customer. Solutions of Method 1 are used as benchmarks to evaluate the contribution of Method 2 & 3.

Static Allocation Method 2 and 3

Using the notation given in Section 3.3 let q_i be the demand of customer i, B is the lifetime of the product, and τ_{0i} and τ_{1i} be the distance to customer i from Plant 1 and Plant 2 respectively. Given $N = 0, 1, 2, ..., n$ and $N' = N \setminus 0, 1$ where Plant 1 and Plant 2 is denoted by $0, 1$, let $R_1 = i \in N' : \tau_{0i} > B$, $R_2 = i \in N' : \tau_{0i} > B$,

$R_3 = \{ i \in N' : \tau_{0i}, \tau_{1i} \leq B \}$ be three sets of customers. Constrained by the limited lifetime B of the product, customers in R_1 can only be served by Plant 1, customers in R_2 can only be served by Plant 2, and customers in R_3 can be served by both plants. This allocation method is based on the assumption that on average two customer orders can be consolidated and served by a single truck trip. This assumption is based on the fact that given that customer demands are uniformly distributed between 1 and the truck capacity. Allocation Method 2 explained below is applied for every customer in set R_3.

The concept of allocation Method 2 is to consider the consolidated distribution cost impact depending on the truck capacity and the product lifetime on both plants. For each customer in the overlapping region, two closest customers in regions R_1 and R_2 are identified and the cost impact on each plant if consolidated with overlapping customer is separately identified. The three possible scenarios are that the overlapping customer can be consolidated with: 1) both customers; calculate the cost of consolidation on both plants and allocate to the least cost plant, 2) only one of them; allocate to that plant, and 3) none of them; allocate to the closest plant, depending on the truck capacity and product lifetime constraints. In each case overlapping customer is allocated to the plant having the least cost impact. This procedure is repeated on all overlapping customers as explained below.

Step 1: Pick a customer $i \in R_3$ and find out the two closest customers $j \in R_1$ and $k \in R_2$.

Go to *Step 2*

Step 2: If i can be consolidated with j at a lower travel cost than consolidating with k then allocate i to R_1 and remove j from R_1. Else if i can be consolidated with k at a lower travel cost than consolidating with j then allocate i to R_2 and remove k from R_2. Else if i can only be consolidated either with j or k then allocate i to that plant and remove j or k from the set accordingly. Else i cannot be consolidated with either j or k so allocate i to the closest plant. Go to *Step 3*

Step 3: Have all $i \in R_3$ been allocated to a plant? If yes stop. Else Go to *Step 1*

The allocation Method 3 is very similar to the allocation Method 2. The only difference is in Step 2 when a customer $i \in R_3$ is consolidated with a customer in R_1 or R_2 that customer is not removed from the set. Pairing a customer in the allocation stage does not necessarily means that those two customers are delivered together in one truck load. Thus leaving all customers in regions R_1 or R_2 throughout the allocation process is expected to find different allocation of customers in region R_3.

Computational Study

A computational study is carried out to differentiate the performance of four static allocation methods. The cost of Method 1, random allocation, is used as the benchmark to evaluate the other static allocation methods. Three problem sizes with 40, 60, and 80 customers are tested with 15 problems for each size. Each problem instance is randomly generated so that for any given problem instance 60 problems are obtained by removing 20 customers (10 from each plant) from the 80 customer problem and 40 problems are obtained by removing another 20 customers (10 from each plant) from the 60 customer problems. The location of two plants is determined so that they are B distance units away from each other. For all problems the planning horizon is 550 units. The other problem parameters, $B = 50$, $C = 60$, $F = 200$ and, $R = 5$ are the same in all problems. A travel speed of 1 unit per unit time and a travel cost of 1 unit per unit distance is assumed. The parameters of IPDSP-GA are as follows. All problems are run for 450 generations and a crossover probability of 90% and a mutation probability of 20% are used for each. Each problem instance using each method is replicated 100 times and the values shown in Table 4.2 through Table 4.4. These tables show the minimum and maximum total cost of both plants over the 100 runs for each problem. Figures 4.5 through 4.7 graphically illustrate the minimum of each of the four allocation heuristics.

Problem Number	Allocation Method 1		Allocation Method 2		Allocation Method 3		Allocation Method 4	
	Min	Max	Min	Max	Min	Max	Min	Max
1	2554	2562	2429	2432	2385	2386	2385	2386
2	2565	2565	2316	2333	2299	2337	2299	2342
3	2619	2620	2517	2517	2517	2517	2517	2517
4	2536	2549	2407	2459	2400	2417	2400	2428
5	2720	2726	2655	2664	2655	2664	2655	2673
6	2338	2374	2278	2337	2269	2340	2278	2342
7	2131	2158	2099	2113	2100	2134	2099	2113
8	2509	2524	2342	2351	2326	2334	2329	2344
9	2479	2482	2222	2245	2287	2315	2222	2240
10	2434	2441	2209	2216	2209	2220	2209	2214
11	2475	2505	2269	2305	2240	2277	2240	2267
12	2262	2264	2247	2274	2247	2274	2230	2243
13	2176	2219	2195	2206	2195	2206	2195	2206
14	2207	2220	2182	2199	2232	2240	2204	2216
15	2572	2734	2274	2290	2274	2290	2274	2290

Table 4.2:Results for problem size 40

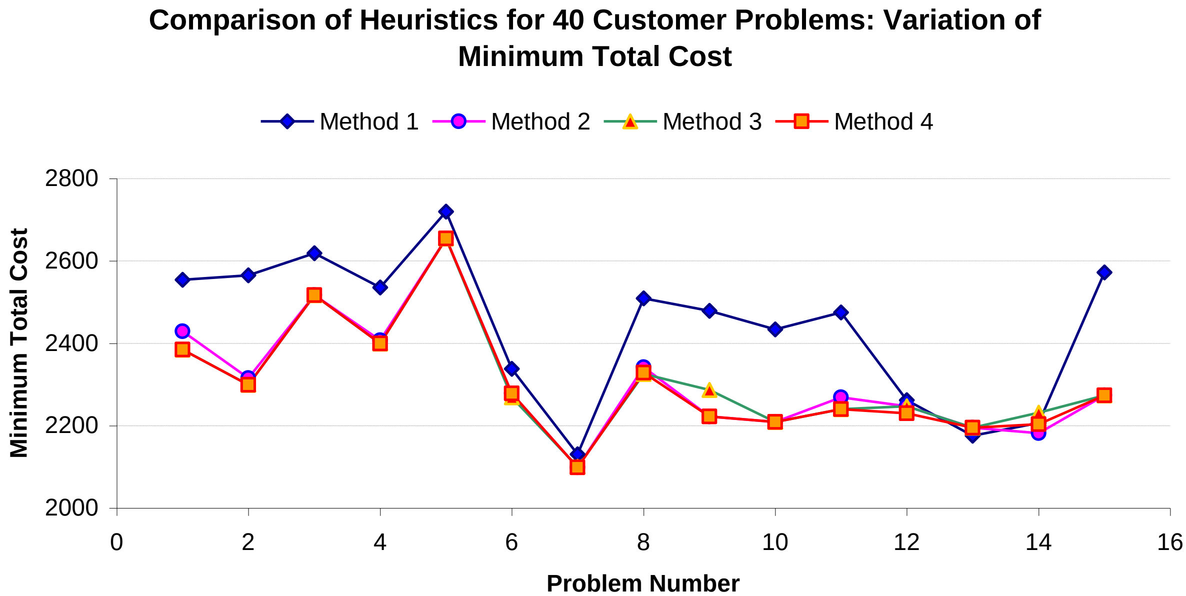

Figure 4.5: Comparison of heuristics for 40 customer problems

Problem Number	Allocation Method 1		Allocation Method 2		Allocation Method 3		Allocation Method 4	
	Min	Max	Min	Max	Min	Max	Min	Max
1	3633	3689	3507	3518	3507	3518	3507	3534
2	3698	3742	3220	3247	3206	3237	3206	3232
3	3725	3791	3788	3792	3788	3792	3750	3757
4	3388	3624	3215	3281	3186	3245	3186	3248
5	4024	4049	3872	3895	3859	3878	3852	3871
6	3224	3281	3168	3226	3146	3211	3166	3232
7	3146	3173	2752	3002	2995	3022	2995	3017
8	3846	3879	3625	3649	3536	3561	3537	3583
9	3039	3192	2634	2704	2634	2691	2634	2696
10	3699	3734	3526	3575	3270	3305	3270	3303
11	3700	3739	3222	3274	3222	3270	3222	3283
12	2755	2795	2958	3009	2944	2962	2944	2964
13	3200	3264	2983	3024	2973	3032	2973	3037
14	2851	3076	2673	2729	2858	2877	2652	2668
15	3127	3158	2724	2789	2669	2713	2669	2704

Table 4.3: Results for problem size 60

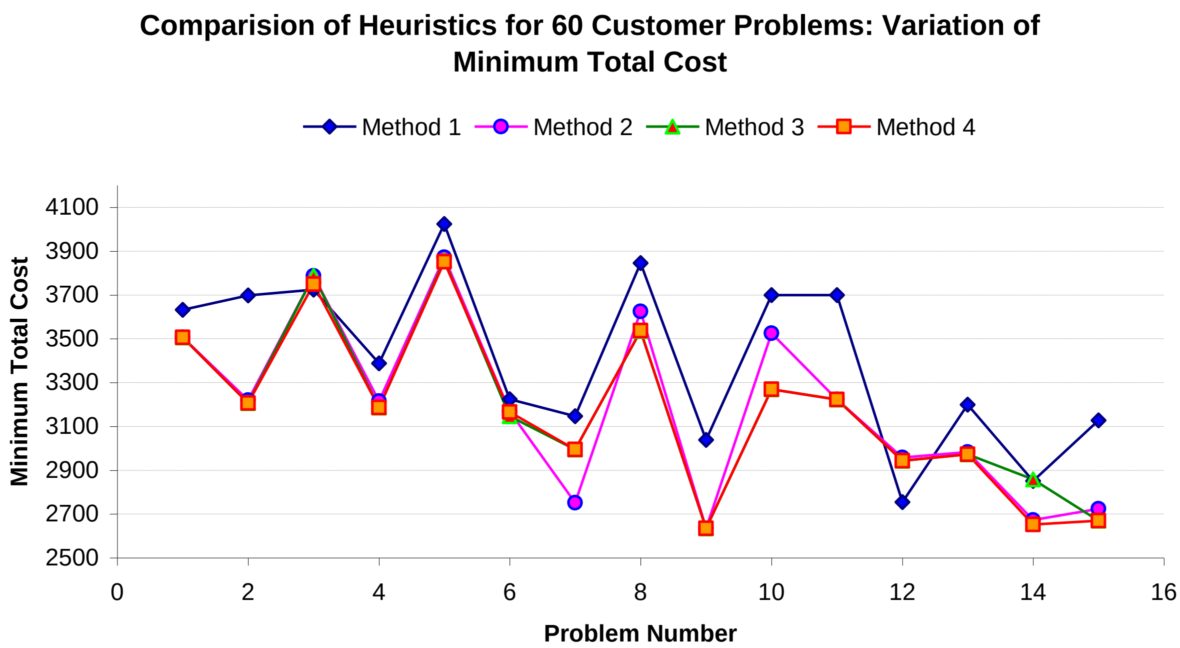

Figure 4.6: Comparison of Heuristics for 60 customer problems

Problem Number	Allocation Method 1		Allocation Method 2		Allocation Method 3		Allocation Method 4	
	Min	Max	Min	Max	Min	Max	Min	Max
1	4464	4558	4021	4121	4023	4124	4024	4119
2	4629	4959	3905	4220	3903	4011	3903	3989
3	4566	5083	5004	5050	5004	5037	4376	5067
4	4052	4136	3826	3939	3815	3906	3823	3911
5	5040	5071	4539	4595	4539	4562	4539	4564
6	4060	4141	3873	3966	3848	4129	3846	3938
7	4509	4538	4239	4305	4084	4142	4235	4305
8	4583	4906	4210	4498	4178	4307	4180	4465
9	3934	4042	3827	3910	3791	3872	3793	3853
10	4700	4757	4228	4430	4228	4511	4228	4289
11	4675	4754	4170	4423	4386	4425	4159	4435
12	3793	3859	3422	3695	3616	3706	3613	3687
13	3625	3766	3616	4047	3795	3872	3559	3818
14	4080	4199	3961	4229	3949	4796	3928	4128
15	3947	4185	3460	3518	3656	3728	3450	3499

Table 4.4: Results for problem size 80

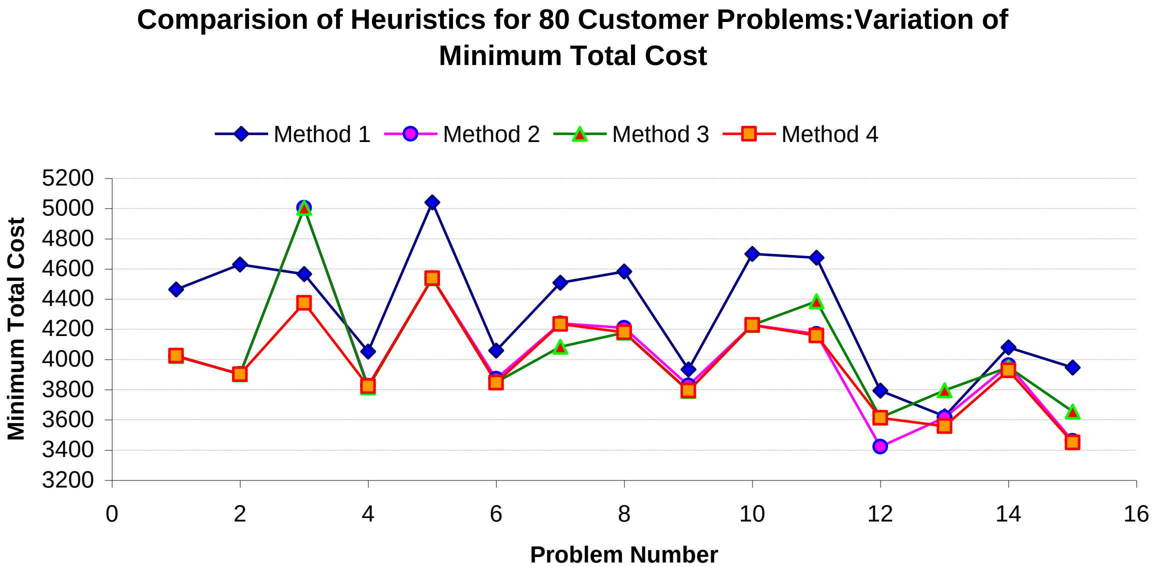

Figure 4.7: Comparison of heuristics for 80 customer problems

A Kruskal-Wallis test is conducted to analyze whether the four allocation heuristics are significantly different using null hypothesis that the medians are statistically equal. The Kruskal-Wallis test is conducted on the transformed values with respect to the minimum total cost obtained using random allocation method (Method 1) for each problem. For each allocation method i the transformed values are calculated by $\left(\frac{Method_i - Method_1}{Method_1}\right)$ which indicates the percentage improvement of $Method_i$ from the random allocation method. In Appendix D, Tables D.1 through D.3 show the Minitab output for problems with 40, 60, and 80 customers. The high *p*-value of 0.028 for 40 customer problems provides a basis to conclude that there is no sufficient evidence to reject the null hypothesis of medians being different. The low *p*-values of 0.000 for 60 and 80 customer problems provide a basis to conclude that at least one median is different. In order to identify which medians are different LSD test is conducted for all pairs and the results are summarized in Table 4.5. Given the total sample size of 4500 and each individual sample size of 1500, for all pairs of samples i and j, $LSD_{i\,j} = 93$.

Problem size	60	80
$\bar{R}_2$	2381	2362
$\bar{R}_3$	2262	2311
$\bar{R}_4$	2108	2079
$\bar{R}_2 - \bar{R}_3$	119	51
$\bar{R}_2 - \bar{R}_4$	273	282
$\bar{R}_3 - \bar{R}_4$	154	231

Table 4.5: Multiple comparisons of Kruskal-Wallis test

As shown in Table 4.5 LSD test for problem size 60 shows that all pairs of medians are significantly different from each other. For 80 customer problems, only allocation methods 2 and 3 are not statistically different while allocation Method 4 is significantly different from both Method 2 and Method 3. In addition, for both 60 and 80 customer problems lowest median is reported under Method 4. A qualitative observation of these conclusions can be drawn by looking at Figures 4.5. through 4.7 where curves corresponding to similar allocation methods overlap. Tables D.1 and D.2 in Appendix D also show that the smallest median for all 40, 60 and 80 customer problems are obtained by using the allocation Method 4. Thus overall, allocation Method 4 corresponding to allocation to the closest plant can be seen as the best static allocation method for two plant case.

Dynamic Allocation Heuristics for MPIPDSP

The main disadvantage of static allocation methods is that for any given problem an overlapping customer is allocated to one plant throughout the evolution of the IPDSP-MA1. Looking at the problem structure of the MPIPDSP, it is hard to find an optimal static allocation of the overlapping customers. The optimal allocation depends both on the demand distribution and location of the customers in R_1 and R_2. Given n overlapping customers, there are 2^n ways of allocating them to two plants. This means that the possible combinations grow exponentially with the number of customers. For example, if a MPIDSP has 20 customers in the overlapping region, then there are 1,048,576 possible combinations of allocation motivating us trying different allocation combinations for a given problem. Mainly there are two approaches of trying multiple allocations: 1) test all allocation combinations and find the impact on the final solution and the best allocation and 2) dynamically allocate customers along the evolution of IPDSP-MA1. To our knowledge there isn't any metric to evaluate the impact of an allocation on the final solution without solving the IPDSP-MA1 for both plants. Thus, the rest of this chapter is committed analyzing the dynamic allocation of overlapping customers during the evolution of the IPDSP-MA1.

Unlike in static allocation methods, a chromosome consists of a permutation of all customers in the problem. For example, if one plant has 10 customers and the other plant has 10 customers including 4 overlapping customers, then a chromosome has 20 genes corresponding to a permutation of customers 1 through 20 whereas in static allocation methods there are two different chromosomes representing a solution, one for each plant. In dynamic allocation IPDSP-MA1 if a generation consists of 100 chromosomes, then 100 possibly different allocations are created in the initial population by arbitrarily assigning overlapping customers to a plant. The solution representation and genetic operators are best illustrated by the following example.

<u>Example 4.2:</u> Consider a two-plant IPDSP with 8 customers where $R_1 = 1,2,3$, $R_2 = 7,8$, and $R_3 = 4,5,6$. A chromosome is a random permutation of 8 customers and each chromosome has an ally chromosome indicating the plant allocation. In this example customer in set R_1 always has 1 in the respective gene of the ally chromosome and customers in set R_2 always has 2 in the respective gene of the ally chromosome. Assume for example, that a sequence of customers is $5 \to 6 \to 1 \to 8 \to 2 \to 4 \to 7 \to 3$ and overlapping customers 4 and 6 are arbitrarily

allocated to Plant 1 and overlapping customer 5 to Plant 2. Then the chromosome and ally chromosome are as follows.

Ally Chromosome →	*2*	*1*	*1*	*2*	*1*	*1*	*2*	*1*
Chromosome →	5	6	1	8	2	4	7	3

Figure 4.8: Solution representation of dynamic allocation

At this stage, based on the ally genes the chromosome is split into two chromosomes for decoding, one for Plant 1 and the other is for Plant 2 as shown below.

Chromosome for Plant 1

1	*1*	*1*	*1*	*1*
6	1	2	4	3

Chromosome for Plant 2

2	*2*	*2*
5	8	7

Figure 4.9: Solution Representation, split chromosomes

These two chromosomes generates two sequences: 1) Plant 1 $6 \rightarrow 1 \rightarrow 2 \rightarrow 4 \rightarrow 3$, and 2) Plant 2 $5 \rightarrow 8 \rightarrow 7$, inherited from the initial chromosome. Each sequence is then used for fitness calculation as explained in Chapter 3. The total fitness value is calculated by summing two fitness values representing the cost of two plants. The memetic algorithm evolves through crossover, mutation, flip mutation, and reproduction as described in the Chapter 3. Initial population is randomly generated with a given amount of feasible candidate solutions. For this research 150 has been selected as the population size. In addition, initial population is seeded with chromosomes representing allocation to the closet plant because as we observed that, allocation to the closest plant produces best solutions over other static allocation methods.

In order to select chromosomes for crossover, a mating pool is created using the roulette wheel selection. The 2-point crossover operator is applied to two randomly selected original chromosomes from the mating pool so that feasible solutions are maintained as shown in Figure 4.11. During the crossover, respective ally chromosomes are also subjected to the crossover operation as shown in Figure 4.11.

The general swap mutation is applied on two randomly selected genes of a randomly selected child. Unlike the single plant case, two swap operations are conducted each time a child is mutated to make sure that mutation is applied on both plants. Figure 4.10 shows an example of a general mutation applied on a chromosome with 8 customers. Note that swap mutation has no effect on the plant assignment since mutation is applied on two customers belongs to the same plant.

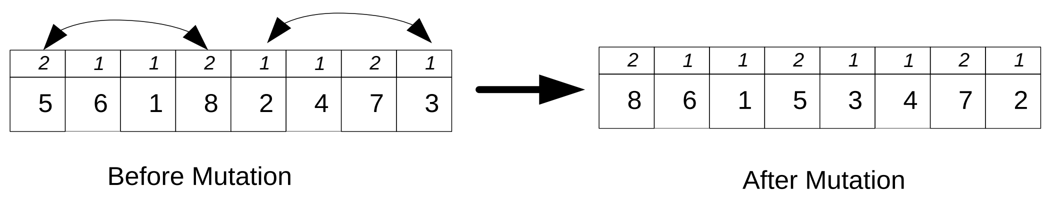

Figure 4.10: Swap mutation

It is important to note that crossover and mutation do not change the allocation of overlapping customers to plants restricting the total number of allocation combinations to the initial population size of the genetic algorithm.

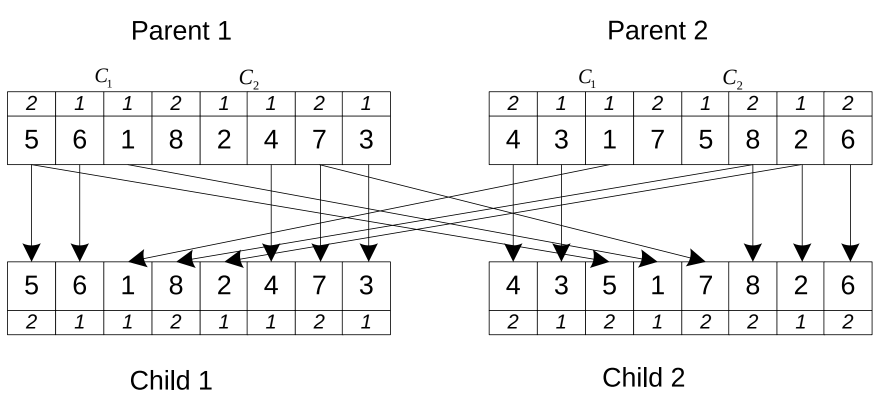

Figure 4.11: Two-point crossover with ally chromosome

As the memetic algorithm evolves, many other combinations of allocations are created by the flip mutation operator which is applied on the ally genes of mutated child population. The flip mutation operates on ally genes of a child chromosome corresponding to overlapping customers. A child chromosome is randomly picked with a predetermined probability for flip mutation. The ally genetic sequence of each selected child chromosome is then checked for genes corresponding to overlapping customers. Each such overlapping ally gene is randomly flipped to the other plant with another predetermined probability. The flip mutation operator does not affect the feasibility and allows generating different allocation combinations of overlapping customers. The values used for general mutation rate, selection probability of a child chromosome for flip mutation, and the probability of flipping a selected child ally gene are determined using a 2^3 full factorial design as explained below.

A 2^3 Full Factorial Design to Select Best IPDSP-MA1 Parameters for MPIPDSP

A two-plant problem with 40 customers is randomly generated with $H = 600$, $F = 200$, $B = 50, C = 60$, and a production rate at each plant 5 units per unit time. Each generation of the genetic algorithm consists with 150 chromosomes and each evolution is run for 450 generations. The three factors, each having two levels, being considered in the design are: 1) the general mutation probability (GMP), 2) the selection probability (FP) of a child chromosome for flip mutation, and 3) the probability of flipping (FMP) a gene for each selected ally child gene selected. Generally, the user of a GA can pick these factor levels at her discretion and there is no set of standard levels. However, high crossover probabilities ensuring diversity and low mutation probabilities ensuring convergence are good practices among evolutionary algorithm users users. In this research, we select the high and low levels of each factor as shown in Table 4.6.

Factor	Probability(%)	
	Low	High
GMP	60	80
FP	20	40
FMP	60	80

Table 4.6: Factor levels of IPDSP-MA1 parameters for MPIPDSP

The genetic algorithm is run for 30 random starts for each of the 8 design experiments and results are given in Appendix B, Table B.1 Results represent the sum of the total costs for plant one and plant two including fixed cost of trucks and the variable cost for miles driven. A Kruskal-Wallis test was conducted and found that the medians were not significantly different at a significant level of 0.05 (p-value is 0.26). Considering the lowest median of all eight treatments (Table B.1) GMP, FP, and FMP factor levels are set at 80%, 20% and 60%, respectively.

Computational Study

The dynamic allocation heuristic is applied to the same problems generated in Section 4.5.2 so that results of the dynamic allocation can be compared to the static allocation heuristics. As explained in Section 4.5.3, each random start of the dynamic allocation heuristic evolution ends at 450 generations. Results are compared with the results of the best static allocation method which was Method 4 allocation to the closest plant and, results of the random allocation method which was Method 1 is used as a benchmark. Tables 4.7 through 4.10 are the minimum total cost and the maximum total cost over 100 runs for each problem. Figures 4.12 through 4.15 graphically compare the performance of dynamic allocation heuristic with others.

