Chapter 10

Routing Vehicles in the Real World: Applications in the Solid Waste, Beverage, Food, Dairy, and Newspaper Industries

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This paper is concerned with the optimum routing of a fleet of gasoline delivery trucks between a bulk terminal and a large number of service stations supplied by the terminal.... A procedure based on a linear programming formulation is given for obtaining a near optimal solution. The calculations may be readily performed by hand or by an automatic digital computing machine.

G.B. Dantzig and J.H. Ramser
The Truck Dispatching Problem,
Management Science, October 1959

10.1 Introduction

It has been nearly 40 years since Dantzig and Ramser first described and formulated the VRP and then solved a problem with 12 delivery points and one terminal. Theory, practice, and computer hardware and software have come a long way since then, so that today vehicle routing is considered one of the great success stories of operations research.

In the last 40 years, there have been hundreds of successful applications in dozen of industries in numerous countries. The successful implementation of vehicle routing software has been aided by the exponential growth in computing power since 1950, the emergence of accurate and sophisticated geographic information systems (GIS) technology, and easy-to-use interface software that enables the customer to integrate routing with other key functions such as billing, inventory tracking, and forecasting (see Hall and Partyka [43]). Vehicle routing software can integrate directly with enterprise resource planning (ERP) systems; for example, the routing software of one company can interface with the sales and distribution module of SAP's transportation planning system to access information on orders, carriers, geography, and transportation requirements (for details, see www.caps.com and www.sap.com).

Many interesting applications of vehicle routing are described in the operations research literature. An early collection of informative vehicle routing case studies carried out in Great Britain is found in Mercer, Cantley, and Rand [60]. Fisher [34], Golden and Assad [37], and Golden and Wong [40] include a nice mix of more recent applications. In a unique book, Eibl [30] surveys users of computerized vehicle routing and scheduling, predominantly in the brewing industry of Great Britain. In total, more than 16 detailed case studies emerge.

Table 10.1 provides a sampling of vehicle routing applications. Most applications involve trucks, but other modes of transportation, such as ships, barges, tugboats, and helicopters, are sometimes used. In addition, a wide variety of applications and locations is represented in Table 10.1.

Today, vehicle routing applications are ubiquitous. They span a wide variety of industries and involve the commercial distribution of many products that range from newspapers

Table 10.1. *Selected vehicle routing applications.*

Reference	Mode	Location	Application
Cline, King, and Meyering [21]	Ships	Long Island Sound and Connecticut	Service Coast Guard buoys
Erkut and MacLean [32]	Trucks	Alberta, Canada	Food distribution
Fiala Timlin and Pulleyblank [33]	Helicopters	Nigeria	Service offshore oil platforms
Holt and Watts [46]	Trucks	Australia	Newspaper distribution
Larson, Minkoff, and Gregory [54]	Barges and tugboats	New York City	Sanitation transport
Levy and Bodin [55]	Walking and trucks	United States	Scheduling of postal carriers
Pape [63]	Trucks	Europe	Transport of automobiles
Solomon et al. [77]	Helicopters	Western Africa	Large-scale larvicide control
van Vliet, Boender, and Rinnooy Kan [85]	Trucks	The Netherlands	Bulk sugar delivery
Wang et al. [86]	Barges and tugboats	Chesapeake Bay, Maryland	Planting of oyster shells
Wunderlich et al. [87]	Trucks	Southern California	Route and schedule meter readers

to soft drinks to groceries to milk on a daily basis. Beyond the commercial distribution setting, there are applications that involve waste collection, street sweeping, and delivery of mail. All these applications contain many characteristics found in basic vehicle routing models (such as constraints on vehicle load and route duration), but they also may contain many complicating issues (such as time windows and periodic or multideliveries to customers) that affect the configuration of routes. (For details, the paper by Assad [6] provides an accessible overview of modeling and implementation issues in vehicle routing.)

In this chapter, we convey the maturity and diversity of applications by focusing on three industries: solid waste; beverage, food, and dairy; and newspaper distribution. We selected these three industries for their rich modeling characteristics, success of solution and implementation, and potential for new research contributions. We intend to build on our previous work in these areas (see the papers by Assad and Golden [7], Golden et al. [38], and Golden and Wasil [39]) by exploring the state of the art within each industry, examining case studies, and presenting exciting new directions in vehicle routing research and practice.

10.2 Computerized Vehicle Routing in the Solid Waste Industry

10.2.1 History

One of the early classics in the vehicle routing literature is the paper by Beltrami and Bodin [11]. This paper focuses on municipal waste collection. In particular, the authors address the problem of efficiently routing garbage trucks for residential collection. This work was sponsored by the New York City Department of Sanitation in the early 1970s.

At that time, the Department of Sanitation had an annual operating budget of $200 million and approximately 11,000 sanitation workers. Each day, 25,000 tons of solid waste needed to be collected.

The problem involved more than just routing. To our knowledge, the first description of the period VRP appeared in this paper. Most sites required three visits per week (Monday–Wednesday–Friday or Tuesday–Thursday–Saturday). A small number of sites required six visits per week. Therefore, each site had to be scheduled before vehicle routes could be established. Russell and Igo [70] later allowed for more than just two frequencies of collection per week. For further information regarding the period VRP see Christofides and Beasley [19], Tan and Beasley [81], Russell and Gribbin [71], and Chao, Golden, and Wasil [18].

Trips to dump sites had to be scheduled to unload vehicles. Demand for service on a street was estimated statistically, based on the number and types of homes on the street. In short, the residential waste collection problem studied was a very rich and challenging vehicle routing problem. The authors proposed several heuristics for solving this problem. These heuristics involved modifications to the Clarke and Wright savings procedure and ideas from node coloring in graph theory

10.2.2 Background

Within the waste industry in the United States there are three primary types of VRP (excluding hazardous waste transportation). Commercial problems involve the collection of refuse from large containers at commercial locations. These are node routing problems. Residential collection involves collecting household refuse along a street network. These are arc routing problems. Roll-on–roll-off problems involve the pickup, transportation, unloading, and drop-off of large trailers (or containers) typically found at construction sites. These combine elements of node routing and bin packing. Each of these three problems is discussed in detail in this chapter.

In the last 10 years, technology advances and new developments in the waste industry have had a major impact on the acceptance of computerized vehicle routing software. (Baker discusses some of the technology-related issues in Chapter 14.) In particular, private haulers have emerged as fierce competition for municipal haulers. Private haulers claim they can do the job for less money. They argue that they can save payroll and overhead expenses for the municipality. Outsourcing has been popular in recent years, so the logic is hard to resist. In response, the internal (municipal) collection group adapts and competes. The result is that both private and municipal haulers are giving serious consideration to new technologies, such as computerized vehicle routing software, to reduce costs and attract business. The private haulers seem to be winning.

Another dramatic development in the waste industry in recent years has been the impact of mergers and acquisitions. In growing numbers, large private haulers are acquiring smaller haulers to fill in territorial gaps. When it is time to renegotiate contracts, the large haulers charge customers more to recover their investment costs. There are even examples of large private haulers buying substantially larger private haulers. For example, Allied Waste bought Laidlaw in 1997 and, in 1998, USA Waste bought Waste Management. To be precise, the last two companies merged, retaining the Waste Management name but operating under the management team of USA Waste. As a result of mergers and acquisitions, haulers tend to have more information technology expertise and greater financial resources at their disposal (no pun intended). At the same time, increased corporate size has led to a greater decentralization of decision making. Therefore, vehicle routing software companies often must sell to private haulers at the local level rather than the corporate level. In addition, the mergers and acquisitions climate has resulted in periods of uncertainty and instability for many private haulers. The overall impact of mergers and acquisitions on the implementation of computerized vehicle routing software within the waste industry has been mixed.

The solid waste management industry is sizeable. In the United States, 1996 revenues were $39.5 billion. The municipal solid waste (MSW) management subsegment saw 1996 revenues of $36.5 billion. The hazardous waste management subsegment accounted for the remaining $3 billion. The amount of MSW generated increased by 3.7% from 1996 to 1997, from 328 million tons to 340 million tons. In fact, MSW increased by 3.8% annually from 1970 to 1997. The five largest private MSW haulers during 1997 are given in Table 10.2, along with their North America revenues (see Friedman [35] for further details).

In the next 10 years, the U.S. Bureau of the Census expects the U.S. population to grow slowly (0.8% annually), and the Environmental Protection Agency projects daily MSW per person also to grow slowly (0.6% annually). The MSW industry will, therefore, continue to grow. Given this and the fact that garbage trucks currently cost between $125,000 and $200,000 each, we expect computerized vehicle routing to play an even larger role in the industry in the next 10 years than it has during the 1990s.

Table 10.2. *Largest MSW haulers in United States.*

Company	1997 Revenues
Waste Management	$5.6 billion
Browning Ferris	4.3 billion
USA Waste	2.6 billion
Republic Industries	1.1 billion
Allied Waste	0.9 billion

10.2.3 Commercial Collection

Businesses and organizations generally place their garbage in large containers (4, 6, or 8 cubic yards in size) for collection. These container sites are visited one or more times per week by garbage trucks, which front-load the containers. Since the sites are scattered throughout the geographic area, the VRP involves point-to-point collection (also known as node routing). In node routing problems, service is required at selected points, as in Figure 10.1. Drivers are limited each day by the amount of time in a workday. When a garbage truck is full, it must travel to the nearest landfill, which usually differs from the central depot. Each truck can make several trips per day to a landfill. The vehicle capacity dictates the number of landfill trips each day. In addition to landfill trips, other complications arise because of time windows at some of the container sites and because the vehicle fleet may be heterogeneous with respect to capacity. For the most part, routes and schedules are planned and real-time routing issues don't arise.

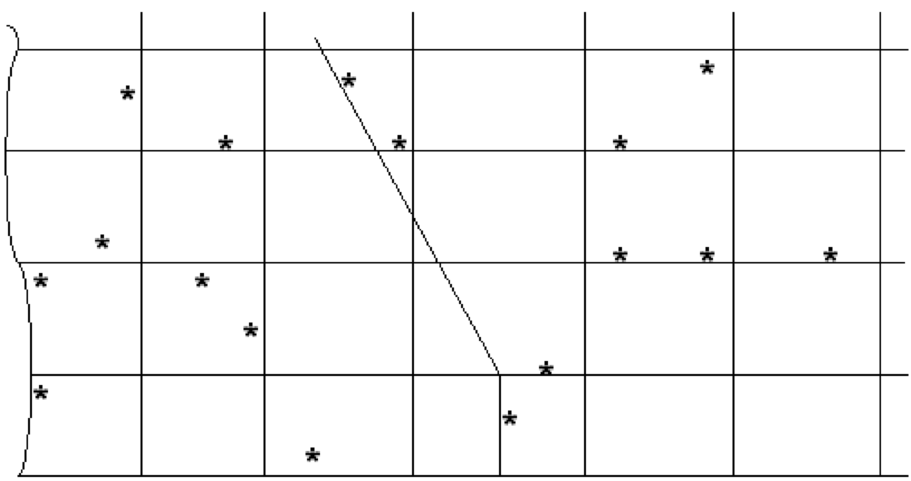

Figure 10.1. *Node routing example.*

10.2.4 Residential Collection

Residential collection involves visiting each of the streets in a residential network. We refer to the resulting VRP as neighborhood (or arc) routing. In arc routing problems, service is required at nearly all locations, as in Figure 10.2. Note that several arcs don't require service. There may be different categories of service, e.g., garbage, recycling, and yard waste. Typically, each category requires one-day-per-week service. Vehicles are either rear-load or side-load and crew size is a function of vehicle type. Drivers are limited each day by the amount of time in a workday. When a garbage truck is full, it must travel to the nearest landfill, which usually differs from the central depot. Each truck can make several trips per day to a landfill. The vehicle capacity dictates the number of landfill trips each day. In addition to landfill trips, other complications arise because the vehicle fleet may be heterogeneous with respect to capacity, and different categories of service may imply different vehicle capacities. For the most part, routes and schedules are planned and real-time routing issues don't arise.

