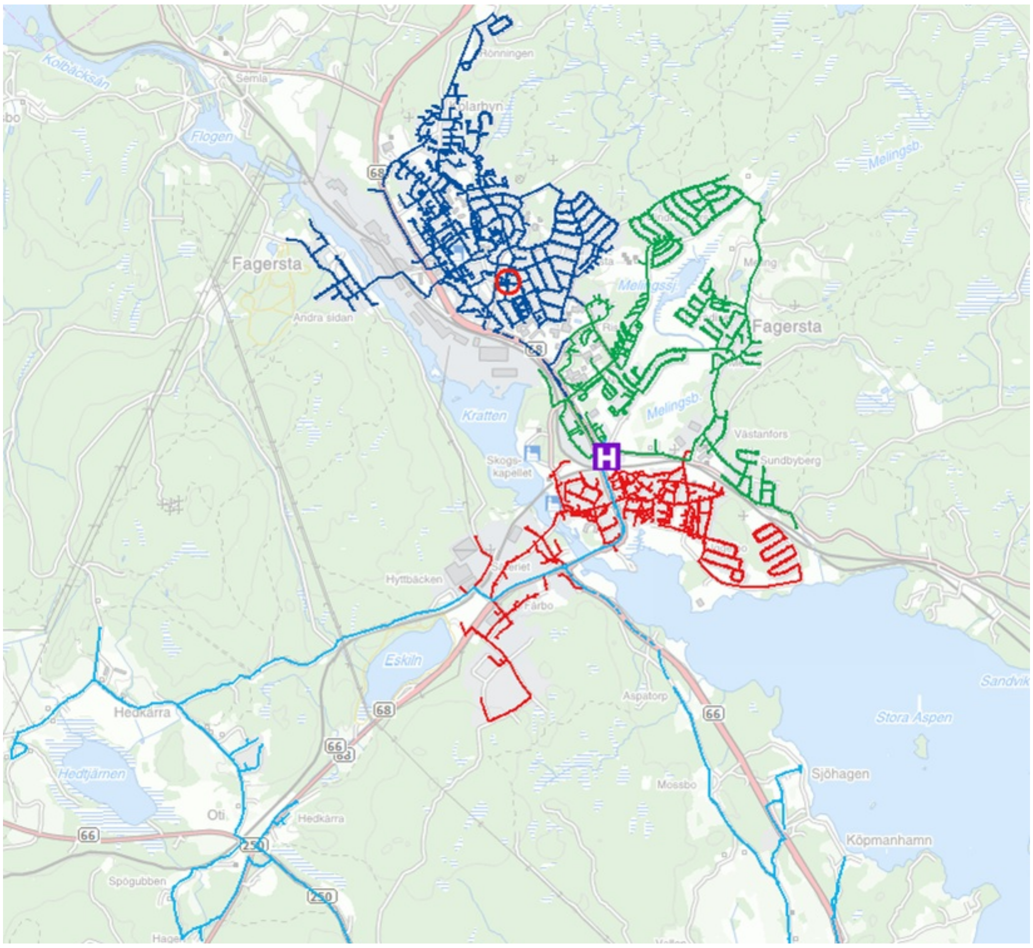
A23753- Unrestricted

Report

Routing Applications in Newspaper Delivery

Author(s)
Geir Hasle



SINTEF ICT
Applied Mathematics
2012-12-13

SINTEF

SINTEF IKT
SINTEF ICT
Address:
Postboks 124 Blindern
NO-0314 Oslo
NORWAY
Telephone:+47 73593000
Telefax:+47 22067350
postmottak.IKT@sintef.no
www.sintef.no
Enterprise /VAT No:
NO 948 007 029 MVA

KEYWORDS:
Newspaper Delivery
Arc Routing
Node Routing
NEARP
MCGRP
Application

Report

Routing Applications in Newspaper Delivery

VERSION 1.0	DATE 2012-12-13
AUTHOR(S) Geir Hasle	
CLIENT(S) The Research Council of Norway	CLIENT'S REF. 205298
PROJECT NO. 90A404	NUMBER OF PAGES/APPENDICES: 28/0

ABSTRACT
The goal of this report is to give an up-to-date account of routing applications in the newspaper business. We describe the newspaper supply chain, and focus on the "last mile" distribution that has been advocated as an application of arc routing in the literature. A literature survey is provided, followed by a discussion of the arc routing model and its adequacy to newspaper applications. A more general and normally more adequate model: The Node, Edge, and Arc Routing Problem, is discussed. Characteristics of routing problems in carrier delivery are presented, together with a case study from the development of a web-based route design and revision system. Finally, summary, conclusions, and prospects for the future are given.

PREPARED BY Geir Hasle	SIGNATURE
CHECKED BY Atle Riise	SIGNATURE
APPROVED BY Tomas Nordlander	SIGNATURE

REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
A23753	978-82-14-05310-4	Unrestricted	Unrestricted

SINTEF IKT
SINTEF ICT

Address:
Postboks 124 Blindern
NO-0314 Oslo
NORWAY

Telephone:+47 73593000
Telefax:+47 22067350

postmottak.IKT@sintef.no
www.sintef.no
Enterprise /VAT No:
NO 948 007 029 MVA

Report

Routing Applications in Newspaper Delivery

KEYWORDS:
Newspaper Delivery
Arc Routing
Node Routing
NEARP
MCGRP
Application

VERSION 1.0	**DATE** 2012-12-13
AUTHOR(S) Geir Hasle	
CLIENT(S) The Research Council of Norway	**CLIENT'S REF.** 205298
PROJECT NO. 90A404	**NUMBER OF PAGES/APPENDICES:** 28/0

ABSTRACT

The goal of this report is to give an up-to-date account of routing applications in the newspaper business. We describe the newspaper supply chain, and focus on the "last mile" distribution that has been advocated as an application of arc routing in the literature. A literature survey is provided, followed by a discussion of the arc routing model and its adequacy to newspaper applications. A more general and normally more adequate model: The Node, Edge, and Arc Routing Problem, is discussed. Characteristics of routing problems in carrier delivery are presented, together with a case study from the development of a web-based route design and revision system. Finally, summary, conclusions, and prospects for the future are given.

PREPARED BY Geir Hasle	SIGNATURE
CHECKED BY Atle Riise	SIGNATURE
APPROVED BY Tomas Nordlander	SIGNATURE

REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
A23753	978-82-14-05310-4	Unrestricted	Unrestricted

Document history

VERSION	DATE	VERSION DESCRIPTION
1.0	2012-12-13	First version

Routing Applications in Newspaper Delivery

Geir Hasle
SINTEF ICT, P.O. Box 124 Blindern, N-0314 Oslo, Norway
E-mail: geir.hasle@sintef.no

1 Introduction

Periodical news publications have been around since Julius Caesar, at the time in the form of government bulletins that were carved in metal or stone. In imperial China, "imperial bulletins" were periodically published for bureaucrats, probably as early as the 3rd century AD. Newspapers proper that were targeted at the general public and had a wide cover of topics first appeared in the early 17th century in Europe. The printing press of Gutenberg, and its further development was of course an important underpinning technology. They soon spread to major cities and to overseas colonies. Newspapers appeared in North-America in the early 18th century. The industrial revolution brought several technological innovations that reduced the printing price. The newspaper communication medium soon covered most areas of the globe.

There are several types of newspapers, depending on the range of topics, the frequency of publication, and the geographical target area for readers. They range from national and international newspapers with a daily frequency and a circulation in the millions, to weekly local papers focused on a specific topic with a circulation of a few hundred. Some have several editions per day; some have focused editions targeted at different geographical areas. Some newspapers are only sold though retailers; some are also regularly delivered directly to household and business readers through subscription.

The World Association of Newspapers and News Publishers (WAN-IFRA) is the global organization of the world's newspapers and news publishers. It represents more than 18,000 publications, 15,000 online sites and over 3,000 companies in more than 120 countries. WAN-IFRA has published a yearly report on world press trends since 1988. The following information on statistics and trends are taken from their 2010 and 2011 reports, and we refer to (WAN10) and (WAN11) for details.

In 2011, the global newspaper publishing industry produced revenue of about US$160 billion annually. Over three billion people, or 72% of literate adults worldwide, read a newspaper regularly. The global daily print newspaper circulation was around 520 million, with a total of some 15,000 titles. The global circulation reached its peak in the 1990ies, and it dropped by some 4 % between 2008 and 2011. There are, however, large differences in trends between regions. Circulation continues to rise in Asia, but declines rapidly in mature markets in the West. The latter is due to a combination of deep technological, structural, economical and cultural changes.

The major sources of revenue for modern newspapers are advertisements, sales through retailers, and subscriptions. For many years, the newspaper industry has struggled hard to meet the competition from other media and the Internet. Media consumption patterns vary widely between regions and countries, but there is a general trend towards less time spent with newspapers compared with other media, with a resulting decline in revenues. Readers have more choices, and are less faithful to newspapers. The Web and new platforms such as smartphones and tablet PCs are attractive alternatives. In many parts of the world, the younger generation by and large does not read news on paper. The newspaper industry has answered by publishing though the new digital channels, but a good business model remains hard to find. The printed circulation decline is more than compensated by the increase in digital reading, but still, advertisement revenues are dropping. Also, the new social media are changing the ways in which media content is produced and disseminated, and newspaper companies have not yet figured out how to adapt. In this climate, it is not surprising that large parts of the global newspaper business has been forced to cut costs, with fewer titles, slimmer newsrooms, and fewer editions as results.

