Real time optimization of a FTL transportation system

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CIRRELT

Outline

Introduction

Delivery is a complex problem addressed under several perspectives

- Time windows assignment [**?**]
- City logistics traffic [Coelho et al., 2016]
- Loading of the truck [**?**]
- Routing of the vehicles [Toth and Vigo, 2014]
- Customer satisfaction

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  - Delivery within desired time window [?]
  - Reduction of service time [?], [?]
  - Additional services [?]

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  - Installation service

Introduction

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What is the DIRPTW?

The DIRPTW is a VRPTW variant with synchronization constraints

- Installation by either deliverymen or installers
- Deliverymen and installers have different installation times
- Deliverymen have higher installation times
- Installer vehicles are faster, smaller, and cheaper than delivery vehicles

Constraints

1. Each customer is served by exactly one delivery vehicle
2. A deliveryman must serve a customer within its time window
3. An installer must serve a customer within its time window after the delivery
4. Each vehicle can wait at the customer until the time window opens
5. Each installation is either performed by a deliveryman or an installer

Definition of the DIRPTW

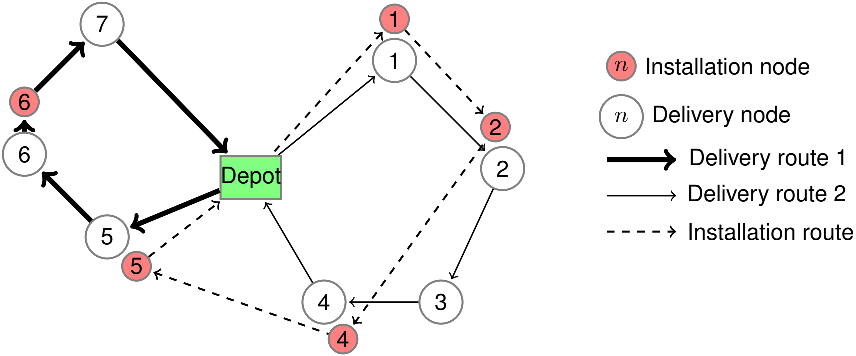


Figure: Solution of a MCDIRP with seven customers

Variables

- x_{ijk} equal to 1 if a deliveryman travels from i to j using vehicle k, and 0 otherwise
- y_{ijk} equal to 1 if an installer travels from i to j using vehicle k, and 0 otherwise
- z_i equal to 1 if a deliverymen installs at customer i location, and 0 otherwise

Subsets

- D is the set of delivery nodes
- I is the set of installation nodes
- D^I is the subset of delivery nodes that require an installation ($D^I \subseteq D$)
- $n(i)$ is the delivery node associated with the installation node i
- $l(j)$ is the installation node associated with the delivery node j

Three-index formulation (1)

$$\min \sum_{k\in K^D}\sum_{(i,j)\in A^D} c_{ijk}x_{ijk} + \sum_{k\in K^I}\sum_{(i,j)\in A^I} c_{ijk}y_{ijk}$$

Usage of vehicles

$$\sum_{j\in\delta^+(0)} x_{0jk} \le 1 \qquad k\in K^D, j\in D$$

$$\sum_{j\in\delta^+(0)} y_{0jk} \le 1 \qquad k\in K^I, j\in I$$

Assignment to deliverymen

$$\sum_{k\in K^D}\sum_{j\in\delta^+(i)} x_{ijk} = 1 \qquad i\in D$$

Degree constraints

$$\sum_{j\in\delta^-(i)} x_{jik} - \sum_{j\in\delta^+(i)} x_{ijk} = 0 \qquad i\in N,\ k\in K^D$$

$$\sum_{j\in\delta^-(i)} y_{jik} - \sum_{j\in\delta^+(i)} y_{ijk} = 0 \qquad i\in I,\ k\in K^I$$

Capacity constraints

$$\sum_{i\in D} q_i \sum_{j\in\delta^+(i)} x_{ijk} \le Q \qquad k\in K^D$$

Flexibility of installation

$$\sum_{k\in K^I}\sum_{j\in\delta^+(i)} y_{ijk} = 1 - z_i \qquad i\in I$$

Three-index formulation (2)

