Overland Move Planning for Intermodal Logistics with Order Uncertainty

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ISERC 2013, Puerto Rico

Outline

Crowley Maritime Corporation

- US owned, Jacksonville, FL based marine solutions, transportation and logistics company.
- $1.6 billion annual revenues and approximately 5,300 employees.
- A fleet of 200 vessels.
- Over 230,000 revenue loads per year.

Problem Definition

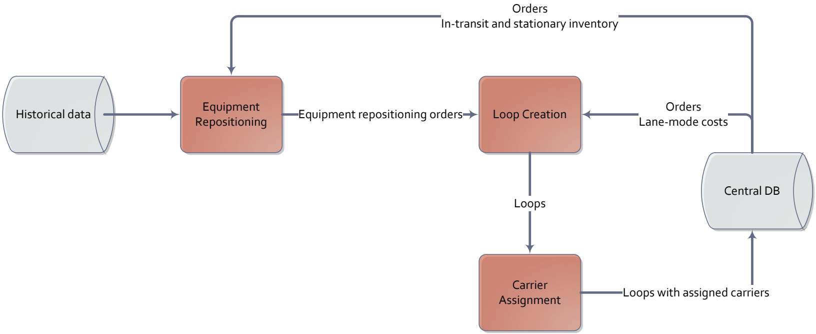
- Overland operations: Point-to-point moves
  - Ships coming northbound: Full truckloads need to be delivered to their final destinations.
  - Ships going southbound: Containers filled at any point in North America need to be picked up and moved to one of the ports.
- Empty container accumulation at some places due to demand imbalance throughout the transportation network.
- Carriers have to be assigned to a set of point-to-point moves.
  - Some carriers work home-based. Some can perform one direction routes.
  - There are regulations on working hours.

Solution Method

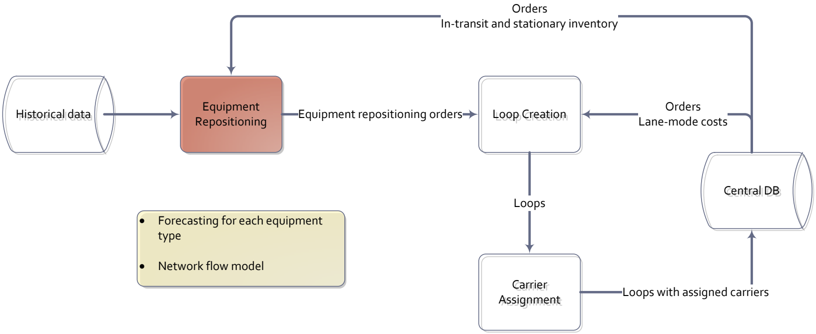
Problem decomposed into three sub-problems:

1. Empty container repositioning. (Jula *et al.* (2006), Imai *et al.* (2009), Song and Dong (2011), Di Francesco *et al.* (2012))
2. Loop creation. (Desrosiers *et al.* (1988), Agarwal *et al.* (1989), Arunapuram *et al.* (2003), Imai *et al.* (2007))
3. Carrier assignment.

Solution Architecture

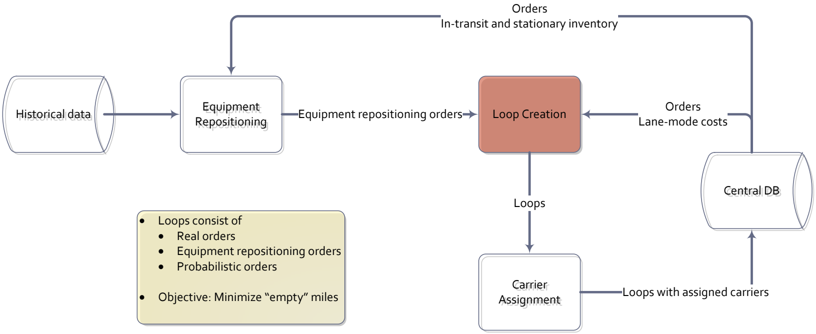


Solution Architecture



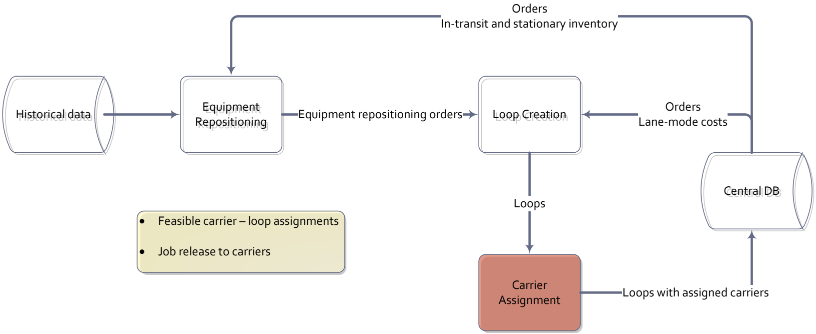
- Forecasting for each equipment type
- Network flow model

