Introduction to Column Generation and hybrid methods for Homecare Routing

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CHAIRE DE RECHERCHE DU CANADA EN ANALYTIQUE ET LOGISTIQUE DE SOINS DE SANTÉ HANALOG

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Acknowledgment

- The nicest slides in this presentation where contributed by several colleagues and students
  - Éric Prescott-Gagnon (JDA labs)
  - Florian Grenouilleau (Hanalog.polymtl)

An example

Vehicle routing problem

Vehicle routing problem

Customers

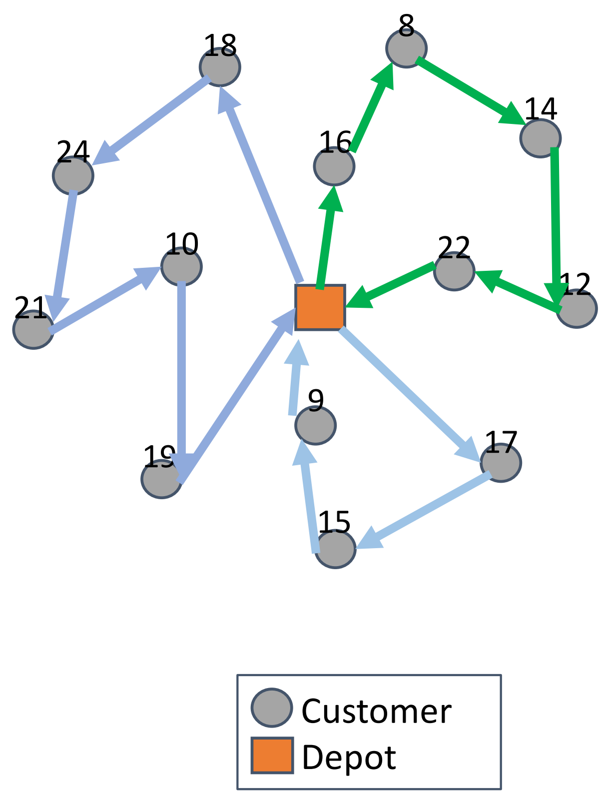
- Demand constraints

Vehicles

- Capacity constraints
- Flow conservation constraints

Objective:

- Find routes that minimize total distance



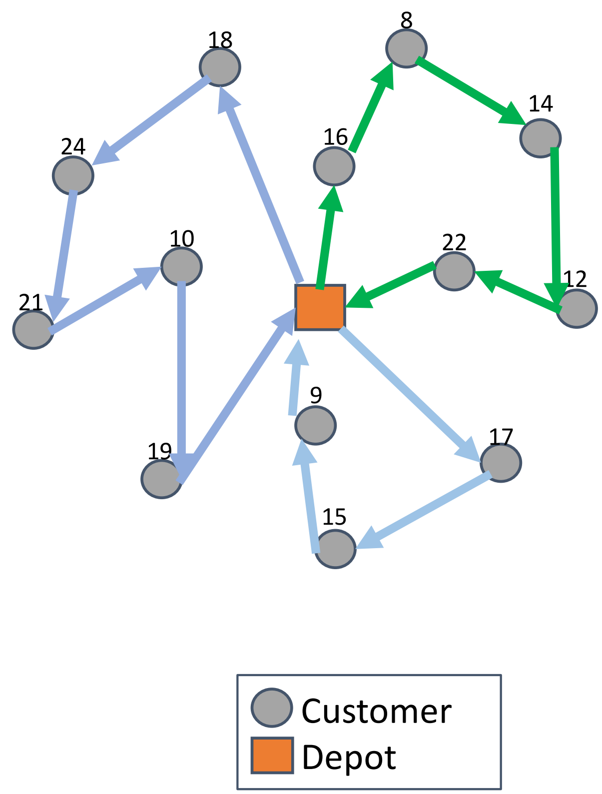
Vehicle routing problem

Standard mip formulation:

- Scaling issues
- Symmetry
- More complex constraints add even more complexity
- Some constraints can lead to bad linear relaxations.

Enumerate all possible routes

- Much simpler formulation
- Vehicle constraints are implicitly considered in route enumeration
- Better Linear Relaxation



Vehicle routing problem

Enumerate all possible routes

$$\text{Minimize} \quad \sum_{p \in \Omega} c_p \theta_p$$

$$\text{subject to:} \quad \sum_{p \in \Omega} v_{ip} \theta_p = 1 \qquad \forall i \in \mathrm{N}$$

$$\theta_p \in \{0,1\} \qquad \forall p \in \Omega$$

Vehicle routing problem

Enumerate all possible routes

$$\text{Minimize} \quad \sum_{p \in \Omega} c_p \theta_p$$

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$$\theta_p \in \{0,1\} \qquad \forall p \in \boxed{\Omega}$$

Set of customers

Set of routes

Vehicle routing problem

Enumerate all possible routes

Minimize $\sum_{p \in \Omega} c_p \theta_p$

subject to: $\sum_{p \in \Omega} v_{ip} \theta_p = 1 \qquad \forall i \in \mathrm{N}$

$\boxed{\theta_p} \in \{0,1\} \qquad \forall p \in \Omega$

$= \begin{cases} \mathbf{0}, & \textbf{\textit{if route p is used}} \\ \mathbf{1}, & \textbf{\textit{otherwise}} \end{cases}$

Vehicle routing problem

Enumerate all possible routes

Minimize $\sum_{p\in\Omega} \boxed{c_p}\theta_p$

Cost of route p

subject to: $\sum_{p\in\Omega} \boxed{v_{ip}}\theta_p = 1 \qquad \forall i \in N$

$= \begin{cases} \mathbf{1}, & \boldsymbol{if\ route\ p\ visits\ customer\ i} \\ \mathbf{0}, & \boldsymbol{otherwise} \end{cases}$

$\boxed{\theta_p} \in \{0,1\} \qquad \forall p \in \Omega$

$= \begin{cases} \mathbf{1}, & \boldsymbol{if\ route\ p\ is\ used} \\ \mathbf{0}, & \boldsymbol{otherwise} \end{cases}$

Vehicle routing problem

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Minimize $\sum_{p \in \Omega} \boxed{c_p} \theta_p$

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$= \begin{cases} 1, & \text{if route } p \text{ visits customer } i \\ 0, & \text{otherwise} \end{cases}$

$\boxed{\theta_p} \in \{0,1\} \quad \forall p \in \Omega$

$= \begin{cases} 1, & \text{if route } p \text{ is used} \\ 0, & \text{otherwise} \end{cases}$

Possibly huge number of routes

Vehicle routing problem

Enumerate all possible routes

Minimize $\sum_{p \in \Omega} \boxed{c_p} x_p$

Cost of route p

subject to: $\sum_{p \in \Omega} \boxed{v_{ip}} x_p = 1 \quad \forall i \in \mathrm{N}$

$= \begin{cases} 1, & \text{if route } p \text{ visits customer } i \\ 0, & \text{otherwise} \end{cases}$

$\boxed{x_p} \in \{0,1\} \quad \forall p \in \Omega$

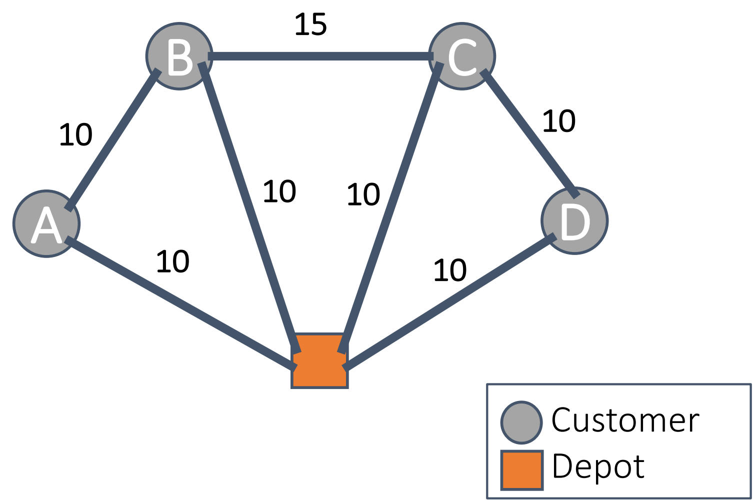
$= \begin{cases} 1, & \text{if route } p \text{ is used} \\ 0, & \text{otherwise} \end{cases}$

Possibly huge number of routes

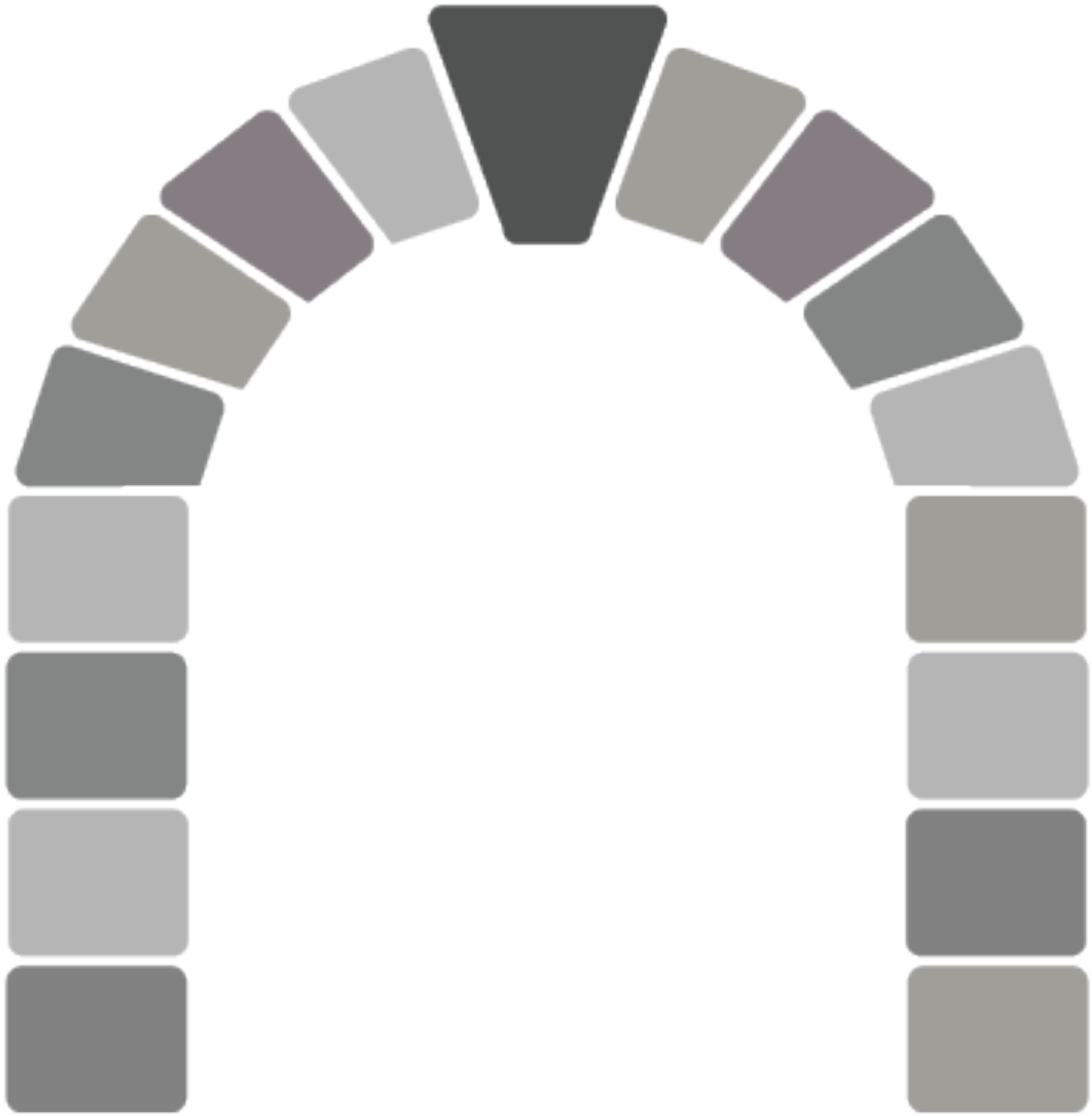
A very small number of routes are interesting

Vehicle routing problem

An example (max 2 clients)



$$
\begin{array}{lcccccccl}
\text{Min} & 20\,x_1 & +20\,x_2 & +20\,x_3 & +20\,x_4 & +30\,x_5 & +30\,x_6 & +35\,x_7 & \\
\text{A :} & x_1 & & & & +x_5 & & & = 1 \\
\text{B :} & & +x_2 & & & +x_5 & & +x_7 & = 1 \\
\text{C :} & & & +x_3 & & & +x_6 & +x_7 & = 1 \\
\text{D :} & & & & +x_4 & & +x_6 & & = 1
\end{array}
$$



An intuitive view of

Column Generation

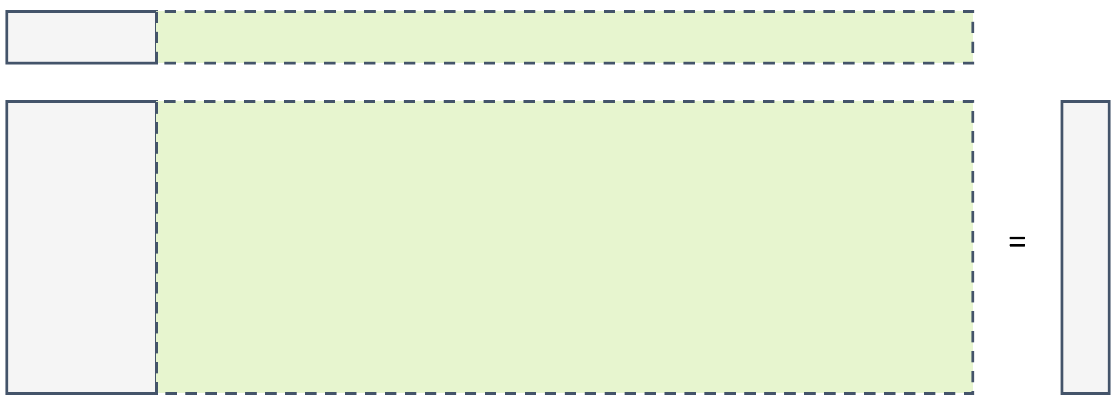
Column Generation

Solve linear programs with a lot of variables

Column Generation

Solve linear programs with a lot of variables

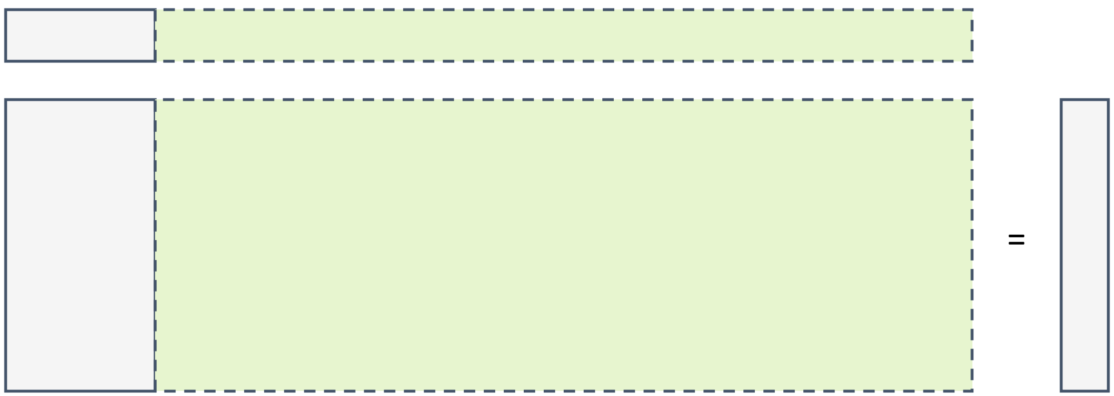
- Solve with a subset of variables



Column Generation

Solve linear programs with a lot of variables

- Solve with a subset of variables



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Solve linear programs with a lot of variables

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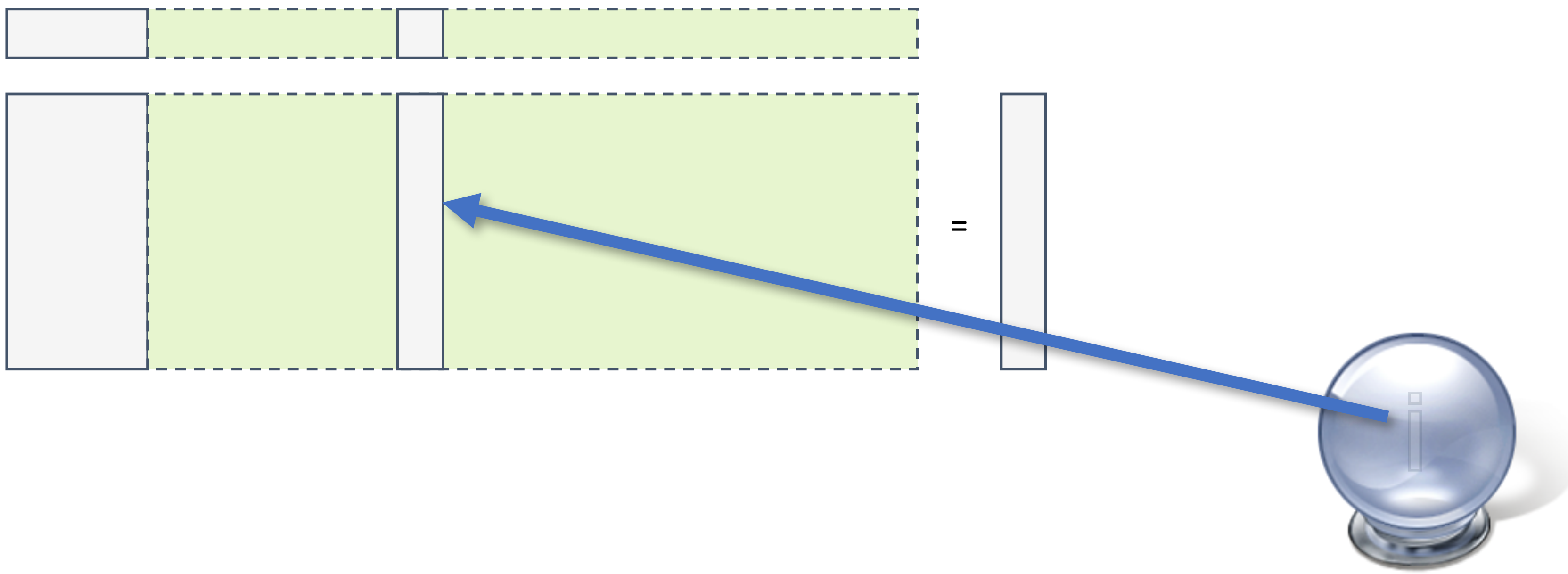

Column Generation

Solve linear programs with a lot of variables

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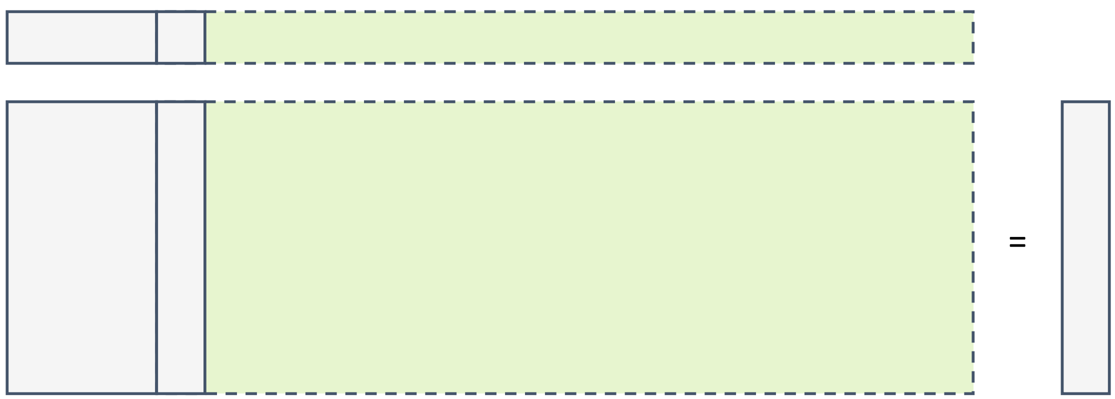

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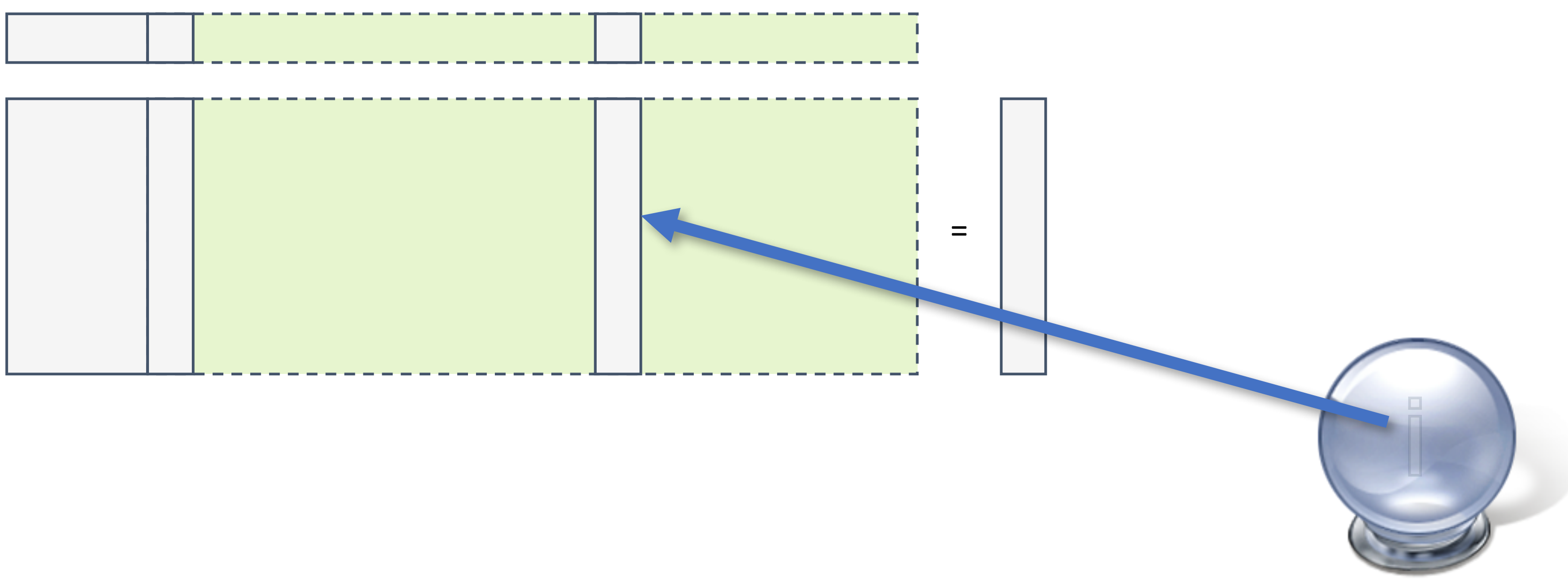

Column Generation

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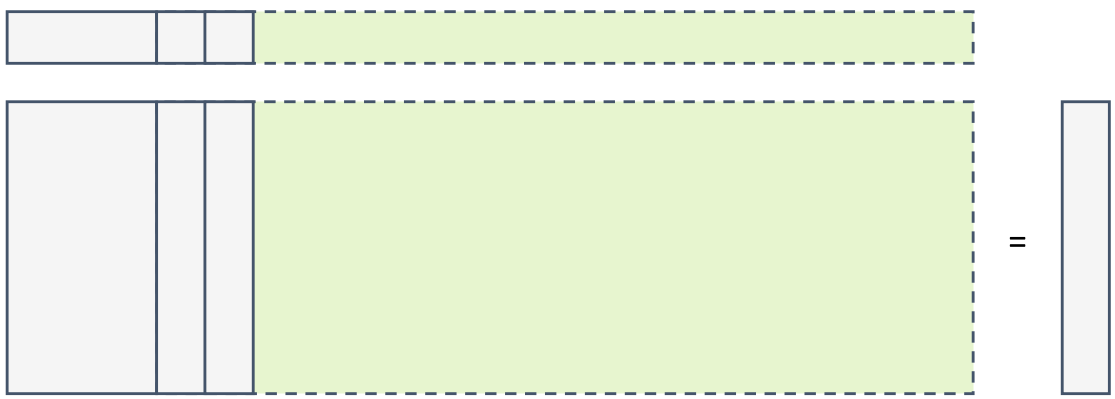

Column Generation

Solve linear programs with a lot of variables

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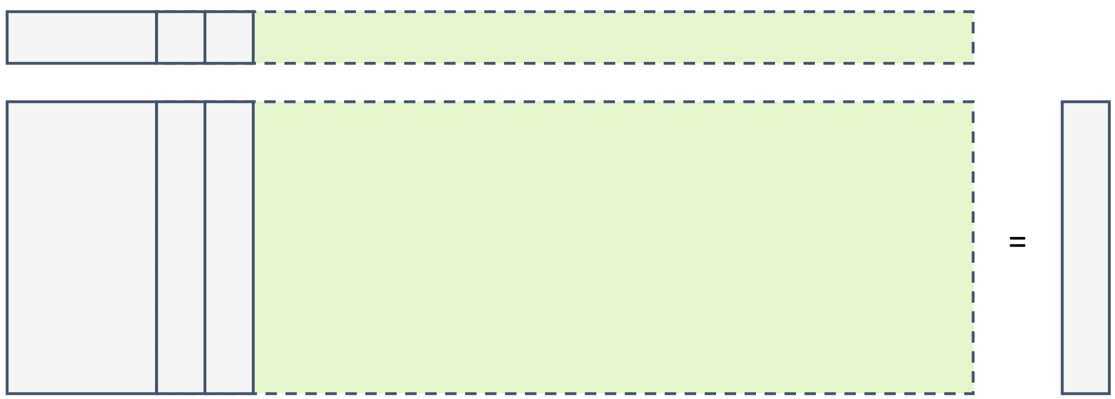
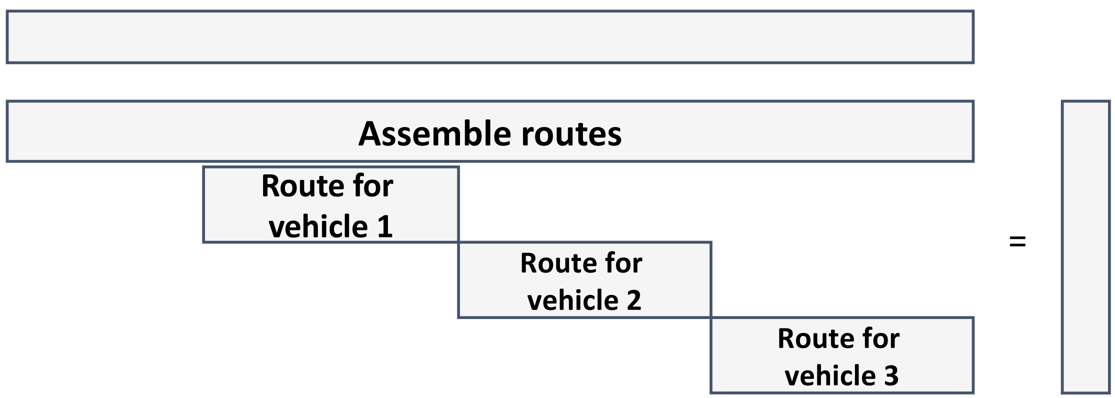


Column Generation

When to use column generation?

