Założenia do modelu optymalizacji taktycznej procesów logistycznych typowego operatora pocztowego

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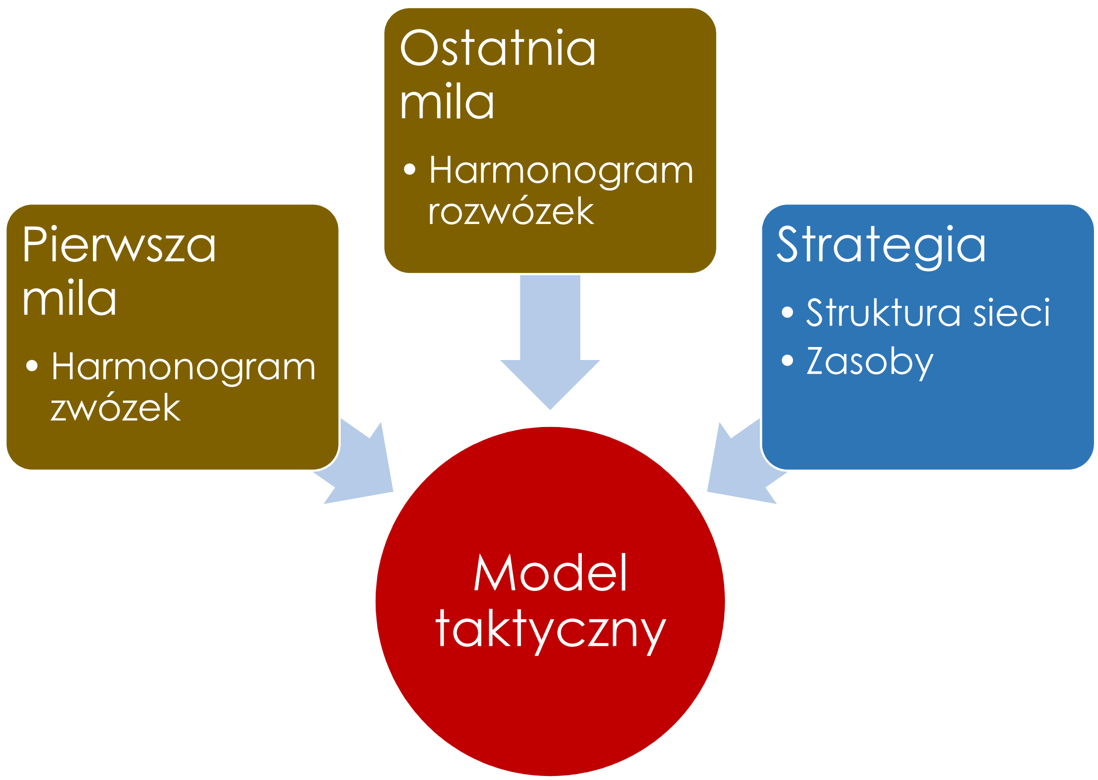
Agenda

1. Typowe wymagania biznesowe
2. Podejście analityczne do rozwiązania problemu

Problem typowego operatora pocztowego

Mając informacje o godzinach wejścia strumieni produktowych do punktów sieci należy ułożyć przebiegi strumieni z przypisanymi ilościami i wielkościami rodzajów transportów.

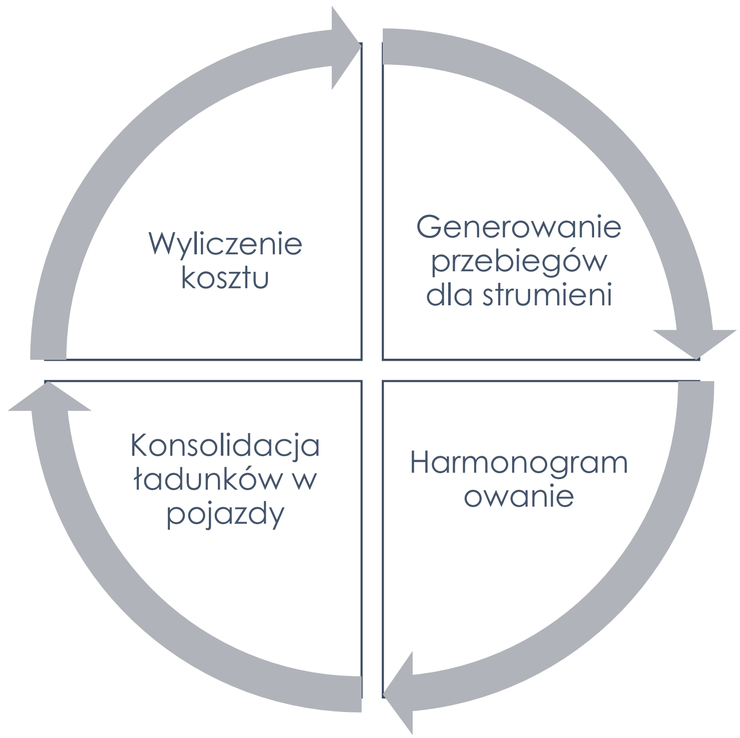
Relacja problemu względem warstwy strategicznej i operacyjnej



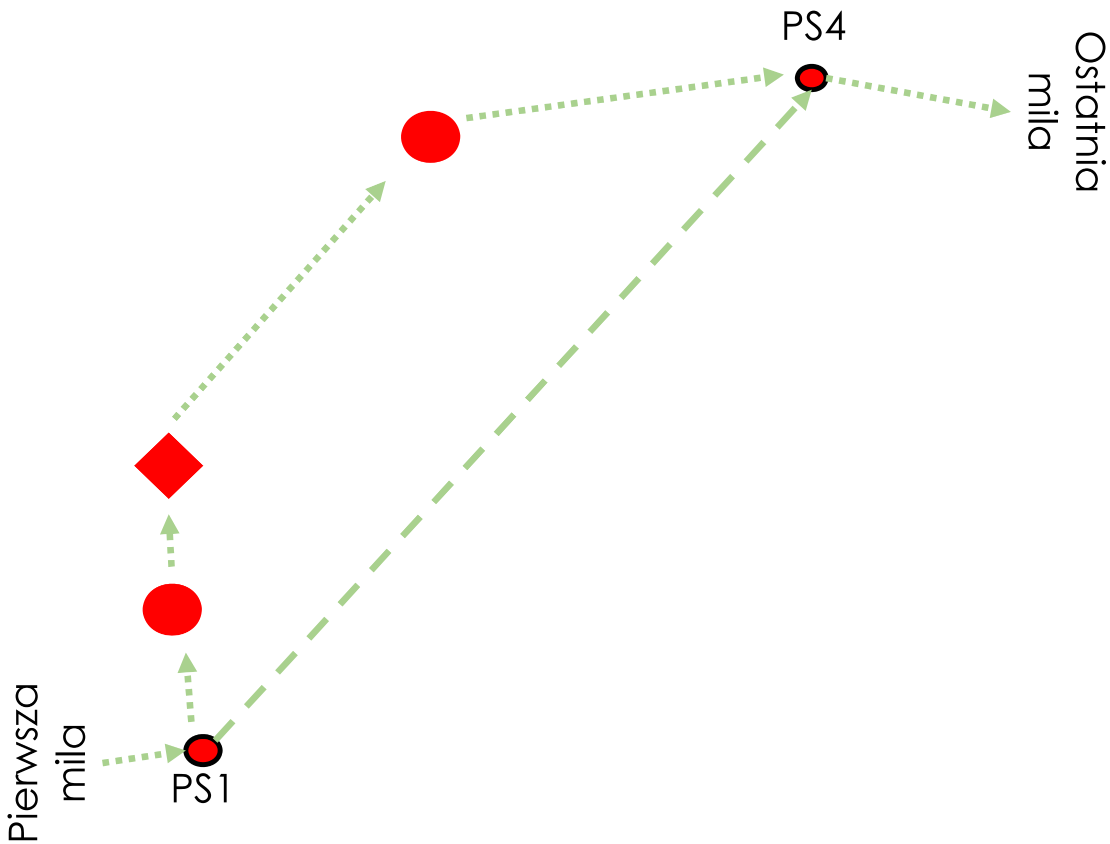
Wymagania odnośnie modelu

- Czas w granulacji minutowej
- Planujemy dla 7 dni (cykl tygodniowy)
- Nie planujemy na poziomie pierwszej i ostatniej mili
- Planujemy komunikację między punktami sieci (kiedy, ile, czym?)