There are large variations between countries, but on average, printing and distribution make up roughly 2/3 of the costs of running a newspaper. Distribution costs are typically 1/3 of cover price, and profits are typically slim, at best. It seems attractive to abandon newsprint and "go all in" for digital publishing, but the lower relative advertisement revenues constitute a counteracting force. Some American newspaper executives project that in five years; many newspapers will print only the Sunday edition or perhaps two or three days per week. An alternative way of cutting costs is to improve coordination in logistics, e.g., though outsourcing and consolidation of printing and distribution between newspaper companies, and though software tool based optimization (BraH13) of logistics. Another way of counteracting the decline of subscription and advertisement income is to create new revenues by utilizing the sophisticated supply chain to distribute other goods. This opportunity has been taken by many companies. It introduces even more variability and demands for agile supply chain management.

With the above introduction as a backdrop, the goal of this chapter is to give an up-to-date account of arc routing applications in the newspaper business. In section 2, we describe in more detail the newspaper supply chain, and focus on the "last mile" distribution that has typically been advocated as being an application of arc routing in the literature. A literature survey follows in 3, followed by a discussion of the arc routing assumption in Section 4. A more general and normally more adequate model: The Node, Edge, and Arc Routing Problem, is discussed in 5. The following section describes characteristics of routing problems in carrier delivery, whereas Section 7 is devoted to a case study where we describe the development of a web-based route design and revision system. We finish the chapter with a summary, conclusions, and prospects for the future.

2 Logistics for Newspaper Distribution

As accentuated by the line "Who wants yesterday's papers?" in a popular rock tune by the Rolling Stones from 1967 (JagR67), newspapers are highly perishable goods[1]. For a major, daily newspaper, large volumes of newsprint are processed in printing presses, and then packaged, loaded on to vehicles, and distributed from the print works to readers, typically in a multi-echelon distribution chain. Either, a newspaper copy is

[1] We here disregard the fact that perished newspapers have secondary utility, e.g., as wrapping for fish'n'chips.

delivered to the home of the reader via subscription, or the reader buys it from a retailer. The final delivery to subscribers is made by carriers, either on foot, by bicycle, or by car.

Newspaper logistics are tightly constrained by deadlines. Subscribers need their morning paper before they go to work. Typically, the newspaper guarantees to place a copy on the reader's doormat before 6AM. On the other hand, the demand for up-to-date news creates a pressure in the other direction: the editor would like to push the deadline as close to delivery as possible. In a time span of a few hours, large volumes of paper are printed, packed, and distributed to retailers and subscribers. Some newspapers have several editions per day, this may contribute to added flexibility, but still, a highly time and cost efficient supply chain is necessary. The guaranteed delivery time has an effect on printing, packaging, and distribution sequences: newspapers destined for far away districts may need to go first.

There are variations in the number of pages in a newspaper between weekdays due to variations in content. Volume variations are demanding for the whole production and distribution system for printed newspapers. The content driven variation between weekdays may be predictable and stable, but still require different distribution solutions for each day. The common direct marketing newspaper inserts add not only revenues, but they also increase variation in transportation volume in a less predictable way than the content variation. Modern readers have become increasingly demanding and less faithful. They move between different types of media and, if they are interested at all, want newspapers to be tailored to their needs, and delivered in their preferred way (electronically or on newsprint) at the times of their choice. Although this demand for flexibility is not necessarily fully satisfied, it has also created more dynamics that need more agile supply chain management with more frequent communication and reactive planning capabilities.

A modern, efficient newspaper supply chain is not only suitable for delivery of newsprint and direct marketing inserts. As alluded to above, this fact has been utilized by newspapers and distribution companies to add much needed revenues. Many side products are suitable, but in practice, printed products such as books, magazines, and direct mail, are most common. Again, the unpredictable patterns of product mix increase dynamics. The idea of static distribution routes that are valid for several months does not go well with this distribution of multiple products with unpredictable demand to a large share of households in a given area. In principle, new, optimized routes should be designed every day based on the actual products and volumes. However, there are conservative forces. The traditional newspaper carrier knows the route by heart and is often well known by the subscribers. She or he has a carrier's book, as illustrated in Figure 1, with all necessary delivery information that is not well suited for dynamics, communication, and interaction. The newspaper/distribution company may want to have a routing plan that covers all households in a given area, for instance for direct mail distribution. We shall return to these issues in Section 6.

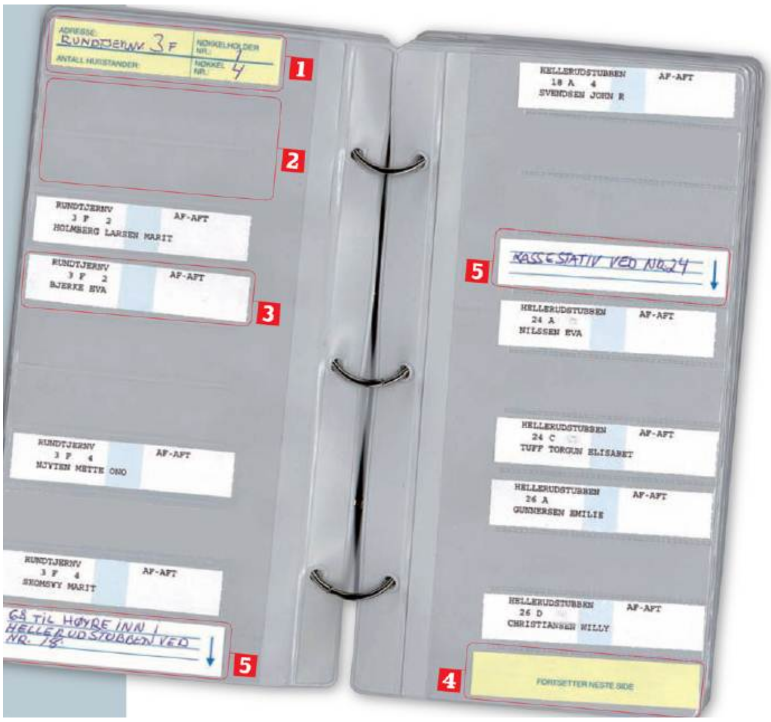


Figure 1. A traditional carrier's book with paper strip delivery information. Courtesy of Aftenposten.

When we disregard content production, the supply chain for paper newspapers largely consists of printing, packaging, first-stage delivery, and final delivery to retailers and subscribers. The time pressure, the volumes involved, and the fact that the paper must be delivered on the doormats of the subscribers, together require a sophisticated supply chain. The economic pressures and increasing dynamics require an optimized supply chain design and a high degree of operational coordination, in addition to outsourcing and consolidation of logistics between companies at the strategic level as described above.

For an earlier account of the newspaper delivery supply chain and what the authors define as the Newspaper Distribution Problem (NDP), we refer to Section 10.4 of on the classical book on the VRP edited by Toth and Vigo (GolAW02). In this section, Golden, Assad and Wasil first give an industrial background that also focuses on the serious challenges that newspaper companies started to face in the mid 1990ies. They proceed to give an overall description of the distribution chain and the NDP, broadly defined as "the downstream movement of newspapers from the printing presses into the hands of the readers", and continue with a literature survey of VRP algorithms for NDP. Furthermore, Golden et al. provide three cases studies; two large dailies in the US, and a European newspaper that all utilize routing software systems for planning and operation. Finally, they reflect on the role of Geographical Information Systems (GIS) in providing realistic time and distance information that enables VRP tools for operational planning, better GUIs with map visualization, and travel directions. They observe that some VRP software vendors begin to specifically target the newspaper industry, and foresee that commercial software will play an important role not only in routing but also in loading and dispatching decisions.

In a modern newspaper distribution supply chain, several newspapers share the same printing and distribution resources. Newspapers with a broad geographical cover may be printed in several, geographically dispersed print works. The editorial content is produced in the newsroom and sent just before (or maybe right after) the deadline to the allocated print work(s). The newspaper is printed, inserts are possibly added, and newspapers are bundled into packages with drop-off information on packing slips. For subscription newspapers that utilize the traditional carrier's book illustrated in Figure 1, route changes are printers on the packing slip. Information on new subscribers appears as new paper strips that the carrier must insert in the right places in her carrier's book to maintain a good route sequence[2].

Newspaper bundles are conveyed to loading ramps, where they are loaded onto lorries for first echelon transportation. As space for inventory is limited, the printing sequence for multiple products or editions and vehicle dispatch are closely related. Often, loading ramps are scare and constitute a bottleneck. Depending on volumes and geographical spread, the transportation to retailers and drop-off points for subscription newspapers is performed with a multiple echelon distribution chain. In general, smaller vehicles are used for the final delivery echelon. In transit points, reloading of different products from several print works takes place.

For non-subscription newspapers, the distribution chain ends with delivery to retailers. However, reverse logistics may be important in the non-subscription supply chain. Normally, retailers only pay for sold copies. Many newspapers require that unsold copies are returned. If sales prognoses are not good, large volumes of paper are transported to central facilities where the copies are counted and then forwarded for recycling. The return and centralized counting of unsold newspaper copies may seem unnecessary, as modern cash registers can provide accurate sales information, but this is unfortunately also a matter of trust.