Timing constraints

$$
\begin{cases}
S_j \geq S_i + s_i^D + \sum_{k \in K^D} t_{ijk} x_{ijk} - M\left(1 - \sum_{k \in K^D} x_{ijk}\right) & (i,j) \in A^D, i \notin D^I \\
S_j \geq S_i + s_i^D + \sum_{k \in K^D} (s_{ik}^I + t_{ijk}) x_{ijk} - M\left(2 - \sum_{k \in K^D} x_{ijk} - z_{l(i)}\right) & (i,j) \in A^D, i \in D^I \\
S_j \geq S_i + \sum_{k \in K^I} (s_{ik}^I + t_{ijk}) y_{ijk} - M\left(1 - \sum_{k \in K^I} y_{ijk}\right) & (i,j) \in A^I \\
S_i \geq S_{n(i)} + s_{n(i)} & i \in I \\
a_i \leq S_i \leq b_i & i \in N
\end{cases}
$$

Domain of variables

$$
\begin{cases}
x_{ijk} \in \{0,1\} & (i,j) \in A, k \in K^D \\
y_{ijk} \in \{0,1\} & (i,j) \in A, k \in K^I \\
z_i \in \{0,1\} & i \in I.
\end{cases}
$$

Adaptive Large Neighorhood Search

First introduced in ? for the pickup and delivery routing problem

- Initial solution
- Destroy operators
- Repair operators

Adaptive Large Neighorhood Search

First introduced in ? for the pickup and delivery routing problem

- Initial solution
- Destroy operators
  - Random delivery removal
  - Related delivery removal
- Repair operators
  - Greedy sequential insertion
  - Regret-k insertion

Preprocessing procedure for insertion

Forward time slack [?]

$$F_i = \min_{i \leq k \leq \gamma+1} \sum_{i < p \leq k} W_p + (b_k - B_k) \quad (1)$$

- γ: number of nodes in a route
- A_i: arrival time at node i
- B_i: beginning service time at node i
- W_i: waiting time at node i

Addition of the waiting time at node i

$$F_i = \min_{i \leq k \leq \gamma+1} \sum_{i \leq p \leq k} W_p + (b_k - B_k) \quad (2)$$

$W_i = \max\{0, a_i - A_i\}$ for a delivery node i
$W_{l(i)} = \max\{0, B_i + s_i - A_{l(i)}\}$ for its installation node $l(i)$

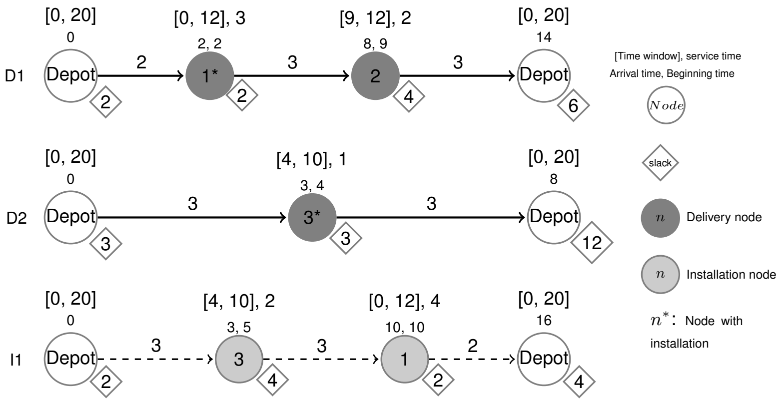
Preprocessing procedure for insertion

Delivery and installation on different routes

- compute the arrival time at all delivery nodes of the route
- compute the arrival time at all installation nodes of the route
- compute $F_{l(i)}$ using equation (2)
- compute F_i as:

$$F_i = \min \left\{ \min_{i<k\leq\gamma+1} \sum_{i<p\leq k} W_p + (b_k - B_k),\ b_i - B_i - s_i,\ F_{l(i)} - W_{l(i)} \right\} + W_i$$