Solution Architecture

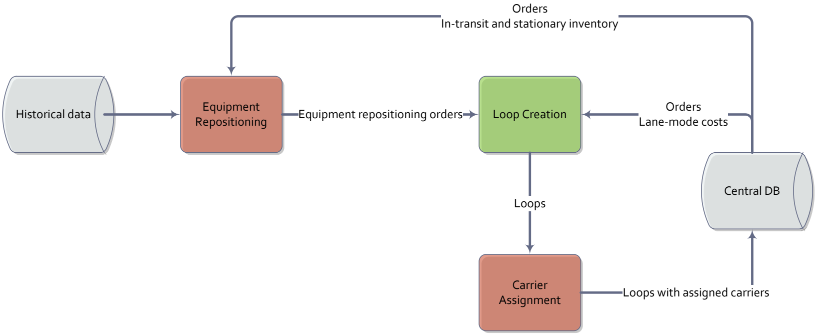


- Loops consist of
  - Real orders
  - Equipment repositioning orders
  - Probabilistic orders
- Objective: Minimize “empty” miles

Solution Architecture



Solution Architecture



Loop Creation Model

Problem: A variant of full truckload vehicle routing problem with time windows

Assumptions:

- Every location in the network can act as a depot.
- All routes have to be loops.
- Necessary equipment is ready at pick-up locations.

Objective: Minimize total number of "empty" miles.

$\rightarrow$ NP-Hard! (Arunapuram *et al.*, 2003)

MILP Formulation

Parameters:

- Orders, J, consisting of
  - Real orders, J_r,
  - Equipment repositioning orders, J_e,
  - Probabilistic orders, J_p.
  - Dummy orders, J_d.
- Locations, L.
- Vehicles, V.
- Time periods (days), T.

MILP Formulation

Parameters: (cont.)

- For each order $j \in J$,
  - $o(j)$: origin of order j,
  - $d(j)$: destination of order j,
  - $pd(j)$: pick-up date of order j,
  - $dd(j)$: delivery date of order j,
  - c_j: cost of transferring order j.
- $\tau(k, l)$: standard traveling time in days from location k to location l.
- α: maximum allowable length in days of any loop.

MILP Formulation

Decision variables:

- x_{jvt}: 1, if order j is moved by vehicle v at time t, 0 otherwise.
- y_{lv}: 1, if location l is first location visited by vehicle v, 0 otherwise.
- z_v: 1, if vehicle v is used, 0 otherwise.

$$\min \sum_{j\in J} c_j \sum_{v\in V}\sum_{t\in T} x_{jvt} \tag{1}$$

$$\text{s.t.} \sum_{v\in V}\sum_{t\geq pd(j)} x_{jvt} = 1, \qquad \forall j \in J_r \cup J_e \tag{2}$$

$$\sum_{j\in J} x_{jvt} \leq z_v, \qquad \forall v \in V \text{ and } t \in T \tag{3}$$

$$t \sum_{v\in V} x_{jvt} + \tau(o(j), d(j)) \leq dd(j), \qquad \forall t \in T, \forall j \in J \tag{4}$$

$$x_{jvt} \leq \sum_{j'\in\sigma(j)}\sum_{t'\in\gamma(j,t)} x_{j'vt'} + y_{d(j)v}, \qquad \forall j \in J,\ v \in V \text{ and } t \in T \tag{5}$$

$$\sum_{l\in L} y_{lv} = z_v, \qquad \forall v \in V \tag{6}$$

$$\sum_{j\in J'(l)}\sum_{t\in T} x_{jvt} = \sum_{j\in J''(l)}\sum_{t\in T} x_{jvt}, \qquad \forall v \in V \text{ and } \forall l \in L \tag{7}$$

$$\sum_{j\in J''(l)}\sum_{t\in T} x_{jvt} \leq 1, \qquad \forall v \in V \text{ and } \forall l \in L \tag{8}$$

$$\sum_{j\in J}\sum_{t\in T} \tau(o(j), d(j))\, x_{jvt} \leq \alpha, \qquad \forall v \in V \tag{9}$$

$$y_{lv} \in \{0,1\}, \qquad \forall l \in L \text{ and } v \in V \tag{10}$$

$$x_{jvt} \in \{0,1\}, \qquad \forall j \in J,\ v \in V \text{ and } t \in T \tag{11}$$

$$z_v \in \{0,1\}, \qquad \forall v \in V \tag{12}$$

Results for MILP

- Computer specs.: Intel(R) Core(TM)2 Quad CPU Q9500 @2.83GHz 4.00 GB RAM 64-bit.
- CPLEX version: 12.1. Time limit: 3600 sec.
- Below table shows the averages of 10 replicates.