For subscription newspapers, the final stage of the supply chain is the carrier delivery from drop points to the mailbox or doormat of each subscriber. For a morning newspaper, bundles marked with route information are delivered to drop-off points, say, before 3:30 AM. Carrier routes are based on various transportation modes:

- pedestrian routes, with trolley
- bicycle routes
- driven routes, normally with car

There are cultural differences regarding the modes that are used, but pedestrian routes and car routes are common. Pedestrian routes are only used in dense urban or suburban districts where the total walking time is comparable to the total service time of the route. Bicycle routes operated by youngsters that were

[2] This operation may be cumbersome, and even painful, for instance at 3AM in a blizzard on a winter morning in Norway.

typical in many parts of the world have become less frequent, as evening subscription newspapers have become more scarce and virtually disappeared in many countries. Partly due to the fact that several titles now use the same distribution chain, and products other than newspapers have also been included, routes have become longer. Morning carrier routes are often designed to take some 2 hours. Driven routes require a certificate, and in most countries, child labor regulations do not permit adolescents as morning paper carriers. Although the salary may not be top-notch, the typical carrier workforce now has a heterogeneous composition of adults with different sex, background, and age. For some, newspaper delivery is their sole occupation and they may operate more than one route.

The carrier picks up her printed media product bundles (possibly consisting of different newspaper titles, magazines, books, direct marketing material) at the drop-off point, and prepares delivery by unpacking the bundles and, possibly, adding inserts to newspapers. Driving carriers load the products into their vehicle, and pedestrian carriers fill their trolley. The carrier takes off to visit all subscribers on the route. Pedestrian carriers will normally return to the drop-off point to park the trolley, but driven routes may be open, if the carrier uses her own car and is only paid until the final subscriber. Depending on the type of vehicle, drivers may deliver products directly in the subscriber's mailbox. It is normal that drivers sometimes have to get out of the car and make a small pedestrian loop to serve a number of customers, for instance in a block of flats. Similarly, the pedestrian carrier will often leave the trolley with an appropriate number of product copies and make a subtour. Particularly in urban areas, carriers need a large bunch of keys to enter blocks.

Pedestrian carriers may of course meander, i.e. zigzag between both sides of a street, if this is time-saving. Driving carriers may do the same for appropriate streets, depending on the type of vehicle and driving regulations. Pedestrian carriers will use pedestrian roads and shortcuts that are not necessarily included in commercial road network data. A shortcut through a backyard may require a key that is only available for one carrier. In hilly areas, a pedestrian route should preferably not start uphill when the trolley is fully loaded. A carrier routing plan should have a certain level of "visual beauty", i.e., users have a preference for routing plans that look nicely on the map. This beauty contest normally involves two sub-criteria: compact routes and/or non-overlapping routes. The motivation for the preferred beauty may seem unclear. It is partly connected with a user belief that plans with compact routes are more efficient, which is only partly true. However, it is not desirable that several carriers run around in the same area with the risk that neighboring subscribers receive their newspaper at different times. These are real-life aspects that make carrier route design more challenging.

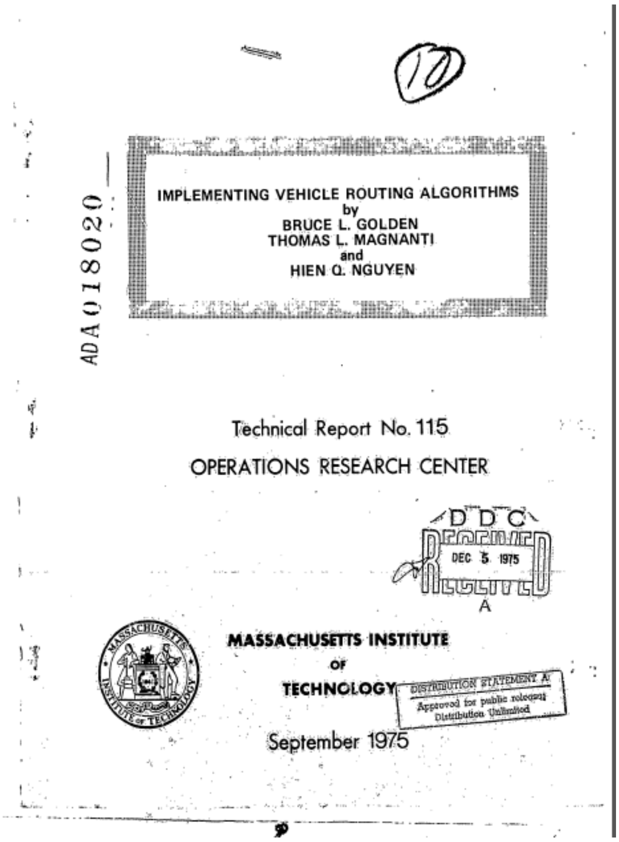
Figure 2. Pedestrian delivery. Pictures from Aftenposten, Norway.

The newspaper supply-chain has always been characterized by movement of large volumes of paper under heavy time pressure. It may reach every household in a given area every day. Lately, newspapers and distribution companies have utilized it also to distribute other products to increase revenues as a compensation for falling advertisement and circulation revenues. Readers have become more varied and selective in their requirements for newspapers. They may require a newsprint-based version only on Sundays, a pdf-version when abroad, and make do with the web version all other days. To cut costs, many newspapers now collaborate and outsource the printing and distribution functions, in particular for "last mile" delivery. These developments have added dynamics that require an even more agile supply-chain. Static routes and the type of information technology illustrated in Figure 1 are no longer adequate.

There are obvious similarities between postal delivery and newspaper delivery. In fact, some newspapers are delivered by the local postal service, and some modern newspaper distributers aim at adding postal mail as one of their product types but are prevented by postal monopoly. Less obvious is maybe the similarity to municipal garbage collection, because one is pickup and the other delivery. One similarity is that routes must visit virtually all households in the area. The time pressure may not be as hard in garbage collection as in newspaper delivery, although it is normally preferable that the routes finish early in the morning. The periodic nature of the garbage collection routing problem, where the selection of weekdays is an important characteristic, is not found in newspaper delivery. Rather, individual routes for each weekday is typically preferable in newspaper delivery due to volume variation, and even routes designed for each individual day without repetition. A full distribution routing plan is often needed by the newspaper (distribution) company, for instance to accommodate distribution of direct marketing leaflets.

It should be clear from the above description that the newspaper distribution chain presents complex and economically important design and coordination challenges. Purely manual decision-making is not adequate even for smaller newspapers. There is a high cost-cutting potential from the use of optimization based supply-chain and routing software (see for instance (BraH13) for a survey of routing software). Several providers of routing software tools specifically target newspaper distribution applications, also for the last mile carrier delivery, and there are many examples of successfully deployed vehicle routing software tools. In Section 4 we present a specific case, namely the development and exploitation of a web-based system for automatic construction and revision of carrier routes for last mile delivery of newspapers and other paper based media products. Before that, we give a brief survey of the routing literature for newspaper applications since 1996.

3 Literature Survey


ADA018020

IMPLEMENTING VEHICLE ROUTING ALGORITHMS
by
BRUCE L. GOLDEN
THOMAS L. MAGNANTI
and
HIEN Q. NGUYEN

Technical Report No. 115
OPERATIONS RESEARCH CENTER

DDC
DEC 5 1975

MASSACHUSETTS INSTITUTE
OF
TECHNOLOGY

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

September 1975

Figure 3. An early scientific publication on routing in the newspaper industry.

For a detailed survey of the early (until 1996) literature on NDP variants, we refer to (GolAW02). The survey contains nine papers, ranging in time from the first (as far as we know) NDP paper of Golden, Magnanti, and Nguyen (GolMN77), to three papers from 1996. The nine papers that are described focus on the first part of the supply chain: distribution from the print works to drop-off points. Two papers consider a multi-echelon supply chain, but none consider the last mile carrier delivery. Hence, none of the papers use an arc routing formulation.

Below, we provide an updated survey of the NDP literature since 1996. Whereas there is a substantial VRP literature for routing in waste management and postal mail delivery, there is little on routing for newspaper applications. As in the survey found in (GolAW02), we have found less than ten relevant papers. Again, these focus on the first part of the supply chain, hence none use an arc routing formulation.

Van Buer, Woodruff, and Olson (VanWO99) study tight coordination of production and distribution. Their case problem is the first-echelon distribution for a concrete medium-sized newspaper, in a setting where printing and distribution are tightly coupled since there is no room for finished goods inventories[3]. The newspaper has several editions targeted at different geographical areas. There is a classical tension between production and transportation concerns; i.e., the sequence determined by minimization of setup times in the press does not necessarily coincide with a good dispatching sequence based on geography. The authors give a mathematical formulation, and propose a heuristic solution method that is partly designed from comparative investigation on instances from the newspaper company. The authors conclude that re-using vehicles by allowing multiple routes per vehicle is the most important way to achieve low-cost solutions. Through this remedy, costs may be reduced dramatically.