Problem Number	Random Allocation (Method 1)		Allocation to Closest Plant (Method 4)		Dynamic Allocation	
	Min	Max	Min	Max	Min	Max
1	2554	2562	2385	2386	2149	2350
2	2565	2565	2299	2342	2074	2320
3	2619	2620	2517	2517	2351	2427
4	2536	2549	2400	2428	2342	2462
5	2720	2726	2655	2673	2587	2663
6	2338	2374	2278	2342	1986	2321
7	2131	2158	2099	2113	1801	1986
8	2509	2524	2329	2344	2388	2446
9	2479	2482	2222	2240	1989	2292
10	2434	2441	2209	2214	1941	2211
11	2475	2505	2240	2267	2134	2420
12	2262	2264	2230	2243	2008	2220
13	2176	2219	2195	2206	1904	2164
14	2207	2220	2204	2216	1940	2185
15	2572	2734	2274	2290	2081	2342

Table 4.7: Results for problem size 40

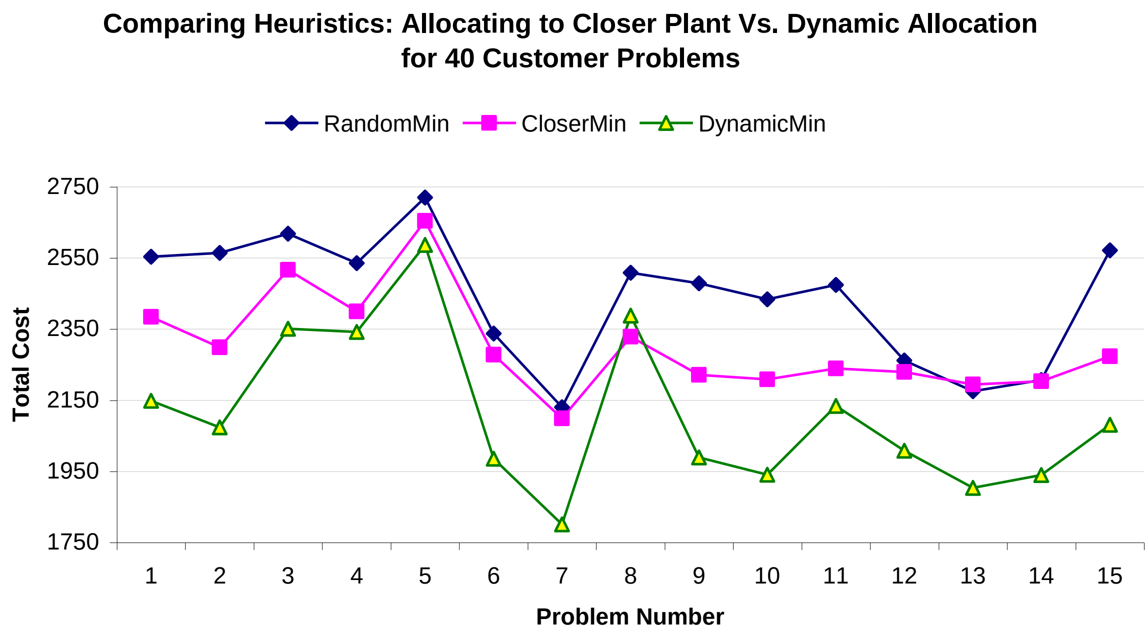

Figure 4.12: Comparison of heuristics for 40 customer problems

Problem Number	Random Allocation (Method 1)		Allocation to Closest Plant (Method 4)		Dynamic Allocation	
	Min	Max	Min	Max	Min	Max
1	3633	3689	3507	3534	3248	3504
2	3698	3742	3206	3232	3028	3247
3	3725	3791	3750	3757	3481	3804
4	3388	3624	3186	3248	3155	3325
5	4024	4049	3852	3871	3756	3882
6	3224	3281	3166	3232	3028	3226
7	3146	3173	2995	3017	2852	3132
8	3846	3879	3537	3583	3397	3665
9	3039	3192	2634	2696	2747	3176
10	3699	3734	3270	3303	3234	3461
11	3700	3739	3222	3283	3195	3334
12	2755	2795	2944	2964	2590	2868
13	3200	3264	2973	3037	2818	3090
14	2851	3076	2652	2668	2648	2962
15	3127	3158	2669	2704	2603	2935

Table 4.8: Results for problem size 60

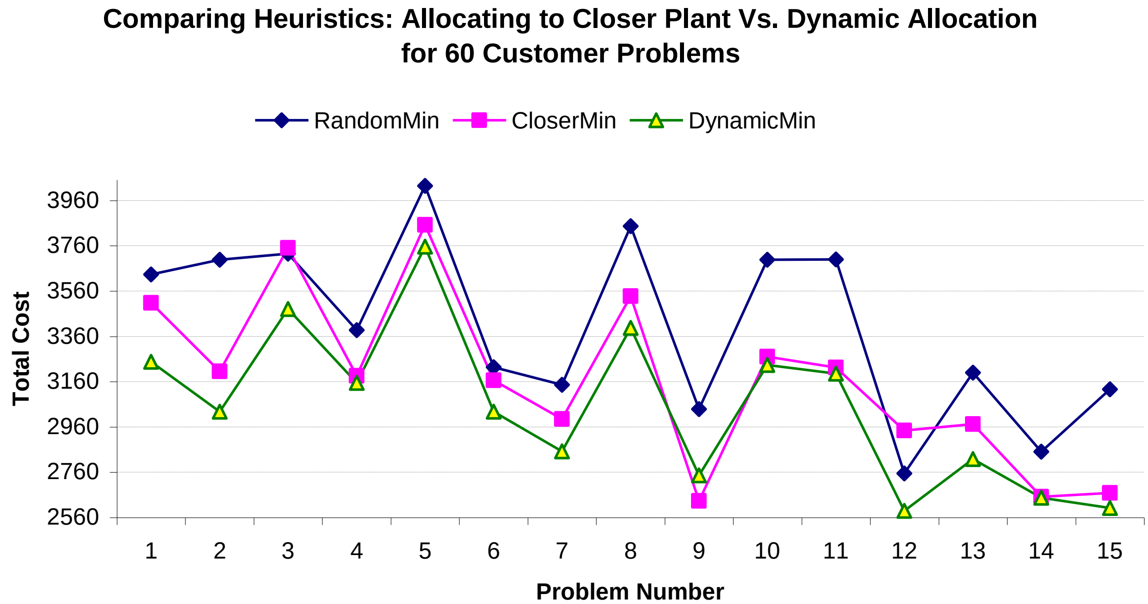

Figure 4.13: Comparison of heuristics for 60 customer problems

Problem Number	Random Allocation (Method 1)		Allocation to Closest Plant (Method 4)		Dynamic Allocation	
	Min	Max	Min	Max	Min	Max
1	4464	4558	4024	4119	4028	5035
2	4629	4959	3903	3989	3910	4666
3	4566	5083	4376	5067	4236	5404
4	4052	4136	3823	3911	3842	4260
5	5040	5071	4539	4564	4539	4722
6	4060	4141	3846	3938	3876	4115
7	4509	4538	4235	4305	4080	4391
8	4583	4906	4180	4465	4210	4597
9	3934	4042	3793	3853	3802	4195
10	4700	4757	4228	4289	4257	4607
11	4675	4754	4159	4435	4171	4515
12	3793	3859	3613	3687	3429	3795
13	3625	3766	3559	3818	3761	3985
14	4080	4199	3928	4128	3584	4217
15	3947	4185	3450	3499	3413	3833

Table 4.9: Results for problem size 80

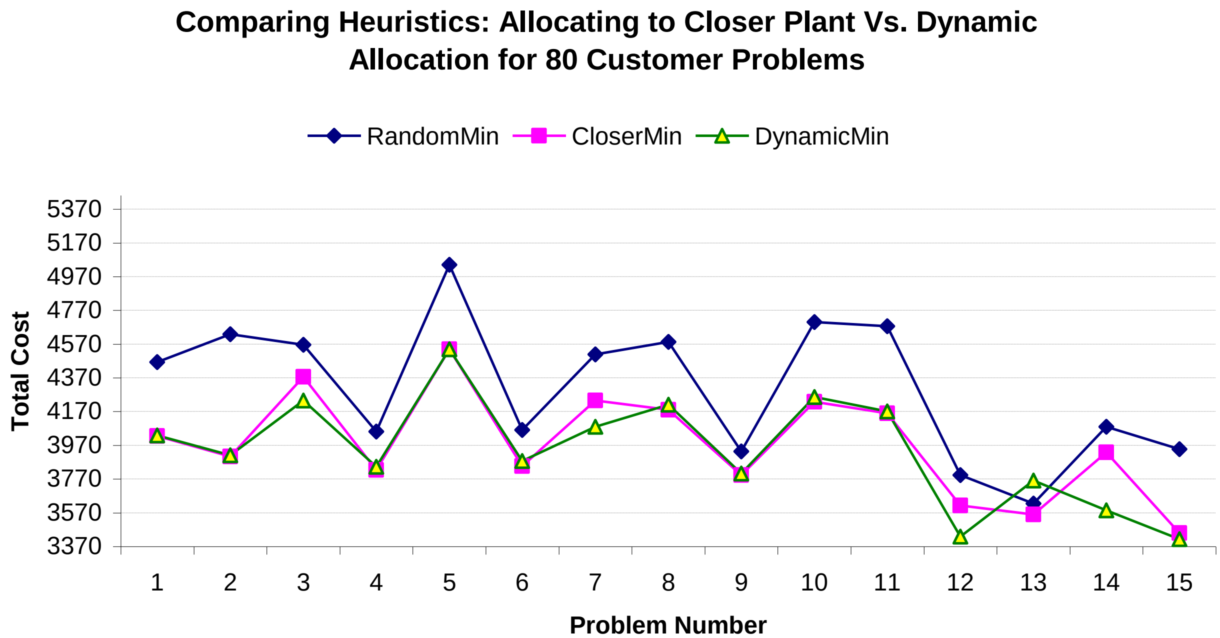

Figure 4.14: Comparison of heuristics for 80 customer problems

Graphs shown in Figures 4.12 through 4.14 indicate that for most of the problems, dynamic allocation heuristic finds a better solution than allocation to the closer plant. For 40 customer problems, except for problem number 8, dynamic allocation has found much better solutions for all other problems. Most likely, the optimal allocation for problem number 8 is allocation to the closer plant. In that case, static allocation Method 4, allocation to the closer plant heuristic performs better since after optimal allocation, GA optimizes the two plants separately throughout the evolution. Thus, optimal allocation is then optimized to find the best sequence for each plant. In order for dynamic allocation heuristic to find a better (or the same) solution than allocation to the closest plant method, dynamic allocation has to run for a large number of generations with a large population size. As the number of customers goes up the performance of dynamic allocation slightly diminishes and approaches the performance of allocation to the closer plant heuristic. In this dissertation for all 40, 60, and 80 customer problems we used a population size of 150 and a stopping criterion of 450 generations.

A Kruskal-Wallis test is conducted to further analyze the aforementioned conclusions statistically. The transformation $\left(\frac{Method_i - Method_1}{Method_1}\right)$ used earlier in this chapter is used to transform the total cost of each replication and the Kruskal-Wallis test is conducted on transformed values. The details of the Kruskal-Wallis test are given in Appendix E, Tables E.1 through E.3. The null hypothesis for each test is that the medians of treatments 2 and 3 are statistically equal. Treatment 2 and 3 represent allocation to the closest plant and dynamic allocation, respectively. The low $p\text{-value} < 0.000$ for 40 customer problems provides evidence to conclude that two medians are significantly different and the dynamic allocation method with lower median -0.09009 is selected as the best method. The high *p*-value of 0.264 for 60 customer problems provides evidence to conclude that medians are statically not different. The low $\text{p-value} < 0.000$ for 80 customer problems provides sufficient evidence to reject the null hypothesis of two medians the same and the allocation to the closest plant with lower median -0.05766 is selected as the best method.

The integrated production and distribution scheduling problem is a cost minimization problem. In the real world managers are looking for the minimum solution obtained from a specified small number of runs. Even though dynamic allocation is statistically inferior for 80 customer problems it finds significantly better solution of the 100 runs for some of the problems (Figure 4.14) that management can use for implementation.

Conclusions and Future Research

As explained earlier, a chromosome's fitness in dynamic allocation represent the total cost of both plants calculated separately by splitting the ally gene. This has the following disadvantage during roulette-wheel selection and elite reproduction. Assume that a given chromosome has the optimal allocation of overlapping customers into two plants. Also assume that the customer sequence of plant 1 extracted from aforementioned chromosome has the optimal sequence that minimizes the cost of plant one, but the customer sequence of plant 2 has a bad sequence with a very high cost. Consequently, the fitness of the chromosome has a lower value corresponding to a higher cost even with an optimal allocation of overlapping customers. If most of the other chromosomes have higher fitness values even with non-optimal allocation at this stage of the evolution, possibly the chromosome explained earlier with optimal allocation might be eliminated. An improvement for this weakness is followed in (3).

We recommend three possible improvements to the dynamic allocation heuristic that improves the evolution of the genetic algorithm.

1) The current dynamic allocation heuristic conducts a local search on the solution chromosome. This search is conducted separately for each plant. Extending this

local search for overlapping customers so that they can switch plants might improve the final solution. However, if dynamic allocation has already found an optimal allocation this local search might not improve the final solution.

2) Another way of improving the current heuristic is to stop the dynamic allocation half way through the evolution and apply the genetic search separately on two plants for the rest of the evolution. However, when the dynamic allocation is stopped has an impact on the final solution. A design of experiment can be used to find when to stop the dynamic allocation so that the best solution is obtained.

3) The dynamic allocation can also be improved by changing the elite reproduction and updating the roulette-wheel selection process of the genetic algorithm. Figure 5.1 shows a sample of a generation, four chromosomes, chr1-4, with cost of each plant and the total cost. The ratio $\frac{P_{1C}}{TC}$ represents the ratio of the cost of plant 1 to the total cost. The chromosome 4 with the highest cost will be eliminated during the evolution due to the high cost of 200. The higher total cost of a chromosome might be a result of bad allocation of overlapping customers. Assume chromosome 3 has an optimal allocation and an optimal sequencing of customers for plant 1, but a bad sequencing for plant 2 creating the highest total cost of chromosome 1-3. Also assume that chromosome 1 and 2 do not have optimal allocations even though they have a lower cost compared to chromosome 3. The slightly lower total cost is a result of the better sequencing as opposed to optimal allocation. If chromosome 3 has the optimal allocation, the optimal sequencing of

customers of plant 1 and 2 should create the best solution with a cost lower than the cost of lowest of chromosome 1 and 2 which is 150.

	Plant 1	Plant 2		
Chr 1	P_{1C} = 50	P_{2C} =100	TC = 150	P_{1C} /TC = 0.37
Chr 2	P_{1C} =45	P_{2C} =110	TC = 155	P_{1C} /TC = 0.29
Chr 3	P_{1C} =40	P_{2C} =120	TC = 160	P_{1C} /TC = 0.25
Chr 4	P_{1C} =20	P_{2C} =180	TC = 200	P_{1C} /TC = 0.1

Figure 4.15: Updating the elite reproduction

If ratios $\frac{P_{1C}}{TC}$ and $\frac{P_{2C}}{TC}$ is considered during the mating pool creation and the elite reproduction chromosome 3 would be carried forward in evolution. For example when a new generation is created certain percentage of population chromosomes is always created by considering the minimum of $\frac{P_{1C}}{TC}$ from plant 1 and $\frac{P_{2C}}{TC}$ for plant 2.

There are a few obvious extensions to multi-plant case. One very realistic extension is to relax the assumption of not being allowed to move trucks between plants. It is always profitable to use a lesser number of trucks due to the high fixed cost paid for the planning horizon. Relaxing this assumption is very important since all trucks are assumed to be hired at the beginning of the horizon. For example if the planning horizon is one week and plant 1 requires two days to satisfy the total demand and plant 2 requires one days to satisfy the total demand 1) If trucks are not allowed to move between plants then two trucks are required, one for each plant 2) If trucks are allowed to move between plants then one truck is enough to satisfy the total demand of both plants (in four days plus the transportation time between plants). However if trucks are hired only when needed and hiring cost is proportional to the number of days a truck is used, then relaxing this assumption might not make a significant difference.

Another extension is to consider a product mix. While this adds another level of complexity, problem becomes more practical. For example, if the product mix consists of two products having the same lifetime, then a customer can be visited at most two times. Any overlapping customers can be served by one or both of the plants depending on the availability of the plant capacity.

CHAPTER FIVE

CONCLUSIONS

A common production and distribution scheduling problem was solved in this dissertation using evolutionary algorithm based heuristics As explained earlier IPDSP is a NP hard problem and no known algorithms exist to solve problems in this class. The significant advantage of using heuristics is the short computational time. A Single plant problem with 20 customers was solved using IPDSP-GA in a computational time as short as 2 minutes.

Three heuristics were given In Chapter 3 to solve IPDSP with a single plant while five heuristics were given in Chapter 5 to solve IPDSP with multiple plants. Both statistical and qualitative analyses showed that performance of heuristics vary with problem size. Given the enormous computational power and the grid computing techniques in today's world, the best approach for any given problem is to solve the problem with all heuristics and to use the best solution.

Future Research

Chapter 3 and Chapter 4 contain the specific research extensions to single plant IPDSP and multi plant IPDSP respectively while this section explains research extensions common to both problems.

Throughout the dissertation we have assumed that each customer accepts deliveries anytime during the planning horizon. The validity of this assumption depends on the nature of the product. For example, in food industry truck divers have keys to the restaurants so that they can deliver food at any time during the day. However, in some other cases customers have a distinct time window to accept deliveries depending on various other business requirements including space availability in the parking lot. The IPDSP can be analyzed with a distinct time window for each customer within the planning horizon. As the time window constraint is introduced the feasible sequences of customers in a sub tour significantly goes down.

All of the heuristics developed in this dissertation are based on route first cluster second heuristics from the vehicle routing literature (Toth and Vigo 2002). Other methods including, sweep heuristics, cluster first route second heuristics (Laporte et al 2000) can also be used to find sub tours that minimizes the total cost of the IPDSP. In addition to GAs and MAs, other global search methods including Tabu Search (Glover 1997) can also be used to find a minimum cost solution to IPDSP. Even if the final solutions obtain using different search techniques might not make a significant difference, it is worthwhile to study the computational time among different search methods.

The overall solution approach used in this dissertation is that different sequences are evaluated with respect to the problem constraints and the lowest cost sequence found using evolutionary algorithms is accepted as the solution to IPDSP. The variable, number of trucks, attached to each sequence is gradually increased until a feasible solution is found and the total cost is calculated by adding the fixed cost of the trucks and the transportation cost. We now explain an insightful extension to IPDSP that suggest a new solution approach that consists of two phases. In the first phase the best sequence and the set of sub tours corresponding to a given set of customers is found considering truck capacity constraint and the effective life time constraint while ignoring the planning horizon constraint. The number of trucks required is not a variable at this phase since the planning horizon constraint is not considered. The solution to the first phase is equivalent to the solution of the corresponding vehicle routing problem with a maximum route time. In the second phase the set of sub tours obtained in the first phase is reordered to obtain the minimum number of trucks with respect to the planning horizon constraint. The solutions of both phases can be obtained using various solutions techniques from the literature. For example GAs can be used in both phases to find the best tour in phase one and to reorder the sub tours to minimize the number of trucks in the second phase.

APPENDICES

Appendix A

Statistical Results: Best Parameters of the IPDSP-MA2

Run	Number of Children									
	2	4	6	8	10	12	14	16	18	20
R1	1515	1464	1460	1444	1441	1437	1436	1447	1448	1445
R2	1499	1475	1453	1437	1436	1444	1444	1451	1449	1444
R3	1455	1447	1446	1444	1435	1444	1437	1445	1440	1444
R4	1469	1463	1444	1451	1444	1438	1445	1445	1444	1447
R5	1476	1447	1448	1444	1444	1446	1444	1456	1444	1436
R6	1453	1456	1438	1444	1436	1441	1444	1447	1437	1444
R7	1487	1448	1448	1435	1436	1438	1444	1436	1443	1444
R8	1457	1447	1447	1444	1448	1436	1447	1454	1442	1435
R9	1467	1456	1447	1444	1442	1452	1445	1447	1446	1444
R10	1501	1444	1444	1447	1436	1436	1447	1444	1436	1436
R11	1469	1480	1448	1447	1449	1444	1442	1444	1437	1436
R12	1471	1448	1446	1444	1437	1444	1444	1444	1444	1437
R13	1467	1452	1445	1452	1438	1444	1447	1445	1444	1443
R14	1447	1453	1446	1446	1445	1445	1436	1447	1435	1436
R15	1464	1453	1444	1447	1451	1444	1437	1446	1444	1444
R16	1477	1456	1448	1447	1438	1444	1436	1449	1435	1444
R17	1497	1452	1450	1440	1444	1445	1444	1440	1445	1436
R18	1467	1456	1444	1443	1435	1436	1446	1444	1445	1437
R19	1464	1454	1444	1450	1436	1442	1449	1444	1444	1440
R20	1478	1467	1437	1454	1445	1444	1435	1436	1444	1437
R21	1477	1462	1449	1436	1444	1436	1437	1437	1444	1447
R22	1472	1461	1445	1437	1444	1444	1435	1444	1444	1435
R23	1500	1448	1438	1447	1444	1435	1437	1462	1447	1438
R24	1461	1454	1444	1444	1448	1444	1447	1436	1444	1437
R25	1460	1445	1450	1451	1445	1444	1436	1455	1444	1436
R26	1471	1464	1444	1444	1444	1444	1444	1444	1444	1437
R27	1484	1458	1448	1447	1444	1445	1444	1436	1444	1447
R28	1480	1444	1475	1447	1445	1448	1444	1437	1444	1442
R29	1480	1462	1445	1449	1436	1444	1444	1444	1436	1444
R30	1462	1454	1454	1445	1444	1444	1441	1451	1444	1444
Mean	1474	1456	1447	1445	1442	1442	1442	1445	1443	1441
Std. Dev	16	9	7	5	5	4	4	6	4	4
Median	1471	1454	1446	1445	1444	1444	1444	1445	1444	1441

Table A.1. Variation of total cost with number of children

Number of Children	N	Median	Ave Rank	Z
2	30	1471	278.9	8.54
4	30	1454	238.8	5.88
6	30	1446	176.7	1.74
8	30	1445	150.8	0.02
10	30	1444	103.9	-3.10
12	30	1444	107.6	-2.85
14	30	1444	106.0	-2.96
16	30	1445	148.0	-0.17
18	30	1444	110.8	-2.64
20	30	1441	83.5	-4.46
Overall	300		150.5	

H = 147.64   DF = 9   P = 0.000
H = 151.14   DF = 9   P = 0.000 (adjusted for ties)

Table A.2. MINITAB output Kruskal-Wallis test

Appendix B

Statistical Results: Best Parameters of the Multi-Plant IPDSP-MA1

Run	Design							
	[60,20,60]	[60,20,80]	[60,40,60]	[80,20,60]	[60,40,80]	[80,20,80]	[80,40,60]	[80,40,80]
R1	2300	2129	2093	2280	2221	2300	2237	2124
R2	2093	2134	2107	2078	2256	2245	2245	2107
R3	2286	2107	2086	2046	2314	2267	2245	2115
R4	2132	2254	2285	2128	2274	2102	2123	2304
R5	2146	2275	2313	2099	2263	2093	2152	2137
R6	2086	2288	2107	2249	2276	2107	2275	2296
R7	2132	2257	2109	2249	2078	2289	2086	2313
R8	2299	2295	2272	2123	2102	2293	2136	2132
R9	2093	2315	2276	2272	2090	2254	2107	2093
R10	2114	2131	2297	2149	2260	2256	2293	2290
R11	2107	2172	2107	2286	2256	2271	2293	2289
R12	2145	2263	2307	2089	2254	2268	2271	2151
R13	2107	2226	2272	2120	2137	2357	2269	2271
R14	2277	2235	2118	2110	2106	2308	2078	2254
R15	2293	2098	2248	2107	2300	2236	2102	2270
R16	2107	2314	2093	2115	2270	2145	2072	2114
R17	2132	2267	2132	2275	2093	2153	2273	2093
R18	2110	2221	2105	2128	2291	2281	2275	2269
R19	2247	2260	2270	2151	2263	2123	2254	2276
R20	2254	2124	2254	2295	2256	2118	2026	2263
R21	2269	2110	2280	2078	2250	2124	2274	2262
R22	2109	2132	2280	2118	2275	2285	2123	2264
R23	2291	2269	2132	2258	2312	2270	2347	2270
R24	2254	2254	2110	2090	2134	2100	2123	2275
R25	2297	2254	2093	2110	2086	2270	2270	2093
R26	2250	2093	2316	2276	2094	2140	2307	2093
R27	2221	2284	2280	2100	2280	2266	2257	2272
R28	2272	2272	2280	2114	2108	2107	2093	2093
R29	2157	2100	2306	2113	2141	2271	2093	2288
R30	2093	2307	2132	2102	2110	2273	2327	2107
Mean	2189	2215	2202	2157	2205	2219	2201	2206
Std. Dev	81	75	89	78	83	79	92	84

Table B.1 Results of the full factorial design.

Treatment	N	Median	Ave Rank	Z
[60,20,60]	30	2152	114.7	-0.49
[60,20,80]	30	2254	130.7	0.86
[60,40,60]	30	2255	120.8	0.02
[60,40,80]	30	2251	127.1	0.55
[80,20,60]	30	2119	89.2	-2.64
[80,20,80]	30	2261	135.6	1.27
[80,40,60]	30	2245	119.1	-0.12
[80,40,80]	30	2263	126.9	0.54
Overall	240		120.5	

H = 8.89 DF = 7 P = 0.260
H = 8.90 DF = 7 P = 0.260 (adjusted for ties)

Table B.2. Kruskal-Wallis test; MINITAB output

Appendix C

Statistical Analysis: Results of the Single Plant Heuristics

Treatment	N	Median	Ave Rank	Z
1	9000	0.2392	13304.2	-2.93
2	9000	0.2392	13199.3	-4.49
3	9000	0.2394	13998.1	7.42
Overall	27000		13500.5	

H = 55.83 DF = 2 P = 0.000
H = 55.84 DF = 2 P = 0.000 (adjusted for ties)

Table C.1: Kruskal-Wallis test for problem size 40; MINITAB output

Treatment	N	Median	Ave Rank	Z
1	9000	0.3318	13770.7	4.03
2	9000	0.3315	13330.0	-2.54
3	9000	0.3276	3400.7	-1.49
Overall	27000		13500.5	

H = 16.60 DF = 2 P = 0.000
H = 16.60 DF = 2 P = 0.000 (adjusted for ties)

Table C.2: Kruskal-Wallis test for problem size 60; MINITAB output

Treatment	N	Median	Ave Rank	Z
1	9000	0.3159	13919.8	6.25
2	9000	0.3086	13433.4	-1.00
3	9000	0.3005	13148.3	-5.25
Overall	27000		13500.5	

H = 45.08 DF = 2 P = 0.000
H = 45.08 DF = 2 P = 0.000 (adjusted for ties)

Table C.3: Kruskal-Wallis test for problem size 80; MINITAB output

Appendix D

Statistical Analysis: Multi Plant Static Allocation Heuristics

Treatment	N	Median	Ave Rank	Z
2	1500	-0.04816	2266.7	0.59
3	1500	-0.05047	2304.2	1.96
4	1500	-0.05047	2180.6	-2.55
Overall	4500		2250.5	

H = 7.14 DF = 2 P = 0.028
H = 7.14 DF = 2 P = 0.028 (adjusted for ties)

Table D.1: Kruskal-Wallis test for problem size 40; MINITAB output

Treatment	N	Median	Ave Rank	Z
2	1500	-0.05460	2381.4	4.78
3	1500	-0.05106	2262.0	0.42
4	1500	-0.06219	2108.1	-5.20
Overall	4500		2250.5	

H = 33.37 DF = 2 P = 0.000
H = 33.37 DF = 2 P = 0.000 (adjusted for ties)

Table D.2: Kruskal-Wallis test for problem size 60; MINITAB output

Treatment	N	Median	Ave Rank	Z
2	1500	-0.04985	2361.7	4.06
3	1500	-0.05668	2310.5	2.19
4	1500	-0.05766	2079.3	-6.25
Overall	4500		2250.5	

H = 40.22	DF = 2	P = 0.000
H = 40.22	DF = 2	P = 0.000 (adjusted for ties)

Table D.3: Kruskal-Wallis test for problem size 80; MINITAB output

Appendix E

Statistical Analysis: Multi Plant Dynamic Allocation Heuristics

Treatment	N	Median	Ave Rank	Z
2	1500	-0.05047	1813.9	19.82
3	1500	-0.09009	1187.1	-19.82
Overall	3000		1500.5	

H = 392.81 DF = 1 P = 0.000
H = 392.90 DF = 1 P = 0.000 (adjusted for ties)

Table E.1: Kruskal-Wallis test for problem size 40; MINITAB output

Treatment	N	Median	Ave Rank	Z
2	1500	-0.06219	1482.8	-1.12
3	1500	-0.05921	1518.2	1.12
Overall	3000		1500.5	

H = 1.25 DF = 1 P = 0.264
H = 1.25 DF = 1 P = 0.264 (adjusted for ties)

Table E.2: Kruskal-Wallis test for problem size 60; MINITAB output

Treatment	N	Median	Ave Rank	Z
2	1500	-0.05766	1247.5	-16.00
3	1500	-0.03504	1753.5	16.00
Overall	3000		1500.5	

H = 255.97 DF = 1 P = 0.000
H = 255.97 DF = 1 P = 0.000 (adjusted for ties)

Table E.3: Kruskal-Wallis test for problem size 80; MINITAB output

Appendix F

Random Test Problems of the Single Plant Computational Study of Chapter 3

54	60	13	11	47	24	39	55	54	2	5	48	5	41	26	43	2	24	17	30

Table F.1: Demand 20.1

0	26	19	49	6	9	27	25	30	48	32	24	28	10	22	8	14	49	23	20	24
26	0	27	63	20	33	52	49	32	73	32	46	15	26	44	22	13	35	45	9	33
19	27	0	36	20	19	40	28	47	62	48	25	18	11	23	13	18	34	22	28	42
49	63	36	0	53	42	50	32	79	67	81	31	51	42	32	46	54	57	30	64	72
6	20	20	53	0	15	33	31	27	53	29	30	24	12	28	8	9	47	28	14	22
9	33	19	42	15	0	22	17	37	44	40	16	32	10	14	13	21	52	15	29	30
27	52	40	50	33	22	0	18	45	23	48	21	53	32	21	34	41	73	23	46	36
25	49	28	32	31	17	18	0	52	38	55	3	44	24	5	28	36	61	6	45	44
30	32	47	79	27	37	45	52	0	58	3	52	45	38	50	34	30	66	52	24	10
48	73	62	67	53	44	23	38	58	0	61	41	75	54	42	55	62	95	43	65	49
32	32	48	81	29	40	48	55	3	61	0	54	45	40	53	36	31	66	54	24	13
24	46	25	31	30	16	21	3	52	41	54	0	42	22	2	26	35	59	3	43	44
28	15	18	51	24	32	53	44	45	75	45	42	0	22	40	20	16	23	39	22	43
10	26	11	42	12	10	32	24	38	54	40	22	22	0	20	5	14	43	20	23	32
22	44	23	32	28	14	21	5	50	42	53	2	40	20	0	24	33	57	2	41	42
8	22	13	46	8	13	34	28	34	55	36	26	20	5	24	0	10	42	24	19	29
14	13	18	54	9	21	41	36	30	62	31	35	16	14	33	10	0	39	33	10	28
49	35	34	57	47	52	73	61	66	95	66	59	23	43	57	42	39	0	56	43	65
23	45	22	30	28	15	23	6	52	43	54	3	39	20	2	24	33	56	0	42	44
20	9	28	64	14	29	46	45	24	65	24	43	22	23	41	19	10	43	42	0	24
24	33	42	72	22	30	36	44	10	49	13	44	43	32	42	29	28	65	44	24	0