Column Generation

When to use column generation?

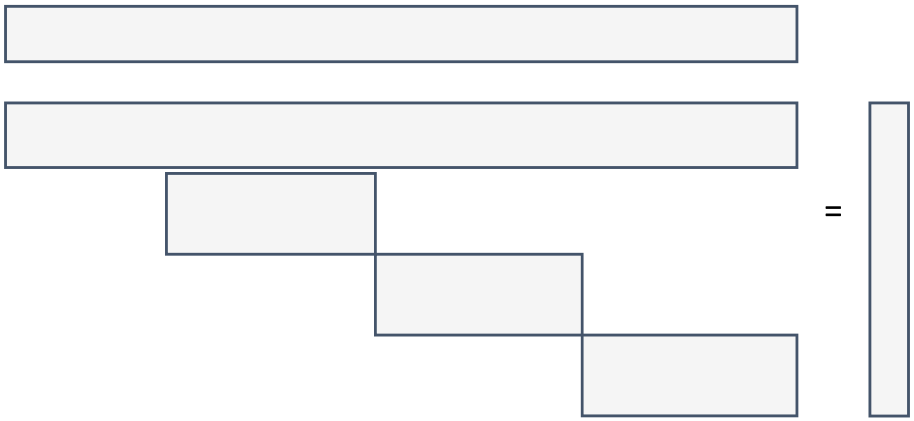


Column Generation

When to use column generation?

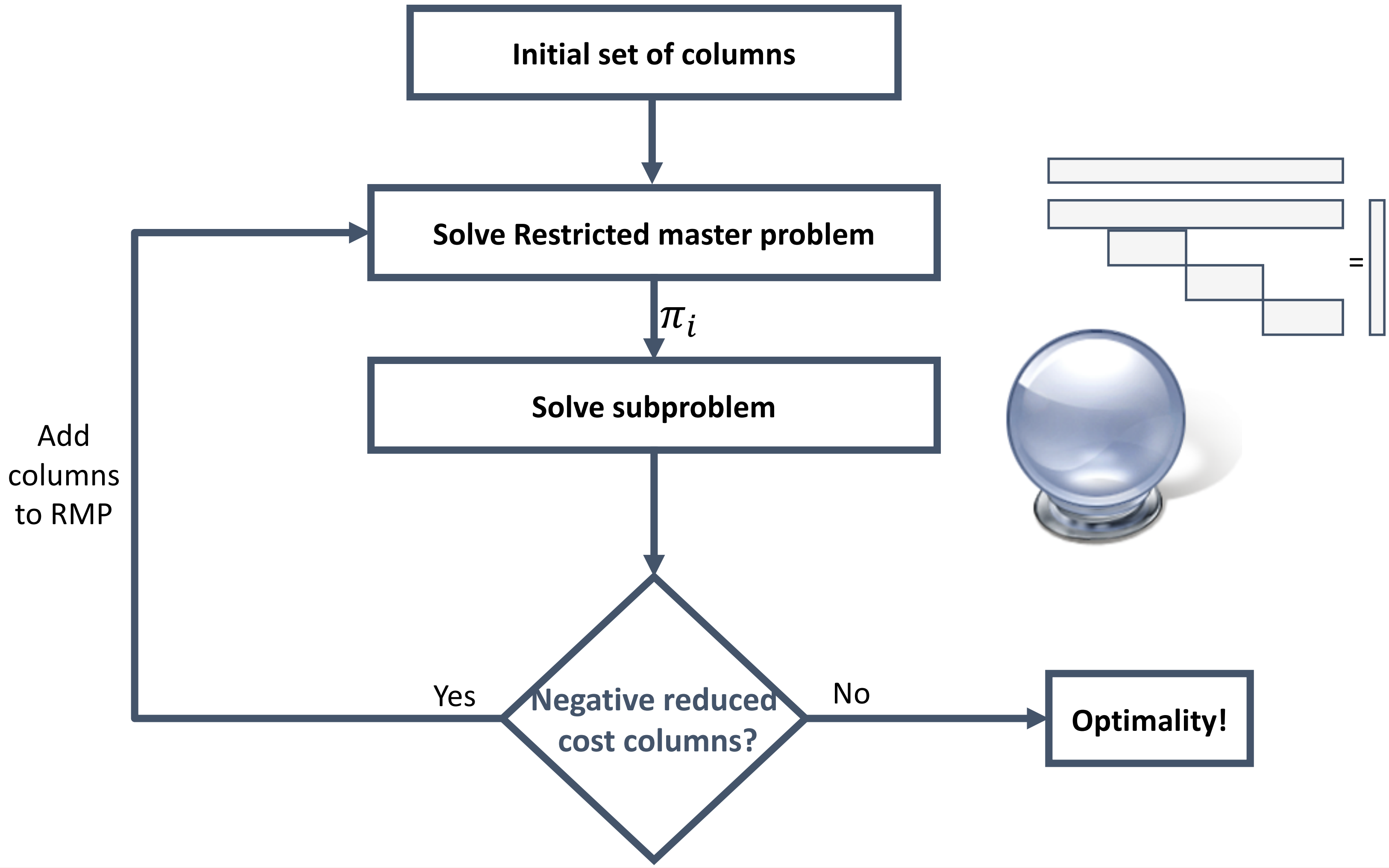
Works well generally on:

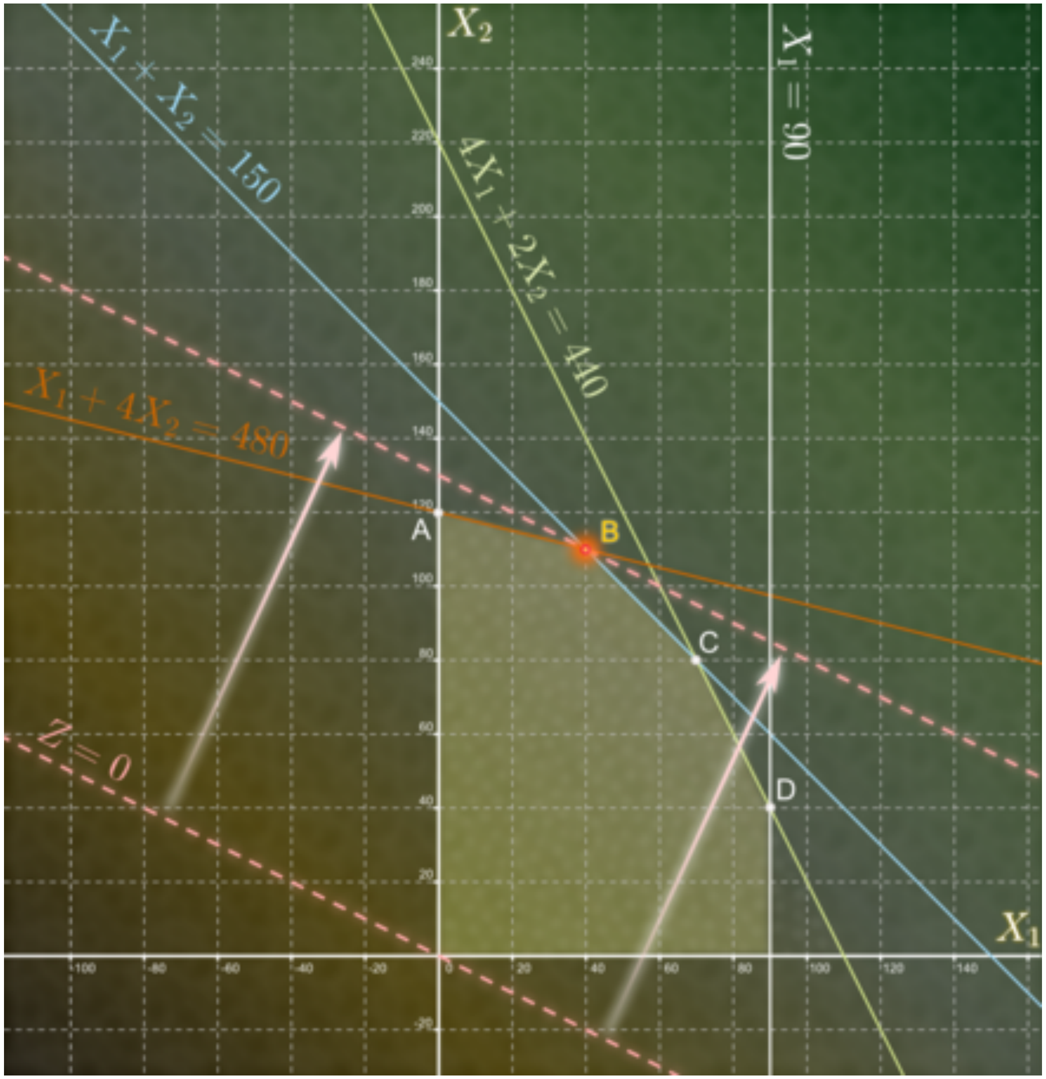
- Vehicle routing
- Airline Scheduling
- Shift Scheduling
- Jobshop Scheduling
- …



Worked the best when part of the problem has an underlying structure: Network, Hypergraph, knapsack, etc…

Column Generation



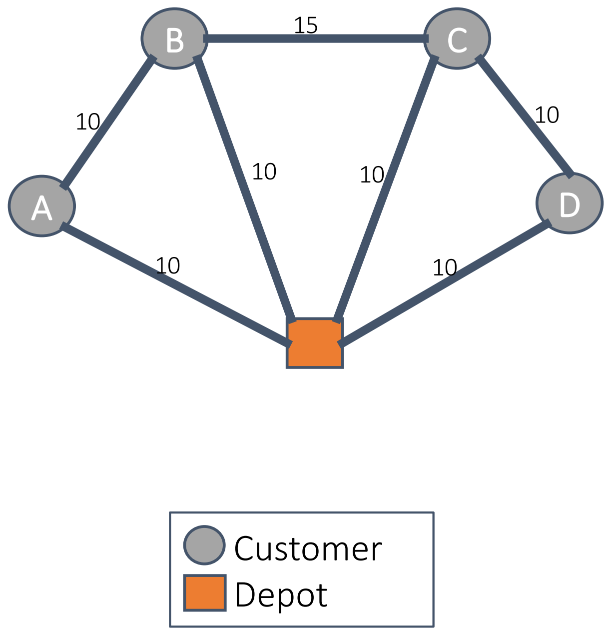


Master Probelm for the

Vehicle routing problem

Vehicle routing problem

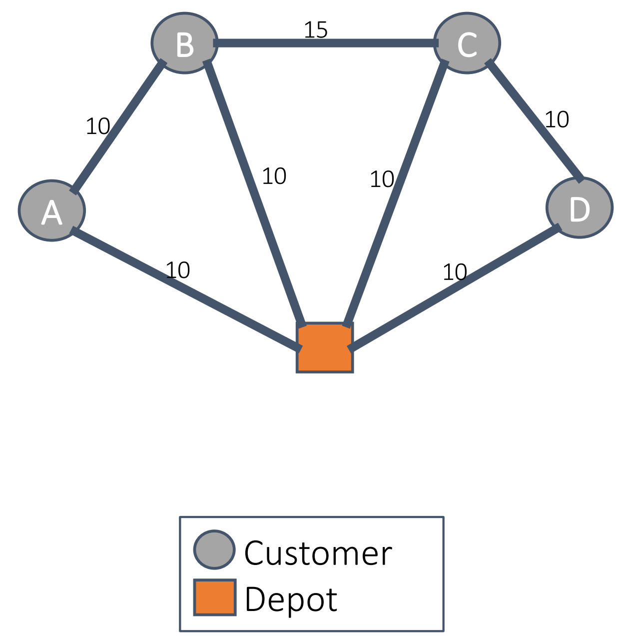
An example (max 2 clients)



Vehicle routing problem

An example (max 2 clients)

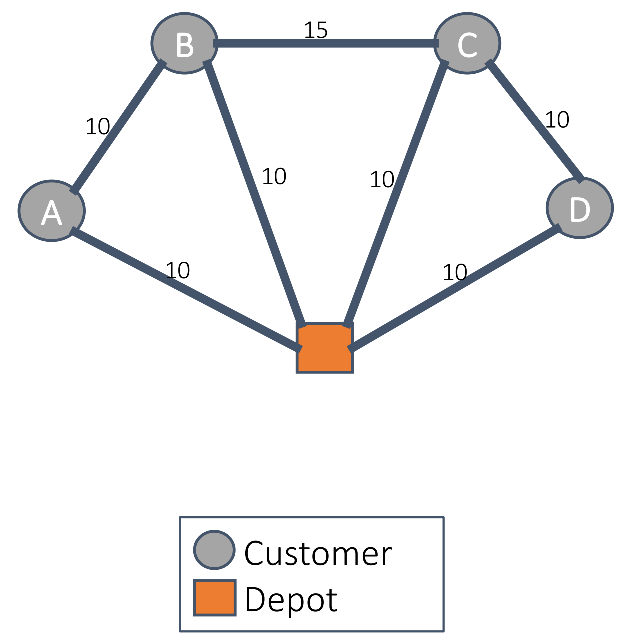
Min	$20\,x_1$	$+20\,x_2$	$+20\,x_3$	$+20\,x_4$	
A :	x_1				= 1
B :		x_2			= 1
C :			x_3		= 1
D :				x_4	= 1



Vehicle routing problem

An example (max 2 clients)

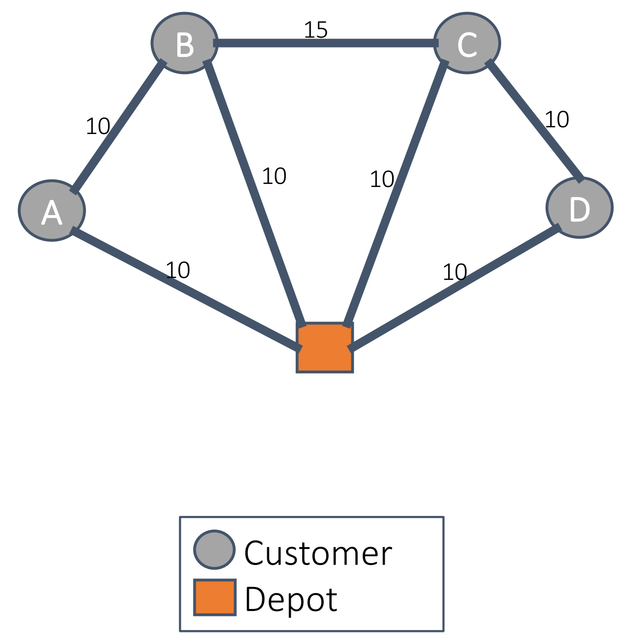
	x_1	x_2	x_3	x_4	
Min	20	20	20	20	
A :	1				= 1
B :		1			= 1
C :			1		= 1
D :				1	= 1



Vehicle routing problem

An example (max 2 clients)

	x_1	x_2	x_3	x_4		
$\hat{c}$	0	0	0	0		π_i
A :	1				= 1	20
B :		1			= 1	20
C :			1		= 1	20
D :				1	= 1	20
	1	1	1	1	$\boxed{80}$	



Vehicle routing problem

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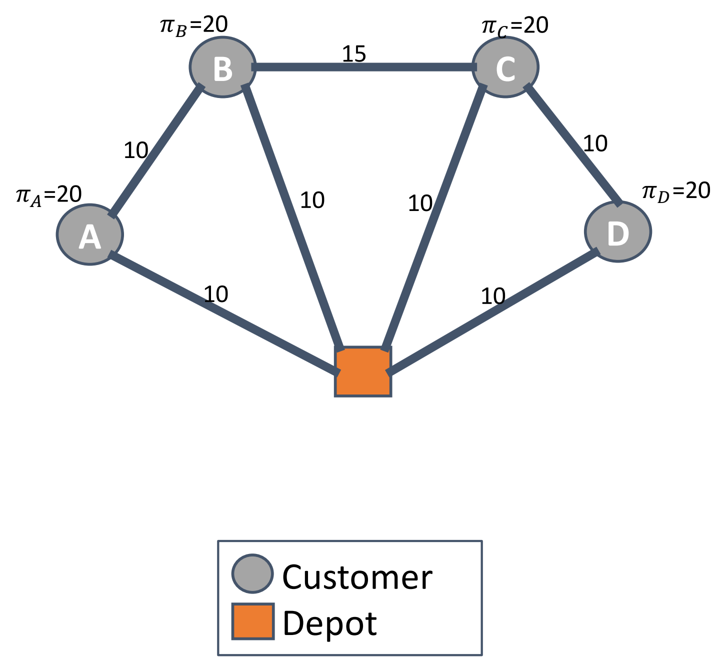
B :		1			= 1	20
C :			1		= 1	20
D :				1	= 1	20
	1	1	1	1	$\boxed{80}$	

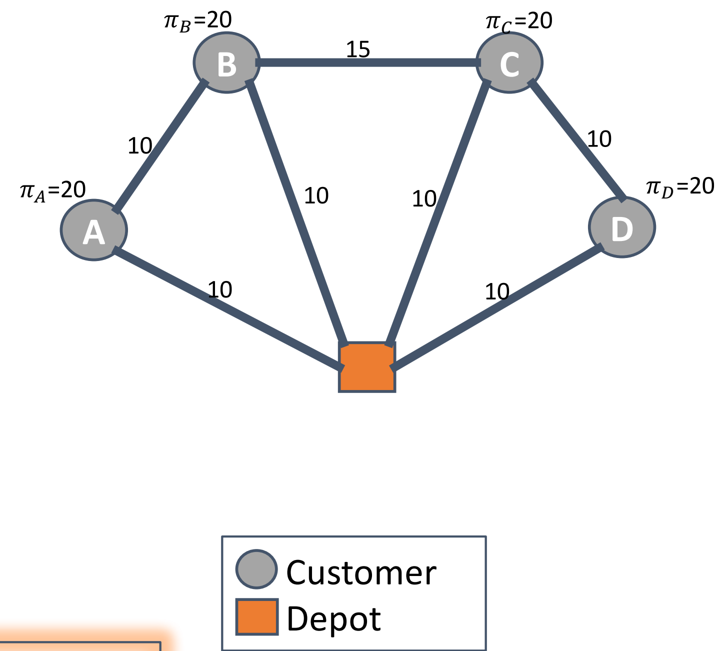
π_i : Marginal price of visiting customer *I*



Vehicle routing problem

An example (max 2 clients)

	x_1	x_2	x_3	x_4		π_i
$\hat{c}$	0	0	0	0		
A :	1				= 1	20
B :		1			= 1	20
C :			1		= 1	20
D :				1	= 1	20
	1	1	1	1	$\boxed{80}$	



π_i : Marginal price of visiting customer *I*

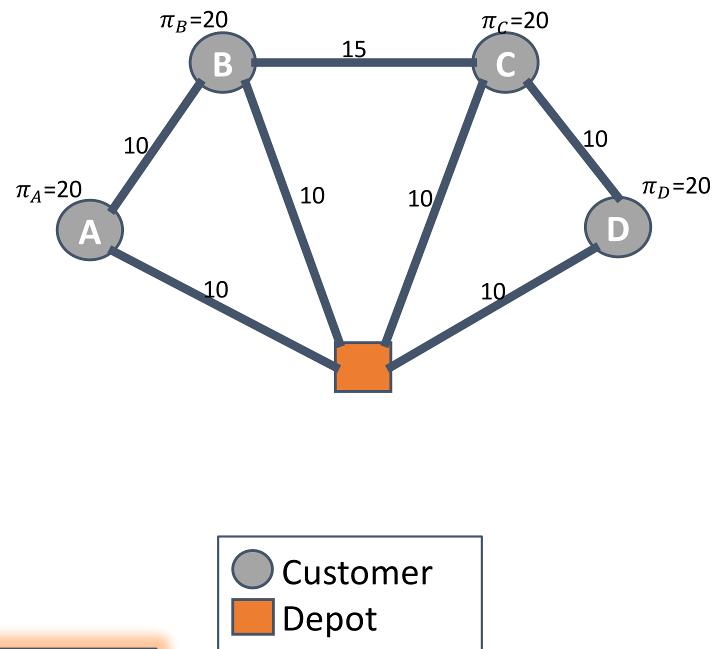
Can I find a route such that:

$$c < \sum \pi_i$$

Vehicle routing problem

An example (max 2 clients)

	x_1	x_2	x_3	x_4		π_i
$\hat{c}$	0	0	0	0		
A :	1				= 1	20
B :		1			= 1	20
C :			1		= 1	20
D :				1	= 1	20
	1	1	1	1	$\boxed{80}$	



π_i : Marginal price of visiting customer *I*

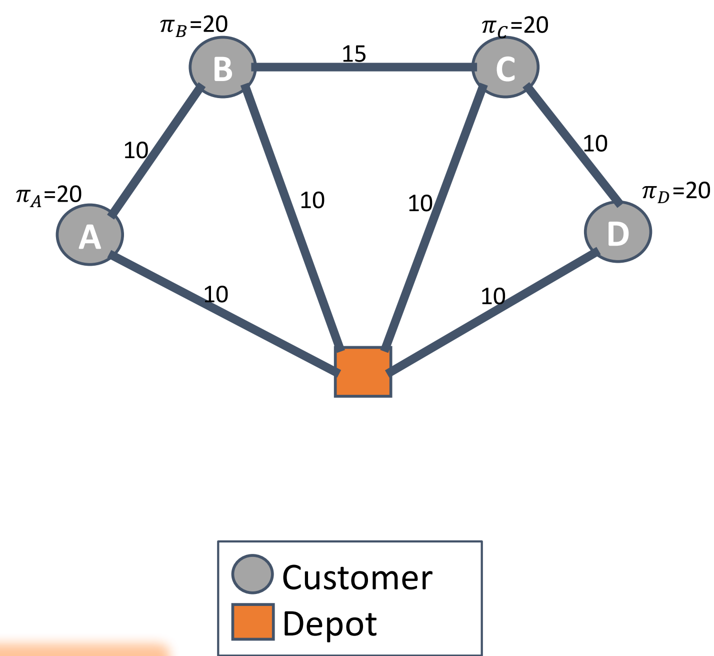
Can I find a route such that:

$$c - \sum \pi_i < 0$$

Vehicle routing problem

An example (max 2 clients)

	x_1	x_2	x_3	x_4		π_i
$\hat{c}$	0	0	0	0		
A :	1				= 1	20
B :		1			= 1	20
C :			1		= 1	20
D :				1	= 1	20
	1	1	1	1	$\boxed{80}$	



π_i : Marginal price of visiting customer *I*

Can I find a route such that:

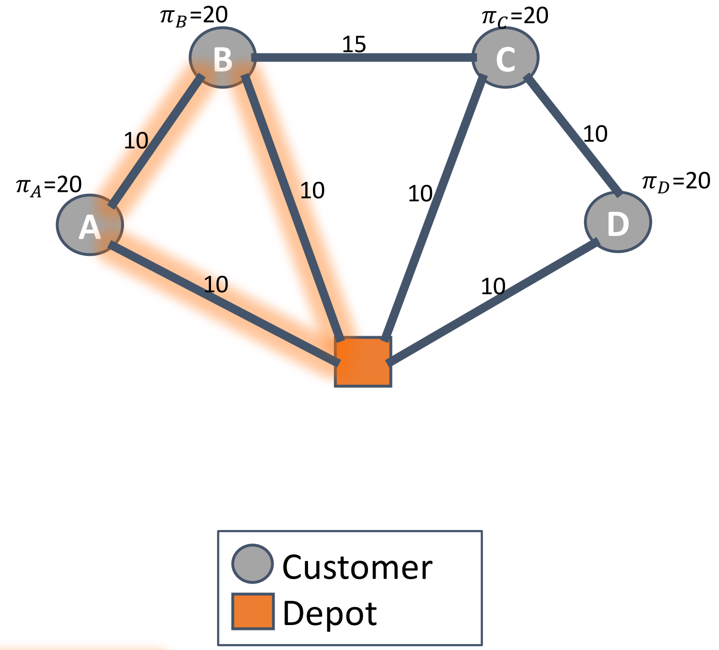
$$c - \sum \pi_i < 0$$

Reduced cost!

