Routing & Scheduling Challenges for a Service Provider

Stephen M. Watt
The University of Western Ontario

Srinivas Chatrathi  Devang Dave
Girish Palliyil  Kenneth Wood
Descartes Systems Group
Descartes Overview

Nearly 30 Years Serving the Logistics Industry

Amsterdam, Eindhoven
Atlanta, GA
Brussels, Belgium
Copenhagen, Denmark
Eindhoven, Netherlands
Gent, Belgium
Lier, Belgium
Madrid, Spain
Montreal, QC
Miami, FL
Namestovo, Slovakia
Ottawa, ON

Paris, France
Pittsburgh, PA
Shanghai, China
Silver Spring, MD
Stockholm, Sweden
Suzhou, China
Tokyo, Japan
Toronto, ON
Washington, DC
Waterloo, ON
Zilina, Slovakia

World’s largest Federated Logistics Network

22 consecutive quarters of profitability

103MM revenue past 4 quarters

TSX: DSGX
NASDAQ: DSG

Proprietary and Copyright of The Descartes Systems Group Inc. All rights reserved.
Descartes is exploiting the convergence of 3 markets:

- Global Trade Compliance
- Supply Chain Execution
- Mobile Resource Management

Manage & Track in Real-Time:
- Shipments/Inventory
- Conveyances
- Equipment
- People
- Commercial, Logistics & Regulatory Documents
Product Groups

Global Trade Compliance
GTC

Supply Chain Execution
SCE

Mobile Resource Management
MRM

Minimize delays at the border
Meet current and future global compliance requirements

Purchased transportation spend of 5% - 15%
Administrative cost reduction, 90%-95% versus manual methods
Billing cycle reduction from months/weeks to weeks/days

Fleet size, workforce, contract carrier cost reduction of 5% - 20%
Mileage & fuel reduction of 10%-50%
Improved delivery reliability and reduced delivery lead-times
Integrated appointment scheduling through delivery.

Move Logistics information up the chain.

Order

Svc Center

Web

Point of Sale

Reservations

Plan

Dynamic & Incremental Scheduler engine

Calculate / Offer / Book Timeslot

Plan Route

Execute

Customer Service

Fully integrated with Scheduler engine

Dispatch AVL

Dispatch, Monitor & Mobile

Proof of Delivery, Assessorials, etc.
Typical Routing Problems

- **Shipment planning**
  - Set of orders to (or from) customers
  - Service customers from depots using available vehicles
  - May be daily or multi-day routes with TWs
  - Maybe heterogeneous vehicles

- **Residential waste pickup**
  - Pickup points with demands
  - Multiple visits to landfill to empty vehicle
  - Daily routes

- **Service technician routing**
  - Dispatching of repair technicians
  - Meter reading
  - Daily routes
The Core Problem

The essential problem in all these requirements:

• Determine the number of vehicles required to service the requirements
• Determine which vehicle services a particular customer

The above represents …
Vehicle Routing Problem

On a complete $G(V, E)$ with $V$ representing the depot (say node:0) and customers, VRP is defined as follows:

- Minimize

$$\sum_{i \in V} \sum_{j \in V} c_{ij} x_{ij}$$

- Subject to

$$\sum_{i \in V} x_{ij} = 1 \quad \forall \quad j \in V \setminus \{0\}$$

$$\sum_{j \in V} x_{ij} = 1 \quad \forall \quad i \in V \setminus \{0\}$$
\[ \sum_{j \in V} x_{0j} = K \]

\[ \sum_{i \in V} x_{i0} = K \]

\[ \sum \sum x_{ij} \leq |S| - r(S) \quad \forall \quad S \subseteq V \setminus \{0\}, S \neq \emptyset \]

\[ x_{ij} \in \{0, 1\} \quad \forall \quad i, j \in V \]
Capacitated VRP (CVRP)

• Has VRP formulation
• Added constraints for capacity restrictions on the vehicle
• Decisions made by CVRP
  – Assignment (customer to vehicle)
  – Routing (the sequence of customers visited by vehicle)
CVRP – Time Window (CVRPTW)

- CVRP formulation
- Added constraints for multiple time windows at the customers/depots
  - TWs e.g., MFW 08:00 – 11:00, MF 15:00 -17:30
- Decisions made by CVRPTW
  - Assignment
  - Routing
  - Scheduling (when to start the vehicle)
A relaxation of the VRP for:

- A single vehicle
- A single depot
- No additional operational constraints

Results in

- Traveling Salesman Problem (TSP)
- A known NP-Hard problem
Can we make CVRPTW harder?