10.2.5 Case Studies

In Table 10.3, we present 10 case studies that describe the use of commercially available vehicle routing software in the solid waste industry. Nine of these involve strictly residential collection. Installation dates range from 1986 to 1998. The three vendors cited are CAPS (based in Atlanta, Georgia), RouteSmart (based in Columbia, Maryland), and GIRO (based in Montreal, Canada). Each of these companies has been in business for approximately 20 years. Most of the case studies involve RouteSmart, since RouteSmart Technologies is the one vehicle routing software firm that specializes in solid waste applications. Many of the details presented in Table 10.3 come from recent articles in trade publications or private conversations (e.g., see [5, 24, 42, 45, 58, 68, 83]). The interested reader is referred to Chapter 11 of this book.

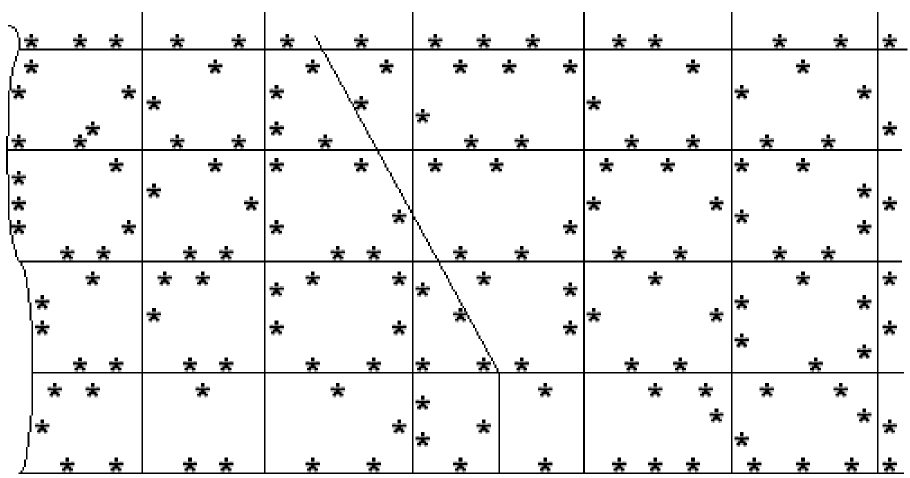

Figure 10.2. *Arc routing example.*

Table 10.3. *Solid waste collection case studies.*

Installation specifics[†]	Comments
• Oyster Bay, New York • RouteSmart • Beginning in 1986 • Residential	• Goal was to balance routes better • Service 72,000 stops, twice per week • Fewer trucks required • Savings of about $1,000,000 per year
• Metro-Dade County, Florida • RouteSmart • 1992 • Residental	• Recent growth in western part of Dade County • County has become deeply involved in recycling • Service 250,000 homes, twice per week • Recyclable wastes are handled by separate routes • County has used GIS since early 1980s • Reevaluate routes once per year • After installation, a typical crew handles 10% to 15% more households per day • Water department now also uses RouteSmart
• Hempstead, New York • RouteSmart • 1993 • Residential	• Service 84,000 homes each week • Hempstead runs RouteSmart several times per year • Seasonal variability in waste volumes • Savings of $200,000 per route per year • Software is also used to better communicate with customers
• Charlotte, North Carolina • RouteSmart • 1994 • Residential	• Saved more than 2,800 labor hours in first year • City administration very satisfied • Purchased an additional system for water department
• Philadelphia, Pennsylvania • RouteSmart • 1994 • Residential	• No U-turns really tested the RouteSmart software • Reduced number of trucks from 23 to 18 • Collection routes are much better balanced than before • Handles site dependencies: size of truck versus type of street
• More than 200 sites in USA serviced by Waste Management, Inc. • CAPS • Beginning in 1995 • Residential and Commercial	• Used CAPS Logistics Toolkit • Cost savings of 5% to 15% • Productivity improvements of 10% to 15%
• Sacramento County, California • RouteSmart • 1997 • Residential	• RouteSmart is used by the county's Waste Management and Recycling Division to bid for services of Sacramento • Used to improve routing efficiency throughout the county

Table 10.3. (continued)

Installation specifics†	Comments
• Grand Rapids, Michigan • RouteSmart • 1997 • Residential	• Curbside garbage pickup • Service 40,000 homes per week • 15 routes per day • Software has balanced the routes • Eliminated two routes • Freed up two people for the recycling program (10,000 homes every two weeks)
• City of Sacramento, California • GIRO • 1997 • Residential	• Pilot project • 40 vehicles for weekly collection of residential waste • The reduction in overtime costs is expected to more than offset the cost of the software in the first year alone • City of Sacramento decided to purchase GIRO's software, GeoRoute
• Midwest Ohio, American Disposal Services, Inc. • RouteSmart • 1998 • Residential	• Saved four trucks • Number of drivers reduced from 17 to 10 • Used software to identify a target market of noncustomers

† Location, vendor, date, and type of service.

10.2.6 Roll-on–Roll-off

The roll-on–roll-off variant of the VRP arises when there are large trailers (or containers) at construction sites, downtown areas, and other high-volume locations. Tractors move between these locations and a disposal facility (or landfill). Each tractor can carry a single trailer at a time. Four basic types of service are provided by the tractor:

- Round trip: the tractor picks up a full trailer at a site, brings it to the landfill for emptying, and returns the empty trailer to the site;
- Exchange trip: the tractor picks up an empty trailer at the landfill, brings it to the site, picks up a full trailer at the site, and brings it to the landfill;
- New site: the tractor brings an empty trailer to a new site; and
- Removal: the tractor picks up a full trailer (for the last time) at an old site.

Drivers are limited by the number of hours in a workday. The goal is to minimize the number of tractors required and, secondarily, to minimize the total travel time incurred by the tractors.

For the most part, trailers to be serviced on a given day are known in advance. However, phone calls may trigger same day service for 20% to 30% of the daily demand. Therefore, real-time issues emerge in practice, making this an especially difficult VRP.

When the tractor performs only exchange-trip service, routes such as the two displayed in Figure 10.3 emerge. The numbers in Figures 10.3 and 10.4 indicate the sequence of moves for each tractor and not arc length. For example, on route 1, the tractor starts at the depot, brings an empty trailer to A, picks up a full trailer, and takes it to the landfill. It then carries an empty to B, picks up a full, takes it to the landfill, and so on. After the initial customers on each route (A and X), the problem becomes one of bin packing. Each trip of the form LF—customer—LF has an estimated time duration, and each tractor has something like 8 hours per day of time availability. Therefore, we seek to pack customers into routes as efficiently as possible. This will help us to minimize the number of tractors used.

When the tractor performs only round-trip service, routes such as the two displayed in Figure 10.4 emerge. For example, on route 1, the tractor travels from the depot to A without a trailer, picks up a full trailer, takes it to the landfill, empties it, returns the empty to A, travels to B, and so on. Since the travel times between the customers (e.g., A, B, C, and D) may be substantial, this problem has a significant routing component.

Figures 10.3 and 10.4 each represent atypical routes. Typically, each tractor performs several types of service during the course of a day. Therefore, the roll-on–roll-off problem involves both routing and bin packing considerations. The problem is further complicated by the fact that some trailer demands may have time windows.

This VRP is just beginning to attract research attention. In particular, Bodin et al. [12] compared three heuristics on 20 diverse test problems. The heuristics are based on set-covering, dynamic programming, and greedy insertion ideas. See Laporte et al. [53] for an alternate approach.

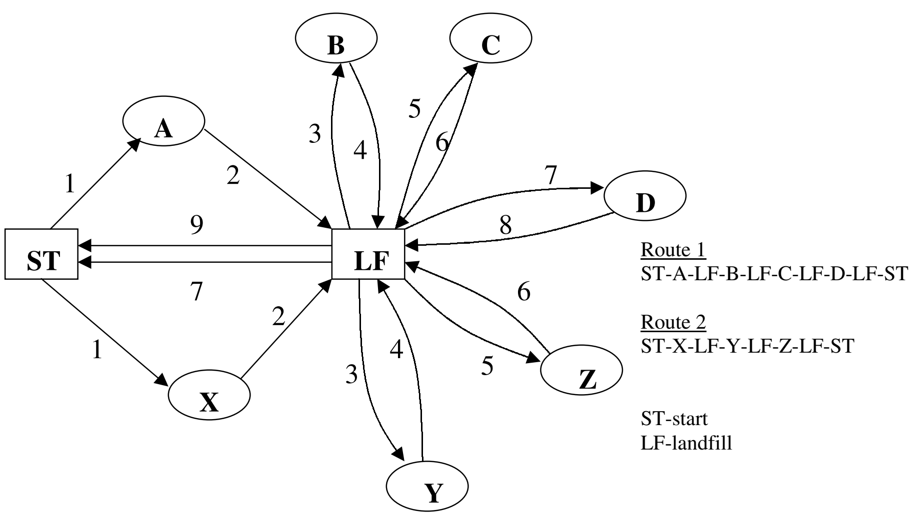

Figure 10.3. *Exchange trip. An empty trailer is brought to each customer. The tractor starts and ends with an empty trailer.*

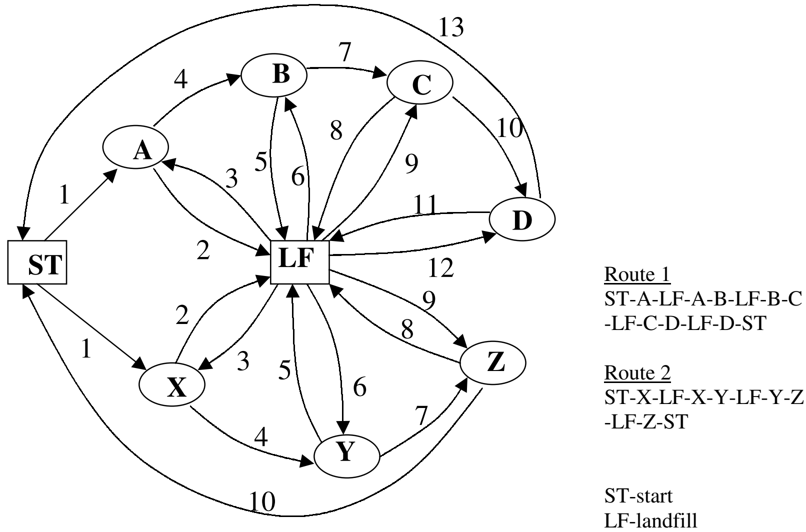

Figure 10.4. *Round trip. Each trailer must be returned to the customer. The tractor starts and ends without a trailer.*

10.2.7 Further Remarks

It should be clear that there are deep and diverse vehicle routing problems facing the solid waste industry today. These problems involve node routing, arc routing, time windows, real-time, and bin packing considerations. Numerous successful applications have been reported to date, but much exciting work remains to be done.