Table F.2:Distance Matrix 20.1

20	20	6	46	44	37	56	19	1	50	13	27	15	27	10	30	50	16	30	53

Table F.3:Demand 20.2

0	49	17	27	25	17	47	18	15	9	47	19	20	5	44	22	13	11	22	41	19
49	0	53	74	73	39	95	41	50	50	68	31	58	52	92	28	59	39	56	11	67
17	53	0	37	32	15	49	13	31	8	31	27	5	19	49	30	26	22	5	44	20
27	74	37	0	6	43	24	44	25	32	64	44	37	23	19	47	15	36	40	67	18
25	73	32	6	0	40	23	40	26	28	58	42	32	21	20	45	14	34	34	65	13
17	39	15	43	40	0	60	4	28	13	38	14	20	21	58	16	29	13	19	29	31
47	95	49	24	23	60	0	60	48	48	69	64	47	43	7	67	37	57	50	87	30
18	41	13	44	40	4	60	0	31	13	34	17	18	23	59	20	31	16	16	31	31
15	50	31	25	26	28	48	31	0	23	61	22	34	13	44	24	13	16	36	44	27
9	50	8	32	28	13	48	13	23	0	38	21	13	12	47	24	20	15	13	40	19
47	68	31	64	58	38	69	34	61	38	0	51	28	50	70	53	56	49	26	58	46
19	31	27	44	42	14	64	17	22	21	51	0	32	22	61	4	29	8	31	23	37
20	58	5	37	32	20	47	18	34	13	28	32	0	22	47	35	28	26	4	48	20
5	52	19	23	21	21	43	23	13	12	50	22	22	0	40	25	9	14	24	44	17
44	92	49	19	20	58	7	59	44	47	70	61	47	40	0	64	33	54	50	84	29
22	28	30	47	45	16	67	20	24	24	53	4	35	25	64	0	32	11	34	21	40
13	59	26	15	14	29	37	31	13	20	56	29	28	9	33	32	0	21	30	52	15
11	39	22	36	34	13	57	16	16	15	49	8	26	14	54	11	21	0	26	31	29
22	56	5	40	34	19	50	16	36	13	26	31	4	24	50	34	30	26	0	46	23
41	11	44	67	65	29	87	31	44	40	58	23	48	44	84	21	52	31	46	0	58
19	67	20	18	13	31	30	31	27	19	46	37	20	17	29	40	15	29	23	58	0

Table F.4:Distance Matrix 20.2

8	60	54	8	25	59	37	49	14	56	37	60	11	7	12	4	57	38	39	46

Table F.5:Demand 20.3

0	41	23	40	22	10	30	24	22	22	45	13	21	20	50	21	28	21	22	20	29
41	0	36	7	60	50	70	27	40	55	85	37	61	53	53	23	52	23	20	25	15
23	36	0	32	43	29	48	36	5	22	61	31	33	42	67	15	17	28	26	29	22
40	7	32	0	60	49	70	31	36	51	85	39	59	55	58	20	48	25	21	26	12
22	60	43	60	0	14	11	37	41	31	27	24	20	11	51	42	42	38	41	37	50
10	50	29	49	14	0	21	32	27	20	36	19	13	17	54	30	29	30	32	29	38
30	70	48	70	11	21	0	48	45	33	17	34	19	21	61	50	44	48	51	47	59
24	27	36	31	37	32	48	0	38	45	64	14	45	29	32	23	48	9	13	8	25
22	40	5	36	41	27	45	38	0	17	57	32	29	41	69	19	13	30	29	31	26
22	55	22	51	31	20	33	45	17	0	42	34	14	36	72	32	11	40	40	40	40
45	85	61	85	27	36	17	64	57	42	0	50	29	37	75	65	53	64	66	63	73
13	37	31	39	24	19	34	14	32	34	50	0	32	17	38	24	40	15	18	13	29
21	61	33	59	20	13	19	45	29	14	29	32	0	27	66	39	25	42	43	41	48
20	53	42	55	11	17	21	29	41	36	37	17	27	0	41	38	45	31	34	29	45
50	53	67	58	51	54	61	32	69	72	75	38	66	41	0	55	77	40	44	39	55
21	23	15	20	42	30	50	23	19	32	65	24	39	38	55	0	31	15	12	16	9
28	52	17	48	42	29	44	48	13	11	53	40	25	45	77	31	0	41	40	42	38
21	23	28	25	38	30	48	9	30	40	64	15	42	31	40	15	41	0	4	2	17
22	20	26	21	41	32	51	13	29	40	66	18	43	34	44	12	40	4	0	6	13
20	25	29	26	37	29	47	8	31	40	63	13	41	29	39	16	42	2	6	0	19
29	15	22	12	50	38	59	25	26	40	73	29	48	45	55	9	38	17	13	19	0

Table F.6:Distance Matrix 20.3

36	59	22	50	55	35	58	57	4	8	34	50	12	28	60	50	3	7	12	9

Table F.7:Demand 20.4

0	48	49	19	40	11	44	4	16	39	26	21	15	19	49	11	4	31	26	23	47
48	0	96	56	60	38	90	45	43	67	72	57	41	32	74	47	52	53	73	55	62
49	96	0	44	60	59	8	52	56	63	25	45	61	68	70	51	46	57	24	48	67
19	56	44	0	24	24	37	22	14	57	20	2	34	35	67	12	19	16	24	6	31
40	60	60	24	0	40	53	42	27	79	40	22	53	50	89	30	41	10	45	18	8
11	38	59	24	40	0	54	9	13	44	35	25	14	12	53	13	14	30	36	26	46
44	90	8	37	53	54	0	47	50	62	19	38	56	63	70	45	40	50	19	41	59
4	45	52	22	42	9	47	0	17	38	29	23	13	16	48	13	7	33	29	26	49
16	43	56	14	27	13	50	17	0	55	31	14	27	24	64	6	18	17	34	14	33
39	67	63	57	79	44	62	38	55	0	52	58	31	40	10	50	39	70	47	62	86
26	72	25	20	40	35	19	29	31	52	0	21	40	45	61	26	23	34	7	25	47
21	57	45	2	22	25	38	23	14	58	21	0	35	36	68	13	20	15	26	5	30
15	41	61	34	53	14	56	13	27	31	40	35	0	11	40	24	18	43	38	37	59
19	32	68	35	50	12	63	16	24	40	45	36	11	0	48	24	23	40	45	37	55
49	74	70	67	89	53	70	48	64	10	61	68	40	48	0	60	49	80	56	72	96
11	47	51	12	30	13	45	13	6	50	26	13	24	24	60	0	13	20	29	14	37
4	52	46	19	41	14	40	7	18	39	23	20	18	23	49	13	0	32	22	23	48
31	53	57	16	10	30	50	33	17	70	34	15	43	40	80	20	32	0	40	11	17
26	73	24	24	45	36	19	29	34	47	7	26	38	45	56	29	22	40	0	30	53
23	55	48	6	18	26	41	26	14	62	25	5	37	37	72	14	23	11	30	0	26
47	62	67	31	8	46	59	49	33	86	47	30	59	55	96	37	48	17	53	26	0

Table F.8:Distance Matrix 20.4

13	1	19	8	21	29	6	28	10	11	22	30	15	3	20	29	14	2	17	15

Table F.9:Demand 20.5

0	18	47	21	23	23	10	20	13	25	11	47	20	20	45	11	24	12	8	21	48
18	0	38	29	34	7	27	38	26	34	9	62	29	13	57	13	20	13	18	37	60
47	38	0	65	40	32	48	58	43	37	40	66	37	50	91	48	58	49	40	53	94
21	29	65	0	42	35	27	31	32	45	25	60	40	19	29	17	16	16	28	35	32
23	34	40	42	0	34	15	20	11	5	27	30	6	41	61	33	46	34	18	14	63
23	7	32	35	34	0	31	41	28	34	13	63	29	19	64	19	26	20	21	40	66
10	27	48	27	15	31	0	12	6	19	19	37	14	30	47	21	33	22	11	11	49
20	38	58	31	20	41	12	0	16	24	30	30	22	39	43	30	40	30	22	7	45
13	26	43	32	11	28	6	16	0	13	19	36	9	31	52	23	35	24	9	12	55
25	34	37	45	5	34	19	24	13	0	28	32	6	42	65	34	47	35	19	18	67
11	9	40	25	27	13	19	30	19	28	0	54	23	14	52	9	21	10	10	29	55
47	62	66	60	30	63	37	30	36	32	54	0	35	66	67	57	69	58	44	27	69
20	29	37	40	6	29	14	22	9	6	23	35	0	36	61	29	42	30	13	17	63
20	13	50	19	41	19	30	39	31	42	14	66	36	0	48	9	8	9	24	40	50
45	57	91	29	61	64	47	43	52	65	52	67	61	48	0	45	43	44	52	49	3
11	13	48	17	33	19	21	30	23	34	9	57	29	9	45	0	13	1	16	31	48
24	20	58	16	46	26	33	40	35	47	21	69	42	8	43	13	0	13	29	43	45
12	13	49	16	34	20	22	30	24	35	10	58	30	9	44	1	13	0	17	32	47
8	18	40	28	18	21	11	22	9	19	10	44	13	24	52	16	29	17	0	20	55
21	37	53	35	14	40	11	7	12	18	29	27	17	40	49	31	43	32	20	0	51
48	60	94	32	63	66	49	45	55	67	55	69	63	50	3	48	45	47	55	51	0

Table F.10:Distance Matrix 20.5

47	20	21	18	45	26	48	26	7	11	6	10	27	36	47	55	40	40	29	29	

Table F.11:Demand 20.6:

0	12	10	20	22	24	15	7	20	47	5	26	12	48	7	9	48	22	8	14	47
12	0	15	31	10	34	13	17	30	44	13	15	15	50	17	19	52	19	19	24	58
10	15	0	24	21	21	23	16	29	56	15	29	2	38	8	19	39	13	10	10	52
20	31	24	0	41	17	29	15	12	54	19	45	26	51	17	16	49	36	14	18	29
22	10	21	41	0	41	21	27	40	48	23	9	21	51	26	29	55	19	28	31	68
24	34	21	17	41	0	37	23	28	67	26	48	22	36	17	26	33	30	16	11	40
15	13	23	29	21	37	0	15	24	33	12	20	25	61	21	14	62	31	22	29	52
7	17	16	15	27	23	15	0	14	45	5	31	18	51	9	4	51	28	9	16	41
20	30	29	12	40	28	24	14	0	43	17	42	31	61	21	12	59	41	20	25	29
47	44	56	54	48	67	33	45	43	0	43	42	57	93	53	41	94	63	53	60	64
5	13	15	19	23	26	12	5	17	43	0	27	17	52	10	6	52	26	11	18	45
26	15	29	45	9	48	20	31	42	42	27	0	29	60	32	31	63	28	34	38	71
12	15	2	26	21	22	25	18	31	57	17	29	0	37	10	21	38	11	12	11	54
48	50	38	51	51	36	61	51	61	93	52	60	37	0	42	55	8	33	43	36	75
7	17	8	17	26	17	21	9	21	53	10	32	10	42	0	13	42	20	3	8	45
9	19	19	16	29	26	14	4	12	41	6	31	21	55	13	0	54	31	13	20	40
48	52	39	49	55	33	62	51	59	94	52	63	38	8	42	54	0	36	42	35	70
22	19	13	36	19	30	31	28	41	63	26	28	11	33	20	31	36	0	23	20	64
8	19	10	14	28	16	22	9	20	53	11	34	12	43	3	13	42	23	0	8	43
14	24	10	18	31	11	29	16	25	60	18	38	11	36	8	20	35	20	8	0	45
47	58	52	29	68	40	52	41	29	64	45	71	54	75	45	40	70	64	43	45	0

Table F.12:Distance Matrix 20.6

9	49	52	25	41	37	54	34	9	14	58	27	32	10	4	1	4	50	34	50

Table F.13:Demand 20.7

0	50	15	19	20	25	4	13	45	45	28	23	8	46	15	14	16	24	20	25	21
50	0	39	38	40	61	50	60	74	64	57	28	56	76	64	56	35	58	69	61	63
15	39	0	5	8	24	13	27	42	38	38	15	22	43	30	28	9	22	32	37	25
19	38	5	0	4	24	16	31	40	34	42	16	26	41	33	32	13	21	34	41	25
20	40	8	4	0	21	18	33	36	31	45	20	28	38	34	34	16	18	34	44	24
25	61	24	24	21	0	22	32	20	24	52	39	29	21	30	37	33	4	24	48	8
4	50	13	16	18	22	0	15	41	42	32	23	11	42	17	18	16	20	20	29	18
13	60	27	31	33	32	15	0	52	55	22	33	6	52	6	8	27	32	16	17	26
45	74	42	40	36	20	41	52	0	15	72	55	49	3	49	57	50	22	41	68	26
45	64	38	34	31	24	42	55	15	0	73	50	51	17	54	59	46	23	47	70	31
28	57	38	42	45	52	32	22	72	73	0	34	24	73	27	16	32	51	37	8	47
23	28	15	16	20	39	23	33	55	50	34	0	28	57	37	30	7	36	42	36	38
8	56	22	26	28	29	11	6	49	51	24	28	0	49	9	9	22	29	17	20	23
46	76	43	41	38	21	42	52	3	17	73	57	49	0	50	58	52	23	41	68	27
15	64	30	33	34	30	17	6	49	54	27	37	9	50	0	12	30	31	11	21	24
14	56	28	32	34	37	18	8	57	59	16	30	9	58	12	0	25	37	23	11	32
16	35	9	13	16	33	16	27	50	46	32	7	22	52	30	25	0	30	35	33	32
24	58	22	21	18	4	20	32	22	23	51	36	29	23	31	37	30	0	25	48	10
20	69	32	34	34	24	20	16	41	47	37	42	17	41	11	23	35	25	0	31	17
25	61	37	41	44	48	29	17	68	70	8	36	20	68	21	11	33	48	31	0	42
21	63	25	25	24	8	18	26	26	31	47	38	23	27	24	32	32	10	17	42	0

Table F.14:Distance Matrix 20.7

44	7	58	20	36	52	41	7	6	16	54	52	37	7	15	9	24	54	12	7

Table F.15:Demand 20.8

0	29	11	28	43	42	5	18	48	22	11	37	23	10	21	31	27	26	19	20	4
29	0	37	34	71	51	34	21	58	11	35	8	51	25	42	59	6	31	11	28	32
11	37	0	25	37	34	8	22	40	32	17	45	16	21	11	25	37	24	29	30	10
28	34	25	0	60	18	29	15	25	35	38	40	39	35	19	48	37	4	31	44	30
43	71	37	60	0	63	38	58	66	63	37	78	22	47	42	13	68	59	61	51	39
42	51	34	18	63	0	41	32	7	53	50	57	44	50	24	52	54	21	49	60	42
5	34	8	29	38	41	0	22	47	27	10	42	18	14	19	26	32	27	24	23	2
18	21	22	15	58	32	22	0	39	21	29	27	37	22	22	46	23	12	17	31	22
48	58	40	25	66	7	47	39	0	59	56	63	49	56	30	57	61	28	55	67	49
22	11	32	35	63	53	27	21	59	0	27	17	45	16	39	52	6	32	5	18	25
11	35	17	38	37	50	10	29	56	27	0	43	21	11	28	26	33	36	25	17	9
37	8	45	40	78	57	42	27	63	17	43	0	59	32	49	67	11	37	18	33	40
23	51	16	39	22	44	18	37	49	45	21	59	0	30	22	10	50	38	42	37	20
10	25	21	35	47	50	14	22	56	16	11	32	30	0	30	36	22	32	15	11	12
21	42	11	19	42	24	19	22	30	39	28	49	22	30	0	31	42	19	35	40	20
31	59	25	48	13	52	26	46	57	52	26	67	10	36	31	0	57	48	49	42	27
27	6	37	37	68	54	32	23	61	6	33	11	50	22	42	57	0	33	9	23	30
26	31	24	4	59	21	27	12	28	32	36	37	38	32	19	48	33	0	28	42	28
19	11	29	31	61	49	24	17	55	5	25	18	42	15	35	49	9	28	0	19	23
20	28	30	44	51	60	23	31	67	18	17	33	37	11	40	42	23	42	19	0	21
4	32	10	30	39	42	2	22	49	25	9	40	20	12	20	27	30	28	23	21	0

Table F.16:Distance Matrix 20.8

40	43	53	9	59	23	12	27	57	13	57	37	24	36	49	60	50	56	42	36

Table F.17:Demand 20.9

0	19	38	15	21	23	21	34	37	22	7	25	18	43	20	13	12	29	36	26	48
19	0	33	9	39	41	33	51	33	16	14	15	29	52	20	29	19	31	53	44	59
38	33	0	41	53	57	58	53	4	19	40	48	29	80	51	39	47	14	53	53	85
15	9	41	0	34	35	25	49	40	22	9	10	30	44	11	28	11	36	51	40	51
21	39	53	34	0	5	19	22	51	40	25	42	26	37	32	15	25	41	23	9	37
23	41	57	35	5	0	18	25	55	43	27	43	30	34	33	19	26	45	26	11	33
21	33	58	25	19	18	0	41	57	41	20	29	36	23	18	26	15	49	42	28	27
34	51	53	49	22	25	41	0	50	46	41	59	26	58	51	23	44	39	2	14	55
37	33	4	40	51	55	57	50	0	19	39	48	26	79	51	36	46	11	51	51	83
22	16	19	22	40	43	41	46	19	0	22	30	20	63	33	27	29	16	47	43	68
7	14	40	9	25	27	20	41	39	22	0	18	24	41	13	19	7	33	42	32	47
25	15	48	10	42	43	29	59	48	30	18	0	40	44	12	37	17	45	60	49	52
18	29	29	30	26	30	36	26	26	20	24	40	0	58	37	11	30	16	28	25	60
43	52	80	44	37	34	23	58	79	63	41	44	58	0	34	48	35	71	59	45	11
20	20	51	11	32	33	18	51	51	33	13	12	37	34	0	31	8	45	53	40	42
13	29	39	28	15	19	26	23	36	27	19	37	11	48	31	0	24	27	24	17	50
12	19	47	11	25	26	15	44	46	29	7	17	30	35	8	24	0	39	45	33	41
29	31	14	36	41	45	49	39	11	16	33	45	16	71	45	27	39	0	41	41	75
36	53	53	51	23	26	42	2	51	47	42	60	28	59	53	24	45	41	0	15	56
26	44	53	40	9	11	28	14	51	43	32	49	25	45	40	17	33	41	15	0	43
48	59	85	51	37	33	27	55	83	68	47	52	60	11	42	50	41	75	56	43	0

Table F.18: Distance Matrix 20.9

29	60	53	3	9	37	59	45	53	45	53	23	7	33	60	53	1	46	6	31

Table F.19:Demand 20.10

0	24	5	20	12	12	25	46	39	22	5	20	32	28	50	20	47	16	20	39	20
24	0	26	39	22	35	36	39	19	22	21	5	47	45	71	43	42	36	34	19	35
5	26	0	15	17	10	20	43	43	19	6	22	36	31	46	21	44	11	24	42	24
20	39	15	0	32	13	14	44	57	25	21	35	45	39	33	25	43	5	35	57	35
12	22	17	32	0	22	36	54	32	30	14	20	26	24	59	24	55	28	13	31	14
12	35	10	13	22	0	24	51	51	28	15	31	32	27	39	14	51	10	23	50	23
25	36	20	14	36	24	0	31	54	16	23	32	55	50	42	37	30	15	43	54	44
46	39	43	44	54	51	31	0	53	25	42	37	78	73	71	64	4	44	65	54	65
39	19	43	57	32	51	54	53	0	40	37	23	53	53	88	56	56	53	42	1	43
22	22	19	25	30	28	16	25	40	0	18	18	53	49	56	40	26	23	40	40	41
5	21	6	21	14	15	23	42	37	18	0	17	36	32	51	25	43	17	23	37	24
20	5	22	35	20	31	32	37	23	18	17	0	46	43	67	40	39	32	33	23	34
32	47	36	45	26	32	55	78	53	53	36	46	0	7	60	22	79	42	14	52	13
28	45	31	39	24	27	50	73	53	49	32	43	7	0	54	16	74	36	11	52	10
50	71	46	33	59	39	42	71	88	56	51	67	60	54	0	40	69	36	57	88	56
20	43	21	25	24	14	37	64	56	40	25	40	22	16	40	0	64	22	17	55	17
47	42	44	43	55	51	30	4	56	26	43	39	79	74	69	64	0	44	66	56	66
16	36	11	5	28	10	15	44	53	23	17	32	42	36	36	22	44	0	32	53	32
20	34	24	35	13	23	43	65	42	40	23	33	14	11	57	17	66	32	0	41	1
39	19	42	57	31	50	54	54	1	40	37	23	52	52	88	55	56	53	41	0	42
20	35	24	35	14	23	44	65	43	41	24	34	13	10	56	17	66	32	1	42	0

Table F.20:Distance Matrix 20.1

28	48	14	23	38	59	17	1	1	1	47	11	26	31	56	37	32	26	58	49	13	2	53	8	7	19	4	25	19	11

Table F.21:Demand 30.1

0	25	26	6	49	23	15	22	22	42	9	14	24	47	17	47	16	25	44	5	50	22	25	16	50	40	17	49	19	27	23
25	0	47	21	35	47	39	30	43	60	17	39	31	69	32	30	24	22	29	26	38	45	49	12	65	34	33	63	40	49	15
26	47	0	28	74	25	21	25	32	18	32	19	24	46	37	58	26	50	55	28	58	27	7	36	28	65	37	28	31	2	38
6	21	28	0	48	29	20	19	28	43	5	19	20	53	21	41	12	25	38	10	45	27	29	10	49	40	22	49	25	30	18
49	35	74	48	0	62	58	63	54	90	43	58	64	76	41	60	56	24	60	46	69	59	73	44	96	14	42	95	52	75	50
23	47	25	29	62	0	9	39	10	41	30	10	40	25	21	68	35	39	66	21	71	4	19	38	52	50	20	52	10	25	45
15	39	21	20	58	9	0	31	13	38	23	2	32	34	18	60	27	34	57	14	63	9	17	30	48	47	18	48	11	22	37
22	30	25	19	63	39	31	0	42	33	23	30	2	64	39	34	8	43	31	27	34	40	29	20	35	58	39	34	40	26	16
22	43	32	28	54	10	13	42	0	49	28	15	43	27	14	68	37	32	65	18	72	6	27	37	60	42	13	60	3	33	45
42	60	18	43	90	41	38	33	49	0	48	36	32	59	54	64	37	67	61	45	62	44	22	49	13	81	54	14	48	17	48
9	17	32	5	43	30	23	23	28	48	0	22	24	54	19	41	15	21	38	10	46	29	33	9	54	36	20	54	25	34	18
14	39	19	19	58	10	2	30	15	36	22	0	30	35	19	59	25	35	56	14	61	11	15	29	46	48	19	46	13	20	35
24	31	24	20	64	40	32	2	43	32	24	30	0	65	40	34	9	44	31	29	34	40	29	21	34	59	41	33	41	26	18
47	69	46	53	76	25	34	64	27	59	54	35	65	0	39	93	60	56	90	44	96	26	40	62	71	63	38	72	29	46	70
17	32	37	21	41	21	18	39	14	54	19	19	40	39	0	59	32	18	56	12	64	18	34	27	63	30	2	63	11	38	36
47	30	58	41	60	68	60	34	68	64	41	59	34	93	59	0	34	52	4	50	9	68	62	32	63	63	60	61	65	60	24
16	24	26	12	56	35	27	8	37	37	15	25	9	60	32	34	0	35	31	21	37	35	29	13	42	50	33	40	34	28	13
25	22	50	25	24	39	34	43	32	67	21	35	44	56	18	52	35	0	50	22	59	36	49	25	74	15	20	73	29	52	34
44	29	55	38	60	66	57	31	65	61	38	56	31	90	56	4	31	50	0	48	10	65	59	30	60	61	58	58	63	57	21
5	26	28	10	46	21	14	27	18	45	10	14	29	44	12	50	21	22	48	0	55	19	27	19	54	37	12	53	15	30	27
50	38	58	45	69	71	63	34	72	62	46	61	34	96	64	9	37	59	10	55	0	71	63	37	59	71	65	57	69	60	28
22	45	27	27	59	4	9	40	6	44	29	11	40	26	18	68	35	36	65	19	71	0	22	37	55	47	17	55	7	28	44
25	49	7	29	73	19	17	29	27	22	33	15	29	40	34	62	29	49	59	27	63	22	0	38	33	63	34	34	27	6	41
16	12	36	10	44	38	30	20	37	49	9	29	21	62	27	32	13	25	30	19	37	37	38	0	54	39	29	53	34	38	10
50	65	28	49	96	52	48	35	60	13	54	46	34	71	63	63	42	74	60	54	59	55	33	54	0	89	64	3	58	27	51
40	34	65	40	14	50	47	58	42	81	36	48	59	63	30	63	50	15	61	37	71	47	63	39	89	0	31	88	40	66	47
17	33	37	22	42	20	18	39	13	54	20	19	41	38	2	60	33	20	58	12	65	17	34	29	64	31	0	64	11	38	38
49	63	28	49	95	52	48	34	60	14	54	46	33	72	63	61	40	73	58	53	57	55	34	53	3	88	64	0	59	28	50
19	40	31	25	52	10	11	40	3	48	25	13	41	29	11	65	34	29	63	15	69	7	27	34	58	40	11	59	0	32	42
27	49	2	30	75	25	22	26	33	17	34	20	26	46	38	60	28	52	57	30	60	28	6	38	27	66	38	28	32	0	40
23	15	38	18	50	45	37	16	45	48	18	35	18	70	36	24	13	34	21	27	28	44	41	10	51	47	38	50	42	40	0

Table F.22:Distance Matrix 30.1

59	42	9	13	3	45	35	38	49	30	54	35	56	4	41	21	24	32	51	43	23	49	58	3	23	18	25	27	31	55

Table F.23:Demand 30.2

0	20	10	14	42	8	29	18	31	29	14	50	14	10	18	14	25	38	20	19	26	44	44	24	30	18	14	50	22	44	25
20	0	29	10	38	14	11	5	29	18	32	62	31	29	30	22	12	35	14	38	45	63	56	44	12	38	17	48	40	39	7
10	29	0	22	49	16	38	26	37	35	5	44	13	0	16	20	34	44	28	11	17	37	39	15	38	10	19	56	13	50	34
14	10	22	0	33	10	21	12	22	26	27	61	22	22	29	13	12	30	8	33	38	54	55	37	22	30	18	43	35	34	13
42	38	49	33	0	43	46	43	12	56	53	91	39	49	60	29	27	5	26	57	58	63	86	58	47	51	50	11	60	2	35
8	14	16	10	43	0	22	11	32	22	19	51	21	16	19	18	21	39	18	25	33	51	45	31	23	25	9	52	27	44	19
29	11	38	21	46	22	0	12	38	13	40	65	42	38	36	33	19	44	24	46	55	73	59	52	1	47	22	56	48	46	11
18	5	26	12	43	11	12	0	33	15	29	57	30	26	26	24	17	39	18	35	43	62	51	41	13	35	12	52	36	43	12
31	29	37	22	12	32	38	33	0	46	42	80	29	37	49	18	19	8	15	47	48	56	75	48	39	41	39	21	49	13	27
29	18	35	26	56	22	13	15	46	0	37	55	43	35	28	37	29	53	32	42	52	72	49	49	12	45	17	65	43	56	22
14	32	5	27	53	19	40	29	42	37	0	39	17	5	14	24	38	49	33	7	15	37	35	13	41	10	20	60	9	55	38
50	62	44	61	91	51	65	57	80	55	39	0	55	44	33	63	72	87	68	37	42	60	7	40	65	45	46	99	34	93	68
14	31	13	22	39	21	42	30	29	43	17	55	0	13	28	13	31	35	24	20	20	33	51	20	42	13	28	45	22	41	35
10	29	0	22	49	16	38	26	37	35	5	44	13	0	16	20	34	44	28	11	17	37	39	15	38	10	19	56	13	50	34
18	30	16	29	60	19	36	26	49	28	14	33	28	16	0	32	39	56	36	17	27	49	27	24	36	23	15	68	16	61	37
14	22	20	13	29	18	33	24	18	37	24	63	13	20	32	0	20	25	13	29	32	44	58	31	34	24	26	37	32	31	25
25	12	34	12	27	21	19	17	19	29	38	72	31	34	39	20	0	25	8	44	49	63	66	48	20	41	27	37	46	28	8
38	35	44	30	5	39	44	39	8	53	49	87	35	44	56	25	25	0	22	53	54	60	82	54	45	47	47	13	56	7	33
20	14	28	8	26	18	24	18	15	32	33	68	24	28	36	13	8	22	0	38	43	56	63	42	25	35	25	35	41	27	14
19	38	11	33	57	25	46	35	47	42	7	37	20	11	17	29	44	53	38	0	11	33	33	8	47	9	26	64	3	59	44
26	45	17	38	58	33	55	43	48	52	15	42	20	17	27	32	49	54	43	11	0	22	40	4	55	9	35	63	12	60	50
44	63	37	54	63	51	73	62	56	72	37	60	33	37	49	44	63	60	56	33	22	0	58	26	74	28	56	65	34	65	67
44	56	39	55	86	45	59	51	75	49	35	7	51	39	27	58	66	82	63	33	40	58	0	37	59	41	40	94	30	88	62
24	44	15	37	58	31	52	41	48	49	13	40	20	15	24	31	48	54	42	8	4	26	37	0	53	8	33	64	9	60	49
30	12	38	22	47	23	1	13	39	12	41	65	42	38	36	34	20	45	25	47	55	74	59	53	0	48	22	57	48	47	12
18	38	10	30	51	25	47	35	41	45	10	45	13	10	23	24	41	47	35	9	9	28	41	8	48	0	29	57	12	53	43
14	17	19	18	50	9	22	12	39	17	20	46	28	19	15	26	27	47	25	26	35	56	40	33	22	29	0	60	27	52	23
50	48	56	43	11	52	56	52	21	65	60	99	45	56	68	37	37	13	35	64	63	65	94	64	57	57	60	0	67	11	45
22	40	13	35	60	27	48	36	49	43	9	34	22	13	16	32	46	56	41	3	12	34	30	9	48	12	27	67	0	62	46
44	39	50	34	2	44	46	43	13	56	55	93	41	50	61	31	28	7	27	59	60	65	88	60	47	53	52	11	62	0	35
25	7	34	13	35	19	11	12	27	22	38	68	35	34	37	25	8	33	14	44	50	67	62	49	12	43	23	45	46	35	0