Oczekiwane wyniki działania modelu



Strumień produktowy i przebieg dla strumienia



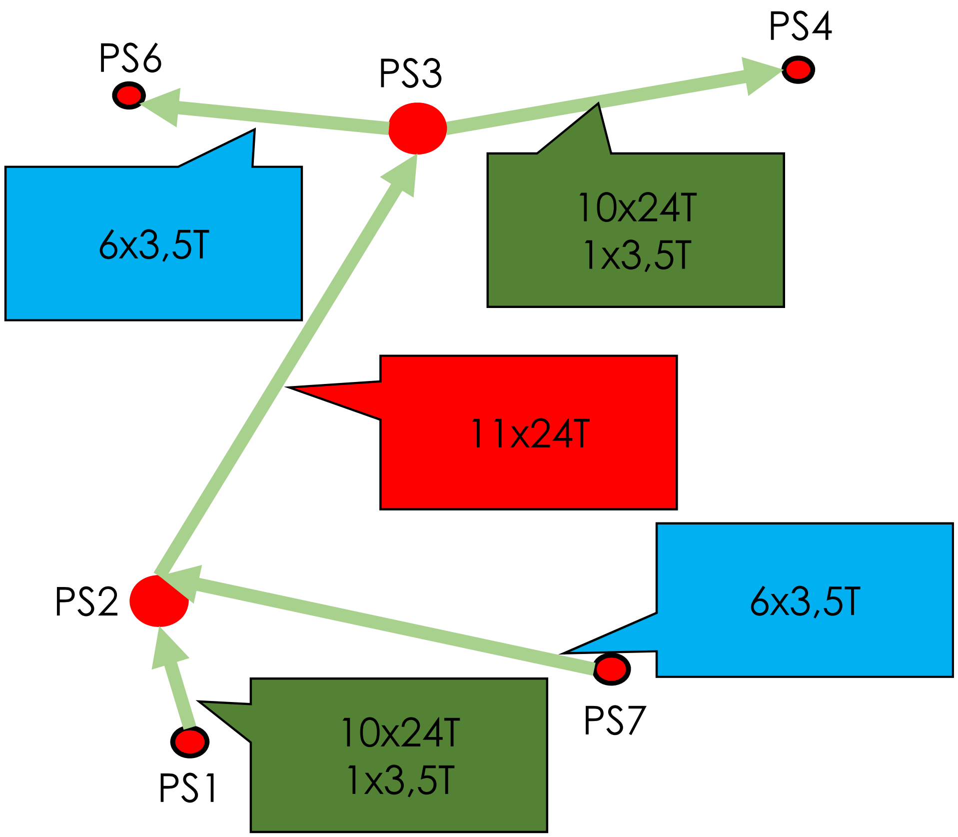
- **Strumień SP1**
  - 300 palet z PS1 do PS4.
- **Dostępność w PS1**
  - Przesyłki zwiezione i opracowane w PS1 o godzinie 18:00
- **Godzina dostawy w PS4**
  - Przesyłki muszą dotrzeć najpóźniej na godzinę 08:00 D+1

Tabela odległości/czasu przejazdu

Założenia:

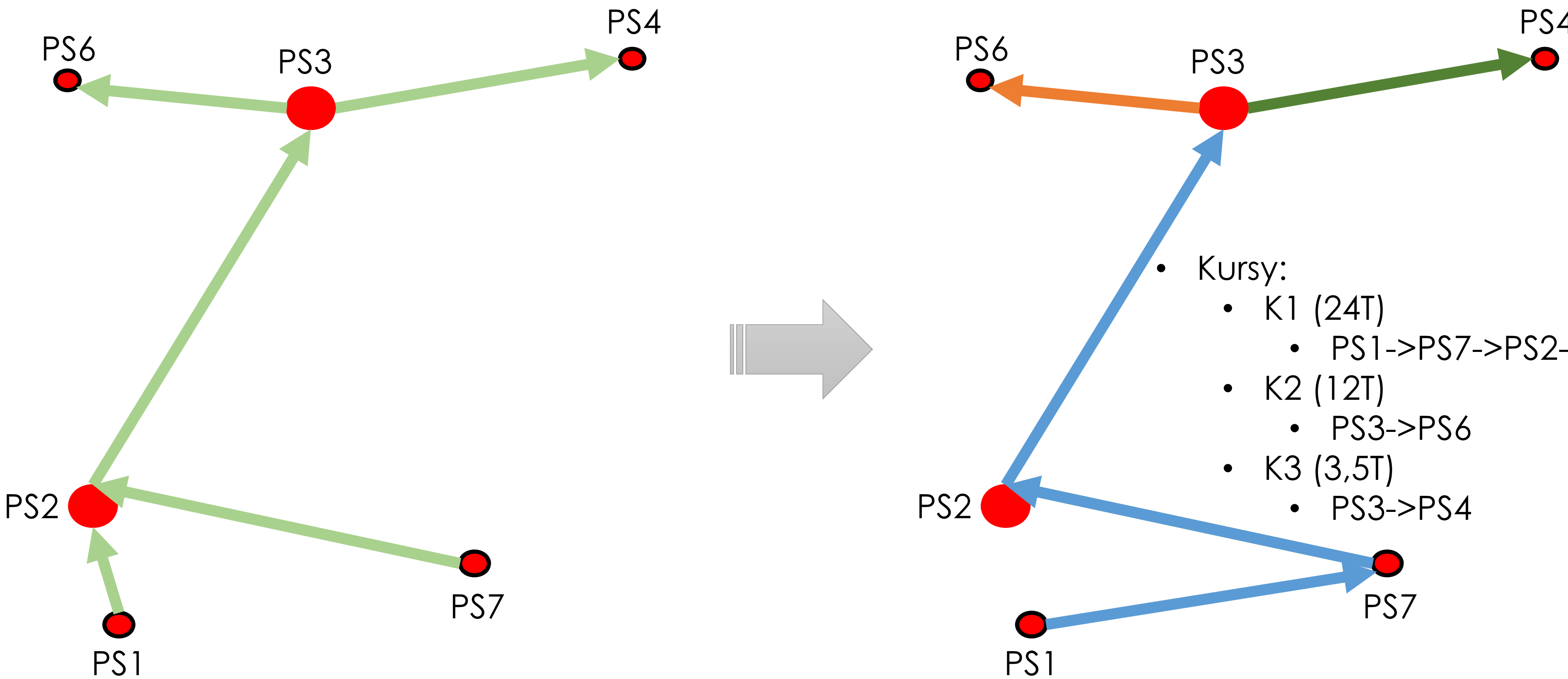
- Dla każdej dopuszczalnej pary punktów sieci
- Niesymetryczna
- Uwzględniająca kategorię drogi
- Odległość i czas (koszty i ograniczenia w czasie pracy kierowców)