10.3 Vehicle Routing in the Beverage, Food, and Dairy Industries

10.3.1 Introduction

In this section, we describe vehicle routing applications in the beverage, food, and dairy industries. These three industries have large volumes of sales so that the expenses associated with distribution activities typically are very large. To illustrate, retail beverage sales in the United States were $178.91 billion in 1997 with soft drink sales of $53.4 billion and beer sales of $53.2 billion (see [4]).

In the food distribution industry, about 3000 companies split $140 billion in annual sales (see Knight [51]). For example, U.S. Foodservice, based in Columbia, Maryland, has more than 6% of the market (about $6 billion in sales for 1998) and is the second-largest distributor of food, supplies, and equipment. Sysco Corporation, based in Houston, Texas, is the largest distributor with $16 billion in sales in 1997. U.S. Foodservice has a nationwide network of 37 distribution centers and 2400 trucks [51].

In the dairy foods industry (this includes processing, distribution, and marketing of milk, cheese, and ice cream), the U.S. market is about $65 billion (see IDFA [48]). For example, Dean Foods, based in Franklin Park, Illinois, controls about 10% of the U.S. market share for fluid milk and is one of the largest dairy companies with $3.28 billion in net sales in fiscal 1998 (Dwyer [28]). Suiza Foods, based in Dallas, Texas, is the largest full-line dairy in the United States with sales of about $1.79 billion (Dwyer [29]).

The costs associated with operating vehicles and crews for delivery purposes form an important part of total distribution costs. (For additional background on costs in the soft drink industry, see the article by Golden and Wasil [39].) In May 1998, *Beverage World* (see Deierlein [25]) reported on the results of its annual survey of trends in beverage trucks. There were 164 respondents from randomly selected readers who managed beverage fleets (33 managed soft drink fleets, 114 managed beer fleets, and 17 managed bottled water fleets). Of the respondents, 36 had a fleet size of 1 to 9 vehicles, 86 had 10 to 49 vehicles, and 42 had more than 50 vehicles. Overall, the respondents were responsible for 7226 vehicles. For all fleets, route trucks averaged 79 miles per day and route tractors averaged 92 miles. In Table 10.4, we show the breakdown of respondents on distribution costs and computer usage. For all fleets, distribution costs were 21% of revenue, and 60% used the computer for route planning. We point out that in the 1999 Databank compiled by *Beverage World*, 22 companies were listed as suppliers of routing and scheduling software.

10.3.2 Beverage Industry

In this section, we examine the use of vehicle routing in the beverage industry (e.g., the distribution of beer, soft drinks, and bottled water). We describe the use of computerized vehicle routing by a large brewing group in Scotland. We also present a brief discussion of two vehicle routing software applications that are found in trade publications.

10.3.2.1 Beer Distribution in Scotland

Eibl, Mackenzie, and Kidner [31] present a detailed case study that focuses on the use of computerized vehicle routing in the brewing industry. We describe the routing problem and the managerial aspects surrounding software implementation. We point out that Eibl [30] reports on an extensive empirical study of the success of vehicle routing software in the

Table 10.4. *Breakdown of respondents on distribution costs and computer usage,* (*Deierlein* [25]).

		Fleet type			Fleet size		
	All fleets	Soft drink	Beer	Bottled water	1–9	10–49	Over 50
Distribution costs as a percent of revenue	21	24	20	32	22	22	16
Computer usage (%) for route planning	60	60	58	73	44	54	84

British brewing industry. (Eibl collected and analyzed data from 151 managers, schedulers, and drivers, conducted expert interviews, and developed 16 case studies.)

10.3.2.2 Routing Problem

Scottish and Newcastle (SN) is one of the largest brewing groups in the United Kingdom with total sales of £1,500 million and profit of £230 million in fiscal year 1991–1992. SN's brewing and drinks division had annual sales of £900 million with distribution costs accounting for £54 million (about 6%). Within SN, there are five regional sales companies and each company operates one or more of SN's 20 distribution depots. The characteristics of SN's routing problem are given in Table 10.5.

10.3.2.3 History of SN's Routing Systems

SN's use of computerized vehicle routing started in the early 1970s with the development of an in-house planning system. The system was not sophisticated enough to handle SN's distribution problems and the company eventually returned to a manual system.

The manual system relied on fixed or semifixed routes that were not cost effective with respect to vehicle utilization and distance traveled. The sequence of customers on a route was determined by geographical location, and delivery constraints, such as time windows and access restrictions, were ignored frequently. The manual system was time consuming to operate and was prone to errors. Furthermore, SN lacked accurate input data, such as precise driving times between customers.

In 1984, SN evaluated four commercially available, computerized vehicle routing systems and selected the brewery version of one system, called System B. System B was interactive, provided a color display of the routes and the road network, and allowed users to develop specialized routing subroutines called strategy files (for example, a user could run a strategy file that would plan deliveries of restricted-access customers).

The implementation of System B (at a depot in northeast England) was carried out by an internal team with expertise in data processing, logistics, and business systems. The team was led by an information transfer specialist selected from top management. The implementation took 20 person-weeks and involved a wide range of SN personnel, including vehicle schedulers and drivers who provided the system with key data (for example, exact geographical locations of customers, preferred time windows for customers, and road speeds). Eibl, Mackenzie, and Kidner point out that data handling (the collection, validation, and fine-tuning of distribution data) accounted for most of the time spent in the implementation phase. In addition, for a period of several weeks, the performance of System B was compared to the performance of the manual routing system.

10.3.2.4 Benefits of the Computerized Routing System

The use of System B resulted in both quantitative and qualitative benefits for SN.

- *Quantitative benefits.* The annual number of kilometers traveled by vehicles was decreased by 8%, and average vehicle utilization in terms of weight was increased by 11%. (The variable routes generated by System B provided more flexible allocations of orders.) The increase in transport productivity allowed SN to remove two large vehicles from its fleet, thereby saving more than 8% in total vehicle fleet costs. The

Table 10.5. *Characteristics of Scottish and Newcastle's routing problem.*

Nature of demand	Delivery of more than 200 products and pickup of returnable empties. Pure deliveries and pure pickups or a mixture.
Demand information	Orders collected by computerized system with an order lead time of 48 hours. Emergency orders accepted if feasible. 200 to 250 customers served per day by a depot. Average delivery quantity is 1.1 tonnes (ranging from a minimum of six bottles to a full vehicle load). Most customers receive deliveries once per week.
Vehicle fleet	20 to 25 vehicles stationed at a depot. Large vehicles (most common) carry 9 to 10 tonnes. Small vehicles carry 1.5 tonnes. Typical route takes nine hours and covers 150 km on average (ranging from 15 km for local deliveries to 400 km for long-distance deliveries).
Crew requirements	Driver pay is a combination of fixed weekly wage and a bonus based on distance traveled and delivered units. Maximum driving time of nine hours. Distribute driver work loads equitably.
Delivery constraints	Tight time windows for customers. Capacity restrictions on vehicles due to orders with high volume or weight. Limited access to customers. Compact delivery areas. One-way streets.

time required to generate routes was reduced from 8 hours with the manual system to an hour and a half with System B. System B paid for itself within the first year of usage. (It had a net present value of more than £119,000; over the system's 5-year lifetime, the net present value was more than £297,000.)

- *Qualitative benefits*. The use of System B led to an improvement in the quality of the delivery service. There were fewer omitted orders, shorter lead times, and better adherence to schedules. Through the use of statistical reports generated by System B, SN increased the control and monitoring of the performance of drivers and schedulers. With System B, planners at SN found their jobs interesting, challenging, and satisfying in contrast to the drudgery of the manual system.

We point out that, from the mid 1980s to the mid 1990s, SN successfully implemented System B in 15 of its 20 distribution depots.

10.3.2.5 Other Applications in the Beverage Industry

In Table 10.6, we provide brief details of two vehicle routing applications in the beverage industry that were reported in trade publications. Each application uses a different commercial software product (Roadshow and Roadnet).

Table 10.6. *Selected vehicle routing applications in the beverage industry.*

Source	Comments
Gourley [41]	Pepsi-Cola Canada services more than 11,000 retailers and had used a manual system of route cards and delivery tickets to generate routes. The company now uses the Roadshow routing and scheduling system to develop routes that are based on actual travel times and distances within its distribution area. Roadshow accounts for vehicle capacity, time windows, dispatch times, on-site standards, and schedules of drivers, and it allows Pepsi-Cola Canada to adjust routes quickly when there are changing business conditions (e.g., new promotions of products). By using Roadshow, the company has reduced its distribution costs significantly.
Sfiligoj [74]	Grey Eagle Distributors, based in Maryland Heights, Missouri, is an exclusive distributor of Anheuser-Busch products. For more than 18 years, Grey Eagle has used computerized vehicle routing and scheduling systems (McDonnell Douglas in 1981, Roadnet 4000 in 1986, and Anheuser-Busch's routing system RAP in the 1990s). In 1996, Grey Eagle implemented Roadnet 5000. With Roadnet 5000, the company takes into account a wide variety of criteria when generating vehicle routes. Each day a driver delivers between 310 and 700 cases (the limits are set by union contract) and there are 85 route drivers. Grey Eagle has a fleet of 100 vehicles (there are 10 different types of vehicle), 1500 customers (some with tight delivery time windows), and a delivery area of 500 square miles. By using Roadnet 5000, the company has reduced the amount of time it takes to generate routes (from 2.5 hours to 1 hour) and has moved back the order cut-off time by 2 hours (this has decreased the number of last-minute orders and the need for secondary routing). Grey Eagle has reduced daily mileage by 5% to 7%, about 48,000 miles per year.

10.3.3 Food Industry

In this section, we examine the use of vehicle routing in the food industry. We describe in detail a complex allocation–routing problem encountered by a grocery distributor in Canada. We also present a brief discussion of four vehicle routing software applications that are found in trade and academic publications and on the Internet.

10.3.3.1 Grocery Distribution in Canada

Carter et al. [17] formulated and solved a distribution problem for a grocery distributor in Mississauga, Ontario. We describe the routing problem, solution algorithm, and computational results.

10.3.3.2 Routing Problem

Each day the distributor delivers products to grocery stores in southern Ontario. There are 179 products, 1263 stores, and a fleet of homogeneous vehicles based at a single warehouse. The decision problem has two parts: a demand allocation component and a vehicle routing component.

In the *allocation problem*, the distributor needs to allocate available inventory to meet the demands of the grocery stores on each day. Of course, the distributor may not have enough inventory of a certain product to satisfy the demands of all grocery stores and will need to determine how much of each store's demand to satisfy to achieve an acceptable level of service.

In the VRP with Time Windows (VRPTW), the distributor needs to generate routes for the vehicles that meet the delivery time windows for each store. Most time windows are wide and cover an entire day, but some are tight and cover a few hours. The distributor needs to consider variable delivery costs as well constraints on vehicle capacity and length of the workday.