Table F.24:Distance Matrix 30.2

23	12	30	22	58	23	52	4	43	40	18	6	34	24	20	1	15	44	14	9	9	56	21	40	6	17	26	25	30	58

Table F.25:Demand 30.3

0	14	21	19	17	20	12	42	44	50	30	5	47	42	9	14	6	16	8	5	6	16	25	29	19	43	10	25	26	29	19
14	0	34	31	19	10	20	54	57	63	28	18	44	55	20	3	9	9	8	12	17	29	38	42	19	31	17	31	25	27	15
21	34	0	14	33	37	25	21	24	31	37	18	52	22	15	34	25	36	27	25	21	8	13	9	29	63	20	23	33	37	38
19	31	14	0	24	38	15	29	32	34	44	14	61	27	19	33	25	30	27	20	15	8	8	22	34	57	24	33	41	44	29
17	19	33	24	0	29	9	51	55	57	45	16	61	50	26	22	20	12	21	13	13	26	31	42	34	36	26	42	41	44	8
20	10	37	38	29	0	28	57	59	67	20	25	35	58	22	8	14	19	12	20	25	34	44	44	13	33	17	27	18	19	25
12	20	25	15	9	28	0	43	47	49	41	9	58	42	19	22	17	16	18	9	6	17	23	33	30	43	21	35	37	40	15
42	54	21	29	51	57	43	0	4	13	54	38	67	5	36	55	46	56	48	45	40	27	21	14	48	83	40	38	51	54	57
44	57	24	32	55	59	47	4	0	13	55	41	67	8	38	57	49	59	50	48	44	30	25	16	50	86	43	39	52	55	60
50	63	31	34	57	67	49	13	13	0	65	46	78	10	46	64	55	64	57	53	48	35	27	26	59	91	51	50	63	65	63
30	28	37	44	45	20	41	54	55	65	0	34	18	56	25	26	25	37	24	33	35	38	47	40	11	52	21	16	4	1	42
5	18	18	14	16	25	9	38	41	46	34	0	51	38	11	19	11	18	13	8	3	12	21	27	23	46	13	27	30	33	20
47	44	52	61	61	35	58	67	67	78	18	51	0	70	42	41	42	53	41	50	53	54	63	54	28	62	38	30	21	18	58
42	55	22	27	50	58	42	5	8	10	56	38	70	0	37	55	47	56	48	45	40	27	20	17	50	83	42	41	53	56	56
9	20	15	19	26	22	19	36	38	46	25	11	42	37	0	20	11	24	13	14	13	14	23	22	16	50	6	17	22	25	28
14	3	34	33	22	8	22	55	57	64	26	19	41	55	20	0	9	12	8	13	19	30	39	42	17	31	16	29	23	25	18
6	9	25	25	20	14	17	46	49	55	25	11	42	47	11	9	0	14	2	8	12	21	31	33	15	39	9	24	22	25	19
16	9	36	30	12	19	16	56	59	64	37	18	53	56	24	12	14	0	15	11	16	30	38	44	27	28	23	38	34	36	6
8	8	27	27	21	12	18	48	50	57	24	13	41	48	13	8	2	15	0	10	14	23	33	34	14	38	9	23	20	23	19
5	12	25	20	13	20	9	45	48	53	33	8	50	45	14	13	8	11	10	0	6	19	27	34	22	39	14	30	29	32	14
6	17	21	15	13	25	6	40	44	48	35	3	53	40	13	19	12	16	14	6	0	14	22	30	25	44	15	30	32	35	17
16	29	8	8	26	34	17	27	30	35	38	12	54	27	14	30	21	30	23	19	14	0	11	17	29	57	18	26	34	38	31
25	38	13	8	31	44	23	21	25	27	47	21	63	20	23	39	31	38	33	27	22	11	0	17	39	65	29	35	44	47	37
29	42	9	22	42	44	33	14	16	26	40	27	54	17	22	42	33	44	34	34	30	17	17	0	34	71	27	25	37	40	46
19	19	29	34	34	13	30	48	50	59	11	23	28	50	16	17	15	27	14	22	25	29	39	34	0	46	11	14	8	10	32
43	31	63	57	36	33	43	83	86	91	52	46	62	83	50	31	39	28	38	39	44	57	65	71	46	0	47	59	50	51	29
10	17	20	24	26	17	21	40	43	51	21	13	38	42	6	16	9	23	9	14	15	18	29	27	11	47	0	16	17	21	27
25	31	23	33	42	27	35	38	39	50	16	27	30	41	17	29	24	38	23	30	30	26	35	25	14	59	16	0	14	17	42
26	25	33	41	41	18	37	51	52	63	4	30	21	53	22	23	22	34	20	29	32	34	44	37	8	50	17	14	0	4	39
29	27	37	44	44	19	40	54	55	65	1	33	18	56	25	25	25	36	23	32	35	38	47	40	10	51	21	17	4	0	41
19	15	38	29	8	25	15	57	60	63	42	20	58	56	28	18	19	6	19	14	17	31	37	46	32	29	27	42	39	41	0

Table F.26:Distance Matrix 30.3

28	18	48	29	55	7	48	34	51	60	30	32	58	57	23	2	20	52	39	31	56	60	43	53	29	46	57	23	4	30

Table F.27:Demand 30.4

0	49	12	32	43	11	31	50	25	49	18	22	40	43	25	18	28	16	17	45	26	22	44	13	20	17	18	46	49	21	21
49	0	38	52	76	58	79	1	62	66	62	33	89	73	52	50	77	42	40	9	33	65	17	46	65	43	38	94	21	35	32
12	38	0	32	47	21	42	39	32	51	27	13	51	46	25	22	40	11	14	33	17	31	33	15	29	14	10	57	39	14	13
32	52	32	0	73	28	43	52	18	19	26	43	52	74	55	14	47	43	19	52	47	26	56	20	50	45	42	55	63	22	25
43	76	47	73	0	47	51	77	63	90	53	44	54	5	25	60	41	37	58	68	44	56	62	55	26	35	41	60	63	60	59
11	58	21	28	47	0	22	58	17	44	7	32	32	49	34	15	22	26	20	54	36	11	54	14	22	28	28	37	59	25	26
31	79	42	43	51	22	0	80	26	52	19	52	10	54	48	33	10	44	41	75	55	18	74	34	29	45	47	15	80	46	48
50	1	39	52	77	58	80	0	63	66	63	34	89	74	53	51	78	43	41	10	34	66	17	46	66	44	39	95	22	35	33
25	62	32	18	63	17	26	63	0	29	11	44	35	65	50	12	31	40	22	60	48	9	62	18	38	42	41	38	69	28	31
49	66	51	19	90	44	52	66	29	0	39	62	60	91	73	31	59	61	37	68	65	37	73	38	66	64	60	61	80	40	42
18	62	27	26	53	7	19	63	11	39	0	39	28	55	41	15	22	33	23	59	43	4	59	17	28	35	35	33	65	29	30
22	33	13	43	44	32	52	34	44	62	39	0	61	42	20	34	48	9	25	26	4	43	23	26	33	11	5	67	28	23	20
40	89	51	52	54	32	10	89	35	60	28	61	0	58	54	43	14	53	51	84	64	27	83	44	34	53	56	7	88	56	57
43	73	46	74	5	49	54	74	65	91	55	42	58	0	23	61	45	36	58	65	41	58	59	55	28	33	39	64	59	59	58
25	52	25	55	25	34	48	53	50	73	41	20	54	23	0	43	40	14	38	44	19	45	39	36	21	11	17	61	41	38	36
18	50	22	14	60	15	33	51	12	31	15	34	43	61	43	0	35	31	11	48	38	16	50	8	36	33	31	47	57	16	19
28	77	40	47	41	22	10	78	31	59	22	48	14	45	40	35	0	39	41	72	51	23	71	35	20	40	43	21	75	46	47
16	42	11	43	37	26	44	43	40	61	33	9	53	36	14	31	39	0	25	35	12	37	32	24	24	3	5	59	37	25	23
17	40	14	19	58	20	41	41	22	37	23	25	51	58	38	11	41	25	0	38	29	25	40	7	37	28	24	55	47	6	9
45	9	33	52	68	54	75	10	60	68	59	26	84	65	44	48	72	35	38	0	25	62	8	43	58	36	31	90	14	33	30
26	33	17	47	44	36	55	34	48	65	43	4	64	41	19	38	51	12	29	25	0	46	21	30	35	12	9	70	25	26	24
22	65	31	26	56	11	18	66	9	37	4	43	27	58	45	16	23	37	25	62	46	0	63	20	31	39	39	31	69	31	33
44	17	33	56	62	54	74	17	62	73	59	23	83	59	39	50	71	32	40	8	21	63	0	44	55	33	28	89	7	35	33
13	46	15	20	55	14	34	46	18	38	17	26	44	55	36	8	35	24	7	43	30	20	44	0	32	26	24	49	51	12	14
20	65	29	50	26	22	29	66	38	66	28	33	34	28	21	36	20	24	37	58	35	31	55	32	0	23	28	40	59	40	40
17	43	14	45	35	28	45	44	42	64	35	11	53	33	11	33	40	3	28	36	12	39	33	26	23	0	7	59	37	27	25
18	38	10	42	41	28	47	39	41	60	35	5	56	39	17	31	43	5	24	31	9	39	28	24	28	7	0	62	33	23	20
46	94	57	55	60	37	15	95	38	61	33	67	7	64	61	47	21	59	55	90	70	31	89	49	40	59	62	0	94	61	62
49	21	39	63	63	59	80	22	69	80	65	28	88	59	41	57	75	37	47	14	25	69	7	51	59	37	33	94	0	42	39
21	35	14	22	60	25	46	35	28	40	29	23	56	59	38	16	46	25	6	33	26	31	35	12	40	27	23	61	42	0	3
21	32	13	25	59	26	48	33	31	42	30	20	57	58	36	19	47	23	9	30	24	33	33	14	40	25	20	62	39	3	0

Table F.28:Distance Matrix 30.4

51	35	19	57	17	41	52	40	31	2	45	2	52	11	43	26	34	48	27	49	27	8	42	49	45	30	58	58	33	23

Table F.29:Demand 30.5

0	24	44	12	16	20	43	22	24	14	32	18	5	18	15	20	24	46	17	8	18	21	33	25	7	26	33	22	4	49	18
24	0	33	34	40	30	32	7	25	29	21	41	26	18	36	33	30	66	39	30	15	36	53	24	30	40	23	34	24	66	41
44	33	0	56	57	60	2	28	22	56	53	56	49	27	59	62	61	66	60	47	46	40	57	22	50	69	55	34	42	93	58
12	34	56	0	9	18	55	33	35	10	36	14	9	30	3	14	21	45	6	11	24	27	32	36	7	18	37	30	15	38	10
16	40	57	9	0	26	56	38	36	19	44	6	15	32	9	22	30	37	8	11	32	23	25	37	11	24	45	28	17	40	2
20	30	60	18	26	0	58	32	43	8	23	31	17	35	17	6	4	62	20	25	16	41	49	43	20	12	23	42	24	38	28
43	32	2	55	56	58	0	27	21	54	51	55	47	25	57	60	60	65	59	45	45	38	56	20	48	67	53	33	40	92	56
22	7	28	33	38	32	27	0	18	30	27	39	25	12	36	35	34	61	38	27	18	31	48	18	28	42	29	28	21	68	39
24	25	22	35	36	43	21	18	0	37	43	34	29	8	38	43	45	47	39	25	32	18	37	1	29	50	45	14	21	73	36
14	29	56	10	19	8	54	30	37	0	27	23	10	30	11	7	12	55	14	18	17	34	42	38	13	13	28	36	18	39	20
32	21	53	36	44	23	51	27	43	27	0	48	30	36	37	28	21	78	40	39	14	50	64	43	35	34	2	50	35	58	46
18	41	56	14	6	31	55	39	34	23	48	0	18	31	14	27	34	32	13	12	35	20	19	35	13	29	49	25	18	44	4
5	26	49	9	15	17	47	25	29	10	30	18	0	22	11	16	20	48	14	9	17	25	35	29	5	22	32	27	9	45	16
18	18	27	30	32	35	25	12	8	30	36	31	22	0	33	36	37	50	34	21	24	20	38	9	24	43	38	17	16	67	32
15	36	59	3	9	17	57	36	38	11	37	14	11	33	0	14	21	46	4	14	26	29	33	39	10	16	38	33	17	35	11
20	33	62	14	22	6	60	35	43	7	28	27	16	36	14	0	9	59	16	24	20	39	46	44	19	8	28	42	24	34	24
24	30	61	21	30	4	60	34	45	12	21	34	20	37	21	9	0	66	24	29	16	44	53	45	24	13	21	46	28	38	31
46	66	66	45	37	62	65	61	47	55	78	32	48	50	46	59	66	0	44	39	64	30	14	48	43	60	79	34	44	69	36
17	39	60	6	8	20	59	38	39	14	40	13	14	34	4	16	24	44	0	15	29	29	32	40	11	17	41	33	19	34	9
8	30	47	11	11	25	45	27	25	18	39	12	9	21	14	24	29	39	15	0	25	17	26	26	5	28	40	19	6	49	12
18	15	46	24	32	16	45	18	32	17	14	35	17	24	26	20	16	64	29	25	0	37	51	33	22	27	15	37	21	53	33
21	36	40	27	23	41	38	31	18	34	50	20	25	20	29	39	44	30	29	17	37	0	19	19	22	44	52	6	17	63	23
33	53	57	32	25	49	56	48	37	42	64	19	35	38	33	46	53	14	32	26	51	19	0	38	30	48	66	24	30	60	23
25	24	22	36	37	43	20	18	1	38	43	35	29	9	39	44	45	48	40	26	33	19	38	0	29	50	45	15	22	73	37
7	30	50	7	11	20	48	28	29	13	35	13	5	24	10	19	24	43	11	5	22	22	30	29	0	23	37	24	8	45	12
26	40	69	18	24	12	67	42	50	13	34	29	22	43	16	8	13	60	17	28	27	44	48	50	23	0	34	47	30	26	25
33	23	55	37	45	23	53	29	45	28	2	49	32	38	38	28	21	79	41	40	15	52	66	45	37	34	0	51	36	58	47
22	34	34	30	28	42	33	28	14	36	50	25	27	17	33	42	46	34	33	19	37	6	24	15	24	47	51	0	18	67	28
4	24	42	15	17	24	40	21	21	18	35	18	9	16	17	24	28	44	19	6	21	17	30	22	8	30	36	18	0	52	18
49	66	93	38	40	38	92	68	73	39	58	44	45	67	35	34	38	69	34	49	53	63	60	73	45	26	58	67	52	0	40
18	41	58	10	2	28	56	39	36	20	46	4	16	32	11	24	31	36	9	12	33	23	23	37	12	25	47	28	18	40	0

Table F.30:Distance Matrix 30.5

9	58	36	36	58	29	44	4	50	6	46	13	55	37	10	59	42	14	48	39	46	18	31	23	29	41	57	45	3	11

Table F.31:Demand 30.6

0	12	25	44	21	24	22	20	14	13	46	44	21	48	21	26	50	13	23	28	49	16	25	47	23	44	25	29	44	26	17
12	0	22	55	26	29	31	24	25	11	57	33	12	46	29	17	39	24	13	32	47	11	17	58	19	48	16	17	33	32	19
25	22	0	56	16	18	46	14	39	32	64	45	16	25	46	34	45	34	31	52	26	11	9	58	4	68	12	25	41	51	39
44	55	56	0	41	40	38	43	37	55	15	87	62	67	43	70	93	32	66	52	68	53	61	6	57	62	63	71	88	48	52
21	26	16	41	0	3	38	3	30	33	49	56	26	31	39	42	58	23	38	47	32	17	23	42	17	63	25	37	54	45	37
24	29	18	40	3	0	40	6	32	36	49	58	29	30	42	45	61	25	41	50	31	20	25	41	20	66	27	40	57	47	40
22	31	46	38	38	40	0	39	8	24	33	57	42	68	6	39	66	15	37	14	69	37	46	43	44	28	46	46	60	11	18
20	24	14	43	3	6	39	0	31	32	51	53	24	30	40	39	56	24	35	47	31	15	20	45	15	63	22	34	51	45	37
14	25	39	37	30	32	8	31	0	20	35	53	35	60	10	35	61	9	33	19	61	30	39	41	37	34	39	41	55	16	16
13	11	32	55	33	36	24	32	20	0	54	34	22	56	20	16	43	23	14	22	58	22	28	59	30	37	27	24	36	22	9
46	57	64	15	49	49	33	51	35	54	0	87	66	78	39	70	95	34	67	46	79	58	67	19	63	53	68	74	89	42	50
44	33	45	87	56	58	57	53	53	34	87	0	30	64	52	18	13	55	21	50	65	39	37	90	42	60	34	20	8	52	40
21	12	16	62	26	29	42	24	35	22	66	30	0	39	40	19	32	33	16	43	40	10	9	65	13	58	6	11	28	43	30
48	46	25	67	31	30	68	30	60	56	78	64	39	0	68	57	61	53	54	75	2	35	31	67	28	91	33	46	59	73	63
21	29	46	43	39	42	6	40	10	20	39	52	40	68	0	35	62	18	33	10	70	36	44	48	44	25	44	43	56	6	13
26	17	34	70	42	45	39	39	35	16	70	18	19	57	35	0	27	38	4	34	59	26	27	73	31	47	25	14	21	36	22
50	39	45	93	58	61	66	56	61	43	95	13	32	61	62	27	0	62	29	61	62	42	37	96	42	72	34	23	7	63	49
13	24	34	32	23	25	15	24	9	23	34	55	33	53	18	38	62	0	35	27	55	26	35	36	33	42	36	41	56	24	22
23	13	31	66	38	41	37	35	33	14	67	21	16	54	33	4	29	35	0	34	55	22	24	70	27	47	21	12	23	35	21
28	32	52	52	47	50	14	47	19	22	46	50	43	75	10	34	61	27	34	0	76	41	49	57	49	17	48	45	54	5	14
49	47	26	68	32	31	69	31	61	58	79	65	40	2	70	59	62	55	55	76	0	37	32	67	29	93	34	48	60	75	64
16	11	11	53	17	20	37	15	30	22	58	39	10	35	36	26	42	26	22	41	37	0	10	56	9	57	10	20	37	40	29
25	17	9	61	23	25	46	20	39	28	67	37	9	31	44	27	37	35	24	49	32	10	0	63	6	65	3	18	33	49	36
47	58	58	6	42	41	43	45	41	59	19	90	65	67	48	73	96	36	70	57	67	56	63	0	59	67	65	74	91	53	56
23	19	4	57	17	20	44	15	37	30	63	42	13	28	44	31	42	33	27	49	29	9	6	59	0	65	9	23	39	48	37
44	48	68	62	63	66	28	63	34	37	53	60	58	91	25	47	72	42	47	17	93	57	65	67	65	0	64	59	66	19	30
25	16	12	63	25	27	46	22	39	27	68	34	6	33	44	25	34	36	21	48	34	10	3	65	9	64	0	15	30	48	35
29	17	25	71	37	40	46	34	41	24	74	20	11	46	43	14	23	41	12	45	48	20	18	74	23	59	15	0	17	46	32
44	33	41	88	54	57	60	51	55	36	89	8	28	59	56	21	7	56	23	54	60	37	33	91	39	66	30	17	0	56	43
26	32	51	48	45	47	11	45	16	22	42	52	43	73	6	36	63	24	35	5	75	40	49	53	48	19	48	46	56	0	15
17	19	39	52	37	40	18	37	16	9	50	40	30	63	13	22	49	22	21	14	64	29	36	56	37	30	35	32	43	15	0

Table F.32:Distance Matrix 30.6

9	58	36	36	58	29	44	4	50	6	46	13	55	37	10	59	42	14	48	39	46	18	31	23	29	41	57	45	3	11

Table F.33:Demand 30.7

0	38	27	5	10	15	49	25	31	15	15	45	12	50	50	12	47	24	46	21	49	15	36	5	17	25	13	5	15	50	15
38	0	47	42	46	28	86	13	69	53	34	52	38	57	56	32	84	29	54	33	86	48	51	39	45	47	34	42	44	69	24
27	47	0	27	22	37	48	37	40	29	16	20	16	26	76	20	49	48	21	15	56	39	10	22	43	2	38	30	41	25	30
5	42	27	0	7	19	45	30	27	11	18	46	13	51	51	15	43	28	47	24	45	13	36	7	17	25	15	4	15	49	19
10	46	22	7	0	24	40	33	24	9	17	42	12	47	57	16	39	34	43	23	42	17	32	8	22	21	22	10	20	44	23
15	28	37	19	24	0	63	17	43	29	22	52	22	58	41	17	60	11	54	27	61	21	45	18	18	37	7	17	17	62	10
49	86	48	45	40	63	0	73	22	34	54	64	49	67	85	55	5	71	64	58	15	46	54	48	52	47	58	47	51	52	63
25	13	37	30	33	17	73	0	56	40	22	46	26	51	52	19	71	21	48	23	74	36	42	26	34	37	23	29	33	60	11
31	69	40	27	24	43	22	56	0	16	40	60	35	64	64	39	18	50	60	46	18	25	49	31	31	38	38	27	31	54	45
15	53	29	11	9	29	34	40	16	0	25	49	20	54	57	24	32	37	50	31	34	15	38	15	21	27	25	13	20	48	29
15	34	16	18	17	22	54	22	40	25	0	31	6	37	62	5	53	33	32	7	58	30	23	12	32	16	25	20	30	40	15
45	52	20	46	42	52	64	46	60	49	31	0	34	6	93	36	65	62	2	26	74	58	12	40	62	22	55	49	59	21	44
12	38	16	13	12	22	49	26	35	20	6	34	0	39	61	7	48	33	35	12	52	26	25	7	29	15	23	16	26	40	17
50	57	26	51	47	58	67	51	64	54	37	6	39	0	98	42	69	68	5	32	78	64	16	46	67	27	61	55	65	20	49
50	56	76	51	57	41	85	52	64	57	62	93	61	98	0	57	81	32	94	67	75	42	85	55	36	75	39	48	38	100	50
12	32	20	15	16	17	55	19	39	24	5	36	7	42	57	0	54	28	37	11	57	26	28	9	27	20	20	17	25	45	10
47	84	49	43	39	60	5	71	18	32	53	65	48	69	81	54	0	68	65	58	11	43	55	46	49	47	56	44	48	54	61
24	29	48	28	34	11	71	21	50	37	33	62	33	68	32	28	68	0	64	37	67	26	56	29	21	47	13	25	20	72	19
46	54	21	47	43	54	64	48	60	50	32	2	35	5	94	37	65	64	0	28	74	59	12	41	63	23	56	50	60	19	45
21	33	15	24	23	27	58	23	46	31	7	26	12	32	67	11	58	37	28	0	63	36	20	18	38	15	30	26	35	38	18
49	86	56	45	42	61	15	74	18	34	58	74	52	78	75	57	11	67	74	63	0	42	63	49	47	54	55	45	47	64	63
15	48	39	13	17	21	46	36	25	15	30	58	26	64	42	26	43	26	59	36	42	0	49	19	6	38	15	10	6	61	26
36	51	10	36	32	45	54	42	49	38	23	12	25	16	85	28	55	56	12	20	63	49	0	31	52	12	47	40	50	18	37
5	39	22	7	8	18	48	26	31	15	12	40	7	46	55	9	46	29	41	18	49	19	31	0	22	20	18	9	20	45	16
17	45	43	17	22	18	52	34	31	21	32	62	29	67	36	27	49	21	63	38	47	6	52	22	0	42	12	13	3	65	25
25	47	2	25	21	37	47	37	38	27	16	22	15	27	75	20	47	47	23	15	54	38	12	20	42	0	37	29	39	26	30
13	34	38	15	22	7	58	23	38	25	25	55	23	61	39	20	56	13	56	30	55	15	47	18	12	37	0	13	10	62	15
5	42	30	4	10	17	47	29	27	13	20	49	16	55	48	17	44	25	50	26	45	10	40	9	13	29	13	0	11	53	19
15	44	41	15	20	17	51	33	31	20	30	59	26	65	38	25	48	20	60	35	47	6	50	20	3	39	10	11	0	64	24
50	69	25	49	44	62	52	60	54	48	40	21	40	20	100	45	54	72	19	38	64	61	18	45	65	26	62	53	64	0	54
15	24	30	19	23	10	63	11	45	29	15	44	17	49	50	10	61	19	45	18	63	26	37	16	25	30	15	19	24	54	0

Table F.34:Distance Matrix 30.7

52	24	48	38	52	11	27	23	39	58	37	28	55	20	35	11	50	13	22	47	13	30	5	6	11	30	4	56	23	8