Vehicle routing problem

An example (max 2 clients)

	x_1	x_2	x_3	x_4		π_i
$\hat{c}$	0	0	0	0		
A :	1				= 1	20
B :		1			= 1	20
C :			1		= 1	20
D :				1	= 1	20
	1	1	1	1	$\boxed{80}$	



π_i : Marginal price of visiting customer *I*

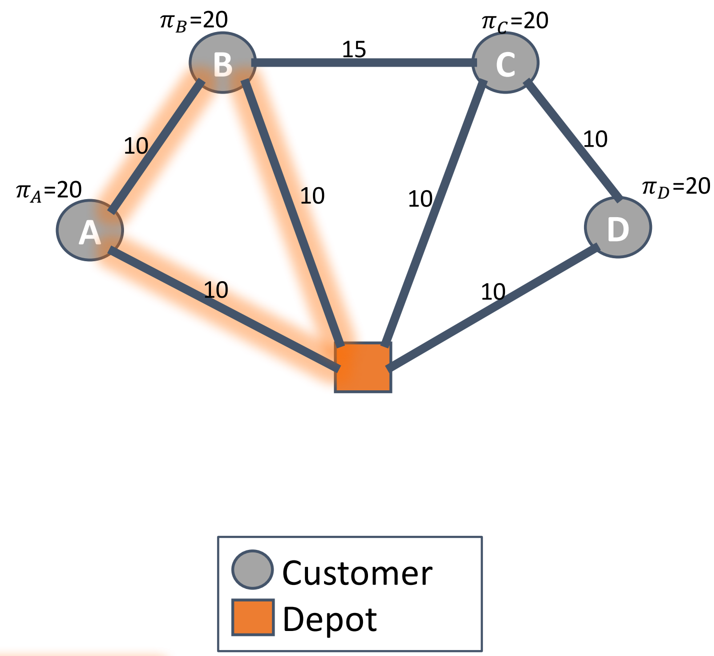
Can I find a route such that:

$$c - \sum \pi_i < 0$$

Vehicle routing problem

An example (max 2 clients)

	x_1	x_2	x_3	x_4	x_5		
$\hat{c}$	0	0	0	0	-10		π_i
A :	1				1	= 1	20
B :		1			1	= 1	20
C :			1			= 1	20
D :				1		= 1	20
	1	1	1	1		$\boxed{80}$	



π_i : Marginal price of visiting customer *I*

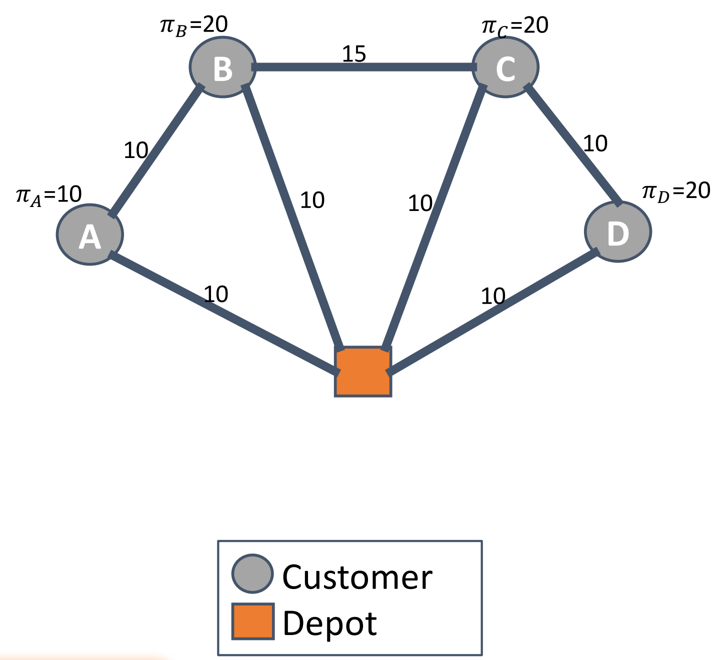
Can I find a route such that:

$$c - \sum \pi_i < 0$$

Vehicle routing problem

An example (max 2 clients)

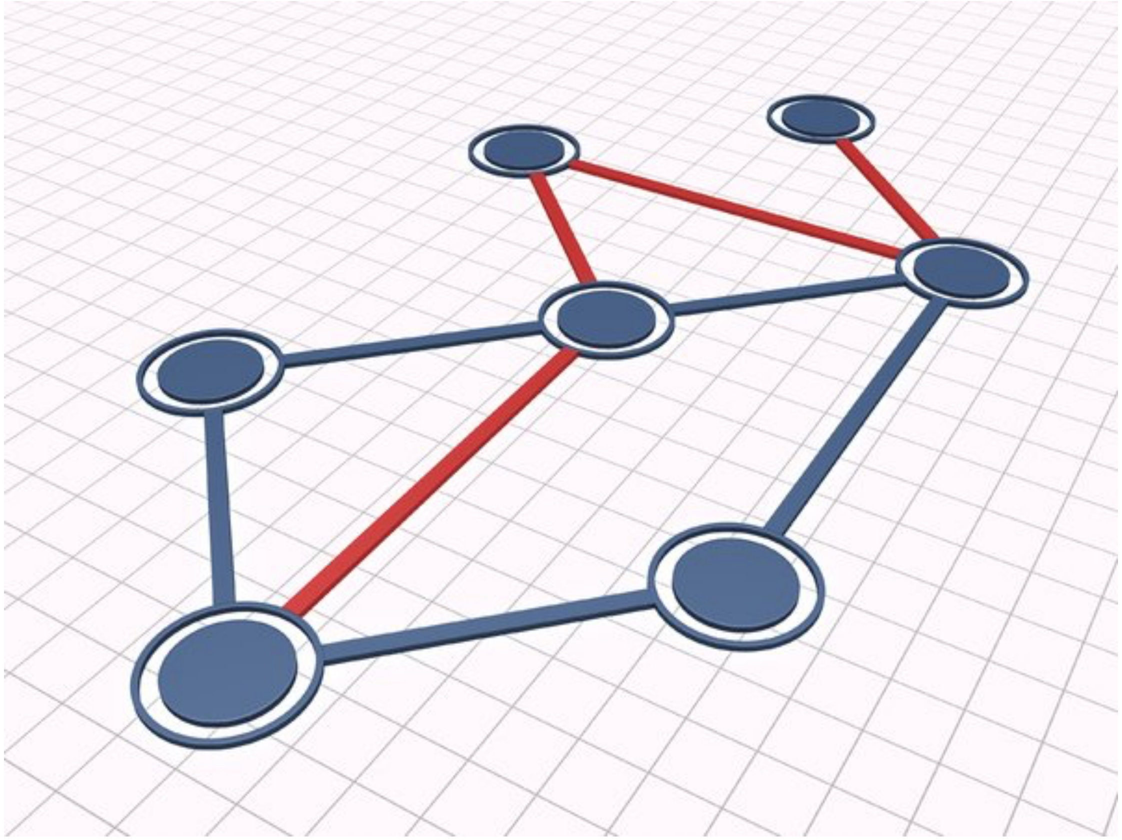
	x_1	x_2	x_3	x_4	x_5		
$\hat{c}$	10	0	0	0	0		π_i
A :	1				1	= 1	10
B :		1			1	= 1	20
C :			1			= 1	20
D :				1		= 1	20
		0	1	1	1	$\boxed{70}$	



π_i : Marginal price of visiting customer *I*

Can I find a route such that:

$$c - \sum \pi_i < 0$$



Sub Probelm for the

Vehicle routing problem

General Subproblem

Implicit representation of all variables

- Every possible solution to the subproblem is a variable

Optimization objective:

→ find variable with (the most) negative reduced cost

$$\text{Min } \hat{c} = c - \sum_i a_i \pi_i \qquad a_i = \begin{cases} 1, & \textit{if customer i is visited} \\ 0, & \textit{otherwise} \end{cases}$$

$$c = \sum_x c_x x$$

General Subproblem

Implicit representation of all variables

- Every possible solution to the subproblem is a variable

Optimization objective:

→ find variable with (the most) negative reduced cost

$$\text{Min } \hat{c} = \sum_x c_x x - \sum_i \pi_i a_i \qquad a_i = \begin{cases} 1, & \textit{if customer i is visited} \\ 0, & \textit{otherwise} \end{cases}$$

Subproblem

Implicit representation of all variables

- Every possible solution to the subproblem is a variable

Optimization objective:

→ find variable with (the most) negative reduced cost

$$\text{Min } \hat{c} = \sum_x c_x x - \sum_i \pi_i a_i$$

$$a_i = \begin{cases} 1, & \textit{if customer i is visited} \\ 0, & \textit{otherwise} \end{cases}$$

Subject to: Capacity constraints

Flow conservation constraints

Shortest-path problem with resource constraints:
Dynamic programming

Resources Constraint SPP

Resource $\mathbf{r = 1,\ldots,R}$

Resource consumption $\mathbf{t^r_{ij} > 0}$ on each arc.

Resources window$[\mathbf{a^r_i}, \mathbf{b^r_i}]$ at each node

- Resources level cannot go above $\mathbf{b^r_i}$ when node $\mathbf{v_i}$ is reached
- If $\mathbf{t^r_{ij}}$ is below $\mathbf{a^r_i}$ when node path reaches $\mathbf{v_i}$ then is it set to $\mathbf{a^r_i}$

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Resources Constraint SPP - DP

Dynamic Programming Algorithm

- L_i : list of labels associated with node v_i
- label $l = (c, T^1, \ldots, T^R)$ where
  - a label represents a partial path from v_0 to v_i
  - c is the cost of the label or
  - T^r is the consumption level of resource r
  - $v(l)$ is the node which to which l is associated

Resources Constraint SPP - DP

Extending a label $\mathbf{l = (c,T^1{}_i,\ldots, T^R{}_i)}$ from $\mathbf{v_i}$ to $\mathbf{v_j}$

- Create a label $\mathbf{(c + c_{ij}, T^1+t^1{}_{ij},\ldots, T^R + t^R{}_{ij})}$
  - Making sure we respect $\mathbf{[a^1{}_j,b^1{}_j],\ldots, [a^R{}_j,b^R{}_j]}$

- Insert the label in the list of labels associated with $\mathbf{v_j}$

- Apply **Dominance Rules**
  - Without such rules, the algorithm would enumerates all possible paths

- Resources constraints make sure the algorithm terminates

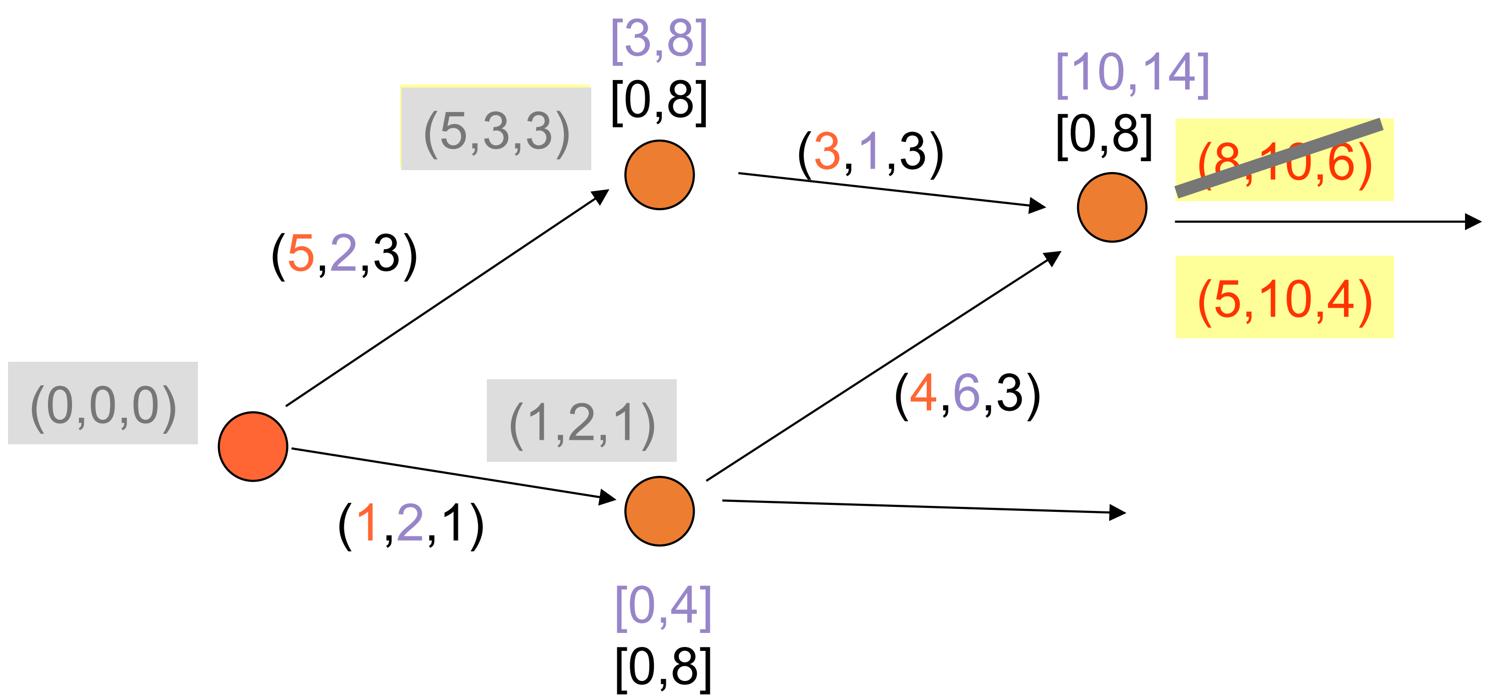
Resources Constraint SPP - DP

Dominance Rules: l_1 **dominates** l_2 iff :

- **$c(l_1) <= c(l_2)$**
- Every feasible **future extensions** of l_2 will be feasible for l_1
  - *Most often* we check that **$T^r(l_1) <= T^r(l_2)$** for all r

Dominance: an example

label : (c, time, capacity)



Subproblem – Constraint Programming

"Arc Flow" model

Objectives:

- Minimize: $\sum_i (\text{ReducedCost}(i, S_i))$

Variables:

• $S_i \in N$	Successor of node i
• $V_i \in \{False, True\}$	Node i visited by current path
• $l_i \in [0..Capacity]$	Truck load after visit of node i

Constraints:

• $S_i = i \rightarrow V_i = False$	S-V Coherence constraints
• AllDiff(S)	Conservation of flow
• Circuit(S)	SubTour elimination constraint
• $S_i = j \rightarrow l_i + D_j = l_j$	Capacity constraints

+ Redundant Constraints from work on TSP(TW)

Subproblem – Constraint Programming

"Position" model

Objectives:

- Minimize: $\sum_k$ (ReducedCost(P_k, P_{k+1}))

Variables:

- $P_k \in N$ — Node visited a position k
- $L_k \in [0..Capacity]$ — Truck load after visiting position k

Constraints:

- **AllDiff(P)** — **Elementarity of the path**
- $L_{k+1} = L_k + D_{Pk}$ — Capacity constraints
- $P_k = depot \rightarrow P_{k+1} = depot$ — Padding at the end of path

Can you compare these models?

"Arc Flow" model

Objectives:

- Minimize: $\sum_i$ (ReducedCost(i, S_i))

Variables:

- $S_i \in N$
- $V_i \in$ {False,True}
- $l_i \in [0..\text{Capacity}]$

Constraints:

- $S_i = i \rightarrow V_i$ =False
- AllDiff(S)
- Circuit(S)
- $S_i = j \rightarrow l_i + D_j = l_j$

"Position" model

Objectives:

- Minimize: $\sum_k$ (ReducedCost(P_k, P_{k+1}))

Variables:

- $P_k \in N$
- $L_k \in [0..\text{Capacity}]$

Constraints:

- AllDiff(P)
- $L_{k+1} = L_k + D_{Pk}$
- $P_k = \text{depot} \rightarrow P_{k+1} = \text{depot}$

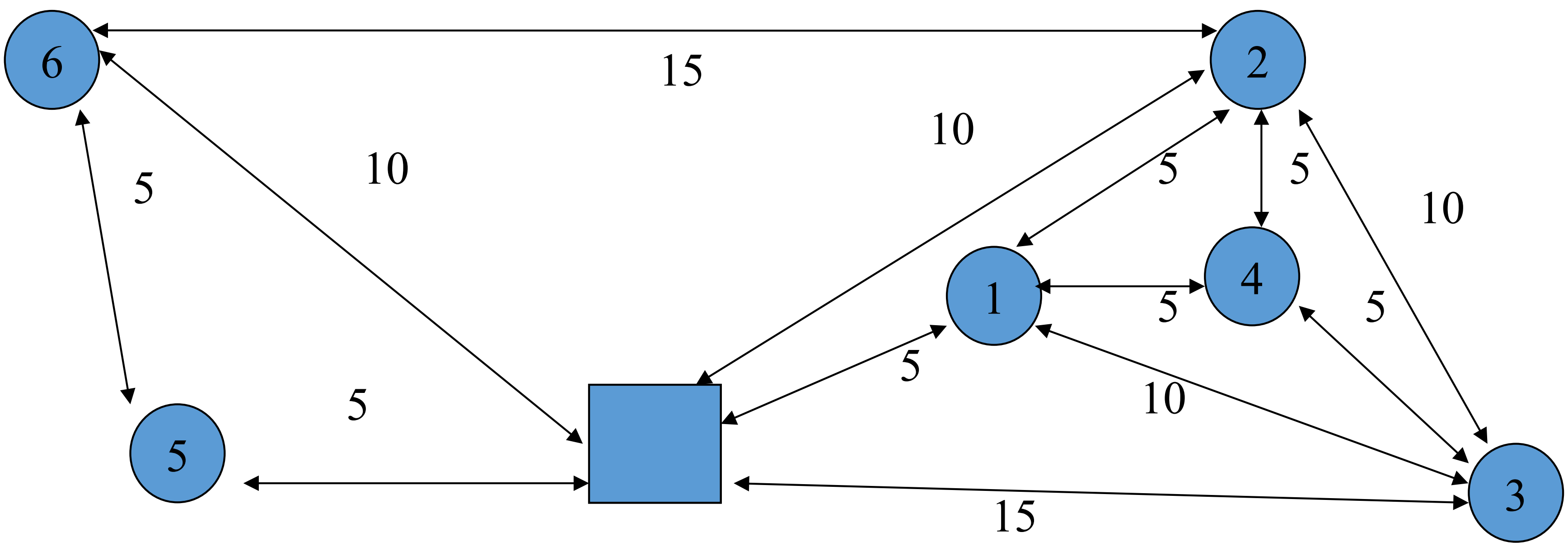
Column generation

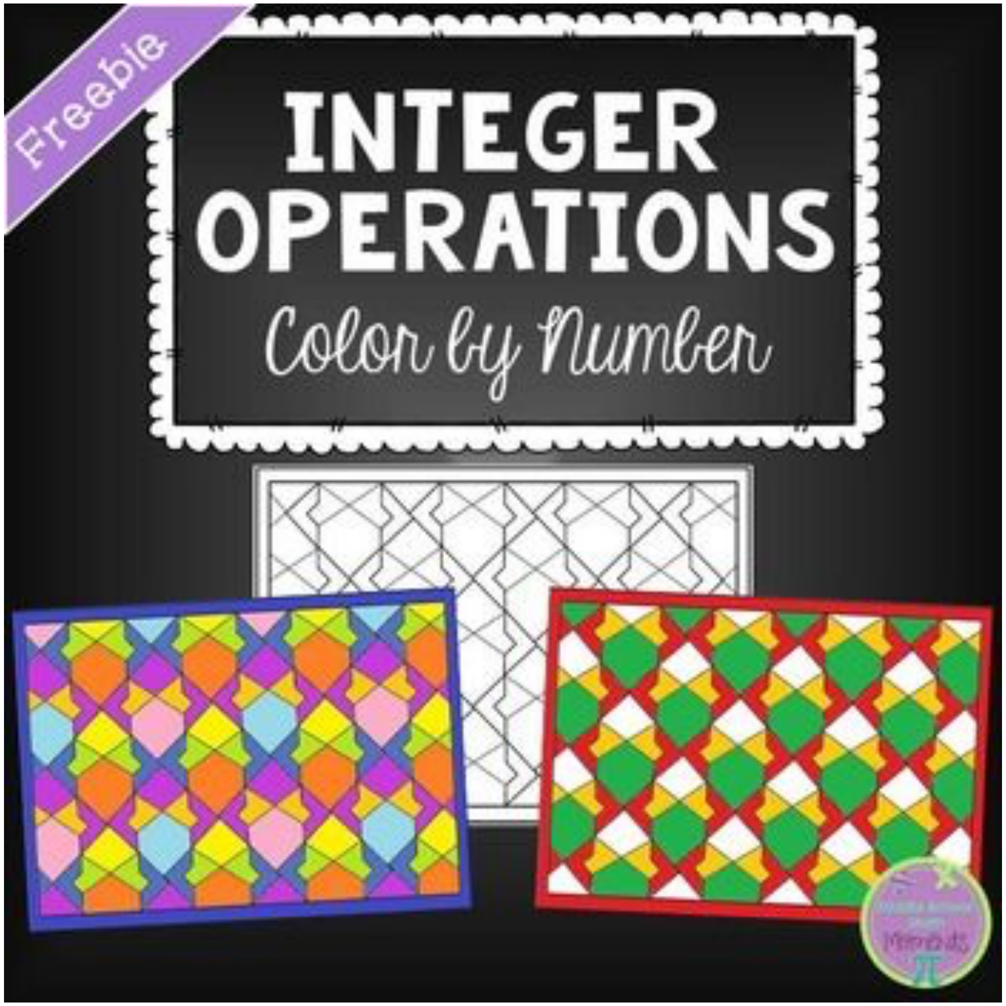
In Practice

"I expect you all to be independent, innovative, critical thinkers who will do exactly as I say!"

DIY in Excell + CP Solver

- Solve the following VRP problem using ColGen, knowing that
  - A route can visit at most 4 customers





Branch-and-price

Obtaining integer solutions

Branch-and-price

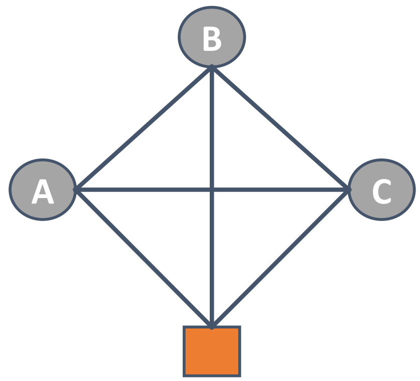
Column generation + MIP : Branch-and-price

- How to obtain integer solutions?
  - Branch-and-bound -> solve LP relaxation at each node
  - Branch-and-price -> column generation to solve LP relaxation at each node

Branch-and-price

Vehicle routing problem

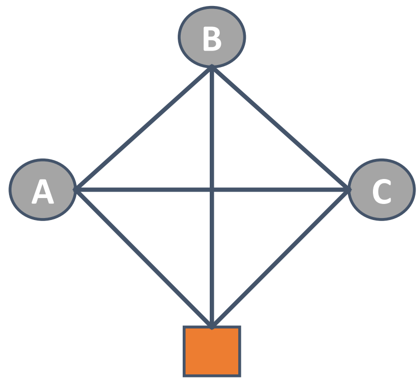
- Max 2 customers
- Cost of all arc : 1



Branch-and-price

Vehicle routing problem

- Max 2 customers
- Cost of all arc : 1

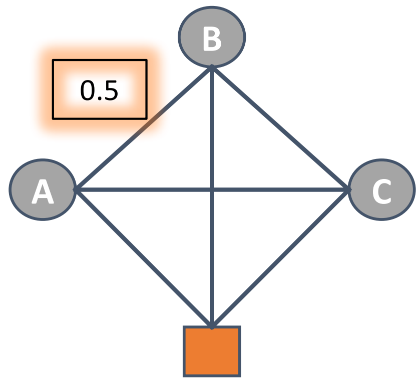


	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
B :	1		1	= 1
C :		1	1	= 1
OptSol:	0.5	0.5	0.5	$\boxed{4.5}$

Branch-and-price

Vehicle routing problem

- Max 2 customers
- Cost of all arc : 1



	x_1	x_2	x_3	
Min	3	3	3	
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B :	1		1	= 1
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Branch-and-price

Vehicle routing problem

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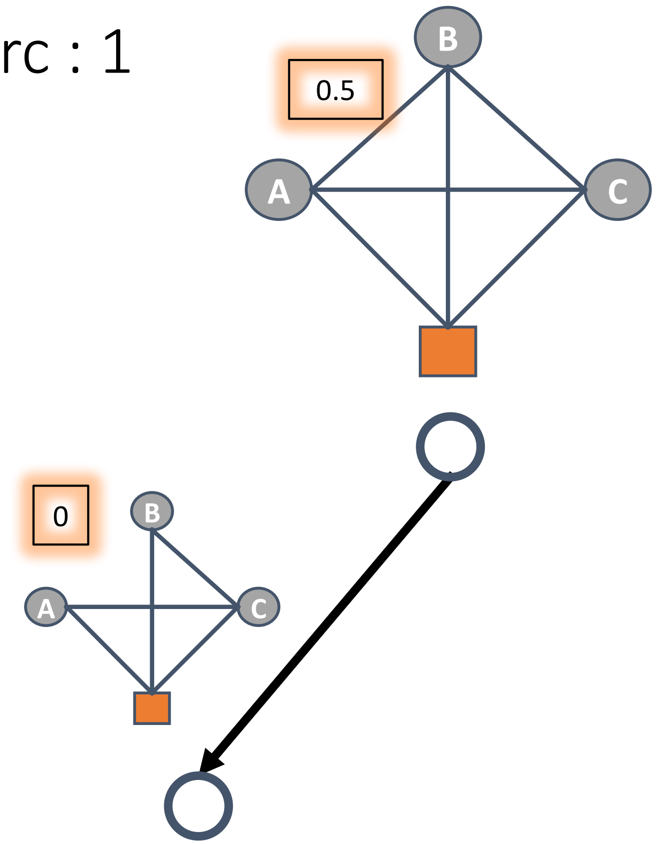

	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
B :	1		1	= 1
C :		1	1	= 1
OptSol:	0.5	0.5	0.5	$\boxed{4.5}$

	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
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Branch-and-price

Vehicle routing problem

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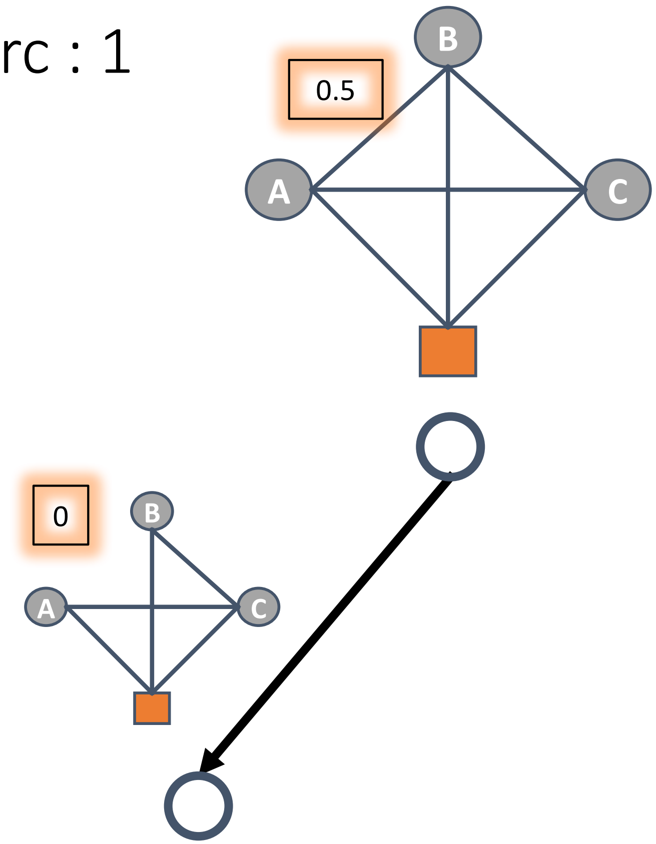


	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
B :	1		1	= 1
C :		1	1	= 1
OptSol:	0.5	0.5	0.5	$\boxed{4.5}$

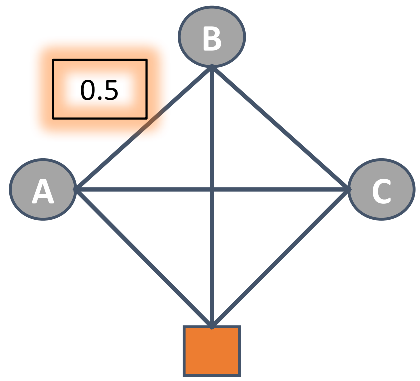
	x_4
	2
A :	1
B :	
C :	

	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
B :	1		1	= 1
C :		1	1	= 1

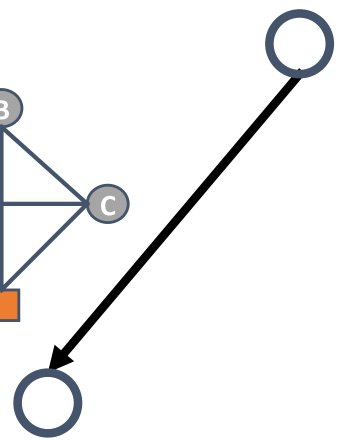
Branch-and-price

Vehicle routing problem

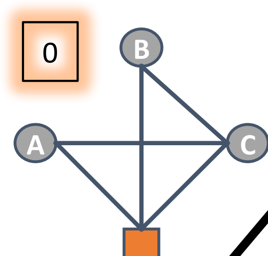
- Max 2 customers
- Cost of all arc : 1



	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
B :	1		1	= 1
C :		1	1	= 1
OptSol:	0.5	0.5	0.5	$\boxed{4.5}$



	x_4
	2
A :	1
B :	
C :	

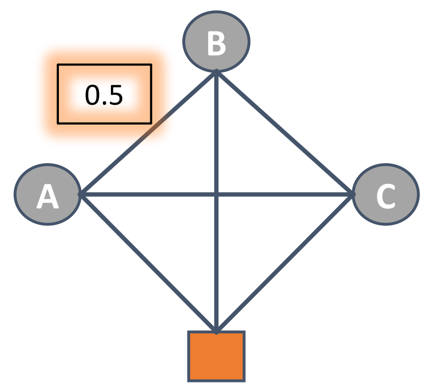


	x_1	x_2	x_3	x_4	
Min	3	3	3	2	
A :	1	1		1	= 1
B :	1		1		= 1
C :		1	1		= 1
OptSol:			1	1	$\boxed{5}$

