EQUIPMENT CONTROL IN CONTAINER SHIPPING

by

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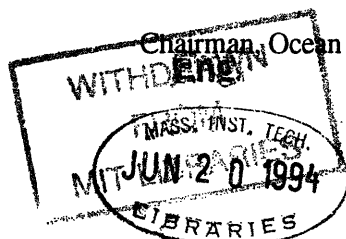
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Abstract

The strategic importance of equipment control is growing in container shipping, because of the development of intermodal networks and the formation of partnerships. The thesis is motivated to develop equipment control techniques by the application of the network simplex algorithm to the empty container network.

The thesis takes a look at current issues in container shipping, and argues why and how equipment control has become one of the most critical issues in today's container shipping. In applying the network simplex algorithm, the thesis examines assumptions and modeling techniques necessary for the creation of a network of empty containers. The pivoting rule of the algorithm is modified in the implementation so that the algorithm finds larger violations in earlier iterations. It is shown that such modification shortens the computation time to one third in a test network.

The thesis examines container movement data of a shipping carrier, then applies the network simplex method to achieve the optimal empty container movements that satisfy all the demands and other constraints. The results of the optimization are displayed graphically.

The thesis discusses the utilization of the dual cost information as a marketing tool, by interpreting dual costs as indicators of the value of empty containers in a time-space network. The thesis also presents a scheme of a decentralized container shipping carrier, which can offer better and quicker customer services, and maintain higher morale.

Thesis supervisor: Ernest G. Frankel
Title: Professor of Marine Systems

Acknowledgments

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Figures, Tables, and Maps

Introduction

The purpose of this thesis is to develop equipment control techniques by applying the network simplex algorithm, and discuss the utilization of these techniques in the management of container shipping carriers. Although equipment control implies the operational management of empty containers, the thesis is more focused on strategies and marketing than on operation. I assume that readers are familiar with container shipping to some extent. Furthermore, the knowledge of operations research is helpful in reading the theoretical and algorithmic review of the network simplex method in Chapter 4.

In Chapter 1, I will survey the recent changes in the container shipping industry, and discuss the expansion of intermodal networks, the establishment of integrated information systems, and the formation of partnerships.

In Chapter 2, I will argue that the unified control of container assets among partners enables more efficient operation and cost advantages. I will also discuss a strategic scheme to utilize integrated information systems for service differentiation.

In Chapter 3, I will explain the creation of a time-space network of empty containers, and discuss modeling assumptions and techniques.

In Chapter 4, I will review the network simplex method mathematically and from the algorithmic point of view. I will modify the pivot rule so that the algorithm finds larger violations in earlier iterations.

In Chapter 5, I will analyze container movement data and network data of Nippon Yusen Kaisha (NYK) Line, and create time-space networks for case study. I will demonstrate the effects of the modified pivot rule, and also show computational results, which will be displayed graphically.

In Chapter 6, I will present a scheme of a decentralized container shipping carrier, which is effective in achieving better customer services and maintaining high morale. I will introduce an idea to treat empty containers as a commodity that is tradable within the company and peripheral offices as independent dealers of empty containers.

Chapter 1

Current Issues in Container Shipping

In this chapter, I would like to argue why equipment control and underlying information technology are becoming more and more important in container shipping.

1.1   Transformation of the Container Shipping Industry

Since the enactment of the Shipping Act of 1984, the international shipping industry has transformed itself to a great extent --- especially on the trans-Pacific side. I will briefly describe the changes in the market, in the technological field, and in the industrial structure during this period.

The U.S. increased the import of commodities form Asian countries substantially during the 1980's. Many kinds of commodities, including automobile, automotive parts, electronic appliances, toys, etc., are now imported from Asia in large quantities, gaining considerable percentages of the U.S. markets.

Although the relative importance of Asian countries as the source of commodities have shifted over the years --- Japan and Taiwan used to be the

center of exports, but now ASEAN countries and China have gained much importance ---, the U.S. seems to have incorporated Asian countries as its production base. The trans-Pacific intermodal transportation system has played an essential role in this change.

When compared with trans-Atlantic cargo, trans-Pacific cargo needs longer inland transportation due to the geographical and demographic structure of the North American continent. More than 80% of cargo that arrives at U.S. West Coast ports heads inland intermodally towards cities east of the Mississippi. The volume and the distance of the inland part of the international cargo flow have made Double Stack Train (DST) systems clearly advantageous over other modes of transportation.

The DST system was first invented by Sea Land, and later American President Line (APL) made the first practical use of it in the mid-1980's. Intermodal transportation, including the DST systems, has been one of the fastest growing sectors in the railway industry since then. Although there is a spectrum of DST management styles, from ones that are solely dedicated to one shipping carrier to ones that are mainly controlled by a railway company and used by several shipping carriers, practically all major trans-Pacific carriers offer intermodal DST network services. Without intermodal DST services, a trans-Pacific shipping carrier would not be regarded as a major player in the industry.

The expansion of DST networks, on the other hand, has developed new challenges to shipping carriers. First, shipping carriers had to establish and maintain inland facilities, such as container depots, all over the U.S. and Canada. In key cities, such as Chicago and Memphis, some shipping carriers operate inland container yards that are as large scale as ones in port terminals. Those facilities required considerable investments, and add to fixed costs.

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          ┌─────────────────┐      ┌──────────────────┐
          │  DST technology │      │    Burgeoning    │
┌──────────────────────┐    │      │  Asian economies │
│ the Shipping Act of 1984 │   │      └──────────────────┘
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                │   Development of    │
                │    DST networks     │
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│ Inland facilities │                 │  Information systems │
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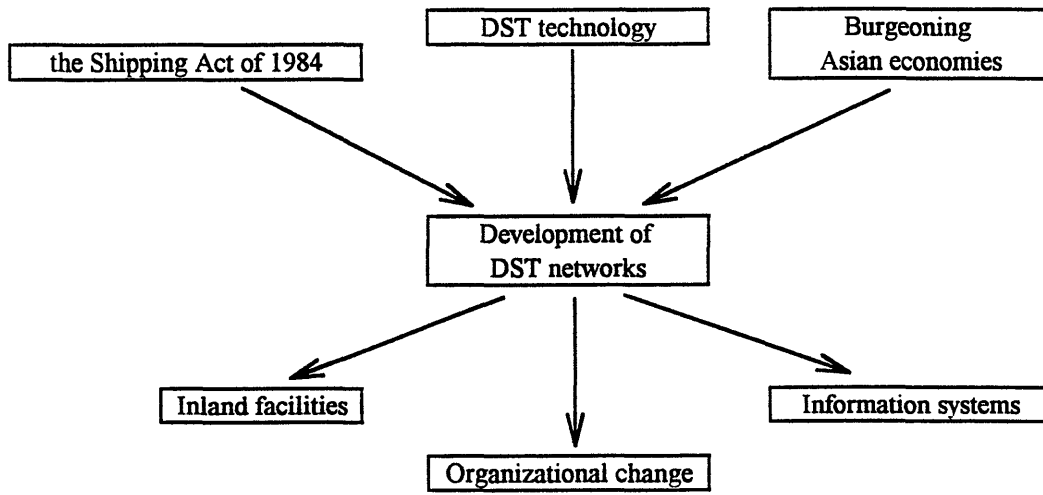
Figure 1-1   Transformation of container shipping

Second, many shipping carriers re-organized operating functions in the U.S. and Canada. In a typical waterborne port-to-port operation in the former days, the operating functions were fulfilled by a mere agent or a branch, which did not have to make substantial decisions. In those days, the operating functions did not mean much more than arranging port facilities and stevedores. Since most of warehouses and shippers' agents were concentrated in the port area, equipment control within the port area was obvious. Empty positioning between ports was conducted by utilizing the carrier's own vessels at inexpensive constant costs, which were made up of the loading and discharging operation costs in the short term. In addition, empty container allocation problem among ports required at most one-dimensional difficulty, because of the simplicity of waterborne networks.

With the expansion of the DST networks, these functions accompany tough decisions. Equipment control has become deeply connected to the marketing policy. For example, a regional branch of a shipping carrier has to decide which

part of the continent it is interested in, and in which direction empty containers have to be sent. Inland empty positioning is conducted by other modes of carriers at substantial costs

With containers scattered across the continent, the issue of equipment control became one of the most serious problems. Many carriers re-organized the operating functions to tackle this issue. Most foreign flag carriers gave up their traditional port agents, and set up their own organizations for the same reasons. Effective marketing in container shipping is also becoming more critical, as the importance of empty container management grows.

As the Asian economies and the U.S. economy become more tightly linked, shipping carriers are expected to function as "belt-conveyors" across the Pacific Ocean. To increase the reliability of their services, shipping carriers tried to have the capacity to inform customers of up-to-date cargo information by setting up a new architecture of information systems, or integrating regional information systems.

The development of integrated information systems also has impacts on equipment control. Such systems will enable the real-time management of empty containers globally. Furthermore, the marketing section, or even the sales forces, could have easier access to equipment information through user-friendly interfaces. Integrated information systems could become even more important as marketing tools than as customer service tools.

The development of information systems, however, has varied among shipping carriers. Some shipping carriers have marketing policies that are targeted on time-sensitive cargo, such as automobile components, and invest in advanced information systems. On the other hand, others are not eager about such costly

systems, and aim at price-sensitive cargo. In this regard, the shipping industry has begun to form a two-layer structure.

In the next chapter, I will focus on the service differentiation and the cost differentiation as strategies of container shipping carriers. The motivation of the next chapter is partly based on the fact that the industry is forming a two-layer structure, and partly based on the necessity to turn such costly systems into a strategic value.

1.2   Competition and Cooperation in Container Shipping

The Shipping Act of 1984 forced conferences to accept independent actions by member carriers, and the maintenance of price levels by the conference has been extremely difficult since then.

Most shipping carriers recorded severe losses in the trans-Pacific trade in 1985 and 1986, and many retreated from the trade, or even went bankrupt. U.S. Line, Happag-Lloyd, Japan Line, YS Line, and Showa Line went out of the trans-Pacific trade, to name a few.

After considerable shake-outs, shipping carriers in the trans-Pacific trade eagerly sought rate stabilization. Almost all the major players (except for China Ocean Shipping) joined the Trans-Pacific Stabilization Agreement (TSA), in which participants agree to freeze a part of vessels' capacity to alleviate the over-capacity problem.

While shipping carriers were getting more and more risk averse, customers were requiring better and better services. One rational conclusion under such circumstances was to form a partnership with one of the former competitors, and achieve better utilization of the assets.

Such partnerships had manifold effects on the performance of the services. First, the service under the partnership can double the frequency, by joining the fleet of each partner. This improvement is advantageous to both shippers and the carriers. Should shippers miss a vessel, many of them would not wait for the next vessel (usually one week later), and begin contacting other shippers in search of the next earliest vessel. However, if the waiting period is only a half week, or 3 days, many shipper would wait for the next vessel of the same carrier. In this case, shippers do not bother to contact other carriers, and the carrier does not lose the cargo. Second, feeder networks can be streamlined. By effectively rearranging the feeder routes, the network can cover broader areas with the same number of vessels. Third, the partnership will realize economies of scale for various kinds of resources. Port terminals, chassis, DST trains, and so on could be better utilized by the joint use of the same resources. However, such uses are not fully put into practice due to the reasons that I will discuss later.

Currently, the trans-Pacific service is dominated by four large groups, each of which is made of a partnership between major players, namely:

Nippon Yusen Kaisha (NYK) - Neptune Orient Line (NOL)

APL - Orient Overseas Container Line (OOCL)

Sea Land - Maersk

Mitsui Osaka Shosen Kaisha (OSK) - Kawasaki (K) Line

All groups offer 5 - 6 port departures from each side of the Pacific Ocean with powerful feeder networks and DST networks.

In conclusion, I would like to point out that relatively recently shipping carriers began to face the situation of equipment scattered all over the continent. The technique of equipment control is still young, and needs to be developed.

Some container shipping carriers have invested in integrated information systems, which will not only enhance customer services, but also support operational and marketing decisions. To maintain and develop such information systems, it will be necessary to realize the strategic value of them.

I believe that there are many possibilities left unrealized in the area of the resource utilization under the partnership scheme. The issue of equipment control is an essential factor to enhance the resource utilization.

Chapter 2

Fundamental Strategies for Container Shipping

Traditionally, the shipping markets are controlled by conferences. Due to the growth of non-conference carriers, however, conferences are losing their powers, and their pricing mechanism no longer functions as effectively as before. I believe that container shipping carriers need new strategic schemes under such markets.

In this chapter, I will first discuss the strategic value of equipment control. Then, I will analyze the mechanism of a conference, and see how a conference stabilizes freight rates, relaxes competition, and realizes the economies of scale. Finally, I will argue how container shipping carriers can utilize the strategic value of information systems that will help the development of equipment management.

2.1   Equipment Control and Cost Differentiation

Container transportation services are quite similar across firms in terms of the cost structure. All carriers use the same standardized containers, and use almost identically structured container terminals. Two conspicuous differences lie in the size of vessels and the nationality of workers. Whereas these two points

have significant, and rather straightforward impacts on the cost structure, I would like to focus the following two questions in this paper:

(a) How can carriers optimize the empty container allocation?

Since a substantial percentage of variable costs comes from moving empty containers, how can the carrier minimize costs associated with empty positioning?

(b) Can shipping carriers take advantage of a better resource utilization through partnership, and curtail costs associated with that resource?

As we have seen in the previous chapter, the partnership can greatly enhance the performance the partners, with little additional investments. Then, can carriers go further along this direction and exploit the merit of asset unification?

With regard to the first question, I would like to discuss the optimization technique applicable to the empty container network in the next chapter. In addition, I will show graphically how actual empty movements can be optimized later in this thesis.
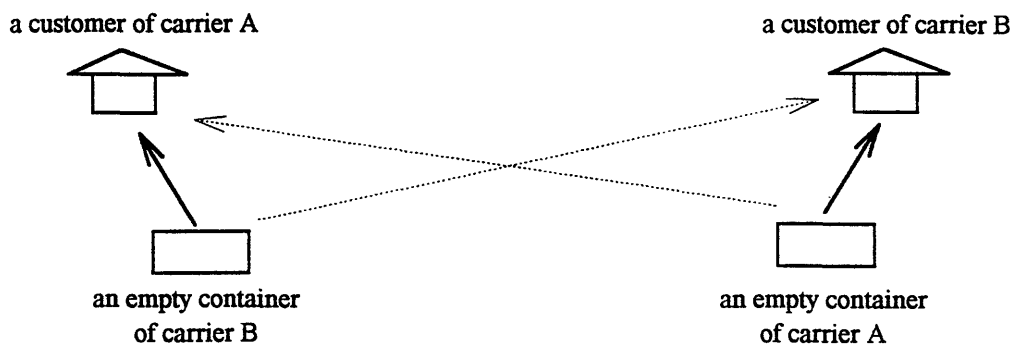
Figure 2-1   Economizing on the distance by asset unification

Let us consider the second question. It is intuitively attractive to combine assets between partners. Suppose there are two customers and two empty containers in an area as illustrated in Figure 2-1.

If the empty containers are regarded as separate resources, both carrier A and B should use their own containers. However, if they are unified (or pooled), the cost of empty movements can be greatly reduced, as this simple illustration suggests.

As I mentioned earlier, however, the joint use of assets between partners is not fully realized. Main obstacles to such a resource unification are:

(1)   **Limited rights of use**

Use of some facilities is considered to be a special advantage. For example, suppose that port terminals are consolidated under the partnership: one of the partners should give up its former terminal, and concentrate its operation to the other's terminal. When the partnership is terminated in the future, it is likely to be difficult for one of the partners to retain the same terminal as it used before the start of the partnership.

(2)   **Administration and liability**

Responsibilities for the assets may be blurred. For example, under the chassis pool system, it may be difficult to clarify responsibilities for damages to chassis. If the bad care of one partner goes unchecked, the other partner will give up taking good care of the joint assets.

(3)   The changing value of empty containers

The value of equipment changes depending upon when and where it is available. Suppose that carrier A and carrier B jointly use containers. Now carrier A decides to undertake transportation of cargo from Chicago to Tokyo at a very low rate, in expectation of getting high yielding cargo in the return trip. After the container gets freed at the destination , carrier B happen to have a suitable cargo in time, but carrier A does not. Should carrier B be allowed to use the container? The value of an empty container in Tokyo is considered to be higher than that in Chicago. What is the reasonable scale to measure the right amount of compensation that carrier A should get? This type of problem is quite essential to container carriers, and is also ubiquitous. Thus, operating container pool system seems to be difficult, unless reasonable rules to measure the value of equipment are established, or the whole cost-profit scheme is pooled.

(4)   Inseparable assets

The separation of the assets may be difficult. For example, a major shipping carrier operates a number of routes at the same time.   Suppose that a carrier operates route A under a partnership, and route B independently. When the other partner wants to use an empty container for route A, can the carrier say, "Sorry, this container is supposed to belong to route B"? The other partner may think the carrier is "hiding" the available containers, whereas the carrier think that the other partner is trying to use everything that it has.

On the other hand, suppose that the carrier decides to dedicate a part of container assets to route A, and the rest of container assets to route B. By separating containers internally, the empty container management can become transparent to the other partner. However, the carrier has to manage the two

separated container assets internally, and can no longer enjoy the merit of unified asset control internally.

Now let us consider whether we can solve those obstacles, and under what conditions those obstacle really matter.

Obstacle (1) may be eased by making the partnership longer term, or providing sufficient lead time before ending. If we return to the example mentioned above, there is a possibility of obtaining a better, newly developed terminal when the partnership expires. A carrier that uses an unfavorably located terminal, on the other hand, can enjoy the better location for the period of the partnership.

Obstacle (2) poses an administrative problem. It may be necessary to set up a joint team which takes the responsibility of the asset management. It is important to streamline the redundant functions in both companies. Otherwise, asset unification will tend to fatten the organization, and expected net benefits cannot be achieved.

As for Obstacle (3), the solution would be adopting a reasonable scale to evaluate empty containers. I would like to present a method of measuring the value of equipment. Since the value of empty containers is closely related to the empty movement optimization, I will discuss it in the next chapter.

With regard to the obstacle (4), if the containers are not separated internally, a route that is operated independently by one of the partners may have positive or negative effects on the route under the partnership. On the positive side, those routes may form a complementary relationship, but on the negative

side, they may compete with each other for the same container. Those effects may be mixed, and change reflecting the market.

By introducing a system of measuring the value of containers, the carriers will be able to reward the cargoes that move from container abundant areas to container scarce areas, and penalize the cargoes that move in opposite ways. The use of the same standards both internally and between the partners will create an agreeable system to each of the partner. Hence, a method to measure the value of empty containers will be one of the most important keys to a successful asset unification.

In conclusion, the development of equipment control techniques will achieve efficient empty container allocation. It will also realize a reasonable scale to evaluate empty containers. A system of measuring the value of empty containers will enable asset unification among carriers that form a partnership.

2.2   Rationale of a Conference

Before discussing the strategic value of information systems, let us consider the mechanism of a conference. We would like to see the rationale of a conference.

(The problem of capacity)

The demands in shipping change in short cycles, whereas the capacity of carriers cannot be changed flexibly. There are basically two ways to solve this contradiction. The first way is to raise the freight rates in peak seasons and lower them in slack seasons. Through the price mechanism, the demands can be

equalized. We can see a typical example in the tramper market. For example, higher freight rates for elastic cargo encourage domestic substitution, and decrease the volume of international trades. For another example, demands for foreign coal in Japan are relatively inelastic with regard to the price. Even if the chartering market soars, the total volume of coal importation may not be affected much. However, users would demand less from farther origins (such as South Africa) and more from nearer origins (such as Australia), and curtail the demand of vessels.

The second method is to provide enough space to meet the peak demands, while maintaining unfluctuating freight rates. Carriers as a whole keep more than enough capacities during the non-peak seasons. The second method, however, cannot be sustained by the market mechanism as we will see shortly.

The main rationale of a conference is to solve the problem of the difference between the demands and the capacity by the second method. A conference is expected to set freight rates artificially, and to provide a sufficient capacity for demands.
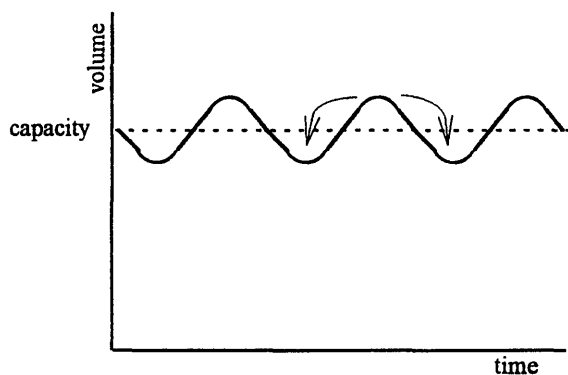
Figure 2-1 (a)
Equalization through price mechanism
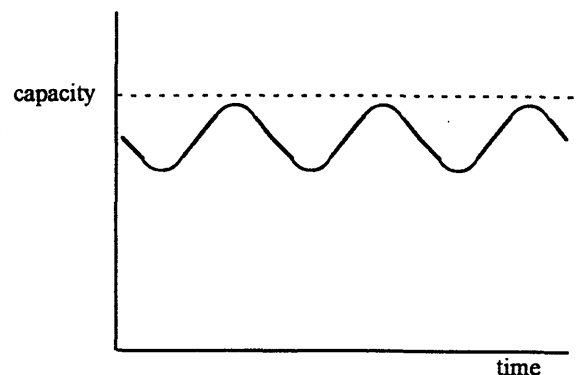
Figure 2-1 (b)
Providing a sufficient capacity

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(Natural tendency toward monopoly)

If there were not a conference, a shipping market would have a natural tendency toward monopolization. Due to various political reasons, however, monopolization of a shipping market by a single company is not welcome. A conference is expected to check the process of natural monopolization by relaxing competition. In order to examine this mechanism, first let us look at the cost functions of a container shipping company.

Container shipping carriers, under normal conditions, have considerably lower marginal cost curves compared to average cost curves, due to high fixed costs and relatively low variable costs in the short term. On the other hand, when the current system fills up (such a situation is an exceptional condition), the marginal costs for an additional container may be prohibitively high.

Consider the port-to-port operation of a container shipping carrier. Under normal conditions, the marginal costs are only loading and discharging operation costs, yard marshaling costs, and possibly small equipment costs (We are ignoring empty positioning costs for the moment). Those costs are almost constant until the system gets saturated. On the other hand, if the carrier daringly decides to provide the service even when the current system is full, it might have to temporarily charter an additional vessel, or buy some space of another ship or even an airplane, for the additional cargo. Hence the marginal cost curve in the short term is almost flat up to near the current system's capacity, then it goes steeply upward.

Figure 2-3 shows an example of the average cost and the marginal cost in a container shipping company under normal and exceptional conditions.

The marginal cost levels under normal conditions are not very different among container shipping carriers. On the other hand, the economy of scale works strongly in terms of the average fixed cost. In the following discussion, we assume that carriers have the same constant marginal cost (corresponding to port-

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cost

AC

MC

volume
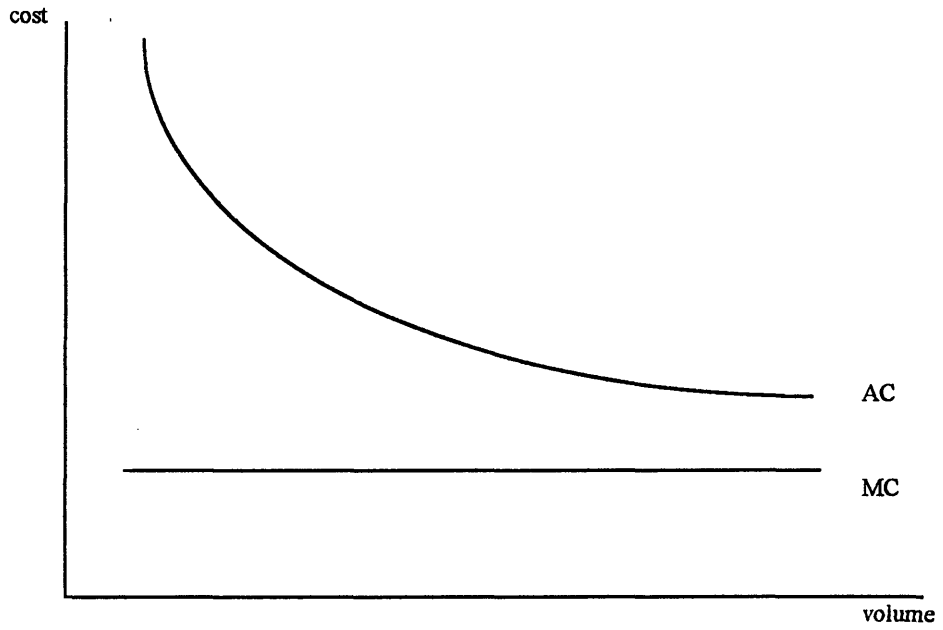
Figure 2-3 (a)   Cost functions under normal conditions

cost

MC

AC

current
capacity

volume
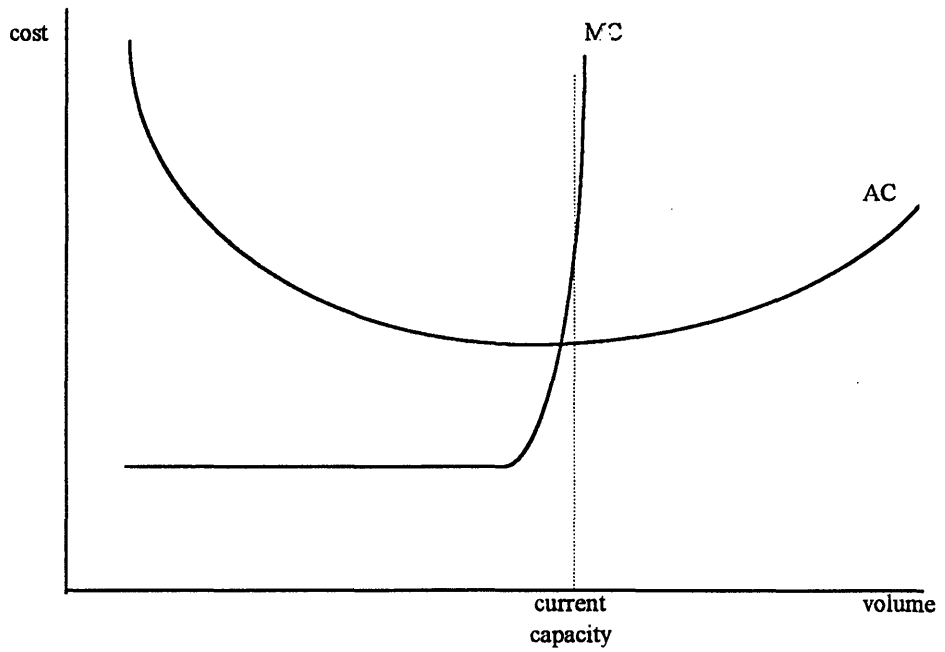
Figure 2-3 (b)   Cost functions under exceptional conditions

to-port operation), and that they have different average fixed costs. For simplicity, a single commodity market is assumed.

Suppose that a marginal company and a larger company coexist in a container shipping market. In a peak season, the carriers as a whole are assumed to have the right capacity to meet demands.