Table F.35:Demand 30.8

0	22	27	23	18	16	42	23	49	14	41	48	31	46	22	8	49	32	24	42	25	22	18	19	24	44	13	13	21	3	14
22	0	38	45	12	22	47	45	50	35	19	70	9	25	35	18	56	54	41	49	11	33	39	39	36	22	10	28	22	20	31
27	38	0	36	41	16	17	35	75	21	53	45	44	61	5	34	74	37	46	68	46	47	26	19	3	55	31	38	18	26	13
23	45	36	0	38	35	52	2	53	17	63	29	53	67	33	28	46	13	17	42	45	26	11	18	35	66	35	21	41	26	26
18	12	41	38	0	25	53	38	40	32	26	65	18	29	37	11	45	49	31	37	8	22	35	37	38	30	10	19	28	17	30
16	22	16	35	25	0	28	34	62	20	38	53	29	46	14	20	64	40	39	57	30	37	26	22	15	40	15	28	6	14	12
42	47	17	52	53	28	0	51	90	37	59	56	52	69	21	48	90	51	62	83	57	63	42	35	19	60	43	54	26	41	29
23	45	35	2	38	34	51	0	54	16	63	29	53	67	31	28	47	12	18	43	45	27	10	17	33	66	35	22	40	25	25
49	50	75	53	40	62	90	54	0	59	56	81	52	52	71	43	15	65	37	13	40	29	58	63	73	60	49	38	66	49	63
14	35	21	17	32	20	37	16	59	0	53	35	43	59	17	22	55	21	27	50	39	30	7	5	19	56	25	21	25	16	9
41	19	53	63	26	38	59	63	56	53	0	88	10	10	51	35	66	73	57	58	20	47	58	57	52	4	29	44	36	39	48
48	70	45	29	65	53	56	29	81	35	88	0	78	93	43	55	71	17	45	69	72	55	31	32	45	91	60	50	58	50	42
31	9	44	53	18	29	52	53	52	43	10	78	0	18	42	26	60	63	48	53	14	39	48	47	42	13	19	35	28	29	39
46	25	61	67	29	46	69	67	52	59	10	93	18	0	59	40	63	78	59	56	22	48	63	64	60	12	34	47	45	44	55
22	35	5	33	37	14	21	31	71	17	51	43	42	59	0	30	70	34	42	64	43	43	22	16	3	53	28	34	16	22	9
8	18	34	28	11	20	48	28	43	22	35	55	26	40	30	0	44	39	24	37	18	18	25	27	31	39	9	11	25	8	22
49	56	74	46	45	64	90	47	15	55	66	71	60	63	70	44	0	57	30	8	47	28	53	60	72	70	52	37	68	50	61
32	54	37	13	49	40	51	12	65	21	73	17	63	78	34	39	57	0	29	53	56	38	15	19	36	75	44	33	46	34	29
24	41	46	17	31	39	62	18	37	27	57	45	48	59	42	24	30	29	0	25	37	12	24	30	44	61	33	14	45	26	34
42	49	68	42	37	57	83	43	13	50	58	69	53	56	64	37	8	53	25	0	40	21	48	54	66	62	45	30	62	43	55
25	11	46	45	8	30	57	45	40	39	20	72	14	22	43	18	47	56	37	40	0	27	42	44	44	24	15	25	32	24	37
22	33	47	26	22	37	63	27	29	30	47	55	39	48	43	18	28	38	12	21	27	0	29	35	45	51	26	10	42	23	35
18	39	26	11	35	26	42	10	58	7	58	31	48	63	22	25	53	15	24	48	42	29	0	8	24	61	30	21	32	20	16
19	39	19	18	37	22	35	17	63	5	57	32	47	64	16	27	60	19	30	54	44	35	8	0	18	60	30	26	27	20	11
24	36	3	35	38	15	19	33	73	19	52	45	42	60	3	31	72	36	44	66	44	45	24	18	0	53	29	36	16	24	11
44	22	55	66	30	40	60	66	60	56	4	91	13	12	53	39	70	75	61	62	24	51	61	60	53	0	32	48	37	42	50
13	10	31	35	10	15	43	35	49	25	29	60	19	34	28	9	52	44	33	45	15	26	30	30	29	32	0	20	18	10	22
13	28	38	21	19	28	54	22	38	21	44	50	35	47	34	11	37	33	14	30	25	10	21	26	36	48	20	0	33	14	25
21	22	18	41	28	6	26	40	66	25	36	58	28	45	16	25	68	46	45	62	32	42	32	27	16	37	18	33	0	20	17
3	20	26	26	17	14	41	25	49	16	39	50	29	44	22	8	50	34	26	43	24	23	20	20	24	42	10	14	20	0	15
14	31	13	26	30	12	29	25	63	9	48	42	39	55	9	22	61	29	34	55	37	35	16	11	11	50	22	25	17	15	0

Table F.36:Distance Matrix 30.8

14	33	28	13	30	3	20	36	41	40	6	14	47	49	26	15	60	8	7	53	52	26	26	39	36	44	31	53	5	50

Table F.37:Demand 30.9

0	46	31	45	16	6	21	8	16	27	24	9	5	31	29	19	25	12	24	28	13	19	6	27	22	45	9	20	29	1	50
46	0	56	5	49	45	54	51	50	22	69	55	48	17	48	36	63	50	66	22	34	44	42	23	34	4	43	58	47	47	6
31	56	0	52	15	26	51	37	15	46	33	31	27	40	59	46	52	20	24	35	36	49	27	33	23	57	24	48	59	30	57
45	5	52	0	46	43	55	51	47	23	68	54	47	15	50	37	64	48	64	19	33	45	41	21	32	8	41	59	49	46	5
16	49	15	46	0	11	36	23	2	35	25	18	12	32	44	32	38	6	19	27	22	35	12	26	15	49	9	34	44	15	51
6	45	26	43	11	0	26	14	11	27	25	12	4	29	34	22	30	8	23	25	14	24	3	24	17	44	3	25	33	6	48
21	54	51	55	36	26	0	14	36	33	33	21	24	43	15	19	10	31	38	43	25	11	26	42	40	52	29	7	15	21	60
8	51	37	51	23	14	14	0	22	31	23	8	11	37	25	19	17	18	26	35	18	17	14	34	30	50	17	12	25	9	56
16	50	15	47	2	11	36	22	0	35	23	17	12	34	45	32	37	5	18	29	23	35	13	27	17	50	10	34	44	15	52
27	22	46	23	35	27	33	31	35	0	51	35	30	13	29	15	42	34	50	17	14	23	25	17	25	20	27	37	28	28	27
24	69	33	68	25	25	33	23	23	51	0	16	22	53	46	41	28	21	10	49	37	39	27	48	39	68	27	27	46	23	73
9	55	31	54	18	12	21	8	17	35	16	0	8	39	33	26	21	13	18	36	22	24	14	35	28	54	14	18	32	8	58
5	48	27	47	12	4	24	11	12	30	22	8	0	32	34	23	27	8	21	29	16	24	6	28	20	47	7	23	33	4	52
31	17	40	15	32	29	43	37	34	13	53	39	32	0	41	26	51	34	50	7	20	34	27	7	19	17	27	46	40	32	20
29	48	59	50	44	34	15	25	45	29	46	33	34	41	0	16	24	40	50	42	26	10	33	42	44	45	36	21	1	30	54
19	36	46	37	32	22	19	19	32	15	41	26	23	26	16	0	28	29	43	27	11	9	20	26	29	34	23	23	15	20	41
25	63	52	64	38	30	10	17	37	42	28	21	27	51	24	28	0	33	35	50	32	21	31	49	46	62	33	6	24	25	69
12	50	20	48	6	8	31	18	5	34	21	13	8	34	40	29	33	0	17	29	21	31	10	28	18	49	8	29	40	11	53
24	66	24	64	19	23	38	26	18	50	10	18	21	50	50	43	35	17	0	45	36	42	25	44	34	66	24	34	50	23	69
28	22	35	19	27	25	43	35	29	17	49	36	29	7	42	27	50	29	45	0	19	35	23	2	13	23	23	45	41	29	24
13	34	36	33	22	14	25	18	23	14	37	22	16	20	26	11	32	21	36	19	0	17	11	18	18	33	14	27	26	14	38
19	44	49	45	35	24	11	17	35	23	39	24	24	34	10	9	21	31	42	35	17	0	23	34	35	42	26	16	10	20	49
6	42	27	41	12	3	26	14	13	25	27	14	6	27	33	20	31	10	25	23	11	23	0	22	16	42	3	26	32	7	46
27	23	33	21	26	24	42	34	27	17	48	35	28	7	42	26	49	28	44	2	18	34	22	0	12	24	22	44	41	27	26
22	34	23	32	15	17	40	30	17	25	39	28	20	19	44	29	46	18	34	13	18	35	16	12	0	35	14	41	43	22	36
45	4	57	8	49	44	52	50	50	20	68	54	47	17	45	34	62	49	66	23	33	42	42	24	35	0	43	56	44	46	10
9	43	24	41	9	3	29	17	10	27	27	14	7	27	36	23	33	8	24	23	14	26	3	22	14	43	0	28	35	9	46
20	58	48	59	34	25	7	12	34	37	27	18	23	46	21	23	6	29	34	45	27	16	26	44	41	56	28	0	21	20	63
29	47	59	49	44	33	15	25	44	28	46	32	33	40	1	15	24	40	50	41	26	10	32	41	43	44	35	21	0	29	53
1	47	30	46	15	6	21	9	15	28	23	8	4	32	30	20	25	11	23	29	14	20	7	27	22	46	9	20	29	0	51
50	6	57	5	51	48	60	56	52	27	73	58	52	20	54	41	69	53	69	24	38	49	46	26	36	10	46	63	53	51	0

Table F.38:Distance Matrix 30.9

10	54	8	2	38	49	36	48	25	22	24	59	18	18	30	52	40	10	45	36	58	29	35	36	54	23	12	53	7	56

Table F.39:Demand 30.10

0	40	46	40	8	25	23	16	25	48	23	17	19	20	14	6	7	13	44	37	12	14	5	48	13	7	19	11	34	36	20
40	0	8	56	37	16	49	54	41	57	58	53	56	59	31	41	34	39	66	54	30	53	40	9	52	45	25	49	54	55	60
46	8	0	57	42	22	52	59	48	57	65	58	60	65	38	46	40	46	67	61	36	59	45	3	58	51	32	54	56	56	65
40	56	57	0	34	45	18	36	64	10	60	33	31	52	50	35	43	52	12	76	44	48	35	60	48	36	51	34	8	6	41
8	37	42	34	0	21	19	18	30	42	31	17	20	26	17	5	9	18	40	43	12	21	4	44	20	10	20	13	29	30	24
25	16	22	45	21	0	36	39	31	49	44	38	40	44	18	25	19	25	54	44	14	38	24	24	36	30	13	33	42	43	44
23	49	52	18	19	36	0	19	48	28	42	16	15	34	35	18	27	35	22	59	30	30	19	55	30	18	38	16	11	14	25
16	54	59	36	18	39	19	0	38	46	25	4	6	16	30	14	22	26	36	46	27	14	15	62	14	9	35	6	29	31	7
25	41	48	64	30	31	48	38	0	71	24	39	43	30	15	31	22	13	69	14	22	26	30	49	26	31	19	35	58	60	39
48	57	57	10	42	49	28	46	71	0	69	43	41	61	57	43	50	60	19	84	51	58	43	60	57	45	57	43	18	16	51
23	58	65	60	31	44	42	25	24	69	0	28	30	10	27	28	26	19	60	26	30	12	28	66	12	25	34	26	52	55	22
17	53	58	33	17	38	16	4	39	43	28	0	4	19	31	13	23	27	33	49	27	17	14	61	17	10	35	6	26	28	10
19	56	60	31	20	40	15	6	43	41	30	4	0	22	33	16	26	30	31	52	30	20	17	63	20	12	38	8	24	26	11
20	59	65	52	26	44	34	16	30	61	10	19	22	0	29	23	25	22	52	34	30	6	23	67	8	19	35	19	45	47	13
14	31	38	50	17	18	35	30	15	57	27	31	33	29	0	19	9	9	56	29	7	24	18	39	22	21	7	25	45	47	33
6	41	46	35	5	25	18	14	31	43	28	13	16	23	19	0	11	18	39	42	15	18	1	48	16	5	23	9	28	30	20
7	34	40	43	9	19	27	22	22	50	26	23	26	25	9	11	0	10	48	34	5	19	10	42	18	14	13	18	37	39	26
13	39	46	52	18	25	35	26	13	60	19	27	30	22	9	18	10	0	57	25	12	17	18	48	15	19	15	23	46	48	28
44	66	67	12	40	54	22	36	69	19	60	33	31	52	56	39	48	57	0	80	51	50	40	70	49	39	58	36	13	11	40
37	54	61	76	43	44	59	46	14	84	26	49	52	34	29	42	34	25	80	0	35	33	42	61	33	42	32	45	70	72	45
12	30	36	44	12	14	30	27	22	51	30	27	30	30	7	15	5	12	51	35	0	24	14	38	23	18	8	22	39	41	31
14	53	59	48	21	38	30	14	26	58	12	17	20	6	24	18	19	17	50	33	24	0	18	61	2	14	30	15	41	43	13
5	40	45	35	4	24	19	15	30	43	28	14	17	23	18	1	10	18	40	42	14	18	0	47	17	6	22	9	29	31	20
48	9	3	60	44	24	55	62	49	60	66	61	63	67	39	48	42	48	70	61	38	61	47	0	60	53	33	56	59	59	67
13	52	58	48	20	36	30	14	26	57	12	17	20	8	22	16	18	15	49	33	23	2	17	60	0	13	28	14	41	43	14
7	45	51	36	10	30	18	9	31	45	25	10	12	19	21	5	14	19	39	42	18	14	6	53	13	0	26	4	29	31	15
19	25	32	51	20	13	38	35	19	57	34	35	38	35	7	23	13	15	58	32	8	30	22	33	28	26	0	30	46	48	39
11	49	54	34	13	33	16	6	35	43	26	6	8	19	25	9	18	23	36	45	22	15	9	56	14	4	30	0	27	29	12
34	54	56	8	29	42	11	29	58	18	52	26	24	45	45	28	37	46	13	70	39	41	29	59	41	29	46	27	0	3	34
36	55	56	6	30	43	14	31	60	16	55	28	26	47	47	30	39	48	11	72	41	43	31	59	43	31	48	29	3	0	36
20	60	65	41	24	44	25	7	39	51	22	10	11	13	33	20	26	28	40	45	31	13	20	67	14	15	39	12	34	36	0

Table F.40:Distance Matrix 30.10

53	46	19	1	49	30	32	40	43	54	15	35	49	52	54	49	57	6	27	24	13	59	26	58	57	34	17	54	43	24	25	43	36	59	25	28	35	16	42	1

Table F.41:Demand 40.1

0	19	28	32	50	50	19	20	31	3	21	27	20	46	26	9	11	50	19	3	18	7	25	19	47	21	23	18	14	41	29	5	46	50	40	18	32	10	19	42	22
19	0	25	47	38	44	3	36	45	21	35	41	15	59	38	27	9	43	4	21	2	16	27	25	33	10	40	11	15	34	26	14	60	64	54	33	45	21	30	55	7
28	25	0	38	27	22	22	46	58	30	48	54	38	45	26	34	26	22	21	27	23	21	9	45	56	34	35	34	35	14	2	27	47	76	67	45	59	36	21	69	31
32	47	38	0	64	51	46	34	45	32	41	42	52	15	12	29	42	54	45	30	46	32	30	48	78	52	11	49	45	49	39	37	14	57	52	37	47	39	19	54	53
50	38	27	64	0	21	36	70	81	53	70	77	52	68	52	58	44	16	35	51	37	44	35	63	58	46	62	48	52	16	26	48	72	100	90	68	81	57	47	91	42
50	44	22	51	21	0	41	67	79	52	70	75	58	53	40	55	48	5	41	49	42	43	27	66	72	53	53	54	56	11	21	49	57	97	89	67	80	58	39	90	50
19	3	22	46	36	41	0	37	47	21	36	43	18	57	36	27	9	40	1	21	1	15	25	27	36	13	39	13	17	31	23	15	59	65	55	34	46	22	28	56	10
20	36	46	34	70	67	37	0	13	17	9	9	30	48	34	13	28	68	37	19	37	26	41	20	57	35	24	31	25	59	47	23	46	31	22	5	15	16	30	24	38
31	45	58	45	81	79	47	13	0	29	11	5	36	59	47	25	38	80	47	31	46	37	54	24	59	41	35	38	32	71	59	33	56	19	10	13	4	25	43	11	45
3	21	30	32	53	52	21	17	29	0	19	25	20	46	26	6	13	52	21	3	21	9	26	19	48	22	22	19	14	43	31	7	45	48	38	16	30	9	20	39	24
21	35	48	41	70	70	36	9	11	19	0	8	26	56	41	16	27	70	36	22	35	28	45	14	50	31	31	27	21	61	50	23	54	30	20	4	11	14	36	21	34
27	41	54	42	77	75	43	9	5	25	8	0	33	56	43	20	34	76	43	27	42	33	49	21	57	38	32	34	28	67	55	29	53	24	14	9	7	21	39	15	41
20	15	38	52	52	58	18	30	36	20	26	33	0	65	45	25	13	57	19	23	17	22	39	13	28	7	42	5	7	48	39	16	65	54	43	26	34	15	37	44	11
46	59	45	15	68	53	57	48	59	46	56	56	65	0	22	43	54	56	57	43	58	44	37	63	91	65	25	63	59	53	45	50	5	70	66	52	62	53	29	68	65
26	38	26	12	52	40	36	34	47	26	41	43	45	22	0	26	34	43	35	24	37	24	18	44	70	44	14	42	39	37	27	30	23	62	55	37	49	34	8	57	44
9	27	34	29	58	55	27	13	25	6	16	20	25	43	26	0	19	56	27	7	27	14	29	20	52	27	19	24	19	47	35	13	42	43	34	13	26	11	20	35	29
11	9	26	42	44	48	9	28	38	13	27	34	13	54	34	19	0	47	10	13	9	10	27	19	37	11	33	9	9	38	27	7	55	56	46	25	37	13	26	47	12
50	43	22	54	16	5	40	68	80	52	70	76	57	56	43	56	47	0	39	49	41	43	28	65	69	51	55	53	55	9	21	49	61	98	89	67	81	57	41	90	48
19	4	21	45	35	41	1	37	47	21	36	43	19	57	35	27	10	39	0	20	2	15	24	28	37	14	38	14	18	30	22	15	58	66	56	35	47	22	28	57	11
3	21	27	30	51	49	21	19	31	3	22	27	23	43	24	7	13	49	20	0	21	7	24	22	49	24	20	20	16	41	29	8	43	49	40	18	32	12	17	42	25
18	2	23	46	37	42	1	37	46	21	35	42	17	58	37	27	9	41	2	21	0	15	26	27	35	12	39	13	16	32	24	15	59	65	55	34	46	22	29	56	9
7	16	21	32	44	43	15	26	37	9	28	33	22	44	24	14	10	43	15	7	15	0	19	25	47	21	24	19	17	34	23	7	45	56	46	25	38	15	16	48	21
25	27	9	30	35	27	25	41	54	26	45	49	39	37	18	29	27	28	24	24	26	19	0	43	60	36	28	35	35	21	9	26	39	71	63	41	55	34	13	64	34
19	25	45	48	63	66	27	20	24	19	14	21	13	63	44	20	19	65	28	22	27	25	43	0	37	19	38	16	11	56	46	18	62	41	31	15	22	11	38	31	23
47	33	56	78	58	72	36	57	59	48	50	57	28	91	70	52	37	69	37	49	35	47	60	37	0	27	69	30	34	61	56	42	92	74	65	52	57	42	62	65	27
21	10	34	52	46	53	13	35	41	22	31	38	7	65	44	27	11	51	14	24	12	21	36	19	27	0	44	4	10	43	34	16	66	60	49	31	40	19	36	50	5
23	40	35	11	62	53	39	24	35	22	31	32	42	25	14	19	33	55	38	20	39	24	28	38	69	44	0	40	36	48	37	28	24	49	43	27	38	29	15	45	44
18	11	34	49	48	54	13	31	38	19	27	34	5	63	42	24	9	53	14	20	13	19	35	16	30	4	40	0	6	44	35	13	63	56	45	27	37	15	34	46	8
14	15	35	45	52	56	17	25	32	14	21	28	7	59	39	19	9	55	18	16	16	17	35	11	34	10	36	6	0	46	36	10	59	50	40	21	31	9	32	41	14
41	34	14	49	16	11	31	59	71	43	61	67	48	53	37	47	38	9	30	41	32	34	21	56	61	43	48	44	46	0	13	40	57	90	80	58	72	49	34	82	39
29	26	2	39	26	21	23	47	59	31	50	55	39	45	27	35	27	21	22	29	24	23	9	46	56	34	37	35	36	13	0	29	48	78	68	47	60	37	22	70	32
5	14	27	37	48	49	15	23	33	7	23	29	16	50	30	13	7	49	15	8	15	7	26	18	42	16	28	13	10	40	29	0	50	52	42	20	33	9	22	43	18
46	60	47	14	72	57	59	46	56	45	54	53	65	5	23	42	55	61	58	43	59	45	39	62	92	66	24	63	59	57	48	50	0	66	62	50	59	53	31	64	66
50	64	76	57	100	97	65	31	19	48	30	24	54	70	62	43	56	98	66	49	65	56	71	41	74	60	49	56	50	90	78	52	66	0	11	32	20	44	60	11	63
40	54	67	52	90	89	55	22	10	38	20	14	43	66	55	34	46	89	56	40	55	46	63	31	65	49	43	45	40	80	68	42	62	11	0	22	9	34	52	2	53
18	33	45	37	68	67	34	5	13	16	4	9	26	52	37	13	25	67	35	18	34	25	41	15	52	31	27	27	21	58	47	20	50	32	22	0	14	13	32	24	34
32	45	59	47	81	80	46	15	4	30	11	7	34	62	49	26	37	81	47	32	46	38	55	22	57	40	38	37	31	72	60	33	59	20	9	14	0	25	45	10	44
10	21	36	39	57	58	22	16	25	9	14	21	15	53	34	11	13	57	22	12	22	15	34	11	42	19	29	15	9	49	37	9	53	44	34	13	25	0	28	35	22
19	30	21	19	47	39	28	30	43	20	36	39	37	29	8	20	26	41	28	17	29	16	13	38	62	36	15	34	32	34	22	22	31	60	52	32	45	28	0	54	36
42	55	69	54	91	90	56	24	11	39	21	15	44	68	57	35	47	90	57	42	56	48	64	31	65	50	45	46	41	82	70	43	64	11	2	24	10	35	54	0	54
22	7	31	53	42	50	10	38	45	24	34	41	11	65	44	29	12	48	11	25	9	21	34	23	27	5	44	8	14	39	32	18	66	63	53	34	44	22	36	54	0

Table F.42:Distance Matrix 40.1

54	57	17	26	5	2	49	41	44	50	20	47	25	55	1	46	5	18	22	28

14	14	14	57	44	20	29	55	41	59	58	55	45	9	40	41	54	9	31	18

Table F.43:Demand 40.2

0	19	5	27	45	40	24	23	17	23	28	46	7	49	45	19	19	50	21	9	28	49	49	25	45	30	12	39	15	22	26	15	7	10	16	22	47	36	24	28	7
19	0	19	45	57	25	22	35	26	41	26	45	23	44	43	29	4	60	33	22	41	59	33	44	43	17	17	35	32	40	16	6	23	26	31	40	64	20	14	36	20
5	19	0	26	50	42	20	20	22	25	24	41	4	44	41	15	20	54	18	14	32	54	51	25	41	32	16	35	17	22	29	14	4	14	20	21	46	38	22	33	2
27	45	26	0	50	67	39	20	37	17	41	49	23	56	51	24	46	56	20	31	36	56	76	5	51	57	37	48	21	9	53	40	23	27	27	5	20	63	45	44	25
45	57	50	50	0	63	69	62	32	34	73	90	50	93	90	61	55	7	60	38	18	8	72	45	90	54	41	84	35	43	50	56	49	36	30	48	58	62	68	23	51
40	25	42	67	63	0	45	60	37	59	49	67	46	64	64	53	23	64	58	38	50	62	10	65	65	11	32	57	50	61	16	31	45	43	47	62	86	6	36	41	44
24	22	20	39	69	45	0	22	39	43	5	25	21	25	22	16	25	74	21	32	51	73	51	40	23	39	31	15	37	38	37	17	22	34	40	35	57	40	10	51	19
23	35	20	20	62	60	22	0	39	30	22	30	16	37	32	7	37	68	2	32	45	67	67	22	32	50	35	29	28	22	47	29	18	30	34	17	36	55	30	50	18
17	26	22	37	32	37	39	39	0	24	44	62	24	64	61	35	24	35	37	8	16	34	47	33	61	26	9	54	16	29	22	25	22	11	11	33	53	34	37	12	23
23	41	25	17	34	59	43	30	24	0	46	59	23	65	61	31	41	39	29	22	19	40	68	13	60	48	27	56	9	9	44	37	22	17	13	15	30	55	46	29	25
28	26	24	41	73	49	5	22	44	46	0	20	24	21	18	17	29	78	22	37	55	77	54	42	18	43	36	11	40	40	41	22	26	38	44	37	58	44	14	55	23
46	45	41	49	90	67	25	30	62	59	20	0	40	10	6	30	49	95	31	55	72	94	72	51	5	62	55	12	56	52	61	41	42	55	60	47	62	63	33	73	40
7	23	4	23	50	46	21	16	24	23	24	40	0	44	40	12	24	55	14	16	32	54	54	22	40	36	19	34	17	19	32	17	2	15	20	18	42	41	24	35	3
49	44	44	56	93	64	25	37	64	65	21	10	44	0	5	35	48	98	37	57	76	97	67	58	7	60	56	10	60	58	60	41	45	58	64	53	71	59	31	76	43
45	43	41	51	90	64	22	32	61	61	18	6	40	5	0	31	46	95	33	54	72	94	68	54	2	59	53	8	56	53	58	39	42	54	60	49	66	59	29	73	39
19	29	15	24	61	53	16	7	35	31	17	30	12	35	31	0	31	66	5	28	43	65	61	25	30	44	30	26	27	24	41	23	13	26	31	20	41	48	24	46	13
19	4	20	46	55	23	25	37	24	41	29	49	24	48	46	31	0	58	35	21	39	57	31	44	46	15	16	38	32	40	13	9	24	25	31	41	65	18	17	34	22
50	60	54	56	7	64	74	68	35	39	78	95	55	98	95	66	58	0	66	42	23	3	73	51	95	55	44	88	40	48	52	60	54	41	35	54	64	63	72	25	56
21	33	18	20	60	58	21	2	37	29	22	31	14	37	33	5	35	66	0	30	44	66	66	21	32	49	33	29	27	21	45	27	16	28	32	16	37	53	29	48	16
9	22	14	31	38	38	32	32	8	22	37	55	16	57	54	28	21	42	30	0	20	41	47	29	54	27	6	47	13	24	23	19	15	5	11	27	50	34	30	19	16
28	41	32	36	18	50	51	45	16	19	55	72	32	76	72	43	39	23	44	20	0	23	60	32	72	40	24	66	17	28	36	39	31	18	13	33	48	48	50	12	33
49	59	54	56	8	62	73	67	34	40	77	94	54	97	94	65	57	3	66	41	23	0	70	52	94	53	43	87	40	49	50	59	53	40	35	54	64	61	70	24	55
49	33	51	76	72	10	51	67	47	68	54	72	54	67	68	61	31	73	66	47	60	70	0	74	69	21	42	61	60	70	26	39	54	52	56	71	95	14	41	51	52
25	44	25	5	45	65	40	22	33	13	42	51	22	58	54	25	44	51	21	29	32	52	74	0	53	54	34	50	18	5	50	39	22	24	23	6	22	61	45	40	24
45	43	41	51	90	65	23	32	61	60	18	5	40	7	2	30	46	95	32	54	72	94	69	53	0	60	53	9	56	53	59	39	42	54	60	48	65	60	30	73	39
30	17	32	57	54	11	39	50	26	48	43	62	36	60	59	44	15	55	49	27	40	53	21	54	60	0	21	52	39	50	5	23	35	32	36	52	75	9	30	31	34
12	17	16	37	41	32	31	35	9	27	36	55	19	56	53	30	16	44	33	6	24	43	42	34	53	21	0	46	19	30	17	16	18	11	16	32	55	28	28	20	18
39	35	35	48	84	57	15	29	54	56	11	12	34	10	8	26	38	88	29	47	66	87	61	50	9	52	46	0	50	49	51	32	36	48	54	45	64	52	22	66	33
15	32	17	21	35	50	37	28	16	9	40	56	17	60	56	27	32	40	27	13	17	40	60	18	56	39	19	50	0	13	35	29	15	8	6	18	38	46	38	23	18
22	40	22	9	43	61	38	22	29	9	40	52	19	58	53	24	40	48	21	24	28	49	70	5	53	50	30	49	13	0	46	35	18	19	19	6	26	57	42	36	21
26	16	29	53	50	16	37	47	22	44	41	61	32	60	58	41	13	52	45	23	36	50	26	50	59	5	17	51	35	46	0	21	32	28	31	48	71	13	29	28	31
15	6	14	40	56	31	17	29	25	37	22	41	17	41	39	23	9	60	27	19	39	59	39	39	39	23	16	32	29	35	21	0	17	23	29	35	59	26	12	36	15
7	23	4	23	49	45	22	18	22	22	26	42	2	45	42	13	24	54	16	15	31	53	54	22	42	35	18	36	15	18	32	17	0	14	19	18	42	41	25	33	3
10	26	14	27	36	43	34	30	11	17	38	55	15	58	54	26	25	41	28	5	18	40	52	24	54	32	11	48	8	19	28	23	14	0	7	23	45	39	33	20	15
16	31	20	27	30	47	40	34	11	13	44	60	20	64	60	31	31	35	32	11	13	35	56	23	60	36	16	54	6	19	31	29	19	7	0	24	43	43	39	17	21
22	40	21	5	48	62	35	17	33	15	37	47	18	53	49	20	41	54	16	27	33	54	71	6	48	52	32	45	18	6	48	35	18	23	24	0	25	58	40	41	20
47	64	46	20	58	86	57	36	53	30	58	62	42	71	66	41	65	64	37	50	48	64	95	22	65	75	55	64	38	26	71	59	42	45	43	25	0	82	64	58	45
36	20	38	63	62	6	40	55	34	55	44	63	41	59	59	48	18	63	53	34	48	61	14	61	60	9	28	52	46	57	13	26	41	39	43	58	82	0	31	40	39
24	14	22	45	68	36	10	30	37	46	14	33	24	31	29	24	17	72	29	30	50	70	41	45	30	30	28	22	38	42	29	12	25	33	39	40	64	31	0	48	22
28	36	33	44	23	41	51	50	12	29	55	73	35	76	73	46	34	25	48	19	12	24	51	40	73	31	20	66	23	36	28	36	33	20	17	41	58	40	48	0	34
7	20	2	25	51	44	19	18	23	25	23	40	3	43	39	13	22	56	16	16	33	55	52	24	39	34	18	33	18	21	31	15	3	15	21	20	45	39	22	34	0