Song et al. (SonLK02) focus on the first echelon of a two-echelon distribution chain from the print works to the readers. Their case is Chosun-Ilbo, one of the major newspapers in South Korea with more than 100,000 readers and multiple editions. The first echelon consists of bulk delivery of newspapers to so-called agents, of which there may be several hundred. A heterogeneous fleet is used, and split delivery may be used to fulfill the demand of each agent, in particular for agents that are close to the print works. The second echelon that is not directly considered is home delivery from each agent by small cars. The authors propose a method for solving the combined factory scheduling, allocation, and routing problem, i.e., the integrated problem of determining the sequence of editions at each print shop, the allocation of agents to individual print shops, and the routes from each print shop to its allocated agents. There are several complicating factors, such as sequence dependent setup times, and incompatibilities between vehicles and agents. The solution method consists of two main stages. First, the allocation of agents to print works is determined by solving a generalized assignment problem, using a regret distance. Based on the allocation, the printing schedules are determined heuristically. In the second stage, the agents that should have split deliveries are determined (maximum two deliveries), and the corresponding volumes are calculated, both with heuristics that take printing completion time and deadlines into account. For the subsequent calculation of routes, a modified savings heuristic is used. Dispatch sequence at the print works is determined by an urgency based heuristic. The paper reports from an empirical study on the Chosun-Ilbo operation with three print works and

[3] As mentioned above, this is typical.

400 agents in the Seoul area, for two specific days. Compared to the actual plans, the proposed method reduced costs and delays by 15% and 40%, respectively.

In their 2005 paper (CunM05), Cunha and Mutarelli develop a MILP model for a concrete media product logistics problem that has some similarities with the Chosun-Ilbo study in (SonLK02). The Brazilian weekly magazine Época has a circulation of some 400,000. The goal is to determine the number and location of the print works to be used, which destinations should be assigned to each selected works; the production sequence, and the mode of transportation, either airplane or truck. Savings of 7.1% of the total costs are reported, equivalent to more than USD 600,000 annually.

Russel, Chiang, and Zepeda also present research on combined production and distribution in the newspaper supply chain in their 2008 paper (RusCZ08). As for the three papers described above, the authors focus on the first part of the logistics chain, and consider the coordination and synchronization of production and delivery for multi-product newspapers to bulk delivery locations. They define the problem as an Open VRP with Time Windows and Zoning Constraints (OVRPTWZC), and report significant improvement relative to current practice at the time for the Tulsa World, a midsize newspaper operation with a circulation of about 150,000. The authors do not consider the problem of production scheduling, but the print sequence considers geography, and the loading of vehicles naturally follows this sequence. As different geographical zones receive different advertising inserts, a zoning constraint is imposed on the routes. The proposed metaheuristic solution method first employs a parallel insertion heuristic with a tabu search improvement procedure that is invoked ten times during construction. Iterative improvement with insert, delete, and swap operators and tabu search with a frequency-based diversification strategy and dynamic tabu tenure then follows. Savings related to fewer vehicles and reduction of total distance relative to manually generated routes that amount to some USD 70,000 are reported.

The same authors, reinforced with Xiaojing Xu, examine larger parts of the supply chain for a midsize US newspaper with both city and state editions in the Midwest that delivers to households and businesses in over 200 zip-codes. They define the problem as an integrated newspaper production and distribution supply-chain management problem. The problems studied in (ChiRXZ09) cover 2-echelon (city edition) and 3-echelon (state edition) distribution from the print works. They extend the work from the 2008 paper by presenting a 3-index mathematical formulation the OVRPTWZC, and include uncertainty that is handled by simulation.

A similar problem is considered by Böhnlein, Gahm, and Tuma in (BohGT07): The design of vehicle routes for first-echelon transportation from newspaper print shops that have to start directly after print finalization in order to meet deadlines. The variant they study allows multiple products (editions) per vehicle, and route planning must consider completion times of editions, as these may have geographical focus. This problem is modeled as a so-called VRPTW with Cluster-Dependent start time. The authors propose a hybrid of Ant Colony Optimization and Tabu Search, and report some 20% savings for a large German newspaper with around 1,400 drop points. Böhnlein, Schweiger, and Tuma, propose a multi-agent solution method for a dynamic variant of the same problem in a later paper (BohGT11).

Again, in a paper by Eraslan and Derya (EraD10), the transportation of newspapers from the print works to newsagents is investigated using a VRP model. The first echelon routes for vehicles of a leading newspaper distributor company in Turkey are examined. An integer linear programming model is proposed. Scenarios with up to 55 newsagents are solved with a commercial MILP solver within reasonable computing times. It is reported that the proposed model reduced the delivery cost by 21% on average when compared to the current manual planning method.

In their TRISTAN VII paper (ArcDT11), Archetti, Doerner, and Tricoire introduce the so-called Free Newspaper Delivery Problem (FNDP), i.e., the distribution of free newspapers from print works to news racks with given capacity and consumption profile at underground, bus and tramway stations. The problem includes time windows, co-ordination of production and distribution, and inventory management. The goal is hierarchical: The primary objective is to minimize the time period at which all stations are subject to stockout, while the secondary objective is to minimize the total number of trips for a homogeneous fleet of vehicles, where each vehicle may take several trips. Once stock-out happens at a given customer, there will be no further replenishment. The authors give a mathematical formulation and propose solution techniques for the FNDP including a decomposition method, heuristic and exact approaches for the subproblems, as well as a hybrid method. Computational experiments were made on instances inspired by real data from a free newspaper in Vienna. Results show that the hybrid approach yields the best solutions.

4 Newspaper Carrier Delivery - Node or Arc Routing?

Our search for specific literature on newspaper routing did not find any relevant scientific papers on the last mile carrier delivery. In contrast, several introductory sections in technical and general papers on the Arc Routing Problem (ARP) briefly mention carrier newspaper delivery, last mile postal mail delivery, and garbage collection as an application where variants of the ARP would be an adequate model.

In a chapter in the Handbook of Transportation Science (BodMM99), Bodin, Maniezzo, and Mingozzi discuss so-called Street Routing and scheduling Problems (SRP). They exemplify these problems with routing of residential and containerized sanitation vehicles, the scheduling of meter readers, the routing of field service operations for public utilities, the routing of vehicles for other traditional local pickup and delivery operations, and the scheduling of vehicles for telephone book and newspaper deliveries. In street routing, the locations to be serviced are assigned to the street segments or intersections of a digital street network database. SRP occur primarily in local delivery operations. The authors provide detailed information on the features and characteristics of SRP and how these problems differ from more traditional VRP: Regarding models and solution methods, they focus on node-based variants such as CVRP, VRPTW, and VRPB. They also outline a cluster-first-route-second generic algorithm for solving SRP, under certain assumptions.

The VRP literature has been dichotomized between node routing problems, first defined by Dantzig and Ramser in 1959 (DanR59), and arc routing problems, introduced by Kwan Mei-Ko in 1962 (Mei62).The equivalent of the basic, capacitated node routing problem (CVRP) is the Capacitated Arc Routing Problem

(CARP) first defined by Golden and Wong in 1981 (GolW81). Although the General Routing Problem, a generalization of the TSP where one must visit both nodes and edges in the graph, was defined by Orloff in 1974 (Orl74), its capacitated and multi-vehicle generalizations have not been much studied.

Some applications are naturally modeled as arc routing problems because the demand is fundamentally defined on arcs or edges in a transportation network. Prime examples are street sweeping, gritting, and snow clearing. However, the arc routing model has also been advocated in the literature for problems where the demand is located in nodes, for instance distribution of subscription newspapers to households, postal mail delivery, and pickup of household waste, particularly in urban areas. In real-life cases, there are often thousands or tens of thousands of points to be serviced along a subset of all road links in the planning area. Such cases may be formulated as CARPs on the road links with demand, typically with a drastic reduction of problem size. An arc routing problem can be converted into an equivalent node routing problem, but at the expense of the size of the instances to be solved.

In their 2004 paper (PriB04), Prins and Bouchenoua motivate further studies of the Node, Edge, and Arc Routing Problem (NEARP), alias the Mixed Capacitated General Routing Problem (MCGRP) that is also called the Capacitated General Routing Problem on Mixed Graphs (CGRP, or CGRP-m). They state that: "Despite the success of metaheuristics for the VRP and the CARP, it is clear that these two problems cannot formalize the requirements of many real-world scenarios.". Their example is urban waste collection, where most demand may adequately be modeled on street segments, but there may also be demand located in points, for instance at supermarkets. The NEARP is a generalization of the CVRP and the CARP, which again may be viewed as a capacitated extension of the General Routing Problem (Orl74). They propose a memetic algorithm for the NEARP and investigate it empirically on standard CVRP and CARP instances from the literature. The authors also create a NEARP benchmark consisting of 23 grid-based test cases, the so-called CBMix-instances with between 20 and 212 required tasks, and provide experimental results for their proposed algorithm.

We would like to enhance the motivation for the NEARP and further emphasize its importance to practice. The arc routing model for node-based demand cases such as subscription newspaper delivery is based on an underlying idea of abstraction. Some form of abstraction may be necessary to contain the computational complexity resulting from a large number of demand points in industrial routing. The assumption that all point-based demands can be aggregated into edges or arcs may be crude in practice. It may lead to solutions that are unnecessarily costly, as partial traversal of edges is not possible. In industry, a route planning task may cover areas that have a mixture of urban, suburban, and rural parts where many demand points will be far apart and aggregation would impose unnecessary constraints on visit sequences.

A more sophisticated type of abstraction is aggregation of demand based on the underlying transportation network topology. Such aggregation procedures must also take capacity, time, and travel restrictions into consideration to avoid aggregation that would lead to impractical or low quality plans. In general, such procedures will produce a NEARP instance with a combination of demands on arcs, edges, and nodes. The generalization of CVRP, GRP, and CARP was therefore an important step to eliminate the arc/node routing dichotomy and thus enable the modeling of the continuum of node and arc routing problems needed for representational adequacy in real-life situations.