Without a conference, the price is determined at the point where the aggregate supply curve and the demand curve intersect (Figure 2-4 (a)) in a peak season. A marginal company would be at its break-even point when the market is at the equilibrium. A larger company would earn profits at that price level, since it has a lower break-even point due to a lower average fixed cost.
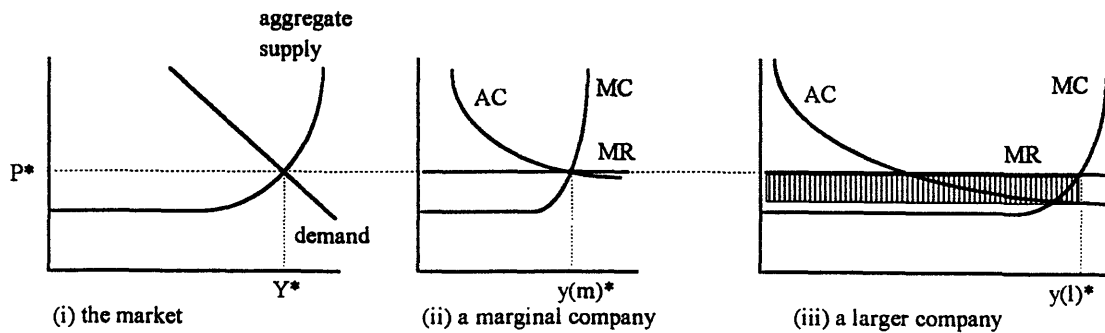
Figure 2-4 (a)   Market equilibrium in a peak season
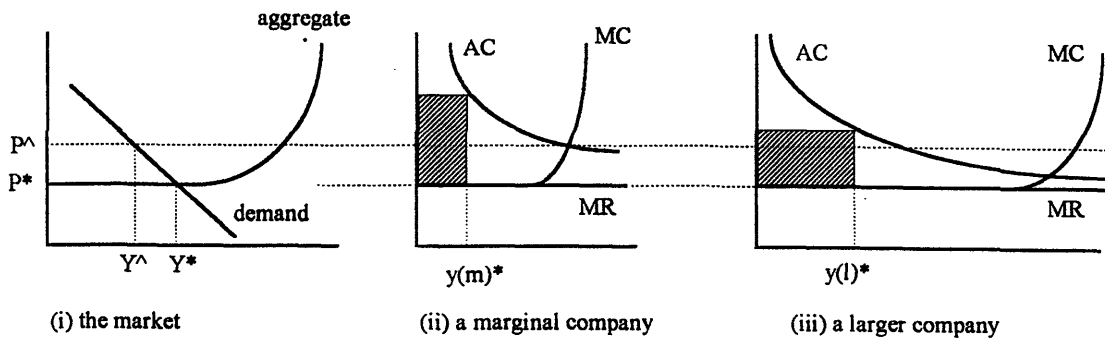
Figure 2-4 (b)   Market equilibrium in a slack season

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In a slack season, the demand curve shifts leftward, and demanded quantity shrinks (to $Y^\wedge$ in Figure 2-4 (b)). Individual companies are pressured to increase the volume by reducing the freight rate in competition. Eventually, the equilibrium (Y^*) is reached at the level where the freight rate is equal to the marginal cost. Each company loses money that is proportional to (or even equivalent to) the total fixed costs.

The traditional marketing policy of liner shipping is characterized by unfluctuating prices and a sufficient capacity to handle peak demands. This traditional policy would do harm to individual companies in a competitive environment. Under competition, the supply curve of a company is pressured to come close to the marginal cost curve. A special problem of liner shipping occurs from the special shape of the marginal cost curve. Because the marginal cost curve is lower than the average cost curve in all range under normal conditions (Figure 2-3 (a)), all companies would incur huge losses.

As long as carriers adopt the traditional business style of liner shipping without conferences, each carrier would be pressured to withdraw from container shipping under competition, except for the relatively short periods of peak seasons. This survival game would last until only one competitor survives in this market, and the market is monopolized.

(Fictitious monopolization)

The process of the natural monopoly may not be acceptable due to political reasons. Shipping lines are often associated with the national security, or national status. A government may not allow its own flag carrier to go out of business.

In international shipping, all carriers are not necessarily on the equal competitive footing. Many governments subsidize their flag carriers through various means and programs. Some governments interfere with cargo and reserve

a part of it for their own carriers. Because of the environment of international shipping as such, it is unjustifiable to allow the process of competition to eliminate some carriers.

So, on one hand, we want carriers to stay in the market. On the other hand, we want to stabilize the market. A conference will satisfy these two requirements by achieving monopolization in a fictitious way. A conference realizes the stability of the market, which normally emerges only under monopolization. A conference behaves as if it were a monopolizing company, but it is made up of several member companies.

Thus, a conference has the power to control and stabilize the market, but only when it monopolizes the market.

(The pricing mechanism of a conference)

The pricing mechanism of a conference works in the following manner: Suppose there are three kinds of commodities, namely, A, B, and C.

A: inelastic cargo (such as high-valued cargo)

B: cargo of medium elasticity

C: elastic and price-sensitive cargo (such as waste paper)

The conference sets different prices for those cargoes:

A: high price

B: medium price

C: low price (can be as low as the marginal cost)

(a) Only commodities A and B are taken

(Price)

commodityA

commodity B

average cost

AC

MC

Demand

total volume   (Quantity)

(b) Commodities A, B, and C are taken

(Price)

commodityA

commodity B

loss of taking
commodity C

average cost

commodity C

AC

MC

profit of taking
commodity C

Demand

total volume   (Quantity)
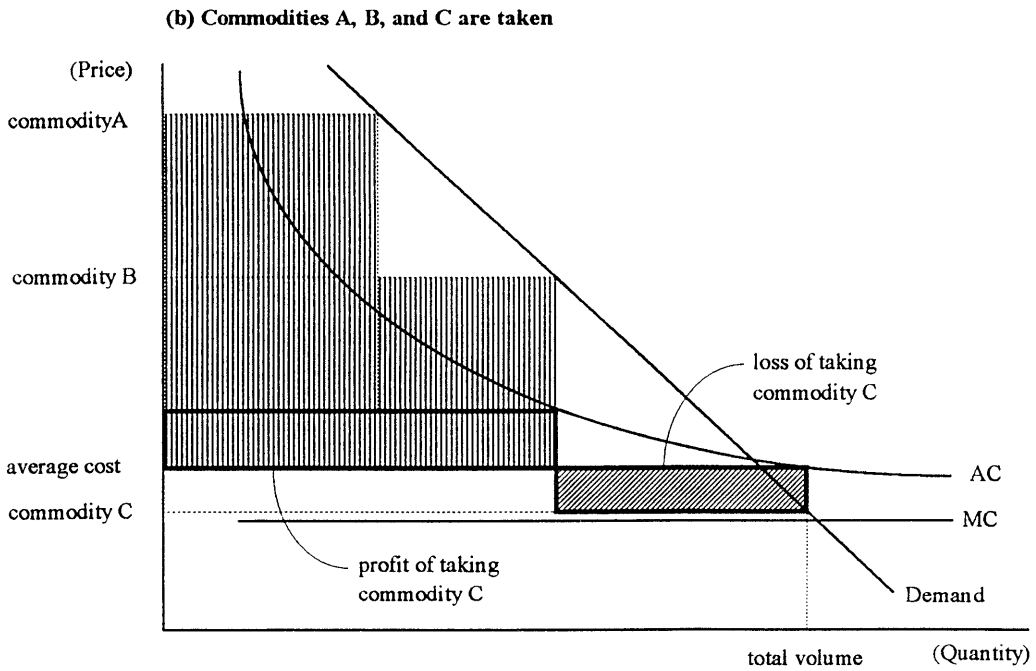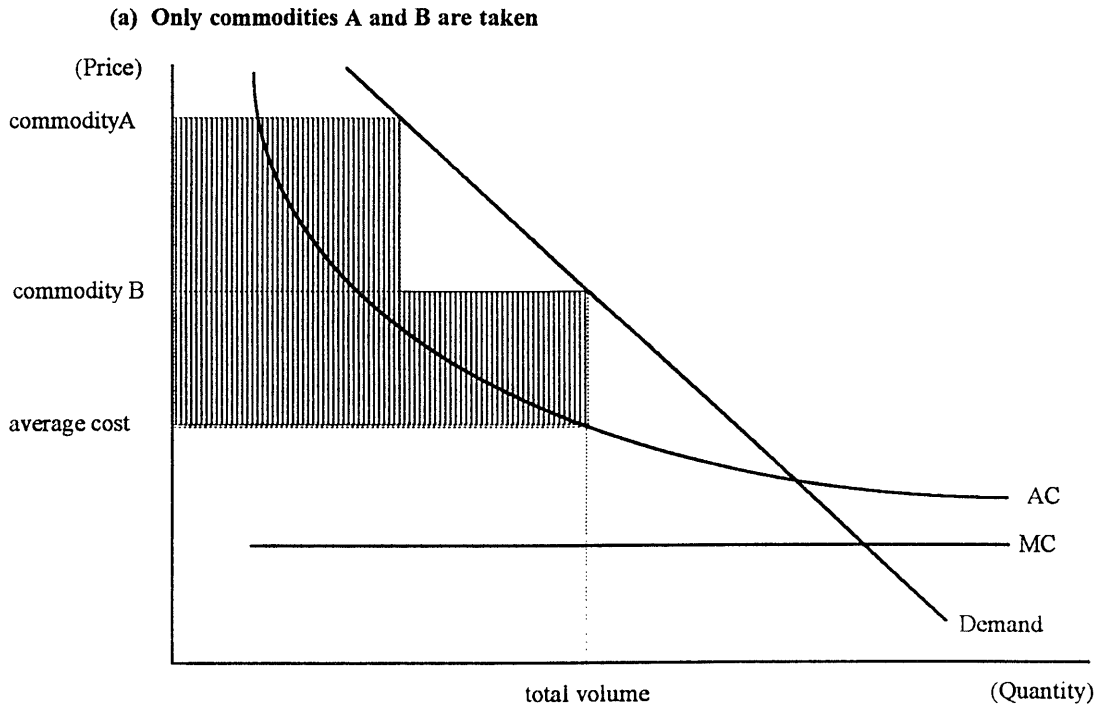
Figure 2-5   Pricing mechanism of a conference

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We regard the conference as if it were a single monopolizing company. Note that member carriers, being different in size, include marginal companies as well as larger and more profitable companies. Apart from the redistribution problem within the conference, however, the average cost and the marginal cost for the conference as a whole can be calculated as an entity.

In Figure 2-5 (b), the area of slanted stripes shows the loss of transporting commodity C, which is priced lower than the average cost. The area of the vertical stripes shows the profit of transporting commodities A and B. In comparison with Figure 2-5 (a), we can observe that commodity C increases the total volume, and lowers the average cost. The area of vertical stripes minus the area of slanted stripes in Figure 2-5 (b) is larger than the area of vertical stripes in Figure 2-5 (a), since the profit of taking commodity C is larger than the loss of taking commodity C.

Notice that by setting the price of commodity C close to the marginal cost, all available demands are effectively realized. Transporting commodity C does not necessarily mean a loss to the entire system. By taking commodity C, the total volume can be increased and the economy of scale can be achieved. That is, the loss from taking commodity C may be offset by its effect of lowering the average fixed costs.

Also notice that the conference takes commodity C, and still stays above the break-even point because of price differentiation. This pricing strategy, however, has a serious problem in container shipping. From the view point of customers, the price differentiation is not based on service levels or anything else that is tangible. It is entirely based on the monopolized power of the conference.

(Lessons of the conference mechanism)

For the sake of the later arguments, let us repeat the following points:

(1)   A conference has the power to control the market, because it monopolizes the market.

(2)   A conference can realize economies of scale by differentiating prices, and by offering a price less than the average cost to an elastic cargo.

2.3   Information Systems as Strategic Tools

Conferences do not assume competitive environments, and so they reacted poorly in the competition with non-conference carriers. Given the fact that conferences are losing monopoly powers, container shipping carriers are urged to create new strategic schemes. I believe that information systems can become effective strategic tools.

Shipping carriers of today do not have any effective mechanisms to establish the differentiated aspects of the service. For example, carrier A offers an advanced cargo tracking system, and carrier B also offers a quite similar system. The competition between the "advanced" carriers lowers the possible premium for using integrated information systems. The use of integrated information systems is open to all customers, no matter how they appreciate it

On the other hand, the conference carriers have failed to harvest the price-sensitive cargo. With the loss of the monopolizing power of conferences, the price differentiation has become less effective. In the price-sensitive segments, the conference carriers are consistently losing their markets.

(Monopolization of advanced services)

In order to make integrated information systems a source of profit, I first claim that advanced services should be monopolized. The monopolization includes two processes; the inter-carrier process and the internal process.

The inter-carrier process is made up of the following events:

(i)   The creation of an entity that fictitiously monopolizes the advanced service;

(ii)   Definition and standardization of the advanced service;

(iii)   Pricing the advanced service.

Most critical point is to standardize the advanced services among member carriers. This process is not different from the process of creating a conference. In place of a conference, a certain body, such as a para-conference or an inter-carrier agreement, will be created.

The internal process is aimed at separating the aspects of advanced services from the ordinary service. The process can be described as follows:

(i)   Alteration of the internal job process so that the advanced service may be selectively applied;

(ii)   Revision of the marketing policy.

It is important that carriers DARE NOT to offer advanced services to ordinary cargo. The relationship between customers and a carrier may be affected by the introduction of service differentiation, and the marketing policy may need to be reconsidered.

(Effective price differentiation)

Once carriers succeed in differentiating the advanced service, they will be able to establish more effective price differentiation. Especially, the freight rates for price-sensitive cargoes should be lowered decisively in order to compete with non-conference carriers effectively.

Apart from the competition with non-conference carriers, conferences should lower freight rates for elastic cargoes to closer level to marginal costs. When I claim that the conference carriers should lower the rates to make themselves more profitable, that claim may require further explanation. Let us briefly analyze under what conditions carriers should lower freight rates. We should check whether the gross margin will be increased when the price is lowered for an elastic cargo.

Let

ε: the price elasticity of demand

p: the current price

q: the current quantity

GM: gross margin

mc: marginal costs (constant)

FC: fixed costs (constants)

According to the definition of the elasticity,

$$\varepsilon = \frac{\Delta q}{\Delta p} \cdot \frac{p}{q}$$

Thus, $\Delta p = \frac{1}{\varepsilon} \cdot \frac{\Delta q \cdot p}{q}$ (1)

Calculate gross margin:

$$GM = p \cdot q - FC - mc \cdot q$$

$$\Delta GM = (p + \Delta p)(q + \Delta q) - FC - mc(q + \Delta q) - \{p \cdot q - FC - mc \cdot q\}$$

$$= q \cdot \Delta p + p \cdot \Delta q + \Delta p \cdot \Delta q - mc \cdot \Delta q \qquad (2)$$

Substitute the first term with (1):

$$\Delta GM = \left(1 + \frac{1}{\varepsilon}\right) p \cdot \Delta q + \Delta p \cdot \Delta q - mc \cdot \Delta q$$

$$= p \cdot \Delta q \left\{\left(1 + \frac{1}{\varepsilon}\right) + \frac{\Delta p}{p} - \frac{mc}{p}\right\} \qquad (3)$$

Now check the sign of the equation (3). The change in the quantity is positive (because the price is reduced), so the factor $p \cdot \Delta q$ is positive. Since the cargo we are studying is elastic, $\varepsilon < -1$ and the first term $\left(1 + \frac{1}{\varepsilon}\right)$ is positive. The second term $\frac{\Delta p}{p}$ (percentage change in the price) and the third term $-\frac{mc}{p}$ (the weight of the marginal costs against the price) are negative.

Let us examine the equation (3) again with some numbers. Suppose the marginal cost is \$ 400, the current price is \$ 1,200, and the carrier is trying to reduce the rate by \$ 100. In order to increase the gross margin, how elastic the cargo should be?

$$\left(1 + \frac{1}{\varepsilon}\right) + \frac{-100}{1200} - \frac{400}{1200} < 0$$

$$\varepsilon < -1.71$$

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Thus, if the magnitude of the elasticity is greater than 1.71, the carrier should lower the rate to increase the gross margin in this case.

There may be cargoes that are more elastic than the above calculation. Low valued and substitutable commodities, such as waste paper, forest products, low-tech manufactured goods, and so on, are usually highly elastic. In such trades, the freight rate is often the most decisive factor in the conclusion of the business, and thus low freight rates for these commodities help increase the total volume.

In conclusion, integrated information systems will serve as indispensable tools for effective equipment control. They may also become one of the key factors in the strategy of price differentiation. Price differentiation is effective in realizing possible premiums for differentiated services, and competing with non-conference carriers.

Chapter 3

Empty Container Allocation Problem
and Dual Cost Analysis

In this chapter, I would like to discuss approaches to the empty container allocation problem and a method to measure the value of empty containers in a network.

3.1   Operational Effects of the Optimization Techniques

I had an opportunity to learn how a shipping carrier --- NYK Line in our case --- allocates empty containers to various cargoes. They divide the North American continent into several regions, and each regional control center independently decides which container goes to which cargo. The North American headquarters decides inter-regional allocation by checking demand forecasts and current inventory levels.

In terms of the size of regions, each region is manageable by a single person who controls the equipment in the region. Although decisions made by regional managers seem to work well, there is a major drawback in this system: decisions can achieve the optimality at the regional level at best.

The application of some optimization techniques to the empty container allocation problem may significantly improve the performance of the system. It is relatively straight forward to apply some optimization algorithms to the empty container allocation problem, though we need a careful examination of the assumptions that we are going to make.

Before discussing the application, I would like to make two caveats.

(1) It may not be easy to obtain accurate demand forecasts.

The application will exactly reflect the demand forecasts, so the accuracy of the forecasts will become much more significant. The company organization should be prepared to provide the best forecasts.

The marketing managers may need to be trained to properly estimate future demands. Furthermore, the marketing managers may have tendencies to report bigger estimates to secure empty containers for their own cargo. Those points should be considered, and proper incentives considered to insure accurate forecasts.

(2) The optimal movements and the dual costs may change in a very short period.

The demand forecasts may be changing at every moment. Since the application responds sharply to the forecasts, the optimal solution may change at every update. The marketing section may feel uneasy about planning sales activities based upon the optimal solution, since it can change so frequently. This difficulty comes from the dynamism of the real world (or the best estimates of the real world), and it seems that the marketing section should not complain about it. However, the claim that the optimal solution is too sensitive to the shortage of

empty containers may be justified under some circumstances. We will see this problem later.

3.2   The Basic Idea of the Application

I will try to apply the network simplex algorithm to the empty container allocation problem by constructing a time-space network of empty containers. A node in that network represents a city, a depot, a port, or a ramp at one time unit. An arc represents a feasible movement (or the passage of time, if the container stays at one place from one time unit to another).

The optimal solution will show the empty container movements that satisfy all the demands and other constraints at the minimum total cost. The dual cost at each node will show the marginal worth of an additional empty container at that node.
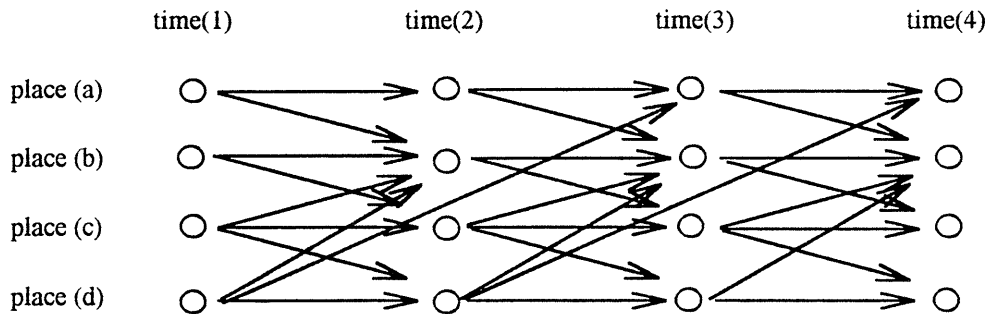
Figure 3-1   Time - space network

By using the dual costs, we can calculate the contribution of an additional cargo in terms of the empty container allocation. Obtaining an additional cargo means subtracting an additional container from the origin node and adding it to the destination node. Hence the contribution of an additional cargo is calculated as:

(contribution) = (revenue) - (direct movement costs)

- (dual cost at the origin) + (dual cost at the destination)

This calculation includes only costs associated with the direct movement and the related empty movements, but they constitute the bulk of the variable costs. There may be other important intangible cost factors --- the long term relationship with customers, the behavior of competitors, or the penalty of a railway company in case of not achieving the minimum guaranteed quantity, and so on --- when the shipping carrier decides to take, or not to take a certain cargo. In this paper, however, we are going to ignore costs other than the direct movement costs and the empty positioning costs. We assume that the value of empty containers can be approximated by the dual costs.

From the property of the dual cost (the strong duality property), the sum of dual costs at surplus nodes minus the sum of dual costs at shortage nodes equals the total empty container movement costs. This property suggests that if we penalize every demanded container and reward every supplied container at the dual cost of the node, the total penalty minus the total rewards would equal to the total empty movement costs.

3.3 Modeling Assumptions

(a) The objective

This application deals with operational decisions to minimize costs, and does not deal with marketing decisions to maximize profits. After using this technique, the operation department can pass the dual cost information to the marketing department, but marketing decisions are up to the marketing department.

As we have seen earlier, this application ignores important factors such as the long term relationship with customers. These factors should be carefully evaluated by the marketing department. We will see how an effective organization takes these factors into consideration in Chapter 6.

(b) Scope of the model

This model assumes that the container fleet size is predetermined, and that the given network remains unchanged during the time horizon. In that sense, the scope of this application is short term. By creating a super-source and a super-sink, however, we would be able to modify the application so that it may deal with the container lease-in lease-out decision problem, though such a modification would require further study about container lease practices. Such a modification would also enable to determine the optimal container fleet size for a given network and supply / demand data.

(c) Types of service

Although there are two types of service, namely LCL (Less than Container Load) and FCL (Full Container Load), we focus only on FCL here. There are door-to-door service (from the shipper's door to the consignee's door) and terminal-to-terminal service. We will include both of these types in the model.

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(d)   Homogeneity

We assume that containers are homogeneous, if they are of the same type. In other words, we do not distinguish containers in this application whether they are new or old, leased or owned.

3.4   Cost Structure

(a)   The variable cost assumption

We should include only variable costs and exclude any fixed costs in the model, because of the scope of the application. For instance, the costs of vessels (fuel, capital costs, manning costs, etc.) are excluded if the vessel has already been invested by the carrier. For another example, suppose that a terminal is run by an affiliate company of the carrier and that the affiliate company pays high fixed costs and low variable costs for the operation of the terminal. Although the group as a whole pays high fixed costs and low variable costs, if the contract between the carrier and the affiliate is based on "per container" rate that is based on the average total cost, we treat that rate as a variable cost.

(b)   Holding costs at depots

There are two types of depots, namely, a common depot and one that is operated by a carrier and used by that carrier (an owned depot). Several carriers use the former, and each carrier pays "per container" rate to the depot operator. The former, therefore, has a linear cost function up to the capacity of the depot.

The variable costs of the latter, on the other hand, are made up with fuel consumption, workers' overtime, etc. and they are quite low when the depot is not congested. However, as it becomes congested, steps necessary to move one

container may increase exponentially due to elevated stacks, and each maneuvering becomes less efficient due to narrowed passages. As many carriers experience, once a depot overflows due to a port strike or some other causes, it takes a considerable amount of time and money to recover normal operating conditions. The cost function at an owned depot is close to flat to a certain point, and it goes up steeply toward the capacity of the depot.

a common depot   an owned depot

cum. marginal costs — current capacity — inventory level

cum. marginal costs — current capacity — inventory level
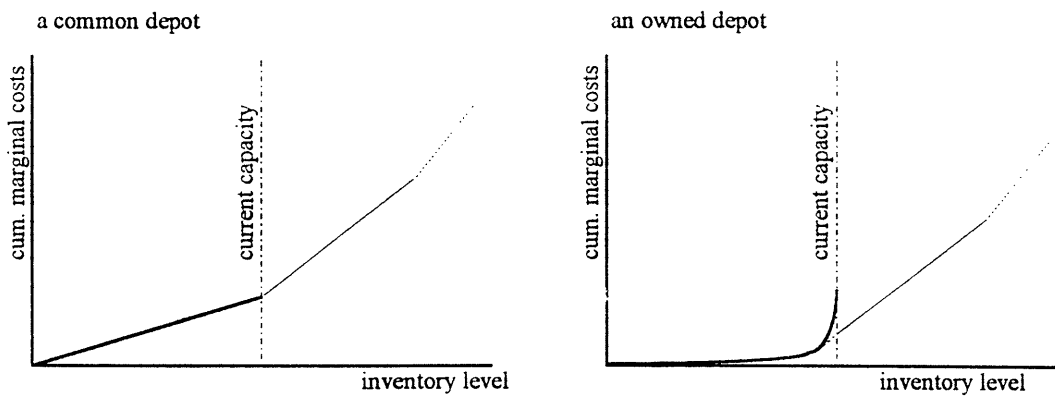
Figure 3-2   Holding cost function

In both cases, as the inventory level comes close to the capacity limit, the carrier has to use other depots at higher costs, or hire an additional piece of land for temporary storage.

In setting the capacity constraint of a depot, we should be careful not to go beyond the economically feasible point. Within the economically feasible range, the slope of the cost function cannot become steeper than that of the next available depot. Within that range, we can treat holding cost functions as linear.

(c)   Separation of a depot from a terminal

Most sea or rail terminals possess the empty container depot function in the same site, or in an adjacent lot. However, we should not treat a terminal and its accompanying depot as the same place, if the terminal functions and the depot functions are physically separated even within the same site. Even the shortest drayage between the terminal and the depot may affect the empty container movement costs significantly.

(d)   Triangular inequality

The costs of moving a container generally hold triangular inequality, if that movement uses only one mode of transportation.

For example, suppose that there are three terminals a, b, and c on the same railway route.

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Figure 3-3   Triangular inequality

The cost of sending an empty container form a to c in one shot is generally less than the sum of sending it from a to b, and then b to c, i.e.

$$\text{cost}(\,a \to c\,) \leq \text{cost}(\,a \to b\,) + \text{cost}(\,b \to c\,)$$

This is mainly because unloading and loading operation costs at terminal b can be saved if it is sent in one move.

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When the movement stretches over more than one transportation mode, the triangular inequality is not always true. Suppose that the section a-b is carried by ocean transportation, and the section b-c is carried by railway transportation. Since one mode of transportation terminates at the intermodal terminal, total movement costs are equal to the sum of modewise movement costs, i.e.

$$\text{cost}(\, a \rightarrow c \,) \;=\; \text{cost}(\, a \rightarrow b \,) + \text{cost}(\, b \rightarrow c \,)$$

We can use this property to simplify a network that represents special geographical structure. For example, consider that there are three separate regions, a, b, and c. Each region has only one port city, namely, a(1), b(1), and c(1), and a(1) - b(1) - c(1) are connected by sea route. Other cities within each region are connected by truck routes.

In Figure 3-4, each region has four cities, and there are 12 cities in total. We would need $_{12}P_2 = 12 \cdot 11 = 132$ decision variables for each time unit, assuming such movements are available.
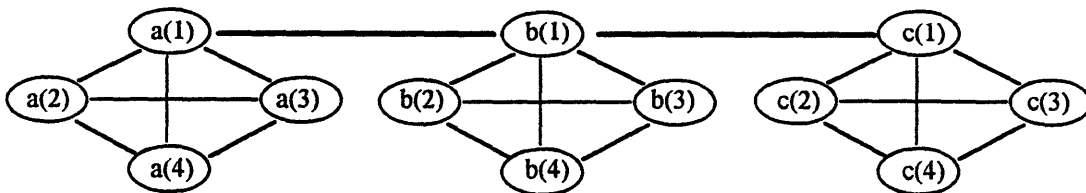
Figure 3-4   Network of isolated regions

Now observe that any empty container that moves from one region to another has to pass through intermodal terminals in port cities. To make use of the

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property that the total costs are the sum of modewise costs, transform the illustration as follows:
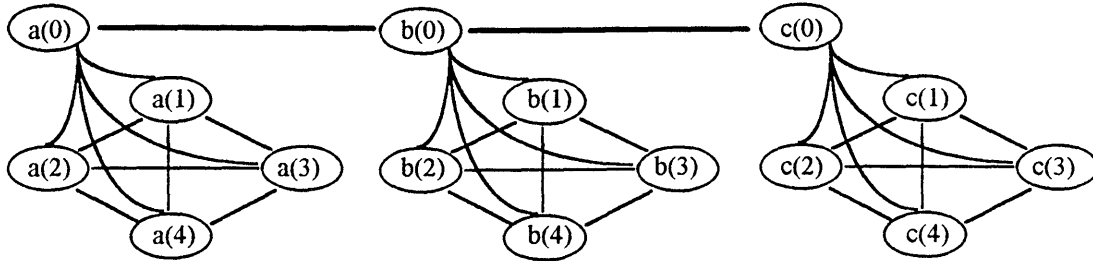
Figure 3-5   Modified network of isolated regions

Let a(0) represent the intermodal terminal (port) of city a(1), and a(1) represent the depot of city a(1). Whereas the regional truck networks remain unchanged, there are new arcs that represent truck movements from depots in each cities to the intermodal terminal. The arc a(0) to a(1) represents the short drayage between the terminal and the adjacent depot.