Table F.44:Distance Matrix 40.2

51	4	12	30	13	32	20	53	29	32	23	32	12	24	50	37	46	11	7	11	6	25	23	40	10	6	10	40	58	51	49	51	26	38	47	40	14	53	24	30

Table F.45:Demand 40.3

0	12	30	50	28	49	25	8	14	2	23	23	20	33	47	49	20	27	50	12	20	17	41	25	9	30	10	25	14	15	30	22	8	42	22	49	24	25	17	18	24
12	0	26	61	37	57	36	17	25	11	29	30	31	23	57	45	9	38	60	21	9	22	37	33	19	40	15	34	10	21	36	12	13	39	32	55	28	31	25	29	14
30	26	0	58	57	78	52	27	40	30	51	27	41	41	56	20	22	42	57	41	21	45	12	31	28	43	38	31	35	44	59	19	35	14	50	78	52	54	47	38	19
50	61	58	0	54	66	43	44	42	52	60	33	34	83	5	67	66	24	1	52	65	60	61	29	42	22	56	29	64	58	66	66	56	61	49	75	65	60	56	34	68
28	37	57	54	0	21	11	31	19	28	11	41	24	49	49	76	45	34	54	17	45	18	68	40	30	36	22	41	31	17	13	48	24	69	8	24	17	10	13	26	50
49	57	78	66	21	0	29	52	39	49	29	61	42	65	61	97	64	51	67	37	65	36	88	59	51	52	42	60	49	37	24	68	44	90	28	11	32	26	32	45	70
25	36	52	43	11	29	0	25	12	26	19	32	14	52	38	70	44	23	43	16	43	22	61	31	24	25	23	32	32	21	23	47	24	63	7	34	24	18	16	16	49
8	17	27	44	31	52	25	0	13	9	28	16	17	39	41	46	23	22	44	17	22	23	37	18	3	24	17	19	21	21	36	25	14	39	24	54	30	30	22	14	26
14	25	40	42	19	39	12	13	0	15	20	23	9	44	38	58	33	19	42	10	33	19	50	22	12	21	15	23	24	17	27	36	15	51	12	43	24	21	15	9	38
2	11	30	52	28	49	26	9	15	0	22	24	21	32	48	49	19	29	51	12	19	17	41	26	10	31	9	27	13	15	30	22	7	42	22	49	23	25	18	19	24
23	29	51	60	11	29	19	28	20	22	0	41	27	38	55	71	36	38	59	12	37	8	63	41	28	40	14	42	21	9	9	40	17	64	12	28	6	3	6	27	42
23	30	27	33	41	61	32	16	23	24	41	0	20	52	30	41	34	16	32	30	33	38	33	5	14	16	31	5	36	36	49	34	30	34	34	65	44	43	36	17	35
20	31	41	34	24	42	14	17	9	21	27	20	0	52	30	59	38	12	34	18	38	26	50	18	15	14	23	19	32	25	34	41	23	52	17	47	31	28	22	4	42
33	23	41	83	49	65	52	39	44	32	38	52	52	0	79	58	21	60	82	36	22	32	52	55	41	62	30	56	21	32	42	24	29	53	46	60	34	40	37	50	24
47	57	56	5	49	61	38	41	38	48	55	30	30	79	0	67	63	20	6	47	62	56	60	26	39	18	52	26	60	54	61	63	52	61	44	70	60	55	51	30	65
49	45	20	67	76	97	70	46	58	49	71	41	59	58	67	0	40	56	66	61	39	65	9	45	47	57	58	44	55	63	79	36	55	8	69	98	71	73	66	56	36
20	9	22	66	45	64	44	23	33	19	36	34	38	21	63	40	0	44	65	29	1	29	33	37	25	46	23	38	16	28	43	5	21	34	40	63	35	39	33	36	6
27	38	42	24	34	51	23	22	19	29	38	16	12	60	20	56	44	0	23	29	44	37	48	12	20	3	33	12	40	35	44	45	32	49	28	57	42	39	33	11	47
50	60	57	1	54	67	43	44	42	51	59	32	34	82	6	66	65	23	0	52	64	60	60	28	42	21	56	28	63	58	65	65	55	61	48	75	64	60	55	34	67
12	21	41	52	17	37	16	17	10	12	12	30	18	36	47	61	29	29	52	0	29	9	52	31	17	31	7	32	16	7	20	32	8	54	11	38	15	14	6	18	34
20	9	21	65	45	65	43	22	33	19	37	33	38	22	62	39	1	44	64	29	0	30	32	37	25	45	24	37	17	29	44	4	21	33	40	63	35	39	33	36	6
17	22	45	60	18	36	22	23	19	17	8	38	26	32	56	65	29	37	60	9	30	0	57	38	24	39	8	39	14	2	15	33	10	58	16	34	7	10	6	26	35
41	37	12	61	68	88	61	37	50	41	63	33	50	52	60	9	33	48	60	52	32	57	0	37	38	49	49	37	47	55	71	29	47	2	61	90	63	65	58	47	29
25	33	31	29	40	59	31	18	22	26	41	5	18	55	26	45	37	12	28	31	37	38	37	0	16	13	33	1	38	36	49	38	31	38	33	64	45	42	36	15	39
9	19	28	42	30	51	24	3	12	10	28	14	15	41	39	47	25	20	42	17	25	24	38	16	0	22	17	17	22	22	36	27	16	40	23	53	30	30	22	12	29
30	40	43	22	36	52	25	24	21	31	40	16	14	62	18	57	46	3	21	31	45	39	49	13	22	0	35	13	43	37	47	47	35	50	30	59	44	41	35	13	49
10	15	38	56	22	42	23	17	15	9	14	31	23	30	52	58	23	33	56	7	24	8	49	33	17	35	0	34	10	6	22	27	3	51	18	41	14	16	10	22	29
25	34	31	29	41	60	32	19	23	27	42	5	19	56	26	44	38	12	28	32	37	39	37	1	17	13	34	0	39	37	50	38	32	38	34	65	46	43	37	16	40
14	10	35	64	31	49	32	21	24	13	21	36	32	21	60	55	16	40	63	16	17	14	47	38	22	43	10	39	0	14	27	20	9	48	27	47	19	23	18	30	22
15	21	44	58	17	37	21	21	17	15	9	36	25	32	54	63	28	35	58	7	29	2	55	36	22	37	6	37	14	0	16	32	9	56	15	35	9	11	6	25	34
30	36	59	66	13	24	23	36	27	30	9	49	34	42	61	79	43	44	65	20	44	15	71	49	36	47	22	50	27	16	0	47	25	72	18	20	9	7	14	35	49
22	12	19	66	48	68	47	25	36	22	40	34	41	24	63	36	5	45	65	32	4	33	29	38	27	47	27	38	20	32	47	0	25	31	43	67	39	43	37	38	2
8	13	35	56	24	44	24	14	15	7	17	30	23	29	52	55	21	32	55	8	21	10	47	31	16	35	3	32	9	9	25	25	0	48	19	44	17	19	13	22	26
42	39	14	61	69	90	63	39	51	42	64	34	52	53	61	8	34	49	61	54	33	58	2	38	40	50	51	38	48	56	72	31	48	0	62	91	65	66	59	48	30
22	32	50	49	8	28	7	24	12	22	12	34	17	46	44	69	40	28	48	11	40	16	61	33	23	30	18	34	27	15	18	43	19	62	0	31	18	12	10	19	45
49	55	78	75	24	11	34	54	43	49	28	65	47	60	70	98	63	57	75	38	63	34	90	64	53	59	41	65	47	35	20	67	44	91	31	0	29	25	32	49	69
24	28	52	65	17	32	24	30	24	23	6	44	31	34	60	71	35	42	64	15	35	7	63	45	30	44	14	46	19	9	9	39	17	65	18	29	0	7	10	32	40
25	31	54	60	10	26	18	30	21	25	3	43	28	40	55	73	39	39	60	14	39	10	65	42	30	41	16	43	23	11	7	43	19	66	12	25	7	0	8	29	44
17	25	47	56	13	32	16	22	15	18	6	36	22	37	51	66	33	33	55	6	33	6	58	36	22	35	10	37	18	6	14	37	13	59	10	32	10	8	0	23	38
18	29	38	34	26	45	16	14	9	19	27	17	4	50	30	56	36	11	34	18	36	26	47	15	12	13	22	16	30	25	35	38	22	48	19	49	32	29	23	0	40
24	14	19	68	50	70	49	26	38	24	42	35	42	24	65	36	6	47	67	34	6	35	29	39	29	49	29	40	22	34	49	2	26	30	45	69	40	44	38	40	0

Table F.46:Distance Matrix 40.3

55	39	45	30	25	16	24	9	38	46	20	13	21	4	53	39	6	35	17	41	60	36	45	60	10	21	41	53	16	30	7	41	53	54	21	49	51	24	15	5

Table F.47:Demand 40.4

0	43	22	19	17	9	22	11	25	23	18	27	20	48	17	20	21	32	14	31	20	29	43	23	49	25	14	21	5	21	20	39	25	11	17	17	22	47	45	25	16
43	0	52	27	55	40	42	47	27	23	33	54	59	60	42	63	37	75	35	13	63	49	85	58	66	57	42	33	42	60	59	4	29	49	46	39	60	10	5	19	44
22	52	0	36	12	16	44	12	43	30	19	48	35	28	39	29	43	34	19	41	25	12	41	41	70	5	11	21	27	15	13	50	44	13	7	14	39	52	53	36	38
19	27	36	0	34	21	18	27	8	16	21	29	33	56	16	37	13	50	19	16	38	39	60	31	45	40	25	23	16	38	38	24	9	28	29	25	33	34	30	11	17
17	55	12	34	0	15	37	9	41	33	24	39	24	39	32	18	37	24	21	43	13	23	32	31	61	11	15	26	21	5	5	52	40	7	13	19	29	57	57	37	31
9	40	16	21	15	0	30	7	28	18	11	35	27	40	25	26	27	36	7	29	24	21	46	31	57	20	6	14	13	20	19	37	28	9	9	9	31	43	42	22	24
22	42	44	18	37	30	0	33	15	33	35	12	24	68	6	32	6	45	32	33	36	50	55	19	29	47	35	38	18	41	41	39	13	33	38	37	22	50	46	29	8
11	47	12	27	9	7	33	0	34	25	16	37	25	39	27	22	32	31	13	35	19	20	40	30	58	14	8	19	15	14	13	44	34	3	8	12	29	49	49	29	26
25	27	43	8	41	28	15	34	0	23	29	27	35	63	16	41	10	54	27	19	43	46	64	33	40	47	33	30	21	45	45	24	2	34	37	32	35	36	31	16	18
23	23	30	16	33	18	33	25	23	0	11	43	42	43	30	43	28	54	12	13	42	28	63	43	61	34	19	11	23	38	37	20	24	27	23	16	44	25	24	8	31
18	33	19	21	24	11	35	16	29	11	0	43	38	35	31	37	32	46	4	23	34	18	55	41	63	24	10	3	21	29	27	31	30	19	13	6	40	34	34	18	31
27	54	48	29	39	35	12	37	27	43	43	0	19	74	14	28	17	40	39	44	33	56	49	11	23	49	41	46	23	41	42	50	25	36	43	43	15	62	58	40	13
20	59	35	33	24	27	24	25	35	42	38	19	0	63	20	10	27	22	34	48	15	45	31	8	39	35	32	41	19	25	26	56	34	24	33	36	5	65	62	42	18
48	60	28	56	39	40	68	39	63	43	35	74	63	0	64	57	66	60	37	53	52	19	65	68	96	29	34	33	52	41	39	59	64	40	32	32	67	55	59	50	63
17	42	39	16	32	25	6	27	16	30	31	14	20	64	0	27	7	40	27	32	31	45	50	17	33	41	30	34	13	35	36	39	15	27	33	32	20	49	45	27	3
20	63	29	37	18	26	32	22	41	43	37	28	10	57	27	0	34	13	33	51	6	40	24	18	49	28	29	39	22	17	18	59	40	20	29	33	14	67	65	44	25
21	37	43	13	37	27	6	32	10	28	32	17	27	66	7	34	0	47	29	28	37	48	57	23	33	45	33	34	17	41	41	34	9	32	36	34	26	45	41	24	9
32	75	34	50	24	36	45	31	54	54	46	40	22	60	40	13	47	0	43	63	13	45	11	29	58	32	38	49	34	20	22	71	53	28	36	42	25	78	77	56	38
14	35	19	19	21	7	32	13	27	12	4	39	34	37	27	33	29	43	0	24	31	20	52	37	60	23	8	7	17	26	25	32	28	15	12	6	36	37	36	18	27
31	13	41	16	43	29	33	35	19	13	23	44	48	53	32	51	28	63	24	0	51	40	73	47	58	46	31	22	30	48	47	9	21	37	35	28	49	18	15	7	33
20	63	25	38	13	24	36	19	43	42	34	33	15	52	31	6	37	13	31	51	0	36	23	23	54	23	26	37	23	11	13	59	43	17	25	31	19	66	65	44	29
29	49	12	39	23	21	50	20	46	28	18	56	45	19	45	40	48	45	20	40	36	0	52	50	77	14	15	18	33	26	24	47	47	22	13	14	49	47	49	35	44
43	85	41	60	32	46	55	40	64	63	55	49	31	65	50	24	57	11	52	73	23	52	0	38	66	38	47	58	45	28	30	81	64	38	44	51	34	88	87	66	48
23	58	41	31	31	31	19	30	33	43	41	11	8	68	17	18	23	29	37	47	23	50	38	0	32	42	36	44	20	32	33	55	31	29	38	40	4	65	61	42	15
49	66	70	45	61	57	29	58	40	61	63	23	39	96	33	49	33	58	60	58	54	77	66	32	0	71	62	66	45	63	64	63	38	58	65	64	35	75	70	56	33
25	57	5	40	11	20	47	14	47	34	24	49	35	29	41	28	45	32	23	46	23	14	38	42	71	0	16	25	29	13	11	54	47	14	12	19	39	57	57	40	40
14	42	11	25	15	6	35	8	33	19	10	41	32	34	30	29	33	38	8	31	26	15	47	36	62	16	0	12	18	20	18	39	33	10	4	5	35	43	43	25	30
21	33	21	23	26	14	38	19	30	11	3	46	41	33	34	39	34	49	7	22	37	18	58	44	66	25	12	0	24	31	29	30	32	21	15	8	43	32	33	18	34
5	42	27	16	21	13	18	15	21	23	21	23	19	52	13	22	17	34	17	30	23	33	45	20	45	29	18	24	0	24	25	38	21	15	21	21	21	47	44	24	12
21	60	15	38	5	20	41	14	45	38	29	41	25	41	35	17	41	20	26	48	11	26	28	32	63	13	20	31	24	0	2	57	45	12	17	24	29	62	62	42	33
20	59	13	38	5	19	41	13	45	37	27	42	26	39	36	18	41	22	25	47	13	24	30	33	64	11	18	29	25	2	0	56	45	11	15	22	30	61	60	41	34
39	4	50	24	52	37	39	44	24	20	31	50	56	59	39	59	34	71	32	9	59	47	81	55	63	54	39	30	38	57	56	0	26	46	43	36	57	13	8	15	40
25	29	44	9	40	28	13	34	2	24	30	25	34	64	15	40	9	53	28	21	43	47	64	31	38	47	33	32	21	45	45	26	0	35	37	33	34	38	33	18	17
11	49	13	28	7	9	33	3	34	27	19	36	24	40	27	20	32	28	15	37	17	22	38	29	58	14	10	21	15	12	11	46	35	0	10	14	27	51	50	31	26
17	46	7	29	13	9	38	8	37	23	13	43	33	32	33	29	36	36	12	35	25	13	44	38	65	12	4	15	21	17	15	43	37	10	0	8	36	47	47	29	32
17	39	14	25	19	9	37	12	32	16	6	43	36	32	32	33	34	42	6	28	31	14	51	40	64	19	5	8	21	24	22	36	33	14	8	0	39	39	39	23	32
22	60	39	33	29	31	22	29	35	44	40	15	5	67	20	14	26	25	36	49	19	49	34	4	35	39	35	43	21	29	30	57	34	27	36	39	0	66	63	43	17
47	10	52	34	57	43	50	49	36	25	34	62	65	55	49	67	45	78	37	18	66	47	88	65	75	57	43	32	47	62	61	13	38	51	47	39	66	0	6	24	51
45	5	53	30	57	42	46	49	31	24	34	58	62	59	45	65	41	77	36	15	65	49	87	61	70	57	43	33	44	62	60	8	33	50	47	39	63	6	0	21	47
25	19	36	11	37	22	29	29	16	8	18	40	42	50	27	44	24	56	18	7	44	35	66	42	56	40	25	18	24	42	41	15	18	31	29	23	43	24	21	0	28
16	44	38	17	31	24	8	26	18	31	31	13	18	63	3	25	9	38	27	33	29	44	48	15	33	40	30	34	12	33	34	40	17	26	32	32	17	51	47	28	0

Table F.48:Distance 40.4

26	57	1	58	47	6	20	30	17	3	35	43	16	26	28	2	19	16	5	44	24	60	36	4	19	4	35	28	1	23	40	33	25	47	19	27	38	44	24	15

Table F.49:Demand 40.5

0	21	39	21	44	29	24	47	8	13	48	17	5	26	19	13	8	45	25	23	43	30	21	15	39	26	23	8	18	11	10	27	15	7	24	19	24	20	44	7	42
21	0	54	38	29	45	43	64	17	20	39	25	17	44	39	32	14	62	39	32	55	20	23	35	56	27	14	14	18	16	17	46	28	27	38	3	21	17	35	27	34
39	54	0	20	59	52	21	62	39	51	87	30	39	47	27	29	44	63	54	23	8	47	60	28	57	64	45	44	57	38	49	46	51	39	16	51	63	40	83	34	81
21	38	20	0	52	35	7	48	22	32	68	17	22	30	10	9	26	48	36	16	25	37	41	9	41	45	33	26	38	23	30	30	32	20	8	36	44	28	64	15	63
44	29	59	52	0	71	58	90	37	48	62	35	39	69	57	50	38	88	67	38	57	15	52	53	82	56	21	38	47	34	44	71	55	50	47	28	49	25	60	47	59
29	45	52	35	71	0	31	19	36	27	54	42	34	6	26	28	34	17	8	47	58	58	29	27	11	30	51	34	32	39	29	7	18	22	42	45	34	48	50	27	49
24	43	21	7	58	31	0	42	27	34	70	23	26	26	7	11	30	43	34	22	28	44	42	9	37	46	39	30	40	28	32	26	32	21	14	41	46	34	66	17	64
47	64	62	48	90	19	42	0	54	45	69	59	51	21	39	43	53	5	26	62	69	76	47	41	8	46	69	53	50	57	48	20	37	40	55	64	52	66	65	44	64
8	17	39	22	37	36	27	54	0	17	49	12	3	33	23	17	5	52	32	19	42	23	25	19	46	30	16	5	21	4	13	34	22	14	23	14	26	13	45	11	44
13	20	51	32	48	27	34	45	17	0	37	28	15	27	28	24	12	43	20	35	55	35	9	25	38	14	29	12	7	20	4	29	9	14	36	20	12	28	32	18	31
48	39	87	68	62	54	70	69	49	37	0	60	49	57	64	60	44	65	46	68	90	57	29	61	63	26	52	44	30	51	39	59	40	50	71	41	25	55	5	54	6
17	25	30	17	35	42	23	59	12	28	60	0	13	39	23	17	17	58	40	8	31	21	36	19	51	41	17	17	32	10	24	39	32	21	15	22	37	12	56	15	55
5	17	39	22	39	34	26	51	3	15	49	13	0	31	22	15	5	50	30	21	42	25	23	18	44	28	18	5	19	6	11	32	20	12	23	16	25	15	44	10	43
26	44	47	30	69	6	26	21	33	27	57	39	31	0	20	23	33	20	12	42	53	55	31	22	14	32	49	33	32	36	28	2	19	20	37	44	36	45	52	24	51
19	39	27	10	57	26	7	39	23	28	64	23	22	20	0	7	25	39	27	24	33	42	36	5	32	40	37	25	35	25	27	21	25	15	17	37	40	32	60	12	58
13	32	29	9	50	28	11	43	17	24	60	17	15	23	7	0	20	42	28	19	34	36	32	3	36	37	30	20	30	18	22	24	23	11	15	31	36	26	56	7	54
8	14	44	26	38	34	30	53	5	12	44	17	5	33	25	20	0	51	30	24	46	24	20	22	45	25	17	0	16	8	8	34	19	14	28	12	21	16	40	13	39
45	62	63	48	88	17	43	5	52	43	65	58	50	20	39	42	51	0	23	61	70	74	43	41	7	43	67	51	47	55	45	19	34	39	55	61	48	64	61	43	60
25	39	54	36	67	8	34	26	32	20	46	40	30	12	27	28	30	23	0	46	60	53	21	27	19	22	47	30	24	35	23	13	12	20	42	39	26	44	42	26	41
23	32	23	16	38	47	22	62	19	35	68	8	21	42	24	19	24	61	46	0	24	25	43	21	55	48	22	24	39	18	31	43	38	27	10	29	45	17	64	20	63
43	55	8	25	57	58	28	69	42	55	90	31	42	53	33	34	46	70	60	24	0	46	64	34	64	69	45	46	61	40	52	53	56	44	20	53	66	40	86	38	85
30	20	47	37	15	58	44	76	23	35	57	21	25	55	42	36	24	74	53	25	46	0	41	38	68	46	7	24	36	20	32	56	43	36	34	17	40	10	54	32	52
21	23	60	41	52	29	42	47	25	9	29	36	23	31	36	32	20	43	21	43	64	41	0	33	39	6	35	20	6	27	13	33	13	22	45	24	6	35	24	27	23
15	35	28	9	53	27	9	41	19	25	61	19	18	22	5	3	22	41	27	21	34	38	33	0	34	37	33	22	31	20	23	22	23	12	16	33	37	28	57	9	55
39	56	57	41	82	11	37	8	46	38	63	51	44	14	32	36	45	7	19	55	64	68	39	34	0	39	61	45	42	49	40	13	29	33	49	56	44	58	59	37	58
26	27	64	45	56	30	46	46	30	14	26	41	28	32	40	37	25	43	22	48	69	46	6	37	39	0	40	25	10	33	18	34	15	26	49	29	8	40	21	31	20
23	14	45	33	21	51	39	69	16	29	52	17	18	49	37	30	17	67	47	22	45	7	35	33	61	40	0	17	30	13	25	50	36	29	31	12	34	5	49	26	48
8	14	44	26	38	34	30	53	5	12	44	17	5	33	25	20	0	51	30	24	46	24	20	22	45	25	17	0	16	8	8	34	19	14	28	12	21	16	40	13	39
18	18	57	38	47	32	40	50	21	7	30	32	19	32	35	30	16	47	24	39	61	36	6	31	42	10	30	16	0	23	9	34	14	20	42	19	6	30	26	24	25
11	16	38	23	34	39	28	57	4	20	51	10	6	36	25	18	8	55	35	18	40	20	27	20	49	33	13	8	23	0	16	37	25	17	22	14	28	10	47	14	45
10	17	49	30	44	29	32	48	13	4	39	24	11	28	27	22	8	45	23	31	52	32	13	23	40	18	25	8	9	16	0	30	12	13	33	17	15	24	35	16	33
27	46	46	30	71	7	26	20	34	29	59	39	32	2	21	24	34	19	13	43	53	56	33	22	13	34	50	34	34	37	30	0	21	21	37	45	38	47	54	25	53
15	28	51	32	55	18	32	37	22	9	40	32	20	19	25	23	19	34	12	38	56	43	13	23	29	15	36	19	14	25	12	21	0	13	37	28	18	34	36	19	35
7	27	39	20	50	22	21	40	14	14	50	21	12	20	15	11	14	39	20	27	44	36	22	12	33	26	29	14	20	17	13	21	13	0	25	26	26	26	45	7	44
24	38	16	8	47	42	14	55	23	36	71	15	23	37	17	15	28	55	42	10	20	34	45	16	49	49	31	28	42	22	33	37	37	25	0	36	47	26	67	19	66
19	3	51	36	28	45	41	64	14	20	41	22	16	44	37	31	12	61	39	29	53	17	24	33	56	29	12	12	19	14	17	45	28	26	36	0	23	14	38	25	36
24	21	63	44	49	34	46	52	26	12	25	37	25	36	40	36	21	48	26	45	66	40	6	37	44	8	34	21	6	28	15	38	18	26	47	23	0	34	20	30	19
20	17	40	28	25	48	34	66	13	28	55	12	15	45	32	26	16	64	44	17	40	10	35	28	58	40	5	16	30	10	24	47	34	26	26	14	34	0	51	22	50
44	35	83	64	60	50	66	65	45	32	5	56	44	52	60	56	40	61	42	64	86	54	24	57	59	21	49	40	26	47	35	54	36	45	67	38	20	51	0	50	2
7	27	34	15	47	27	17	44	11	18	54	15	10	24	12	7	13	43	26	20	38	32	27	9	37	31	26	13	24	14	16	25	19	7	19	25	30	22	50	0	48
42	34	81	63	59	49	64	64	44	31	6	55	43	51	58	54	39	60	41	63	85	52	23	55	58	20	48	39	25	45	33	53	35	44	66	36	19	50	2	48	0

Table F.50:Distance Matrix 40.5

49	14	32	41	2	40	25	36	11	21	58	58	40	41	33	25	41	20	47	48	11	53	35	7	36	40	36	41	60	39	13	47	3	47	24	13	3	57	33	10