Illustration of the forward time slack computation



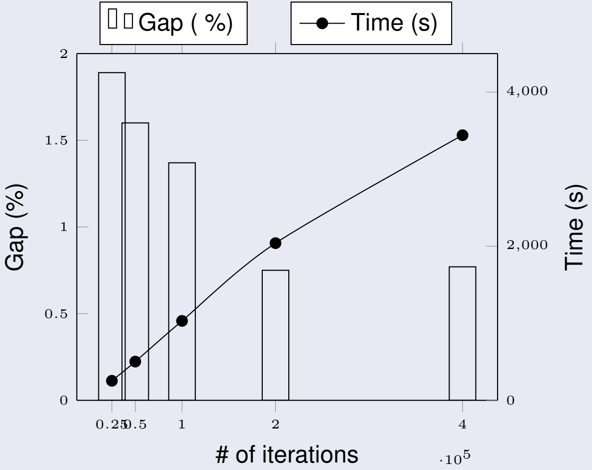
Instances generation

Modification of Solomon instances [?] for the VRPTW

- Customers: 15, 25, 50, 100
- Speeds of each delivery/installation vehicle: 1/2
- Costs of the delivery/installation vehicles: 2/1, 5/1 and 10/1
- Efficiency of the deliverymen when installing: [30%, 50%], [60%, 80%]
- Percentage of customers with installation: 20%, 50% and 75%

ALNS parameters tuning

Number of iterations



ALNS parameters tuning

Operators available

- Destroy operators: random and related removal
- Repair operators: greedy sequential (seq), regret-3, regret-m, regret-$3n$, regret-mn

Operators selection

Table: Quality of the solution when combining the operators

Combination of operators	Gap (%)	Time (s)	% of improvement
seq, regret-3, regret-m, regret-$3n$, regret-mn, related	-1.20	643.7	86.9
seq, regret-3, regret-m, regret-$3n$, regret-mn, random, related	-1.08	648.5	85.2
seq, regret-m, regret-mn, random	-0.98	690.6	84.3
seq, regret-3, regret-m, regret-$3n$, regret-mn, random	-0.96	649.5	83.5
seq, regret-m, regret-mn, random, related	-1.10	680.8	82.6
seq, regret-3, regret-$3n$, related	-0.62	531.1	82.6
seq, regret-m, regret-mn, related	-0.96	667.4	80.9
seq, regret-3, regret-$3n$, random, related	-0.59	535.9	79.1
regret-3, regret-mn, related	-0.80	708.4	78.3
regret-3, regret-m, related	-0.80	708.6	78.2
regret-$3n$, regret-mn, related	-0.80	712.2	78.3
seq, random	-0.36	132.3	78.3
seq, related	-0.35	131.1	78.3
seq, regret-3, regret-$3n$, random	-0.49	534.2	77.4
regret-m, regret-$3n$, related	-0.71	707.8	75.6
regret-3, regret-mn, random	-0.61	727.5	75.6
regret-3, regret-m, random	-0.60	732.0	75.6
regret-3, regret-m, random, related	-0.82	711.8	74.8
regret-$3n$, regret-mn, random, related	-0.82	712.6	74.8
regret-3, regret-mn, random, related	-0.82	714.8	74.8
regret-$3n$, regret-mn, random	-0.58	737.2	74.8
regret-m, regret-$3n$, random	-0.87	728.5	73.9
regret-m, regret-$3n$, random, related	-0.80	720.2	73.9
seq, random, related	-0.54	133.4	73.9

Results

Table: Results for all instances

		[30%, 50%]						[60%, 80%]					
Del cost	%Inst	Best(%)	Avg(%)	Del	Inst	Time(s)	Gap	Best(%)	Avg(%)	Del	Inst	Time(s)	Gap
	20%	0.0	0.2	3.3	0.2	51.3	16.5	0.0	0.2	3.2	0.1	51.7	15.6
2	50%	0.1	0.4	3.5	0.4	126.8	19.5	0.0	0.2	3.5	0.2	128.7	18.5
	75%	0.0	0.4	3.8	0.6	190.2	22.6	0.0	0.4	3.7	0.3	190.2	21.3
	20%	0.0	0.2	3.3	0.3	50.5	16.6	0.0	0.2	3.2	0.2	52.4	15.7
5	50%	0.0	0.3	3.4	0.6	128.5	19.3	0.0	0.3	3.3	0.4	129.1	19.0
	75%	0.0	0.4	3.5	0.9	200.3	21.6	0.0	0.5	3.5	0.7	203.4	21.5
	20%	0.0	0.2	3.2	0.4	51.0	17.1	0.0	0.2	3.1	0.2	52.5	16.0
10	50%	0.0	0.3	3.3	0.9	131.2	18.9	0.0	0.2	3.2	0.6	127.4	18.5
	75%	0.0	0.4	3.4	1.3	200.7	21.2	0.0	0.4	3.3	0.9	197.2	21.0
Average		0.0	0.3	3.4	0.6	125.6	19.2	0.0	0.3	3.3	0.4	125.8	18.6