In this modified graph, we need $_5P_2 = 20$ decision variables in each region, and $_3P_2 = 6$ decision variables as inter regional decision variables. The total number of decision variables is only 66, and we can considerably simplify the network in this way. The effect of this technique becomes even greater when a network becomes larger. We can apply this technique to isolated areas, islands, or port-hinterland structures.

3.5 Network Structure

(a) Multiple routes

There may be multiple routes between two places, though the costs of those routes are different. We can simply add arcs that correspond to additional routes between nodes. Optimization will automatically decide the priority among those routes.

(b) Bundle constraints

Since several decision variables use the same route at the same time, it seems that we should introduce bundle constraints to the network. However, those constraints are not introduced in this research due to the following reasons.

i)   A shipping carrier does not necessarily control the capacity of its inland transportation network. A shipping carrier is usually a mere "user" of trucking or railway companies, and the capacity of its inland network is subject to the policies of trucking or railway companies.

ii)   The bundle constraints become critical when a part of the network becomes saturated. Such a situation occurs only in peak seasons, and we can regard such a situation as an exception.

iii)   Empty container movements are generally much more flexible than loaded movements, and we could shift the timing of some empty movements a little bit forward or backward to smooth the total volume.

3.6 Resolution and Boundary Problem

What should be the unit that represents a node in our model? There can be several resolution levels. A node in the network can represent a customer, a facility, a city, or a region. The followings are examples of resolution levels:

(1) All FCL customers and all facility sites are represented by nodes in the network. This level is the finest resolution.

(2) Influential customers and major facility sites are represented by nodes in the network. Demands and supplies at smaller customers and minor facilities are added to nearby nodes.

(3) Major facility sites are represented by nodes. Demands and supplies generated at other places are added to nearby nodes.

The resolution level 1 (all FCL customers and all facility sites) will be unmanageable and inefficient, partly because the number of decision variables would become astronomical, and partly because there are a considerable number of infrequent small customers.

If the resolution level is less fine than level 1, there exists another problem, that is, the boundary problem. Let us examine this problem. Suppose that we have chosen level 3 (major facilities). Which node should a customer belong to? Well, we can define the following rule for instance: Consider the customer to belong to the territory of a node that is the closest in terms of the cost of truckage. The demands and supplies of a node will be the sum of demands and supplies generated in the territory.
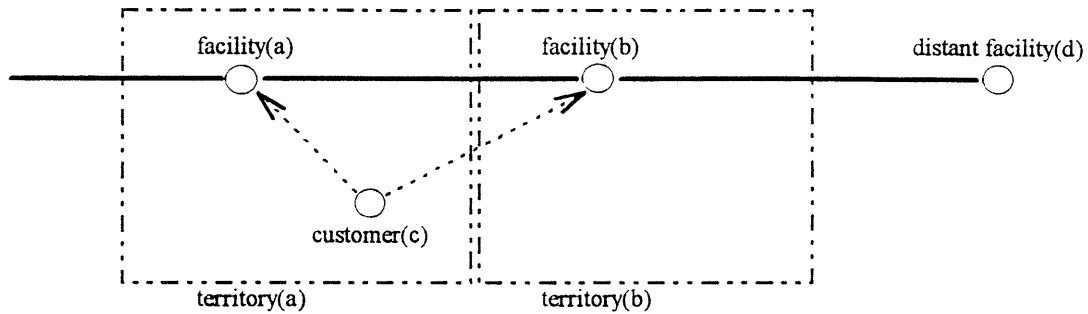
Figure 3-6   Boundary problem

Let us look at an example of a territory map (Figure 3-6). The line between facility(a) and facility(b) can be a truck route or a railway route. Now the customer(c) returns an empty container. Suppose the truckage c→a is, say, $ 200 and the truckage c→b is $ 250. According to the rule, the customer(c) belongs to the territory of facility(a).

Suppose that the optimal solution tells that we should send all the surplus empty containers from both facility(a) and facility(b) to facility(d), because of great shortage at facility(d). If the cost of a→d is, say, $800 and that of b→d is $700, should we still return the empty container from c to a? Obviously, we should return the empty container to facility(b), if we know that it will eventually go to facility(d). How can we know in practice that the empty container should be returned to a node to which it does not belong?

We can solve this problem by examining dual costs and doing range analysis. Let $\pi_{t,n}$ be the dual cost of node n at time t, and $\beta_{t,n \to m}$ be the dual cost of the bundle constraint in arc n-m that departs from node n at time t, and $c_{n \to m}$ be the transportation cost between node n and m. The time-space network of the above situation is as follows:

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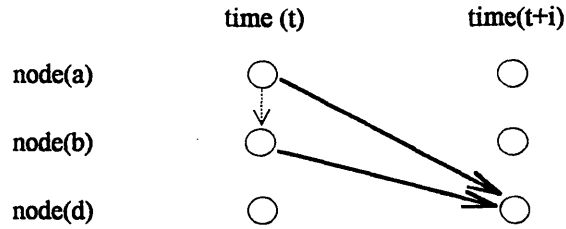
Figure 3-7   Correction of the optimal solution

where i is the transit time between a→d, or b→d.

The relationships between node a and d, and between b and d at the optimality are:

$$\pi_{t,a} = \pi_{t+i,d} + \Sigma_{(j\in a\to d)}\beta_{t',j} + c_{a\to d}$$

$$\pi_{t,b} = \pi_{t+i,d} + \Sigma_{(j\in b\to d)}\beta_{t',j} + c_{b\to d}$$

For the sake of simplicity, assume that arc(t, a→d) and arc(t, b→d) are not saturated. Then,

$$\Sigma_{(j\in a\to d)}\beta_{t',j} = \Sigma_{(j\in b\to d)}\beta_{t',j} = 0$$

and therefore,

$$\pi_{t,a} = \pi_{t+i,d} + 800$$

$$\pi_{t,b} = \pi_{t+i,d} + 700$$

The dual cost of a customer is calculated as follows:

Let Node be the node to which the customer belong.

If the customer is an importer,

$\pi_{t, \text{customer}} = \pi_{t', \text{Node}} +$ (truckage between the customer and the node)

If the customer is an exporter,

$\pi_{t, \text{customer}} = \pi_{t', \text{Node}} -$ (truckage between the customer and the node)

In our example, the customer(c) is considered to belong to facility(a), and so the dual cost of the customer(c) at time t is

$$\pi_{t, c} = \pi_{t, a} + 200$$
$$= \pi_{t+i, d} + 1000$$

Now suppose that the operator of the system luckily finds that the truckage c→b costs only \$ 250, and that the dual cost of facility(b) at time t is $\pi_{t+i, d} + 700$. The operator has found a way to reduce the dual cost of the customer (c) by using the truck route c→b. These figures suggests that the operator can improve the total empty movement costs by \$ 50 by sending the empty container from c to b, instead of c to a.

Once we get the optimal solution, the dual cost of every node and customer will become known. The operator should carefully watch the difference of the dual costs between a node and other places. If the operator finds a way to send containers at less cost, the operator can "correct" the optimal solution.

Can the operator correct the optimal solution as much as they can find in this way? The answer is no, and they will need to conduct range analysis. If the customer(c) returns quite a few empty containers at a time in the above example, the operator can improve the solution by sending empty containers from c to b, but some of the arcs on the way may become saturated after sending a certain number of containers.

Changing the node that empty containers are returned to has an effect of adding an artificial arc between nodes (in the above example, a vertical arc between node a and b). The cost of this arc is $c_{c \to b} - c_{c \to a}$ and the capacity of the arc is the amount that the customer returns. By adding this arc in the above example, arc(t, a→b), arc(t, b→d), and arc(t, a→d) form a unique cycle, and continue to improve the total transportation costs until (i) the flow along arc(t, a→ d) goes down to zero, (ii) arc(t, b→d) gets saturated and the positive cost $\beta_{t', b \to d}$ prohibits sending any more, or (iii) empty containers are sent up to the capacity of arc(t, a→b).

We can see that there is a trade-off between the resolution and the number of corrections necessary afterwards. The finer the resolution, the more complex the computation is, but the fewer corrections that will become necessary.

3.7 Time Horizon Problem

Suppose that a period in which the optimization is applied is given. To provide containers for a node that corresponds to a shortage place in the first time unit, containers should have been sent to that node from before the application period begins. Similarly, if it is expected that a place needs to be sent containers in the next time unit after the end of the application period, the decision to send empty containers should be made before the application ends.

In other words, the model may need to have empty containers in movement at the beginning and at the end of the application period. There can be several types of models to include empty movements at the both starting and ending time horizons. Let us examine possible types of models.

(i)   **Penalizing model** (for initialization)
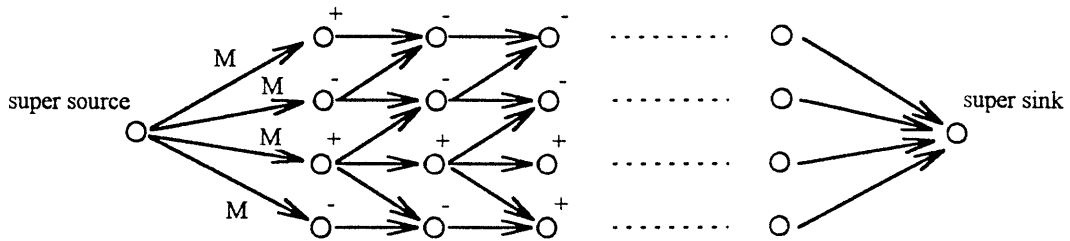
Figure 3-8   Penalizing model

This model adds the super source node and connects it to nodes that correspond to the first time unit by arcs that have a punitively high cost. This model minimizes the number of empty containers used in the network. However, the model does not reflect the current inventory distribution.

(ii)   **Preceding network model** (for initialization)
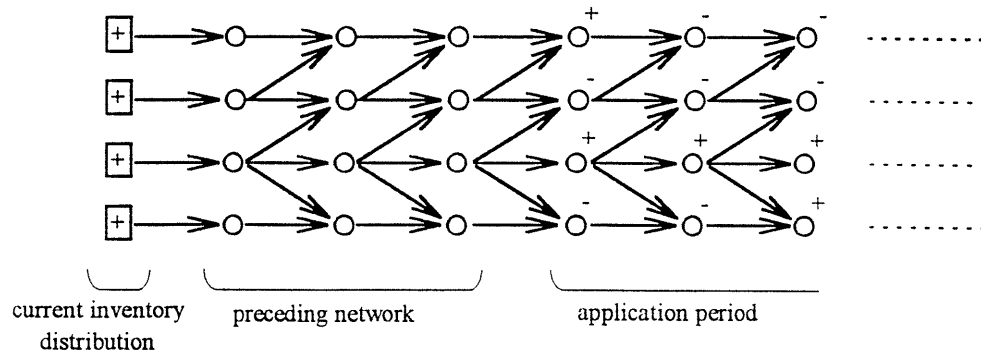
Figure 3-9   Preceding network model

This model creates a preceding network for several time units. Nodes in the first time unit are supplied with empty containers equivalent to the current inventory distribution. Otherwise, there are no supplies and demands in the preceding network. If empty containers are necessary at the beginning of the application period, they will be sent through the preceding network. In that sense, the preceding network functions as a waiting period in which initial empty movements can be generated.

(iii)   **Simple ending model** (for finalization)
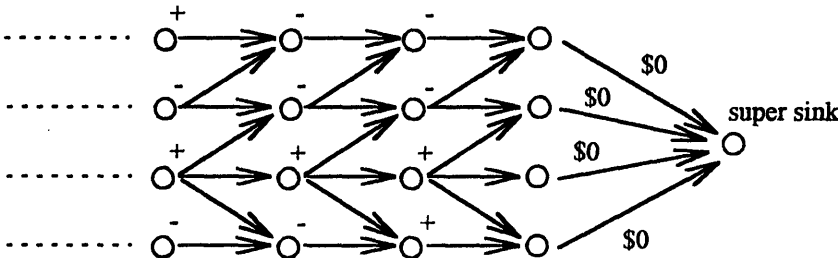
Figure 3-10   Simple ending model

This model simply connects nodes in the last time unit to the super sink node by arcs that have zero cost. It sets no restrictions on the inventory distribution when the application period ends. The model may optimize the application period without considering the inventory distribution after the application period. However, this model is easy to create without the apprehension of infeasibility.

(iv) Standard inventory distribution model (for finalization)
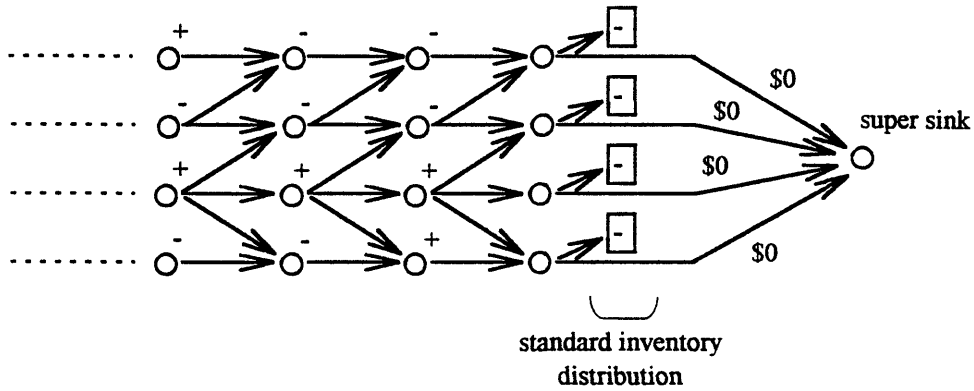
Figure 3-11   Standard inventory distribution model

Before we construct the model, we set a standard inventory level for each place. The model subtracts the standard inventory level of empty containers from each node in the last time unit. Nodes in the last time unit are also connected to the super sink, so that surplus empty containers may be sucked up.

This model guarantees that at least the standard inventory levels will be maintained when the application period is over. Since the standard inventory levels are determined manually, however, they may not be the optimal inventory distribution.

(v) Accumulation model

This model separates the application period into three sections; the preceding period, the core period, and the succeeding period. Nodes in the first time unit are supplied with empty containers equivalent to the current inventory distribution. In the preceding period, surplus nodes supply empty containers, but

shortage nodes do not subtract empty containers. Shortages are set to zero and ignored in the preceding period. In the succeeding period, shortage nodes subtract empty containers, but surplus nodes do not supply containers. Surpluses are set to zero and ignored.
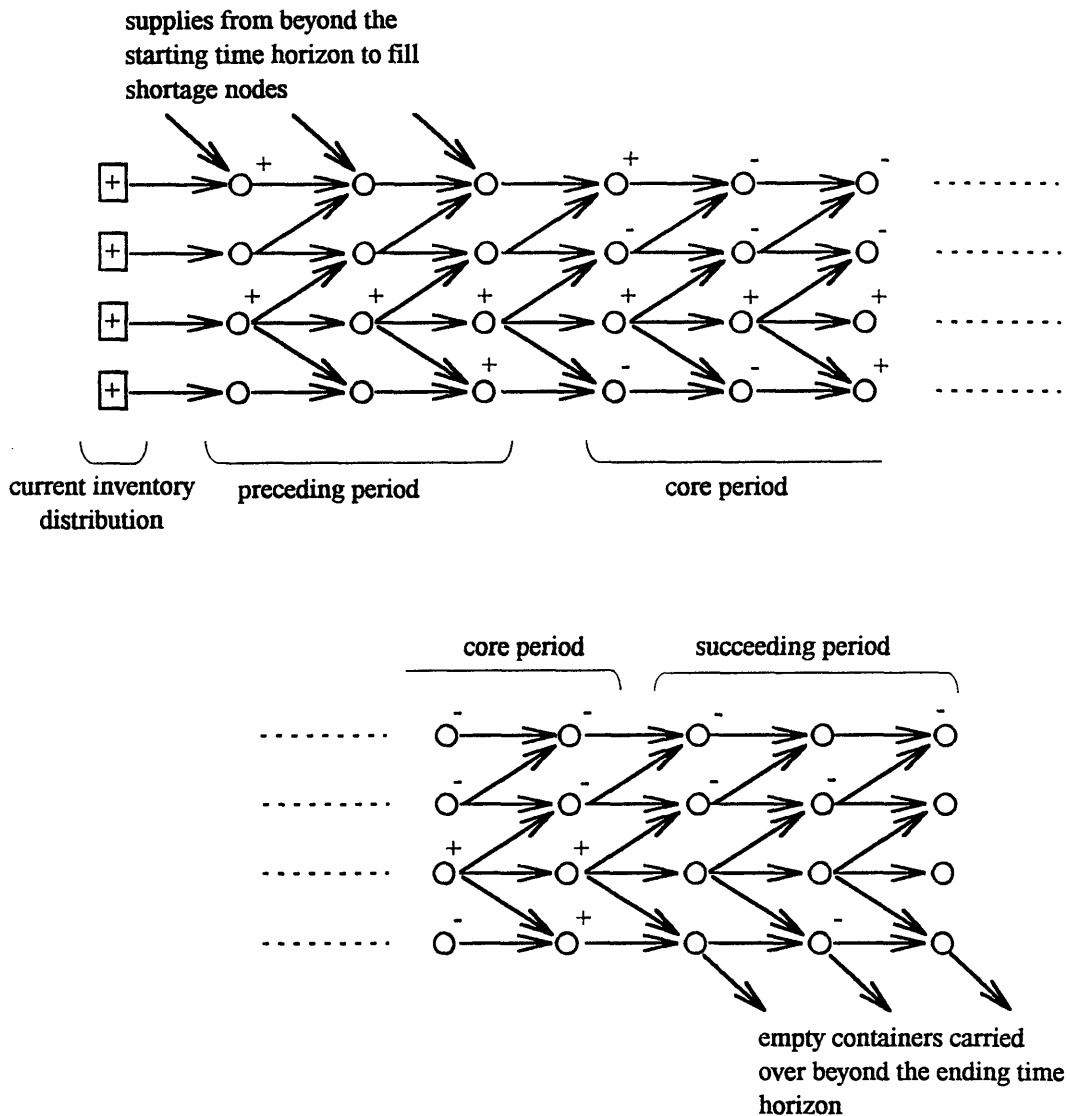
Figure 3-12   Accumulation model

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The reason for ignoring shortages in the preceding period is based on an assumption that they have been satisfied by empty movements that are already decided before the application period begins. Symmetrically, in the succeeding period the model supplies empty containers to satisfy future shortages that are beyond the core period.

At the end of the application period, this model will have an inventory distribution that just satisfies demands in the upcoming several time units. Thus this model leaves a well prepared inventory distribution at the end of the application period. However, since empty containers in movement accumulate during the preceding period without being subtracted at shortage nodes, the inventory levels in the model are greater than in reality.

3.8 Range Analysis

The optimal solution may change from time to time, reflecting the changes of the demand forecasts. However, a user of the dual cost information may feel that the optimal solution is too sensitive to even small changes in the demand forecast.

Let us begin with an example. Suppose there is city x, where the average shortage is only a few containers per week. Being far away from the nearest container abundant place, city x has a high dual cost. The marketing department notices the high dual cost of city x, and aggressively procures cargo to city x, in expectation of taking advantage of the high dual cost. A while later, empty containers begin to gather in city x. Since the depot in city x is not very big, excessive containers have to be sent to the nearest depot. Being far away from it, city x now has a very low dual cost.

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Besides the above story, city x may have a natural oscillation in demand, and the dual cost of city x may seem to swing from one extreme to the other.

We can manage such a situation by giving users the results of range analysis. Users are warned by the results of range analysis that the current dual cost will likely change if the number of containers goes out of the range. Users can make more careful decisions by paying attention to the narrow limits of the range.

However, I have not incorporated range analysis into this research so far, since this feature would be more effective to implement after obtaining response from actual users.

Chapter 4

Network Simplex Algorithm

In this chapter, I will review the theory and the algorithm of the network simplex method. I followed the mathematical reasoning to reach the network simplex method from a standard linear programming formulation. I tried to be concise in the theoretical review, while maintaining mathematical rigor to some extent.

The network simplex method gives impressive and interesting graphical interpretations of the algorithm. In the algorithmic review, I will focus on the graphical implications, and omit detailed description of the algorithm.

4.1 Theoretical Review

The network simplex is one of linear programming methods with a special structure. Let us formulate the network simplex algorithm as a linear programming problem.

(primal formulation)

$$\min cx$$

subject to:

$$Ax = b \quad (\pi)$$
$$x \le u \quad (\mu)$$
$$x \ge 0 \quad (\lambda)$$

where

x: the vector of decision variables that correspond to arcs in the network

c: the cost vector

A: the node-arc incidence matrix

b: the vector of shortage or surplus at each node

u: the vector of the capacity of each arc

(π, μ, λ are corresponding dual variables)

We can observe a special structure in this linear programming. Let m be the number of arcs and n be the number of nodes in the network. The dimension of the matrix A is n x m.

Each column of the matrix A has one entry of 1, which corresponds to the starting node, and one entry of -1, which corresponds to the ending node. Other entries in each column are all zeroes.

A base of the matrix A corresponds to a spanning tree, which has n-1 arcs. Even in a non-degenerate case, the rank of the matrix A is n-1, and one row is redundant.

The matrix A has the property of total unimodularity, which satisfies the condition that every square submatrix of A has determinant +1, -1, or 0. Thus the determinant of every base B of the matrix A is +1 or -1 (unimodularity). Given the unimodularity of the matrix A, we can easily see the integrality property of

network problems. Every basic feasible solution x_B of a network problem is integral, because the right hand side vector b is integer in the network problem, and because by Cramer's Law, the solution of the system of equation $Bx_B = b$ is

$$x_j = \frac{|B_j|}{|B|}$$

where B_j is a matrix obtained by replacing the j th column of B with the vector b. The integrality property guarantees that the flow of each arc is integer throughout the algorithm process.

Whereas the differences among the dual costs matter, the absolute level of the dual costs can be arbitrary. Let us examine the dual objective πb:

$$\pi b = \sum_i \pi_i b_i$$

Suppose that the value of every element in π is changed by Δ. Then the new objective value becomes:

$$\pi' b = \sum_i (\pi_i + \Delta) b_i$$

Calculating how much the objective value changed:

$$\pi' b - \pi b = \sum_i (\pi_i + \Delta) b_i - \sum_i \pi_i b_i$$
$$= \Delta \sum_i b_i$$

Because the network as a whole should balance, the sum of the all elements of the shortage/surplus vector b is zero, and therefore the objective value is not affected by the level of the dual costs.

The important implication of this observation is the relativity of the dual costs in network problems. While the differences among the dual costs show the level of the dual cost at each node, the absolute value of a dual cost does not mean much.

Next, let us examine the optimality conditions. The Karush-Kuhn-Tucker optimality conditions can be expressed as follows:

(primal feasibility)
$$Ax = b$$
$$x \le u$$
$$x \ge 0$$

(dual feasibility)
$$\pi A - \mu + \lambda = c$$
π: unrestricted in sign
$$\mu \ge 0$$
$$\lambda \ge 0$$

(complementary slackness)
$$\pi(Ax - b) = 0$$
$$\mu(x - u) = 0$$
$$\lambda x = 0$$

Suppose that the value of x_j is at its upper bound, namely, $x_j = u_j$. Then, from the complementary slackness conditions, $\lambda_j = 0$, and μ_j can take non-zero value. (Note

that $\mu_j \geq 0$, $x_j - u_j \geq 0$, $\lambda_j \geq 0$, $x_j \geq 0$ for all j from the primal dual feasibility).

If the value of x_j is at its lower bound, namely, $x_j = 0$, then $\mu_j = 0$, and λ_j can take non-zero value. If the value of x_j is in between $(0 < x_j < u_j)$, then $\mu_j = \lambda_j = 0$.

Conversely, if the reduced cost of x_j (that is, $c_j - \pi A_j$) is strictly negative, because of the dual feasibility conditions, $\mu_j > 0$. This implies that $x_j = u_j$ from the complementary slackness conditions. If the reduced cost of x_j (that is, $c_j - \pi A_j$) is strictly negative, then $\lambda_j > 0$, and thus $x_j = 0$. Hence the optimality conditions can be summarized as follows:

$$c_j - \pi A_j \geq 0 \qquad \text{if } x_j = 0$$
$$c_j - \pi A_j = 0 \qquad \text{if } 0 < x_j < u_j$$
$$c_j - \pi A_j \leq 0 \qquad \text{if } x_j = u_j$$

where A_j is the j th column of the matrix A. In order that a basic variable may be able to take a value between the lower bound and the upper bound, the reduced cost associated with a basic variable should be set to zero. A non-basic variable should be either at its lower bound, or at its upper bound.

Now let us look at the structure of the matrix A. Let the j th arc starts from the node s, and terminates at the node t. The j th column of the matrix has 1 at the s th entry, -1 at the t th entry, and zeroes at all other entries. Thus,

$$\pi A_j = \pi_s - \pi_t$$

Applying the above equation to the optimality conditions, we get

$$\left.\begin{array}{ll} c_j - \pi_s + \pi_t \geq 0 & \text{if } x_j = 0 \\ c_j - \pi_s + \pi_t = 0 & \text{if } 0 < x_j < u_j \\ c_j - \pi_s + \pi_t \leq 0 & \text{if } x_j = u_j \end{array}\right\} \quad \cdots(*)$$

The same conditions can be written in a slightly different way:

$$
\left.
\begin{aligned}
x_j &= 0 && \text{if } c_j - \pi_s + \pi_t > 0 \\
x_j &= u_j && \text{if } c_j - \pi_s + \pi_t < 0 \\
c_j - \pi_s + \pi_t &= 0 && \text{if } x_j \text{ is a basic variable}
\end{aligned}
\right\} \quad \cdots (**)
$$

The above conditions (**) implies that if the difference of the dual costs between the starting node and the terminating cost is less than the cost of the arc, the arc is empty. If the difference is greater than the cost of the arc, the arc is saturated. If the arc corresponds to a basic variable, in other words, if the arc belongs to the optimal spanning tree, the reduced cost is zero.

The flows along the arcs seem to behave as if they were fluid, when we compare the difference in the dual costs between the starting node and the terminating node to the slope of a tube. When the slope of a tube is steeper than the corresponding cost, the fluid flows at the full capacity of the tube. (The arc is non-basic and at its upper bound). When the slope is more gradual than that, the fluid does not flow. (The arc is non-basic and at its lower bound). When the slope is equal to the corresponding cost, the fluid flows at a level within the capacity. (The arc is basic and a part of the spanning tree).

4.2   Algorithmic Review

First, I will sketch the outline of the algorithm. I assume that readers have some familiarity with the simplex method.

The network simplex starts from a feasible solution. This initial feasible solution has to be feasible, but may not be optimal. A feasible solution is made up

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of three types of arcs, namely, (i) an arc that is non-basic and at its upper bound, (ii) an arc that is non-basic and at its lower bound, and (iii) a basic arc. Due to the rank of the network matrix, there are at most (the number of nodes - 1) basic arcs, and such basic arcs graphically form a spanning tree.

We look through non-basic arcs and calculate the reduced cost of each arc. If all non-basic arcs satisfies the optimality conditions, we are done. The current solution is optimal. If we find a non-basic arc that violates the optimality conditions, we add that arc to the spanning tree and remove one of arcs in the spanning tree. (Note that the leaving arc and the entering arc may be the same). We now have a different spanning tree with a better objective value. The operation that adds one arc and removes one arc is called pivoting. The algorithm iterates the pivoting and keeps improving the spanning tree until it reaches optimality.

4.3   Algorithm Flowchart

To illustrate the outline of the algorithm, let us take a look at the flowchart of the algorithm.