10.3.3.3 Solution Algorithm

Carter et al. develop an iterated procedure for solving the allocation–routing problem. First, the problem is formulated as a large-scale mathematical program that determines the quantity of each product to deliver to each store on a day. There are hard constraints on product availability (supply) and vehicle capacity, and the objective is to minimize cost. This problem is solved approximately using a Lagrangian-based heuristic. (The hard constraints are moved into the objective function and a dual-ascent procedure is applied.)

Second, vehicle routes are determined using the solution from the allocation problem. The I1 insertion heuristic of Solomon [76] and the 2-opt* procedure of Potvin et al. [65] are used to generate and improve routes. We point out that the solution to the VRPTW could be infeasible or contain unbalanced routes. The infeasibilities and imbalances are eliminated by changing the delivery capacity of certain days when solving the allocation problem. For example, if a day requires too many vehicles, the delivery capacity on that day is reduced and the allocation problem is resolved. If a day requires too few vehicles, then the delivery capacity is increased and the allocation problem is resolved.

10.3.3.4 Computational Results

The heuristic for solving the allocation problem was tested on 10 problems. Each problem had 100 stores, five products, and five delivery days. There were 10 parameters whose values needed to be set. (Four parameters had values generated from a uniform distribution.)

The overall solution algorithm that combined allocation and routing was tested on a subset of confidential data provided by the grocery distributor. There were 20 vehicles of capacity 1000 that were available each day for delivery to 1263 stores over a 5-day week. Six of 179 products were of stock on each day. A vehicle had to complete its route within 720 minutes. Furthermore, 95% of all deliveries took place in the first 600 minutes of the workday and the remaining 5% of deliveries were in tight time windows.

The overall solution algorithm required seven iterations to reach feasibility and took 1316.4 seconds. The final solution had an allocation problem cost of $26,646 and the VRPTW had a total distance traveled of 17,226. These values compared favorably to the values of the grocery distributor's solution—estimated allocation problem cost of $35,381.8 and VRPTW total distance traveled of 27,820. We note that the grocery distributor typically solves this problem once a week.

In addition, the authors conducted a series of computational experiments that were designed to test the effects of the geographical distribution of customers (e.g., randomly located customers versus clustered customers), costs of delivery patterns, demand distributions, and number of delivery days on the behavior of the overall solution algorithm. For example, the authors found that the algorithm is insensitive to geographical distribution.

10.3.3.5 Other Applications in the Food Industry

In Table 10.7, we provide brief details of selected vehicle routing applications in the food industry that have been reported in trade publications, on the website of a vehicle routing software company, and in an academic journal. Three applications use commercial software products (Roadnet, Roadshow, and CAPS Logistics).

10.3.4 Dairy Industry

In this section, we examine the use of vehicle routing in the dairy industry. We describe in detail a system that generates milk tanker schedules for a dairy in New Zealand. We also present a brief discussion of six vehicle routing software applications that are found in trade and academic publications and on the Internet.

10.3.4.1 Milk Tanker Scheduling in New Zealand

Igbaria et al. [49] and Basnet, Foulds, and Igbaria [9] reported on the development and implementation of a vehicle routing system known as FleetManager for the New Zealand dairy industry. We describe the routing problem, the routing system, and the benefits and impact of the system for the Westland Dairy Company of Hokatika, New Zealand.

Table 10.7. *Selected vehicle routing applications in the food industry.*

Source	Comments
Cullen [23]	Joyce Foods, Inc., based in Winston-Salem, North Carolina, is a seafood and poultry processor with a fleet of 15 tractors and 25 drivers. Each day there are 25 delivery routes that cover customers in North Carolina, South Carolina, Virginia, and Georgia. In the past, Joyce kept in contact with drivers by telephone and pager. Recently, Joyce equipped each truck with an on-board computer system that has mobile communications and is linked to the Roadnet routing software. Joyce can track the movement of each truck and record route data, such as time spent at a customer. Joyce expects that the computer system will produce significant savings in fuel costs. The route data could be used to improve customer service (for example, providing a customer with an accurate vehicle arrival time).
Valero [84]	Associated Wholesale Grocers, Inc., based in Kansas City, Kansas, services customers in Iowa, Kansas, Missouri, and Nebraska. Associated operates a fleet of 186 refrigerated trailers, 40 drive trailers, and 89 tractors and ships 130 loads per night. In 1994, Associated began scheduling vehicles based at its Kansas City facility using the Roadshow routing and scheduling system. In the first year that Roadshow was implemented, Associated decreased outbound transportation expenses by 6%, decreased the number of drivers by 6%, increased payloads by 11%, and saved $780,000 in transportation costs. Roadshow allowed dispatchers to take backhauls into account when generating routes and reduced the time to develop routes from 2 hours (by manual methods) to 45 minutes.
Sperber [78], CAPS [16]	Tom's Foods, Inc., based in Columbus, Georgia, manufactures and distributes snack food. It operates seven plants and delivers to customers in 42 states. Tom's wanted a computerized system to help with the daily dispatching at four locations including Columbus. It selected CAPS Logistics routing software. With CAPS, Tom's found that it could adjust routes with respect to new, daily orders, add backhauls to routes, generate reports for management (in the past, reports were manually generated), and help with strategic planning (for example, developing routes for a 6-month period). Dispatchers spend more time improving the utilization of vehicles (Tom's switched from 43-foot to 48-foot trailers that carry more pallets) and generating better routes. In one region, Tom's saved $233,000 annually by eliminating two routes.

10.3.4.2 Routing Problem

In general, dairy companies in New Zealand collect milk from supplier farms using tanker vehicles that deliver the milk to processing factories. The amount of milk that will be collected at each farm must be estimated, and each farm is usually serviced daily. The tankers operate two shifts a day and are located at bases that may be different from the factories.

Table 10.7. (continued)

Source	Comments
Chung and Norback [20]	Kraft, Inc., is a large food distributor with more than 100,000 customers in 24 North American regions. Kraft developed an interactive distribution decision support system (DDSS) to carry out its daily routing. As Kraft's food distribution network expanded and its food distribution goals became more complicated (e.g., Kraft wanted reliable delivery, that is, timely arrival of food products on specific days or during specific time windows), it realized that DDSS was not providing satisfactory solutions and it needed to revise DDSS. Using data from 3 days of deliveries in four regions, Chung and Norback developed new clustering and insertion procedures to generate routes and allocate drivers and vehicles to routes. The authors implemented their new procedures in an interactive decision support program and tested the program using data from six regions for problems with 4 to 5 days of deliveries. The problems had 5 to 24 routes per region and 69 to 308 stops per day. The new procedures produced an average improvement of 5.4% of delivery costs per day (over the previous DDSS). The lower costs were due mainly to a reduction in the number of routes.

In 1992, Westland Dairy took in about 142 million liters of milk from 322 supplier farms using 10 tanker vehicles that traveled about 1.3 million kilometers. Vehicle schedulers in the transport office at Westland Dairy had to develop a specific sequence of suppliers for each tanker to visit on each shift. The schedulers had to take into account more than a dozen factors, including the level of customer satisfaction, access problems involving vehicle-customer combinations, equity of routes, and labor and traffic codes. Typically, a tanker would begin at its initial base, visit the suppliers in sequence, and then end at the factory (this could be different from the initial base). The schedulers also had to take into account that, at certain times of the year, some suppliers had a low output of milk and would not be visited daily.

10.3.4.3 Routing System

Traditionally, a large map with colored pins was used to develop routes for the Westland Dairy tankers. One supervisor performed nearly all the scheduling and frequently experienced problems in developing satisfactory routes that met various company objectives. Westland Dairy wanted to improve the productivity and efficiency of its operations and turned to researchers in the Department of Management Systems at the University of Waikato for help. The multiyear collaboration led to the FleetManager decision support system that allowed schedulers to use their experiences and preferences in developing routes for tankers. FleetManager was written in Turbo Pascal for an IBM-compatible personal computer with a high-resolution color monitor. It is a mouse-driven user-friendly system with pull-down menus.

FleetManager has three parts: the database, the user-system interface, and the model base. The database contains information on suppliers, factories, bases, tankers, and roads.

Routes can be saved in the database. FleetManager also accesses Westland Dairy's mainframe computer for data on supplier milk output.

The user interface is a window-based graphical interface that can generate all routes automatically. The routes are displayed on a digitized map and can be modified by a scheduler clicking on a location.

The model base contains procedures for generating routes (a sweep algorithm and a farthest insertion algorithm) and forecasting milk output (a linear interpolation scheme). The sweep algorithm forms clusters of suppliers that are allocated to a tanker. The farthest insertion algorithm then determines the sequence of suppliers on a route that minimizes the distance traveled. FleetManager uses the algorithms to automatically suggest routes to the schedulers. In generating these routes, FleetManager can accommodate various constraints, including multiple shifts, suppliers visited less frequently than daily, and tanker capacity. However, all suggested routes may not satisfy all constraints; these suggested routes would then be modified by the scheduler to take the missed constraints into account.

FleetManager can also be used as a planning tool to answer what-if questions. Schedulers can examine the effects on the routes of changes in tanker capacity, factory demand, and supplier milk output.

10.3.4.4 Benefits and Impact

The transport office at Westland Dairy considers the FleetManager system a major success. FleetManager has

- *Improved decision making*. Schedulers can develop routes automatically and fine-tune them manually with respect to a wide variety of criteria and constraints (e.g., vehicle-customer combinations). Schedulers can perform extensive what-if analysis to determine the impact of changes to problem inputs (such as the milk output of suppliers) on vehicle routes. It is now easy to schedule suppliers on a 3-day rotation instead of the customary daily visit. From 1992 to 1994, Westland Dairy's milk volume increased by 25% and the number of drivers was reduced. The transport office was able to handle the increased workload effectively with FleetManager.

- *Saved scheduler's time*. Scheduling now takes 60 to 90 minutes, instead of the 6 hours required by the manual system, thereby saving upwards of 30 scheduling hours per week. The transport manager and the schedulers are available for more important tasks and are more productive.

- *Increased satisfaction*. The job satisfaction and morale of the transport manager and the schedulers have increased. They are confident that, with FleetManager, they can handle complex, unanticipated routing events. They believe that they are more effective and efficient in their jobs.

Basnet [8] reported that Westland Dairy still uses FleetManager. Some formatting and user interface changes have been made over the years to make the system more user friendly. We note that Basnet, Foulds, and Wilson [10] describe the development of a decision aid that schedules tankers when they return to unload milk at a processing factory.