Results

Table: Results for all optimal instances

% of inst	Perf	2				5				10			
		Opt	Best (%)	Time	Gap	Opt	Best (%)	Time	Gap	Opt	Best (%)	Time	Gap
20	[30%, 50%]	30	0.1	9	37	29	0.1	5.9	37.6	26	0.1	8.5	36.7
	[60%, 80%]	30	0.1	5.3	33.7	30	0.0	9.6	34.7	28	0.0	8.8	34.6
50	[30%, 50%]	27	0.2	10	43.8	24	0.2	13.9	41.8	22	0.1	13.5	39.2
	[60%, 80%]	25	0.1	8.1	39.2	21	0.2	7.2	38.8	23	0.1	8.4	39
75	[30%, 50%]	18	0.0	13.4	45.1	18	0.0	14.5	43.5	16	0.0	24.6	41.1
	[60%, 80%]	22	0.0	14.5	44.5	17	0.0	11.2	43	18	0.0	13.2	42.4
Solved		152				139				133			

Results

$$\sum_{k\in K^I}\sum_{j\in\delta^+(i)} y_{ijk} = 1 - z_i \qquad i\in I$$

Comparison when deliverymen efficiency are within [30%, 50%]

	20%				50%				75%			
Del cost	Opt	$z_i = 1$	$z_i = 0$	DIRPTW	Opt	$z_i = 1$	$z_i = 0$	DIRPTW	Opt	$z_i = 1$	$z_i = 0$	DIRPTW
2	28	909.6	908.6	**864.2**	26	722.6	803.3	**696.1**	17	896.1	1106.9	**855.2**
5	29	2247.8	2014.7	**1972.4**	24	2481.6	2107.0	**2020.0**	28	2107.9	1860.2	**1709.8**
10	26	4507.6	3875.3	**3838.4**	22	5008.6	3985.3	**3899.5**	16	5887.6	4174.9	**4051.2**

Comparison when deliverymen efficiency are within [60%, 80%]

	20%				50%				75%			
Del cost	Opt	$z_i = 1$	$z_i = 0$	DIRPTW	Opt	$z_i = 1$	$z_i = 0$	DIRPTW	Opt	$z_i = 1$	$z_i = 0$	DIRPTW
2	27	635.0	719.9	**633.4**	24	**619.6**	794.6	640.3	21	**913.2**	1268.8	920.7
5	30	2256.3	2275.2	**2182.8**	21	1589.9	1724.3	**1574.6**	17	1446.8	1630.2	**1424.9**
10	28	4066.8	3868.1	**3795.7**	23	3052.3	3112.8	**2972.6**	18	3429.5	3299.0	**3182.9**

Results

$$\sum_{k \in K^I} \sum_{j \in \delta^+(i)} y_{ijk} = 0 \qquad i \in I$$ Deliverymen make all installations

Comparison when deliverymen efficiency are within [30%, 50%]

Del cost	20% Opt	$z_i = 1$	$z_i = 0$	DIRPTW	50% Opt	$z_i = 1$	$z_i = 0$	DIRPTW	75% Opt	$z_i = 1$	$z_i = 0$	DIRPTW
2	28	909.6	908.6	**864.2**	26	722.6	803.3	**696.1**	17	896.1	1106.9	**855.2**
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Results

$$\sum_{k \in K^I} \sum_{j \in \delta^+(i)} y_{ijk} = 1 \qquad i \in I$$ Deliverymen never install

Comparison when deliverymen efficiency are within [30%, 50%]

Del cost	20% Opt	20% $z_i = 1$	20% $z_i = 0$	20% DIRPTW	50% Opt	50% $z_i = 1$	50% $z_i = 0$	50% DIRPTW	75% Opt	75% $z_i = 1$	75% $z_i = 0$	75% DIRPTW
2	28	909.6	908.6	**864.2**	26	722.6	803.3	**696.1**	17	896.1	1106.9	**855.2**
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Comparison when deliverymen efficiency are within [60%, 80%]