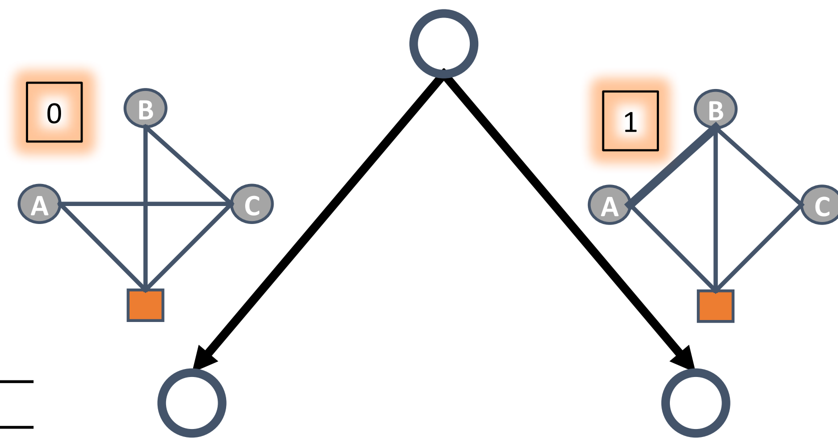
Branch-and-price

Vehicle routing problem

- Max 2 customers
- Cost of all arc : 1



	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
B :	1		1	= 1
C :		1	1	= 1
OptSol:	0.5	0.5	0.5	$\boxed{4.5}$



	x_1	x_2	x_3	x_4	
Min	3	3	3	2	
A :	1	1		1	= 1
B :	1		1		= 1
C :		1	1		= 1
OptSol:			1	1	$\boxed{5}$

	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
B :	1		1	= 1
C :		1	1	= 1

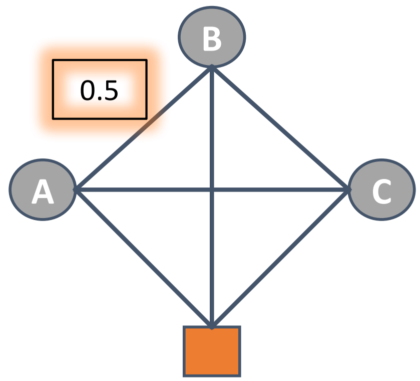
Branch-and-price

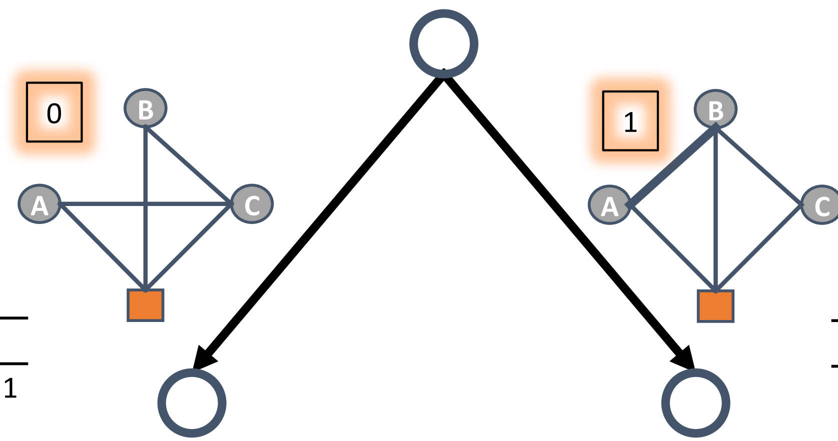
Vehicle routing problem

- Max 2 customers
- Cost of all arc : 1

Why branch on arc-flow variables?

	x_1	x_2	x_3	
Min	3	3	3	
A :	1	1		= 1
B :	1		1	= 1
C :		1	1	= 1
OptSol:	0.5	0.5	0.5	$\boxed{4.5}$





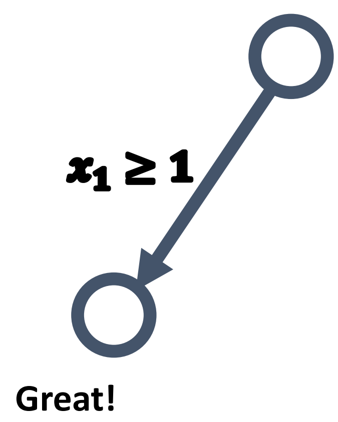
	x_1	x_2	x_3	x_4	
Min	3	3	3	2	
A :	1	1		1	= 1
B :	1		1		= 1
C :		1	1		= 1
OptSol:			1	1	$\boxed{5}$

	x_1	x_2	x_3	x_5	
Min	3	3	3	2	
A :	1	1			= 1
B :	1		1		= 1
C :		1	1	1	= 1
OptSol:	1			1	$\boxed{5}$

Branch-and-price

Branching possibilities

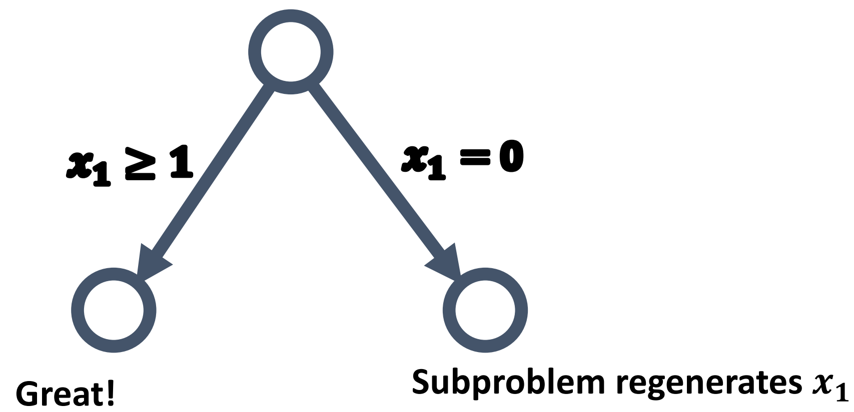
- Branch on master variables



Branch-and-price

Branching possibilities

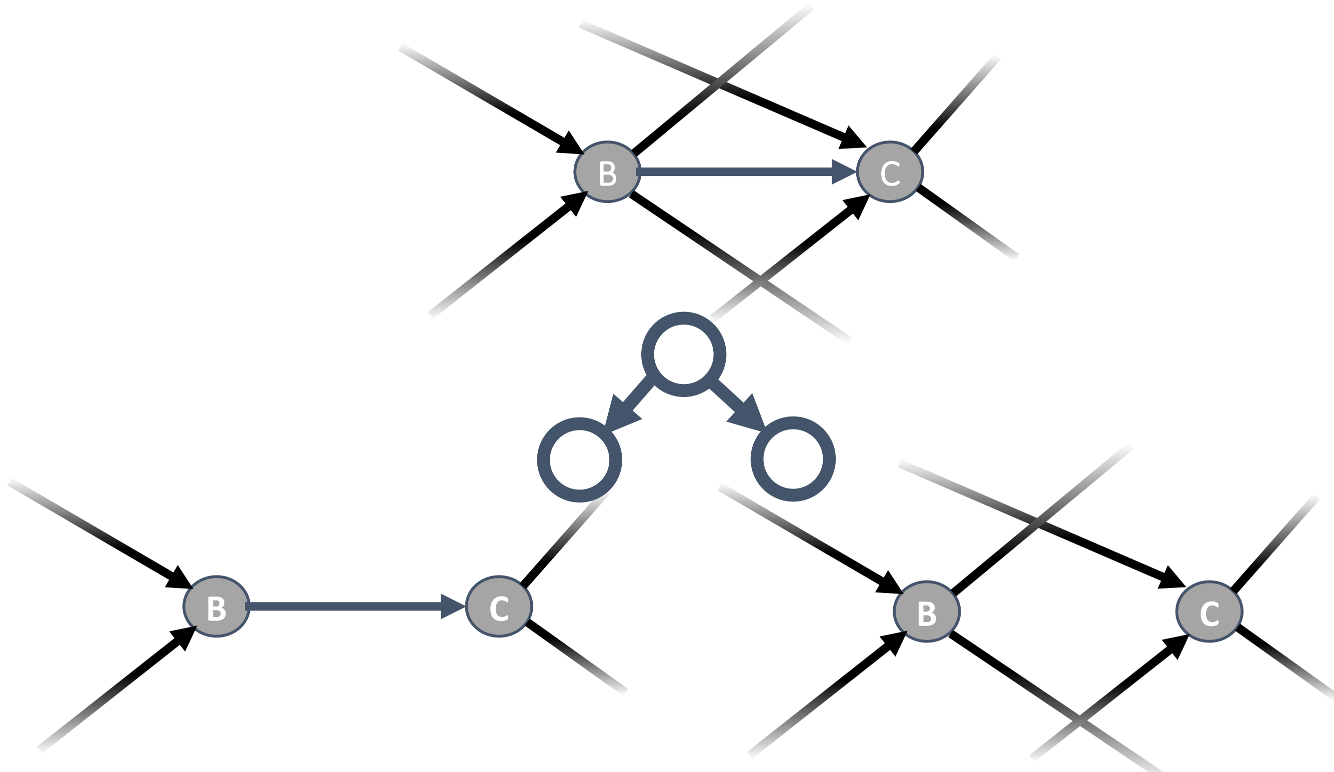
- Branch on master variables



Branch-and-price

Branching possibilities

- Branch on master variables… NO!
- Branch on subproblem variables

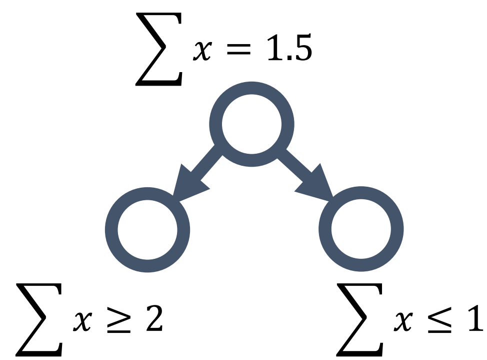


Branch-and-price

Branching possibilities

- Branch on master variables… NO!
- Branch on subproblem variables
- Branch on the master problem constraints
  - **BUT** adding a constraints c **requires** its dual value π_c must be handled in the subproblems
  - Example: Branch on the total number of vehicle used

Best branching for shift scheduling problem



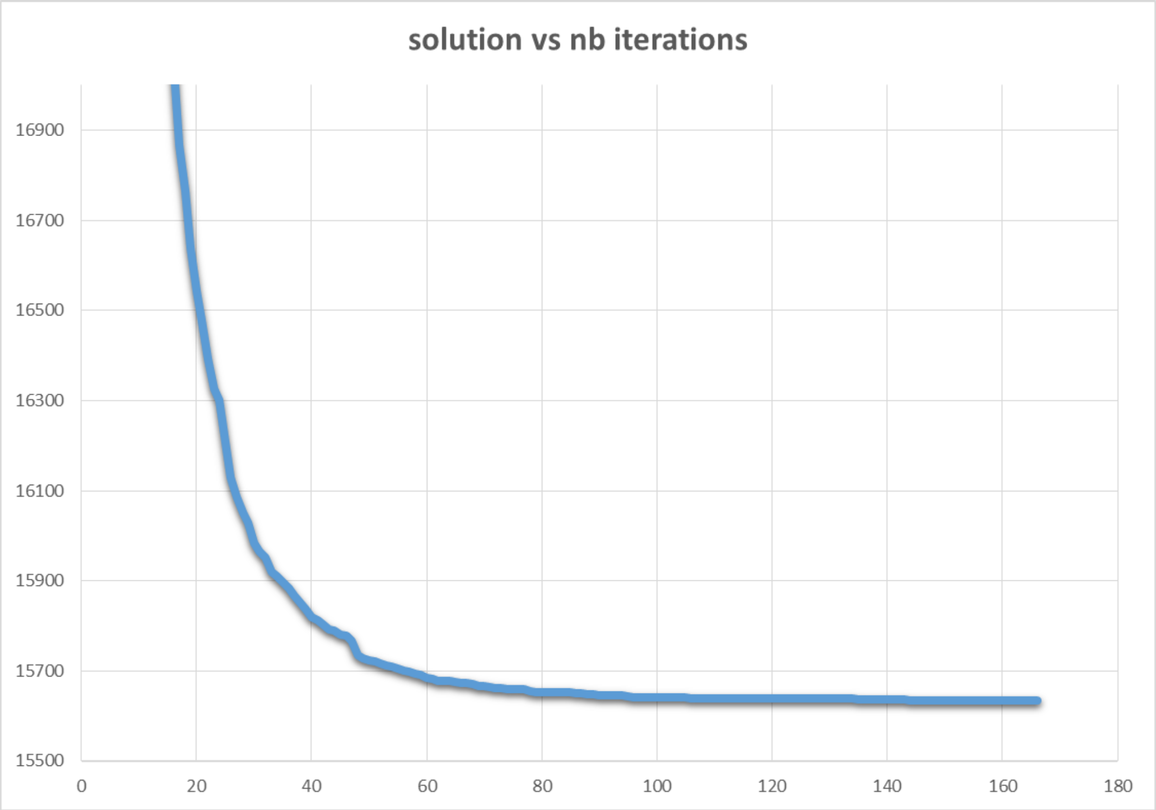
Applied column generation

Main Challenges

Applied column generation

Evolution of costs

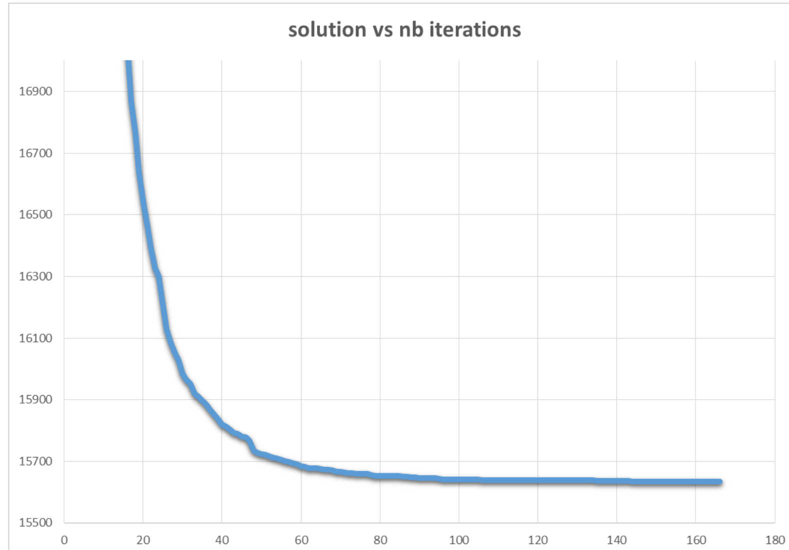
- Long convergence time



Applied column generation

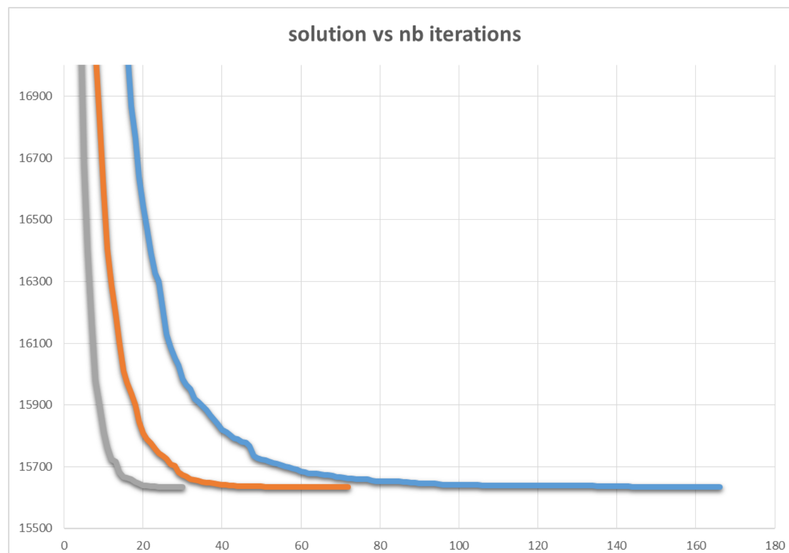
Evolution of costs

- Long convergence time



Speed-up techniques

- Spend more time to generate new columns
- Delete variables in RMP



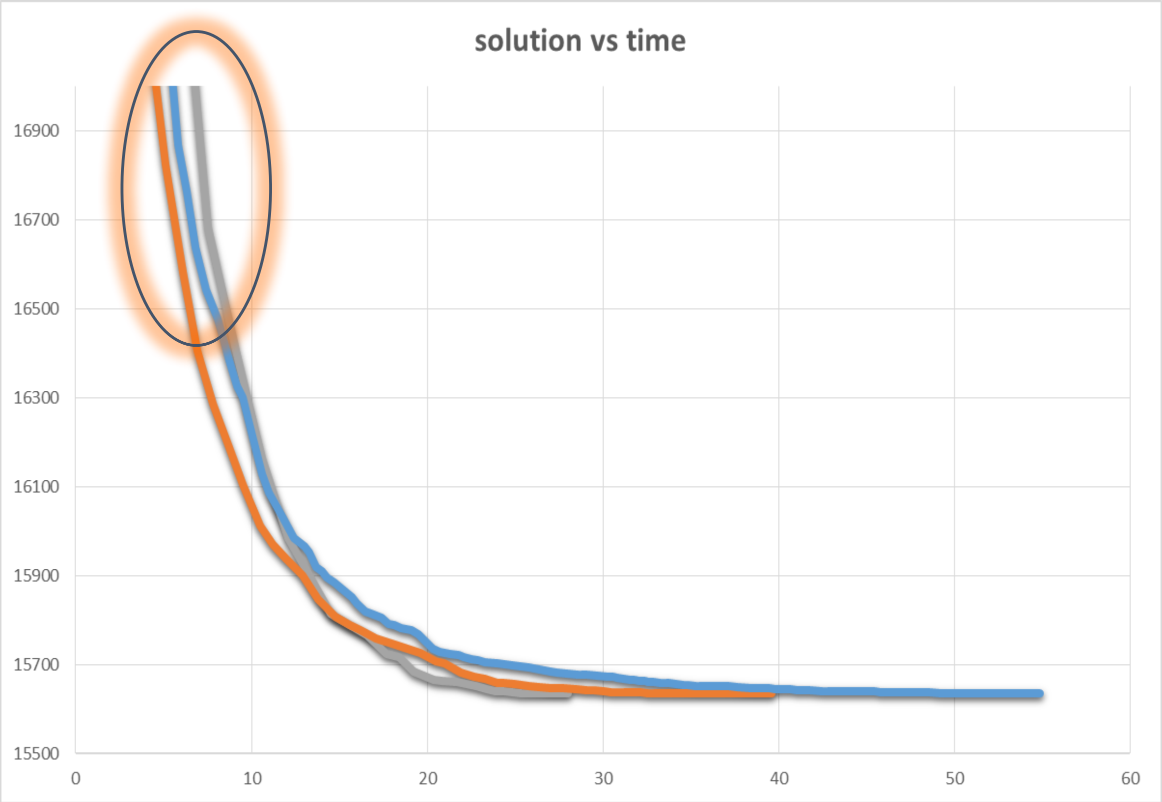
Applied column generation

Evolution of costs

- Long convergence time

Speed-up techniques

- Spend more time to generate new columns
- Delete variables in RMP

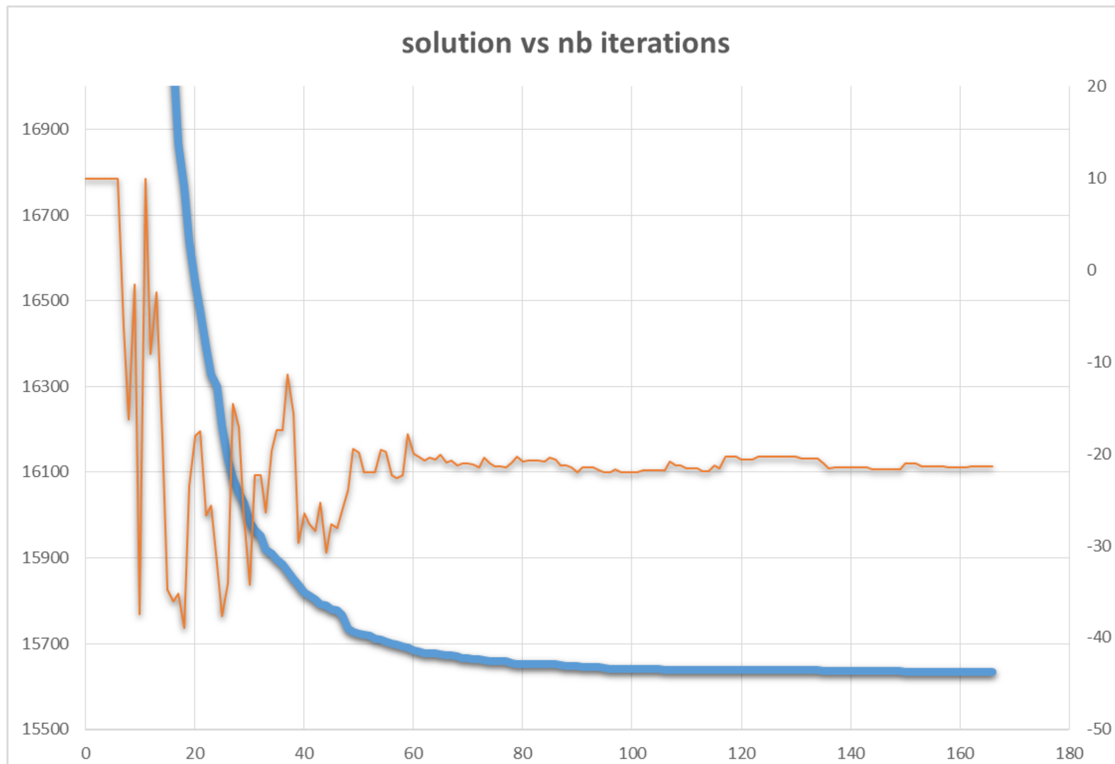


Balance between subproblems and master problem

Applied column generation

Stabilization

- Duals are extreme points
- Master problem is degenerated
- Tail-off effect is due to difficulty finding the right dual vector



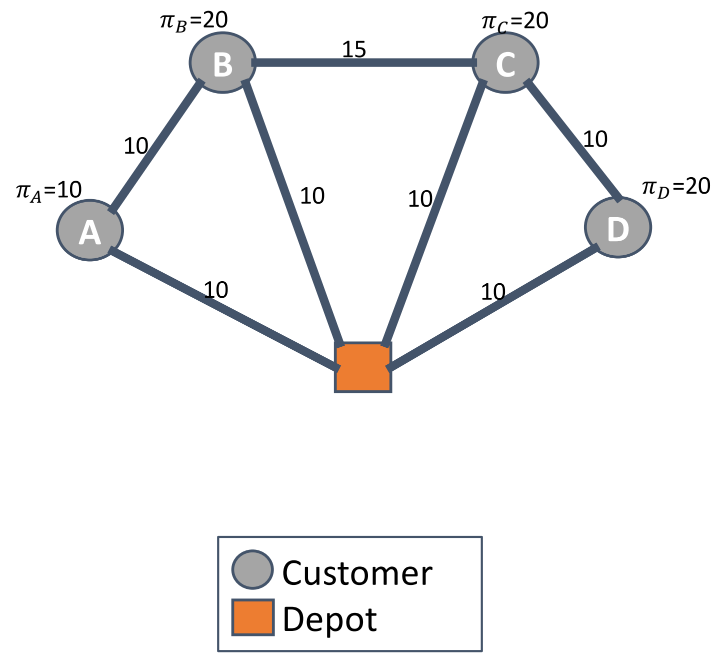
A quick look at

Stabilization issues

Column Generation

Stabilization

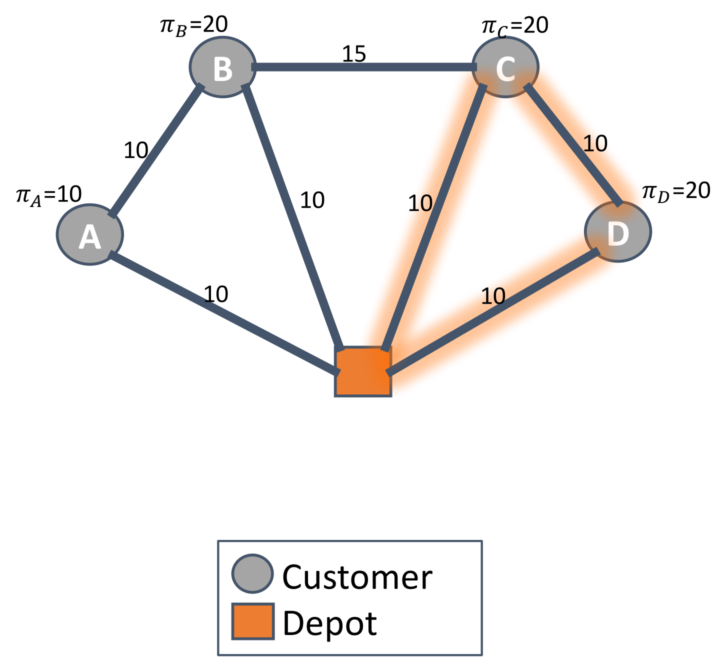
	x_1	x_2	x_3	x_4	x_5		
ĉ	10	0	0	0	0		π_i
A :	1				1	= 1	10
B :		1			1	= 1	20
C :			1			= 1	20
D :				1		= 1	20
		0	1	1	1	$\boxed{70}$	



Column Generation

Stabilization

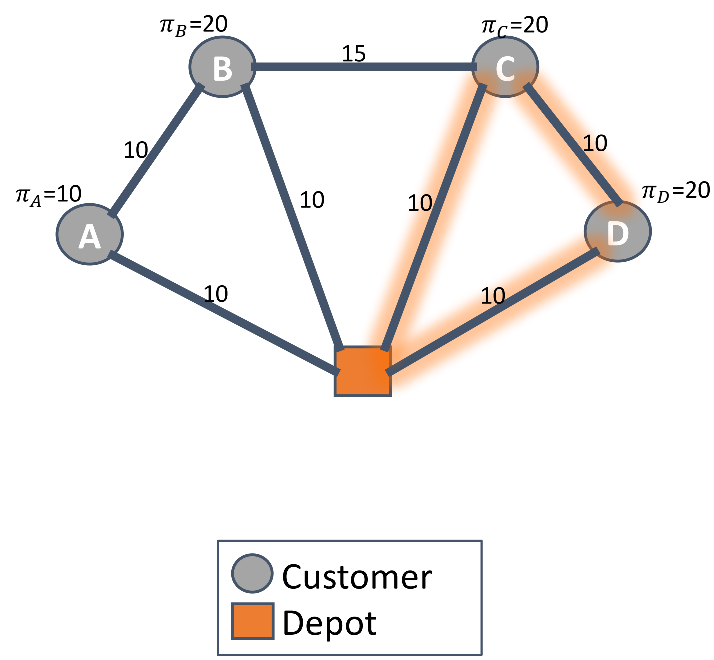
	x_1	x_2	x_3	x_4	x_5		
$\hat{c}$	10	0	0	0	0		π_i
A :	1				1	= 1	10
B :		1			1	= 1	20
C :			1			= 1	20
D :				1		= 1	20
		0	1	1	1	$\boxed{70}$	