(Construction of an initial spanning tree)

The algorithm begins by constructing an initial spanning tree. The easiest way of constructing an initial feasible spanning tree is adding artificial arcs to the network.

```
              ┌────────────────────────────────┐
              │  Construct an initial spanning tree  │
              └────────────────────────────────┘
                            │
                            ▼
                      ╱─────────────╲
            ┌────────▶   Optimality test  ├──────────────┐
            │         ╲─────────────╱                     ▼
            │               │                      ┌──────────────┐
            │               │                      │  Termination │
            │               ▼                      └──────────────┘
            │   ┌────────────────────────────┐
            │   │   Select the next entering arc │
            │   └────────────────────────────┘
            │               │
            │               ▼
            │   ┌────────────────────────────┐
            │   │      Add the entering arc      │
            │   │      to the spanning tree      │
            │   └────────────────────────────┘
            │               │
            │               ▼
            │   ┌────────────────────────────┐
            │   │     Determine the leaving arc  │
            │   └────────────────────────────┘
            │               │
            │               ▼
            │   ┌────────────────────────────┐
            │   │     Update the tree structure  │
            │   │        and other indices       │
            │   └────────────────────────────┘
            │               │
            └───────────────┘
```
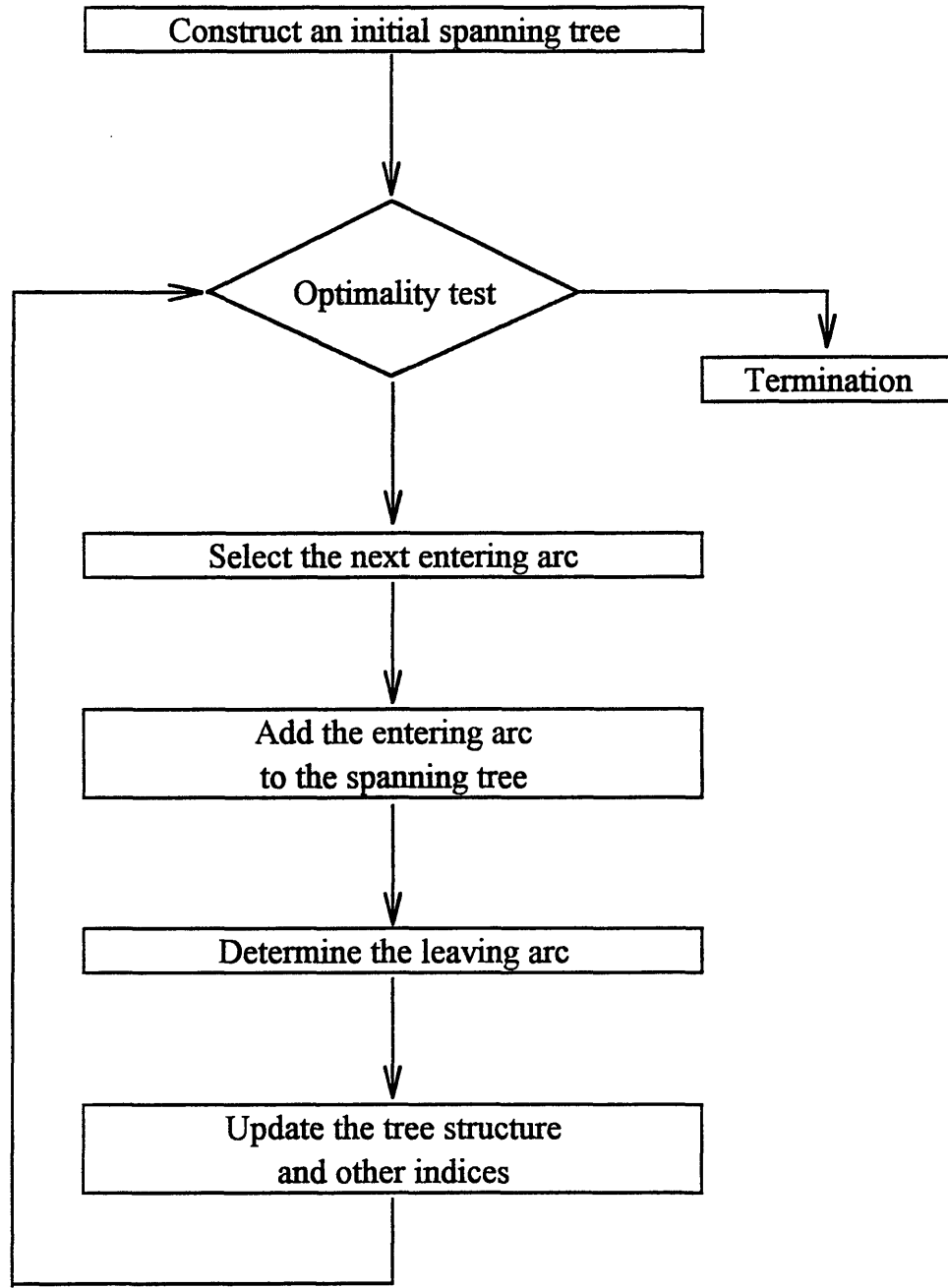
Figure 4-1   Algorithm flowchart

An artificial arc should have at least as large a capacity as the demand/supply of the node, with a punitively high cost. We can arbitrarily choose one node as the source node, then link the source node with every other node by

an artificial arc in the following manner. If the node has demands, or a negative right hand side value, link from the source node to that node. If the node has supplies, or a positive right hand side value, link them in the opposite direction. The initial spanning tree is composed of all artificial arcs, and all the non-artificial arcs are empty at the initial stage.
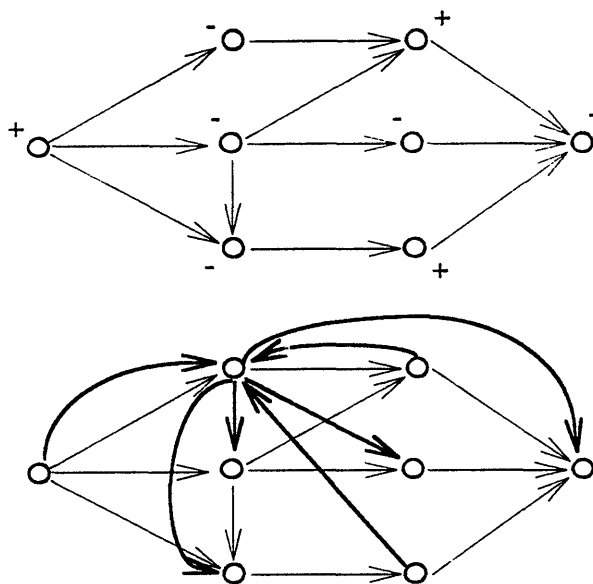
Figure 4-2   Initial feasible spanning tree

(Optimality test)

If all the costs of arcs are non-negative, there is no way that the problem can become unbounded, and the total cost goes down to negative infinity. In this research, we do not have to worry about the problems being unbounded, because we do not use any negative datum.

At every iteration, we need to test whether there are still non-basic arcs that violate the optimality conditions. If all the non-basic arcs satisfy the optimality

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conditions, the program terminates there. If there are still non-empty artificial arcs after the termination, the program is infeasible. Otherwise, the program has reached optimality.
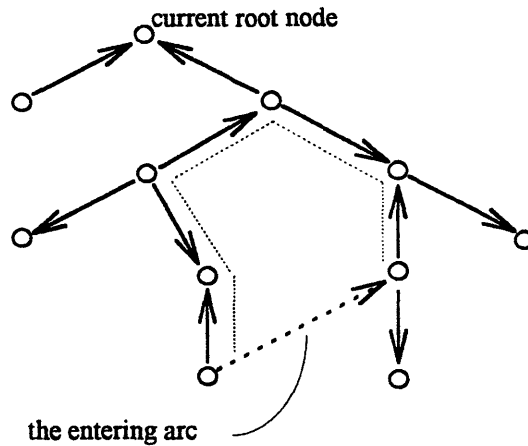
(Selection of an entering arc)

Every non-basic arc that violates the optimality conditions is entitled to enter the spanning tree. Among them, we would like to chose the arc that violates the optimality conditions most, because the entering of such an arc will improve the objective value most in one iteration. However, we are in a trade-off situation in doing that. If we search for the very best candidate for the next entering arc, we have to scan all the non-basic arcs, which may require a considerable amount of time to go through. If we scan only a part of non-basic arcs, we can reduce the time for scanning at each iteration, though the improvement at each iteration may be smaller, and hence the number of iterations necessary to reach the optimality may increase. This situation will be looked into later in this chapter.

(Determining the leaving arc)

If we add an arc to a spanning tree, a cycle will be formed. Flows along that cycle will be changed, while flows along other parts of the tree remain unaffected.

Flows along the cycle continue to change until (at least) one of the arcs gets saturated, or becomes empty. Then, the arc that is saturated or empty becomes a non-basic arc and leaves the tree structure. The algorithm continues by going back to the optimality test.

Figure 4-3   Finding a cycle

4.4   Modification of the Pivot Rule

The process of selecting the next entering arc is the most critical part of the algorithm. The classical method, also known as **Dantzig's pivot rule**, selects an arc with the maximum violation at each iteration. Since this method selects the best candidate as the entering arc, the objective value is most improved at each iteration, and the number of iterations necessary to reach the optimality is fewer than other methods. However, the time required for scanning all the non-basic arcs may be very expensive.

In contrast, the **first eligible arc pivot rule** selects the violating non-basic arc that is found first. This method minimizes the time required for scanning at each iteration. However, the improvement of the objective value at each iteration may be very small, and the number of iterations necessary to reach the optimality may be greater than other methods.

If Dantzig's pivot rule may be considered one extreme, and the first eligible arc pivot rule the other, the **candidate list pivot rule** consists of a point on the

spectrum between them. This method first scans a portion of the non-basic arcs and creates a candidate list of a specified size. It goes through this candidate list at each iteration, and selects the arc of the maximum violation in the list. It uses the same candidate list for a specified number of pivots. Then it begins to scan other sets of non-basic arcs, and creates a new candidate list. Iteration continues with the new list in the same fashion. The list can be smaller than the specified size when there no longer exist as many violating arcs as the specified size limit, and the number of pivots from one list may be smaller than the specified number when violating candidates no longer exist in the list. By properly setting the size of the candidate list and the number of pivots per list, we can fine tune this method so that it may best fit the scale of the problem.

Another pivot rule that I tried in this research is the **variable violation criteria rule**. We set several criteria, in order of greatness. At first, this method selects non-basic arcs that violate more than the first (and the greatest) criterion, and creates a candidate list that is at most the specified size. At each iteration, this method scans the entire list and pivots on the arc of the maximum violation. After pivoting a specified number of times with the list, it scans other portions of the non-basic arcs and collects those arcs that violate the criterion. When no more arcs that violate the first criterion, the second criterion is used and the list is made in the same manner. The algorithm goes on by using different criteria in orderly way. This method collects only effective arcs into the candidate list in accordance with the development of the algorithmic process. We will see how the pivot rules affect the computational performance in the next chapter.

4.5 Process of Pivoting

Let us see what graphical implications the process of pivoting has. When the entering arc is added to the spanning tree, a cycle is formed, and flows along the cycle begin to change. When (at least) one of the arcs in the cycle becomes empty or saturated, that arc leaves the tree structure, and a new tree structure is formed.

There are three cases that may be encountered in updating the tree structure. In Figure 4-4, the direction of an arc is pointing to the current root node, instead of indicating the direction of the flow. Also, thicker arcs indicates that they are stems.
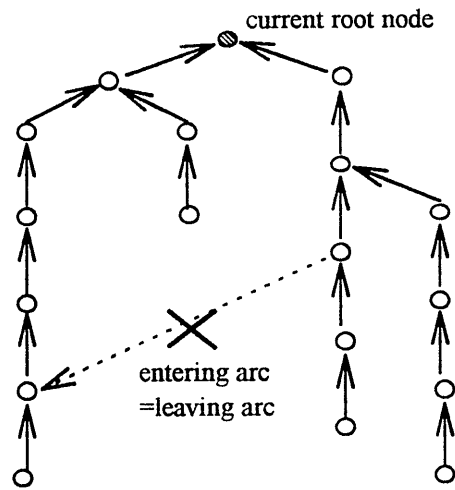
(Case 1: No change)

The entering arc and the leaving arc may be the same in one pivot. In such a case, the tree structure does not change at all.
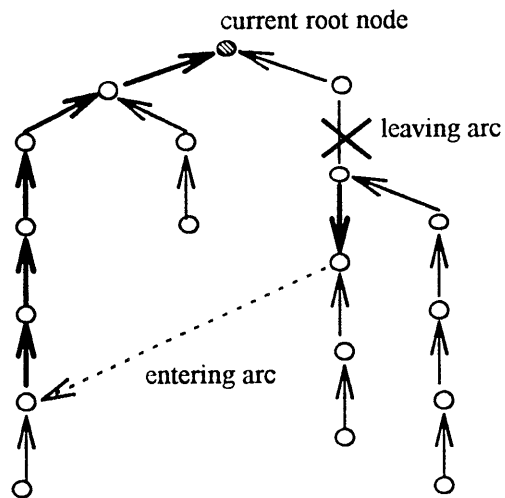
(Case 2: Grafting)

When the entering arc and the leaving arc are different, those two arcs separate the tree into two parts. Let us call the part that contains the current root node the rooted tree, and the other part the separated tree. Define the stem of the rooted tree to be the arcs between the current root node and one end of the entering arc, and also define the stem of the separated tree to be the arcs between one end of the entering arc and one end of the leaving arc. If the stem of the separated tree is shorter than that of the rooted tree, we reverse the direction of the arcs along the stem of the separated tree and graft the separated tree by the entering arc.

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(i) Case 1
(no change)

current root node

entering arc
=leaving arc

(ii) Case 2
(grafting)

current root node

leaving arc

entering arc

(iii) Case 3
(re-rooting)

leaving arc   previous root node
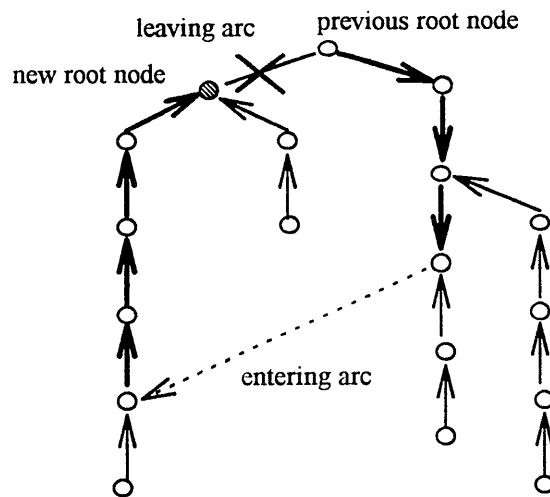
new root node

entering arc

Figure 4-4   Process of pivoting

Notice that the structure of the rooted tree remains intact, and that the structure of branches of the separated tree also remains unchanged in this case. We only have to reverse the stem of the separated tree, and graft it to the other part, in addition to updating other tree indices.

(Case 3: Re-rooting)

If the stem of the separated tree is longer than that of the rooted tree, on the other hand, we set one end of the leaving arc in the separated tree as the new root. We reverse the direction of the arcs along the stem of the previously rooted tree, and graft it to the new rooted tree by the entering arc. Basically, we do the same operation as in the case 2, except that we choose the shorter of the two trees to reverse.

Chapter 5

Case Study

Using actual shipping data of a container shipping carrier, I will conduct the application of the network simplex algorithm. We will focus on the Asia - North American system of NYK Line.

5.1   NYK's Asia - North American System

I will briefly describe the NYK's Asia - North American system as follows.

(i)   DST network

Map 5-1 and map 5-2 illustrate the east bound and west bound DST networks respectively. NYK Line concentrates DST operations on a few railway companies. As a result, NYK Line does not use as DST providers such major railway companies as Union Pacific (UP) or Atchison, Topeka and Santa Fe (ATSF). The NYK's DST providers have the following characteristics:
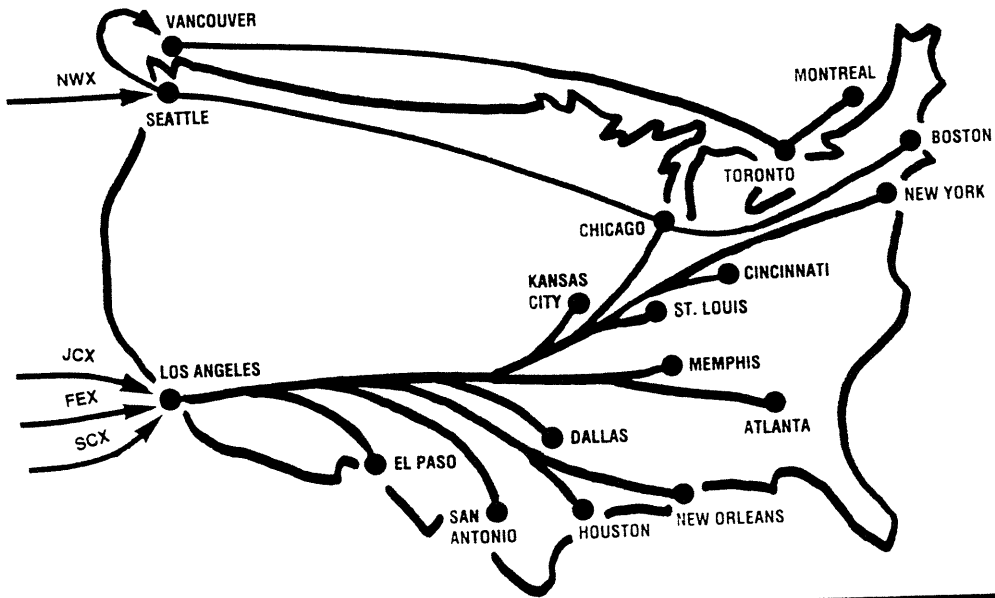
EASTBOUND

Map 5-1   East bound DST network
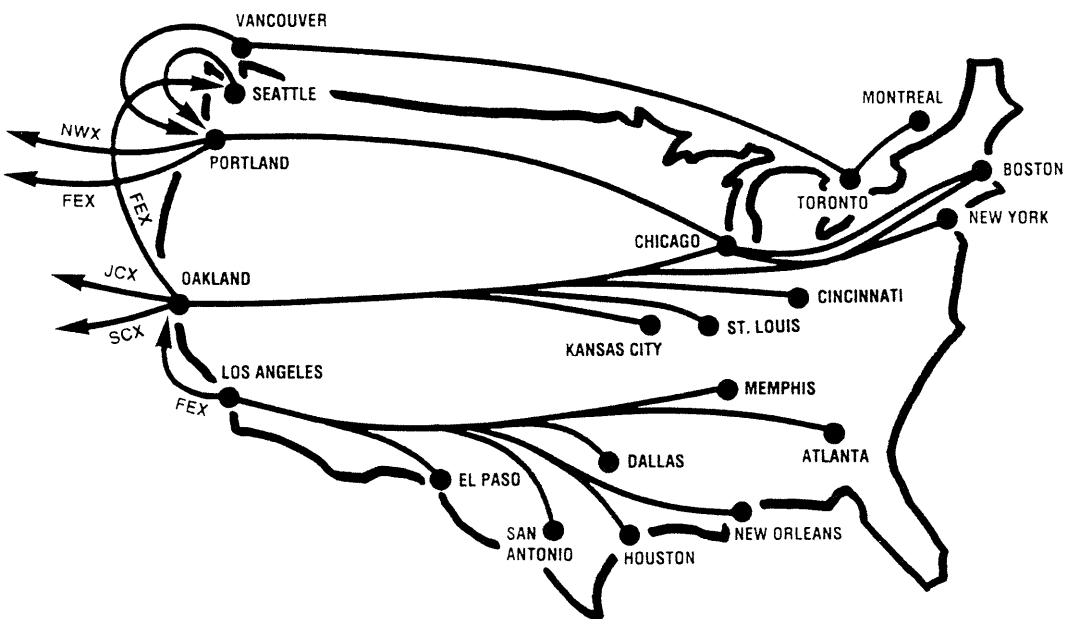
WESTBOUND

Map 5-2   West bound DST network

(Southern Pacific)

NYK Line uses Southern Pacific (SP) as the main DST provider between California ports and Midwestern cities (Chicago, Memphis, Cincinnati, etc.). SP offers frequent departures from Los Angeles to the Midwest, and frequent arrivals from the Midwest at Oakland. Such triangular operations coincide with the rotation of vessels that call California ports. SP also provides DST services between Los Angeles and Texas cities, and between Los Angeles and Mexico City. Since NYK Line owns 5% of the stock of SP's holding company, those two companies maintain a close relationship in terms of operation and the use of facilities.

(ConRail)

Some DST's go directly to New York / New Jersey via Chicago. ConRail operates the section between Chicago and the North Jersey Intermodal Terminal (NJIT), which is also operated by ConRail. ConRail has introduced a volume incentive program; if NYK Line uses ConRail above a specified volume, ConRail reimburses to NYK Line a certain percentage of NYK's total charges paid to ConRail.

(Norfolk Southern)

Norfolk Southern (NS) operates the sections of DST between Memphis and Atlanta, and between New Orleans and Atlanta. NS sets minimum annual volumes at a certain percentage of the total volume of NYK-controlled container traffic that go through specified areas.

(Burlington Northern)

Burlington Northern (BN) operates DST's between the Pacific Northwest ports and various interior points. BN is positive about offering its own DST services to container shipping carriers. By setting up connected services with other railway companies, BN provides services to / from areas that are not covered by the BN network. BN also offers a fairly extensive truck network that mainly covers the areas between BN ramps and final destinations.

BN offers considerably lower rates for west bound empty container movements than loaded, or east bound movements. Partly because of the BN's pricing policy, and partly because of the fact that the Pacific Northwest is usually in demand of empty containers, BN's DST system effectively collects many west bound empty containers.

(Canadian Pacific)

Canadian Pacific (CP) operates DST's between Vancouver, BC. and Toronto / Montreal.

(ii)   COFC / TOFC network

The efficiency of ordinary train services (COFC / TOFC) is less than half of that of DST, because of the difference in capacity and intermediate switching and blocking. Although thousands of origin - destination pairs are offered as available COFC / TOFC services, only a portion of them is actually being used. It is expected that the empty movement optimization will find competitive aspects of ordinary train services.

Some rules of ordinary train services poses difficult elements for problem formulation. ATSF and CSX offer cheaper rates for empty containers, provided

that those containers are used for loaded movements carried by the same railway company immediately prior to or after the empty movements.

(iii)   Trucking network

The trucking industry contains a large number of small companies in a competitive environment. Rates and capacities are changing more than other modes of transportation. NYK Line uses several trucking companies in the same area at the same time in order to grasp the lowest market rates.

Some inland depots are consigned to local trucking companies, which manage empty containers for NYK Line.

(iv)   Trans-Pacific routes

During the period to which this research applies the optimization program, NYK Line operated with the partner carriers (NOL and Hyundai) four departures every week from Asia to the west coat of North America, one departure every 10 days from Asia to the east coast of the U.S. via the Panama canal, one departure every 10 days from the east coast of North America to southern Asia via the Suez canal, and one departure every two weeks from Asia to Hawaii. NYK Line uses smaller types of vessels, when compared with other competitors, that range from 1900 TEU's to 3000 TEU's.

(v)   Intra-Asia routes

NYK Line, together with Tokyo Senpaku Kaisha (TSK) Line as the main partner in Asian routes, operates a dense intra-Asia network. Asian waters are also covered by other major routes, including North American routes, European routes, and Australian routes. Equipment control in Asia is complicated, because many routes intersect there. The container team in the Tokyo head office decides empty

container allocation in Asia, and collects empty positioning costs from each line. So far, this research does not include Asia as a full-scale subject, because of the complexity of the problem.

5.2   U.S. Domestic Cargo in the NYK's System

It is obvious that the NYK's system is intended for international cargo. However, U.S. domestic cargo also plays a positive role in the system. Whereas many east bound cargoes reach the Midwest or the east coast of North America, relatively few west bound cargoes originate from those areas. Instead, a large number of west bound cargoes start from the west coast of North America. Therefore, west bound domestic cargoes effectively complete the circular container movements.

The NYK's offices do not accept the booking of the domestic cargo, however. The following organizations act as the collectors of domestic cargo in cooperation with NYK Line.

(i)   GST Corporation

GST Corporation is one of the top-rated freight forwarders in the U.S., and was acquired by NYK Line for the purpose of collecting domestic cargo. While GST continues its own business independently, it uses NYK's empty containers for the west bound domestic cargo.

(ii)   Centex

Centex is a wholesaler of DST services to NYK Line, freight forwarders, and large domestic shippers. Centex practically manages the NYK's DST system.

Assisted by the logistics team in the NYK Chicago office, Centex targets important freight forwarders and shippers to improve the container movements in the North American continent.

(iii)   CP and Canadian National Railway (CN)

CP and CN are in need of empty containers for their domestic intermodal services. CP and CN use NYK's empty containers in Toronto and Montreal, and return them at cities in western Canada. NYK Line simply allow CP and CN to use containers, and no money is paid between them.

5.3   NYK's Information System

NYK Line maintains an integrated information system, called WINS. WINS enables global retrieval of cargo information and container movement information. It also includes such features as EDI and an automated telephone answering system.

Although all data is retrievable globally, the source data of WINS are stored by area. Cargo and container information in North America is stored in the computer system in Seattle, and the same information in Asia is stored in the system in Tokyo. Codes and data formats of the source data are different between the North American system and the Asian system.

The container movement data in the North American system records events in the order of occurrence. For example, the first record of a day may be an empty container's leaving the Savannah terminal at 00:00, the second record may be loading of a container onto a vessel at Los Angeles at 00:01, and so on. The data

is in the form of huge stack structure, and the bottom part of data is moved to a different file system regularly.

The advantages of this data structure are the ease of adding new records and the simplicity of the structure. The structure, however, is inefficient in searching specific data, and unsuitable for checking wrong data when inputting new data. As the prices of memory and disk systems come down rapidly, I suggest the use of a data structure that can be more easily searched and checked in the NYK's information system.

5.4   Creation of Databases

NYK Line provided container movement data from June through December in 1992. The original data was about 850 megabytes in size, and contained about 1.8 million movements.

I first sorted records by container, and made a distinction between empty events and loaded events. Naturally, containers alternates between empty periods and loaded periods. I assumed that the movement between the last event in the empty period and the first event in the loaded period means the provision of the empty container to the shipper, followed by the reception of the loaded container. Similarly, I assumed that the movement between the last event in the loaded period and the first event in the empty period means the delivery of the cargo, followed by the return of the empty container.

I created a movement database, which contains four distinct events in the container transportation, namely:

(i)   Provision of the empty container

(ii)   Reception of the loaded container

(iii)   Delivery of the loaded container

(iv)   Return of the empty container

I considered that demand for an empty container is generated at the time of the provision of an empty container, and that an empty container is supplied to the system at the time of the return of the empty container from the shipper. I calculated supplies minus demands, and defined container shortage as the negative number in this calculation, and container surplus as the positive number. The data includes U.S. domestic cargo movements. Thus, supplies and demands generated by domestic cargo are included in those numbers. In the empty period in the container history, I followed every movement in the data. I assumed that a container makes up a given node's inventory if it stayed at the same place for more than two days.