Planowanie zasobów – konsolidacja ładunku



- Zapotrzebowanie na zasoby wyliczane jest dla każdego połączenia między punktami.
- Strumienie można konsolidować jeśli jest taka możliwość:
  - pojemność środka transportu
  - wymagane czasy

Planowanie zasobów – kursy

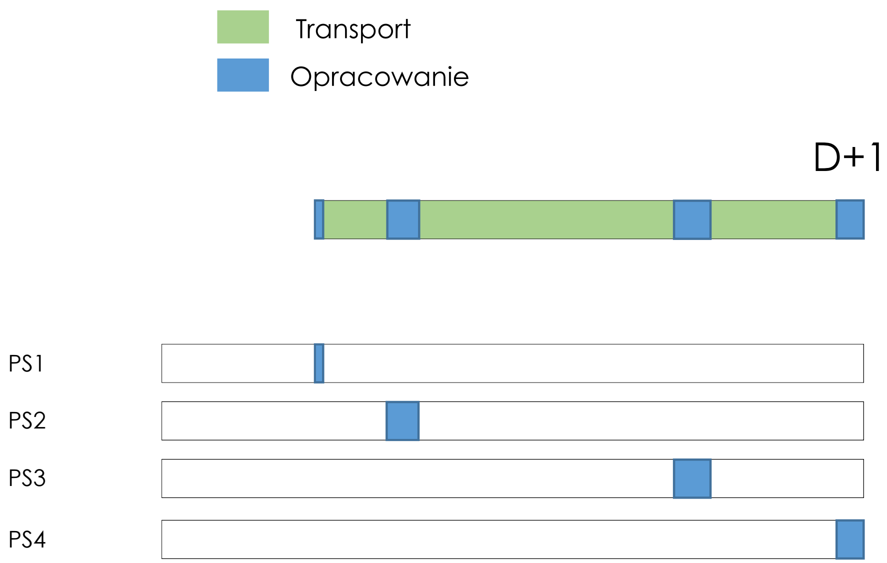


- Kursy:
  - K1 (24T)
    - PS1->PS7->PS2->PS3
  - K2 (12T)
    - PS3->PS6
  - K3 (3,5T)
    - PS3->PS4

Wynik planowania

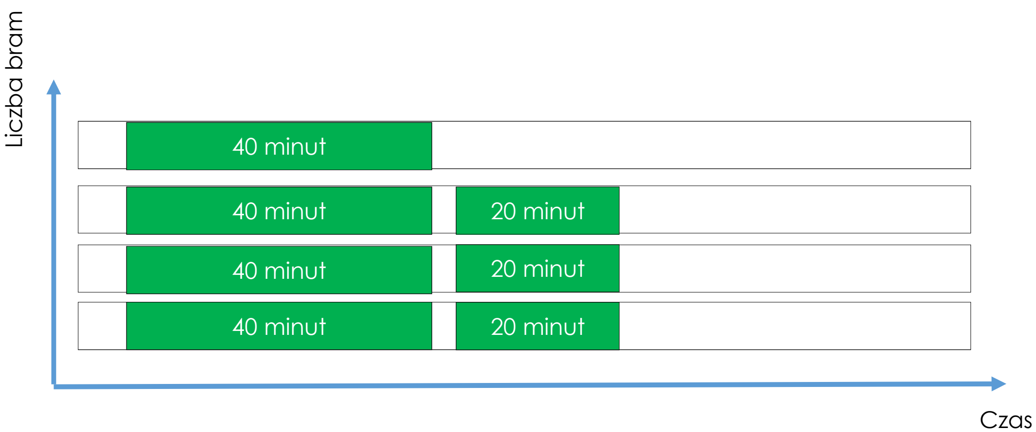
- **Przebieg strumienia**
  - Lista punktów sieci
  - Harmonogram opracowania i transportu
- **Kurs**
  - Lista punktów sieci z czasami odwiedzin
  - Jeden rodzaj pojazdu
  - Wielkość obsady
  - Miks strumienia (ładunek)
- **Plan**
  - Lista kursów

SLA – czas dostawy



- Granulacja minutowa
- Pochodna przebiegu
- Uwzględnia całkowity czas
- Uwzględnia ograniczenia w punktach

Przepustowość punktu sieci (bramy)



- **Przykład:**
  - Załadunek 7 pojazdów:
    - 4 x 24T
    - 3 x 12T
- **Czas załadunku/rozładunku**
  - Zależny od wielkości pojazdu
- **Liczba bram**
  - Ogranicza liczbę jednoczesnych załadunków/rozładunków

Wyliczanie czasu opracowania

- Ładunek na pojazdach stanowi zadania dla punktu sieci
- Potok jednocześnie przetwarza jeden strumień produktowy

Ograniczenia na czas otwarcia punktów sieci

- Wszelkie operacje:
  - Załadunek
  - Rozładunek
  - Opracowywanie
- Muszą odbywać się w godzinach otwarcia punktów sieci.
- Godziny otwarcia są zdefiniowane:
  - Dla każdego punktu sieci
  - Dla dni roboczych
  - Dla weekendów
  - Dla strumieni produktowych (sortowanie priorytet vs ekonomia)

Czas pracy kierowców

- Uwzględnia pauzę po 4,5h jazdy
  - Uwzględnia rozbicie 45 minut na dwie pauzy 15 i 30 minut
- Obsada jedno/dwuosobowa

Kompatybilność zasobów i punktów sieci

- Każda punkt sieci obsługuje rodzaje transportu ze ściśle zdefiniowanej listy. Inne pojazdy nie mogą do tej lokalizacji wjechać. Kryteria:
  - Wyposażenie pojazdu
  - Możliwości techniczne

Kompatybilność między strumieniami produktowymi a punktami sieci

- Każda punkt sieci obsługuje strumienie produktowe ze ściśle zdefiniowanej listy. Kryteria:
  - Na bazie funkcji logistycznych.

Ładowność pojazdów

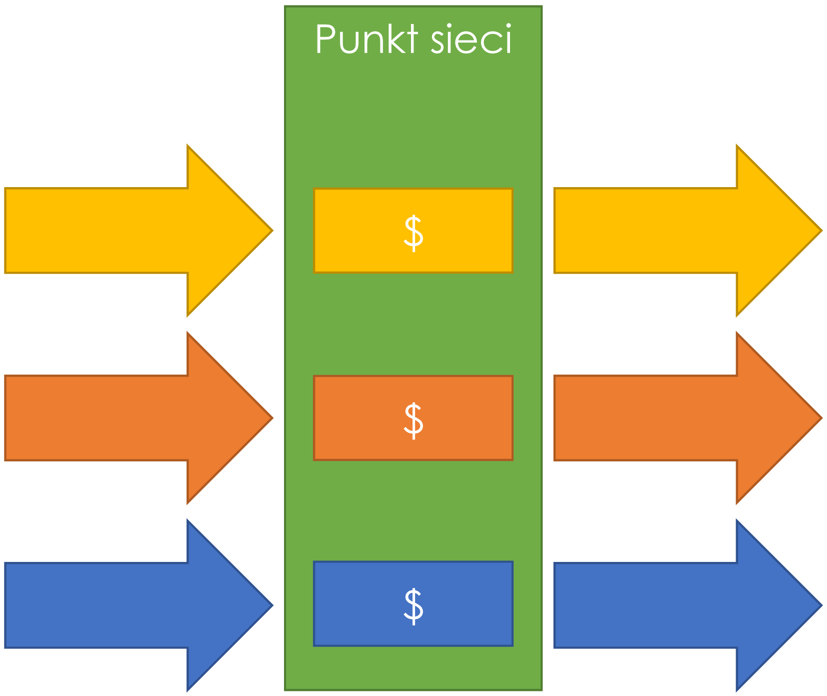
- Liczymy w oparciu o jednostki paletowe.
- Każdy pojazd opisany jest wartościami:
  - Maksymalna masa ładunku w kg
  - Maksymalna liczba palet
  - Maksymalna objętość