Column Generation

Stabilization

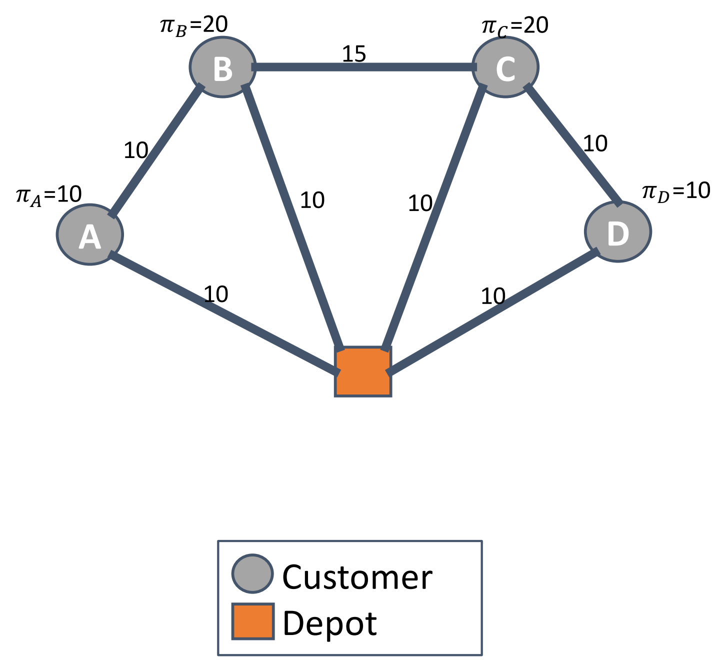
	x_1	x_2	x_3	x_4	x_5	x_6		
ĉ	10	0	0	0	0	-10		π_i
A :	1				1		= 1	10
B :		1			1		= 1	20
C :			1			1	= 1	20
D :				1		1	= 1	20
		0	1	1	1		$\boxed{70}$	



Column Generation

Stabilization

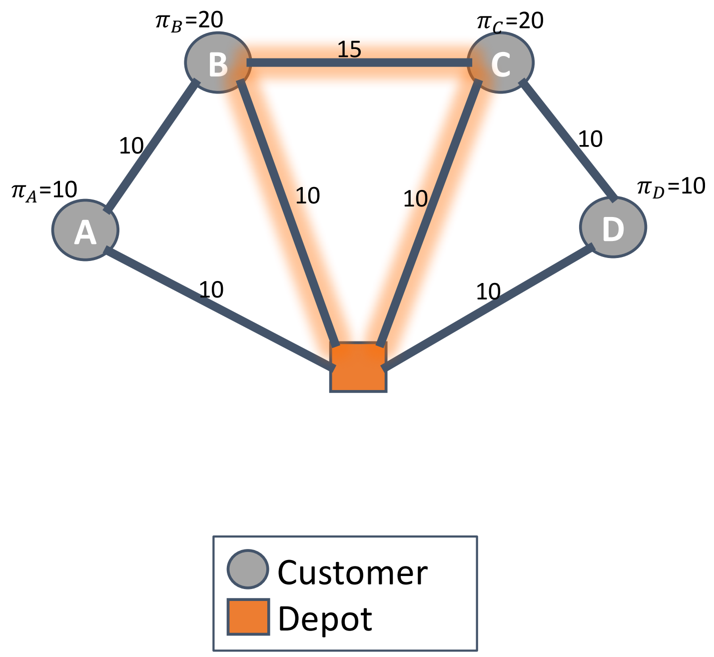
	x_1	x_2	x_3	x_4	x_5	x_6		
ĉ	10	0	0	10	0	0		π_i
A :	1				1		= 1	10
B :		1			1		= 1	20
C :			1			1	= 1	20
D :				1		1	= 1	10
		0	0		1	1	$\boxed{60}$	



Column Generation

Stabilization

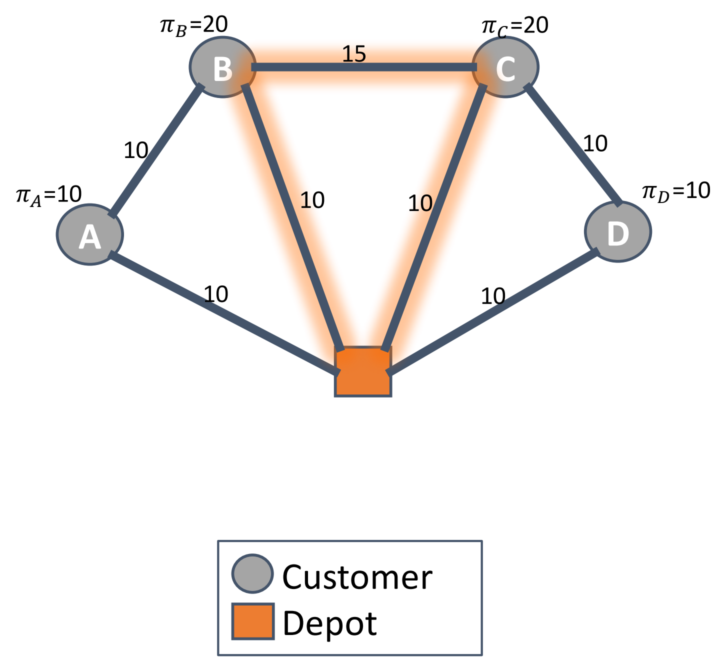
	x_1	x_2	x_3	x_4	x_5	x_6		
ĉ	10	0	0	10	0	0		π_i
A :	1				1		= 1	10
B :		1			1		= 1	20
C :			1			1	= 1	20
D :				1		1	= 1	10
		0	0		1	1	$\boxed{60}$	



Column Generation

Stabilization

	x_1	x_2	x_3	x_4	x_5	x_6	x_7		
ĉ	10	0	0	10	0	0	-5		π_i
A :	1				1			= 1	10
B :		1			1		1	= 1	20
C :			1			1	1	= 1	20
D :				1		1		= 1	10
		0	0		1	1		$\boxed{60}$	

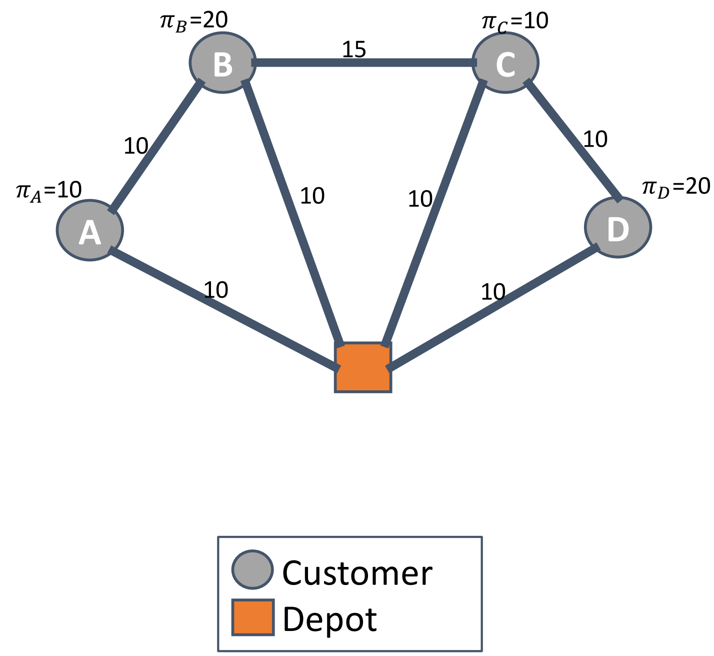


Column Generation

Stabilization

BUT THIS COLUMN IS USELESS

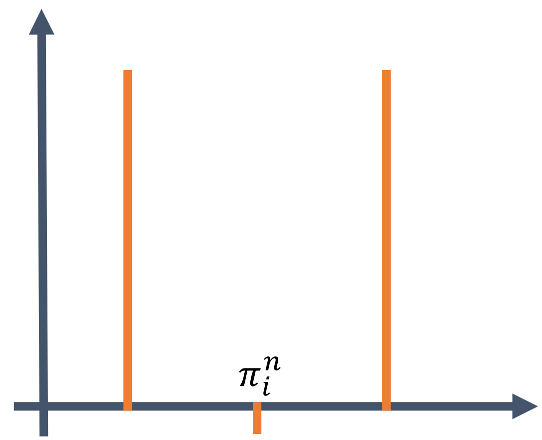
	x_1	x_2	x_3	x_4	x_5	x_6	x_7		
ĉ	10	0	10	0	0	0	5		π_i
A :	1				1			= 1	10
B :		1			1		1	= 1	20
C :			1			1	1	= 1	10
D :				1		1		= 1	20
		0		0	1	1		$\boxed{60}$	



Column Generation

Stabilization!

- What to do?
- Popular technique
  - Box penalization



Column Generation

Stabilization!

- What to do?
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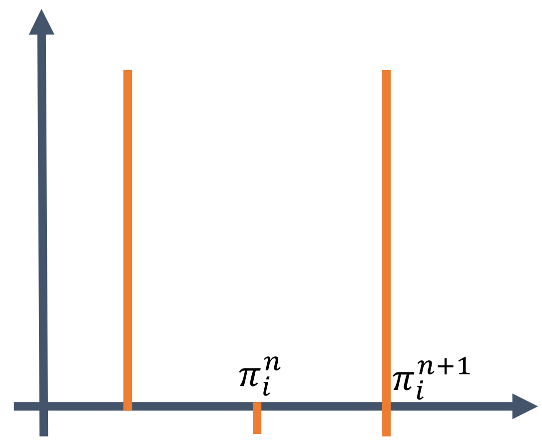

Column Generation

Stabilization!

- What to do?
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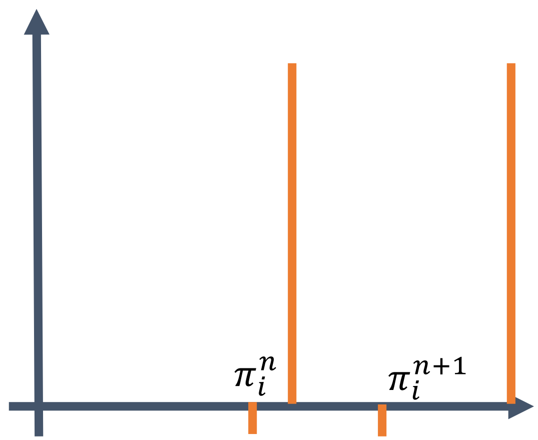
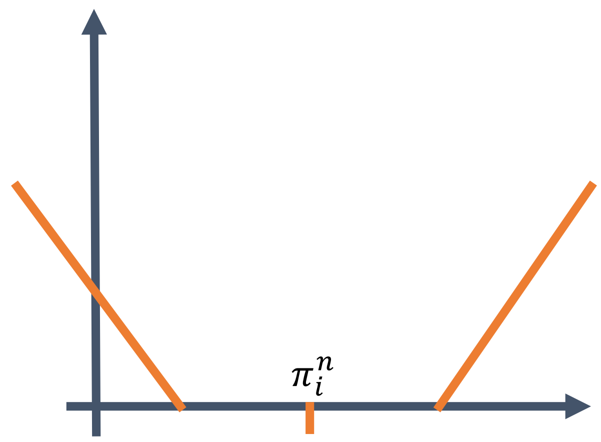


Column Generation

Stabilization!

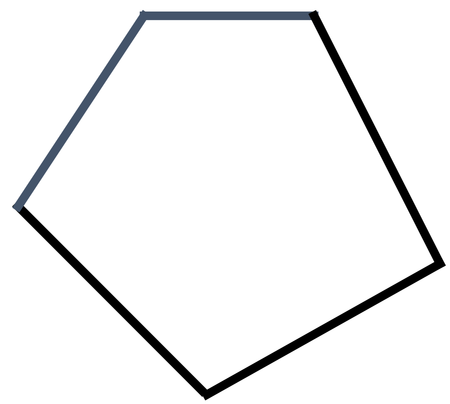
- What to do?
- Popular technique
  - Box penalization



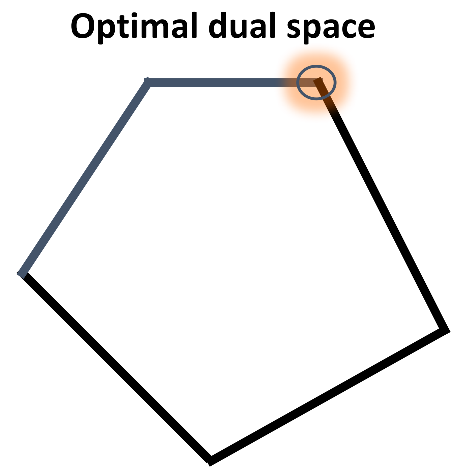
Column Generation

Stabilization!

- What to do?
- Popular technique
  - Box penalization
- Interior point stabilization



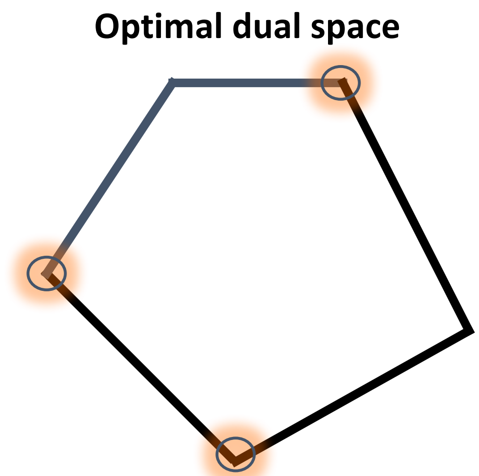
Column Generation



Stabilization!

- What to do?
- Popular technique
  - Box penalization
- Interior point stabilization
  - Adding a variable to the primal is equivalent to adding a cut to the dual

Column Generation

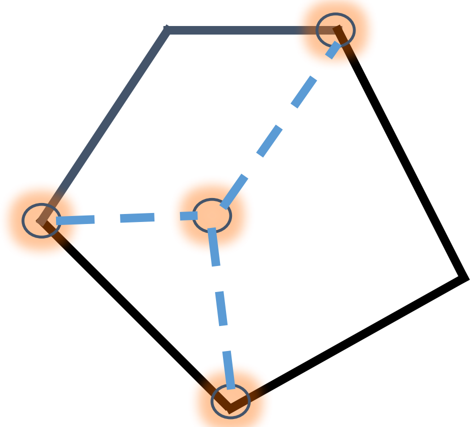


Stabilization!

- What to do?
- Popular technique
  - Box penalization
- Interior point stabilization
  - Find multiple dual optimal extreme points

Column Generation

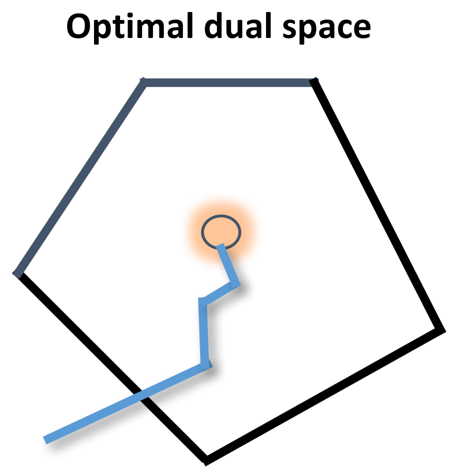
	Average time	Average nb Iterations
Unstabilized	384.4 s	72.6
Box penalization	389.1 s	61.0
IPS	277.9 s	37.1



Stabilization!

- What to do?
- Popular technique
  - Box penalization
- Interior point stabilization
  - Find multiple dual optimal extreme points
    - Do a linear combination

Column Generation



Stabilization!

- What to do?
- Popular technique
  - Box penalization
- Interior point stabilization
  - Find multiple dual optimal extreme points
    - Do a linear combination
  - **Simple idea: barrier algorithm without crossover**

Back to the Primal

Finding good solution fast: An Homecare Application

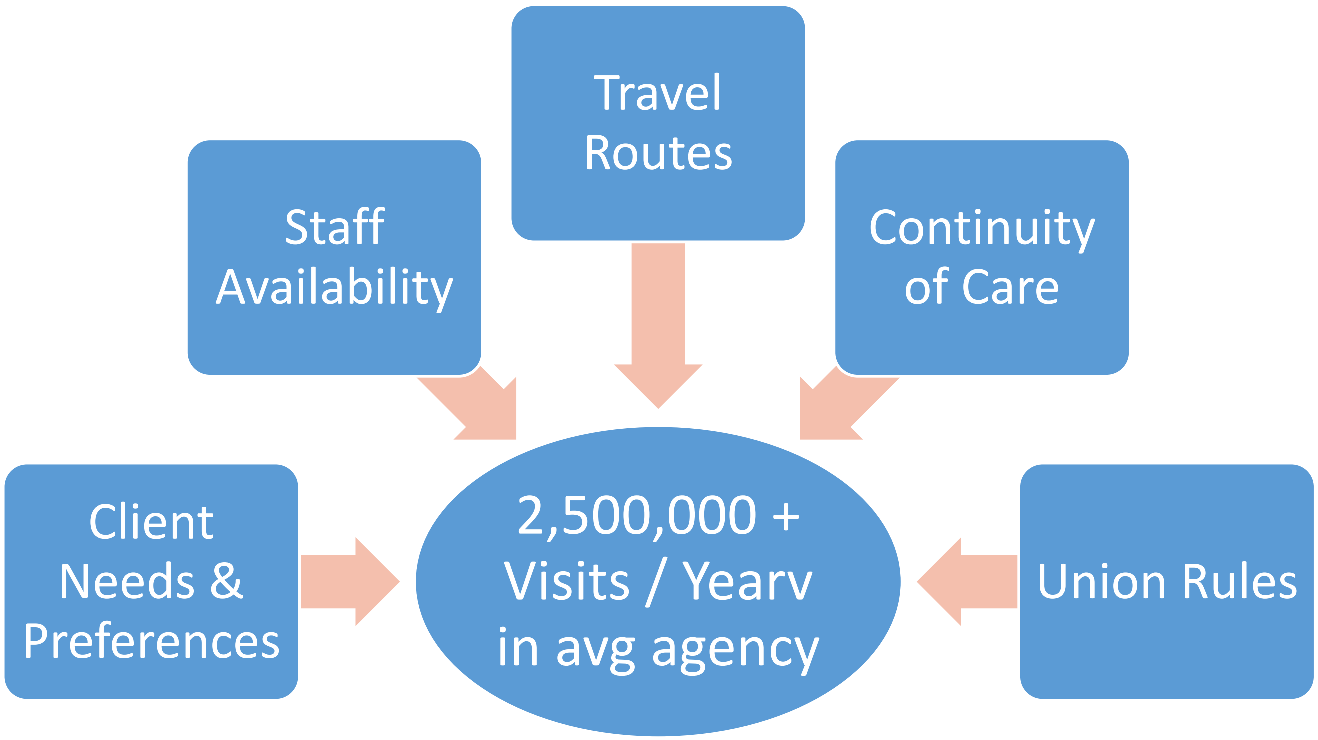
Problem Definition

- **Problem Definition**
- Mathematical Formulation
- Resolution Method
- Computation Results
- Conclusion

The home care in Canada

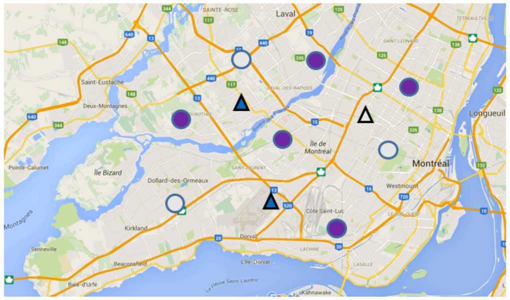
- People want to stay at home as long as possible
- In 2012, approximately 2.2 million people relied on home care services
- For the same cares, a patient at home costs 90% less than a patient at the hospital
- Homecare services is one of the fastest growing market in the US and Canada

The Scheduling Challenge

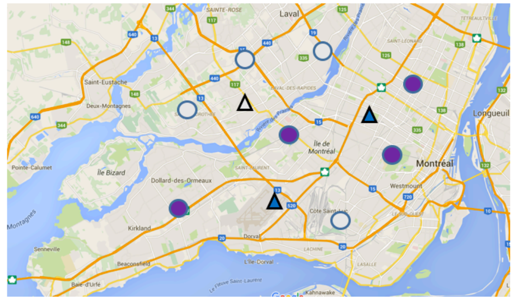


An example

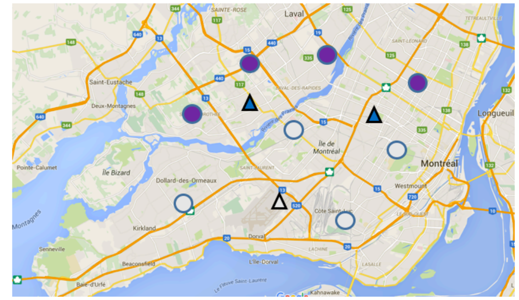
Monday



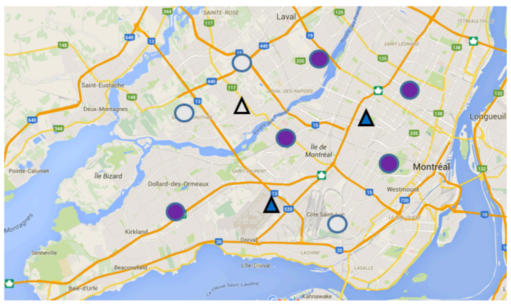
Tuesday



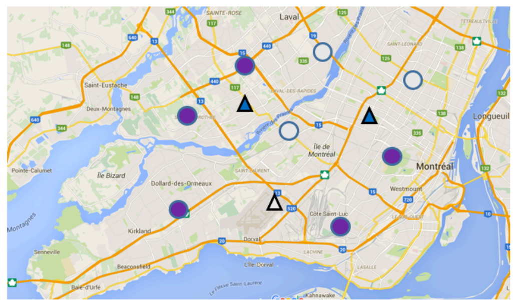
Wednesday



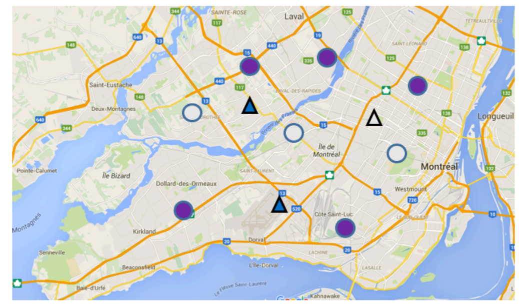
Thursday



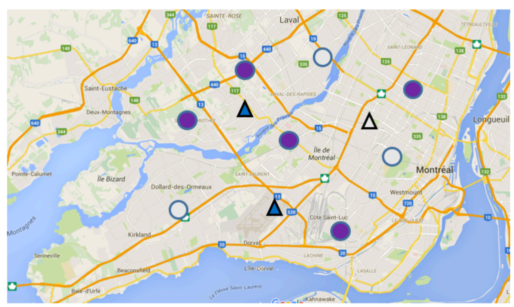
Friday



Saturday



Sunday

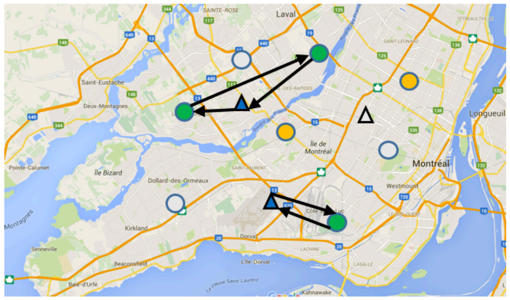


- Available day for the patient
- Work day of the nurse
- Patient/Nurse not available

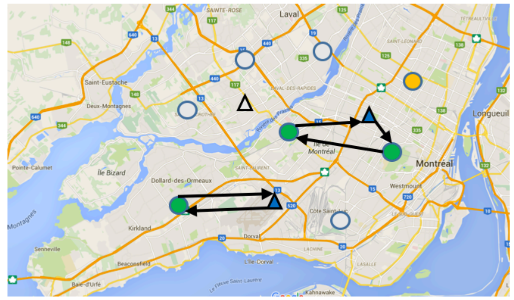
Each patient needs 3 visits

An example

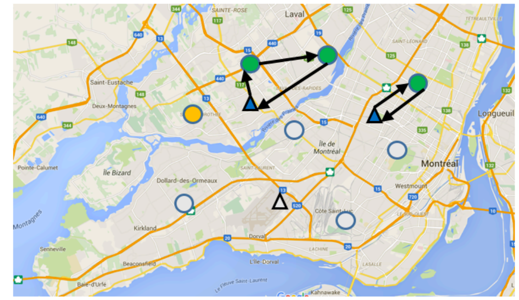
Monday



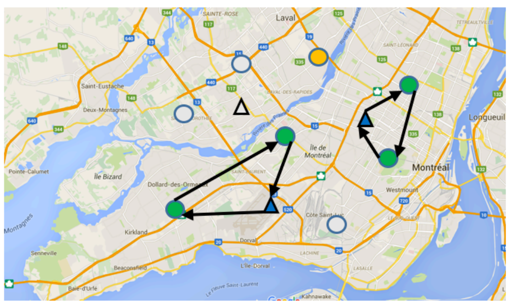
Tuesday



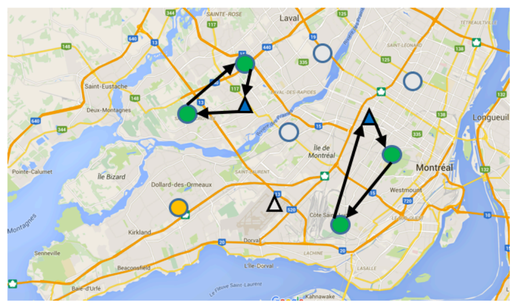
Wednesday



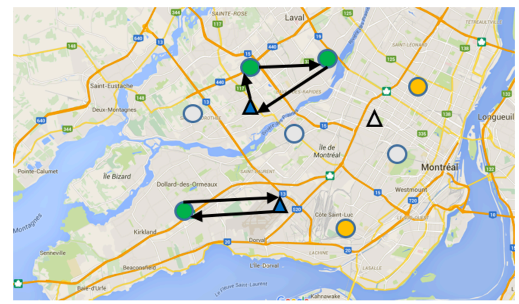
Thursday



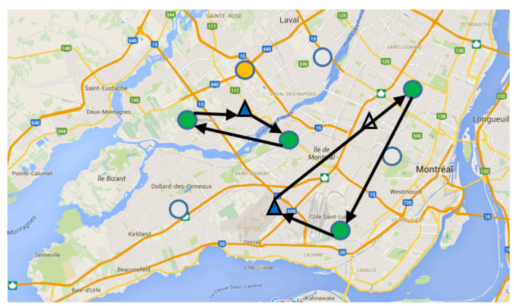
Friday



Saturday



Sunday



- Unused available day
- Used available day
- Patient/Nurse not available

Problem Definition

- This Homcare routing problem (HHCRSP) can be described as mix between an assignment problem

Hard constraints	Soft constraints
• Mandatory requirements : nurse skills, type of care, … • Forbidden nurses	• Continuity of care • Optional requirements

Problem Definition

- The HHCRSP can be described as mix between an assignment problem and a multi-attributes VRP

Hard constraints	Soft constraints
• Mandatory requirements : nurse skills, type of care, … • Forbidden nurses • Time windows • Available days • Workdays • Time-dependent travel time	• Continuity of care • Optional requirements • Travel time • Min/Max worktime week • Min/Max worktime workday • Number of visits over the week

Problem Definition

- The HHCRSP can be described as mix between an assignment problem and a multi-attributes VRP

Hard constraints	Soft constraints
• Mandatory requirements : nurse skills, type of care, …	• Continuity of care
• Forbidden nurses	• Optional requirements
• Time windows	• Travel time
• Available days	• Min/Max worktime week
• Workdays	• Min/Max worktime workday
• Time-dependent travel time	• Number of visits over the week

Objective function = weighted sum

Mathematical Formulation

- Problem Definition
- **Mathematical Formulation**
- Resolution Method
- Computation Results
- Conclusion

Formulation

- The HHCRSP can be formulated as a set partitioning problem

- The decision variables correspond to the feasible routes for each nurse for each one of his/her workdays