5.5   Analysis of Container Data

I selected the months of August, September, and October as the application periods. I conducted three separate optimizations, one for each month. I analyzed only 40 foot dry containers, which constitute about half of all movements.
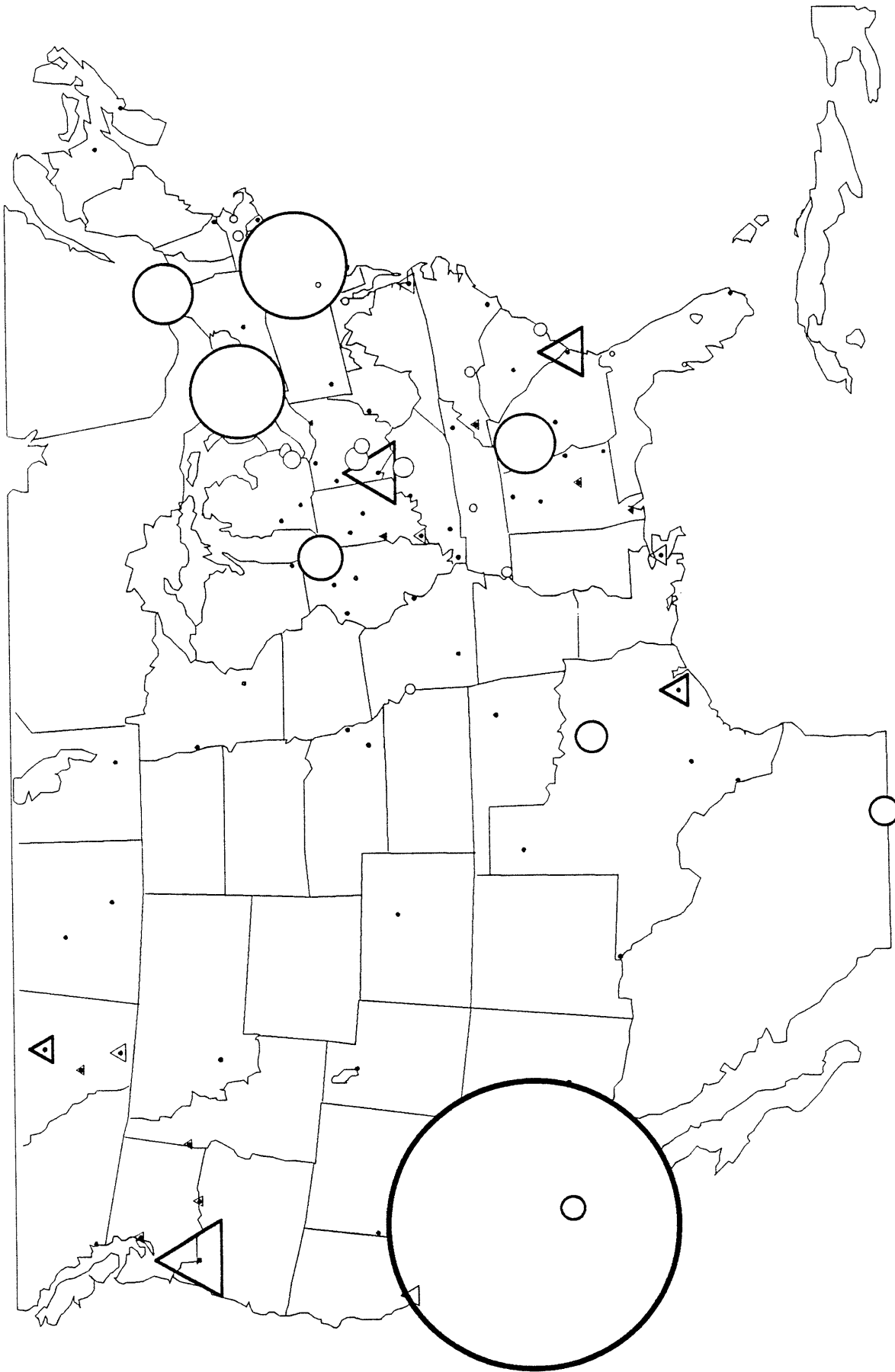
(i)   Trends of container supplies and demands

Map 5-3 through map 5-8 show the cumulative supplies and demands in each of the three months. Circles show the container surplus, and triangles show
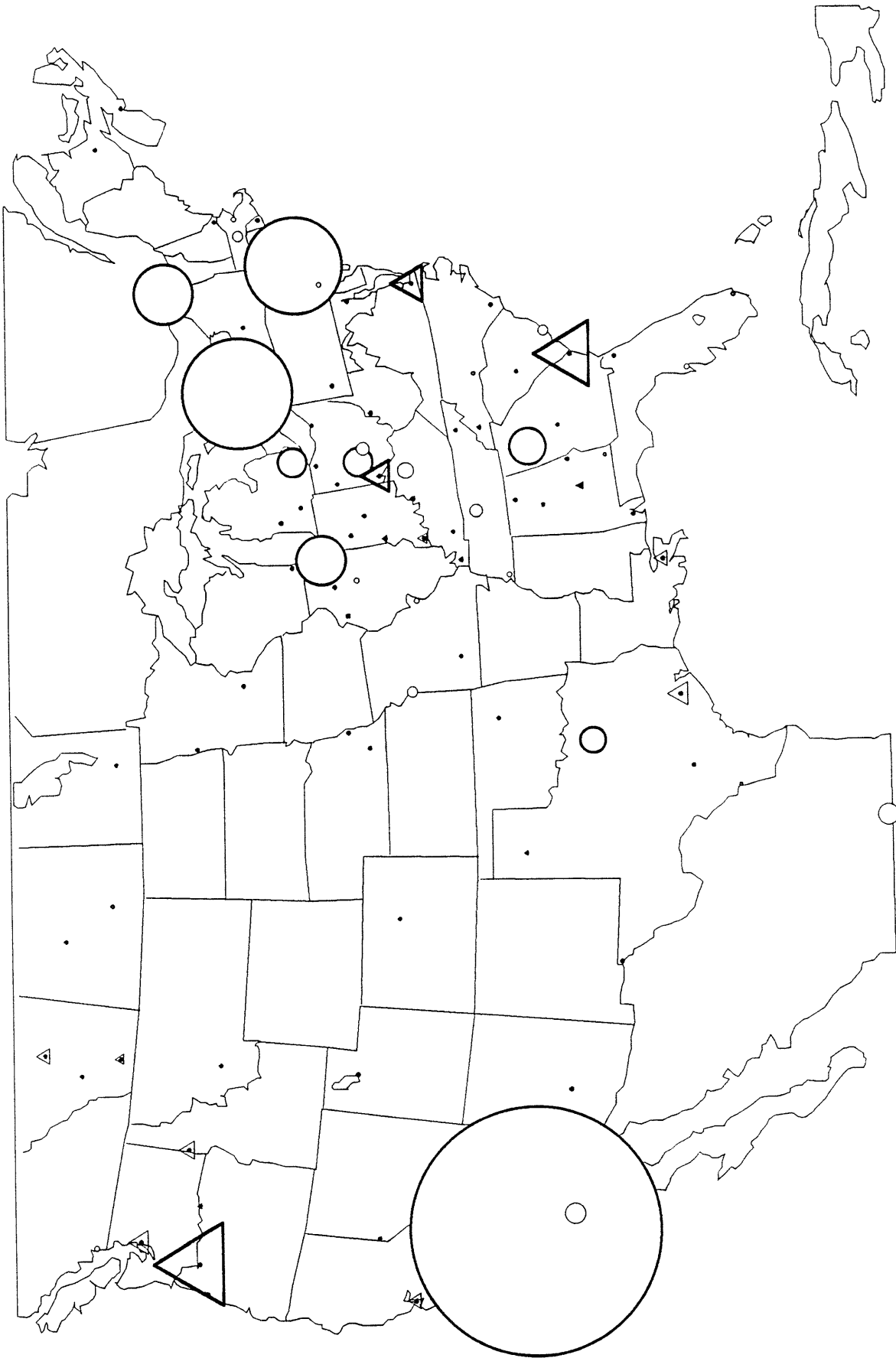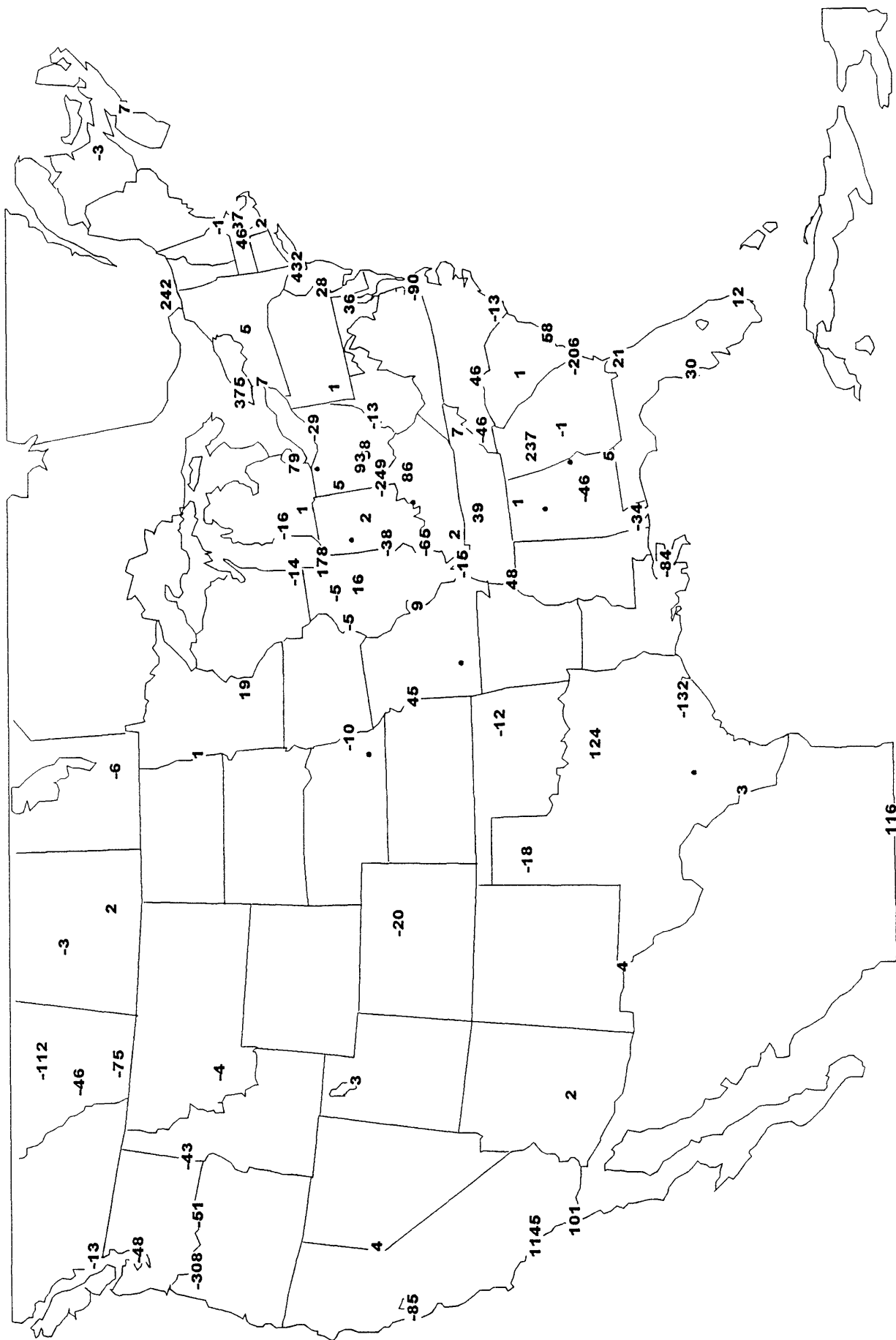
Map 5-3   Cumulative supplies and demands (August, 1992)
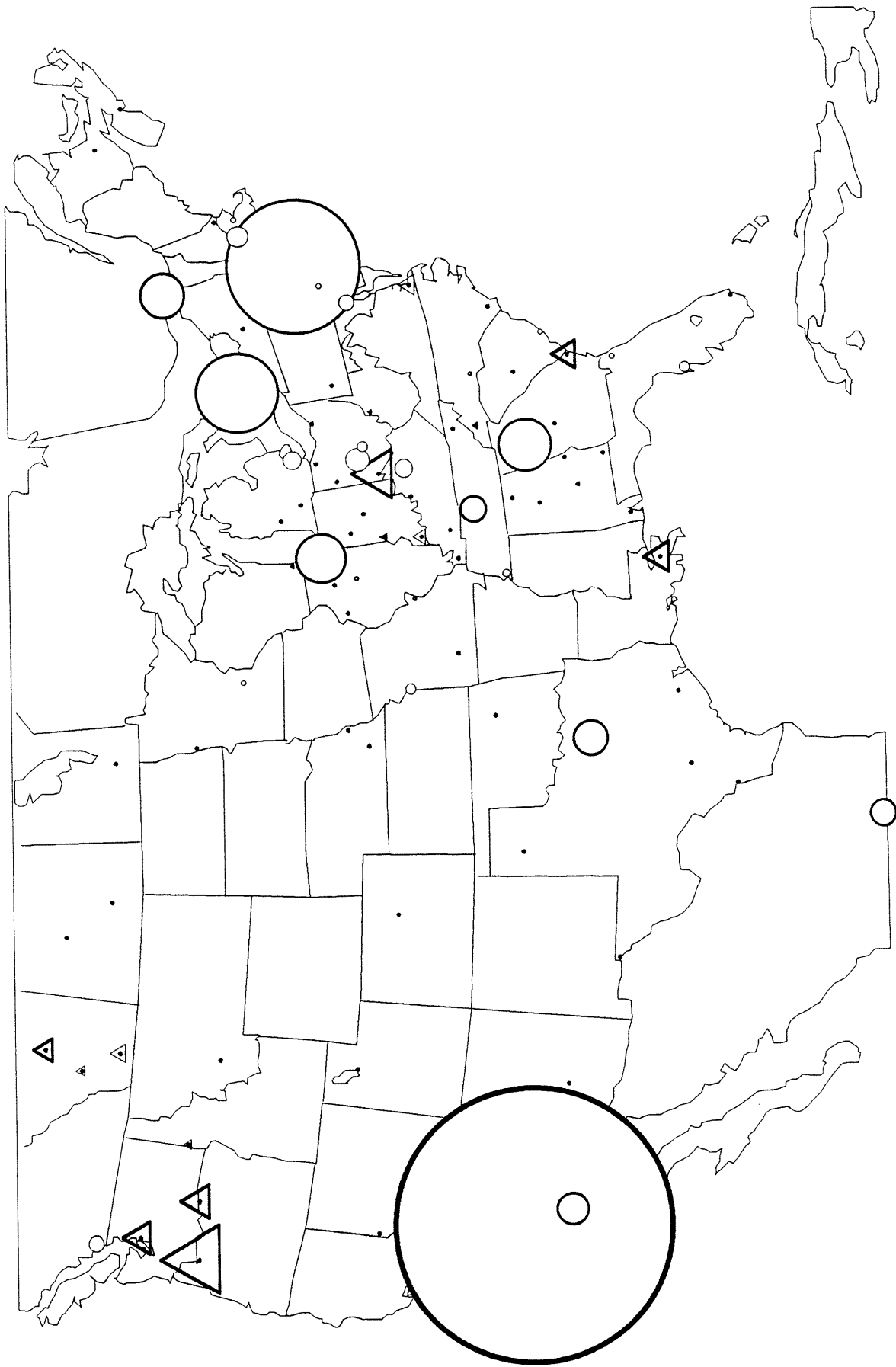
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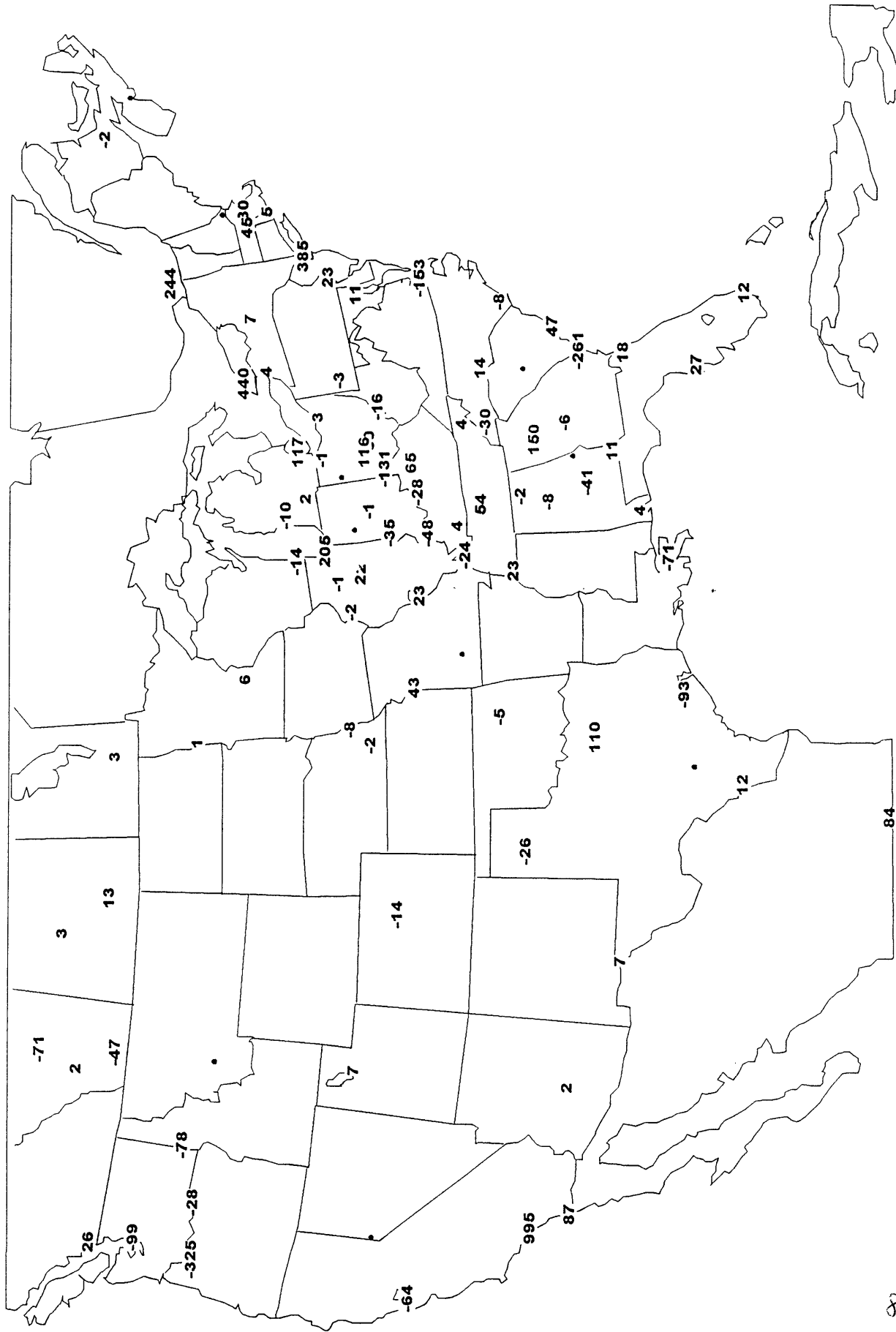
Map 5-4   Cumulative supplies and demands (August, 1992)
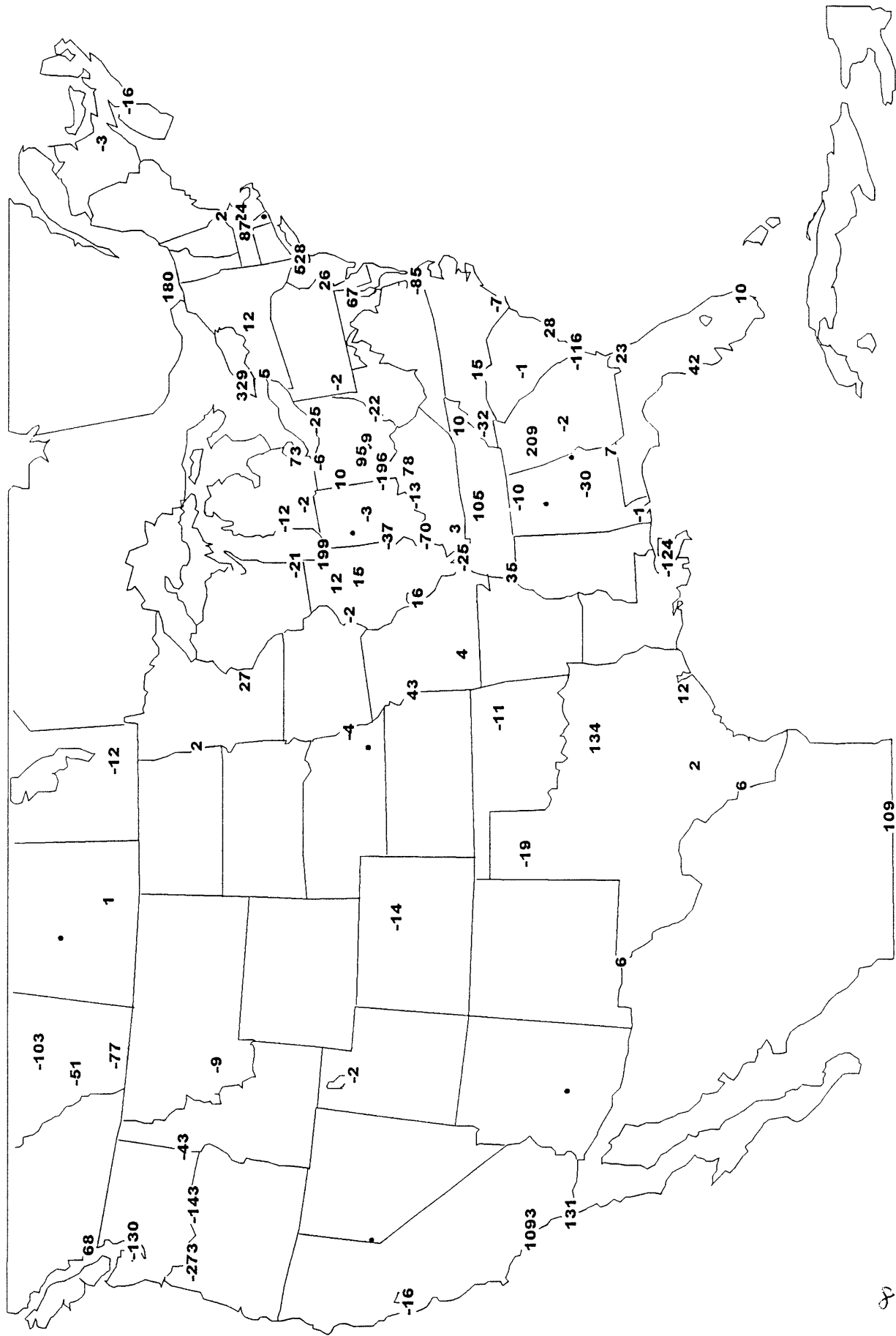
Map 5-5   Cumulative supplies and demands (September, 1992)

Map 5-6   Cumulative supplies and demands (September, 1992)

Map 5-7   Cumulative supplies and demands (October, 1992)

Map 5-8   Cumulative supplies and demands (October, 1992)

the container shortage. The size of a circle or a triangle is proportional to the magnitude of supplies or demands, respectively.

At a glance, we can observe that the following areas are consistently in short of containers:

(a)   The Pacific Northwest and western Canada (especially Portland)

(b)   Southern Atlantic ports (Savannah, GA and Norfolk, VA)

(c)   The Gulf coast and Alabama

(d)   Southern Ohio and Indiana (especially Cincinnati)

On the contrary, container surplus areas are areas that include large cities where substantial consumption takes place. For example, Los Angeles, New York, Toronto, Montreal, Chicago, Atlanta, Dallas, and so on have large surplus.

Supplies and demands in Asian cities are also incorporated in the application. Supplies and demands in Asia are generated only from the Asia - North American trades in this application. Although a severe intra-Asian container imbalance problem exists in reality, we separate this problem from our scheme. In other words, we assume that container imbalances that are caused by the North American system are to be rectified under the responsibility of the North American system, without making use of the intra-Asian cargo.

(ii)   Container inventory distribution

There may be dead stocks of container inventories that stayed at depots throughout the data period. Since I calculated the container inventory in the way I explained earlier, my calculation does not reflect such dead stocks.