Del cost	20% Opt	20% $z_i = 1$	20% $z_i = 0$	20% DIRPTW	50% Opt	50% $z_i = 1$	50% $z_i = 0$	50% DIRPTW	75% Opt	75% $z_i = 1$	75% $z_i = 0$	75% DIRPTW
2	27	635.0	719.9	**633.4**	24	**619.6**	794.6	640.3	21	**913.2**	1268.8	920.7
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Results

$$\sum_{k\in K^I}\sum_{j\in\delta^+(i)} y_{ijk} = 1 - z_i \qquad i \in I$$ Both can install

Comparison when deliverymen efficiency are within [30%, 50%]

	20%				50%				75%			
Del cost	Opt	$z_i = 1$	$z_i = 0$	DIRPTW	Opt	$z_i = 1$	$z_i = 0$	DIRPTW	Opt	$z_i = 1$	$z_i = 0$	DIRPTW
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Comparison when deliverymen efficiency are within [60%, 80%]

	20%				50%				75%			
Del cost	Opt	$z_i = 1$	$z_i = 0$	DIRPTW	Opt	$z_i = 1$	$z_i = 0$	DIRPTW	Opt	$z_i = 1$	$z_i = 0$	DIRPTW
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Managerial insights

- The proposed strategy is better than the traditional strategies
- No need for installation fleet in the following cases:
  - A small number of customers with very few having an installation regardless of the cost or the performance of the deliveryman
  - Low deliveryman cost, higher efficiency, medium size of customers
- Use a distinct installation fleet is better when:

  Deliverymen efficiency are low and the cost range from medium to high
  - Deliverymen efficiency and cost are both high

Performance on the VRPMS instances set I

? studied the delivery and installation of large items

- Two distinct fleets are used
- A deliveryman and its installer arrival must be synchronized at a certain number of customer locations
- The installer must visit the customer within **ten** units of time after the start of the delivery service

Results on the VRPMS instances set

Performance on the VRPMS instances

	?				ALNS				
	Best(%)	Del	Inst	Time (s)	Best(%)	Avg (%)	Del	Inst	Time (s)
Average	6.9	8.4	3.7	63681.0	0.0	0.3	7.6	3.4	170.7

Results on the VRPMS instances set

Performance on the VRPMS instances

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	Best(%)	Del	Inst	Time (s)	Best(%)	Avg (%)	Del	Inst	Time (s)
Average	6.9	8.4	3.7	63681.0	0.0	0.3	7.6	3.4	170.7

Results for instances solved optimally with CPLEX

	?				ALNS					Exact method				
	Best (%)	Del	Inst	Time (s)	Best (%)	Avg (%)	Del	Inst	Time (s)	Opt	Gap(%)	Del	Inst	Time (s)
Average	3.0	9.1	4.3	33319.8	0.2	0.3	8.5	4.1	72.7	20.3	34.2	8.5	4.1	505.7
Solved	44				122					139				

Performance on the VRPTWDST instances set I

?

- Drivers have different efficiency with their customers
- Drivers have specific travel and service times in order to model their familiarity with the customers to visit
- No synchronization constraints

Performance on the VRPTWDST instances set II

Table: Lower and upper bounds for the VRPTWDST for the secondary objective of minimizing travelled distance

	?			ALNS			Exact	
	Best (%)	Opt	Time	Best (%)	Opt	Time	Gap(%)	Opt
C1	0.0	28/90	6.9	0.0	28/90	33.7	22.0	28/90
C2	0.0	24/80	10.5	0.0	24/80	46.8	4.1	24/80
R1	2.4	0/120	94.7	0.2	4/120	37.6	28.7	8/120
R2	6.6	0/110	45.3	0.1	0/110	73.2	19.6	0/110
RC1	3.8	0/80	53.1	0.3	0/80	32.6	40.2	0/80
RC2	10.7	0/80	67.4	0.1	0/80	54.1	28.6	0/80
Average	3.9	-	52.8	0.1	-	46.9	24.0	-
Solved		52/560			56/560		60/560	

Conclusion

- Novel distribution strategy proposed
- Insights about existing distribution and installation strategies
- An exact and heuristic algorithm to solve the DIRPTW
- New best-know and optimal solutions for the VRPMS and the VRPTWDST

Applications of the DIRPTW

Choose between a specialist and a generalist in the home care staff scheduling problem

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