Set partitioning model

Use the route ω

P : Patients
N : Nurses
Ω : Routes

$$\underset{x}{\text{minimize}} \quad \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n + u_n) + U.\sum_{p\in P} z_p$$

$$\text{subject to} \quad \sum_{\omega\in\Omega_d} a_{\omega,p} x_\omega \le 1 \qquad \forall_{p\in P}, \forall_{d\in A_d}$$

$$\sum_{\omega\in\Omega} a_{\omega,p} x_\omega + z_p = n_p \qquad \forall_{p\in P}$$

$$\sum_{\omega\in\Omega_d\cap\Omega_n} x_\omega \le 1 \qquad \forall_{n\in N}, \forall_{d\in W_d}$$

$$\sum_{\omega\in\Omega} l_\omega x_\omega + u_n \ge min_n \qquad \forall_{n\in N}$$

$$\sum_{\omega\in\Omega} l_\omega x_\omega - o_n \le max_n \qquad \forall_{n\in N}$$

$$x_\omega \in \{0,1\} \qquad \forall_{\omega\in\Omega}$$

$$z_p \in \mathbb{N} \qquad \forall_{p\in P}$$

$$o_n, u_n \ge 0 \qquad \forall_{n\in N}$$

Set partitioning model

Overtime of the nurse

P : Patients
N : Nurses
Ω : Routes

$$\underset{x}{\text{minimize}} \quad \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n + u_n) + U.\sum_{p\in P} z_p$$

$$\text{subject to} \quad \sum_{\omega\in\Omega_d} a_{\omega,p} x_\omega \leq 1 \qquad \forall_{p\in P}, \forall_{d\in A_d}$$

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$$\sum_{\omega\in\Omega} l_\omega x_\omega + u_n \geq min_n \qquad \forall_{n\in N}$$

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$$z_p \in \mathbb{N} \qquad \forall_{p\in P}$$

$$o_n, u_n \geq 0 \qquad \forall_{n\in N}$$

Set partitioning model

Under-used time of the nurse

P : Patients
N : Nurses
Ω : Routes

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n + u_n) + U.\sum_{p\in P} z_p & \\
\text{subject to} \quad & \sum_{\omega\in\Omega_d} a_{\omega,p} x_\omega \leq 1 & \forall_{p\in P}, \forall_{d\in A_d} \\
& \sum_{\omega\in\Omega} a_{\omega,p} x_\omega + z_p = n_p & \forall_{p\in P} \\
& \sum_{\omega\in\Omega_d\cap\Omega_n} x_\omega \leq 1 & \forall_{n\in N}, \forall_{d\in W_d} \\
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& x_\omega \in \{0,1\} & \forall_{\omega\in\Omega} \\
& z_p \in \mathbb{N} & \forall_{p\in P} \\
& o_n, u_n \geq 0 & \forall_{n\in N}
\end{aligned}
$$

Set partitioning model

Non-scheduled visits

P : Patients
N : Nurses
Ω : Routes

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p & \\
\text{subject to} \quad & \sum_{\omega\in\Omega_d} a_{\omega,p} x_\omega \le 1 & \forall_{p\in P}, \forall_{d\in A_d} \\
& \sum_{\omega\in\Omega} a_{\omega,p} x_\omega + z_p = n_p & \forall_{p\in P} \\
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\end{aligned}
$$

Set partitioning model

P : Patients
N : Nurses
Ω : Routes

$$
\begin{aligned}
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& o_n, u_n \geq 0 && \forall_{n\in N}
\end{aligned}
$$

Max 1 visit per day

Set partitioning model

P : Patients
N : Nurses
Ω : Routes

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p \\
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\end{aligned}
$$

Max 1 visit per day

Nb visits per week

Set partitioning model

P : Patients
N : Nurses
Ω : Routes

$$\underset{x}{\text{minimize}} \quad \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p$$

$$\text{subject to} \quad \sum_{\omega\in\Omega_d} a_{\omega,p} x_\omega \leq 1 \qquad \forall_{p\in P}, \forall_{d\in A_d}$$

Max 1 visit per day

$$\sum_{\omega\in\Omega} a_{\omega,p} x_\omega + z_p = n_p \qquad \forall_{p\in P}$$

Nb visits per week

$$\sum_{\omega\in\Omega_d\cap\Omega_n} x_\omega \leq 1 \qquad \forall_{n\in N}, \forall_{d\in W_d}$$

Route per day

$$\sum_{\omega\in\Omega} l_\omega x_\omega + u_n \geq min_n \qquad \forall_{n\in N}$$

$$\sum_{\omega\in\Omega} l_\omega x_\omega - o_n \leq max_n \qquad \forall_{n\in N}$$

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Set partitioning model

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N : Nurses
Ω : Routes

$$\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p \\
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& z_p \in \mathbb{N} && \forall_{p\in P} \\
& o_n, u_n \ge 0 && \forall_{n\in N}
\end{aligned}$$

Max 1 visit per day

Nb visits per week

Route per day

Minimum worktime

Maximum worktime

Ways to solve the problem

- Find the routes in a reasonable computation time is complex, the possibilities are :

  - Solve a heuritistic Branch-And-Price using a column generation → Does not allow a current primal solution

  - Adapt a metaheuristic framework and add it some enhancements to make it the most efficient

Outline

- Problem Definition
- Mathematical Formulation
- **Resolution Method**
- Computation Results
- Conclusion

Methodology

- Our algorithm is based on 2 main components :
  - An ALNS-based framework
  - A heuristic concentration method

Adaptive Large Neighborhood Search

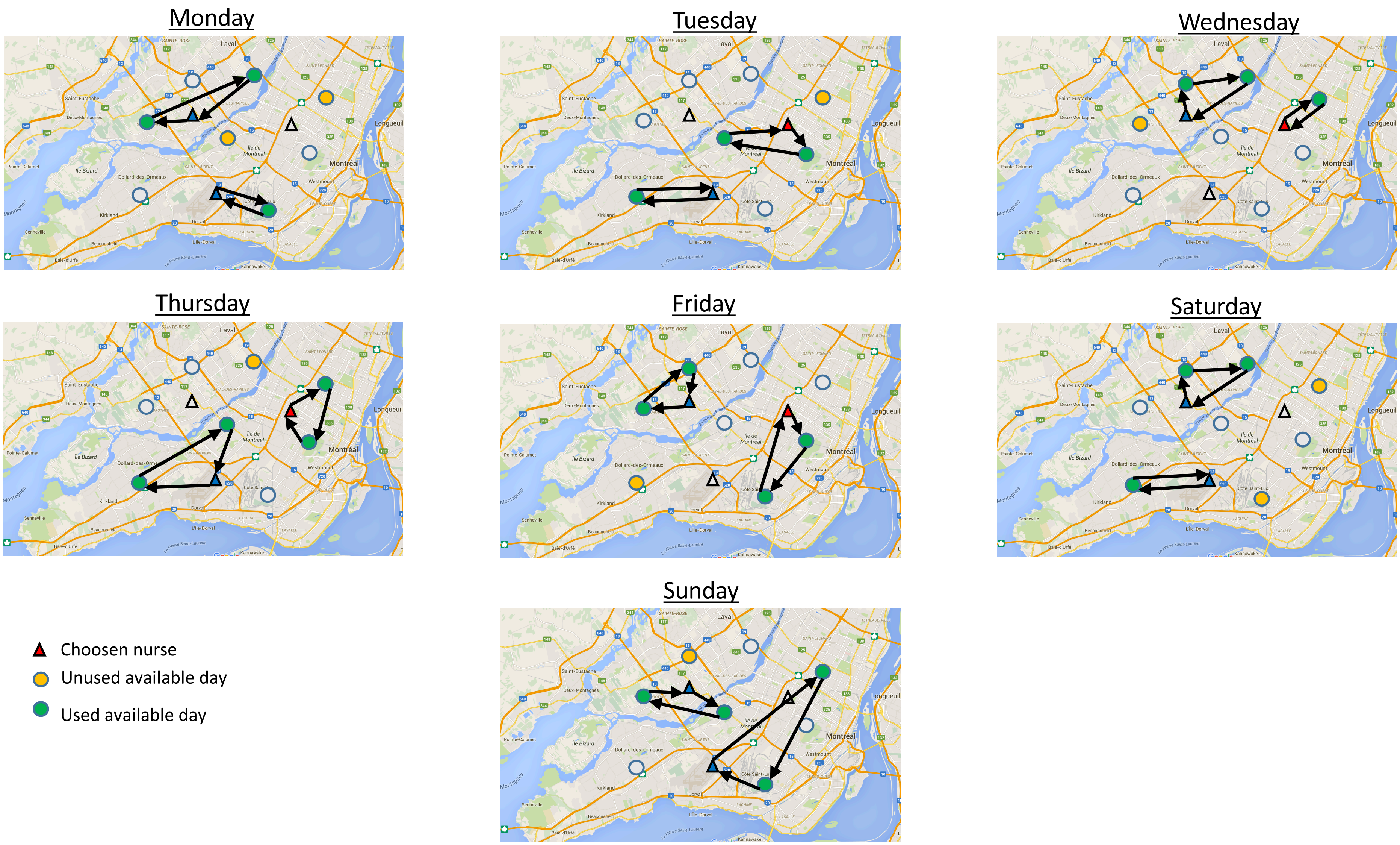
- ALNS: introduced by Ropke and Pisinger in 2006

- Considers :
    - A large number of visits
    - A large set of constraints

- Allows to test different operators associated with different strategies

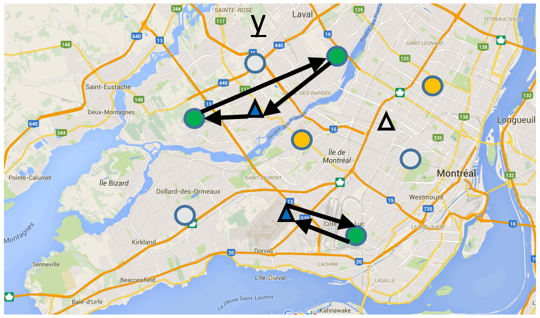
Algorithm 1: LNS Heuristic.

Function LNS($s \in \{solutions\}$, $q \in \mathbb{N}$)
  solution $s_{best} = s$;
  repeat
    $s' = s$;
    remove q requests from s'
    reinsert removed requests into s';
    if $(f(s') < f(s_{best}))$ **then**
      $s_{best} = s'$;
    if accept(s', s) **then**
      $s = s'$;
  until stop-criterion met
return s_{best};


Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Choosen nurse
Unused available day
Used available day

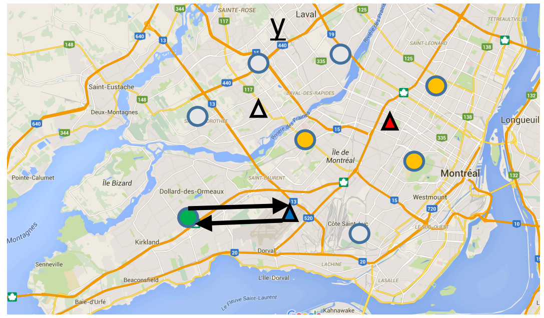
Monda

y



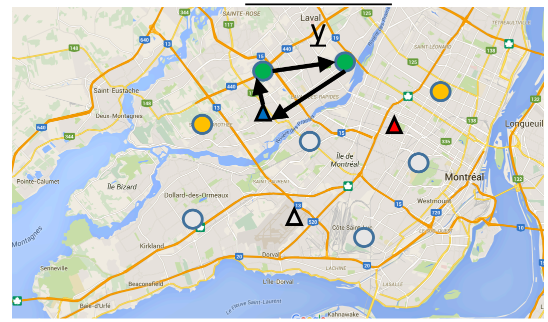
Tuesda

y

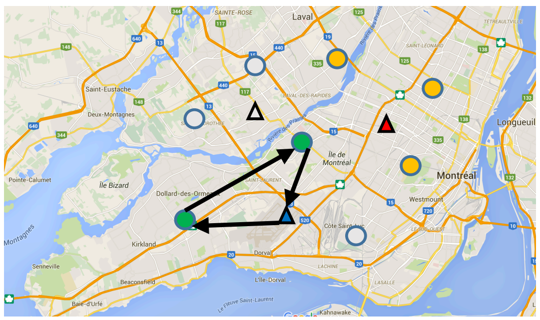


Wednesda

y



Thursday



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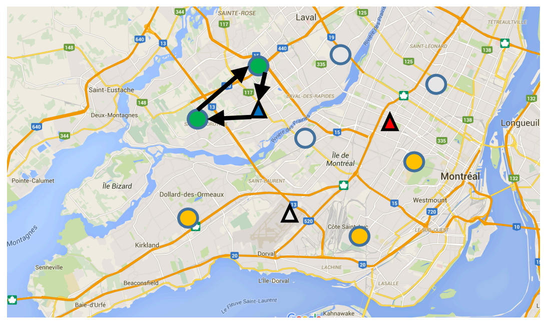
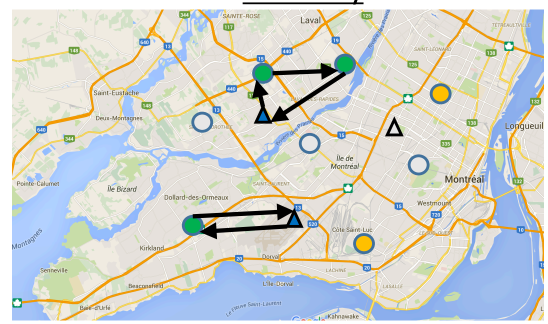
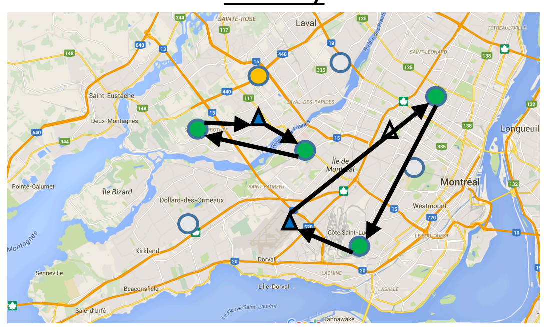


Saturday



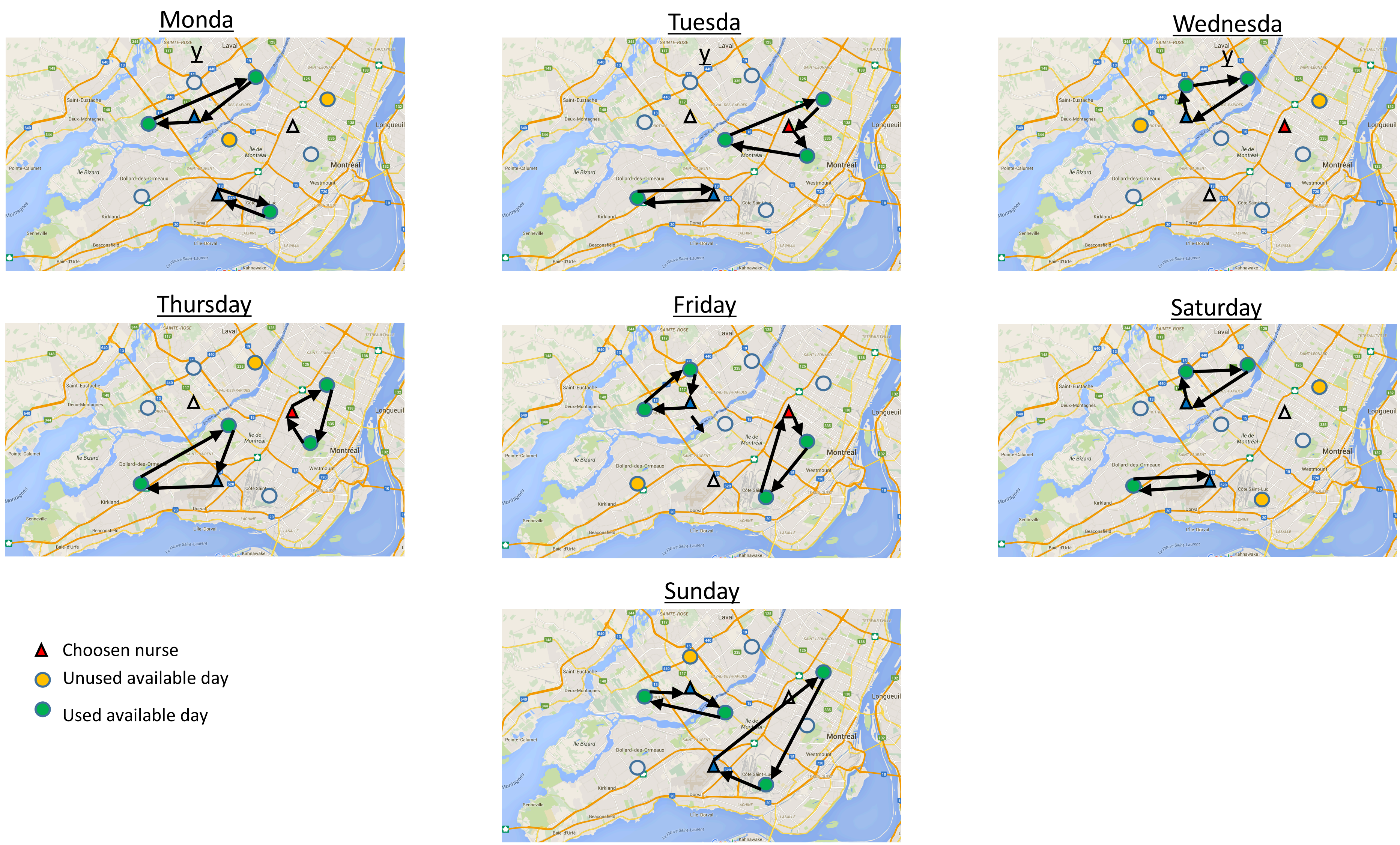
Sunday



▲ Choosen nurse

● Unused available day

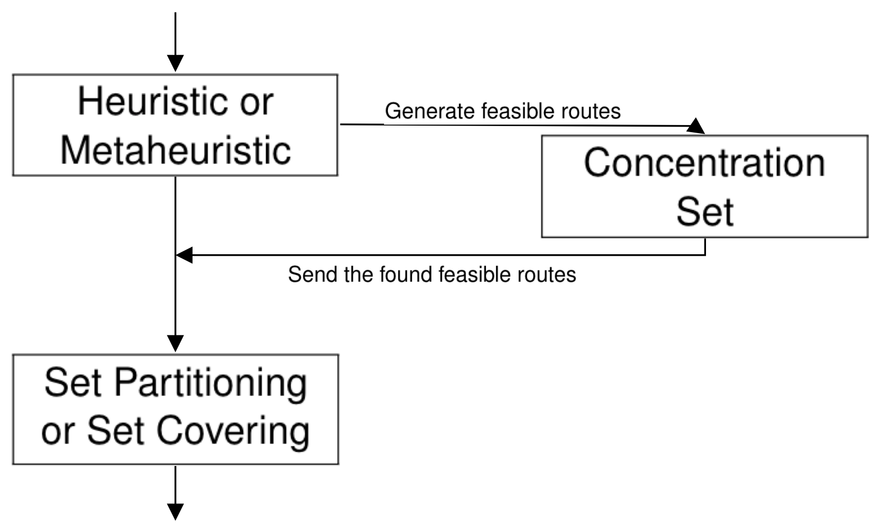
● Used available day


Monday
Tuesday
Wednesday
Thursday
Friday
Saturday
Sunday
Choosen nurse
Unused available day
Used available day

Heuristic concentration

- The heuristic concentration principle has been proposed by Rosing et al. in 1996

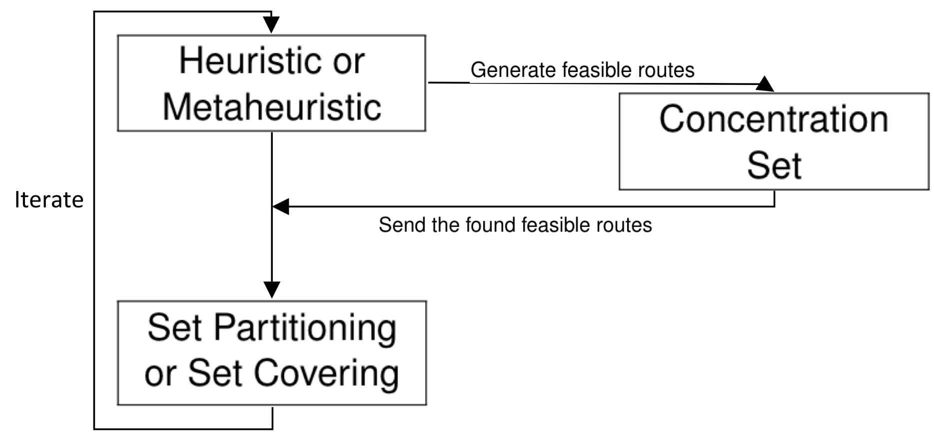
- The goal is to keep the generated feasible routes during the heuristic or metaheuristic then use these routes in the resolution of a set partitioning



Heuristic concentration

- Our version of the HC is close to the one developed by Subramanian et al. in 2013. They implemented an ILS-RVND + set part method

- They iteratively call the set partitioning to quickly guide the search to a good solution



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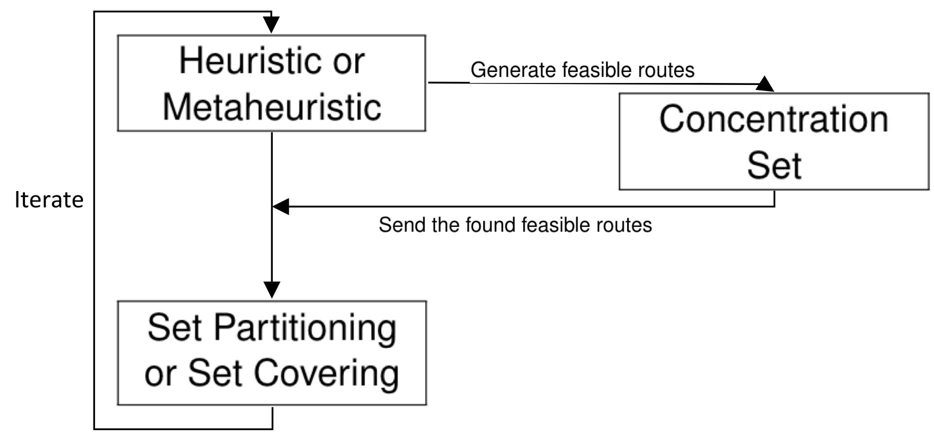

PROBLEM : Set partitioning in MIP = **Slow !**

Heuristic concentration

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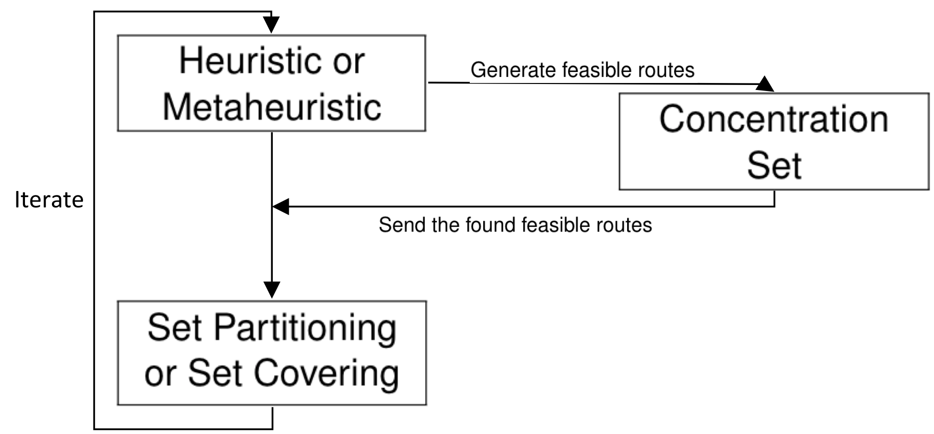

<u>PROBLEM</u> : Set partitioning in MIP = **Slow !**

<u>SOLUTION</u> : **Relax it !**

Overview of the method

Find an initial solution ;

while *No termination criteria met* **do**

  $s \leftarrow currentSolution$;

  Select and apply a destroy operator on s ;

  Select and apply a repair operator on s ;

  Analyze the solution s ;

  if *A end of segment is met* **then**

    Do the relaxed HC method ;

    Apply the local search ;

    Reset the operators' scores ;

  end

end

Return the best solution found ;

Overview of the method

```
Find an initial solution ;
while No termination criteria met do
    s ← currentSolution ;
    Select and apply a destroy operator on s ;
    Select and apply a repair operator on s ;
    Analyze the solution s ;
    if A end of segment is met then
        Do the relaxed HC method ;
        Apply the local search ;
        Reset the operators' scores ;
    end
end
Return the best solution found ;
```

Find an initial solution heuristically

Overview of the method

Find an initial solution ;
while *No termination criteria met* **do**
  $s \leftarrow currentSolution$;
  Select and apply a destroy operator on s ;
  Select and apply a repair operator on s ;
  Analyze the solution s ;
  if *A end of segment is met* **then**
    Do the relaxed HC method ;
    Apply the local search ;
    Reset the operators' scores ;
  end
end
Return the best solution found ;

Find an initial solution heuristically

Remove a subset of the visits

Overview of the method

Find an initial solution ;

while *No termination criteria met* **do**

$s \leftarrow currentSolution$;

Select and apply a destroy operator on s ;

Select and apply a repair operator on s ;

Analyze the solution s ;

if *A end of segment is met* **then**

Do the relaxed HC method ;

Apply the local search ;

Reset the operators' scores ;

end

end

Return the best solution found ;

Find an initial solution heuristically

Remove a subset of the visits

Insert the non-scheduled visits

Overview of the method

Find an initial solution ;
while *No termination criteria met* **do**
    $s \leftarrow currentSolution$;
    Select and apply a destroy operator on s ;
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    Analyze the solution s ;
    if *A end of segment is met* **then**
        Do the relaxed HC method ;
        Apply the local search ;
        Reset the operators' scores ;
    end
end
Return the best solution found ;

Find an initial solution heuristically

Remove a subset of the visits

Insert the non-scheduled visits

Update the best / current solutions

Overview of the method

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while *No termination criteria met* **do**
    $s \leftarrow currentSolution$;
    Select and apply a destroy operator on s ;
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    Analyze the solution s ;
    if *A end of segment is met* **then**
        Do the relaxed HC method ;
        Apply the local search ;
        Reset the operators' scores ;
    end
end
Return the best solution found ;

Find an initial solution heuristically

Remove a subset of the visits

Insert the non-scheduled visits

Update the best / current solutions

Apply a heuristic concentration

Overview of the method

```
Find an initial solution ;
while No termination criteria met do
    s ← currentSolution ;
    Select and apply a destroy operator on s ;
    Select and apply a repair operator on s ;
    Analyze the solution s ;
    if A end of segment is met then
        Do the relaxed HC method ;
        Apply the local search ;
        Reset the operators' scores ;
    end
end
Return the best solution found ;
```

Find an initial solution heuristically

Remove a subset of the visits

Insert the non-scheduled visits

Update the best / current solutions

Apply a heuristic concentration

Apply a local search

Overview of the method

Find an initial solution ;	*Find an initial solution heuristically*
while *No termination criteria met* **do**	
$s \leftarrow currentSolution$;	
Select and apply a destroy operator on s ;	*Remove a subset of the visits*
Select and apply a repair operator on s ;	*Insert the non-scheduled visits*
Analyze the solution s ;	*Update the best / current solutions*
if *A end of segment is met* **then**	
Do the relaxed HC method ;	*Apply a heuristic concentration*
Apply the local search ;	*Apply a local search*
Reset the operators' scores ;	*Update the operators' scores*
end	
end	
Return the best solution found ;	