Map 5-9 through map 5-14 show the inventory distribution of each month. The size of a rectangular is proportional to the magnitude of container inventory levels.
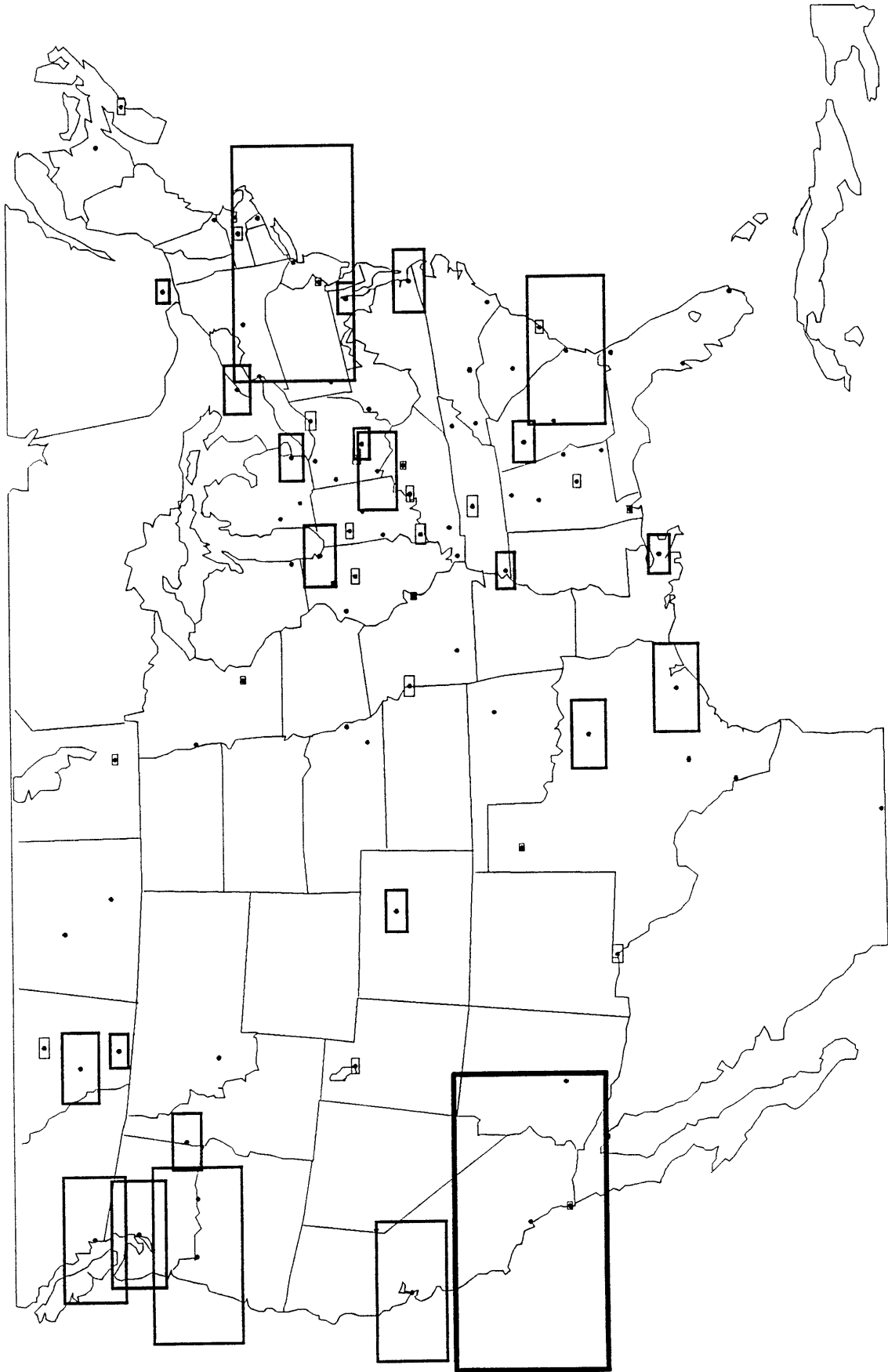
Map 5-9   Container inventory distribution (August 1, 1992)
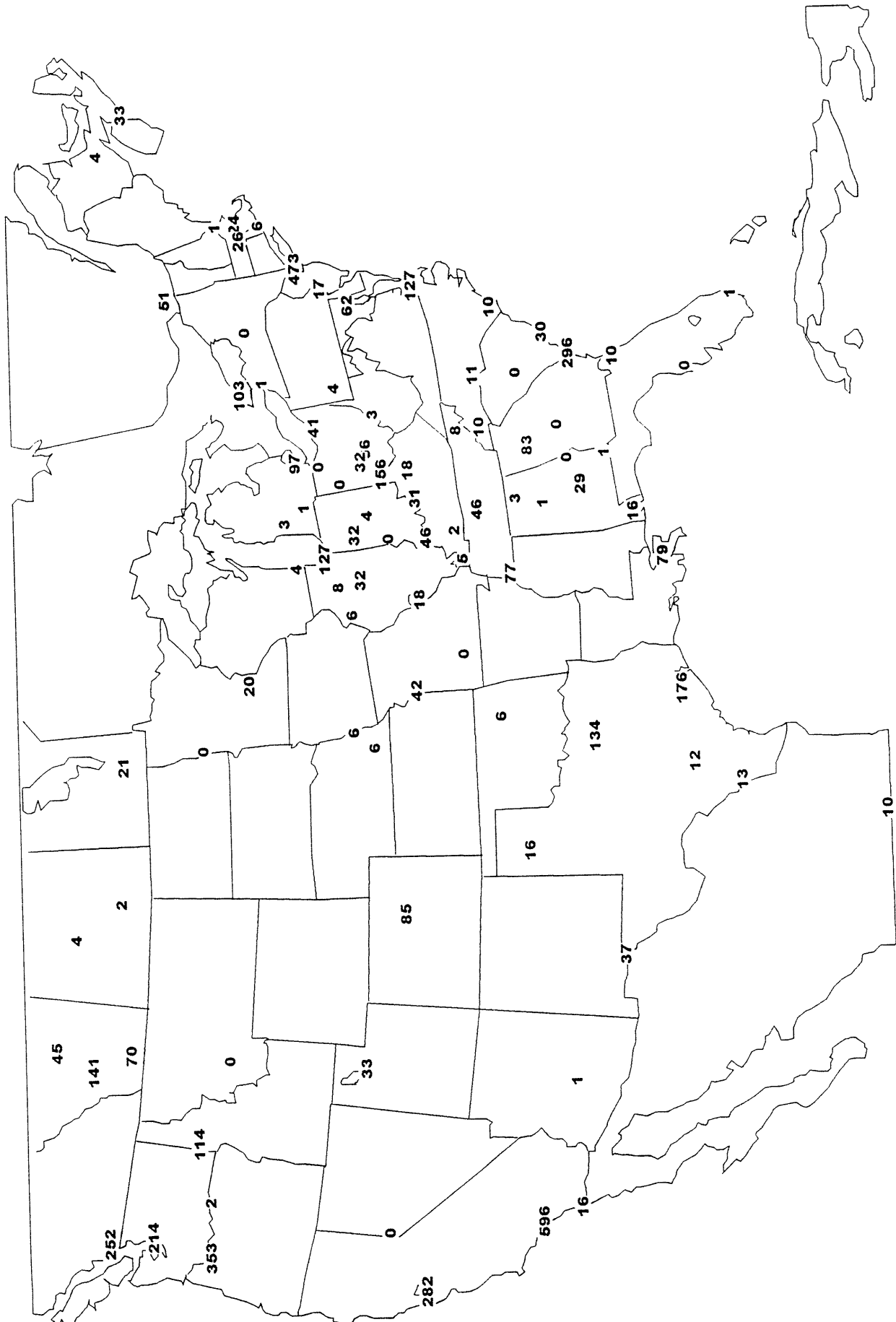
Map 5-10   Container inventory distribution (August 1, 1992)
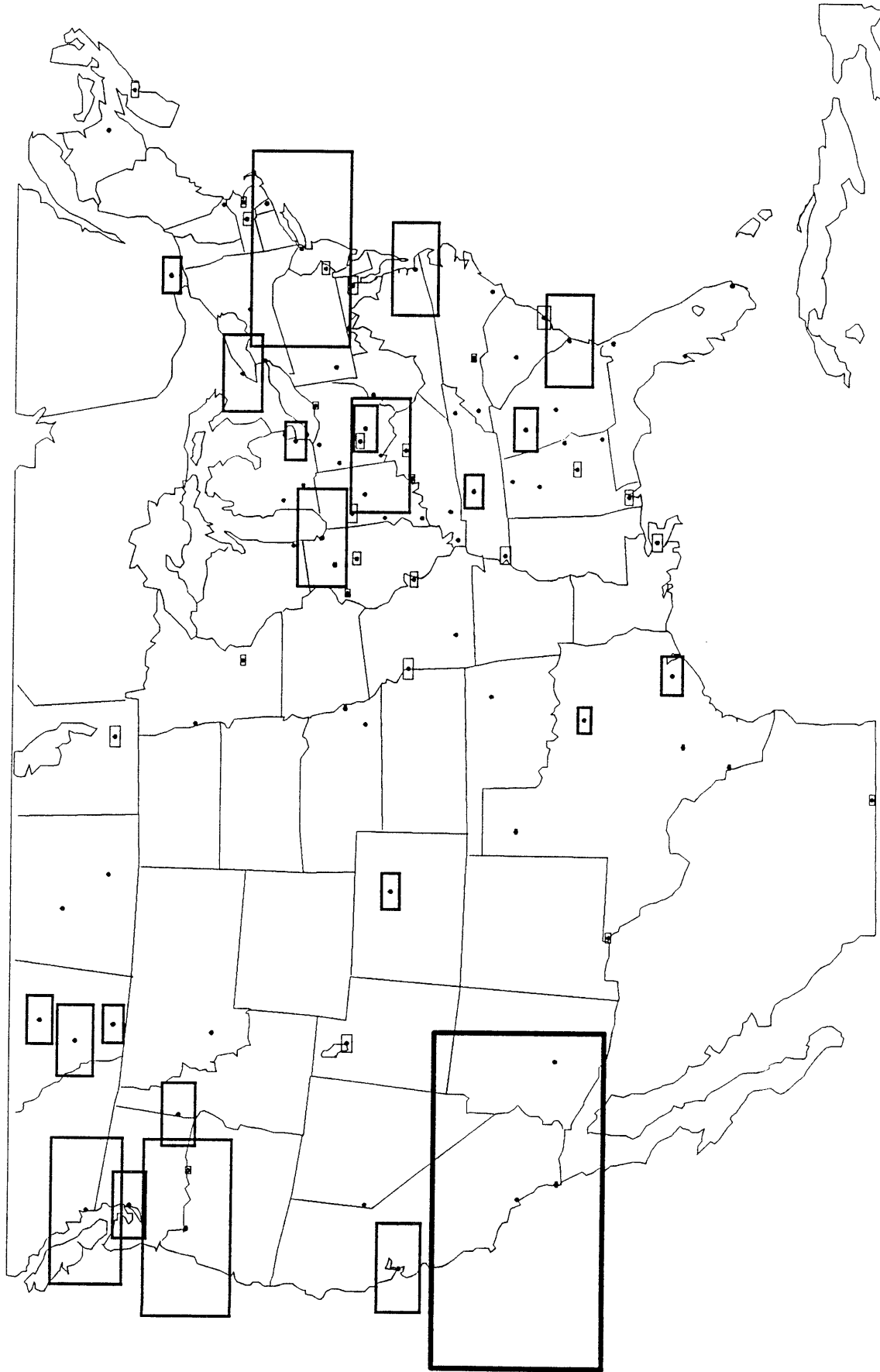
Map 5-11   Container inventory distribution (September 1, 1992)
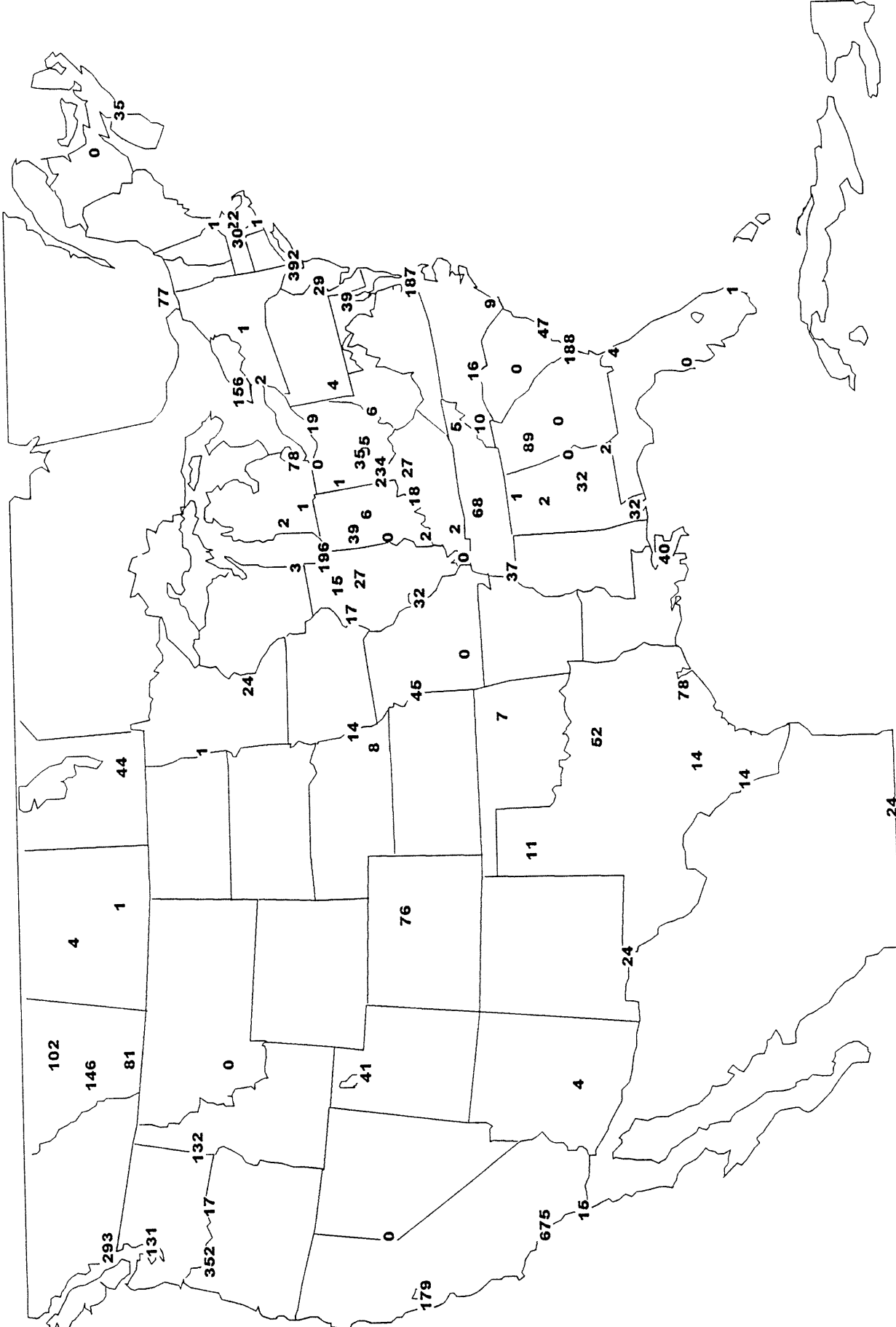
Map 5-12   Container inventory distribution (September 1, 1992)

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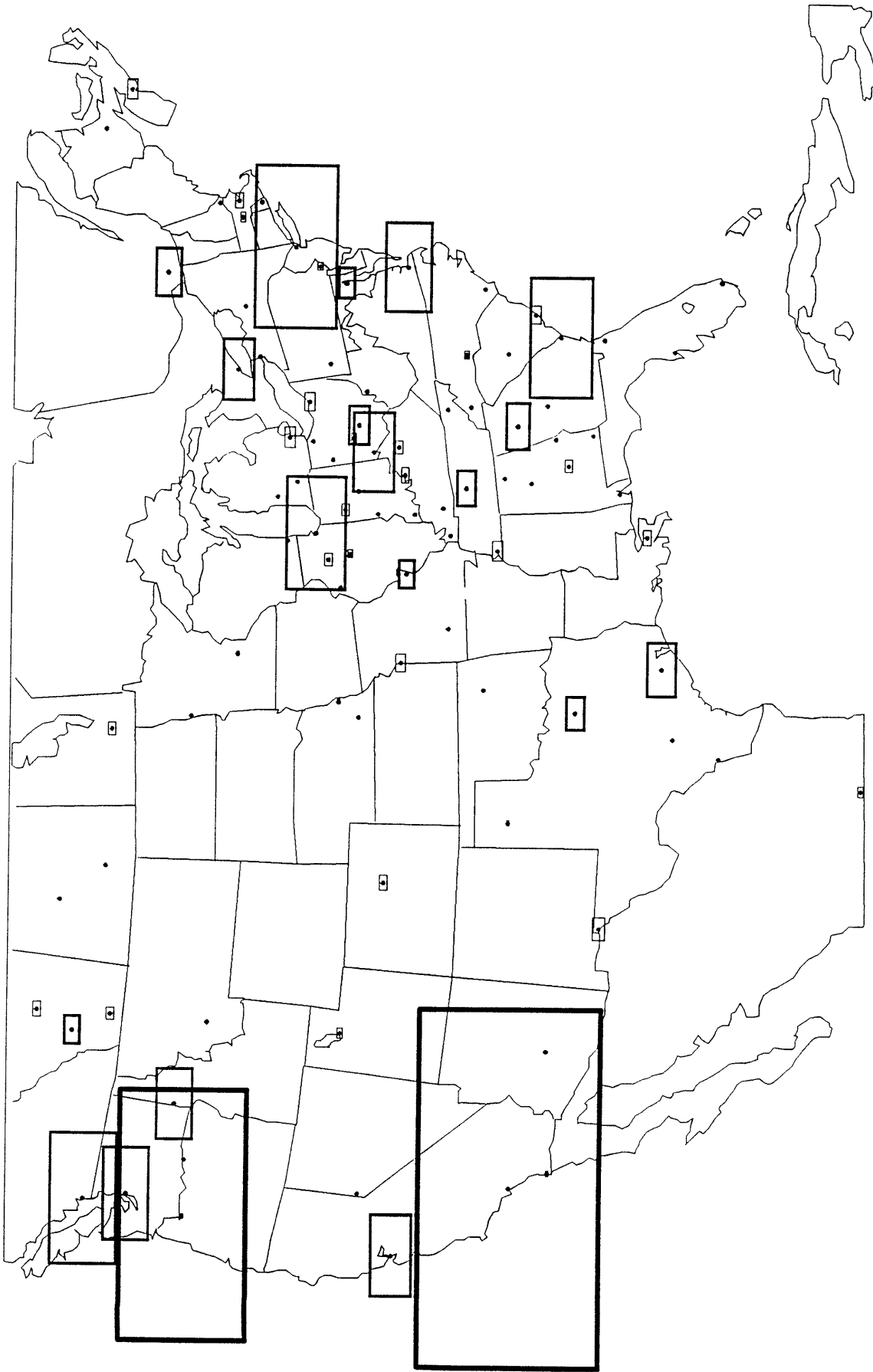
Map 5-13   Container inventory distribution (October 1, 1992)

94
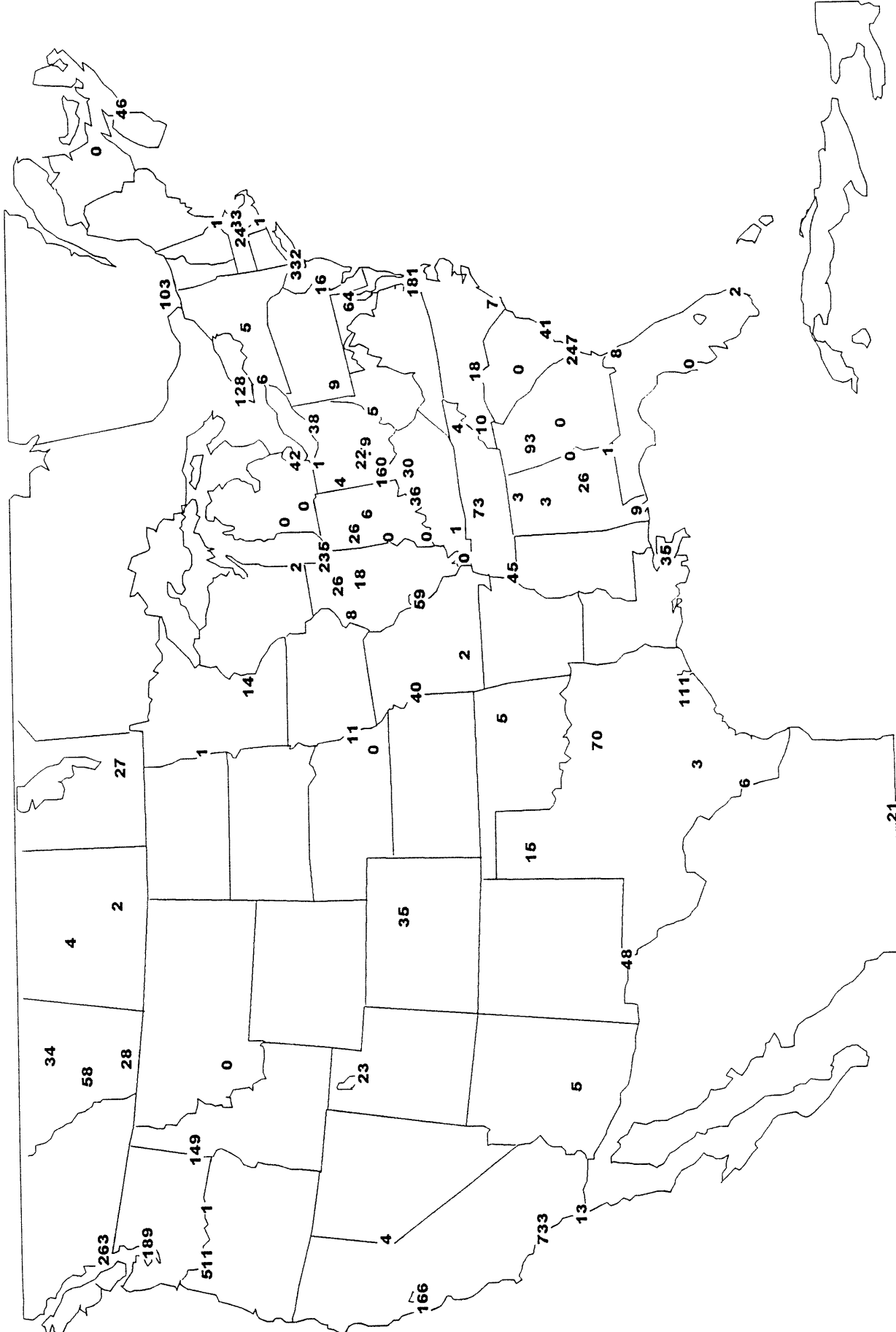
Map 5-14 Container inventory distribution (October 1, 1992)

It is natural that large inventories are stored where large facilities exist. Every port where NYK's vessels call has a large container inventory, and so do major DST terminals, such as Chicago, Cincinnati, Toronto, etc.

We can also observe that container shortage areas tend to have larger inventories. For example, Portland, OR, where a big shortage occurs, has a larger inventory than Seattle or Vancouver, BC. Houston has a larger inventory than Dallas, whereas Houston is a shortage place and Dallas is a surplus place. The same relationship exist between Cincinnati and Columbus. It seems that empty containers are sent to necessary places well ahead of time under the current NYK operation.

5.6 Analysis of Network Data

(i) Railway network

I built a database of railway costs that include all available DST, COFC, and TOFC services. The frequency of services are mixed: some are available every day, some are available five days a week, and so on. Since I do not have every detail of the frequency, I assumed that each service is available once everyday. With regard to the volume incentive program of ConRail, I ignored the effect of the rate reduction of the program. NS's minimum volume requirements are also ignored. As for ATSF and CSX, I used the less expensive empty container rates without assigning extra restrictions. The network of ATSF covers almost the same area as that of SP, and the network of CSX covers nearly the same area as that of NS. If the optimization of empty movements suggests the use of ATSF or CSX, NYK Line could negotiate with SP or NS to come down to the competitor's level, or study using ATSF or CSX exclusively in certain sections.

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CP and CN move empty containers from Toronto and Montreal to western Canada without incurring any movement costs to NYK Line. However, I restricted the number of containers that CP and CN combined can accept at 10 per day for Vancouver, BC and 5 per day for other cities, since the capacity of CP and CN needs to be determined at a certain level. Furthermore, I assumed that their transit time takes two weeks longer than ordinary empty positioning.

(ii)   Trucking network

It is difficult to determine exact and up-to-date trucking costs. I used the following rule of thumb:

$$(\text{Trucking cost}) = (\text{mileage}) \times \$1.00 + \$50.00$$

The $ 50.00 stands for the base rate that should be paid no matter how short the distance may be. It is also considered to represent the cost of moving in urbanized areas, where mileage does not necessarily determine the cost. I modified this rule of thumb so that truck transportation to or from a larger city may charge a higher base rate.

It is assumed that a short drayage is required to transport a container between any of the two items in the following points:

(a)   Empty container depot

(b)   Railway ramp

(c)   Port terminal

(d)   Shipper's location
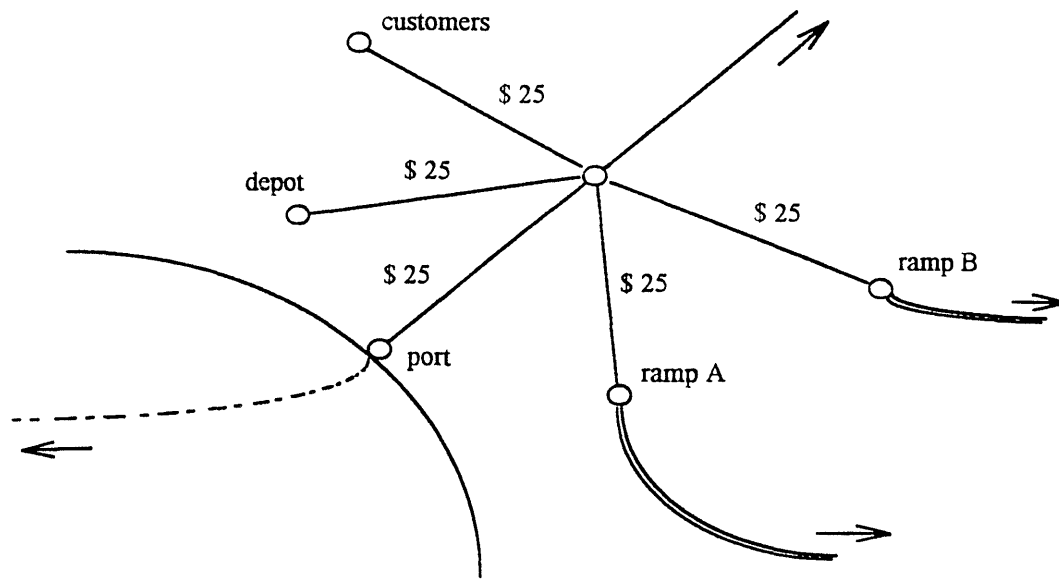
Figure 5-1   Structure of a city

Each city in the network is assumed to have a structure like Figure 5-1. This structure allows the insertion of short drayage between any of the two points.

It is an exception that empty containers are directly moved from one customer to another in the same city, because the conditions of containers are to be checked at the time of the provision and return. Thus, I ignored such movements.

(iii)   Shipping network

It is assumed that vessels maintain constant intervals throughout the application period. I considered that intra-Asian routes are available for the North American system to send empty containers, but I excluded other major routes, such as European and Australian routes from the network.

Matson Line offers services between Honolulu and the U.S. west coast ports. I assumed that NYK Line can use Matson Line as a feeder that complement the system.

5.7   Size and Complexity of the Network

One time unit was determined to be one day. In order to minimize the effect of container lease-in / lease-out, I set the container distribution at end of the application period to be similar to that at the beginning of the application period. I constructed the preceding network and the succeeding network at the both ends of the core network. Nodes in the first day are supplied with empty containers equivalent to the distribution at the first day in the core period. The same distribution of empty containers are subtracted from nodes in the last day. I set the preceding period as 16 days, the core period as 31 (or 30) days, and the succeeding period as 15 days.

I selected 104 places, where more than 10 containers are demanded or supplied per month on average. After dividing those 104 places according to their functions (such as port, ramp, depot, etc.), I obtained 404 nodes.

The number of nodes in the network, therefore, is

$$404 \ \times \ (16 + 31 + 15) \ = \ 25{,}048$$

The number of arcs reflects the frequency and transit time of services, and the calculation of the number of arcs is not as straightforward as that of the number of nodes. The number of arcs of the August-core-period network is 214,223, that of the September-core-period network is 210,569, and that of the October-core-period network is 214,199.

5.8   Effects of Pivot Rules

As we have seen in Chapter 4, the selection of the pivot rule affects the performance of the algorithm. I tested four pivot rules with a small network to find the differences in the performance. I was especially interested in the performance of the variable violation criteria rule, since this rule is my original modification of the candidate list pivot rule. The variable violation criteria rule turned out to be by far the best of the four, and I used this rule in the rest of this research.

The small network used in the test of four pivot rules was constructed as follows. I determine the duration of the application period to be one day (September 1, 1992). I used the preceding network model for initialization, and the simple ending model for finalization. This small network contains 7,272 nodes plus one super sink, and 55,523 arcs.

	time (min : sec)	number of pivots
variable violation criteria rule		
(first criterion)	1:33	7,547
(second criterion)	0:48	4,306
(last criterion)	0:28	3,685
(total)	**2:49**	**15,538**
candidate list pivot rule	**8:36**	**27,933**
first eligible arc pivot rule	**16:38**	**43,509**
Dantzig's pivot rule	more than 1 hour	-

Table 5-1   Effects of pivot rule modification

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For the candidate list pivot rule, I set the size of the candidate list at 10,000, and the number of pivots per list at 2,000. For the variable violation criteria rule, I used the same size of the candidate list and the same number of pivots per list. The first criterion was 4,000, the second was 400, and the last was 0.

I used a DEC 5000/133 workstation for this test.

The results of the test are summarized in Table 5-1.

5.9   Computation Results

Since the full-scale computation was expected to take many times longer to complete, I decided to use the DEC 3000 workstation at the Center for Transportation Studies in MIT. Because this workstation allows many users to log in at the same time, the time required for computation was affected by other users.

The summary of computation results are as follows:

(August Program)

the application period	August, 1992	
the preceding network begins at	92-07-16	
the core period begins at	92-08-01	
the core period ends at	92-08-31	
the succeeding network ends at	92-09-15	
the number of nodes	25,049	
the number of arcs	214,199	
first criterion	48,448 pivots	improve by $ 3,824,660,647
second criterion	94,916 pivots	improve by $ 27,465,784
third criterion	104,651 pivots	improve by $ 1,565,174

computation ended at	248,016 pivots	$ 2,308,395

(September Program)

the application period	September, 1992
the preceding network begins at	92-08-16
the core period begins at	92-09-01
the core period ends at	92-09-30
the succeeding network ends at	92-10-15
the number of nodes	24,645
the number of arcs	210,569

first criterion	52,676 pivots	improve by $ 3,923,197,677
second criterion	87,713 pivots	improve by $ 23,194,665
third criterion	98,036 pivots	improve by $ 1,230,788
computation ended at	238,426 pivots	$ 2,376,870

(October Program)

the application period	October, 1992
the preceding network begins at	92-09-15
the core period begins at	92-10-01
the core period ends at	92-10-31
the succeeding network ends at	92-11-15
the number of nodes	25,049
the number of arcs	214,199

first criterion	59,324 pivots	improve by $ 3,828,040,444
second criterion	91,899 pivots	improve by $ 23,210,211

| third criterion | 97,726 pivots | improve by $ 1,583,171 |
| computation ended at | 248,950 pivots | $ 2,166,174 |

Table 5-2   Computation Results

(Note: the improved values during the computation are listed just as indications. Those values may not be exactly the ones that correspond to the criteria.)

(The average improvement per pivot)

	first criterion	second criterion	third criterion
August program	$ 78,943.62	$ 289.37	$ 14.96
September program	$ 74,477.90	$ 264.44	$ 12.55
October program	$ 64,527.69	$ 252.56	$ 16.20

Table 5-3   Improvement per pivot

5.10   Analysis of Results

(i)   The optimal empty container movements

I would like to show the optimal empty container movements in a graphical manner. Map 5-16 through map 5-21 display the optimal movements in each month. The width of an arrow corresponds to the volume of the movement. Since the Midwest region shows a complicated configuration of movements, enlarged maps of the region are also presented.

The left end of the map corresponds to Honolulu and Asian cities. Map 5-15 indicates the locations of cities in the map. Because our primary interest lies in

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North America, the empty movements within Asia are not given proper space, and seem to be vertical arrows overlapped with each other at the left end of the map.

For the sake of comparison, the actual empty container movements in each month are also displayed in map 5-22 through map 5-24. Arrows in those maps show how empty containers that were returned from the customers during the month were actually positioned before the next loaded movements began. The NYK's North American container movement data do not have information about which city in Asia an empty container was sent to. They just have a record that indicates the fact that an empty container was loaded onto a vessel bound for Asia. That is the reason why all trans-Pacific arrows in map 5-22 through map 5-24 point to one place.

Let us examine the optimal empty container movements. In all three maps, we can observe the following characteristics.

(a)   Empty containers to Asia are loaded on vessels at Los Angeles, Vancouver, and New York.

(b)   A large number of empty containers are sent from Toronto / Montreal to Vancouver.

(c)   Portland attracts empty containers from Chicago, Dallas, and Kansas City.

(d)   Savannah and New Orleans gather empty containers in the Southern states.