5 NEARP – Definition and Literature Survey

The NEARP, or MCGRP, is defined on a connected multi-graph $G = (N,E,A)$, where N is the set of nodes, E is the set of undirected edges, and A is the set of directed arcs. Let c_e denote the non-negative traversal cost for $e \in E \cup A$, also known as deadheading cost, i.e., the cost for traversing the edge/arc without servicing it. The traversal cost is zero for nodes. Let $N_R \subseteq N$ be the set of required nodes, and let q_i denote the demand and s_i the servicing cost of node $i \in N_R$. Similarly, let E_R and A_R be the set of required edges and arcs, respectively, and let q_e and s_e denote the demand and service cost of $e \in E_R \cup A_R$. A fleet of identical vehicles each with capacity Q is initially located in a special depot node, denoted node 1. It is assumed that the size of the fleet is unbounded.

The goal is to identify a number of tours for the vehicles such that

1) Every node $i \in N_R$, every edge $e \in E_R$, and every arc $e \in A_R$ is serviced by exactly one vehicle
2) The sum of demands serviced by each vehicle does not exceed Q, and
3) The total cost of the tours is minimized.

We note that for the basic NEARP, the total service cost is constant over all feasible solutions, so it is sufficient to minimize the sum of traversal costs.

Studies of the NEARP are scarce in the literature. The first we know of is the paper by Pandit and Muralidharan from 1995 (PanM95). They address a generalized version of the NEARP, i.e., routing a given heterogeneous set of vehicles over specified segments and nodes of a street network, under a route duration constraint. The problem is denoted the Capacitated General Routing Problem (CGRP). The authors formally define the CGRP and design a heuristic for solving it. They generate random test instances inspired from curb-side waste collection in residential areas on a network with 50 nodes and 100 links. They also investigate the proposed method on random instances of the Capacitated Chinese Postman Problem for which they had two lower bound procedures. The authors integrated their solver in a micro-computer based interactive route planning system.

In (GutSH02), the homogeneous fleet version of the CGRP studied by Pandit and Muralidharan is investigated by Gutierrez, Soler, and Hervaz. The number of vehicles is given. They call it the problem CGRP-m and devise a heuristic that is investigated on a set of 28 instances with between 20 and 50 vertices, 25 and 97 edges, and 0 and 16 arcs. They compare with the heuristic proposed by Pandit and Muralidharan and conclude that their heuristic is substantially better for the homogeneous fleet version of the problem.

In (BacHW12), Bach, Hasle, and Wøhlk provide the first combinatorial lower bound procedure for the NEARP. They also present two new benchmarks: BHW, consisting of 20 instances based on well-known CARP instances with between 29 and 410 required tasks; and DI-NEARP with 24 instances that are based on 6 real cases from last mile newspaper delivery. The number of required tasks varies between 240 and 833.

They report numerical results for the proposed lower bounds for the three benchmarks, and also the best known upper bounds from the literature. Their only source of upper bounds for the BHW and DI-NEARP benchmarks was a technical report by Hasle et al. (HasKSG12) that describes results from experiments on NEARP test instances using SINTEF's industrial VRP solver Spider (HasK07,Spi12). This technical report provides new best-known results for the CBMix benchmark and the first upper bounds for the BHW and DI-NEARP benchmarks. For three of the BHW instances the gap is closed: BHW2, BHW4, and BHW6. They also refer to a web page (NEARP12) devoted to NEARP benchmarks and corresponding best known upper and lower bounds that is intended to be a central resource for NEARP researchers.

Bosco, Lagana, Musmanno, and Vocaturo (BosLMV12) propose the first integer programming formulation for the NEARP[4] with three indices for links and two indices for nodes. They extend some inequalities originally introduced for the CARP, and discuss identification procedures for these inequalities and some relaxed constraints. They propose a branch and cut algorithm and present computational experiments on 12 datasets that they have constructed from classical datasets (egl and mval) for the undirected and mixed CARP. The number of required tasks varies between 8 and 129, and they only solve instances with a number of vehicles less than 8. The optimal solution is found for 154 of 264 instances, whereas the average and maximum gaps for the non-closed instances are 2.56 and 12.82, respectively. The algorithm is also tested on the four CBMix instances that require a small number of tours. It finds the proven optimal solution for CBMix12 and CBMix23 and provides good upper bounds for CBMix1 and CBMix22.

6 Arc Routing Problems in Newspaper Delivery

The routing problems in newspaper distribution where variants of the ARP are adequate models are of course located in the final, "last mile" carrier delivery. This may be characterized as a Street Routing Problem, with many of the complications pointed out by Bodin et al. in (BodMM99). As demand is fundamentally node-based, an arc routing problem model must be based on some form of abstraction, e.g. through demand aggregation based on links the street network. In our experience, it is not uncommon for newspaper companies to have manually made, first level aggregates of households in their area of interest into *modules* that will never be split between carrier routes. Such aggregates will typically reduce the number of points in a natural planning session by an order of magnitude. Often a module corresponds to a place where the carrier stops her car or leaves her carriage to make a small subtour. The module's service time includes the walking time between the households.

Despite this first level aggregation into modules, the number of modules in an actual planning session may be in the thousands, so a second level aggregation may be useful. The aggregation heuristics must take the underlying road topology into account, and constraints on meandering, U-turns etc. There must be limits on the duration of aggregates to allow planning flexibility. This type of aggregation will result in aggregated orders whose location is an edge or an arc. Even in dense urban areas, not all modules will become part of an

[4] The authors use the name Mixed Capacitated General Routing Problem (MCGRP).

aggregate. Hence, the result will be a NEARP with side constraints. Despite two levels of aggregation, the number of required nodes or links in a real-life routing session will easily be in the hundreds or even thousands, so large size is a common characteristic of ARP for last mile newspaper delivery.

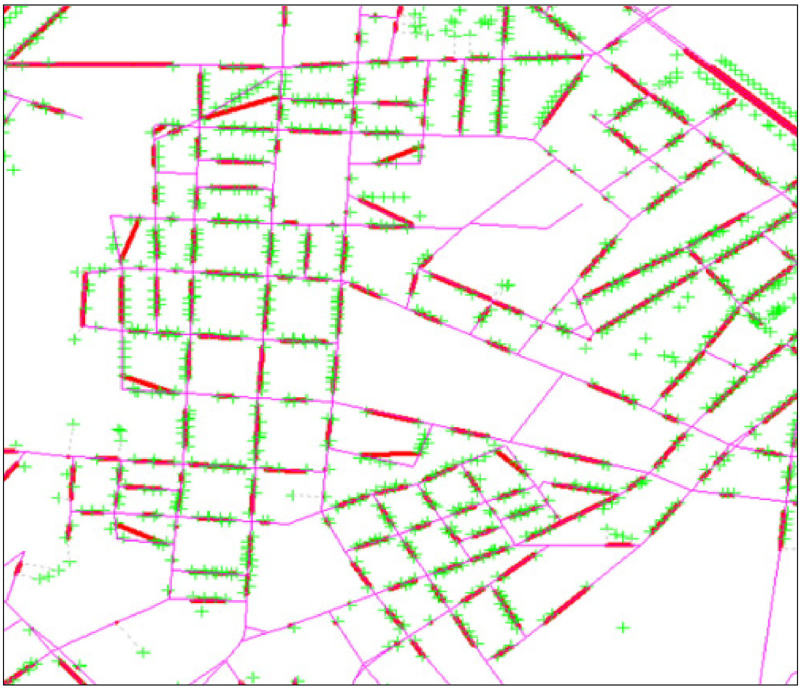


Figure 4. Road Topology Based Aggregation of modules in a dense urban part of Oslo.

Figure 4 illustrates the result of an aggregation heuristic[5]. applied to modules in a dense urban part of Oslo. Green crosses represent individual modules, and the red segments represent aggregates. The figure also illustrates the difficulties encountered when the electronic road network is not of sufficient quality and level of detail.

We have alluded to other characteristics of newspaper carrier delivery routing above, but emphasize them below. Time is a very important dimension. Delivery is severely time-constrained, and the primary cost criterion is often dominated by salary that is typically closely related to route duration. High quality, detailed address and road topology information is a prerequisite for high quality planning. Good service time and travel time models are also vital. There is a hard upper bound on route duration, or, rather, the time of delivery for the last subscriber on the route. Weight and volume capacity is normally a non-binding constraint. Balanced routes duration-wise is an important criterion to ensure flexibility and fairness between carriers. The route balance requirement may be regarded as a soft constraint, with a penalty and a hard upper bound on the maximum difference, perhaps in the order of 10%. However, carriers may have route duration preferences, and one may envisage that such preferences could be given as input to a solver.

[5] The aggregation heuristic of the commercial solver Spider (Spi12).

The planners often want to specify the number of routes, or, alternatively, minimize the number of routes for the given area of interest. Each route starts from one of a set of alternative drop-off points. Due to noise, visual impact and other environmental concerns, drop-off points cannot be selected at will. However, the solution of an integrated optimization of route design and selection of drop-off points, i.e. a location routing problem, is certainly relevant. The choice of drop-off points may influence the first-echelon distribution, but typically not to a large degree.

The area of interest may encompass urban, suburban, and rural areas with highly varying density of deliveries that require a mixture of driven and pedestrian routes. Depending on modality, whether the carriers are subcontracted or hired, and the types of equipment involved, carrier routes should be closed or open as explained above. Choice of modality and, in case, type of car, will also determine whether a given demand aggregate may be regarded as an edge or must be modeled as two arcs. For pedestrian routes, topography may be an important factor. In areas with steep hills, routes should not start uphill when the trolley is full and heavy.