Overview of the method

Find an initial solution ;	*Find an initial solution heuristically*
while *No termination criteria met* **do**	
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Apply the local search ;	*Apply a local search*
Reset the operators' scores ;	*Update the operators' scores*
end	
end	
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Overview of the method

Find an initial solution ;

while *No termination criteria met* **do**

  $s \leftarrow currentSolution$;

  Select and apply a destroy operator on s ;

  Select and apply a repair operator on s ;

  Analyze the solution s ;

  if *A end of segment is met* **then**

    Do the relaxed HC method ;

    Apply the local search ;

    Reset the operators' scores ;

  end

end

Return the best solution found ;

Find an initial solution heuristically

Remove a subset of the visits

Insert the non-scheduled visits

Update the best / current solutions

Apply a heuristic concentration

Apply a local search

Update the operators' scores

Relaxed heuristic concentration

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega \in \Omega} c_\omega x_\omega + C.\sum_{n \in N}(o_n + u_n) + U.\sum_{p \in P} z_p \\
\text{subject to} \quad & \sum_{\omega \in \Omega_d} a_{\omega,p} x_\omega \leq 1 && \forall_{p \in P}, \forall_{d \in A_d} \\
& \sum_{\omega \in \Omega} a_{\omega,p} x_\omega + z_p = n_p && \forall_{p \in P} \\
& \sum_{\omega \in \Omega_d \cap \Omega_n} x_\omega \leq 1 && \forall_{n \in N}, \forall_{d \in W_d} \\
& \sum_{\omega \in \Omega} l_\omega x_\omega + u_n \geq min_n && \forall_{n \in N} \\
& \sum_{\omega \in \Omega} l_\omega x_\omega - o_n \leq max_n && \forall_{n \in N} \\
& x_\omega \in \{0,1\} && \forall_{\omega \in \Omega} \\
& z_p \in \mathbb{N} && \forall_{p \in P} \\
& o_n, u_n \geq 0 && \forall_{n \in N}
\end{aligned}
$$

Relaxed heuristic concentration

$$
\begin{array}{lll}
\underset{x}{\text{minimize}} & \displaystyle\sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p & \\
\text{subject to} & \displaystyle\sum_{\omega\in\Omega_d} a_{\omega,p} x_\omega \leq 1 & \forall_{p\in P}, \forall_{d\in A_d} \\
& \displaystyle\sum_{\omega\in\Omega} a_{\omega,p} x_\omega + z_p = n_p & \forall_{p\in P} \\
& \displaystyle\sum_{\omega\in\Omega_d\cap\Omega_n} x_\omega \leq 1 & \forall_{n\in N}, \forall_{d\in W_d} \\
& \displaystyle\sum_{\omega\in\Omega} l_\omega x_\omega + u_n \geq min_n & \forall_{n\in N} \\
& \displaystyle\sum_{\omega\in\Omega} l_\omega x_\omega - o_n \leq max_n & \forall_{n\in N} \\
& x_\omega \in \{0,1\} & \forall_{\omega\in\Omega} \\
& z_p \in \mathbb{N} & \forall_{p\in P} \\
& o_n, u_n \geq 0 & \forall_{n\in N}
\end{array}
$$

$$\Downarrow$$

$$
\begin{array}{lll}
\underset{x}{\text{minimize}} & \displaystyle\sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p & \\
\text{subject to} & \displaystyle\sum_{\omega\in\Omega_d} a_{\omega,p} x_\omega \leq 1 & \forall_{p\in P}, \forall_{d\in A_d} \\
& \displaystyle\sum_{\omega\in\Omega} a_{\omega,p} x_\omega + z_p = n_p & \forall_{p\in P} \\
& \displaystyle\sum_{\omega\in\Omega_d\cap\Omega_n} x_\omega \leq 1 & \forall_{n\in N}, \forall_{d\in W_d} \\
& \displaystyle\sum_{\omega\in\Omega} l_\omega x_\omega + u_n \geq min_n & \forall_{n\in N} \\
& \displaystyle\sum_{\omega\in\Omega} l_\omega x_\omega - o_n \leq max_n & \forall_{n\in N} \\
& \boxed{\begin{array}{l} x_\omega \in [0,1] \\ z_p \geq 0 \\ o_n, u_n \geq 0 \end{array}} & \begin{array}{l} \forall_{\omega\in\Omega} \\ \forall_{p\in P} \\ \forall_{n\in N} \end{array}
\end{array}
$$

Relaxed heuristic concentration

$$\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p \\
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& \sum_{\omega\in\Omega} a_{\omega,p}x_\omega + z_p = n_p && \forall_{p\in P} \\
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& \sum_{\omega\in\Omega} l_\omega x_\omega - o_n \le max_n && \forall_{n\in N} \\
& x_\omega \in \{0,1\} && \forall_{\omega\in\Omega} \\
& z_p \in \mathbb{N} && \forall_{p\in P} \\
& o_n, u_n \ge 0 && \forall_{n\in N}
\end{aligned}$$

$$\Downarrow$$

$$\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p \\
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& \boxed{x_\omega \in [0,1]} && \forall_{\omega\in\Omega} \\
& \boxed{z_p \ge 0} && \forall_{p\in P} \\
& \boxed{o_n, u_n \ge 0} && \forall_{n\in N}
\end{aligned}$$

We then call a constructive heuristic based on the LP solution

```
L : list of the route sorted by decreasing order of x_ω
forall route ω in L do
    forall visit v in ω do
        if the schedule of the visit is possible then
            schedule the visit in the route ω ;
        end
    end
end
```

Heuristic Concentration

Best Solution	Concentration Set
Route 1	*Route 1*
Route 2	*Route 2*
Route 3	*Route 3*

Iteration : 0

Heuristic Concentration

Best Solution
Route 1
Route 4
Route 3

Concentration Set
Route 1
Route 2
Route 3
Route 4
Route 5

Iteration : 145

Heuristic Concentration

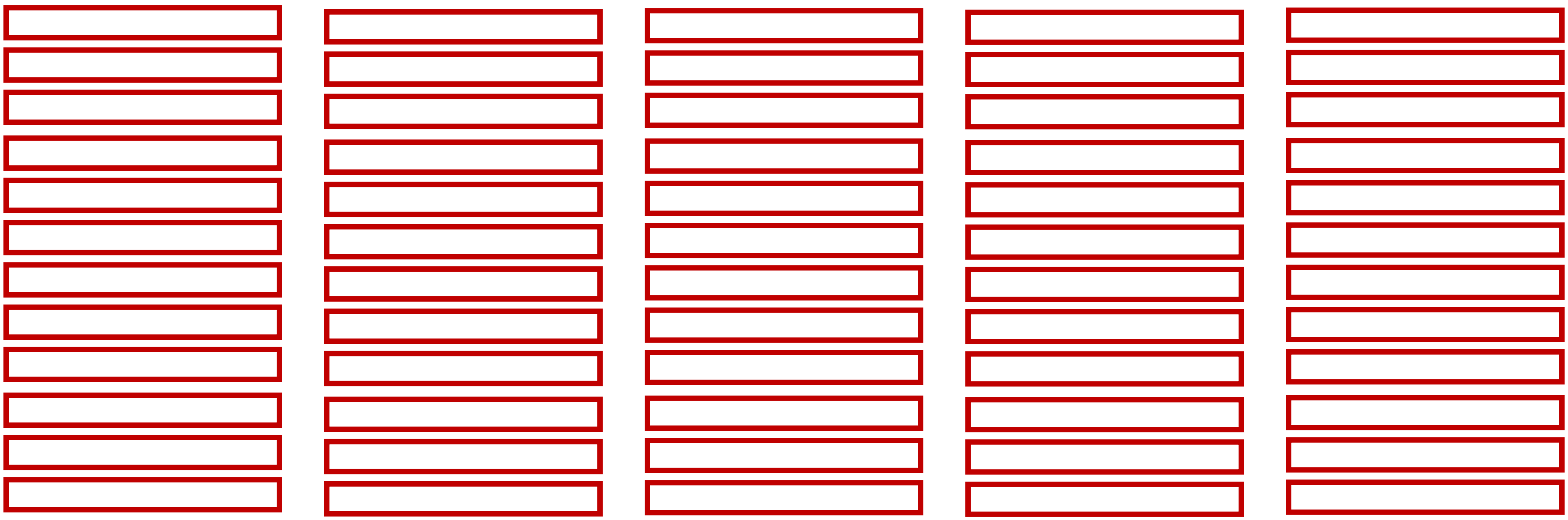
Best Solution
Route 7
Route 4
Route 12

Concentration Set
Route 1
Route 2
Route 3
Route 4
Route 5
Route 6
Route 7
Route 8
Route 9
Route 10
Route 11
Route 12

Iteration : 319

Heuristic Concentration

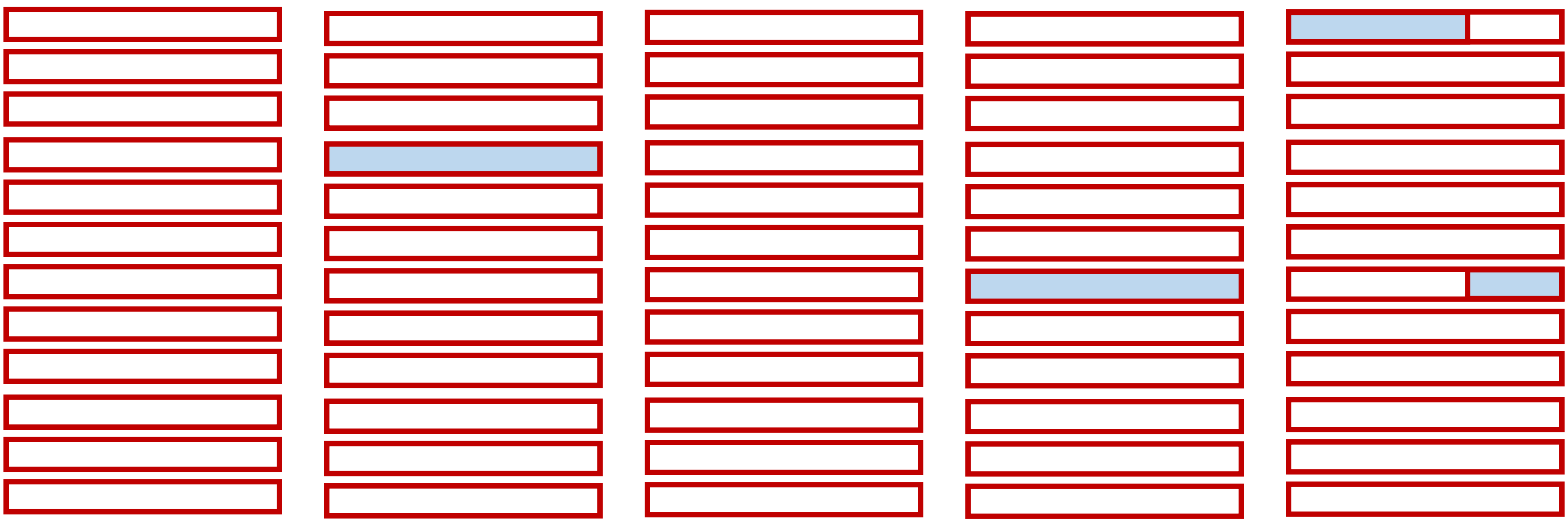
Concentration Set



Iteration : 1000 → Solve the relaxed set partitioning

Heuristic Concentration

Concentration Set



Relaxed set partitioning solution

Heuristic Concentration

New Solution

Heuristic Concentration Selection

Route 11
Route 32
Route 45
Route 75

Iteration : 1000

Heuristic Concentration

New Solution
Route 11
Route 32

Heuristic Concentration Selection
Route 11
Route 32
Route 45
Route 75

Iteration : 1000

Heuristic Concentration

New Solution	
Route 11	
Route 32	
Route 45	?

Heuristic Concentration Selection
Route 11
Route 32
Route 45
Route 75

Iteration : 1000

Heuristic Concentration

New Solution
Route 11
Route 32
Route 45

Heuristic Concentration Selection
Route 11
Route 32
Route 45
Route 75

→ And we analyse the new solution

Iteration : 1000

Overview of the method

Find an initial solution ;
while *No termination criteria met* **do**
  $s \leftarrow currentSolution$;
  Select and apply a destroy operator on s ;
  Select and apply a repair operator on s ;
  Analyze the solution s ;
  if *A end of segment is met* **then**
    Do the relaxed HC method ;
    Apply the local search ;
    Reset the operators' scores ;
  end
end
Return the best solution found ;

Find an initial solution heuristically

Remove a subset of the visits

Insert the non-scheduled visits

Update the best / current solutions

Apply a heuristic concentration

Apply a local search

Update the operators' scores

Classic ALNS operators

Classic Destroy operators :

Worst removal → Visits which cost the most

Classic ALNS operators

Classic Destroy operators :

Worst removal → Visits which cost the most

Random Removal → Randomly select q visits

Classic ALNS operators

Classic Destroy operators :

Worst removal → Visits which cost the most

Random Removal → Randomly select q visits

Related removal → Randomly select a visit and remove it and the q-1 most related

Classic ALNS operators

Classic Destroy operators :

- Worst removal → Visits which cost the most
- Random Removal → Randomly select q visits
- Related removal → Randomly select a visit and remove it and the q-1 most related

Classic Repair operators :

- Greedy heuristic → Scheduled at lowest cost

Classic ALNS operators

Classic Destroy operators :

- Worst removal → Visits which cost the most
- Random Removal → Randomly select q visits
- Related removal → Randomly select a visit and remove it and the q-1 most related

Classic Repair operators :

- Greedy heuristic → Scheduled at lowest cost
- Regret-2/Regret-3 → Take into account the regret after insertion

New Operators

New Destroy operators :

Random Patient → Randomly select a patient and remove all his visits

New Operators

New Destroy operators :

Random Patient → Randomly select a patient and remove all his visits

Flexible patient → Remove the most flexible : Nb_available / Nb_visits

New Operators

New Destroy operators :

Random Patient → Randomly select a patient and remove all his visits

Flexible patient → Remove the most flexible : Nb_available / Nb_visits

New Repair operators :

Random Patient → Randomly select a patient and schedule all his visits

New operators

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p \\
\text{subject to} \quad & \sum_{\omega\in\Omega_d} a_{\omega,p} x_\omega \le 1 && \forall_{p\in P}, \forall_{d\in A_d} \\
& \boxed{\sum_{\omega\in\Omega} a_{\omega,p} x_\omega + z_p = n_p} && \forall_{p\in P} \\
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& \sum_{\omega\in\Omega} l_\omega x_\omega - o_n \le max_n && \forall_{n\in N} \\
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\end{aligned}
$$

New operators

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega \in \Omega} c_\omega x_\omega + C. \sum_{n \in N} (o_n + u_n) + U. \sum_{p \in P} z_p \\
\text{subject to} \quad & \sum_{\omega \in \Omega_d} a_{\omega,p} x_\omega \leq 1 && \forall_{p \in P}, \forall_{d \in A_d} \\
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& z_p \geq 0 && \forall_{p \in P} \\
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\end{aligned}
$$

Dual power

New operators

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & \sum_{\omega\in\Omega} c_\omega x_\omega + C.\sum_{n\in N}(o_n+u_n) + U.\sum_{p\in P} z_p \\
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& x_\omega \in [0,1] && \forall_{\omega\in\Omega} \\
& z_p \geq 0 && \forall_{p\in P} \\
& o_n, u_n \geq 0 && \forall_{n\in N}
\end{aligned}
$$

Dual power

Focus on the highest dual values !

New Operators

New Destroy operators :

Random Patient → Randomly select a patient and remove all his visits
Flexible patient → Remove the most flexible : Nb_available / Nb_visits
Dual Patient → Remove the patients with **the lowest dual value**

New Repair operators :

Random Patient → Randomly select a patient and schedule all his visits
Dual Patient → Prioritize the patient with the highest dual values

Outline

- Problem Definition
- Mathematical Formulation
- Resolution Method
- **Computation Results**
- Conclusion

Instances generation

- We have generated 3 sets of 20 pseudo-instances

Instance	Patient	Visits	Nurse	Workdays
Small	40	120	5	25
Medium	80	225	10	45
Large	150	430	20	90

Table 1: Instances' characteristics

- The algorithm is implemented in C++, the set partitioning calls Cplex and each instance runs during 10 minutes / 10^5 iterations

Experiments: Impact of the new operators

	Classic	All	
		Gap	CPU
Small	512169,0577	**-9,38%**	<4 min
Medium	613572,3348	**-6,48%**	10 min
Large	799746,4565	**-8,19%**	10 min
Mean		**-8,01%**	

Table 1: Evolution of the costs with the new operators

Experiments: Impact of the set partitioning

	Classic	All		All + Set Part	
		Gap	CPU	Gap	CPU
Small	512169,0577	-9,38%	<4 min	**-15,29%**	<6 min
Medium	613572,3348	-6,48%	10 min	**-18,32%**	10 min
Large	799746,4565	-8,19%	10 min	**-18,70%**	10 min
Mean		-8,01%		**-17,44%**	

Table 2: Evolution of the costs with the set partitioning

Experiments: Impact of the dual operators

	Classic	All		All + Set Part		All + SP + Dual	
		Gap	CPU	Gap	CPU	Gap	CPU
Small	512169,0577	-9,38%	<4 min	-15,29%	<6 min	-15,28%	<6 min
Medium	613572,3348	-6,48%	10 min	-18,32%	10 min	-18,29%	10 min
Large	799746,4565	-8,19%	10 min	-18,70%	10 min	**-20,53%**	10 min
Mean		-8,01%		-17,44%		**-18,03%**	

Table 3: Evolution of the costs with the dual operators

Analysis of the operators

$\boxed{\text{Can we remove some useless operators ?}}$

Analysis of the operators

$\boxed{\text{Can we remove some useless operators ?}}$

Goal : Keep the top-3 destroy and repair operators

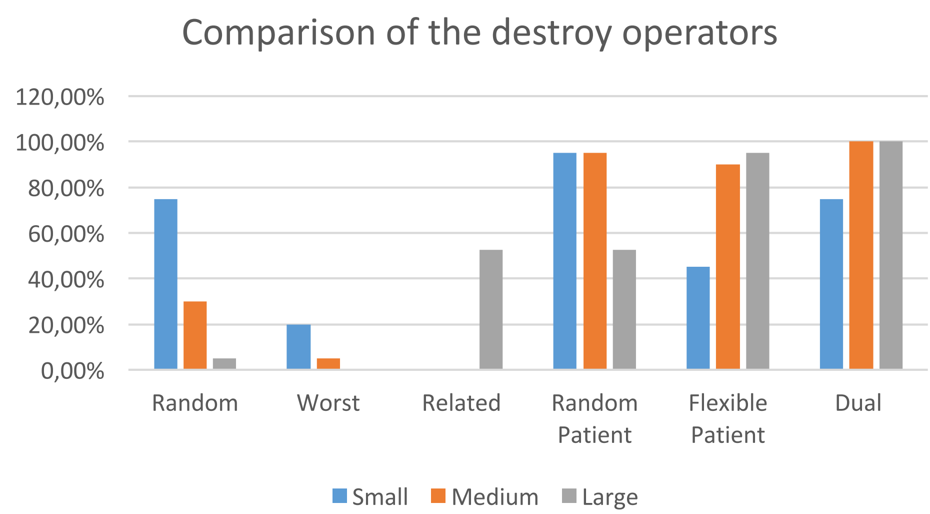
Analysis of the operators

Can we remove some useless operators ?

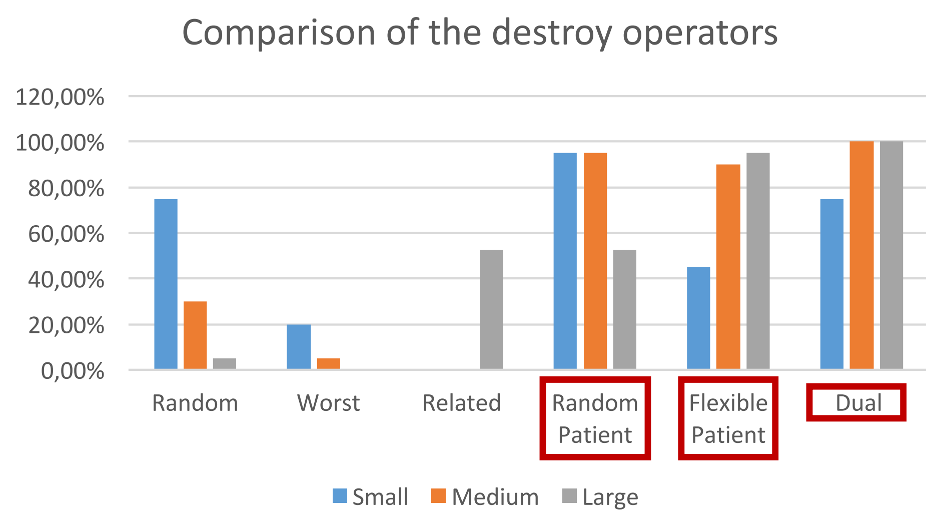
Goal : Keep the top-3 destroy and repair operators

Idea : Keep the operators which are the less often rejected at the end of the iteration

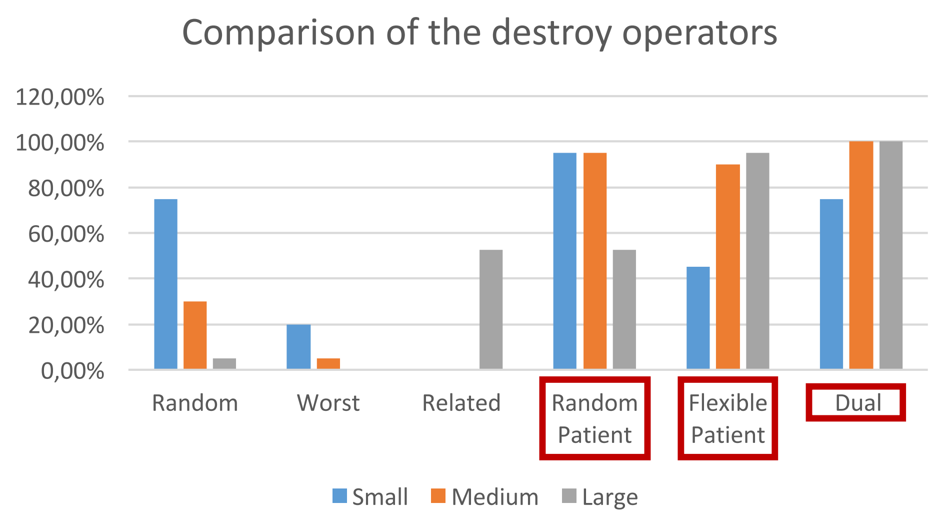
Analysis of the operators

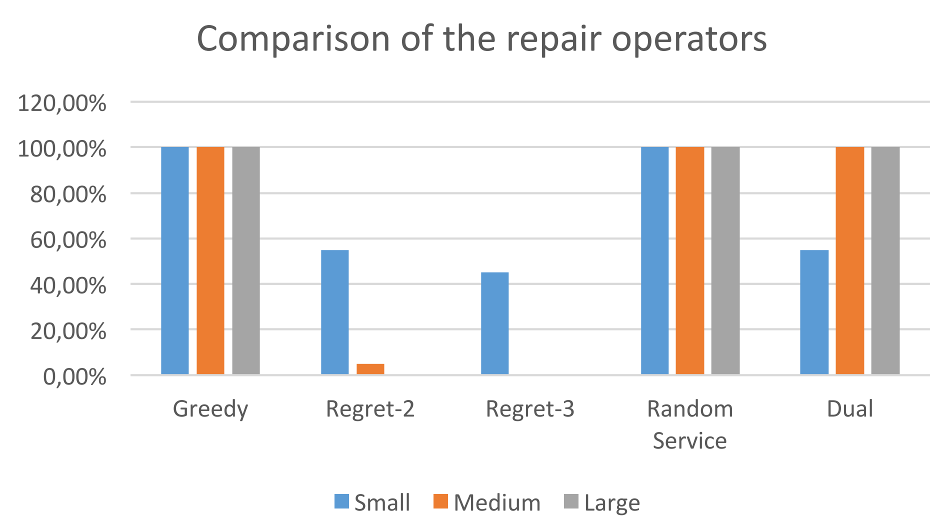


Analysis of the operators

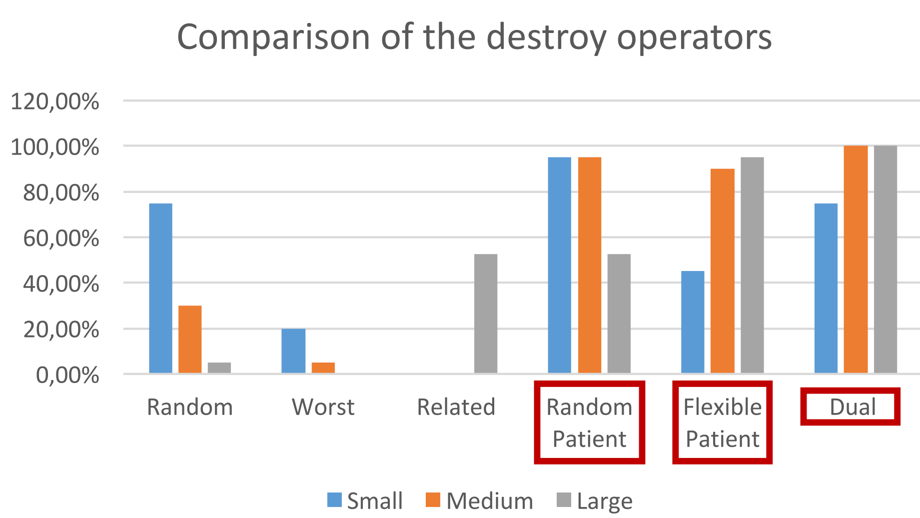


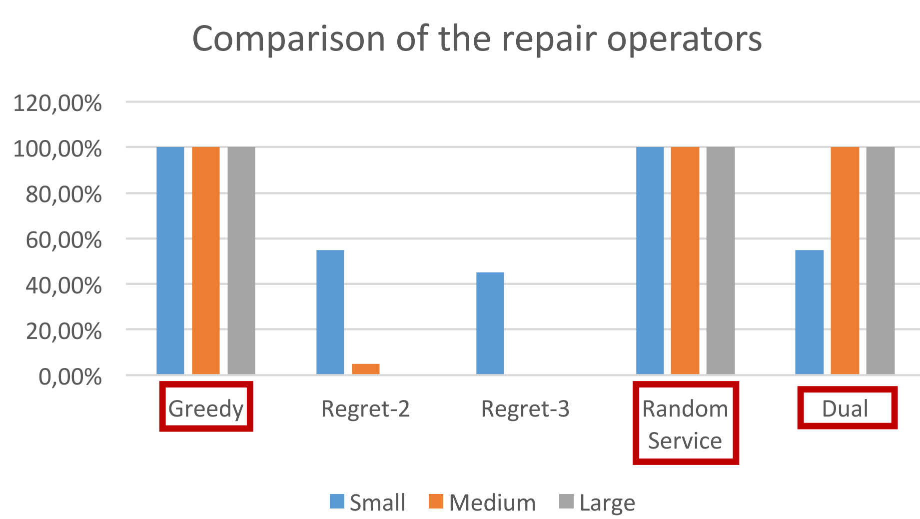
Analysis of the operators





Analysis of the operators





Experiments: Selection of the best operators

	Classic	All		All + Set Part		All + SP + Dual		Selected	
		Gap	CPU	Gap	CPU	Gap	CPU	Gap	CPU
Small	512169,0577	-9,38%	<4 min	-15,29%	<6 min	-15,28%	<6 min	-14,86%	<4 min
Medium	613572,3348	-6,48%	10 min	-18,32%	10 min	-18,29%	10 min	**-18,86%**	10 min
Large	799746,4565	-8,19%	10 min	-18,70%	10 min	-20,53%	10 min	**-20,92%**	10 min
Mean		-8,01%		-17,44%		-18,03%		**-18,22%**	