Funkcja celu

Składowe funkcji celu

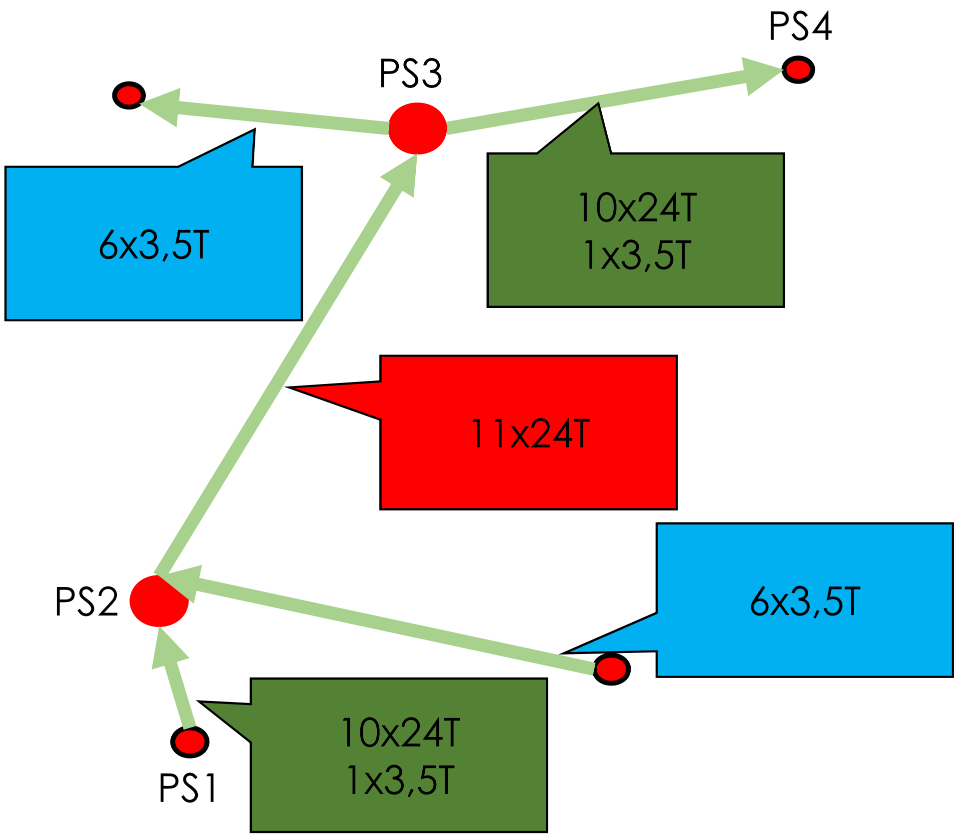
Koszt	Koszt transportu
	Koszt opracowania
Czas	Czas przejścia strumienia przez sieć
Jakość	SLA

Koszt opracowania



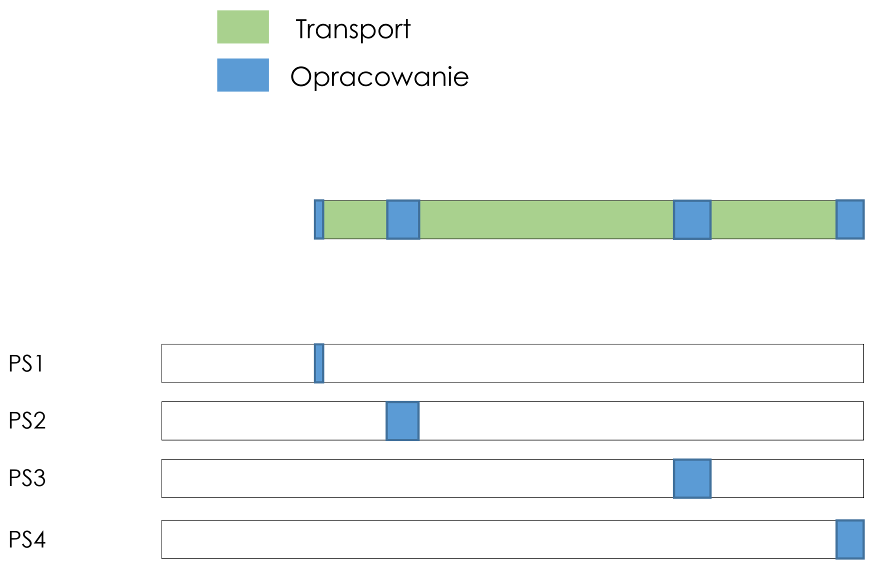
- Jednostkowy koszt dla pojedynczej przesyłki
- Zależny od strumienia produktowego oraz punktu sieci.

Koszt transportu



- Suma kilometrów x koszt jednostkowy
- Suma godzin jazdy x koszt jednostkowy

Czas przejścia przez sieć



- Różnica między godziną wejścia a godziną zakończenia opracowania.

Podsumowanie

- Wymagania
  - Struktura problemu
  - Ograniczenia
  - Funkcja celu
- Rzeczywistość
  - Ograniczenia w dostępie do danych
  - Problemy z jakością danych
  - Poziom złożoności zadania optymalizacyjnego

Redukcja do problemu rozwiązywalnego

Integrating Resource Acquisition and Repositioning Decisions into Tactical Transportation Planning under Uncertainty

With Mike Hewitt, Loyola University Chicago

What does a consolidation carrier do?