The criteria for mode selection for routes may be complex, but accessibility and the relation between travel and service time are the most essential. Ideally, many newspaper companies would like to see functionality in a route optimization system that could automatically construct optimized carrier routes, and decide modality and drop-off points for the routes simultaneously. These decisions are closely intertwined. Even the type of link chosen to represent a demand aggregate partly depends on modality. We believe there are many interesting research challenges buried in these issues.

Finally, we return to the multi-criteria aspect of the newspaper carrier delivery problem. We have already discussed the two most important objectives: total cost and route duration balance. In addition, there is the "visual beauty" concern, as described in Section 2 above. The users want compact, non-overlapping routes, but not at all cost.

In summary, the ARP found in newspaper distribution is at the final carrier delivery. It is in our opinion a case for rich variants of the NEARP model, after aggregation of point-based demand. There is a hard duration constraint, and traditional capacity constraints are non-binding for most operations. The primary objective is cost that is closely related to total duration, whereas there is an important secondary objective to balance route duration. Moreover, users prefer solutions with compact, non-overlapping routes.

We have given an account of the routing literature specifically targeted at newspaper applications in 3 above. Moreover, we have given an extensive (to our knowledge) survey of the literature on the Node, Edge, and Arc Routing Problem, alias the (multi-vehicle) Mixed Capacitated General Routing Problem (MCGRP), alias the (multi-vehicle) Capacitated General Routing Problem, in 5. Let us now also point to general literature that relates to the more exotic problem characteristics described above.

The dichotomy between node and arc routing and the presence of mixed cases in real life is addressed by a paper of Oppen and Løkketangen (OppL06). They consider borderline cases, namely VRPs based on a graph representing a road network, where customers are situated along the arcs. Garbage collection and newspaper delivery are among their application examples. They define "Stringed VRP" as a problem where some customers are close and form "strings" in the graph. They comment that it often seems obvious that the nodes of such a string should be visited by the same vehicle, and claim that such a string of nodes can naturally be replaced by an arc between the first and last node in the string. The paper proposes aggregation heuristics, but the aggregates are represented as nodes rather than arcs or edges.

Although important to many applications, there is surprisingly little literature on VRP with route balance aspects. We refer to work by Tsouros et al. (TsoGT06), Pasia et al. (PasDHR07), Borgulya (Bor08), and Jozefowiez et al. (JozST09). "Visual beauty" issues are addressed in (LuD05), (HaoM06), and (Mat08). The combination is a topic of (KimKS06) and (HeXSZ09).

7 Case study: A web-based service for Carrier Route Design

Together with inhabitants of Japan, Switzerland, and the other Nordic countries, Norwegians are among the most newspaper-reading people in the world. Print newspapers are read every day by over 80% of the population. However, circulation numbers have kept falling steadily since the 1990ies. Norway is also the country where newspapers have the highest percentage of advertising revenues from digital versions, at some 17%. A polynomial regression analysis from 2011, for what it is worth, shows that there will be no print newspapers left in Norway October 9 2025.

Norwegian newspaper companies saw the writing on the wall. Ideas of consolidation, both regarding ownership and logistics emerged. The need for a more efficient supply chain with reduced distribution costs led to a new practice where several titles utilized the same resources. Also, ideas of distributing other products through the newspaper distribution chain to create new revenues emerged. The added dynamics called for new ICT technology for carrier route management, including a system for route optimization. The idea of replacing the old carrier's book illustrated in Figure 1 came early, maybe even before Personal Digital Assistants (PDAs), also called palmtops, with Internet became widespread in the mid 1990ies.

In 2000, Aftenposten, the largest Norwegian subscription newspaper, took contact with SINTEF, a large contract research institute in Oslo. Their idea was to develop an industry standard system for logistics management for paper-based media products. The first critical step was to develop an electronic version of the carrier's book. The requirements on usability were extremely high, as user acceptance was absolutely crucial to the success of the whole system. Newspaper carriers of today in Norway constitute a heterogeneous group of people, with many nationalities and different levels of education and backgrounds. The PDA-based guide was to be used in a possibly very hash and difficult working environment, with darkness, cold temperatures, and humidity.

The project started in 2001, with Aftenposten as project owner, several newspaper and distribution companies as partners, SINTEF as the research partner, and financial support by the Research Council of Norway. The main priority in the beginning was the development of the PDA-based carrier's book. A focus group of carriers was established, and this was instrumental in the research based development that proved to be successful (FølR03). Also, requirements for route optimization were collected, and VRP solver prototypes based on SINTEF's industrial solver Spider were investigated on real data. A spin-off company called

Distribution Innovation AS (DI) was established for industrial dissemination of the logistics management system (DI12).

Figure 5. The PDA/Smartphone based carrier's book.

In parallel, a logistics management system was developed, partly based on re-engineering and partial reuse of earlier systems such as product, subscriber, and carrier route databases. A main design feature was a web-based interface and a cloud computing architecture that allows ready access to the functionality from "anywhere" without software installation and hardware investment –a web browser and a commodity PC suffices. Hence, the system became attractive also for small newspapers and distribution companies. Soon, the DI system became market leading in Norway, with customers that covered more than 50% of the Norwegian households.

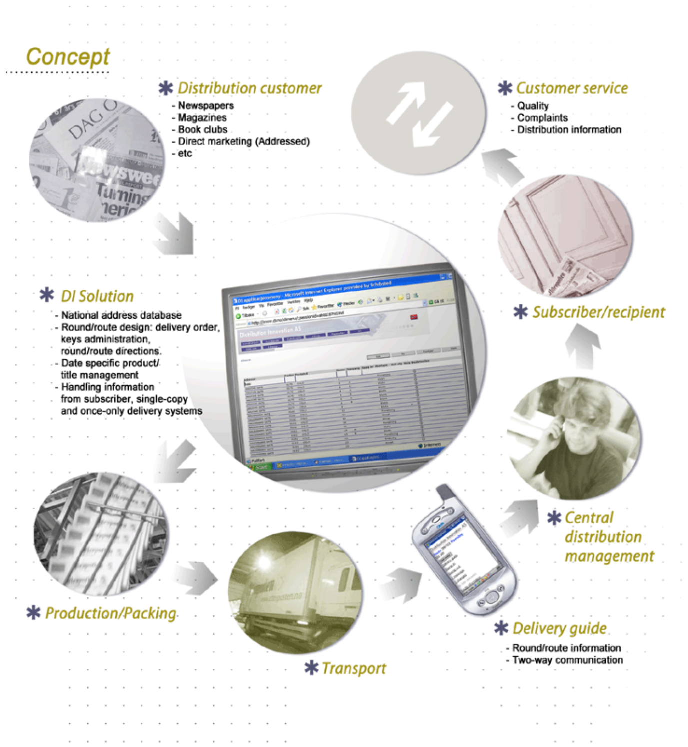


Figure 6. The DI solution concept.

The electronic carrier's book of course has many advantages over the traditional one. It has Internet, and two-way communication is possible. In principle, carrier route information could be updated while the carrier is en route, but in practice, she downloads her route a few hours before start. The route information contains the delivery sequence, specification of products per subscriber, detailed travel and delivery directions, and aggregated information such as total number of copies for each title.

Figure 7. The DI web-solution architecture.

The web-solution has been further developed over time, also through several RTD projects. A major step was the integration of a VRP solver for automatic and optimized route construction and revision. Earlier, full revision of carrier routes in Oslo could require several man-years and take many months. Hence, revisions were not performed frequently enough, with less than optimal route plans and unnecessary high costs as a result. Before this, functionality for manual revision of existing, manually planned routes, and map visualization, had been added to the web solution. Moreover, a set of performance indicators were developed that allows monitoring the efficiency of routing plans to identify areas where a route revision is called for.

A challenge that became apparent with map visualization and automatic route planning was geocoding of addresses. The official household register did not have sufficient quality, so DI had to build its own address database. Similarly, the commercially available electronic road networks also had quality problems, and lacked information at the very detailed level that is necessary to design pedestrian routes automatically. The high user expectations of fully automatic route planning from Day 1 had to be lowered. Functionality for editing the road network was added, so the users could gradually increase the accuracy of the underlying road topology for their area of interest and soon reach an acceptable quality.

Similarly, good models for travel and service times are critical. Several such models had already been developed by user partners with different types of operation, but they were different and needed to be reconciliated and tuned. Observed data were the basis for regression analyses and tuning of parameters. For routes driven by car, the travel time model had to be extended with retardation and acceleration phases for each stop.

As for the electronic carrier's book, great emphasis was put on usability, simplicity, and a good user interface for the vehicle routing functionality. The target user is a planner at a newspaper or distribution company. This group consists of people that are highly skilled at manual route planning and know their district extremely well, but typically have much lower levels of proficiency regarding operations research, computing science, and software engineering. Hence, to be accepted, the routing functionality needed to be easily accessible through a web GUI, and the number of choices and parameters had to be at a minimum. Low quality plans would of course not be acceptable, although the manual planning functionality could be used for robustness. A user vision for response time was route revision for a major area during the time it takes to fetch a cup of coffee.