Table 4: Evolution of the costs with the selected operators

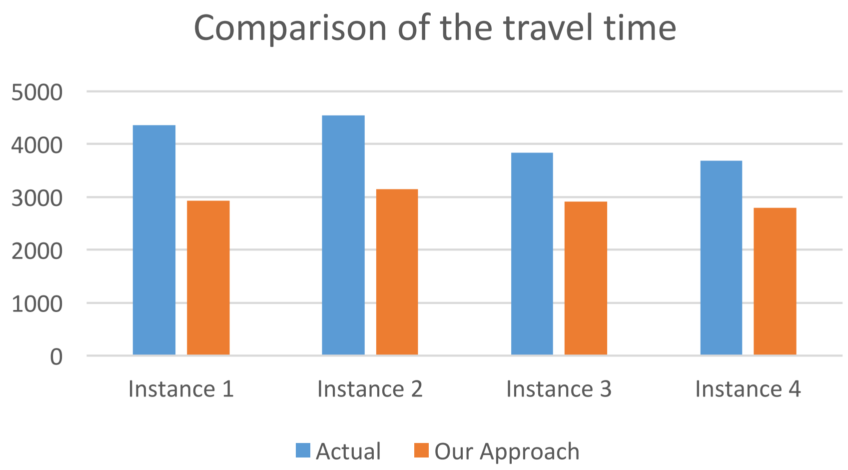
Real instances

We have taken 4 real instances corresponding to 1 week of work

Name	Patient	Visit	Nurse	Workday
Instance 1	149	325	11	40
Instance 2	137	340	11	40
Instance 3	145	311	11	35
Instance 4	146	324	11	40

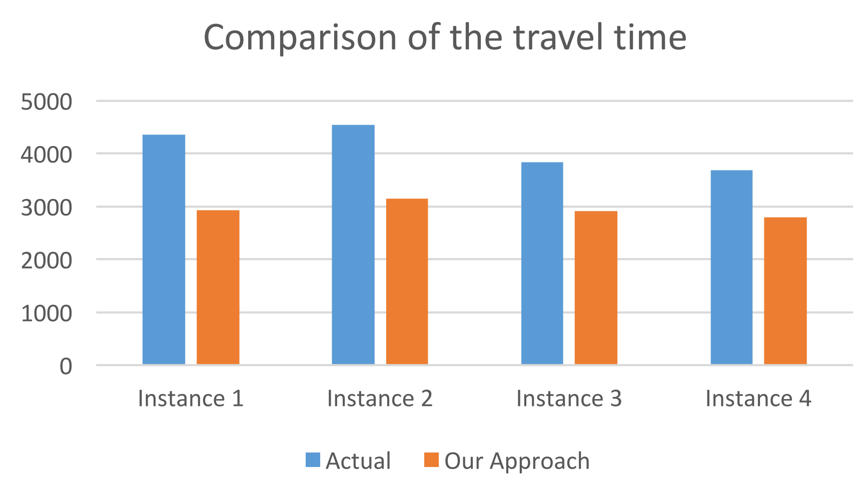
Table 5: Real instances

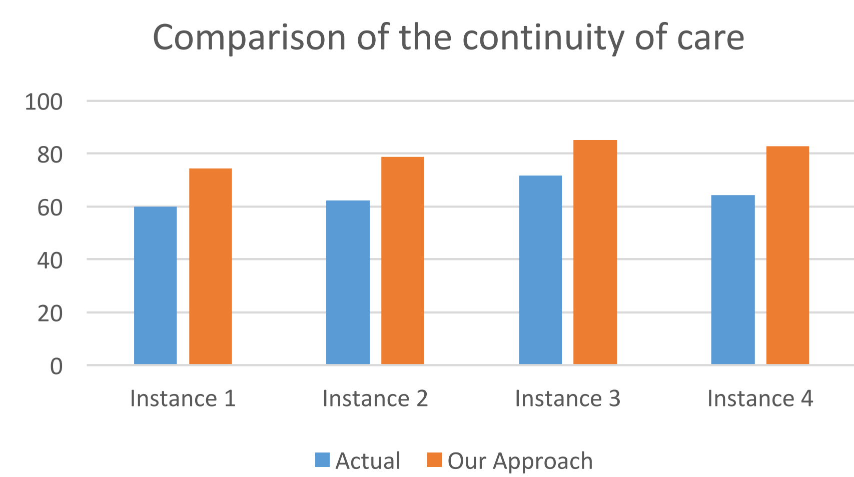
Real instances' results



Reduction of the travel time by **28,31%** in comparaison with the actual solution

Real instances' results



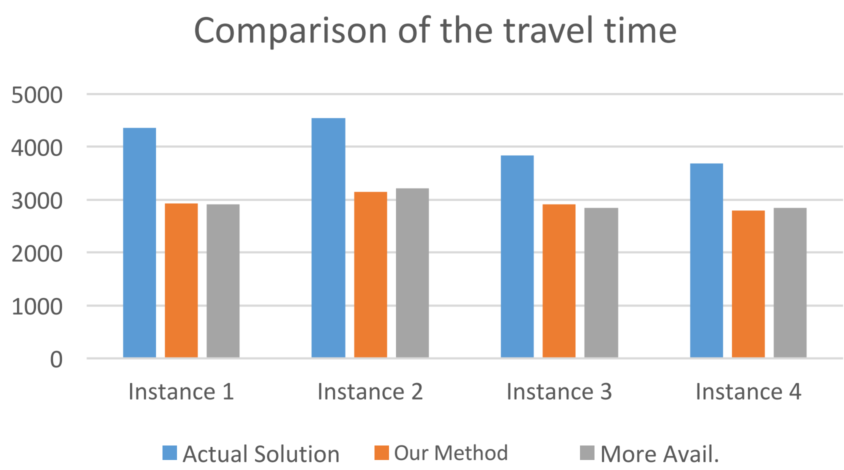


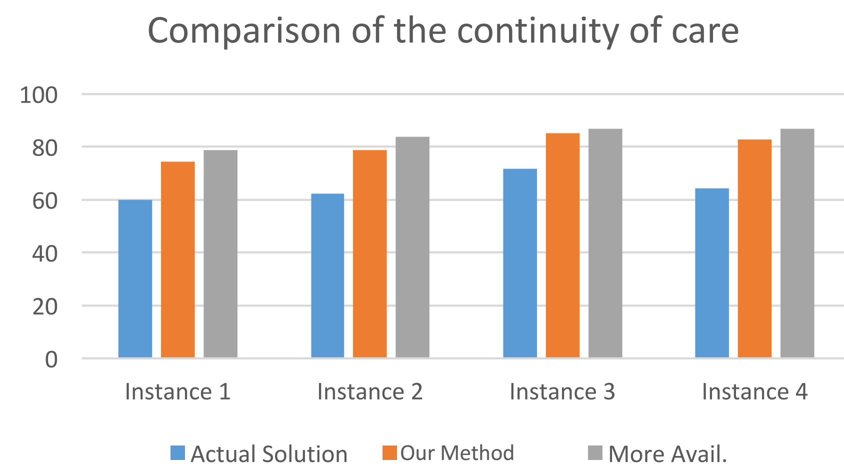
Reduction of the travel time by **28,31%** in comparaison with the actual solution

Increase of the fidelity by **15,70%** in comparaison with the actual solution

Real instances' results

+ 1 available day for 40% of the patients

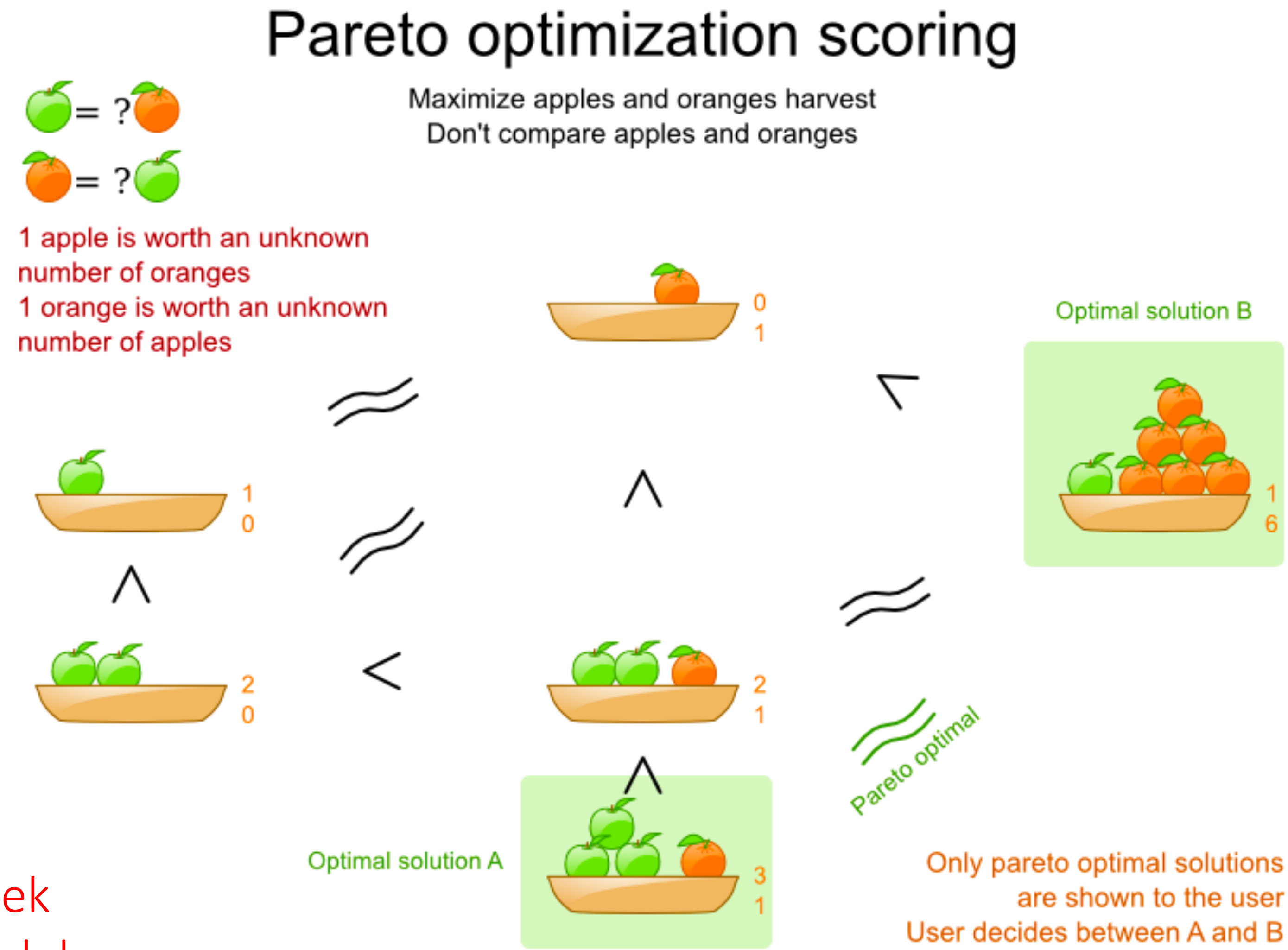




Reduction of the travel time by **28,03%** in comparaison with the actual solution

Increase of the fidelity by **19,44%** in comparaison with the actual solution what?s next

The multi-objective nature of the challenge



Soft constraints

- Continuity of care
- Optional requirements
- Travel time
- Min/Max worktime week
- Min/Max worktime workday
- Number of visits over the week

Controlling the Transition

Actual
schedule

Fully reshuffled
optimized schedule

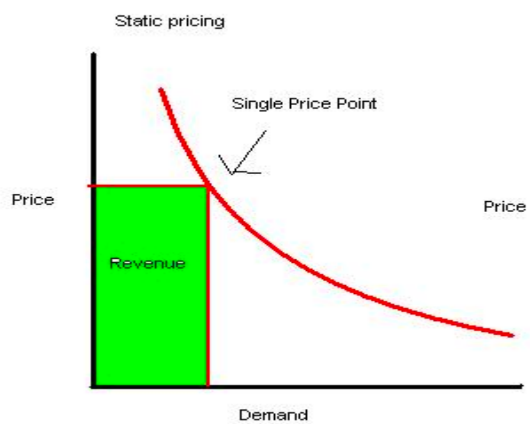
Daily scheduling decision

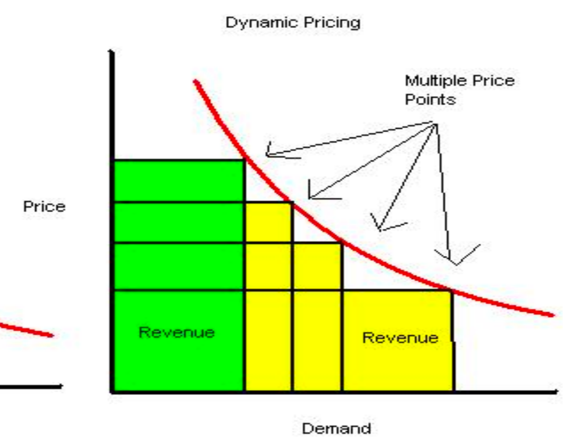
Operational
optimized schedule

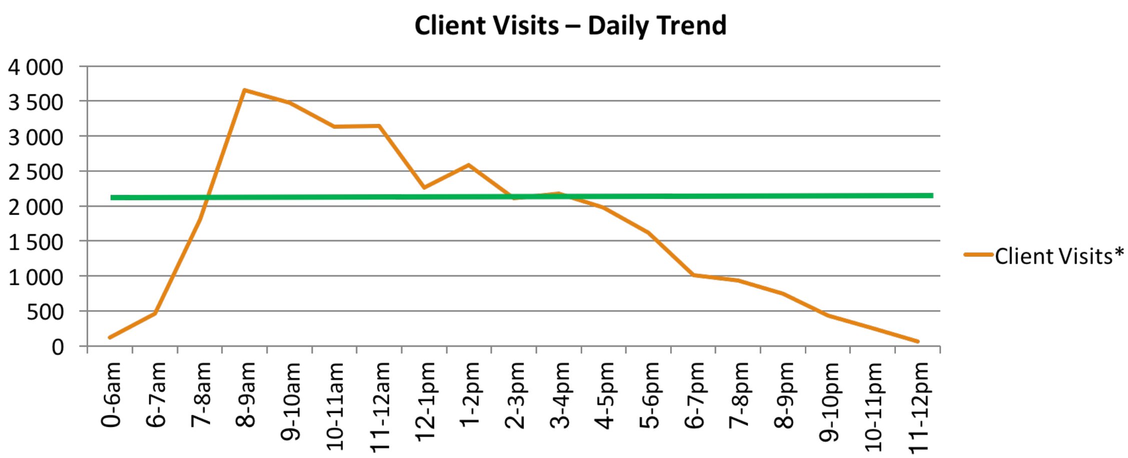
Self Service and Dynamic Pricing

As demand for service, and **self-service** increases…

→ how can we balance **resource utilization**



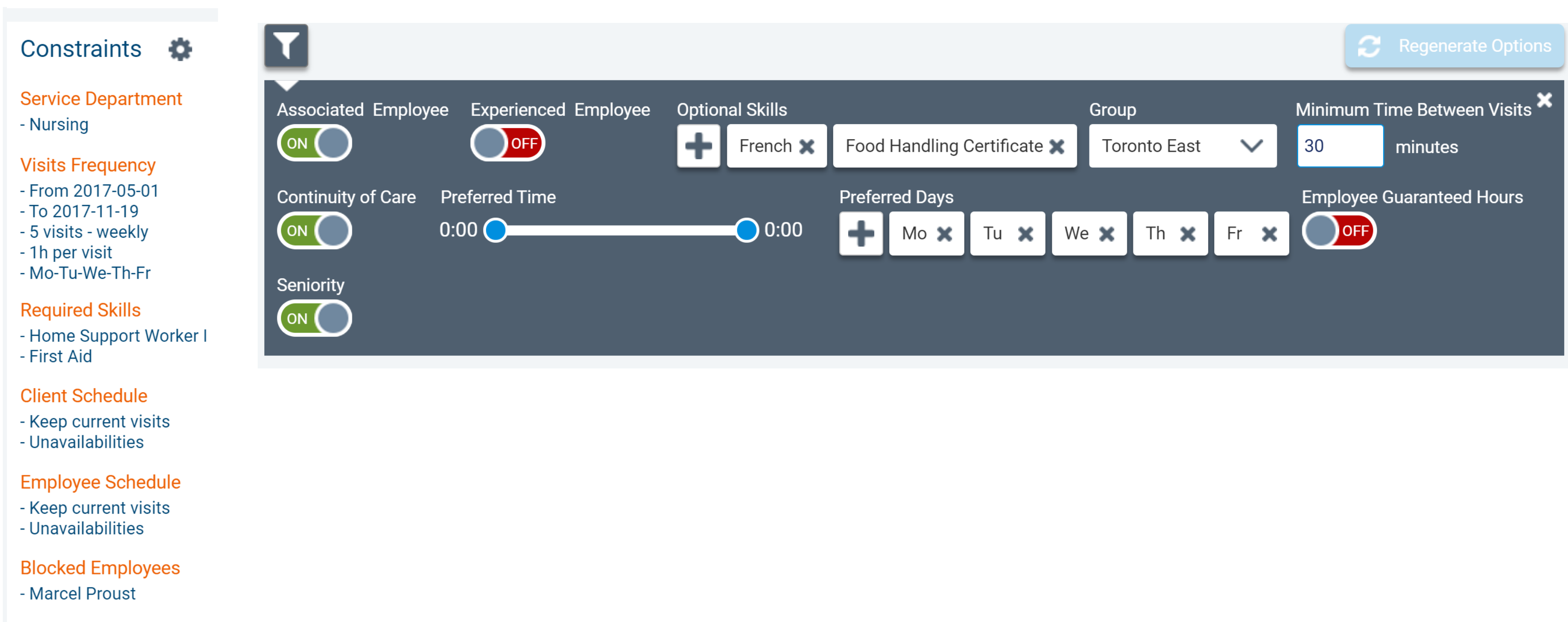




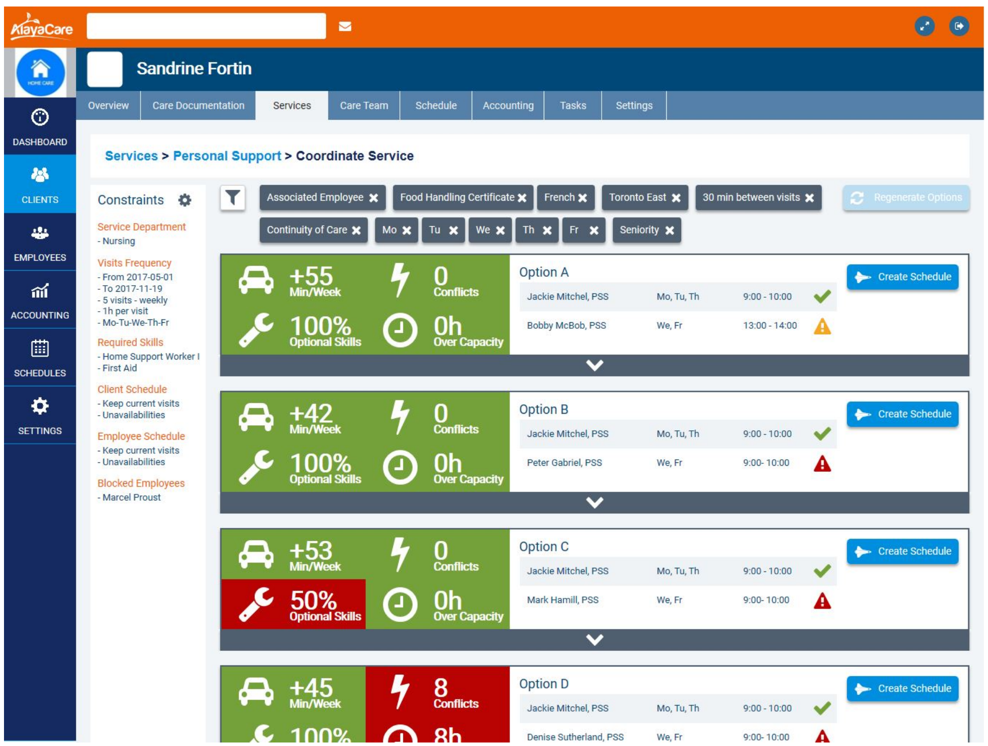
User Experience

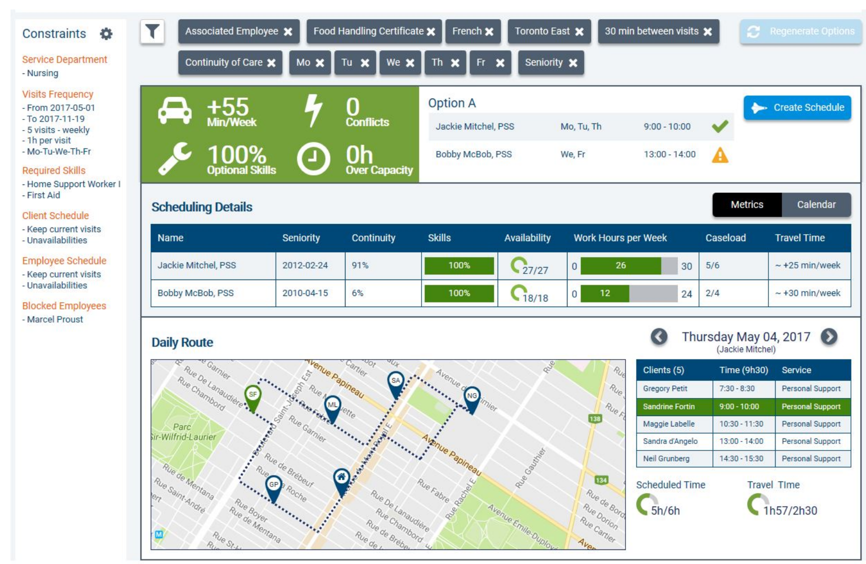
- Fully-automated scheduling (i.e. without human intervention) is highly complex.
- How do we leverage the optimization engine for decision support?
- Decision: Focus on our primary use case - *new client schedule setup.*

User Experience



User Experience

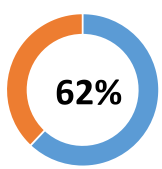




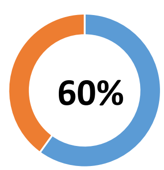
User Experience

System Usability Scale Results

Current System

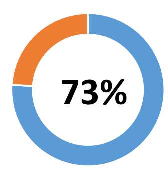


Usability

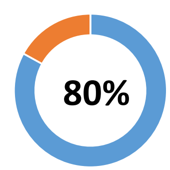


Learnability

Prototype



Usability



Learnability

"I really like it. This is stimulating"

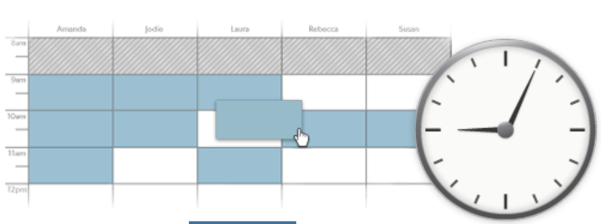
"Straight forward and not repetitive"

"It saves a lot of time"

"Pretty simple after getting used to it"

ROI

Reduced Time to Schedule



33 %

~$115,000 / annually

Lower Recruitment Costs

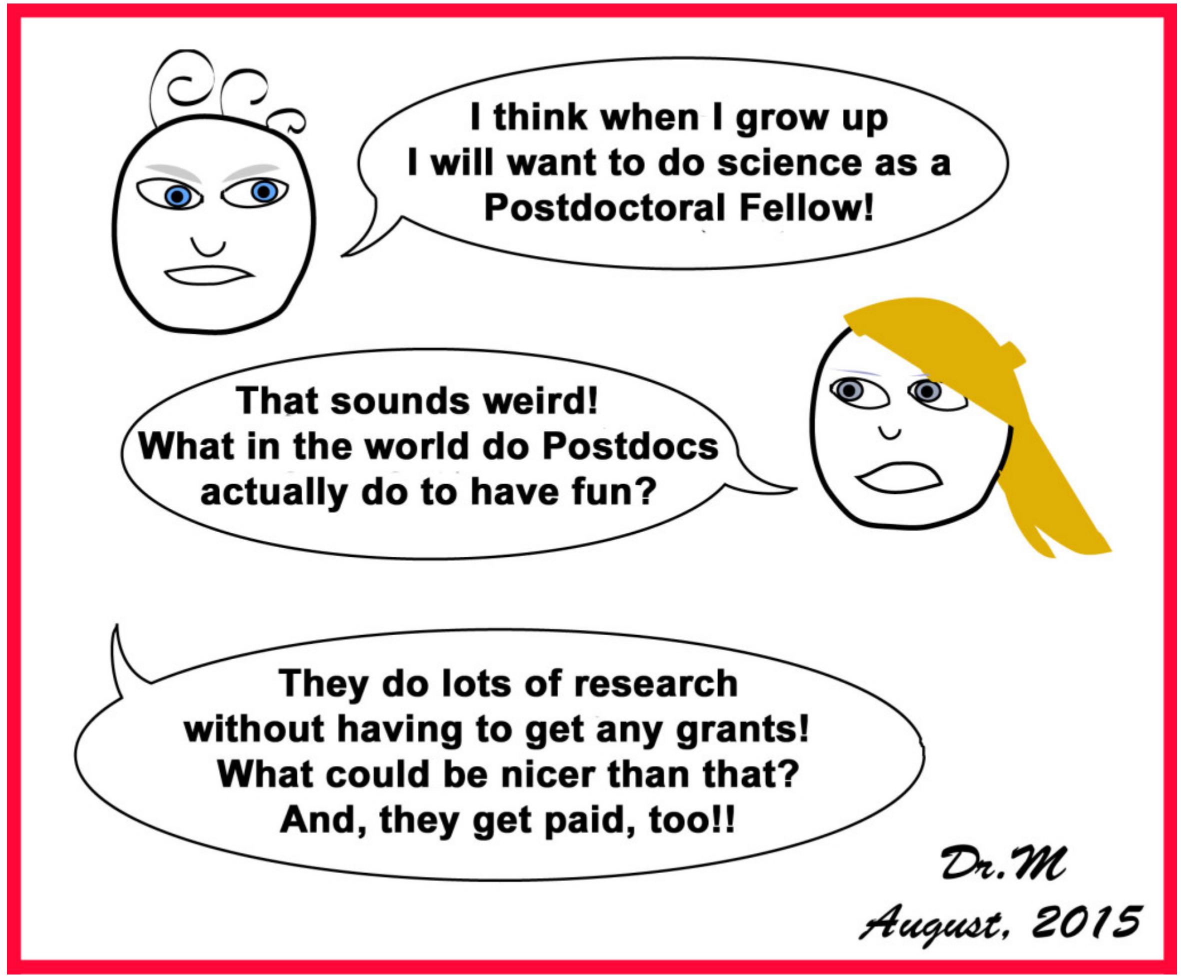
6% *

~$24,000 / annually

* Based on a 25% reduction in employee turnover.

Any Questions ?

Thank you !



If you are on the Postdoc market

Contact US !