Table F.51:Demand 40.6

0	16	46	5	24	26	17	22	15	26	29	26	16	15	6	23	19	49	27	38	14	11	20	30	25	14	22	8	20	47	26	20	26	9	22	46	11	28	22	13	29
16	0	61	13	33	38	32	11	13	32	43	19	31	28	21	23	34	58	13	26	24	17	34	20	40	29	31	9	17	61	23	19	37	9	16	41	26	15	13	17	44
46	61	0	48	35	27	30	67	53	58	18	60	30	34	43	62	28	60	72	83	39	46	39	75	28	34	38	53	55	10	56	52	47	54	58	69	35	74	67	47	18
5	13	48	0	23	26	19	20	10	30	31	21	19	15	10	25	22	53	25	37	13	8	24	30	28	18	21	5	16	49	22	15	30	8	18	42	14	27	21	9	31
24	33	35	23	0	8	19	42	22	48	22	26	18	11	26	46	20	65	45	58	11	17	34	51	30	23	4	27	22	32	22	19	44	30	26	36	19	48	43	17	18
26	38	27	26	8	0	16	46	28	48	14	34	15	12	26	47	15	61	50	63	15	22	31	55	25	21	12	31	30	24	30	26	41	34	33	44	19	52	47	23	10
17	32	30	19	19	16	0	38	26	33	13	36	2	10	14	34	3	47	43	54	14	20	16	46	12	6	20	24	31	32	34	28	26	25	34	52	6	44	37	22	15
22	11	67	20	42	46	38	0	23	27	50	29	38	35	25	17	40	55	6	17	32	26	35	10	44	34	40	15	26	68	33	29	36	13	26	50	32	7	3	26	51
15	13	53	10	22	28	26	23	0	39	36	11	26	19	20	32	29	63	25	38	14	8	34	32	37	26	19	12	6	52	12	7	40	14	8	32	22	27	25	6	35
26	32	58	30	48	48	33	27	39	0	43	49	34	38	23	11	34	28	33	36	38	36	20	29	31	28	47	28	44	63	50	44	13	25	45	70	29	32	25	38	47
29	43	18	31	22	14	13	50	36	43	0	45	13	18	26	45	10	51	55	66	23	29	24	58	15	17	24	35	40	21	42	37	34	37	43	57	18	56	49	31	6
26	19	60	21	26	34	36	29	11	49	45	0	35	28	31	42	38	74	29	42	23	17	45	38	47	36	23	22	6	57	5	8	51	24	4	22	32	32	31	15	42
16	31	30	19	18	15	2	38	26	34	13	35	0	9	14	35	3	48	42	54	13	18	17	46	14	6	19	23	30	32	33	27	27	25	33	51	6	44	37	21	14
15	28	34	15	11	12	10	35	19	38	18	28	9	0	16	36	11	55	39	52	5	12	24	44	22	13	11	20	23	34	25	20	33	23	26	43	9	42	36	14	17
6	21	43	10	26	26	14	25	20	23	26	31	14	16	0	21	16	44	30	40	16	15	14	32	20	10	25	12	26	45	31	25	21	13	28	51	9	31	24	17	28
23	23	62	25	46	47	34	17	32	11	45	42	35	36	21	0	36	38	23	26	36	32	25	19	35	29	45	21	38	65	44	38	21	19	38	63	29	22	15	33	48
19	34	28	22	20	15	3	40	29	34	10	38	3	11	16	36	0	47	45	56	16	21	17	48	11	7	21	26	33	30	36	30	27	27	36	53	9	47	40	24	13
49	58	60	53	65	61	47	55	63	28	51	74	48	55	44	38	47	0	61	62	58	58	32	55	37	43	66	53	69	68	74	68	23	51	70	94	47	60	52	61	57
27	13	72	25	45	50	43	6	25	33	55	29	42	39	30	23	45	61	0	14	36	29	41	10	49	39	43	20	27	73	33	30	42	18	26	48	37	3	9	29	55
38	26	83	37	58	63	54	17	38	36	66	42	54	52	40	26	56	62	14	0	49	42	49	9	58	50	56	32	41	85	46	44	47	30	39	61	48	11	17	42	67
14	24	39	13	11	15	14	32	14	38	23	23	13	5	16	36	16	58	36	49	0	8	27	42	26	16	10	17	18	38	20	15	35	20	21	38	12	38	33	9	21
11	17	46	8	17	22	20	26	8	36	29	17	18	12	15	32	21	58	29	42	8	0	29	35	30	19	14	12	12	45	16	10	36	15	15	36	15	32	27	3	28
20	34	39	24	34	31	16	35	34	20	24	45	17	24	14	25	17	32	41	49	27	29	0	41	11	12	35	26	39	44	44	38	11	26	42	64	15	42	34	31	29
30	20	75	30	51	55	46	10	32	29	58	38	46	44	32	19	48	55	10	9	42	35	41	0	50	42	49	25	36	77	42	38	39	22	34	58	40	7	9	36	59
25	40	28	28	30	25	12	44	37	31	15	47	14	22	20	35	11	37	49	58	26	30	11	50	0	12	32	32	42	33	45	39	20	32	44	64	16	50	43	33	20
14	29	34	18	23	21	6	34	26	28	17	36	6	13	10	29	7	43	39	50	16	19	12	42	12	0	24	21	31	37	35	29	21	22	33	54	5	41	34	22	20
22	31	38	21	4	12	20	40	19	47	24	23	19	11	25	45	21	66	43	56	10	14	35	49	32	24	0	25	19	35	19	16	44	28	22	33	20	45	41	14	21
8	9	53	5	27	31	24	15	12	28	35	22	23	20	12	21	26	53	20	32	17	12	26	25	32	21	25	0	17	54	23	18	31	3	18	43	18	22	16	12	36
20	17	55	16	22	30	31	26	6	44	40	6	30	23	26	38	33	69	27	41	18	12	39	36	42	31	19	17	0	53	7	4	46	20	4	26	26	30	29	10	38
47	61	10	49	32	24	32	68	52	63	21	57	32	34	45	65	30	68	73	85	38	45	44	77	33	37	35	54	53	0	53	50	53	56	56	64	38	75	68	46	18
26	23	56	22	22	30	34	33	12	50	42	5	33	25	31	44	36	74	33	46	20	16	44	42	45	35	19	23	7	53	0	7	51	26	8	20	30	36	35	14	39
20	19	52	15	19	26	28	29	7	44	37	8	27	20	25	38	30	68	30	44	15	10	38	38	39	29	16	18	4	50	7	0	45	20	7	27	24	33	31	8	34
26	37	47	30	44	41	26	36	40	13	34	51	27	33	21	21	27	23	42	47	35	36	11	39	20	21	44	31	46	53	51	45	0	29	48	71	25	41	34	38	39
9	9	54	8	30	34	25	13	14	25	37	24	25	23	13	19	27	51	18	30	20	15	26	22	32	22	28	3	20	56	26	20	29	0	20	45	19	20	14	15	38
22	16	58	18	26	33	34	26	8	45	43	4	33	26	28	38	36	70	26	39	21	15	42	34	44	33	22	18	4	56	8	7	48	20	0	26	29	29	28	13	41
46	41	69	42	36	44	52	50	32	70	57	22	51	43	51	63	53	94	48	61	38	36	64	58	64	54	33	43	26	64	20	27	71	45	26	0	49	51	52	34	53
11	26	35	14	19	19	6	32	22	29	18	32	6	9	9	29	9	47	37	48	12	15	15	40	16	5	20	18	26	38	30	24	25	19	29	49	0	39	32	17	20
28	15	74	27	48	52	44	7	27	32	56	32	44	42	31	22	47	60	3	11	38	32	42	7	50	41	45	22	30	75	36	33	41	20	29	51	39	0	9	31	57
22	13	67	21	43	47	37	3	25	25	49	31	37	36	24	15	40	52	9	17	33	27	34	9	43	34	41	16	29	68	35	31	34	14	28	52	32	9	0	27	51
13	17	47	9	17	23	22	26	6	38	31	15	21	14	17	33	24	61	29	42	9	3	31	36	33	22	14	12	10	46	14	8	38	15	13	34	17	31	27	0	30
29	44	18	31	18	10	15	51	35	47	6	42	14	17	28	48	13	57	55	67	21	28	29	59	20	20	21	36	38	18	39	34	39	38	41	53	20	57	51	30	0

Table F.52:Distance Matrix 40.6

23	19	21	45	24	48	9	44	51	32	36	54	59	47	4	58	24	34	4	34	42	14	44	47	14	33	50	36	5	13	20	60	48	35	23	16	19	39	56	51

Table F.53:Demand 40.7

0	20	17	20	50	23	4	12	16	47	26	47	37	26	13	19	10	14	50	15	25	24	22	24	14	25	21	18	22	22	34	15	9	23	14	14	24	48	22	26	49
20	0	12	17	50	8	22	31	28	66	43	66	56	34	8	37	30	32	57	20	29	12	17	22	21	32	37	24	8	42	53	34	29	42	19	24	34	66	23	43	43
17	12	0	6	59	19	17	28	18	63	33	63	53	22	11	28	26	24	45	25	35	22	7	30	11	37	27	29	19	35	50	28	25	34	8	27	23	64	12	33	53
20	17	6	0	64	24	20	31	17	66	32	66	55	19	17	29	30	25	41	30	40	28	2	35	10	42	26	34	24	37	53	30	27	35	8	31	20	67	7	32	59
50	50	59	64	0	43	54	49	66	61	73	61	59	76	48	66	50	62	100	36	26	39	65	30	62	27	69	33	42	62	57	58	53	65	62	37	74	62	69	73	16
23	8	19	24	43	0	25	32	33	65	47	65	56	40	11	41	31	36	64	17	24	5	24	16	27	27	41	20	2	44	53	37	31	45	26	22	40	66	30	47	35
4	22	17	20	54	25	0	12	13	47	23	47	37	23	16	16	10	11	47	19	28	27	21	27	12	28	17	21	25	20	34	13	8	20	13	17	21	48	21	23	53
12	31	28	31	49	32	12	0	23	36	25	36	26	33	24	18	2	15	55	19	24	31	33	27	23	22	22	18	30	15	23	10	6	17	25	14	29	37	32	25	51
16	28	18	17	66	33	13	23	0	54	16	54	43	11	23	13	21	10	35	31	41	36	18	39	7	40	10	34	33	22	40	17	18	20	10	30	8	54	13	16	64
47	66	63	66	61	65	47	36	54	0	46	0	12	62	58	42	38	44	79	49	47	63	68	55	57	43	47	46	64	33	14	37	39	35	59	44	58	1	66	46	71
26	43	33	32	73	47	23	25	16	46	0	46	35	19	37	8	24	13	34	40	48	49	33	49	23	47	6	42	46	15	33	16	21	12	25	37	15	46	28	0	74
47	66	63	66	61	65	47	36	54	0	46	0	12	62	58	42	38	44	79	49	47	63	68	55	57	43	47	46	64	33	14	37	39	35	59	44	58	1	66	46	71
37	56	53	55	59	56	37	26	43	12	35	12	0	51	49	31	27	33	67	41	42	56	57	48	46	38	36	39	55	21	4	26	29	24	48	36	46	12	55	35	68
26	34	22	19	76	40	23	33	11	62	19	62	51	0	31	20	31	20	25	41	51	44	20	48	15	51	16	44	40	30	49	27	28	27	15	40	5	62	13	19	73
13	8	11	17	48	11	16	24	23	58	37	58	49	31	0	30	22	25	55	15	25	13	17	19	17	27	31	19	10	35	46	27	22	35	16	18	31	59	22	37	43
19	37	28	29	66	41	16	18	13	42	8	42	31	20	30	0	16	5	40	33	40	42	30	41	19	39	5	34	40	10	29	9	13	8	21	29	16	43	26	8	67
10	30	26	30	50	31	10	2	21	38	24	38	27	31	22	16	0	13	53	19	25	31	31	27	21	23	20	19	30	15	25	9	4	16	23	14	27	38	30	24	52
14	32	24	25	62	36	11	15	10	44	13	44	33	20	25	5	13	0	41	28	37	37	26	37	15	35	8	30	35	13	31	8	10	11	17	25	16	44	23	13	62
50	57	45	41	100	64	47	55	35	79	34	79	67	25	55	40	53	41	0	65	75	67	41	72	39	74	35	68	64	48	67	47	50	45	39	64	27	79	34	34	97
15	20	25	30	36	17	19	19	31	49	40	49	41	41	15	33	19	28	65	0	11	15	31	9	27	13	35	5	15	33	38	26	20	34	27	6	39	50	34	40	35
25	29	35	40	26	24	28	24	41	47	48	47	42	51	25	40	25	37	75	11	0	21	41	9	37	5	44	8	23	39	39	33	28	41	37	12	49	48	45	48	28
24	12	22	28	39	5	27	31	36	63	49	63	56	44	13	42	31	37	67	15	21	0	28	12	30	24	43	18	4	45	52	38	32	45	29	20	43	64	34	49	32
22	17	7	2	65	24	21	33	18	68	33	68	57	20	17	30	31	26	41	31	41	28	0	36	12	43	28	35	24	38	54	32	29	37	10	33	22	68	8	33	59
24	22	30	35	30	16	27	27	39	55	49	55	48	48	19	41	27	37	72	9	9	12	36	0	34	13	44	10	15	41	45	35	29	43	34	14	46	56	40	49	26
14	21	11	10	62	27	12	23	7	57	23	57	46	15	17	19	21	15	39	27	37	30	12	34	0	37	17	30	26	27	44	20	19	25	3	27	14	57	10	23	59
25	32	37	42	27	27	28	22	40	43	47	43	38	51	27	39	23	35	74	13	5	24	43	13	37	0	42	8	26	36	35	31	26	38	38	11	48	44	46	47	31
21	37	27	26	69	41	17	22	10	47	6	47	36	16	31	5	20	8	35	35	44	43	28	44	17	42	0	37	40	15	34	13	17	12	19	32	11	47	23	6	69
18	24	29	34	33	20	21	18	34	46	42	46	39	44	19	34	19	30	68	5	8	18	35	10	30	8	37	0	19	33	36	27	21	35	30	5	41	47	38	42	34
22	8	19	24	42	2	25	30	33	64	46	64	55	40	10	40	30	35	64	15	23	4	24	15	26	26	40	19	0	43	52	36	30	44	25	20	40	64	30	46	35
22	42	35	37	62	44	20	15	22	33	15	33	21	30	35	10	15	13	48	33	39	45	38	41	27	36	15	33	43	0	20	8	14	4	29	28	25	33	35	15	66
34	53	50	53	57	53	34	23	40	14	33	14	4	49	46	29	25	31	67	38	39	52	54	45	44	35	34	36	52	20	0	24	26	23	45	33	45	14	52	33	65
15	34	28	30	58	37	13	10	17	37	16	37	26	27	27	9	9	8	47	26	33	38	32	35	20	31	13	27	36	8	24	0	7	9	23	22	22	38	29	16	60
9	29	25	27	53	31	8	6	18	39	21	39	29	28	22	13	4	10	50	20	28	32	29	29	19	26	17	21	30	14	26	7	0	15	20	17	24	40	28	21	54
23	42	34	35	65	45	20	17	20	35	12	35	24	27	35	8	16	11	45	34	41	45	37	43	25	38	12	35	44	4	23	9	15	0	28	30	23	36	33	12	68
14	19	8	8	62	26	13	25	10	59	25	59	48	15	16	21	23	17	39	27	37	29	10	34	3	38	19	30	25	29	45	23	20	28	0	27	15	59	8	25	58
14	24	27	31	37	22	17	14	30	44	37	44	36	40	18	29	14	25	64	6	12	20	33	14	27	11	32	5	20	28	33	22	17	30	27	0	37	45	35	37	38
24	34	23	20	74	40	21	29	8	58	15	58	46	5	31	16	27	16	27	39	49	43	22	46	14	48	11	41	40	25	45	22	24	23	15	37	0	58	15	15	72
48	66	64	67	62	66	48	37	54	1	46	1	12	62	59	43	38	44	79	50	48	64	68	56	57	44	47	47	64	33	14	38	40	36	59	45	58	0	66	46	72
22	23	12	7	69	30	21	32	13	66	28	66	55	13	22	26	30	23	34	34	45	34	8	40	10	46	23	38	30	35	52	29	28	33	8	35	15	66	0	28	65
26	43	33	32	73	47	23	25	16	46	0	46	35	19	37	8	24	13	34	40	48	49	33	49	23	47	6	42	46	15	33	16	21	12	25	37	15	46	28	0	74
49	43	53	59	16	35	53	51	64	71	74	71	68	73	43	67	52	62	97	35	28	32	59	26	59	31	69	34	35	66	65	60	54	68	58	38	72	72	65	74	0

Table F.54:Distance 40.7

2	31	4	26	48	51	22	48	57	39	53	11	28	37	39	8	47	41	39	12	41	50	7	5	41	57	57	7	20	59	7	42	54	44	42	41	60	59	33	5

Table F.55:Demand 40.8

0	24	24	20	9	23	45	22	18	48	20	38	14	29	48	18	50	25	22	29	10	40	27	17	20	30	44	15	23	39	17	22	25	26	9	18	16	24	28	18	19
24	0	45	5	28	41	48	30	39	55	38	15	18	38	25	23	59	46	9	52	24	45	6	14	44	54	22	9	32	15	39	40	45	29	29	21	17	17	5	20	40
24	45	0	41	29	36	37	22	6	65	7	57	28	21	68	25	67	32	45	23	21	32	49	41	20	20	61	36	21	58	11	34	1	48	17	42	29	35	49	42	5
20	5	41	0	24	37	47	27	35	53	35	19	15	35	29	21	57	42	8	48	20	43	9	11	39	49	26	6	29	20	35	37	41	27	25	19	15	16	9	18	36
9	28	29	24	0	15	53	31	23	39	26	42	23	37	52	26	42	18	24	26	18	49	30	18	17	29	50	21	32	43	19	14	28	20	15	15	25	32	31	15	24
23	41	36	37	15	0	66	44	32	30	35	54	37	49	62	40	31	9	34	22	32	61	41	28	18	28	62	35	44	55	25	3	35	21	27	22	39	46	43	23	32
45	48	37	47	53	66	0	23	37	92	33	53	35	18	63	29	95	64	54	59	35	6	53	54	54	56	51	43	22	53	44	64	38	68	39	60	33	31	52	59	37
22	30	22	27	31	44	23	0	19	69	16	40	13	9	50	7	72	43	34	41	13	19	35	32	34	39	42	22	2	40	25	42	23	46	17	38	13	15	35	37	20
18	39	6	35	23	32	37	19	0	60	5	52	23	21	63	20	62	28	39	22	16	32	43	35	18	20	57	30	19	53	7	29	7	42	11	36	25	31	44	36	1
48	55	65	53	39	30	92	69	60	0	64	65	59	76	69	64	6	36	46	50	57	87	52	43	47	56	74	53	70	66	54	32	65	26	54	35	61	66	54	36	61
20	38	7	35	26	35	33	16	5	64	0	51	22	17	62	18	66	32	40	27	15	28	43	36	22	24	55	30	15	51	11	33	8	45	12	38	23	29	43	37	4
38	15	57	19	42	54	53	40	52	65	51	0	30	47	11	34	70	60	20	66	37	52	14	26	58	68	10	23	41	1	53	54	58	40	43	34	29	25	12	33	53
14	18	28	15	23	37	35	13	23	59	22	30	0	21	40	7	63	39	21	41	8	31	22	20	33	41	34	10	15	30	25	36	29	35	15	26	2	10	23	25	24
29	38	21	35	37	49	18	9	21	76	17	47	21	0	58	15	78	47	42	43	20	13	43	40	37	40	48	31	7	47	27	47	22	53	22	45	21	23	43	45	21
48	25	68	29	52	62	63	50	63	69	62	11	40	58	0	45	74	69	29	76	48	61	23	35	68	78	13	34	52	11	64	63	68	46	53	41	39	35	21	40	64
18	23	25	21	26	40	29	7	20	64	18	34	7	15	45	0	67	41	28	40	9	25	29	26	33	39	37	16	9	35	24	38	25	40	15	32	6	11	28	31	21
50	59	67	57	42	31	95	72	62	6	66	70	63	78	74	67	0	36	51	50	60	90	57	47	47	56	79	57	73	71	56	33	66	31	57	39	64	70	59	40	63
25	46	32	42	18	9	64	43	28	36	32	60	39	47	69	41	36	0	40	15	33	59	47	34	12	20	67	39	44	61	22	7	31	29	27	29	41	48	48	29	29
22	9	45	8	24	34	54	34	39	46	40	20	21	42	29	28	51	40	0	49	25	51	7	7	40	51	29	12	36	21	38	35	45	21	29	14	22	24	9	13	40
29	52	23	48	26	22	59	41	22	50	27	66	41	43	76	40	50	15	49	0	33	54	54	43	9	6	73	44	41	67	17	21	22	42	26	39	43	50	56	40	23
10	24	21	20	18	32	35	13	16	57	15	37	8	20	48	9	60	33	25	33	0	31	28	22	25	33	42	15	14	37	18	30	22	34	7	26	10	17	29	26	17
40	45	32	43	49	61	6	19	32	87	28	52	31	13	61	25	90	59	51	54	31	0	50	50	49	51	51	39	18	52	39	59	33	64	34	56	30	29	50	55	32
27	6	49	9	30	41	53	35	43	52	43	14	22	43	23	29	57	47	7	54	28	50	0	13	46	56	23	14	37	15	43	41	49	26	33	20	23	22	2	19	44
17	14	41	11	18	28	54	32	35	43	36	26	20	40	35	26	47	34	7	43	22	50	13	0	34	45	35	12	34	27	33	28	41	17	25	9	21	25	15	8	36
20	44	20	39	17	18	54	34	18	47	22	58	33	37	68	33	47	12	40	9	25	49	46	34	0	12	64	35	35	59	11	15	20	35	19	32	35	42	47	32	18
30	54	20	49	29	28	56	39	20	56	24	68	41	40	78	39	56	20	51	6	33	51	56	45	12	0	73	45	39	68	16	26	19	46	26	43	42	49	58	43	20
44	22	61	26	50	62	51	42	57	74	55	10	34	48	13	37	79	67	29	73	42	51	23	35	64	73	0	29	43	9	58	62	62	49	48	42	33	27	21	41	57
15	9	36	6	21	35	43	22	30	53	30	23	10	31	34	16	57	39	12	44	15	39	14	12	35	45	29	0	24	24	30	34	36	28	20	19	10	14	14	18	31
23	32	21	29	32	44	22	2	19	70	15	41	15	7	52	9	73	44	36	41	14	18	37	34	35	39	43	24	0	42	25	43	22	47	18	39	15	17	37	39	19
39	15	58	20	43	55	53	40	53	66	51	1	30	47	11	35	71	61	21	67	37	52	15	27	59	68	9	24	42	0	54	55	58	41	43	35	29	25	13	34	53
17	39	11	35	19	25	44	25	7	54	11	53	25	27	64	24	56	22	38	17	18	39	43	33	11	16	58	30	25	54	0	23	11	38	11	33	27	34	44	33	8
22	40	34	37	14	3	64	42	29	32	33	54	36	47	63	38	33	7	35	21	30	59	41	28	15	26	62	34	43	55	23	0	33	22	26	22	38	44	43	23	30
25	45	1	41	28	35	38	23	7	65	8	58	29	22	68	25	66	31	45	22	22	33	49	41	20	19	62	36	22	58	11	33	0	48	17	42	30	36	50	42	6
26	29	48	27	20	21	68	46	42	26	45	40	35	53	46	40	31	29	21	42	34	64	26	17	35	46	49	28	47	41	38	22	48	0	34	9	36	41	28	10	43
9	29	17	25	15	27	39	17	11	54	12	43	15	22	53	15	57	27	29	26	7	34	33	25	19	26	48	20	18	43	11	26	17	34	0	26	17	24	34	26	12
18	21	42	19	15	22	60	38	36	35	38	34	26	45	41	32	39	29	14	39	26	56	20	9	32	43	42	19	39	35	33	22	42	9	26	0	28	32	22	1	37
16	17	29	15	25	39	33	13	25	61	23	29	2	21	39	6	64	41	22	43	10	30	23	21	35	42	33	10	15	29	27	38	30	36	17	28	0	8	22	27	25
24	17	35	16	32	46	31	15	31	66	29	25	10	23	35	11	70	48	24	50	17	29	22	25	42	49	27	14	17	25	34	44	36	41	24	32	8	0	22	31	32
28	5	49	9	31	43	52	35	44	54	43	12	23	43	21	28	59	48	9	56	29	50	2	15	47	58	21	14	37	13	44	43	50	28	34	22	22	22	0	21	45
18	20	42	18	15	23	59	37	36	36	37	33	25	45	40	31	40	29	13	40	26	55	19	8	32	43	41	18	39	34	33	23	42	10	26	1	27	31	21	0	37
19	40	5	36	24	32	37	20	1	61	4	53	24	21	64	21	63	29	40	23	17	32	44	36	18	20	57	31	19	53	8	30	6	43	12	37	25	32	45	37	0

Table F.56:Distance Matrix 40.8

32	34	42	54	25	41	18	9	37	57	8	40	37	52	59	38	15	45	27	15	6	5	14	9	57	41	58	34	49	1	32	49	40	29	40	11	16	12	33	5

Table F.57:Demand 40.9

0	24	13	10	46	41	26	30	48	13	6	16	15	10	30	24	23	17	48	22	13	24	24	23	44	41	44	24	27	5	13	12	23	28	26	18	25	21	6	20	3
24	0	13	29	45	64	3	45	63	29	19	33	36	33	42	33	15	20	70	36	34	17	16	39	40	63	66	44	33	19	36	16	46	42	44	28	36	16	29	28	21
13	13	0	22	48	54	14	34	52	18	10	22	27	22	31	23	12	10	61	31	25	21	13	27	45	54	57	31	32	8	25	12	35	31	32	24	33	11	18	18	10
10	29	22	0	39	36	32	37	54	22	12	24	7	15	38	34	32	27	41	12	6	24	33	31	38	34	37	30	19	15	11	14	19	36	32	11	16	31	10	30	13
46	45	48	39	0	63	47	75	93	59	42	61	41	53	75	69	58	58	62	30	42	29	59	68	7	56	56	68	20	47	49	38	53	73	70	29	25	58	48	64	46
41	64	54	36	63	0	66	44	53	43	46	41	30	34	49	53	63	54	12	37	31	59	63	43	66	10	14	36	47	46	29	49	19	47	39	43	41	60	36	52	44
26	3	14	32	47	66	0	46	63	31	20	35	38	35	43	33	14	21	72	38	36	19	15	40	42	65	68	45	35	21	38	18	48	42	44	30	38	16	31	28	23
30	45	34	37	75	44	46	0	19	17	35	14	37	23	6	15	35	26	55	48	35	52	34	7	73	51	55	10	55	30	29	40	32	5	7	46	52	32	27	19	30
48	63	52	54	93	53	63	19	0	36	53	32	54	40	21	31	51	43	64	65	51	71	50	26	91	61	65	25	73	48	45	58	46	22	23	64	69	48	45	35	49
13	29	18	22	59	43	31	17	36	0	18	4	25	11	17	13	22	12	52	34	22	35	22	11	56	46	50	15	39	13	18	23	26	15	15	31	37	19	13	10	13
6	19	10	12	42	46	20	35	53	18	0	21	18	16	34	27	21	17	52	22	16	19	22	28	39	45	48	30	24	5	18	6	28	33	31	16	24	20	12	22	5
16	33	22	24	61	41	35	14	32	4	21	0	25	11	14	13	26	16	50	35	23	39	25	8	59	44	48	11	42	17	18	26	24	13	11	33	39	22	14	12	17
15	36	27	7	41	30	38	37	54	25	18	25	0	15	39	37	38	31	35	12	3	30	39	32	41	27	30	29	21	20	9	20	14	37	32	15	16	36	12	33	18
10	33	22	15	53	34	35	23	40	11	16	11	15	0	24	23	29	20	42	26	13	34	29	17	52	36	39	15	33	14	7	22	16	22	17	25	30	27	6	20	13
30	42	31	38	75	49	43	6	21	17	34	14	39	24	0	10	31	22	60	49	36	51	30	8	73	55	59	14	55	29	31	39	36	2	11	47	53	28	28	15	29
24	33	23	34	69	53	33	15	31	13	27	13	37	23	10	0	21	13	63	45	34	43	20	11	66	57	61	19	50	22	30	32	37	11	17	42	49	18	25	5	23
23	15	12	32	58	63	14	35	51	22	21	26	38	29	31	21	0	10	70	42	35	29	2	29	53	64	67	35	43	18	35	22	44	30	34	36	44	4	28	17	21
17	20	10	27	58	54	21	26	43	12	17	16	31	20	22	13	10	0	62	38	28	31	10	20	54	56	59	25	40	13	26	21	36	22	25	32	40	7	20	8	14
48	70	61	41	62	12	72	55	64	52	52	50	35	42	60	63	70	62	0	39	37	62	71	53	65	8	6	46	48	53	36	55	27	58	49	46	42	68	43	61	51
22	36	31	12	30	37	38	48	65	34	22	35	12	26	49	45	42	38	39	0	14	25	43	42	30	32	33	40	11	26	20	21	24	48	43	8	5	41	22	41	24
13	34	25	6	42	31	36	35	51	22	16	23	3	13	36	34	35	28	37	14	0	29	36	29	42	29	33	27	22	17	7	19	14	35	29	15	18	33	9	30	15
24	17	21	24	29	59	19	52	71	35	19	39	30	34	51	43	29	31	62	25	29	0	30	46	25	55	57	48	19	23	34	13	42	50	49	17	23	30	29	38	23
24	16	13	33	59	63	15	34	50	22	22	25	39	29	30	20	2	10	71	43	36	30	0	28	55	64	67	35	44	19	35	24	45	30	34	37	45	3	28	16	21
23	39	27	31	68	43	40	7	26	11	28	8	32	17	8	11	29	20	53	42	29	46	28	0	66	48	52	8	49	23	24	33	29	6	6	40	46	26	21	13	24
44	40	45	38	7	66	42	73	91	56	39	59	41	52	73	66	53	54	65	30	42	25	55	66	0	59	59	67	20	44	48	35	54	71	69	28	26	54	47	61	44
41	63	54	34	56	10	65	51	61	46	45	44	27	36	55	57	64	56	8	32	29	55	64	48	59	0	4	42	41	46	30	47	21	53	45	39	35	61	37	55	44
44	66	57	37	56	14	68	55	65	50	48	48	30	39	59	61	67	59	6	33	33	57	67	52	59	4	0	46	42	49	33	50	25	57	49	40	36	65	40	59	47
24	44	31	30	68	36	45	10	25	15	30	11	29	15	14	19	35	25	46	40	27	48	35	8	67	42	46	0	48	26	20	35	23	12	3	40	44	32	21	20	25
27	33	32	19	20	47	35	55	73	39	24	42	21	33	55	50	43	40	48	11	22	19	44	49	20	41	42	48	0	29	29	21	34	54	50	9	7	42	28	46	27
5	19	8	15	47	46	21	30	48	13	5	17	20	14	29	22	18	13	53	26	17	23	19	23	44	46	49	26	29	0	18	10	28	28	27	20	28	16	10	17	3
13	36	25	11	49	29	38	29	45	18	18	18	9	7	31	30	35	26	36	20	7	34	35	24	48	30	33	20	29	18	0	22	10	29	23	21	25	32	8	27	15
12	16	12	14	38	49	18	40	58	23	6	26	20	22	39	32	22	21	55	21	19	13	24	33	35	47	50	35	21	10	22	0	32	38	36	14	22	22	16	27	10
23	46	35	19	53	19	48	32	46	26	28	24	14	16	36	37	44	36	27	24	14	42	45	29	54	21	25	23	34	28	10	32	0	34	26	28	28	42	18	35	25
28	42	31	36	73	47	42	5	22	15	33	13	37	22	2	11	30	22	58	48	35	50	30	6	71	53	57	12	54	28	29	38	34	0	9	45	51	28	27	15	28
26	44	32	32	70	39	44	7	23	15	31	11	32	17	11	17	34	25	49	43	29	49	34	6	69	45	49	3	50	27	23	36	26	9	0	42	47	31	23	19	26
18	28	24	11	29	43	30	46	64	31	16	33	15	25	47	42	36	32	46	8	15	17	37	40	28	39	40	40	9	20	21	14	28	45	42	0	9	35	20	37	19
25	36	33	16	25	41	38	52	69	37	24	39	16	30	53	49	44	40	42	5	18	23	45	46	26	35	36	44	7	28	25	22	28	51	47	9	0	42	25	44	26
21	16	11	31	58	60	16	32	48	19	20	22	36	27	28	18	4	7	68	41	33	30	3	26	54	61	65	32	42	16	32	22	42	28	31	35	42	0	25	13	19
6	29	18	10	48	36	31	27	45	13	12	14	12	6	28	25	28	20	43	22	9	29	28	21	47	37	40	21	28	10	8	16	18	27	23	20	25	25	0	21	9
20	28	18	30	64	52	28	19	35	10	22	12	33	20	15	5	17	8	61	41	30	38	16	13	61	55	59	20	46	17	27	27	35	15	19	37	44	13	21	0	19
3	21	10	13	46	44	23	30	49	13	5	17	18	13	29	23	21	14	51	24	15	23	21	24	44	44	47	25	27	3	15	10	25	28	26	19	26	19	9	19	0