SINTEF's industrial VRP solver Spider (HasK07,Spi12) was the starting point. The model had been extended and the accompanying, uniform solution algorithm had been improved through exposure to new industrial cases. Good performance had been demonstrated also on several academic benchmarks, although running times are generally higher for a generic solver that cannot utilize all speedup tricks of a highly specialized solver. The most important novel problem features of newspaper carrier routing that were exposed by the newspaper and distribution companies were the potentially very large number of customers, the route balance constraint, and the visual beauty criteria. In addition there were important trivialities related to road network traversal such as meandering and U-turns.

The initial idea was to keep the uniform solution algorithm, but add a route imbalance penalty to the objective. A clustering objective component that at least partially addressed the visual beauty aspect was already implemented. To accommodate very large instances, a road topology based demand aggregation framework was designed, and a concrete heuristic based on the road topology was developed. The model was extended with aggregate orders. These have a geographical extension that is a part of one or more consecutive road segments. Hence, the VRP solver was now equipped to represent arc routing problems on a mixed graph, and also NEARPs. Very few changes had to be made on the solution algorithm. We became aware of the paper of Prins and Bouchenoua (PriB04) and tested the solver on the 23 CBMix instances, with reasonably good average results (average error < 1%) and six best known results[6].

However, clear feedback from users on prototype versions for the real-life problem said that solution quality was not consistently good. As could be expected, determining generally valid weights in a scalar combination of the three major objective components turned out to be difficult. A true multi-objective approach was deemed too expensive. The remedy became a new method that imposes the desired structure, i.e. balanced routes that look good in the map in an initial solution, and then performs iterative improvement without destroying that structure.

The general idea is one of cluster-first-route-second, where clustering is performed by solving a capacitated clustering problem with route duration as capacity. The problem is solved heuristically by a *k*-means like algorithm. There are issues regarding clustering in a non-Euclidean space that have been solved by combining real and Euclidean distances. Duration is estimated by local search with 2-opt to a local optimum. The number of clusters is either user defined, or estimated. If the estimated or given number is not adequate, the process is repeated with an adjusted number. Finally, each route is post-optimized.

The revised solution method gives high quality plans that are accepted by the users. Automatic planning of carrier routes is now taken for granted by the user companies; manual route revision is no longer performed. As the DI solution database also contains manually generated routes that have not yet been optimized, there is a good basis for comparison. Cost improvement varies widely between a few percent for routing plans that have evolved naturally, to more than 30% for areas where there have been drastic changes such as addition of new products or new residential areas. Figure 8 shows a case where a manually generated routing plan with 3 routes is compared to an automatically generated routing plan for the same set of households. The user has specified one more route, but the total distance has decreased by some 27% and the total time has been reduced with approximately 22%. Figure 9 shows an example of an optimized routing plan that has considerable beauty in the map.

[6] Three of the instances had been improved before in (KokMK07), a paper that we were not aware of at the time.

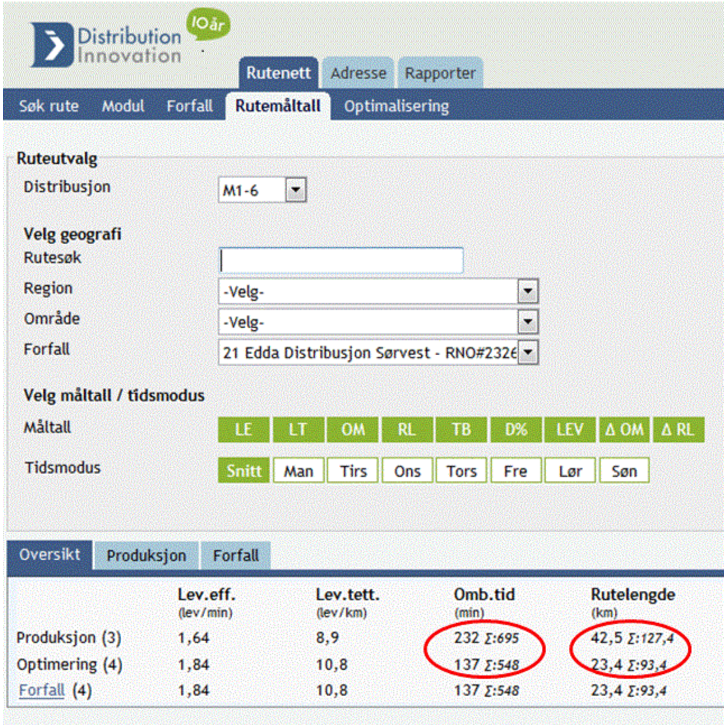


Figure 8. Screenshot from the DI solution. Comparison of performance indicators.

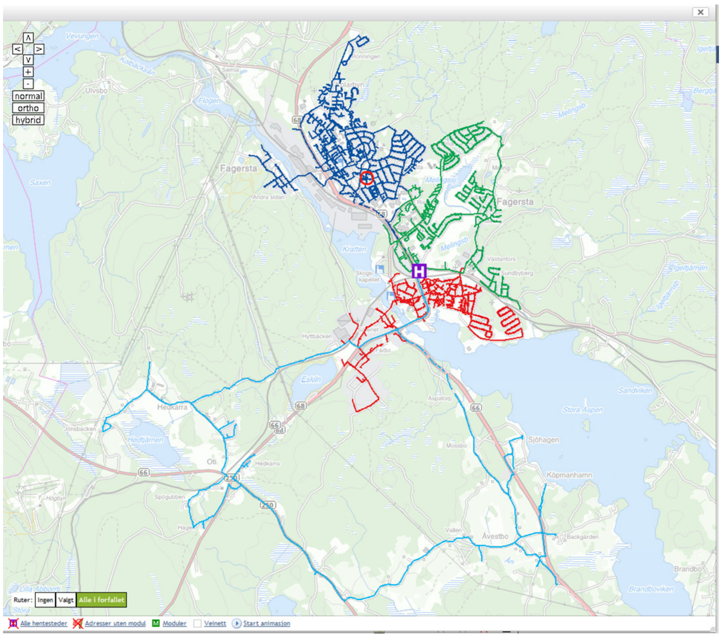


Figure 9. An example of a routing plan with considerable beauty.

The functionality for automatic carrier route design is routinely used by more than 35 distribution companies and newspapers in Norway, Sweden, and Finland. The Norwegian users cover more than 80% of the Norwegian households. Every evening, some 6,300 carriers that perform more than a million deliveries daily download their route for the next morning. The time to get that cup of coffee while the route was optimized may have been somewhat longer than usual, but further VRP research and hardware development will soon get us there.

The DI system is a rich source of industrial case data. With permission, SINTEF has downloaded six sets of case data and from these generated a suite of 24 NEARP instances that have been used for experiments also in academia. A web page devoted to NEARP benchmarks has been established (NEARP12), and it is our hope that SINTEF in this way provides a small bridge between industry and academia.

8 Summary

In this chapter, our goal was to describe arc routing applications in the newspaper business. Judging from the literature that we have found, there are none. In line with this fact, we have argued that "last mile" carrier deliveries to households is fundamentally a node routing problem, as is also mail delivery and collection of household waste, contrary to statements in the introduction of many technical arc routing papers. However, abstraction and problem size reduction, e.g. by qualified aggregation heuristics that utilize the road topology, will typically produce a combined arc and node routing problem. We have emphasized the importance of the Mixed Capacitated General Routing problem, also known as the Node, Edge, and Arc Routing Problem, as an adequate model for such applications, and provided a survey of the relevant literature. We have also provided a narrative style case description: the development of a web based system for management and optimization of carrier delivery in Norway.

The dire straits that large parts of the global newspaper business have been in the past two decades do not seem easily navigable. Circulation numbers and advertisement revenues are falling, and a good business model for digital newspapers seems hard to find. These pressures have motivated consolidation of the newspaper business, and cooperation between companies on better efficiency and utilization of the supply chain. Other products are distributed through this supply chain to increase revenues. It is relatively easy to motivate the use of good software tools for better coordination. As we have illustrated, the routing problems in question are complex, and the newspaper supply chain is in our opinion a rich source of industrially relevant and scientifically exciting research that has not been much exploited yet.

One may argue that the best way of tackling a computationally hard discrete optimization problem is to remove it. Personally, we like to read even yesterday's papers on newsprint, but we may belong to the last generation with such inclinations. It is difficult for us to see, however, that a supply chain that reaches every household every early morning within a strict time frame will become totally useless in the future.

Acknowledgments

We extend our sincere thanks to the Distribution Innovation AS company that has made screenshots from their web-based carrier route design system to us, and allowed us to publish information on their case and the development of their system. We also thank Norway's largest subscription newspaper Aftenposten for permission to use illustrations from their carrier's manual.

The preparation of this chapter has been supported by the eVita and SMARTRANS programs of the Research Council of Norway under contract numbers 205298/V30 (DOMinant II), 192905/I40 (Collab), and 217108 (Respons).