Honolulu
Tokyo/Yokohama
Nagoya
Kobe
Hakata
Busan
Keelung
Kaohsiung
Hong Kong
Singapore
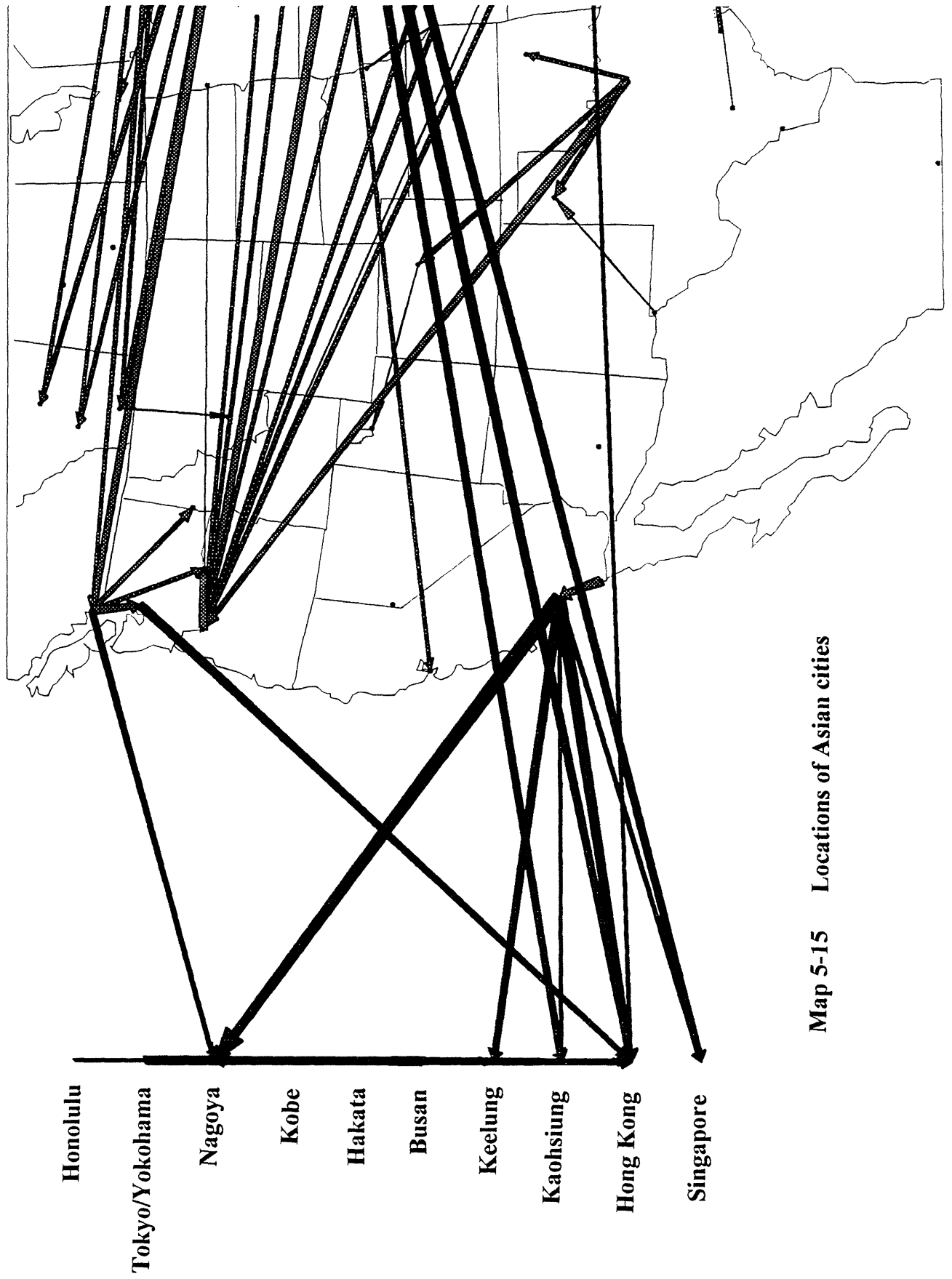
Map 5-15   Locations of Asian cities
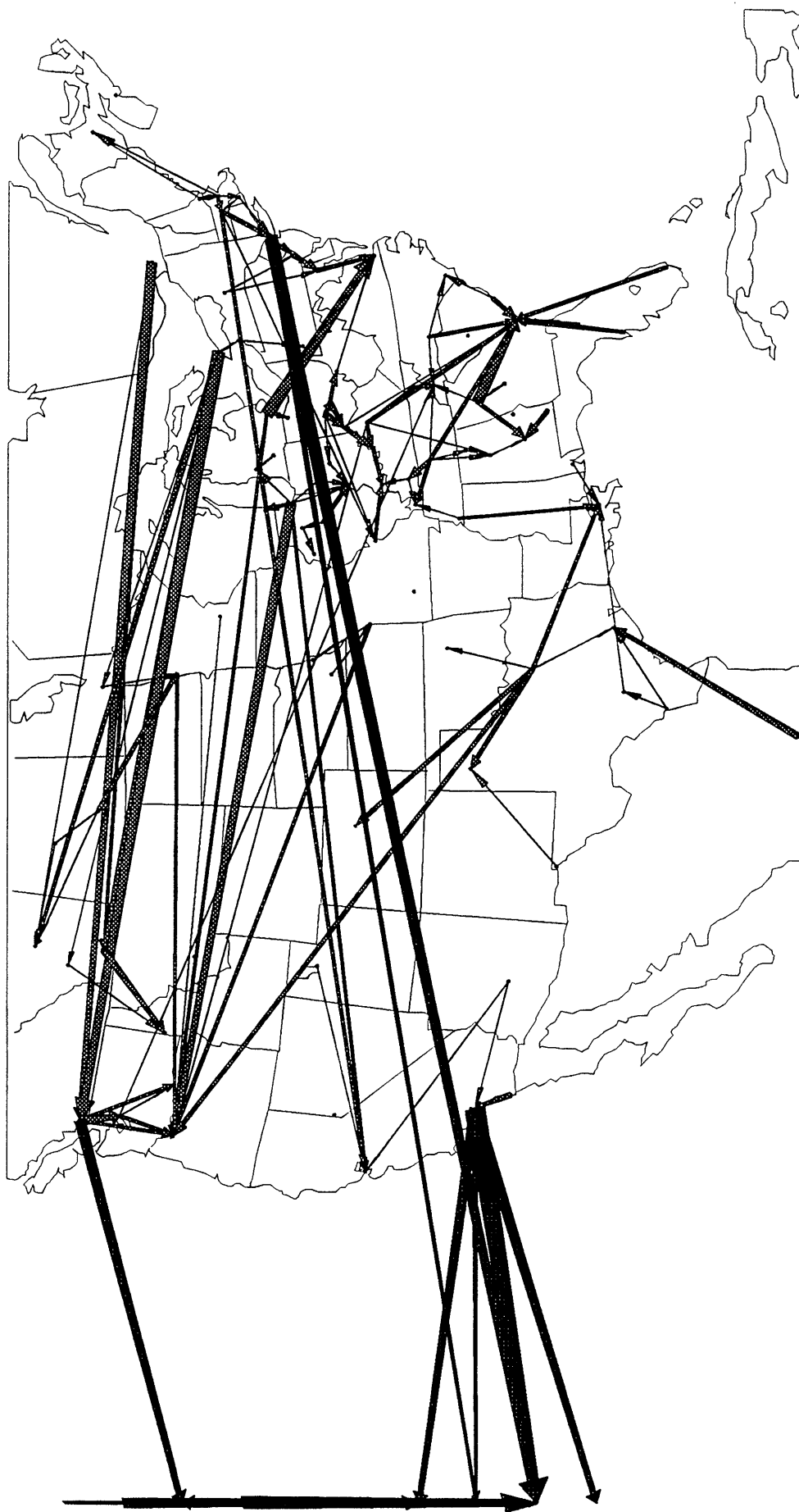
Map 5-16   Optimal empty container movements (August, 1992)
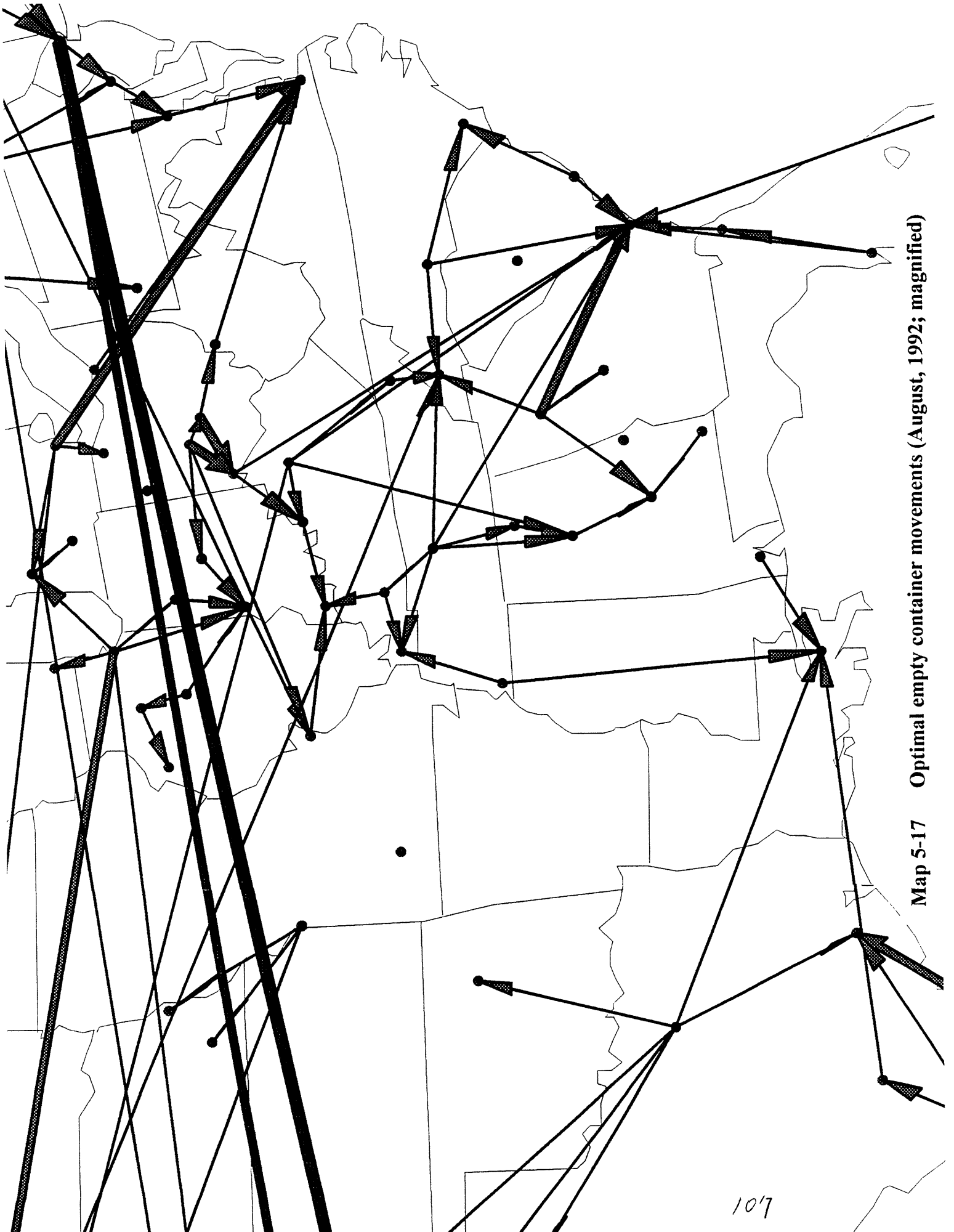
Map 5-17   Optimal empty container movements (August, 1992; magnified)

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Map 5-18   Optimal empty container movements (September, 1992)
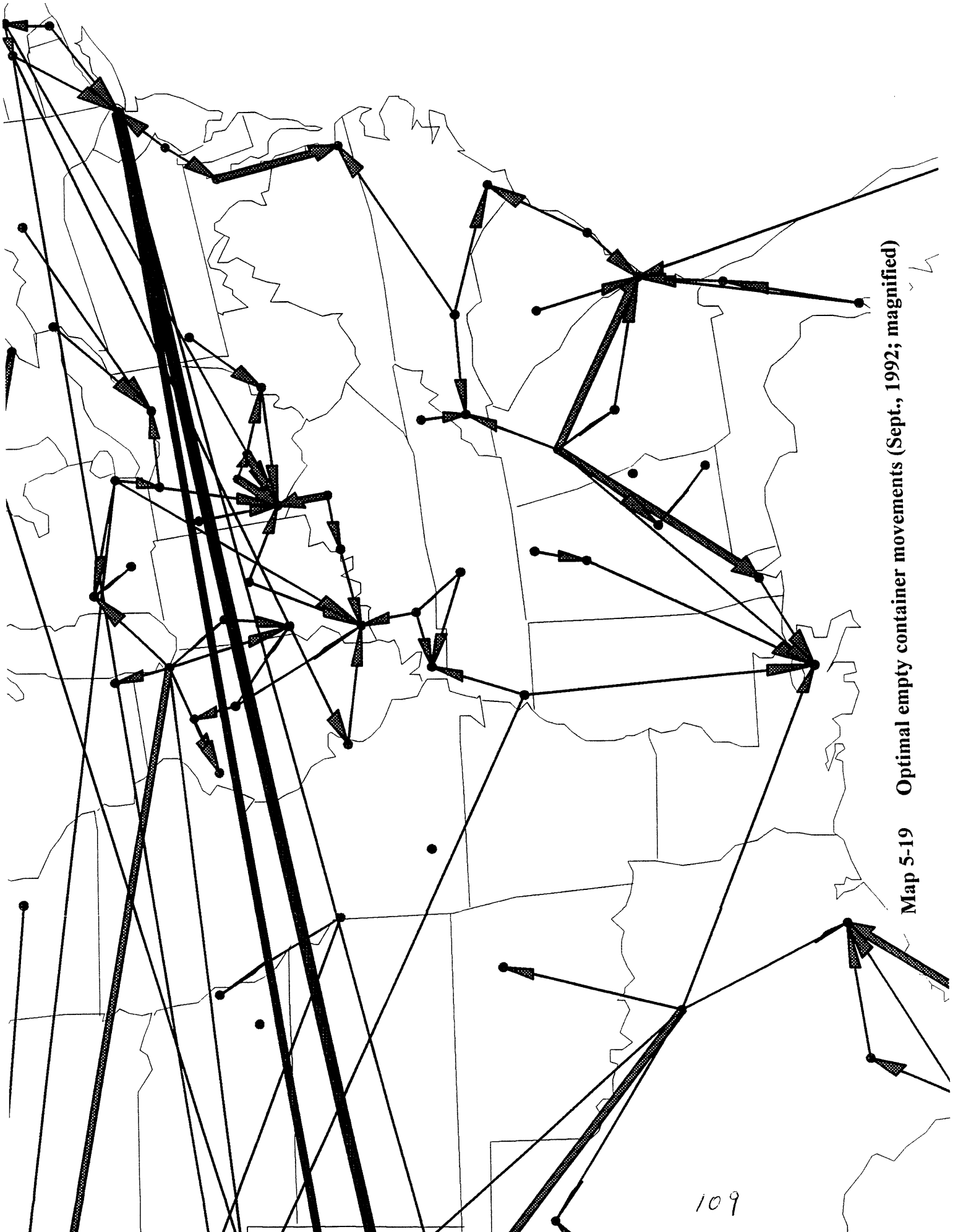
Map 5-19   Optimal empty container movements (Sept., 1992; magnified)

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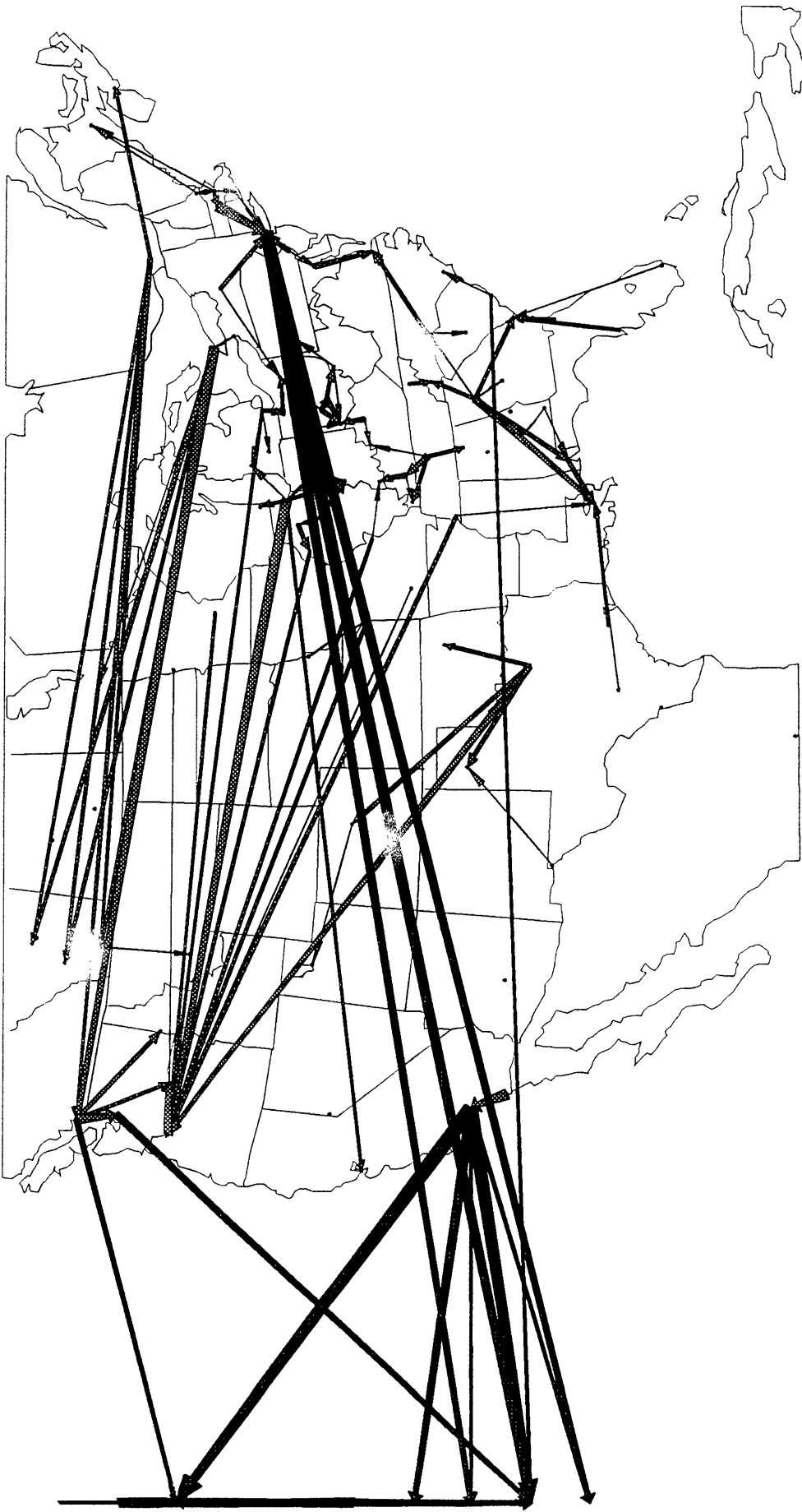
Map 5-20   Optimal empty container movements (October, 1992)
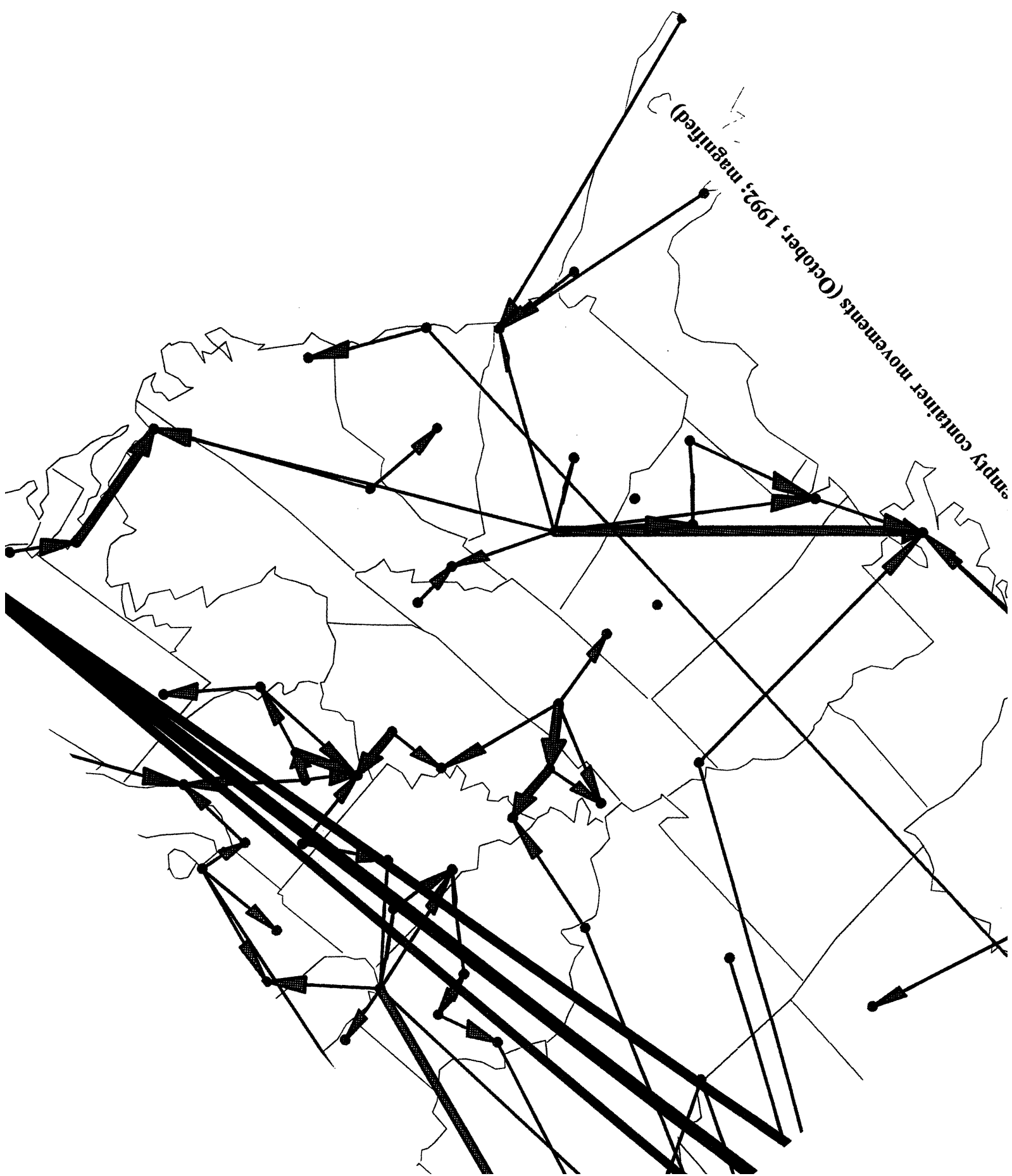
Empty container movements (October, 1992; magnified)
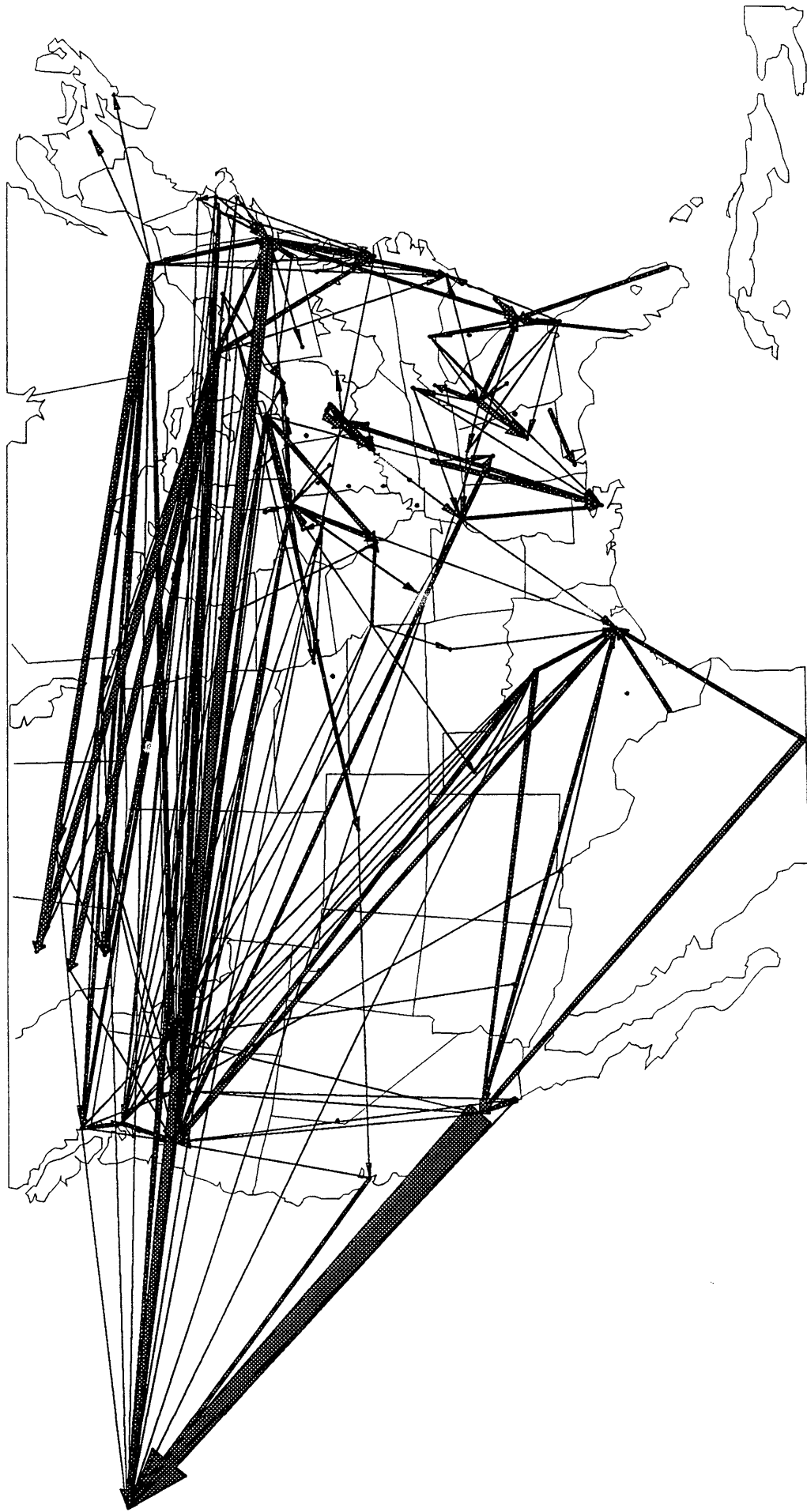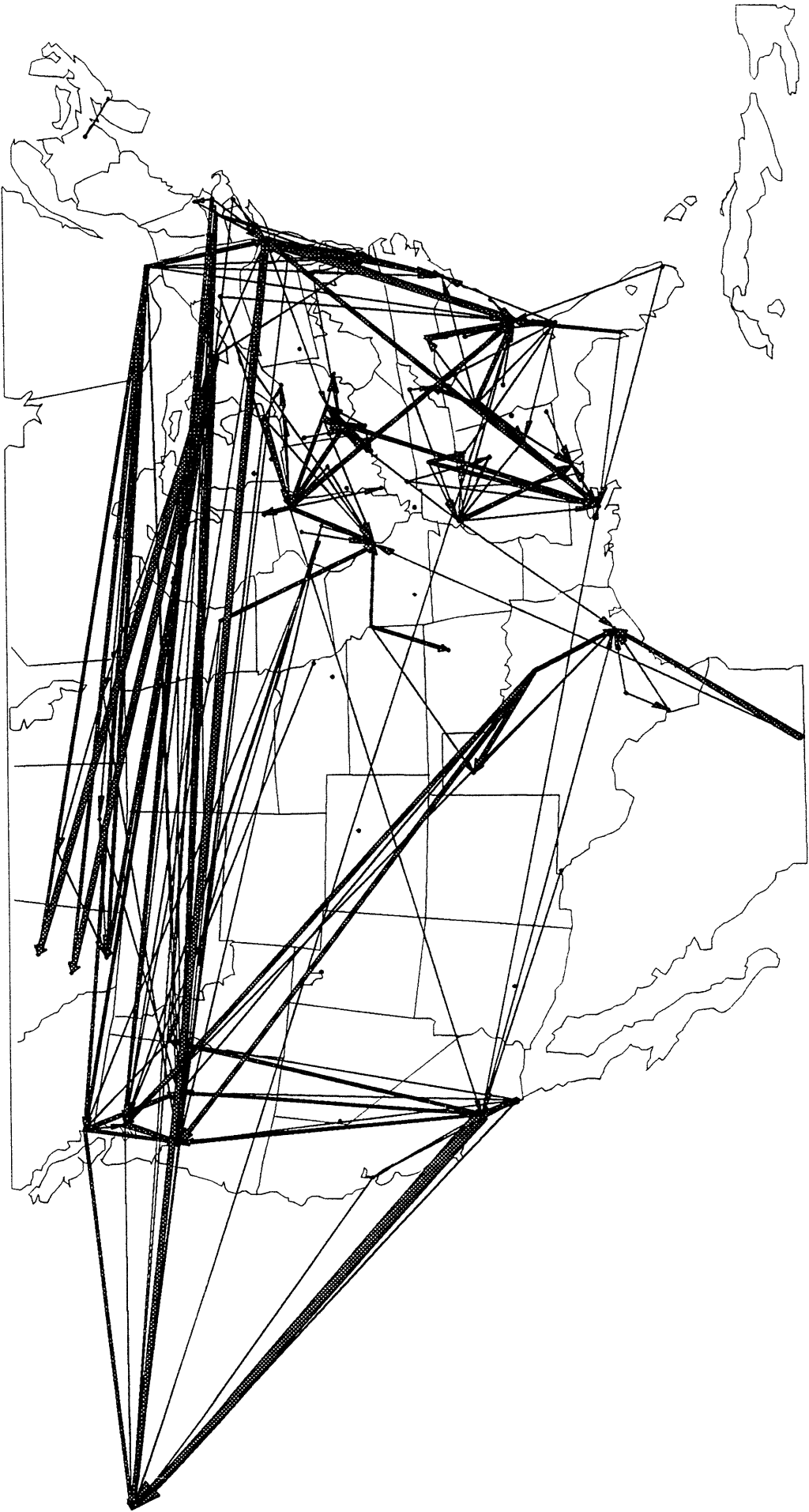
Map 5-22   Actual empty container movements (August, 1992)

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Map 5-23   Actual empty container movements (September, 1992)

Map 5-24   Actual empty container movements (October, 1992)

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The comparison of the optimal empty container movements with the actual movements may be useful for analyzing the empty container allocation. In comparing them, we should be careful not to blindly consider that the optimal movements are right, and the actual ones wrong. There might be facts that are not reflected in our research, and our assumptions might not completely agree with the reality.