Table 10.8. *Selected vehicle routing applications in the dairy industry.*

Source	Comments
Adenso-Dìaz et al. [1]	Central Lechera Asturiana (CLAS) is the largest dairy in the north of Spain. It processes 1.3 million liters of milk per day and distributes its products through 19 distributors. Each distributor has 5 to 10 teams of vendors, who deal directly with client shops. Each team is headed by a sales promoter who is responsible for about 1500 client shops. CLAS selected the distributor in Asturias as a pilot center for a new system for managing the distribution of four types of dairy products (each product, e.g., yogurt, requires trucks with different characteristics). The authors structured the problem as a five-level hierarchical system. At upper levels, they decide on the number of visits to each client per week and various assignments (e.g., clients to teams of vendors). At lower levels, they develop routes for vehicles (a local search algorithm is used to solve a traveling salesman problem with time windows). The authors discuss implementation issues with their decision support system (e.g., sales promoters saw the system as a competitor that took away their decision making). The system, implemented in February 1996, found a fair distribution of clients to vendors and was able to reduce the kilometers in each vendor's route by 10%.
Mans [57], CAPS [15]	Mayfield Dairy Farms (a division of Dean Foods), located in Athens, Tennessee, services more than 14,000 customers from 19 distribution centers. It delivers milk and ice cream on more than 400 direct store delivery routes. Vehicles travel more than 11 million miles annually. Mayfield Dairy performed an eight-part routing analysis using the CAPS routing software. This analysis led to a resequencing and consolidation of existing routes (there was a reduction of up to six routes at individual distribution centers). In addition, total miles driven and hours worked were decreased and the use of assets increased (for example, new morning and afternoon routes were created). Mayfield Dairy was able to add a significant amount of new business on existing routes.

10.3.4.5 Other Applications in the Dairy Industry

In Table 10.8, we provide brief details of six vehicle routing applications in the dairy industry that have been reported in an academic journal, in trade publications, and on the websites of vehicle routing software companies. Two applications involve commercial software products.

Table 10.8. (continued)

Source	Comments
RiMMS [67]	Tuscan/Lehigh Valley Dairy, based in Philadelphia, uses the RiMMS software system to develop daily routes for 500 trucks that are located in the Northeast and Mid-Atlantic regions. The trucks deliver milk and dairy products. With RiMMS, the dairy can take into account such variables as truck capacity and loading time at the depot when developing routes. Last-minute changes can be scheduled quickly with the software (in the past, the dairy required a full day to generate routes).
Anonymous [3]	Baskin-Robbins supplies two-thirds of its 2500 stores with ice cream from four distribution centers. The company has a fixed customer base and, since 1992, has used the Performance Truck Routing System to develop a weekly master schedule at its distribution centers. The software also provides daily route recommendations. Baskin-Robbins estimates that, with the optimized delivery routes, it has saved 10% on mileage alone (about $180,000 annually).
Sankaran and Ubgade [72]	Etah Dairy is located in Uttar Pradesh, India, and has 70 milk collection centers (MCCs) within a radius of 150 km from Etah (the town is located 300 km from New Delhi). Each day the dairy sends tankers to collect milk at the MCCs and deliver the milk to the dairy for processing. The availability of the milk depends on the season and ranges from 45 tons in spring and summer to 170 tons in fall and winter. The dairy hires 24 tankers (capacity ranges from 4 to 12.5 tons), which leave the dairy by 6:00 am. The authors developed a heuristic (using the nearest insertion approach) to route the tankers. In constructing the routes, the authors considered constraints on route length (between 50 and 350 km), maximum elapsed time on a trip (from 5 hours in summer to 10 hours in winter), and maximum number of tanker trips (at most three). The heuristic is embedded in a decision support system called CARS (computer-aided routing system) that runs on a microcomputer. CARS was implemented in fall 1992 and management estimated a savings of 800,000 rupees in transportation costs. In addition, CARS reduced the amount of curdled milk by constraining long trips in very hot weather.
Sperber [78]	Johanna Dairies tests vehicle routing software on 29 store-door delivery routes. The company analyzes the number of stops per route, vehicle utilization, service time, and drive time. Mileage is reduced by 9% for an annual savings of $176,000.

10.4 Distribution and Routing in the Newspaper Industry

10.4.1 Industry Background

The newspaper industry has always had one of the largest distribution problems, measured by the number of units distributed. In 1998, the circulation for the top 20 daily newspapers of the world ranged from 14.53 million to 1.73 million. As expected, Asian papers (Chinese, Japanese, and Korean) dominate this list, which includes only one U.S. newspaper. The corresponding range of circulation figures for the top 20 U.S. dailies was 1,740,000 to 378,000 [13]. In the United States, the average circulation of a daily paper is about 38,000. More than half the daily newspapers in the United States have circulations under 25,000, and more than two-thirds fall under 50,000. Only about a quarter have circulations between 50,000 and 500,000, and fewer than 5% of U.S. dailies have a circulation greater than 500,000. On the average, a daily newspaper serves a market of 163,000 persons within an area of approximately 3000 square miles (the median area served is 1600 square miles) (see Picard and Brody [64]). The combined circulation of all daily newspapers in the United States has decreased from 62.2 million in 1980 to 56.7 million in 1997, despite a significant decrease in the number and circulation of evening papers [80]. For an overview of the structure of the newspaper industry, see the informative books by Picard and Brody [64] and Thorn and Pfeil [82]. For an economic or international perspective, see Lacy and Simon [52] and Dunnett [27].

In certain countries, the distribution of newspapers may be integrated with other printed materials, notably magazines and some low-price paperbacks. Describing the German wholesale distribution problem for newspapers and magazines, Dillmann, Becker, and Beckefeld [26] stated that the problem involves more than 200 publishers that deliver products to 96 wholesalers who supply 110,000 retail outlets on a daily basis. In this problem, each wholesaler operates as the sole supplier for 3000 different items (titles) in the wholesaler's region. These authors also estimate a delivered value of DM 9 billion for a German wholesaler of magazines and newspapers. The cost of printed goods is approximately DM 6 billion per year, while the overall delivery costs for this operation are estimated at DM 150 million, or 2.5% of the cost of goods sold. The overall wholesale distribution involves about 3000 vehicles that cover 150 million kilometers to deliver a total volume of about 3000 metric tons of press.

Based on data collected for 1978–1990, Stanley [79] reported that the circulation expense as a percent of the total expenses of a newspaper averaged 10.5% to 13.3% over this period, depending on the size of the paper (smaller percentages are associated with the smaller papers). In all size categories, this percentage has decreased (over time) for all size categories.

Before turning to the distribution of newspapers from the printing sites to the ultimate readers, a brief review of industrywide challenges may help set the stage. After a long period of relative stability, the newspaper industry is facing unprecedented challenges. First, direct marketing has been capturing an increasing portion of the advertising dollars. In 1990, the estimated annual advertising expenditures in the United States in direct mail was slightly more than 72% of the $32.28 billion spent on newspaper advertising; this had grown to almost 90% by 1996, when newspaper advertising totaled $38.4 billion [2].

Second, projecting into the future, newspapers must respond to challenges of customization. Advertising forms the main source of this pressure as advertisers move from blanket distribution to focused targeting of households informed by more refined market segmentation and consumer profiles. One example of customization is greater emphasis on zoned editions. A *zoned edition* of a newspaper is produced with special contents aimed at a distinct region that do not appear in other editions of the paper. Customization also may be driven by content alone. *The Roanoke Times* (Virginia) was reported to be considering the removal of stock listings from the daily newspaper. Instead, this firm would deliver a 20-page tabloid only to those subscribers who require it and are willing to pay the additional tabloid subscription fee (see Burks [14]). In the early 1990s, the ability to target newspaper contents at a fine level (*microzoning*) was considered as imminent, but this promise has not been realized (see Memmott [59]). Nonetheless, as Gauldin [36], Ostrofsky [62], and Siebert [75] described, there is software that allows targeted marketing at zip-code level. Although this software does not perform routing, it allows the distribution personnel to calculate the load on each route and its composition (the multiproduct manifest) based on consumption patterns.

A third challenge is the significant shift in the nature of the carrier force. In the past, youngsters delivered papers to 50 homes by foot or bike; today's typical carrier is in his or her mid-thirties and delivers a variety of products to 400 homes per day. To make the routes more financially rewarding to the carrier, some firms have moved toward a broader mix of delivered products. Burks [14] reported how *The Roanoke Times* significantly increased the mix of the products delivered by its carriers. According to Burks, in March 1991, the metropolitan carrier for *The Roanoke Times* delivered about 1.4 million papers. In March 1995, it "delivered the same number of newspapers, plus 110,000 Express Lines, 85,000 telephone directories, 80,000 Pinpoint Plus coupons, 54,000 magazines, 32,000 department store flyers, 20,000 *Wall Street Journals*, and 113,000 market saturation pieces" [14].

A fourth challenge involves the rise of new media channels in the information marketplace. Media ranging from web-based information services to interactive TV threaten to become formidable competitors as information providers. This multiplicity of channels has caused newspapers to examine how they can defend their position as the "primary information provider, regardless of the pipeline" (Consoli [22]).

Presenting a strategic plan for the industry for the Newspaper Association of America, Consoli [22] set forth a list of six technical challenges faced by the industry. At the top of the list is the ability to target advertising to specific demographic and geographic audiences. This is followed by technology that would support the delivery of news and advertising through new media channels. The first priority involving targeting reflects the challenge of mass customization in the newspaper industry. To cite one example, Ostrofsky [61] described a futuristic scenario whereby each customer receives a customized version of the newspaper providing the news and contents of special interest to the customer, containing the advertisements and inserts tailored to the demographic segment to which the customer belongs, and leaving out the contents or sections in which the customer has no interest.

Clearly, another trend that easily lends itself to customization is the use of digital newspapers. Since this option eliminates the need for physical distribution altogether, we do not discuss it in this chapter.

10.4.2 Newspaper Distribution Problem

Broadly defined, the *Newspaper Distribution Problem* (NDP) involves the downstream movement of newspapers from the printing presses into the hands of the readers. A major metropolitan morning paper in the United States has the daily task of handling several hundred thousand newspapers in multiple editions to subscribers at both homes and businesses. For some leading Asian newspapers, this number goes up to millions of copies.

The operations of a daily newspaper follow a deadline-driven cycle that is repeated daily, 365 days a year. The following description of this cycle is from Picard and Brody [64]. For a morning paper, the cycle starts after dawn when the editorial employees report to work. By 10:00 a.m., the newsroom comes to life as the assignments for the day take shape. While the reporters leave the office to cover events and to gather materials, the business operations, particularly circulation and advertising, continue throughout the 8-hour work day. By midafternoon, reporters return from their assignments and start crafting their stories, and by early evening the editors finalize the news budget. As the evening progresses, various sections are completed and sent to production in ascending order of importance, saving the front page for the end. A few pages are withheld for late-breaking news and sports events (for instance, coverage and results of night games). The bulk of the contents must be ready for placement on the presses at least 1 hour before printing time.

From the perspective of production and distribution, the cycle starts at midnight, when press operators start rolling the presses. Printing may continue until 4:00 a.m., depending on the circulation and capacity of the presses. As papers come off the press line, they are bundled and placed in trucks for delivery. In a large metropolitan area, trucks begin their trips shortly after midnight; in a smaller geographical area, they may not depart until an hour or two later.

If we consider the process flow from the presses to the customer site, the newspaper goes through several operations that are generically captured in Figure 10.5. The production may be divided into three steps: printing (at the presses), inserting the advertising supplements, and bundling for delivery. The inserting step used to be performed manually but now calls for sophisticated automated mechanical equipment. This step can easily be the bottleneck step limiting the production. Similarly, conveyors and feeds may be used to carry the papers directly to the docks, where the trucks are loaded. The number of docks may be limiting, thereby delaying the dispatch of trucks. The loading and dispatching decisions interact in two ways. First, the desired start time for a truck's route determines when the truck should be loaded. Second, the demand on the route governs the amount loaded onto a truck, as well as the mix of products.