Transports customer time/day-“definite” shipments

Customer shipments small relative to trailer capacity

Customer A
From: Miami, FL
To: Chicago, IL

Customer B
From: Atlanta, GA
To: Chicago, IL

Two primary industries

Small package/Parcel

Less-than-truckload (LTL) freight

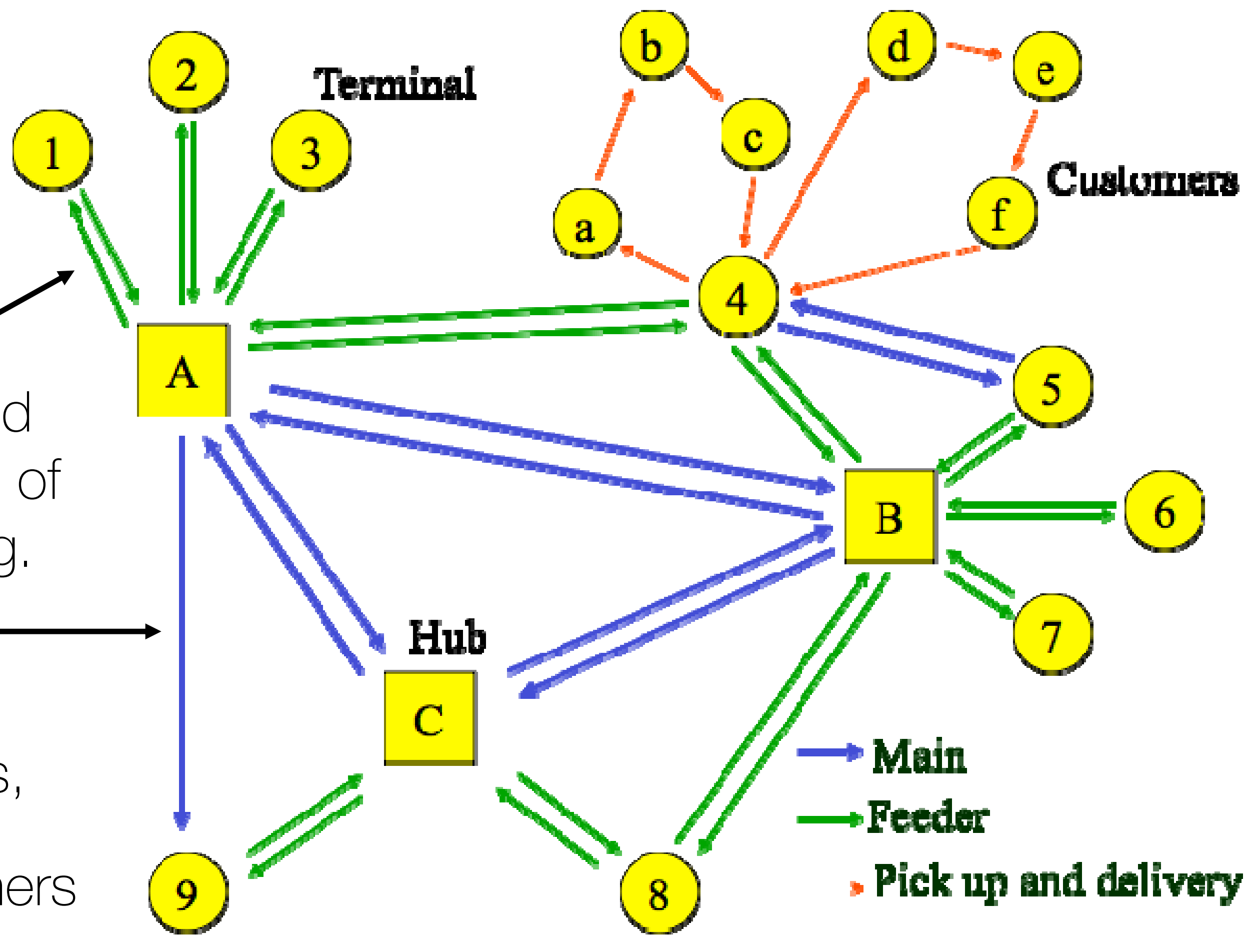
Consolidation enabled by a hub-and-spoke network

Moves executed by/with the use of "resources," e.g.