#Regions	#Orders/day	#Days	Avg. run time (sec.)
5	5	7	51.3934
5	10	7	1729.217$^{(*)}$
5	15	7	Time limit reached
10	10	7	Memory limit reached
10	15	7	Memory limit reached

(*) Average of 4 instances. For remaining no solution within an hour.

A typical real instance size: over 600 regions, over 7500 orders in a week.

Column Generation

Set-partitioning formulation:

Parameter a_{ji}:

$$a_{ji} = \begin{cases} 1 & \text{if order } j \text{ is in loop } i \\ 0 & \text{otherwise} \end{cases}$$

Decision variable x_i:

$$x_i = \begin{cases} 1 & \text{if loop } i \text{ is selected} \\ 0 & \text{otherwise} \end{cases}$$

Column Generation

Set-partitioning formulation:

$$\min \sum_{i \in I} f_i \, x_i \tag{13}$$

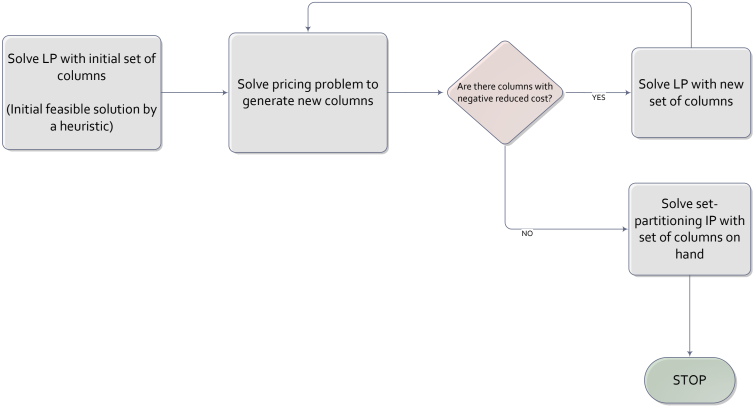
$$\text{s.t.} \sum_{i \in I} a_{ji} \, x_i = 1, \qquad \forall j \in J \tag{14}$$

$$x_i \in \{0, 1\}, \qquad \forall i \in I \tag{15}$$

where

- I: Set of all possible loops.
- f_i: Cost of performing loop i.

Column Generation Scheme



Column Generation

Pricing problem:

$$\min_{i \in I} \left\{ f_i - \sum_{j \in J} u_j \; a_{ji} \right\},$$

where

$$f_i = \sum_{j \in J} c_j \; a_{ji}.$$

We have

$$\min_{i \in I} \left\{ \sum_{j \in J} (c_j - u_j) \; a_{ji} \right\}$$

Column Generation

Solving pricing problem:

- Using an heuristic approach.
  1. Choose order j with lowest $(c_j - u_j)$ value and let k be $o(j)$.
  2. Populate eligible orders originating from $d(j)$.
  3. Choose order j with lowest $(c_j - u_j)$ value.
  4. If $d(j) = k$ or loop length exceeds α, STOP. Else go to step 2.

- Solving a smaller version of the "big" MILP formulation.
  1. Generating only one loop with negative reduced cost.

Preliminary Results

- Same computer and CPLEX as before.
- Below table shows the averages of 10 replicates.

#Regions	#Orders/day	#Days	Avg. run time (sec.)	Opt. gap
5	5	7	15.9429	0.0544$^{(*)}$
5	10	7	35.6537	0.1417
5	15	7	92.882	0.2468
10	10	7	69.1036	0.0237
10	15	7	155.3416	0.0484

(*) Objective function obtained by the algorithm is compared to real optimum. In other cases, gap from LP relaxation bound investigated.

Summary

- We study a practical logistics planning problem faced by Crowley: optimizing overland operations.
- We decomposed problem into three subproblems: Equipment repositioning, loop creation, and carrier assignment.
- In this talk, we focus on loop creation problem which is a variant of full truckload vehicle routing problem with time windows.
- We developed a full MILP formulation and a column generation based algorithm.

Future Work

- We work on improvements in column generation algorithm.
  - Generating initial set of columns.
  - Better heuristic to solve pricing problem.
  - Development of a branch-and-price algorithm.
- We will test our algorithm with real instances.

Thank you!