Table F.58:Distance Matrix 40.9

47	56	46	24	45	31	52	25	4	3	37	15	13	39	11	38	50	1	7	59	40	55	32	5	57	21	15	59	18	22	51	28	45	44	25	18	2	32	31	51

Table F.59:Demand 40.10

0	14	24	15	11	22	25	17	30	28	14	39	26	27	44	47	24	27	6	20	17	26	44	23	28	25	47	39	15	27	20	22	39	16	17	19	24	31	17	27	40
14	0	26	9	15	24	31	10	39	38	27	33	36	24	56	60	23	34	14	32	30	39	53	29	40	20	36	47	28	20	27	29	52	28	31	7	20	26	24	39	37
24	26	0	34	14	2	9	35	52	21	32	23	47	11	38	44	8	49	29	39	30	32	64	46	30	15	61	61	24	18	8	44	37	19	29	24	45	17	39	47	21
15	9	34	0	21	32	37	2	32	42	25	41	31	32	59	62	31	27	12	29	31	41	47	22	42	28	32	40	30	29	33	23	54	31	31	15	12	34	19	35	45
11	15	14	21	0	12	17	22	40	24	22	29	36	17	42	47	14	37	16	29	22	29	54	34	28	17	51	49	17	19	13	32	39	15	22	16	32	22	27	36	30
22	24	2	32	12	0	9	33	50	21	30	23	45	10	39	45	8	47	27	37	29	32	63	45	30	14	59	59	22	18	7	43	37	18	28	22	43	16	38	45	22
25	31	9	37	17	9	0	38	50	12	29	31	45	19	30	36	16	48	31	36	25	26	61	46	23	23	67	59	19	26	5	44	29	14	25	30	47	25	39	43	27
17	10	35	2	22	33	38	0	33	44	26	42	32	33	61	64	32	27	13	30	32	42	48	22	44	29	31	40	32	29	34	23	56	33	32	15	11	35	20	35	46
30	39	52	32	40	50	50	33	0	47	22	68	6	56	56	55	54	6	26	16	27	35	15	12	39	55	55	9	33	57	47	10	49	37	28	45	28	61	15	11	70
28	38	21	42	24	21	12	44	47	0	26	43	41	31	19	24	28	47	33	32	21	16	56	46	13	35	74	55	16	38	14	43	17	12	20	39	51	37	39	38	39
14	27	32	25	22	30	29	26	22	26	0	50	16	38	39	40	35	21	14	8	7	18	33	20	21	38	56	30	12	40	26	17	33	16	8	32	29	43	13	15	51
39	33	23	41	29	23	31	42	68	43	50	0	64	13	59	66	17	64	43	57	50	54	82	60	52	14	58	77	45	13	30	59	59	40	50	27	52	8	54	65	8
26	36	47	31	36	45	45	32	6	41	16	64	0	52	50	49	49	9	23	10	21	29	18	13	33	51	57	14	27	53	42	10	43	32	22	42	29	57	13	6	66
27	24	11	32	17	10	19	33	56	31	38	13	52	0	48	54	4	53	32	45	37	41	70	49	40	6	55	65	32	9	17	48	47	27	37	20	43	6	43	53	14
44	56	38	59	42	39	30	61	56	19	39	59	50	48	0	8	46	58	49	42	32	22	61	58	19	53	91	63	30	56	32	55	7	29	31	57	67	54	52	46	55
47	60	44	62	47	45	36	64	55	24	40	66	49	54	8	0	52	57	51	42	33	23	58	58	20	58	94	61	32	62	38	55	9	32	33	62	69	60	53	44	62
24	23	8	31	14	8	16	32	54	28	35	17	49	4	46	52	0	50	29	42	34	38	67	47	37	8	55	62	28	11	15	45	44	24	34	19	42	10	40	50	17
27	34	49	27	37	47	48	27	6	47	21	64	9	53	58	57	50	0	22	16	27	36	21	6	39	51	50	14	32	52	45	5	51	36	28	40	22	56	10	15	66
6	14	29	12	16	27	31	13	26	33	14	43	23	32	49	51	29	22	0	19	19	30	40	18	32	29	43	34	20	31	26	17	44	22	20	20	18	35	12	25	45
20	32	39	29	29	37	36	30	16	32	8	57	10	45	42	42	42	16	19	0	12	20	26	17	24	44	58	24	18	47	33	14	35	22	13	37	31	50	13	8	58
17	30	30	31	22	29	25	32	27	21	7	50	21	37	32	33	34	27	19	12	0	11	36	26	14	38	62	35	7	41	23	23	26	12	1	35	36	43	20	18	50
26	39	32	41	29	32	26	42	35	16	18	54	29	41	22	23	38	36	30	20	11	0	41	36	5	44	73	42	12	47	25	33	16	15	10	43	47	47	31	25	52
44	53	64	47	54	63	61	48	15	56	33	82	18	70	61	58	67	21	40	26	36	41	0	26	45	69	69	10	43	71	59	25	54	48	37	60	43	74	30	19	83
23	29	46	22	34	45	46	22	12	46	20	60	13	49	58	58	47	6	18	17	26	36	26	0	40	47	45	18	31	48	42	4	52	34	27	35	18	53	8	18	63
28	40	30	42	28	30	23	44	39	13	21	52	33	40	19	20	37	39	32	24	14	5	45	40	0	43	74	46	13	46	23	36	13	14	13	43	49	46	34	29	50
25	20	15	28	17	14	23	29	55	35	38	14	51	6	53	58	8	51	29	44	38	44	69	47	43	0	50	63	33	4	21	46	51	30	38	15	39	6	41	52	17
47	36	61	32	51	59	67	31	55	74	56	58	57	55	91	94	55	50	43	58	62	73	69	45	74	50	0	60	62	48	63	48	86	63	63	37	28	54	46	62	64
39	47	61	40	49	59	59	40	9	55	30	77	14	65	63	61	62	14	34	24	35	42	10	18	46	63	60	0	41	65	56	18	56	45	36	53	34	69	23	18	79
15	28	24	30	17	22	19	32	33	16	12	45	27	32	30	32	28	32	20	18	7	12	43	31	13	33	62	41	0	36	17	28	25	5	6	32	37	37	24	25	44
27	20	18	29	19	18	26	29	57	38	40	13	53	9	56	62	11	52	31	47	41	47	71	48	46	4	48	65	36	0	24	47	54	33	41	14	39	6	42	54	18
20	27	8	33	13	7	5	34	47	14	26	30	42	17	32	38	15	45	26	33	23	25	59	42	23	21	63	56	17	24	0	40	30	12	22	27	43	23	35	40	28
22	29	44	23	32	43	44	23	10	43	17	59	10	48	55	55	45	5	17	14	23	33	25	4	36	46	48	18	28	47	40	0	48	32	24	35	20	51	5	15	61
39	52	37	54	39	37	29	56	49	17	33	59	43	47	7	9	44	51	44	35	26	16	54	52	13	51	86	56	25	54	30	48	0	24	25	54	61	53	46	39	55
16	28	19	31	15	18	14	33	37	12	16	40	32	27	29	32	24	36	22	22	12	15	48	34	14	30	63	45	5	33	12	32	24	0	11	30	39	33	28	30	39
17	31	29	31	22	28	25	32	28	20	8	50	22	37	31	33	34	28	20	13	1	10	37	27	13	38	63	36	6	41	22	24	25	11	0	35	37	42	21	19	49
19	7	24	15	16	22	30	15	45	39	32	27	42	20	57	62	19	40	20	37	35	43	60	35	43	15	37	53	32	14	27	35	54	30	35	0	26	20	31	44	31
24	20	45	12	32	43	47	11	28	51	29	52	29	43	67	69	42	22	18	31	36	47	43	18	49	39	28	34	37	39	43	20	61	39	37	26	0	45	18	34	56
31	26	17	34	22	16	25	35	61	37	43	8	57	6	54	60	10	56	35	50	43	47	74	53	46	6	54	69	37	6	23	51	53	33	42	20	45	0	47	57	12
17	24	39	19	27	38	39	20	15	39	13	54	13	43	52	53	40	10	12	13	20	31	30	8	34	41	46	23	24	42	35	5	46	28	21	31	18	47	0	17	56
27	39	47	35	36	45	43	35	11	38	15	65	6	53	46	44	50	15	25	8	18	25	19	18	29	52	62	18	25	54	40	15	39	30	19	44	34	57	17	0	66
40	37	21	45	30	22	27	46	70	39	51	8	66	14	55	62	17	66	45	58	50	52	83	63	50	17	64	79	44	18	28	61	55	39	49	31	56	12	56	66	0

Table F.60:Distance Matrix 40.10

Appendix G

Test Problems for Comparing CPLEX Optimal Solution and Heuristic Solution: Single Plant Scenario

50	10	15	5

Table G.1:Demand-4 customers

0	26	10	7	11
26	0	35	22	23
10	35	0	16	19
7	22	16	0	5
11	23	19	5	0

Table G.2:Distance Matrix4 customers

30	45	50	20	25

Table G.3:Demand-5 customers

0	34	20	17	48	36
34	0	25	18	17	50
20	25	0	20	34	52
17	18	20	0	34	35
48	17	34	34	0	65
36	50	52	35	65	0

Table G.4:Distance Matrix-5 customers

5	10	15	40	20	50

Table G.5:Demand-6 customers

0	49	12	13	22	37	28
49	0	56	43	34	54	22
12	56	0	25	34	30	36
13	43	25	0	11	45	21
22	34	34	11	0	50	14
37	54	30	45	50	0	43
28	22	36	21	14	43	0

Table G.6:Distance Matrix-6 customers

25	40	25	50	20	45	35

Table G.7:Demand-7 customers

0	19	11	49	29	40	22	19
19	0	23	38	24	32	38	26
11	23	0	45	23	50	16	10
49	38	45	0	23	64	58	39
29	24	23	23	0	55	36	16
40	32	50	64	55	0	61	56
22	38	16	58	36	61	0	20
19	26	10	39	16	56	20	0

Table G.8:Distance Matrix-7 customers

45	50	50	50	30	50	50	15

Table G.9:Demand-8 customers

0	11	18	25	28	20	24	20	18
11	0	16	19	37	18	33	18	23
18	16	0	34	36	4	33	2	15
25	19	34	0	51	37	47	36	41
28	37	36	51	0	35	5	36	22
20	18	4	37	35	0	32	2	13
24	33	33	47	5	32	0	33	20
20	18	2	36	36	2	33	0	15
18	23	15	41	22	13	20	15	0

Table G.10:Distance Matrix-8 customers

50	45	5	50	20	50	20	50	50

Table G.11:Demand-9 customers

0	27	22	25	25	22	48	23	20	27
27	0	36	38	25	26	57	44	46	3
22	36	0	3	14	43	70	43	37	34
25	38	3	0	15	45	72	44	38	36
25	25	14	15	0	40	71	47	44	23
22	26	43	45	40	0	32	23	29	28
48	57	70	72	71	32	0	31	40	59
23	44	43	44	47	23	31	0	10	44
20	46	37	38	44	29	40	10	0	45
27	3	34	36	23	28	59	44	45	0

Table G.12:Distance Matrix-9 customers

45	50	50	5	45	40	30	50	25	20

Table G.13:Demand-10 customers

0	20	16	23	43	49	24	24	43	44	29
20	0	7	40	57	63	40	31	36	62	27
16	7	0	37	51	57	34	25	41	59	30
23	40	37	0	52	57	35	43	45	23	31
43	57	51	52	0	6	20	28	86	60	71
49	63	57	57	6	0	25	33	92	63	77
24	40	34	35	20	25	0	16	67	47	52
24	31	25	43	28	33	16	0	64	60	51
43	36	41	45	86	92	67	64	0	63	16
44	62	59	23	60	63	47	60	63	0	50
29	27	30	31	71	77	52	51	16	50	0

Table G.14:Distance Matrix-10 customers

50	35	10	10	35	20	50	40	20	40	30	30

Table G.15:Demand-12 customers

0	17	49	15	15	29	17	46	10	48	19	24	46
17	0	38	31	25	29	24	38	13	62	16	17	31
49	38	0	59	61	66	61	68	39	96	31	53	18
15	31	59	0	20	38	24	57	22	39	28	37	59
15	25	61	20	0	19	5	39	24	38	32	21	55
29	29	66	38	19	0	14	23	36	47	43	14	56
17	24	61	24	5	14	0	35	26	40	34	17	54
46	38	68	57	39	23	35	0	49	68	53	23	54
10	13	39	22	24	36	26	49	0	57	9	27	38
48	62	96	39	38	47	40	68	57	0	65	56	92
19	16	31	28	32	43	34	53	9	65	0	32	32
24	17	53	37	21	14	17	23	27	56	32	0	42
46	31	18	59	55	56	54	54	38	92	32	42	0

Table G.16:Distance Matrix-12 customers

50	20	50	15	50	50	5	25	45	15	25	25	35	50	20

Table G.17:Demand-15 customers

0	50	22	25	12	50	23	22	17	11	22	18	21	48	12	14
50	0	33	75	59	97	61	45	52	57	53	55	49	97	46	51
22	33	0	46	33	71	29	14	32	32	22	22	17	69	14	19
25	75	46	0	16	26	33	42	28	18	37	32	39	23	34	31
12	59	33	16	0	39	30	32	14	3	31	26	31	38	23	23
50	97	71	26	39	0	56	67	47	41	62	57	64	10	59	56
23	61	29	33	30	56	0	17	39	30	9	8	13	51	18	12
22	45	14	42	32	67	17	0	37	32	9	12	5	63	11	11
17	52	32	28	14	47	39	37	0	12	38	34	37	48	27	30
11	57	32	18	3	41	30	32	12	0	30	26	30	40	21	22
22	53	22	37	31	62	9	9	38	30	0	5	5	57	13	9
18	55	22	32	26	57	8	12	34	26	5	0	8	52	11	5
21	49	17	39	31	64	13	5	37	30	5	8	0	60	10	8
48	97	69	23	38	10	51	63	48	40	57	52	60	0	56	52
12	46	14	34	23	59	18	11	27	21	13	11	10	56	0	6
14	51	19	31	23	56	12	11	30	22	9	5	8	52	6	0

Table G.18:Distance Matrix-15 customers

45	50	15	5	10	45	50	50	35	15	15	40	45	45	30	5	50	45	40	50

Table G.19:Demand-20 customers

0	45	49	15	46	23	19	45	22	47	50	42	8	17	14	21	20	25	25	50	50
45	0	67	31	75	61	32	88	42	66	92	57	49	29	39	26	61	53	22	92	55
49	67	0	54	19	69	41	74	70	3	83	91	56	53	39	59	39	24	49	83	97
15	31	54	0	55	32	14	58	19	52	62	40	18	3	16	7	33	32	14	62	45
46	75	19	55	0	62	45	60	68	18	69	87	51	55	40	62	30	24	55	69	95
23	61	69	32	62	0	42	31	22	67	33	30	17	35	37	36	33	46	45	33	41
19	32	41	14	45	42	0	63	33	39	68	54	26	13	8	19	30	22	11	68	59
45	88	74	58	60	31	63	0	51	73	9	57	40	60	56	63	39	56	69	9	69
22	42	70	19	68	22	33	51	0	68	54	22	18	21	32	19	40	46	32	54	28
47	66	3	52	18	67	39	73	68	0	81	89	53	51	37	57	36	22	48	81	95
50	92	83	62	69	33	68	9	54	81	0	56	45	65	62	67	46	63	75	0	68
42	57	91	40	87	30	54	57	22	89	56	0	37	42	53	38	59	67	52	56	13
8	49	56	18	51	17	26	40	18	53	45	37	0	20	22	24	23	32	31	45	45
17	29	53	3	55	35	13	60	21	51	65	42	20	0	16	7	34	32	12	65	46
14	39	39	16	40	37	8	56	32	37	62	53	22	16	0	22	22	17	17	62	59
21	26	59	7	62	36	19	63	19	57	67	38	24	7	22	0	40	38	14	67	41
20	61	39	33	30	33	30	39	40	36	46	59	23	34	22	40	0	18	39	46	68
25	53	24	32	24	46	22	56	46	22	63	67	32	32	17	38	18	0	32	63	74
25	22	49	14	55	45	11	69	32	48	75	52	31	12	17	14	39	32	0	75	54
50	92	83	62	69	33	68	9	54	81	0	56	45	65	62	67	46	63	75	0	68
50	55	97	45	95	41	59	69	28	95	68	13	45	46	59	41	68	74	54	68	0

Table G.20:Distance Matrix-20 customers

Appendix H

Test Problems for Comparing CPLEX Optimal Solution and Heuristic Solution: Multi Plant Scenario

30	25	50	45	10	40

Table H.1: Demand-6 customers

0	49	23	23	43	74	44
49	0	64	37	90	120	78
23	64	0	45	47	77	60
23	37	45	0	54	83	41
43	90	47	54	0	32	30
74	120	77	83	32	0	48
44	78	60	41	30	48	0

Table H.2: Distance from Plant 1-6 customers

0	91	61	54	19	32	17
91	0	64	37	90	120	78
61	64	0	45	47	77	60
54	37	45	0	54	83	41
19	90	47	54	0	32	30
32	120	77	83	32	0	48
17	78	60	41	30	48	0

Table H.3: Distance from Plant 2-6 customers

30	25	50	40	45	10	40	50

Table H.4: Demand-8 customers

0	49	23	23	44	43	74	44	64
49	0	64	37	69	90	120	78	98
23	64	0	45	64	47	77	60	77
23	37	45	0	35	54	83	41	62
44	69	64	35	0	42	62	14	30
43	90	47	54	42	0	32	30	36
74	120	77	83	62	32	0	48	38
44	78	60	41	14	30	48	0	22
64	98	77	62	30	36	38	22	0

Table H.5: Distance from Plant 1-8 customers

0	91	61	54	31	19	32	17	18
91	0	64	37	69	90	120	78	98
61	64	0	45	64	47	77	60	77
54	37	45	0	35	54	83	41	62
31	69	64	35	0	42	62	14	30
19	90	47	54	42	0	32	30	36
32	120	77	83	62	32	0	48	38
17	78	60	41	14	30	48	0	22
18	98	77	62	30	36	38	22	0

Table H.6: Distance form Plant 2-8 customers

30	25	50	40	40	45	10	40	50	15

Table H.7: Demand-10 customers

0	49	23	23	44	11	43	74	44	64	71
49	0	64	37	69	56	90	120	78	98	115
23	64	0	45	64	29	47	77	60	77	76
23	37	45	0	35	23	54	83	41	62	78
44	69	64	35	0	36	42	62	14	30	54
11	56	29	23	36	0	34	65	34	54	62
43	90	47	54	42	34	0	32	30	36	29
74	120	77	83	62	65	32	0	48	38	10
44	78	60	41	14	34	30	48	0	22	41
64	98	77	62	30	54	36	38	22	0	29
71	115	76	78	54	62	29	10	41	29	0

Table H.8: Distance from Plant 1-10 customers

0	91	61	54	31	41	19	32	17	18	25
91	0	64	37	69	56	90	120	78	98	115
61	64	0	45	64	29	47	77	60	77	76
54	37	45	0	35	23	54	83	41	62	78
31	69	64	35	0	36	42	62	14	30	54
41	56	29	23	36	0	34	65	34	54	62
19	90	47	54	42	34	0	32	30	36	29
32	120	77	83	62	65	32	0	48	38	10
17	78	60	41	14	34	30	48	0	22	41
18	98	77	62	30	54	36	38	22	0	29
25	115	76	78	54	62	29	10	41	29	0

Table H.9: Distance from Plant 2-10 customers

50	25	40	20	50	10	5	50	10	50	15	25

Table H.10: Demand-12 customers

0	46	12	18	8	24	24	49	81	74	67	57	73
46	0	55	62	51	46	53	63	51	52	50	37	72
12	55	0	8	5	21	18	43	83	76	68	59	69
18	62	8	0	12	27	23	47	91	83	75	66	74
8	51	5	12	0	19	18	43	81	74	66	56	68
24	46	21	27	19	0	8	26	64	56	48	40	50
24	53	18	23	18	8	0	26	70	62	53	47	52
49	63	43	47	43	26	26	0	60	49	40	40	28
81	51	83	91	81	64	70	60	0	12	21	25	47
74	52	76	83	74	56	62	49	12	0	10	19	36
67	50	68	75	66	48	53	40	21	10	0	14	29
57	37	59	66	56	40	47	40	25	19	14	0	38
73	72	69	74	68	50	52	28	47	36	29	38	0

Table H.11: Distance from Plant 1-12 customers

0	46	50	56	48	29	35	24	38	28	19	17	27
46	0	55	62	51	46	53	63	51	52	50	37	72
50	55	0	8	5	21	18	43	83	76	68	59	69
56	62	8	0	12	27	23	47	91	83	75	66	74
48	51	5	12	0	19	18	43	81	74	66	56	68
29	46	21	27	19	0	8	26	64	56	48	40	50
35	53	18	23	18	8	0	26	70	62	53	47	52
24	63	43	47	43	26	26	0	60	49	40	40	28
38	51	83	91	81	64	70	60	0	12	21	25	47
28	52	76	83	74	56	62	49	12	0	10	19	36
19	50	68	75	66	48	53	40	21	10	0	14	29
17	37	59	66	56	40	47	40	25	19	14	0	38
27	72	69	74	68	50	52	28	47	36	29	38	0

Table H.12: Distance from Plant 2-12 customers

50	25	40	20	50	10	5	5	50	10	50	15	25	50

Table H.13: Demand-14 customer problems

0	46	12	18	8	24	24	46	49	81	74	67	57	73	62
46	0	55	62	51	46	53	64	63	51	52	50	37	72	51
12	55	0	8	5	21	18	54	43	83	76	68	59	69	61
18	62	8	0	12	27	23	55	47	91	83	75	66	74	68
8	51	5	12	0	19	18	52	43	81	74	66	56	68	59
24	46	21	27	19	0	8	68	26	64	56	48	40	50	41
24	53	18	23	18	8	0	69	26	70	62	53	47	52	46
46	64	54	55	52	68	69	0	94	113	110	105	92	116	101
49	63	43	47	43	26	26	94	0	60	49	40	40	28	31
81	51	83	91	81	64	70	113	60	0	12	21	25	47	29
74	52	76	83	74	56	62	110	49	12	0	10	19	36	18
67	50	68	75	66	48	53	105	40	21	10	0	14	29	9
57	37	59	66	56	40	47	92	40	25	19	14	0	38	15
73	72	69	74	68	50	52	116	28	47	36	29	38	0	23
62	51	61	68	59	41	46	101	31	29	18	9	15	23	0

Table H.14: Distance from Plant 1-14 customer problems

0	46	50	56	48	29	35	91	24	38	28	19	17	27	12
46	0	55	62	51	46	53	64	63	51	52	50	37	72	51
50	55	0	8	5	21	18	54	43	83	76	68	59	69	61
56	62	8	0	12	27	23	55	47	91	83	75	66	74	68
48	51	5	12	0	19	18	52	43	81	74	66	56	68	59
29	46	21	27	19	0	8	68	26	64	56	48	40	50	41
35	53	18	23	18	8	0	69	26	70	62	53	47	52	46
91	64	54	55	52	68	69	0	94	113	110	105	92	116	101
24	63	43	47	43	26	26	94	0	60	49	40	40	28	31
38	51	83	91	81	64	70	113	60	0	12	21	25	47	29
28	52	76	83	74	56	62	110	49	12	0	10	19	36	18
19	50	68	75	66	48	53	105	40	21	10	0	14	29	9
17	37	59	66	56	40	47	92	40	25	19	14	0	38	15
27	72	69	74	68	50	52	116	28	47	36	29	38	0	23
12	51	61	68	59	41	46	101	31	29	18	9	15	23	0

Table H.15: Distance from Plant 2-14 customer problems

50	25	40	20	50	10	5	20	5	50	10	50	15	25	50	50

Table H.16: Demand-16 customer problems

0	46	12	18	8	24	24	46	30	49	81	74	67	57	73	62	46
46	0	55	62	51	46	53	64	75	63	51	52	50	37	72	51	20
12	55	0	8	5	21	18	54	26	43	83	76	68	59	69	61	51
18	62	8	0	12	27	23	55	20	47	91	83	75	66	74	68	59
8	51	5	12	0	19	18	52	29	43	81	74	66	56	68	59	48
24	46	21	27	19	0	8	68	46	26	64	56	48	40	50	41	36
24	53	18	23	18	8	0	69	42	26	70	62	53	47	52	46	43
46	64	54	55	52	68	69	0	49	94	113	110	105	92	116	101	77
30	75	26	20	29	46	42	49	0	66	109	102	93	85	93	87	76
49	63	43	47	43	26	26	94	66	0	60	49	40	40	28	31	47
81	51	83	91	81	64	70	113	109	60	0	12	21	25	47	29	37
74	52	76	83	74	56	62	110	102	49	12	0	10	19	36	18	34
67	50	68	75	66	48	53	105	93	40	21	10	0	14	29	9	31
57	37	59	66	56	40	47	92	85	40	25	19	14	0	38	15	17
73	72	69	74	68	50	52	116	93	28	47	36	29	38	0	23	53
62	51	61	68	59	41	46	101	87	31	29	18	9	15	23	0	31
46	20	51	59	48	36	43	77	76	47	37	34	31	17	53	31	0

Table H.17: Distance from Plant 1-16 customer problems

0	46	50	56	48	29	35	91	75	24	38	28	19	17	27	12	27
46	0	55	62	51	46	53	64	75	63	51	52	50	37	72	51	20
50	55	0	8	5	21	18	54	26	43	83	76	68	59	69	61	51
56	62	8	0	12	27	23	55	20	47	91	83	75	66	74	68	59
48	51	5	12	0	19	18	52	29	43	81	74	66	56	68	59	48
29	46	21	27	19	0	8	68	46	26	64	56	48	40	50	41	36
35	53	18	23	18	8	0	69	42	26	70	62	53	47	52	46	43
91	64	54	55	52	68	69	0	49	94	113	110	105	92	116	101	77
75	75	26	20	29	46	42	49	0	66	109	102	93	85	93	87	76
24	63	43	47	43	26	26	94	66	0	60	49	40	40	28	31	47
38	51	83	91	81	64	70	113	109	60	0	12	21	25	47	29	37
28	52	76	83	74	56	62	110	102	49	12	0	10	19	36	18	34
19	50	68	75	66	48	53	105	93	40	21	10	0	14	29	9	31
17	37	59	66	56	40	47	92	85	40	25	19	14	0	38	15	17
27	72	69	74	68	50	52	116	93	28	47	36	29	38	0	23	53
12	51	61	68	59	41	46	101	87	31	29	18	9	15	23	0	31
27	20	51	59	48	36	43	77	76	47	37	34	31	17	53	31	0

Table H.18: Distance from Plant 2-16 customer problems

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