drivers,

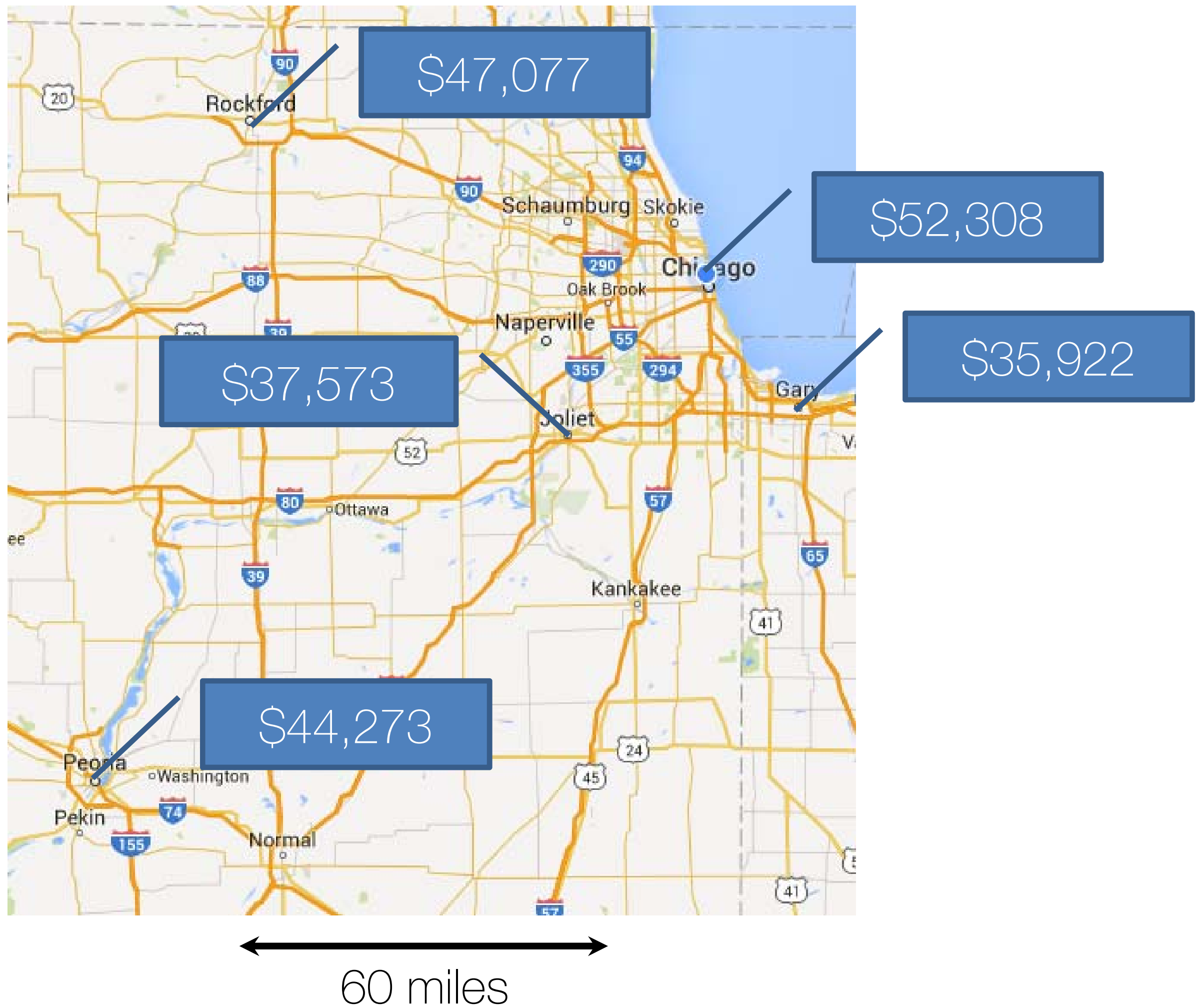
tractors,

containers



Every resource is not the same

Median annual salary, Truck Driver

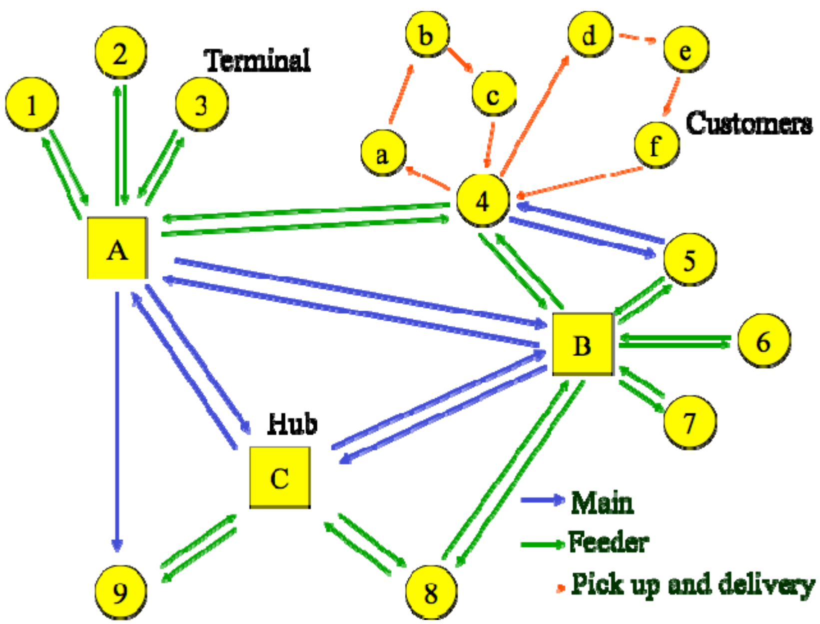


Source: www.payscale.com

Every resource is not the same

- What are the per mile rates for
  - Your own fleet?
  - A contracted fleet?
  - The spot market?
- When you make resource allocation decisions, what information is considered?

Three levels of planning



Strategic

Where should terminals be located?

How many resources should we acquire and where should they be located?

Tactical

What is the baseline plan for routing freight through terminal network?

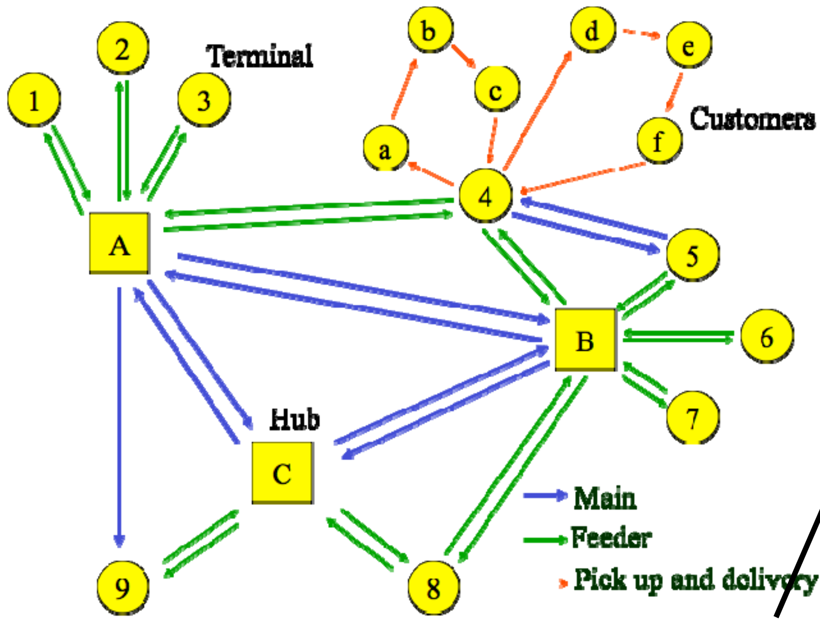
Should resources be reallocated?

Operational

Pickup and delivery routing

Trailer routing and matching

What we are doing



One model to answer these questions while recognizing uncertainty in freight volumes

<u>Strategic</u>

Where should terminals be located?

How many resources should we acquire and where should they be located?

<u>Tactical</u>

What is the baseline plan for routing freight through terminal network?

Should resources be reallocated?

<u>Operational</u>

Pickup and delivery routing

Trailer routing and matching

More explicitly recognizing resource moves and rules

Crainic, Hewitt, Touluse, Vu. Service Network Design with Resource Constraints. *Transportation Science,* to appear.

Model that recognizes terminal-level resource limits when designing service network and matheuristic that quickly produces high quality solutions

Deterministic models

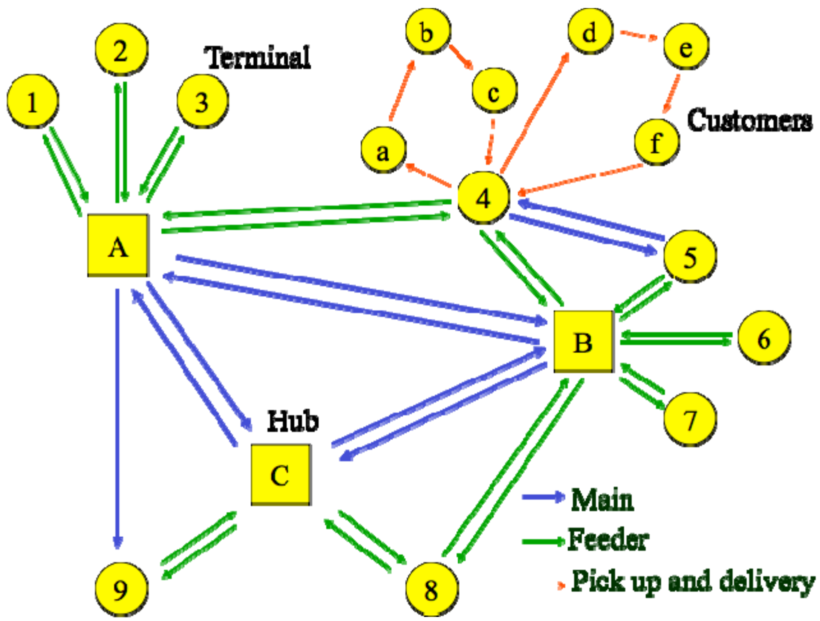
Crainic, Hewitt, Touluse, Vu. Location and Service Network Design with Resource Constraints. In preparation.

Model that (re-)allocates resources to terminals while recognizing terminal-level resource limits when designing service network and matheuristic that quickly produces high quality solutions

Stochastic model

Today's talk:
Same model as above, but recognizing uncertainty in freight volumes

Scheduled service network design with resource constraints model



- Select services/transportation moves to execute including when they should depart/dispatch
  - Route demand through resulting network of services
- Recognize that services require resources to operate
  - Restrictions on how resources may be used
  - Represent in model how resources move and when they should depart/dispatch