The delivery operation generally involves two legs: from the presses to transfer points (which can be drop-off points, the location of the news agents, or newspaper racks), and from the transfer points to the ultimate customer. We use the term transfer point in a generic sense to mark the point at which the responsibility for the delivery changes hands. In some cases, additional work (sorting or packaging) is performed at the transfer point before release of the goods to the second stage. Most of the routing studies reported in the literature focus on the first leg of the distribution problem. Nationwide, circulation ensures that the paper arrives at the residential customer's doorstep before 6:00 or 6:30 a.m., in time to be read at breakfast.

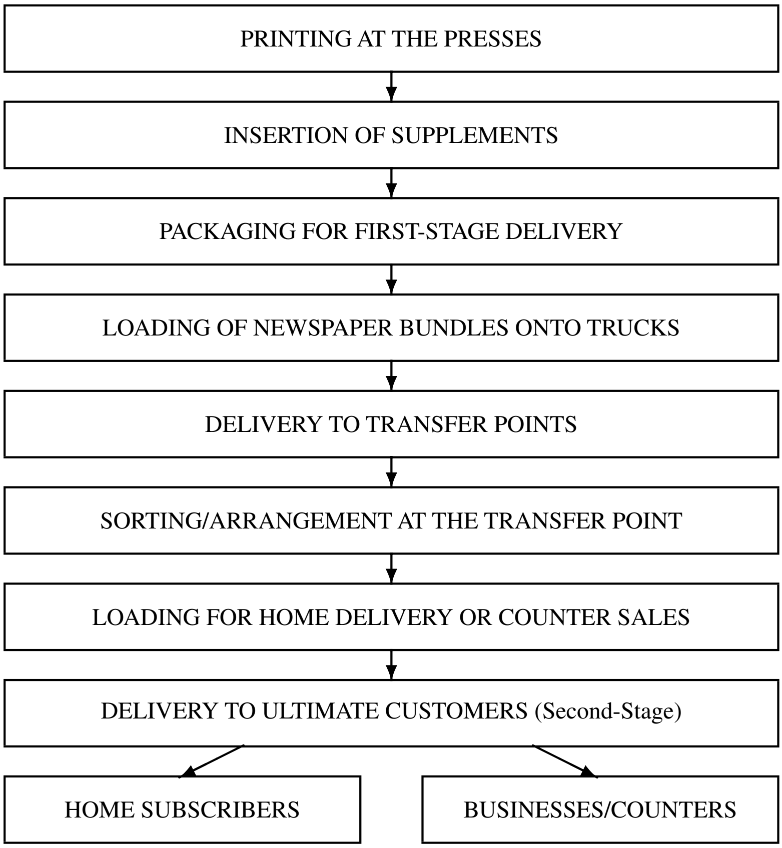

Figure 10.5. *Process view of newspaper production and distribution.*

From a distribution perspective, newspaper delivery has a number of characteristics that complicate the routing and require special handling beyond the simple delivery operation captured by the standard VRP. Below, we list and discuss these distinctive features of the distribution problem.

Multiple Commodities. Newspapers often are printed in multiple editions, which may differ in news and editorial content (early and late morning editions), or in the run of advertisements, or in the mix of inserts. Holt and Watts [46] mentioned an air edition for remote places, a country edition for rural areas, a home edition for the metropolitan regions, and a late city edition for an Australian paper. However, they noted that earlier editions are printed and dispatched before the home edition starts. It is therefore important to assess the extent of coupling between the various editions. When editions that differ in content and advertising are distributed in the same time frame, then the multicommodity nature of the product assumes greater importance, especially as the pressure of customizing the delivery to different geographic or demographic profiles increases.

Hierarchical Distribution Problem. Newspaper delivery often involves two or more distinct stages. The main first step is from the production facility to the transfer points. As Hurter and Van Buer [47] noted, some larger papers may have an additional layer of distribution centers so that the first movement of the papers is from the printing facility to the distribution centers. We can regard transfer points as bases (or secondary depots) from which the retail delivery routes fan out. The NDP can therefore be viewed as a hierarchical routing problem. If we include the choice of locations for the transfer points in the overall problem, then NDP becomes a location-routing problem.

Time Windows. Since newspapers are a perishable commodity, timely delivery is important. The challenge of newspaper delivery is to work with tight time windows. In home delivery, for instance, the paper must be delivered before the household members leave for work. As commuting times increase (due to more remote suburbia or increased congestion), this window shrinks for the delivery operation. On the other hand, the earliest time a delivery can be made is governed by the start time of the presses, which editors wish to delay as much as possible to capture the latest news. Thus, the time horizon for delivery is defined from the start time of the presses to the last allowable delivery time to the customer. As Holt and Watts [46] put it: "It has been said that if the Home Edition went to press an hour earlier, all the distribution problems would be solved immediately." Although this statement oversimplifies the issue, it does point out the crucial impact of press time on the design of routes. As the total allowable time for delivery becomes more constricted, the size of the required fleet can be expected to increase. As discussed below, the number of vehicles required for delivery is often the key cost driver.

Nature of the Demand. We mentioned that, in the future, the demand for newspapers can be considerably more customized. However, even for standard versions of the newspaper, the demand exhibits variation by day of the week. The demand for Saturday and Sunday papers typically is different from the weekday demand, and other seasonal effects may be present as well. In delivery planning, the size of the demand plays an important role. Weekend papers are significantly larger, and in some cases, midweek advertising (on Wednesdays, for instance) can increase the size beyond that of other weekdays. At a minimum, one may expect these effects to result in different routes for Saturday and Sunday delivery.

Interaction Between Production and Distribution. An interesting feature of the NDP is the interaction between production planning and the distribution component. For a large newspaper, presses generally run for several hours. As the printing progresses, trucks are being loaded and dispatched. Generally, the newspapers for the remote centers (which have the tightest due times) must be printed and dispatched first. This suggests sequencing production by the geographic locations of the transfer points. On the other hand, the desired production sequence is one that minimizes the set-up and changeover times for production. The two sequences geared to the production and distribution economies may be quite different; following either one in isolation is suboptimal. In theory, in the presence of demands for multiple commodities (defined by different editions, contents, and inserts) at each transfer point, one can think of the optimal production sequence as the one that minimizes the sum of production and distribution costs, a problem that is likely intractable.

In practice, one has to devise a production schedule that offers a compromise between production economies and the vehicle scheduling requirements.

Production Rates. Since trucks are dispatched as soon as they can be loaded with the required bundles, the rate of production (number of papers per minute) is an important parameter in determining the planning horizon. Often, the limiting factor determining the production rate is not just the speed of the press but that of the automatic inserting equipment.

Vehicle Fleet and Capacities. The fleet needed to provide the first stage of transportation may involve vehicles of different sizes and capacities. A number of applications fill vehicles to capacity, making it an important parameter of the problem. Different studies report capacities ranging from 3400 newspapers for a 1-ton van (see Hurter and Van Buer [47]) to 10,000 newspapers for a large truck (see Sciarrone [73]).

10.4.3 Vehicle Routing Algorithms for NDP

To our knowledge, the first systematic application of vehicle routing to newspaper delivery reported in OR publications was in the work of Golden et al. [38], concerning the *Worcester Telegram*, an evening paper with a circulation of 92,000 within the city of Worcester, Massachusetts. The authors were able to decrease the number of routes from 20 to 13, reporting an average utilization of 67% across the fleet. Since that study, a number of more detailed reports on routing for newspaper delivery have appeared in the literature. Table 10.9 summarizes the application environment of each study and compares some key input parameters. In the following, we highlight the key features of these applications and the role played by the routing algorithms.

Sciarrone [73] describes an application of vehicle routing that is similar to Golden's study. It involves the distribution of the daily newspaper *La Stampa* in the metropolitan area of Turin from the central office of the paper to 400 newsstands over a period of 90 minutes. The demand at each newsstand is assumed to be known, and some newsstands have one-sided time windows. However, the overall demand for the paper is subject to variation. For instance, the daily number of papers distributed averaged 120,000 in 1986 but could reach 160,000 depending on the day of the week and the events reported. A fleet of 15 vehicles is used, and each vehicle holds a maximum of 10,000 papers. Possible breakdowns in the printing process could cause the available delivery time to shrink. Since the problem is essentially a single-depot VRP with one-sided time windows, Sciarrone described an algorithm that consists of an insertion heuristic, followed by a 2-opt improvement step, implemented in Pascal to run on a personal computer. The solution technique reduced the number of vehicles used from 15 to 13, produced savings of 7% in the travel time, and created more balanced routes.

The studies by Holt and Watts [46] and Hurter and Van Buer [47] add an important element to the analysis: both explicitly considered the interaction between the routing and production decisions. Holt and Watts [46] described a routing system used to develop routes for the morning newspapers of three different companies in three Australian cities. The system constructs routes that deliver the papers from the printing facility to the news agents (see Figure 10.5) by developing routing and dispatching schedules simultaneously.

Table 10.9. *Key characteristics of selected ND studies.*

Source	Hurter and Van Buer [47]	Ree and Yoon [66]	Sciarrone [73]	Holt and Watts [46]	Jacobsen and Madsen [50]
Paper	Unidentified morning paper	Hankook-Ilbo	La Stampa	Three different firms in Australia	Two Danish morning papers
Distribution area	Metro area in midwest	Seoul metro area	Turin metro area	Three different cities	Western region of Denmark
Circulation	37,000	1,150,000	120,000–160,000		150,000
Transfer points (Number & type)	513 drop-off points	250 local centers	400 newsstands	1000 news agents	42 transfer points
Production rate	18,000 per hour	4 truckloads per hour			1000 per minute
Fleet size	14		15	23 to 35	26 trucks
Vehicle capacity	1,000 papers		10,000 papers		12,000 papers
Time constraints	Delivery to drop-off points by 4:30 a.m.	Delivery to centers during 1:30–4:00 a.m.	Maximum route duration of 1.5 hours	Route durations of two hours	Delivery from 8:45 to 11:30 a.m. (2 stages)
Special features	Multiple editions. Zoned delivery regions. Interaction between production and routing.	Work takes place at local centers before second leg begins. Multiple deliveries to same site allowed.	Open tours end at the last delivery point.	Interaction of routing and dispatching is key.	Two-stage distribution problem. Location of transfer points may be chosen. More than 4500 sales points served by secondary routes.

The interaction between loading and routing decisions, as described below, is a feature that is specific to the NDP.

To develop a set of routes, the algorithm starts by placing each customer on a separate route initially. It then combines routes seeking to reduce the total number of routes and the distance traveled. Within each route, a 2-opt procedure is applied to improve distance. At each stage, partially developed routes are combined with a dispatch order and checked for feasibility (with respect to time windows). In particular, the procedure computes a critical time that equals the latest time the route can start and still meet its deadlines. These times are used to determine the loading sequence at the dock: whenever a dock is released, the truck with the earliest critical time is selected to start loading. The authors provided some indicators of savings achieved. In one problem, the number of vehicles was reduced from 35 to 30 on weekends, and from 28 to 23 on weekdays. In another exercise, the algorithm produced a savings of 8% in distance traveled compared to routes already refined by the dispatchers. In another application, the procedure allowed the company to cope with an increase of 20% in the paper size (100 pages increased to 120) without requiring additional trucks. We should note that using an entirely different methodology, Han [44] also addressed optimal sizing of districts and vehicle size for home delivery.