The difference in the shape of the trans-Pacific arrows causes considerably different impressions. Having said that, it is almost remarkable that the optimal movements and the actual movements resemble each other to a significant extent. I would like to point out minor, but suggestive differences between the two.

(a)   In the actual movement maps, Chicago functions as a regional center of empty movements. Many empty containers come into and go out of Chicago, which is the center of the U.S. railway network. In the optimal movement maps, Chicago is merely a surplus place, and we can observe only outward movements from Chicago to Portland and nearby places.

(b)   In the actual movement maps of August and October, there are arrows from Houston to Los Angeles and from Houston to Portland. On the other hand, the optimal movements show no outward movements from Houston, which is a place showing consistent container shortage.

(c)   Denver was supplied with containers from Midwestern cities. However the optimal movements suggest that Denver should be supplied with containers from Dallas.

(d)   Savannah gathers many containers from New York, Detroit, and Chicago, besides the Southern states. However, the optimal movements suggest that the shortage of Savannah can be filled by containers from Atlanta, Wilmington, Georgetown (KY), Charlotte, Tampa, and Miami.

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(e)   The shortage of New Orleans was filled by containers from Nashville (TN), Marysville (OH), and Memphis. The optimal movements suggest Atlanta and Memphis as the origins of supplies to New Orleans.

(f)   The surplus containers at Nashville were sent to New Orleans. However, they may be sent to Evansville (IL), Hopkinsville (KY), or Huntsville (AL).

5.11   Demonstration of Dual Costs

Although the dual costs are calculated for every day - every place, I present only one day from each of the three months. Map 5-25, 26, and 27 show the dual costs on August 15, September 15, and October 15, respectively. The length of a bar indicates the level of a dual cost in the negative direction; in other words, the longer the bar, the more we could reduce the total costs, were there an additional container at that place on that date. I set the lowest dual cost at zero. Thus the length of a bar shows the difference between the dual cost of that place and the lowest dual cost.

During the three months, Mexico City happens to be the city of the lowest dual cost. When we look at the optimal movement maps, we find movements between Mexico City and Houston in August and September, but not in October. In August and September, empty containers in Mexico City need to be sent back to Houston at substantial costs, and hence the bottom (namely, Mexico City) is deep. On the other hand, the bottom is shallower in October, since no such back-haul movements are necessary. That is why most bars in August map and September map seem taller than those in October map.
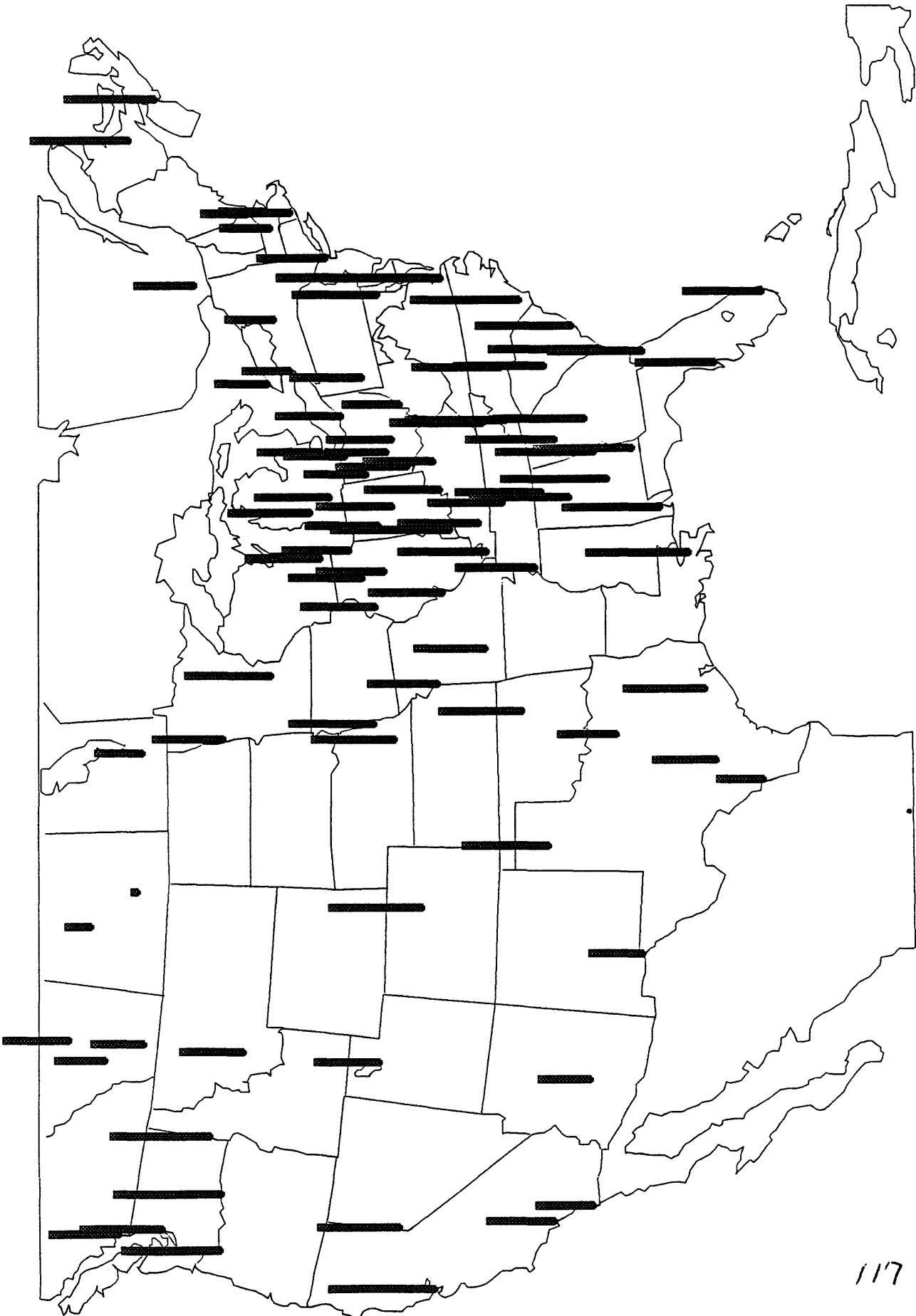
Map 5-25   Dual costs (August 15, 1992)
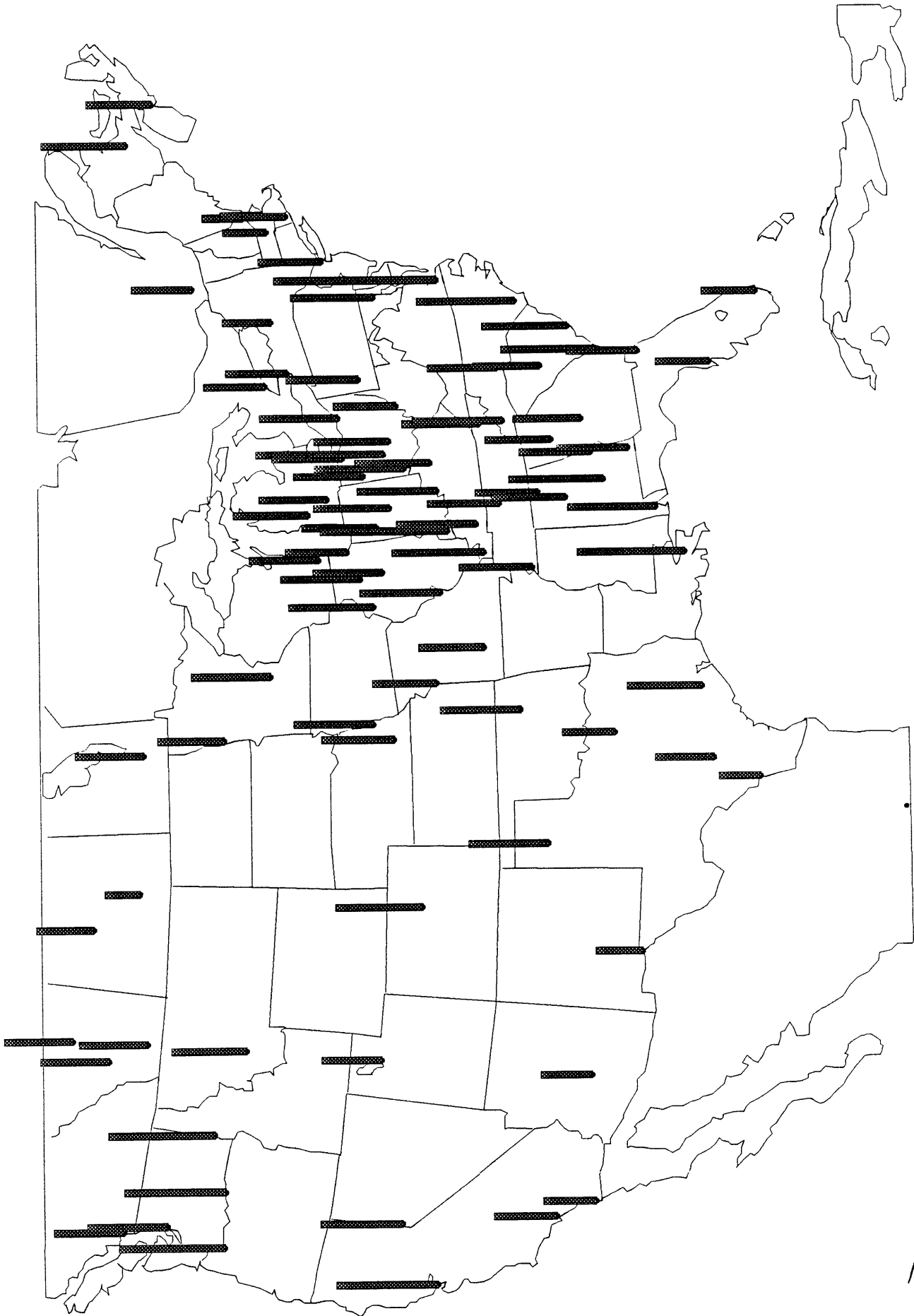
Map 5-26   Dual costs (September 15, 1992)
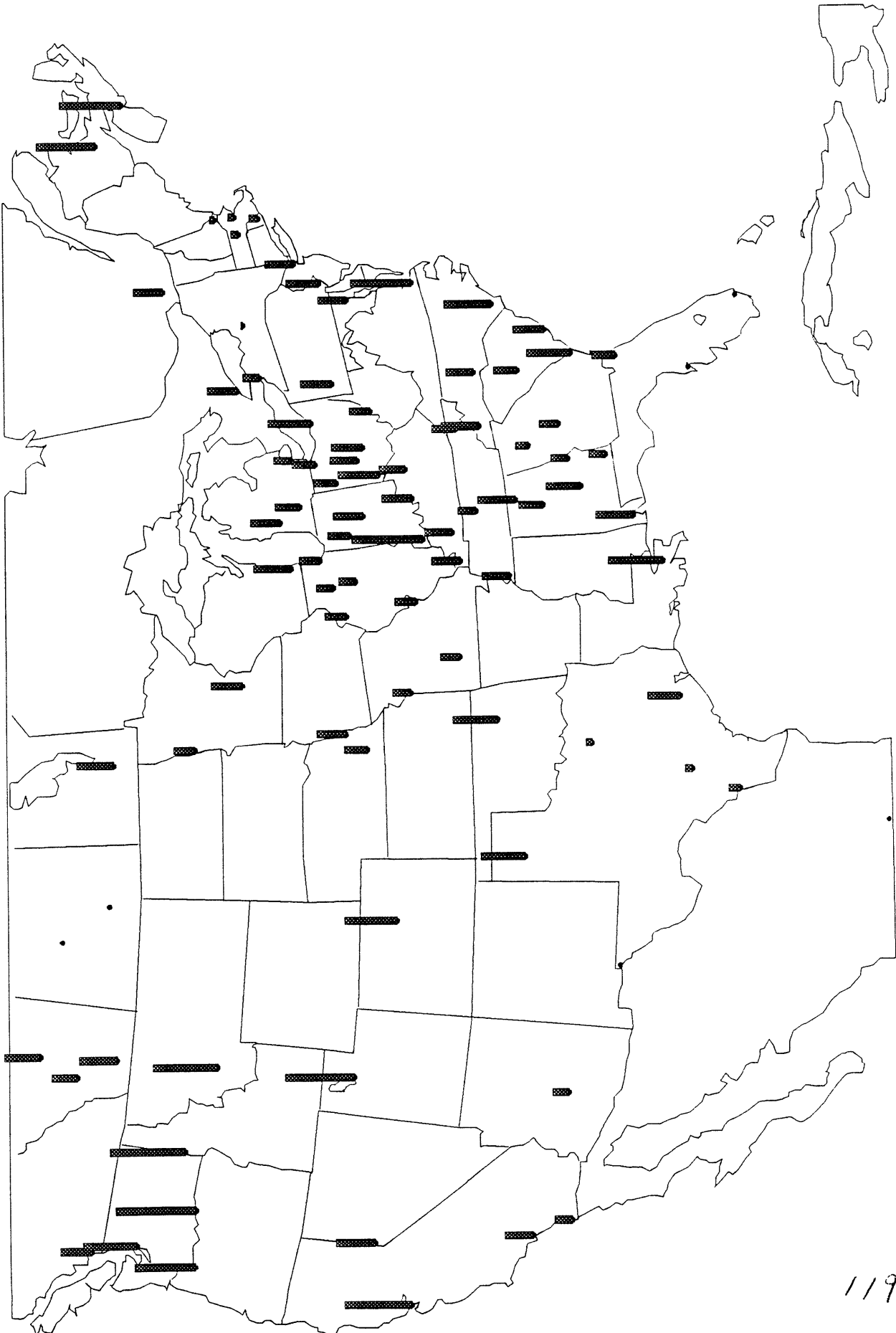
Map 5-27   Dual costs (October 15, 1992)

Chapter 6

Utilization of Dual Costs in Marketing

In this chapter, I will argue how the dual cost information can be utilized in the management of a container shipping carrier. Impacts of introducing the dual cost analysis on the corporate organization are also considered.

6.1 Impacts on the Evaluation System

Most container shipping carriers use revenue as the criterion in evaluating activities or organizations. For example, the evaluation of cargo, sales staff, or agencies is based on the revenue that they generate. The drawback of the revenue criterion, however, is the fact that it does not reflect empty positioning costs and direct movement costs that are associated with the revenue.

The introduction of the dual cost analysis will enable another evaluation criterion that takes empty positioning costs and direct movement costs into account. Since the direct movement costs plus empty positioning costs constitute most of the tangible variable costs, such an evaluation criterion is reliable as an indicator of cost and profit.

6.2 Centralized Organization vs. Decentralized Organization

Before presenting a scheme of decentralization, I would like to illustrate the advantages of a centralized organization in container shipping, as well as those of a decentralized one.

(i) Advantages of a centralized organization

(a) Harmonization with the policy of the conference

A centralized organization is good at responding to decisions made by the conference, since it is quick at turning the entire organization around in accordance with the policy of the conference. In addition, it can reach its own opinions in a short time, and hence it can give its opinions back to the conference effectively.

(b) Consistency in pricing

In order to maintain consistency in pricing, centralized decision systems are better suited. Consistent pricing is considered to be important because of the following reasons. Shipping carriers are allowed to form a conference that is immune to anti-trust regulations. In exchange for such an exceptional standing, shipping carriers are required to be impartial to all users. The freight rate difference of a commodity may result in the difference in the competitiveness of the commodity, and so the inconsistent pricing may end up in damaging some of the customers.

(c)   Efficient empty container allocation

A centralized organization concentrates information in the head office so that decision makers may survey information efficiently. Such an organization can also save redundant investments by eliminating information related tools, such as computers or data transfer equipment, from peripheral offices.

(ii)   Advantages of a decentralized organization

(a)   Better customer service

Peripheral offices are good at paying meticulous attention to individual customers. They can spend a reasonable amount of time for each customer in analyzing the customer information, compared to the busy head office. By allowing peripheral offices to make their own decisions, they can respond to the needs of their customers quickly and easily.

(b)   Quicker decisions

Sometimes it takes a long time for the head office to make decisions, especially minor decisions, because of the flood of information from peripheral offices, or because of the unavailability of a key person. Decentralization eases such a problem, and also saves the time of communication between the head office and the peripheral office.

(c)   Competition inside of the organization

Decentralization stimulates competition among peripheral offices. Competition is a source of improvements and innovation in container shipping.

(d)   Higher morale

A decentralized organization can encourage people in peripheral offices to be spontaneous, and to be profit-oriented. Competition with other peripheral offices also helps maintain high morale.

I would like to point out here that the advantages of a centralized organization are becoming weaker. Conferences are losing their powers, and container shipping carriers can no longer rely on them to maintain profitability. It is becoming less critical for carriers to lead conferences and keep up with changes in the policies of conferences. With the growth of non-conference carriers, conferences have ceased to be the price leader in many trades. In some instances, conferences themselves give up maintaining the consistency in pricing due to the competition with non-conference carriers. Thus, the reasons for remaining with the consistency in pricing are becoming less substantial. With the development of optimization techniques and information systems, the efficient allocation of empty containers does not necessarily need a centralized corporate structure. The above argument suggests that all three points listed as the advantages of a centralized organization are becoming less important.

6.3   Scheme of a Decentralized Carrier

I would like to present an example of a decentralized container carrier. We will see in this example how the fixed costs, the variable costs, and the intangible cost factors are allocated among the peripheral offices. The scheme of a decentralized container carrier would be described as follows:

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Each peripheral office has the right to decide its marketing policy and carry out empty positioning. In other words, each office can determine whether or not it will take an available cargo, what type of customers it concentrates its sales activities on, and when and where it provides empty containers. Pricing is a delicate problem here, because of the existence of conferences. We assume in this example that each office accepts the given freight rates, and that it does not change them. In reality, it is reasonable to assume that each office actively gives its opinions about pricing to the head office, which checks whether the opinions of peripheral offices are in harmony with the policies of the conferences, and consistent with other freight rates.

At the beginning, the head office divides the fixed costs, and allocates a portion of the fixed costs to each peripheral office as the overhead cost. Each peripheral office sets its contribution target that is at least as high as its overhead cost.

We regard empty containers as a commodity that is tradable within the company. Each office can be compared to a dealer of empty containers. The head office gives preliminary dual costs to each office, before the trade begins. Guided by the preliminary dual costs that indicate the price of an empty container at given time-places, each office gives trade orders, such as "Buy two units of 40 foot containers this week at Chicago, and sell them 5 weeks from now at Tokyo". All buying orders have to be accompanied by corresponding selling orders.

When all orders are dispatched from peripheral offices, the head office sums orders up and calculates the optimal container movements that satisfy all orders. After the calculation, the definitive dual costs are announced, and trade orders are finalized.

Between the time of buying and selling, peripheral offices have the control and responsibility over the container. Peripheral offices can use their containers to

transport their cargo, or just hold them for future use. Each office is responsible for returning the containers at specified time-spaces. Each office can use the company's transportation system at the price equivalent to the tangible variable costs.

In a typical cargo transportation, a peripheral office buys an empty container at the origin, transports it to the destination , and sells it at the destination. Therefore, the office would earn:

(Revenue) - (Direct movement costs)

- (Dual cost at origin) + (Dual cost at destination)

As we have seen in Chapter 3, this value is equivalent to the contribution the office obtains from the cargo.

Some intangible cost factors are managed by peripheral offices, and others are managed by the head office. For example, peripheral offices are responsible for managing long term relationships with customers. An office may undertake an unprofitable cargo for the sake of the long term relationship with the customer. It is up to the peripheral offices to carefully consider the intangible cost factors associated with individual cargoes. For another example, maintaining the minimum guaranteed volume with a railway company is the responsibility of the head office, which can impose some restrictions on the activities of peripheral offices, if necessary.

This scheme does not necessarily prohibit peripheral offices from earning profits just by buying and selling empty containers. However, some regulations may be required to prevent too speculative activities, and achieve efficient utilization of the container fleet.

The transportation system may become congested at times. When trains or vessels fill up, some cargoes have to be postponed or canceled. The head office will impose a congestion cost on cargoes that use the congested section of the system. A congestion cost is equivalent to the highest forgone contribution. Although a congestion cost theoretically corresponds to the dual cost of a bundle constraint, we are not in the position of imposing bundle constraints in the model, because of intangible cost factors. Each office would have freedom of not obeying the results of the optimal cargo selection, even though such results are known. In stead, this process resembles an auction, in which the head office raises the congestion cost until a certain number of cargoes are foregone.

By making the empty container trade open to other carriers, we can achieve container asset unification, which we discussed in Chapter 2. Before the container asset unification is put into practice, the participating carriers determine the costs of empty movements in the common empty container network. The participating carriers regard their containers as the same commodity, and observe the same regulations.

The freight rates may be different among carriers even for the same cargo, and the direct movement costs may be different among them even for the same origin and the destination. The fixed costs may be different, and thus the target contributions may be different among carriers. Those differences are acceptable in this scheme, as long as participants pay the same price for the same type of container at the same time-place.

Carriers are expected to build their own areas of strength so that carriers form complementary relationships with each other. Such strength may arise from the good balance of back-haul cargo in certain areas, relative cost strength in some areas, or particular marketing policies.

6.4   Importance of Graphical User Interface

In a decentralized organization such as one described above, we should consider the differences between the head office and a peripheral office. Experts in data analysis may not be available in peripheral offices. A peripheral office may have to attend more than one route, and may not be able to spend much time on any one route. It will be compulsory for the head office to give concise and understandable information to peripheral offices.

Graphical user interfaces will help achieve that purpose, since it can give an intuitive solution in very little time. I believe that graphical user interface is indispensable in circulating information in a decentralized organization.

Availability of computer terminals may become an important issue. By decentralization, the number of decision makers may increase significantly; so does the number of necessary computer terminals. Because of recent technological development, personal computers can offer high performance at moderate prices. A network of personal computers may be suitable for the implementation of graphical user interface.

6.5   Considerations for Data Collection

The most difficult part in the utilization of the dual costs will be collecting accurate demand forecast data. Since every calculation is based on this data, obtaining better data is critical.

Peripheral offices basically take full responsibility for what they forecast. Each office can buy empty containers whether or not the office succeeds in obtaining the forecasted cargo. It is also responsible for returning containers as

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promised, or otherwise appropriate penalties can be imposed. However, since accurate forecasts are the base of all activities, we need to provide incentives and support for peripheral offices to become good at estimating future demands.

The staffs of the peripheral offices may need to be trained to use some demand forecasting techniques. For example, a technique to calculate a safe inventory level from a given information about the average and variance would be useful. Also it would be helpful to learn skills to estimate the relationship between the production plan of a factory and the demand for containers.

Chapter 7

Conclusions

First, I would like to state the motivation behind this research. The application of the minimum cost flow optimization to empty container networks may have been tried before. However, I have selected the theme in this research because of the following reasons:

(i)   The rapid development of intermodal networks has made the application of network optimization more effective and desirable in the management of container shipping carriers.

(ii)   Many container shipping carriers have invested in integrated information systems, which can provide up-to-date and reliable information about current container movements.

(iii)   Major container shipping carriers have recently developed partnerships. Under the scheme of partnership, container asset unification, such as a container pool system, will become practicable by introducing dual cost analysis.

(iv)   The idea of computer networks throughout the corporate organization has been made possible by the recent progress in computer and data transfer

technologies. With computer networks, the utilization of dual cost information becomes attractive in marketing.

Next, I will summarize the points that are argued in this thesis:

(i)   I have surveyed the recent trends in the container shipping industry, and discussed the expansion of intermodal networks, the development of integrated information systems, and the formation of partnerships.

(ii)   I have argued that container asset unification can differentiate the cost structure of carriers under partnerships, and that dual cost analysis is the key factor to realize container asset unification.

(iii)   I have pointed out that integrated information systems can turn out to be a strategic value, if the advanced aspects of the service are monopolized and standardized among advanced carriers, and separated from the ordinary service.

(iv)   I have examined modeling assumptions and techniques that are particular to the network of empty containers. I have shown techniques to reduce the number of decision variables in isolated regions, solve the boundary problem, and settle the time horizon problem.

(v)   I have reviewed the mathematical and algorithmic essence of the network simplex.

(vi)   I have modified the pivot rule in the algorithm so that the algorithm finds larger violation in earlier iterations, and improved the computational performance significantly.

(vii)   I have applied the algorithm to actual container movement data, and obtained results that are suggestive in improving equipment control. The results are also graphically displayed in the thesis.

(viii)   I have demonstrated the following example to show the utilization of dual cost information in marketing. Since a cargo subtracts an empty container from the origin, and adds it to the destination, the contribution of a cargo is calculated as follows:

(contribution) = (revenue) - (direct movement costs)

$\qquad\qquad$ - (dual cost at origin) + (dual cost at destination)

In a decentralized organization, empty containers are considered to be a commodity that is tradable within the company, and each office is compared to a dealer of empty containers. Each office is allowed to use the transportation network at the variable costs (direct movement costs). A portion of the fixed costs is assigned to each office as the overhead costs. An office would buy empty containers at the origins at the rate equal to the dual costs, transport its cargoes by using containers, and sell the containers at destinations at the rate equal to the dual costs. Hence, each office, which acts as if it were an independent entity, earns the contributions from the operation.

Finally, I suggest the following directions for further studies:

(i)   Simulation of container pool system

As I mentioned in Chapter 2, as the scale of container fleets grows, more efficient empty positioning will become possible. The simulation would demonstrate how attractive it is to unify container assets among partner carriers. The simulation may be based on actual demand data, or theoretically created with a demand generating model.

(ii)   Stochastic optimization

Demand forecasts essentially contain probabilistic factors. We will be able to construct models based on the assumption that every demand is expressed as a probabilistic listribution. Although the stochastic models would be considerably harder to implement, they would be closer to the reality.

(iii)   Route optimization

As shipping routes extend globally, it is becoming more and more difficult to find the best shipping routes. By using the techniques of integer programming, we would be able to construct a model that finds the most desirable routes, rotation, and ports of call.

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