• We need more operational constraints such as
  – Driver work time limits (daily and weekly)
  – Order incompatibility (two orders cannot be on the vehicle at the same time)
  – Smaller number of available roads when vehicle is carrying hazardous materials
  – Roads in urban areas subject to congestion if vehicle uses these roads during peak travel time
TSP heuristics do not help much when operational constraints are present.

Set partition/cover based algorithms are able to handle operational constraints better but these solutions do not scale well beyond small to medium size problem instances.
Typical Solution Requirements

• Solve medium to large size problems
  – 50 vehicles
  – 2500 stops
• Typical computers used to solve
  – 2 GHz machines
  – 4 GB RAM
• Solve times in minutes
• Solution should satisfy dispatchers and drivers
Solution Methodology

• Clustering heuristics
  – Identify orders that are close
    • By geographical metrics
    • Meet vehicle/customer requirements

• GRASP
  – Greedy Randomized Adaptive Search Procedure
  – Heuristic for combinatorial problems

• Improvement heuristics

• Background Optimizer (BGO)
GRASP

• Two phase solution methodology

• Phase I – sequential construction of feasible solutions

• Phase II – Local search to arrive at a local optimum
GRASP – Phase I

• Initialization
  – Build a starting (partial) solution for the number of routes to be created
  – Candidate jobs having similar insertion cost metric or are “difficult” jobs are added to a restricted candidate list (rcl)

• Construction
  – Candidates from rcl are randomly chosen to build routes
  – Assign all customers to one of these initialized routes based on a cost metric which attempts to assign “difficult” jobs first
GRASP – Phase II

• Local search in an attempt to find local optimum by route elimination
• Run improvement heuristics for current routes
• Accept worsening route moves with a certain probability to allow the solution to jump out of a local optima
• Look at one route at a time to
  – Remove crossovers between route legs within a route
  – Swap stops within a route (k-opt)
• Look at 2 or more routes at a time
  – Remove crossovers between routes
  – Swap/merge stops from one route to its neighbor
Background Optimizer (BGO)

• A service that continuously solves sub-problems in an attempt to improve the current best solution in the database
• Tailor BGO processing rules to a client’s need
• Works with the GRASP method to search for solutions
• BGO keeps working on the main problem set or sub-problems to find an improvement over the current best solution
BGO: Types of optimizations

BGO can be tailored in different operating environments to perform

- **Assignment**
  - When orders become available through an Order Management System

- **Improvement**
  - Set triggers to evaluate and check routes for improvements
    - Within a route (intra)
    - Between two routes (inter)

- **Batch assignment**
  - Re-optimize a subset of the original problem

- **Check status and fix**
  - If an order has changed, check for (and fix) any violation
Controlling Rules for BGO

• Use different strategies at different times during the day.

• The length of time an individual optimization is allowed to run before it is halted.

• The length of time the optimizer spends running sub-optimizations before moving on to the next kind of optimization.
Controlling Rules for BGO (cont.)

• Selecting the sub-problem:
  – Set of resources
  – Set of unassigned jobs

• Order of optimization (example: prioritize the most recently changed)
Change of State & BGO

- The state of the system is constantly changing because of
  - New orders
  - Changed orders
  - Vehicle updates

- BGO can be tailored keep working with the updated changes

- It can help a client to have a continuous optimization service
Moving from Optimization as an "Event" to Continuous Optimization

Orders/Trucks/Territories...

Rapidly Changing Data

Dynamically Accessed and Modified Routes

Schedules

Check out - Check In

Lights out, Continuously Optimized Routes

Opt 1
Opt 2
Opt N

Planners
Dispatchers
Sales & Service
Warehouse Ops
A Typical Midsize Problem

- Customers and depots in a 250 mile x 250 mile area
- 21 depots, 970 customers
- 95% of customers have 5 – 7 time windows for delivery
- 110 vehicles based at the depots
  - Max time limit and distance limits on routes
  - Driver daily breaks
  - Cost per mile, cost per hour with overtime rates
  - Capacity restrictions
- Road network includes interstates, state highways, county roads and local roads (data provided by Navteq)
- 2GHz machine, 2GB RAM
Routing Solution

- 961 orders
- 119 routes
- 21 depot
- Solution time 73 seconds (on 2GHz/2GB machine)
- On average:
  - 8+ stops/route
  - 6.4 hours/route
  - 170 miles/route
Optimization Challenges

• Real time routing
  – May yield a non-convex cost function
  – Performance: Re-routing v/s cache lookups

• Generate visually attractive routes

• Solving larger problem data sets
  (of up to a few thousand customers)

• Solving sub-problems by special methods
  (c.f. “Parametric Quantified SAT Solving”
  Sturm+Zengler, ISSAC 2010)