References

[Aftxx] Aftenposten. Carrier's Manual. *http://avisbud.aftenposten.no/GetElement.do?id=614*

[ArcDT11] C. Archetti, K. Doerner, F. Tricoire (2011). Free newspapers delivery optimization. *Book of abstracts, TRISTAN VII, Tromsø, Norway. http://www.sintef.no/tristan*

[BacHW12] L. Bach, G. Hasle and S. Wøhlk (2012). A lower bound for the node, edge, and arc routing problem. *Submitted.*

[BodMM99] Bodin L, Maniezzo V, Mingozzi A (1999). Street routing and scheduling problems. *In: Hall RW (ed) Handbook of transportation science. Kluwer, Dordrecht.*

[BohGT09] D. Böhnlein, C. Gahm, A. Tuma (2009). A hybrid meta-heuristic for the VRPTW with cluster-dependent tour starts. *Proceedings of the 42nd Hawaii International Conference on System Sciences.*

[BohGT11] D. Böhnlein, K. Schweiger, A. Tuma (2011). Multi-agent-based transport planning in the newspaper industry. *Int. J. Production Economics 131 146–157.*

[Bor08] I. Borgulya (2008). An algorithm for the capacitated vehicle routing problem with route balancing. *Central European Journal of Operations Research, Vol 16 (4), 331-343, http://dx.doi.org/10.1007/s10100-008-0062-2*

[BosLMV12] A. Bosco, D. Lagana, R. Musmanno and F. Vocaturo (2012). Modeling and solving the mixed capacitated general routing problem. *Optimization Letters. Published online September 2012. DOI: 10.1007/s11590-012-0552-y.*

[BraH13] O. Bräysy and G. Hasle (2013). Software Tools and Emerging Technologies for Vehicle Routing and Intermodal transportation. *Chapter 12 in P. Toth and D. Vigo (eds): Vehicle Routing: Problems, Methods and Applications. Submitted.*

[ChiRXZ09] W-C Chiang, R. Russel, X. Xu and D. Zepeda (2009). A simulation-metaheuristic approach to newspaper production and distribution supply chain problems. *Int. J. Production Economics 121 752–767.*

[CunM05] Cunha and Mutarelli (2007). A spreadsheet-based optimization model for the integrated problem of producing and distributing a major weekly newsmagazine. *European Journal of Operational Research 176, 925–940.*

[DanR59] G. B. Dantzig and J. H. Ramser (1959). The truck dispatching problem. *Management Science, 80(6), 1959*.

[DI12] Distribution Innovation AS, home page. http://www.di.no Accessed 2012-10-08.

[EraD10] E. Eraslan, T. Derya (2010). Daily newspaper distribution planning with integer programming: an application in Turkey. *Transportation Planning and Technology, vol. 33, no. 5, pp. 423-433.*

[FølR03] A. Følstad, O.-W. Rahlff (2003). Basic User Requirements for Mobile Work Support Systems - Three Easy Steps. In *A. Olivé, M. Yoshikawa, and E. S. K. Yu (eds): Advanced Conceptual Modeling Techniques. Lecture Notes in Computer Science, Vol 2784, pp 217-228, doi 10.1007/978-3-540-45275-1_19.*

[GolAW02] B. L. Golden, A. A. Assad and E. A. Wasil (2002). Routing Vehicles in the Real World: Applications in the Solid Waste, Beverage, Food, Diary, and Newspaper Industries. *Section 10.4 in [TotV02]*.

[GolMN75] B. L. Golden, T. L. Magnanti, H. Q. Nguyen (1975). Implementing Vehicle Routing Algorithms. *Technical Report no 115, Operations Research Center, MIT.*

[GolMN77] B. L. Golden, T. L. Magnanti, H. Q. Nguyen (1977). Implementing Vehicle Routing Algorithms. *Networks Volume 7, Issue 2, pages 113–148.*

[GolW81] B. L. Golden, R. T. Wong. Capacitated arc routing problems. *Networks 1981; 11: 305-315.*

[GutSH02] J. C. A. Gutiérrez, D. Soler, and Antonio Hervás (2002). The capacitated general routing problem on mixed graphs. *Revista Investigacion Operacional, 23(1):15 – 26, 2002.*

[HalP12] R. Hall, J. Partyka (2012). Vehicle routing software survey. *OR/MS Today 39:1.*

[HasK07] G. Hasle and O. Kloster. Industrial vehicle routing. In *G. Hasle, K.-A. Lie, and E. Quak (eds), Geometric Modelling, Numerical Simulation, and Optimization - Applied Mathematics at SINTEF, pp 397–435. Springer, 2007.*

[HasKSG12] G. Hasle, O. Kloster, M. Smedsrud and K. Gaze. Experiments on the node, edge, and arc routing problem. *Technical Report A23265, SINTEF, 2012. ISBN 978-82-14-05288-6.*

[HeXSZ09] R. He, W. Xu, J. Sun, and B. Zu (2009). Balanced K-Means Algorithm for Partitioning Areas in Large-Scale Vehicle Routing Problem. *In Proceedings of the 2009 Third International Symposium on Intelligent Information Technology Application - Volume 03 (IITA '09), Vol. 3. IEEE Computer Society, Washington, DC, USA, 87-90. DOI=10.1109/IITA.2009.307 http://dx.doi.org/10.1109/IITA.2009.307*

[JagR67] M. Jagger and K. Richards (1967). Yesterday's papers. *Between the buttons*, Decca.

[JozST09] N. Jozefowiez, F. Semet, E.-G. Talbi (2009). An evolutionary algorithm for the vehicle routing problem with route balancing. *European Journal of Operational Research, Volume 195, Issue 3, 16 June 2009, Pages 761-769, ISSN 0377-2217, 10.1016/j.ejor.2007.06.065.*

[KimKS06] B.-I. Kim, S. Kim, and S. Sahoo (2006). Waste collection vehicle routing problem with time windows. *Computers & Operations Research 33, 3624–3642.*

[LuD05] Q. Lu and M. M. Dessouky (2005). A new insertion-based construction heuristic for solving the pickup and delivery problem with hard time windows. *European Journal of Operational Research, Vol 175, 672-687.*

[Mat08] P. Matis (2008). DSS for the street routing problem. *Transport, vol. 23, no. 3, pp. 230-235, DOI: 10.3846/1648-4142.2008.23.230-235.*

[Mei62] Kwan Mei-Ko (1962). Graphic Programming Using Odd or Even Points. *Chinese Math., 1:273-277, 1962.*

[KokMK07] H. Kokubugata, A. Moriyama and H. Kawashima (2007). A practical solution using simulated annealing for general routing problems with nodes, edges, and arcs. In *Proceedings of the 2007 international conference on Engineering stochastic local search* *algorithms: designing, implementing and analyzing effective heuristics, SLS'07, pages 136–149, Berlin, Heidelberg. Springer-Verlag.*

[NEARP12] NEARP web pages. *http://www.sintef.no/Projectweb/TOP/nearp . Accessed: 05/10/2012.*

[Orl74] C. S. Orloff (1974). A fundamental problem in vehicle routing. *Networks, 4:35–64.*

[OppL06] Arc routing in a node routing environment. *Computers & Operations Research 33 (2006) 1033–1055.*

[PanM95] R. Pandit and B. Muralidharan (1995). A capacitated general routing problem on mixed networks. *Computers & Operations Research, 22(5):465 – 478.*

[PasDHR07] J. M. Pasia, K. F. Doerner, R. F. Hartl, and M. Reimann (2007). Solving a bi-objective vehicle routing problem by Pareto-ant colony optimization. *In Proceedings of the 2007 international conference on Engineering stochastic local search algorithms: designing, implementing and analyzing effective heuristics (SLS'07), Thomas Stützle, Mauro Birattari, and Holger H. Hoos (Eds.). Springer-Verlag, Berlin, Heidelberg, 187-191.*

[PriB04] C. Prins and S. Bouchenoua (2004). A memetic algorithm solving the VRP, the CARP and general routing problems with nodes, edges and arcs. *In W Hart, N Krasnogor, and J Smith (eds), Recent Advances in Memetic Algorithms, Studies in Fuzziness and Soft Computing, pages 65–85. Springer.*

[RusCZ08] R. Russel, W-C Chiang and D. Zepeda (2008). Integrating multi-product production and distribution in newspaper logistics. *Computers & Operations Research 35 1576 – 1588.*

[SonLK02] S. H. Song, K. S. Lee and G. S. Kim (2002). A Practical Approach to Solving a Newspaper Logistics Problem using a Digital Map. *Computers & Industrial Engineering 43 315-330.*

[Spi12] Spider web pages. *http://www.sintef.no/Projectweb/Transportation-planning/Software/Spider/ . Accessed: 05/10/2012.*

[TanM06] H. Tang, and E. Miller-Hooks (2006). An Interactive Heuristic for the Vehicle Routing Problem with Solution Shape Constraints. *Transportation Research Record, 1964, pp 9-18.*

[TotV02] P. Toth and D. Vigo (2002). The Vehicle Routing Problem. *SIAM, ISBN 0-89871-498-2*.

[TsoGT06] M. Tsouros, M Pitsiava, K. Grammenidou, K. Tsouros (2006). Routing-Loading Balance Heuristic Algorithms for a Capacitated Vehicle Routing Problem. *Information and Communication Technologies, 2006 (ICTTA '06), DOI: 10.1109/ICTTA.2006.1684915*.

[VanWO99] M. G. Van Buer, D. L. Woodruff, R. T. Olson (1999). Solving the medium newspaper production/distribution problem. *European Journal of Operational Research 115, 237-253*.

[WAN10] WAN-IFRA (2010). World Press Trends 2010. *ISBN 978-2-918652-01-4*. http://www.wan-ifra.org/worldpresstrends2010

[WAN11] WAN-IFRA (2011). World Press Trends: Newspapers Still Reach More Than Internet. http://www.wan-ifra.org/articles/2012/04/17/world-press-trends-2011

Technology for a better society

www.sintef.no