Model time with a time-space network

Assume fixed schedule length

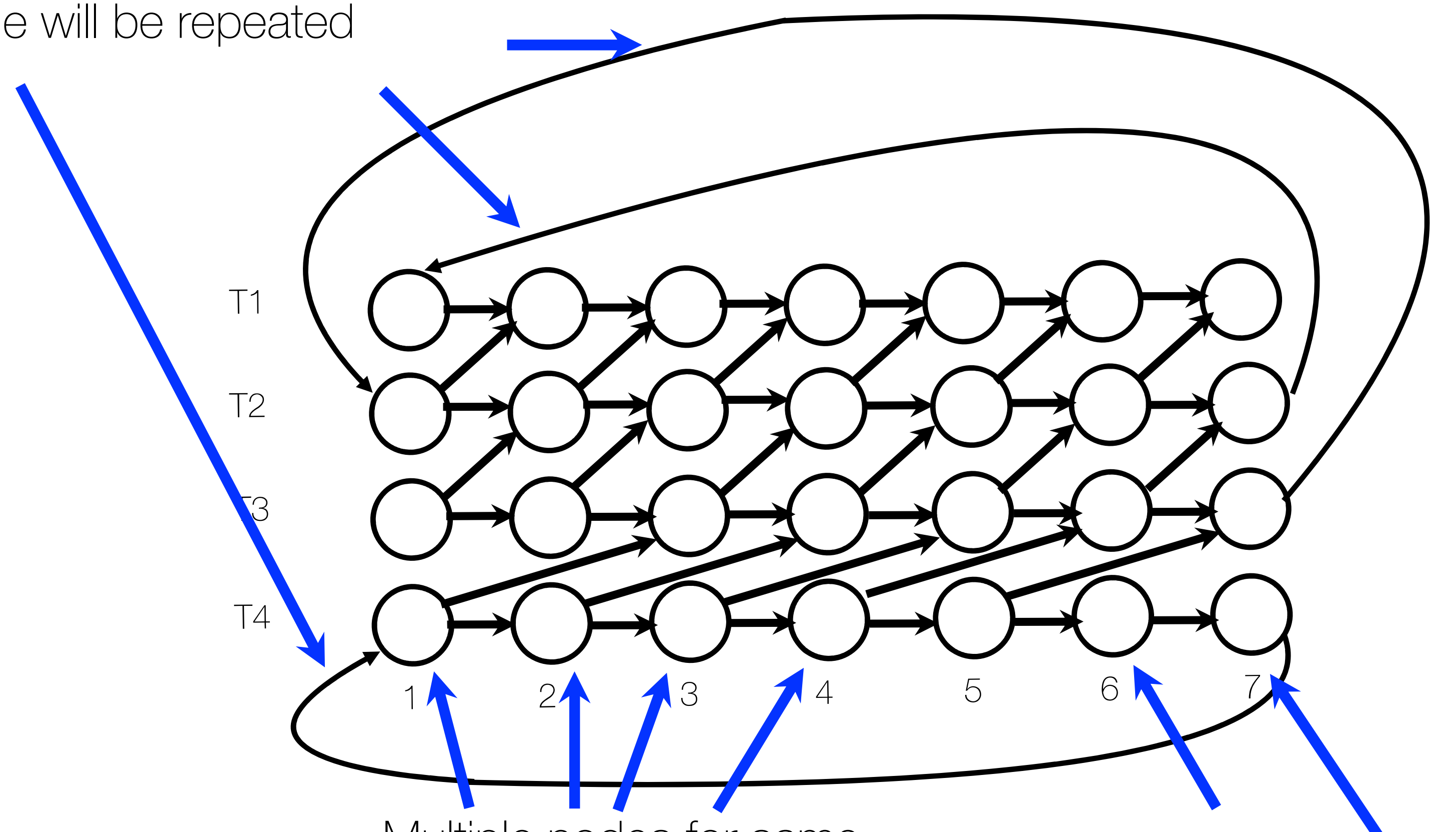
Solve model to produce a repeatable plan/schedule

Model uncertainty through scenario planning

Generate numerous scenarios based on distribution of past demand

Time-space network

"Wrap-around" arcs model that schedule will be repeated



Not all arcs shown

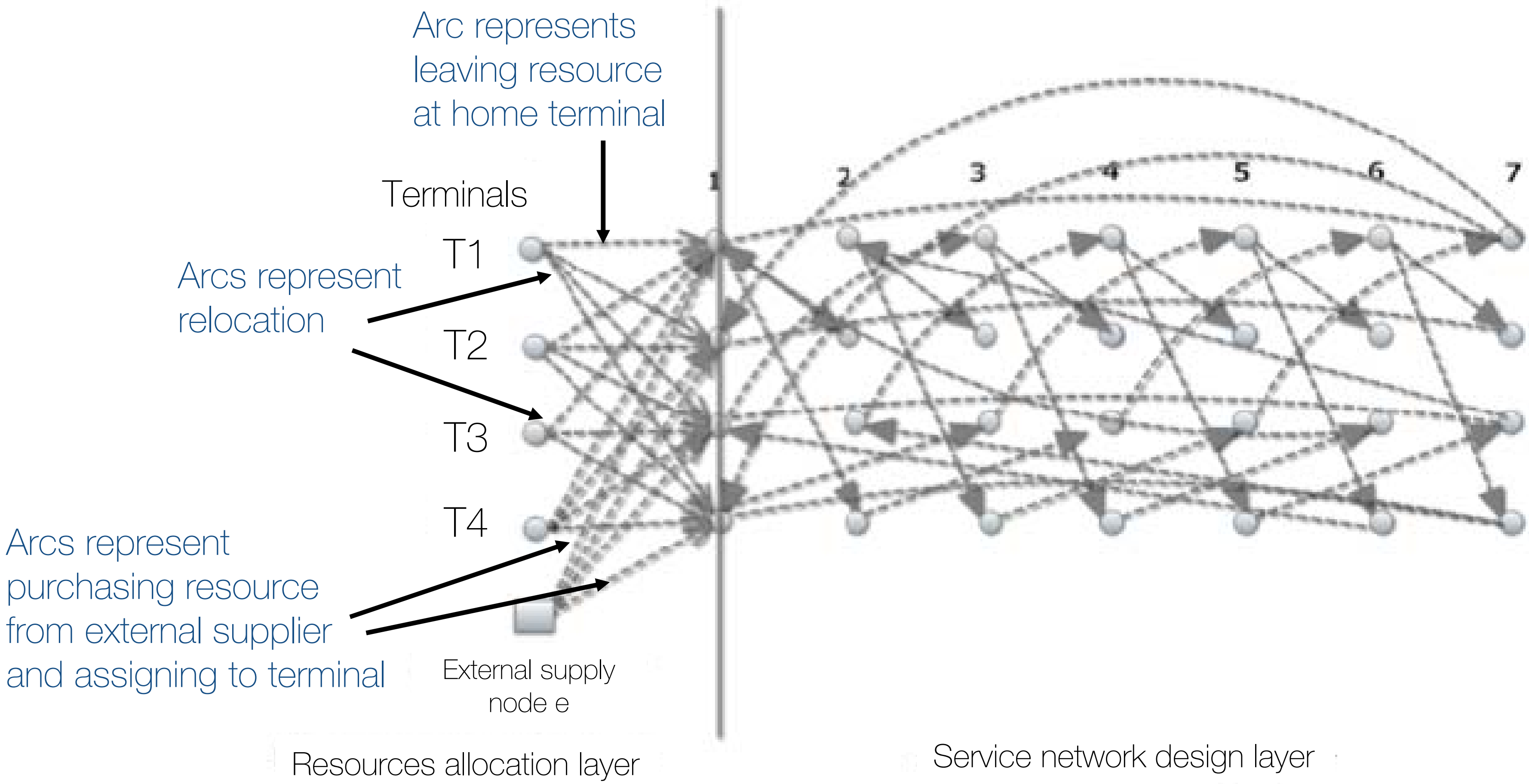
Multiple nodes for same terminal represent dispatching at different times

Model freight being held at a terminal or a resource idling

“Location” decisions

- Re-allocate resource to a new “home” terminal to account for demand modifications (e.g. change in season)
  - Fixed (resource) reposition cost by terminal pair
- Buy
  - Fixed (resource) cost = amortized buying cost + transportation to desired “home” terminal
- Outsource a given service (need not be covered by a resource cycle)
  - Fixed cost = transportation (at a markup)

Model location decisions by extending what a cycle variable encodes



Cycle variable now encodes:

- Original source of resource (it's own home terminal, a terminal from which it was repositioned, or an external supplier)
- The resource's (potentially new) home terminal
- The schedule for the resource for the planning horizon