Hurter and Van Buer [47] described a comprehensive study of the NDP for a morning paper that serves a midwest metropolitan population of 80,000 plus its semirural surroundings. The circulation figure of 37,000 for this paper includes 33,000 home subscribers. The production rate is 18,000 newspapers per hour. The limiting operation governing this rate is the speed of the inserting and folding equipment. By contrast, the press itself prints at the rate of 55,000 papers per hour. The presses begin at 1:30 a.m. and complete the printing by 3:30 a.m.

The distribution area fits within a rectangle 25 by 12 miles, with most of the demand concentrated within a metropolitan area 6 by 3 miles. The distribution problem has two levels: from the printing facility to the transfer points (called drop-off points) and from each drop-off point to the customer homes. There are 513 drop-off points, and each corresponds to a home delivery route. To carry out the distribution, the firm uses a fleet of 14 1-ton vans, each with a capacity of 3400 papers. On average, each van visits 37 drop-off points on its route.

The newspaper in this application has multiple editions, so that the distribution involves multiple products, and switching between two editions involves set-up at the printing press (typically 5 to 10 minutes per switchover). However, in addition to set-ups, the production plan must also consider the loading sequence since vans that are loaded and dispatched to the distribution centers must deliver the product mix required by the areas served by the vans. When loading a given van, the correct mix of editions should be available from the printing press based on the needs of the areas served by the van. Because of time constraints, the firm prefers to load vans destined for the furthest distribution centers first. The problem is therefore best viewed as a combined production-distribution problem because the production and loading decisions interact.

The routing problem addressed in this study is a VRP with time windows. The set of routes designed for the vans must visit all drop-off points by about 4:30 a.m. The objective is to minimize the number of vehicles required. As mentioned, the problem has multiple products and each product is distributed only within certain designated geographical zones (there are seven zones). Initially, the authors assumed that each van is loaded with a single product. Under this assumption, the problem decomposes into separate routing problems by product (over the relevant zones). In each zone, the authors first construct a grand tour through all drop-off points and then partition it into a number of routes for single vehicles. Finally, they check the time constraints to ensure that the delivery windows are met. To check route feasibility with respect to time, the route start time is required. This, in turn, depends on the completion time for the loading of the van, which is computed from the production schedule. If infeasibilities arise, the production schedule is altered until a consistent production-distribution schedule is found.

The next step of the distribution procedure is to relax the zoning constraints. In this phase, one attempts to combine adjacent zones for a vehicle that has slack capacity. This relaxation stops short of allowing a vehicle to possibly visit all zones. But, as the authors point out, as one traverses zones, a greater number of dissimilar products are assigned to the same vehicle, and since these products are generally produced at different times at the press, the route start time is delayed. Combined with the additional travel time of crossing zones, the route will rapidly bump against the time windows governing deliveries.

Hurter and Van Buer established a base case by replicating the company's routes before any improvements. This base case uses a fleet of 14 vehicles with a pooled utilization rate of just under 75%. However, while there is slack capacity, four routes violate the delivery deadlines. The improved solution obtained by using VRP techniques saves two vans and reduces the total combined duration of all routes by 24%. An interesting feature of this study is the sensitivity analysis conducted for some key parameters. For instance, it was found that if the limiting production rate can be increased by 33 percent (from 18,000 to 24,000 per hour), the number of tardy routes can be reduced to one (from four in the base case). Similarly, a reduction of the time required to unload the paper at a drop-off point from 40 to 30 seconds reduces the number of tardy routes to one. Finally, a solution requiring only 11 vans is available if two zones are combined.

While the preceding two studies sought to coordinate production and vehicle schedules, Ree and Yoon [66] tried to overlap routing with work performed one step downstream at the local centers. Their work studied newspaper delivery for Hankook-Ilbo, a Korean newspaper that ranks among the top-40 largest dailies in the world with a circulation of over 1.15 million. In the Seoul metropolitan area, this paper has three main printing facilities that also serve as distribution centers. We call these the main centers or depots interchangeably. There are also 250 local distribution centers that serve as the transfer points for the second stage of distribution. The delivery planning problem is focused on the first stage of the distribution spanning the delivery of papers from the printing facilities to the local centers. The objective is to minimize the number of trucks used within the available time horizon.

Since papers are printed between 1:30 and 3:30 a.m. and deliveries to the local centers must be completed by 4:00 a.m., the relevant time horizon for routing is approximately 2.5 hours. An interesting feature of this problem is the use of split deliveries that allows the distribution and sorting activities to proceed in parallel rather than in a strictly sequential fashion. Here, the sorting activity takes place at the local centers and involves the preparation of the newspapers for home delivery by the carriers, an activity called arrangement by Ree and Yoon. Since this sorting time at the local centers is significant, the firm makes multiple (partial) deliveries to each local center. In this way, the local center can start the arrangements on the initial partial deliveries while papers are still being printed and delivered. The specific decisions addressed by Ree and Yoon are as follows:

1. Decide which main center (or depot) serves each local center.
2. Determine the number of trucks trips needed at each main center and their departure times.
3. Construct the delivery route for each truck, and determine, for each trip, the delivery quantity (number of papers) at each local center.

The authors used a two-stage procedure to make the preceding decisions. The first decision is similar to the clustering performed in assigning stops to depots in a multi-depot problem. The authors solved this as a Generalized Assignment Problem (GAP), where the printing capacities for the main centers provide the right-hand sides of the demand constraints. Once the GAP is solved, the problem decomposes (by main center) into decoupled single-depot problems. Moreover, by dividing the total demand assigned to the center by the vehicle capacity, the authors obtained an estimate of the number of truck trips originating at that center, thereby partially addressing the second decision. In the second stage of their procedure, Ree and Yoon addressed decisions 2 and 3 as follows.

Consider the distribution center as a depot from which K trucks originate to visit n delivery sites (these sites correspond to the local centers) as in the VRP. For each of the K trucks, one must decide the time the truck leaves the depot and the amount it delivers to each of n delivery points. Ree and Yoon restricted the delivery amounts to half or full loads, so that each truck delivers either half or all the demand at a delivery site if it visits the site. This allows the problem to benefit from split deliveries but controls the growth in problem size by considering only half-loads (rather than more general fractions of the site demand). The objective function for the VRP is the weighted total lateness at all sites, weighted by the site demands.

To solve this problem, they build routes sequentially by using a seed that is the most distant point from the depot and clustering the points near it until the truck capacity is exhausted. Next, they sequence each route and compute the time the route visits its last site. If demands of all sites are satisfied within the delivery deadline, this solution is accepted. Otherwise, the procedure combines a route that violates the deadline with a neighboring route and considers delivering half-loads. By shrinking the delivery times due to the smaller load, this last step effectively reduces the longest completion time by constructing more balanced routes. Finally, simulated annealing is used to improve the solution. Although the authors illustrate the possible improvements with an example, they unfortunately do not provide indicators of how the procedure produced savings in the actual newspaper delivery problem.

The last two studies of this section, performed in Denmark and Germany, consider problems of broader scope involving the full hierarchy of distribution stages in newsprint delivery. Jacobsen and Madsen [50] studied a location-routing problem for a newspaper delivery problem in western Denmark. In their study, two competing papers share production and distribution facilities. The combined daily circulation is 150,000, and the daily distribution cost was 35,000 Danish Kroner.

Small trucks are used to transport the papers from the printing facility to 42 transfer points dispersed over an approximate area of 200 by 300 kilometers. At the transfer points, the newspapers are loaded onto vans or cars that make the final deliveries to the 4510 points of sale (or customer sites). Typically, a truck visits 1 to 3 transfer points. Each transfer point serves as the base for five tours that visit 24 sites. The newspapers all must arrive at the customer sites by 11:30 a.m. The printing operation therefore runs from 6:15 a.m. to 8:45 a.m.

The objective of the hierarchical location-routing problem (see Madsen [56]) is to minimize the total distribution cost by deciding on

- the number and location of the transfer points,
- the primary routes feeding the transfer points out of the printing facility, and
- the design of the secondary routes based at each transfer point to feed the customer sites.

Jacobsen and Madsen [50] compared three heuristics that solve this problem. We do not describe these here, but we summarize how the solutions compare for costs. Let TCP and TCS denote the travel costs (based on mileage only) for the primary and secondary tours, respectively, and let FCS be the fixed costs for the secondary tours (these costs are proportional to the number of secondary tours). The other cost component is the cost of visiting a site, which is simply proportional to the number of sales points and therefore fixed in any solution. Together, these four cost components account for more than 90% of the total distribution cost. As shown in Table 10.10, the two algorithms ALA-SAV and SAV-DROP produce solutions comparable with the baseline in total costs (1.2% above and 1.7% below the baseline costs, respectively), but they differ significantly in the relative magnitude of TCP and TCS. This is because SAV-DROP opts for a substantially lower number of transfer points.

The application described by Dillmann, Becker, and Beckefeld [26] has a somewhat different focus from the preceding studies. In their applications, the distribution problem involves 200 publishers that produce a variety of printed materials. In fact, the distributed goods include magazines and inexpensive books, in addition to daily newspapers (which form only a fraction of the total volume of goods). The customers' locations of interest are retail outlets, deliveries to which are subject to one-sided time windows. The delivery volume changes by day of the week; Tuesday deliveries form 12% of the weekly volume while Thursday amounts to 23%. There is also a significant backhaul component: about one third of the delivered goods are returned to the wholesaler on a daily or weekly basis.

The authors describe the scope and challenges of the routing study performed for this application. The VRP algorithm employed is a parallel tour-building procedure in which the customer sites are successively inserted into the partial routes in ascending order of their opening times. A minimum insertion cost rule is used. The authors do not report the magnitude of the savings achieved, but they note that a major contribution of the study was to move from a route structure based on geographical clustering to one that gave primary importance to time constraints.

10.4.4 Three Case Studies

We now present three case studies to illustrate certain practical details of newspaper distribution and the role of routing software as a tool for planning and operation. We refer to these newspapers by fictitious names. As described below, these case studies refer to two

Table 10.10. *Comparison of cost components for the hierarchical NDP. (Cost ratio is the total cost of each solution divided by the baseline total costs.)*

Solution	TCP	TCS	FCS	Cost ratio
Baseline	17.6%	17.40%	35.95%	1.000
ALA-SAV	15.5%	16.96%	40.59%	1.012
SAV-DROP	8.1%	22.65%	43.14%	0.983

large dailies in the United States and one European operation. All three companies are involved in residential and commercial newsprint distribution over wide geographic areas. We emphasize that the names used have no relation to actual publications with similar names.

10.4.4.1 Two Newspaper Delivery Problems in the United States

The Morning Courier (MC) is a daily newspaper distributed in a major metropolitan area and its surroundings. Its subscribers, which involve both residential and business addresses, are served by more than 2000 delivery routes. The routing problem faced by MC has both node and arc routing components. A distinctive feature of this application is the notion of delivery types associated with routes. Because the deliveries of this paper can be quite concentrated in certain regions, such as downtown, a route may correspond to the papers destined for a single office building or an apartment complex. Accordingly, in addition to the physical location of the delivery site, the type of the delivery made is of utmost importance in planning the routes. The delivery types are divided into a number of categories:

- *toss*—a bundle is simply deposited at the site;
- *doorman delivery*—a bundle is delivered to the doorman alone, as in a hotel;
- *doorman up*—a doorman lets in the delivery person, who is responsible for the work; and
- *gates*—involves a delivery to a gated community.

MC is completing the change from a compensation formula based on total miles driven and the number of deliveries to a scheme that considers the types of deliveries made on each route. Since the delivery type determines the service time at the site (the amount of time spent at the site to make the delivery), it becomes economically important for the paper to capture the mix of deliveries on each route. Moreover, since the route duration is key to the design of balanced routes, the service times form important input to the routing system.

In its metropolitan distribution area, MC faces a two-stage distribution. as described for the generic NDP. By 3:00 a.m., the newspaper bundles are delivered from the presses to approximately 50 depots that serve as the transfer points from which the individual carrier routes originate. Typically, more than 50 routes are based at a depot. The routes begin around 4:30 a.m. but all deliveries must be completed by 6:30 a.m., leaving an interval of 2 hours for the routes. As mentioned, the desire to capture late-breaking news induces the paper to delay final printing, thereby compressing the amount of time available for distribution. The objective of the routing problem is to redesign the routes to save the number of routes used in the tight time horizon available for delivery.

In the last 2 years, MC has directed its attention to route adjustment. This activity is performed regularly when routes need to be realigned or adjusted for better balance. For example, one may decide to merge three shorter routes into two full ones. It is crucial that the routing system and the associated GIS support this activity even if the candidates for adjustments are already selected. To appreciate why, one needs to understand the structure of the data files for newspaper distribution.

First, a key component of the system is the street file, which contains the address for every subscriber and the route to which this subscriber is assigned. In effect, route planning involves the assignment of a given street address or range of addresses on the same street to a specific route. Suppose the dispatcher has determined to move five subscribers from Route A to Route B. Because the assignment to routes is stated in terms of street segments (this is a case of arc routing), not only the customers but the entire street segments on which these customers lie must be transferred from A to B. This change must be entered into a delivery file that shows street names and specifies the route each address range is currently assigned to. Moving customers from A to B will, therefore, result in a change of the route number field for all address ranges corresponding to street segments on which the reassigned customers reside. For instance, if a cul-de-sac abuts the street segments to be moved, the GIS capabilities of the system must detect the cul-de-sac and move it onto Route B although it contains no subscribers.

The carriers operate from a route manifest that lists all the subscribers who must be visited on the route. For the carrier's convenience, the list starts with deletions and highlights the new subscribers added to the route. Deletions and additions may result from shifts in demand or route adjustments, but the list of active subscribers is dynamic by nature. For example, subscribers often put a stop to their home deliveries for periods of 2 weeks or longer. Thus, changes in the delivery list occur on a daily basis. The routing system is run in batch mode daily. Between 2:00 and 3:00 a.m., a list of all subscribers to be routed for that day is prepared. The new customers are geocoded and entered into the GIS for the routing system. The system then processes the routes one at a time, solving a travel path problem to arrive at the sequence in which these customers should be visited. This travel path algorithm makes full use of the information on the street network available in the GIS. For example, it includes turn penalties and can accommodate various modes of traversing the street segments. The system then prints out travel directions that are handed out to the carrier for that route. The information on the route is saved locally at the depot. If new customers arise, they can be inserted onto an existing route locally. Typically, it takes less than 10 minutes to process 60 to 70 routes based at a single depot.

Periodically, the planner may consider reconfiguring several routes together. In this case, the pooled set of subscribers is fed into the routing system to solve a VRP. This problem is solved as a node routing problem, but the system is careful to present the final output in terms of traveling along street segments.

The Union Dispatch is another large newspaper based in the United States. However, the deliveries of this paper are much sparser than those of *The Morning Courier*. In fact, the number of delivery addresses on each street segment is actually quite small for *The Union Dispatch* so that the delivery problem is best viewed as a node routing problem. Another difference between the two papers is that while the cost function for MC is largely driven by the delivery times, the objective of the *Dispatch* is to reduce the total number of miles driven. The paper has used routing software in selected regions for the last 6 years and continues to refine its delivery operation by expanding the number and size of regions where computer-assisted routing is used.

On a daily basis, the dispatchers download the customer set for a region to a central location. This customer list already has an assigned route number. The software is then used to geocode the customers and to determine the best sequence for visiting them on the route. The dispatcher also heavily uses the interactive features of the system to make changes in the routes. For the most part, therefore, the dispatcher uses the system's algorithmic capabilities to modify routes, one route at a time. Decisions about moving customers between routes or splitting routes are made by the user interactively. Naturally, the routing system provides a highly convenient visual interface and good database support with which to carry out these interactive changes.

10.4.4.2 Case Study from Europe

Euro Press (EP) publishes and distributes newspapers and other publications in a European country. The distribution area is highly residential, making the problem an arc routing problem, generally with two-sided service of the street segments. Accordingly, this firm has devoted much effort to developing extremely detailed street maps, incorporating more detail than in either of the last two applications. For example, the distribution department explicitly models walkways to houses as separate entities in the street network, making it one of the most detailed geographic databases we have encountered in routing applications.

EP uses both driving and walking routes. Both start around 4:00 a.m. and delivery must be completed by 6:00 a.m. In the driving routes, the main delivery activity is to place the paper in the customer's paper box. Interestingly, to service both sides of a street segment in this mode, the vehicle must traverse the street twice, each time against the normal direction of the arc, so that the driver can have direct access to the boxes along the curb. In the walking problem, the routes are designed for newspaper delivery individuals who deliver the paper by walking along the streets. Since, by law, there is a maximum weight that this person can carry, a new supply of papers must be picked up at various points along the route. These *relay points* are predefined locations where the paper is stored, and the route must ensure that the carrier ends up near a relay point whenever the carrier's supply of papers is exhausted. In this sense, this problem is similar to the *relay box problem* for postal delivery (see Assad and Golden [7]) except that the focus is on the design of the routes, not on the location of the relay boxes.

The objective of the walking problem is to minimize the distance traveled, because pay is based on this distance. The routing system is used to plan the routes by partitioning the service area into a collection of balanced routes. The system then specifies a travel path for each route. Generally, each route covers a distance of about 5 miles and takes less than 2 hours.

EP also has a node routing problem that is linked to the preceding component. At the beginning of the work day, the newspaper carriers may report to work at a central location (the depot) or be available for pickup at a given location. Vans must pick up this delivery personnel and transport them to the starting points of their routes (already determined by the preceding route-planning procedure). This defines a node routing problem for the operation of dropping off the carriers. It is advantageous to include the dropping off of newspaper bundles (at stands, for instance) into the same delivery problem. The vehicle routing problem is to route the vans through these drop-off points.

10.4.5 Further Remarks

The preceding case studies give some indication of the role of routing software in newspaper delivery. The availability of integrated routing–GIS software has made route adjustment a frequent exercise that would have taken the unaided human operator a prohibitively long time. As we reflect on the evolution of newspaper delivery routing, we can draw a distinction between planning and operational systems. Most delivery systems dating from the 1980s appear to have used routing capabilities primarily for planning purposes. Operational adjustments and modifications to existing routes often were made manually, and the routing systems did not provide the extensive interactive capabilities required for newspaper delivery operations as outlined in the preceding case studies. A key factor in making newspaper delivery systems operationally viable is the integration of routing and GIS software.

Although general-purpose GIS software was emerging in the late 1980s, few GIS vendors targeted routing applications (notable early exceptions were Caliper Corporation and Roadnet Technologies). Accordingly, until the mid 1990s, the newspaper delivery applications we reviewed all relied on road distances expressed as a function of Euclidean distances, as discussed by Assad [6]. The current GIS capabilities make this unnecessary and provide a wealth of additional features, such as convenient maps and travel directions. In the case of newspaper delivery, the GIS capabilities can be used to model and track the nature of deliveries as well. Overall, the marriage of GIS and routing has become a must-have feature of an operational system. As confirmed by the case studies described, convenient linkages between the GIS and routing capabilities make the difference between a system that is run infrequently for planning purposes and a tool that the dispatchers rely on day in and day out.

We expect commercial software to play a larger role in the loading and dispatching operations of newspapers as well as in routing per se. We are beginning to see software designed for targeted delivery of newsprint. For routing, one well-known family of routing software lists the newspaper industry as a specific focus area (RouteSmart [69]) and advertises such capabilities as arc routing, the design of balanced routes, and reductions in the number of vehicles, distance traveled, and carrier personnel. As the use of software becomes more prevalent in the upstream operations preceding routing, we might expect to see increased integration of circulation and delivery databases.

We have already seen how zoned editions and targeted marketing can affect newspaper distribution. Two other trends are the use of third-party delivery systems and the change in the nature of the carrier force. We know of one major U.S. newspaper that is completely refashioning its routes in one of the metropolitan regions in the south to account for the use of a third-party distributor that delivers other printed materials in addition to the daily newspapers. The example of *The Roanoke Times* cited above shows how these trends can combine with the pressures of customization to make the newsprint distribution problem a significantly richer and more challenging routing problem in the future.

10.5 Conclusions

In this chapter, we reported on numerous and diverse applications of vehicle routing. These applications involve routing over land, sea, and air, and they take place in countries around the world. To narrow the scope, we focused on vehicle routing within three broad and significant industries: solid waste; beverage, food, and dairy; and newspaper distribution.

Within the solid waste industry, we identified three separate types of vehicle routing problem: commercial collection, residential collection, and roll-on–roll-off. Commercial collection problems can be viewed as standard node routing problems with several special locations (landfills). Residential collection problems can be viewed as arc routing problems that also involve landfills. Commercial software is available for handling these two types of problems. Roll-on–roll-off problems are quite different in that they involve bin packing as well as routing (and, possibly, real-time) components. Commercial software is not yet available for roll-on–roll-off problems, which are just beginning to attract research attention. We anticipate that effective solution procedures will emerge in the next several years.

On a daily basis, fleets of vehicles deliver soft drinks, bottled water, beer, groceries, and milk to many thousands of retail outlets in the United States alone. The real-world operations of fleets, with complications such as time windows and periodic deliveries, are modeled by sophisticated vehicle routing computer programs and commercial software products that are used by such well-known companies as Pepsi-Cola, Anheuser-Busch, and Kraft. Computerized vehicle routing has had a significant impact both quantitatively (e.g., decreased fleet mileage by roughly 10%) and qualitatively (e.g., improved quality of the delivery system and increased job satisfaction of routing personnel) on distribution activities in the beverage, food, and dairy industries.

Newspapers published in cities all around the world have challenging distribution problems. Circulations range from thousands to millions, and the task of getting newspapers from the printing presses to readers is always complicated by the linkage between production and distribution, tight time windows, and multiple editions. We explored these and related issues in several case studies, but further research into more advanced solution techniques would be beneficial.

It is clear that the many algorithmic advances made by operations researchers over the last 40 years have had an enormously positive effect on the field of logistics and distribution management. Based on our numerous case studies, we believe that plentiful opportunities still exist for operations researchers to contribute to this important area

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