Stochastic program for location and service network design under uncertainty (LSND-U)

$$\text{minimize} \sum_{w\in W}\sum_{h\in N}\sum_{\tau\in\theta_h} F^{\tau}_{wh} z^{\tau}_{wh} + \sum_{(i,j)\in A} f_{ij} y_{ij} + \sum_{s\in S} p_s \sum_{k\in K}\sum_{(i,j)\in A} c^{k}_{ij} x^{ks}_{ij}$$

subject to

$$y_{ij} \le \sum_{w\in W}\sum_{h\in N}\sum_{\tau\in\theta_h} z^{\tau}_{wh} \quad \forall (i,j)\in A, \tag{1}$$

$$\sum_{h\in N}\sum_{h'\in N: h'\neq h}\sum_{\tau\in\theta_h} z^{\tau}_{hh'} \le ub_h \quad \forall h\in N, \tag{2}$$

Commodity flow balance and capacity constraints per scenario

$$\sum_{j:(i,j)\in A} x^{ks}_{ij} - \sum_{j:(j,i)\in A} x^{ks}_{ji} = d^{ks}_i \quad \forall i\in N, k\in K, s\in S, \tag{3}$$

$$\sum_{k\in K} x^{ks}_{ij} \le u_{ij} y_{ij} \quad \forall (i,j)\in A, s\in S. \tag{4}$$

$$z^{\tau}_{wh} \in \{0,1\} \;\; \forall w\in W, h\in N, \tau\in\theta_h, y_{ij}\in\{0,1\} \;\; \forall (i,j)\in A, \tag{5}$$

$$x^{ks}_{ij} \ge 0 \;\; \forall (i,j)\in A, k\in K, s\in S. \tag{6}$$

Should you choose resource with source w and home terminal h and schedule represented by cycle tau?

For each commodity have an “auxiliary” flow variable that represents outsourcing shipment transportation

Model where services can be outsourced

$$\text{minimize} \sum_{w\in W}\sum_{h\in N}\sum_{\tau\in\theta_h} F^{\tau}_{wh} z^{\tau}_{wh} + \sum_{(i,j)\in A} f_{ij}y_{ij} + \sum_{(i,j)\in A} f^{o}_{ij}y^{o}_{ij} + \sum_{s\in S} p_s \Big(\sum_{k\in K}\sum_{p\in P(k,s)} c^{k}_{p} d^{ks} x^{ks}_{p} + \sum_{(i,j)\in A} f^{os}_{ij} y^{os}_{ij}\Big)$$

subject to

Note outsourcing variables do not need to be covered by a resource cycle

$$y_{ij} \le \sum_{w\in W}\sum_{h\in N}\sum_{\tau\in\theta_h} z^{\tau}_{wh} \quad \forall (i,j)\in A, \tag{1}$$

$$\sum_{h\in N}\sum_{h'\in N:h'\neq h}\sum_{\tau\in\theta_h} z^{\tau}_{hh'} \le ub_h \quad \forall h\in N, \tag{2}$$

$$\sum_{j:(i,j)|inA} x^{ks}_{ij} - \sum_{j:(j,i)\in A} x^{ks}_{ji} = d^{ks}_{i} \quad \forall i\in N, k\in K, s\in S, \tag{3}$$

$$\sum_{k\in K} x^{ks}_{ij} \le u_{ij}y_{ij} \quad \forall (i,j)\in A, s\in S. \tag{4}$$

Model outsourcing as part of tactical planning (e.g. long-term contracts)

$$\sum_{k\in K} x^{ks}_{ij} \le u_{ij}(y_{ij} + y^{o}_{ij})$$

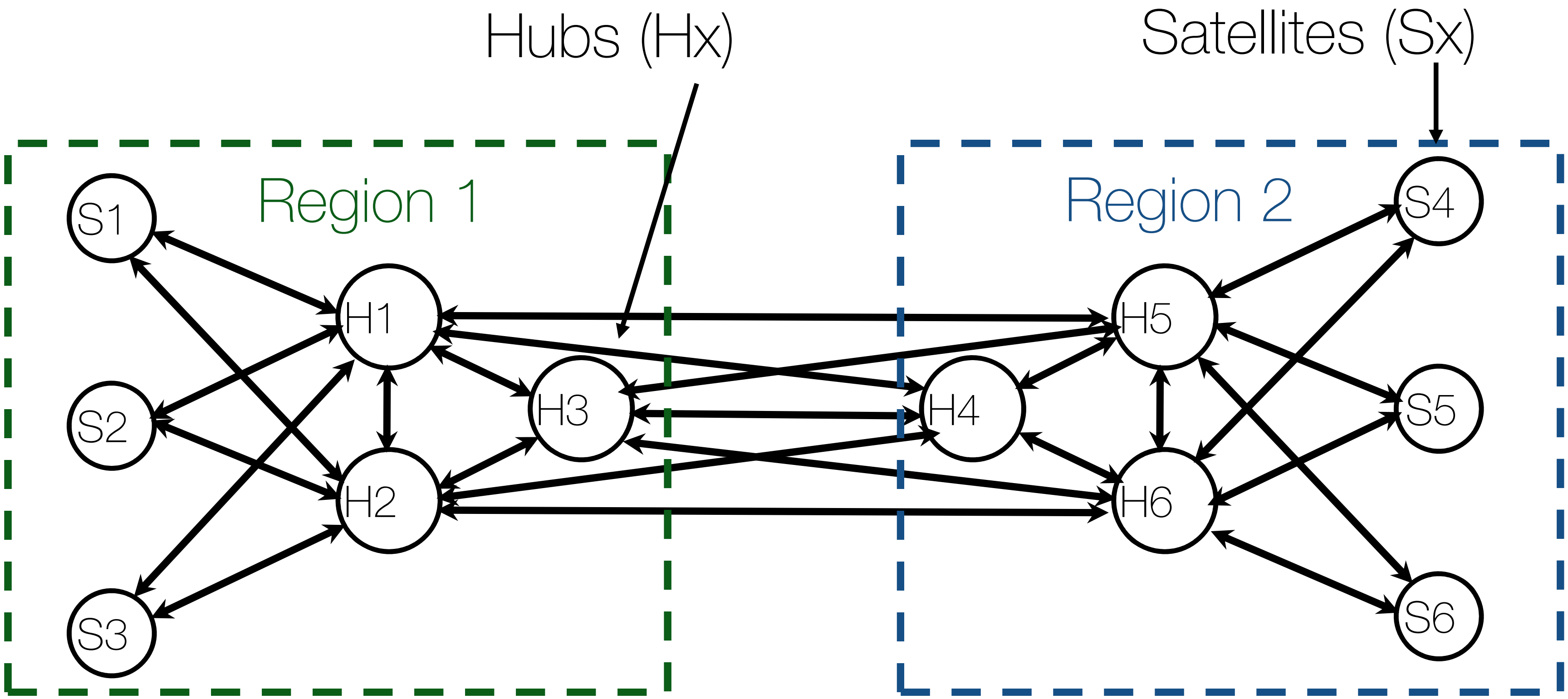
Also model outsourcing via on-demand "spot" market. Assume cost is higher than long-term contract cost

$$\sum_{k\in K} x^{ks}_{ij} \le u_{ij}(y_{ij} + y^{o}_{ij} + y^{os}_{ij})$$

What do we want to do with these models?

- Answer questions such as
  - How does uncertainty impact where you locate resources?
  - How does uncertainty impact outsourcing decisions?
  - How do various model parameters (e.g. contracting and spot-market outsourcing costs) impact decisions?

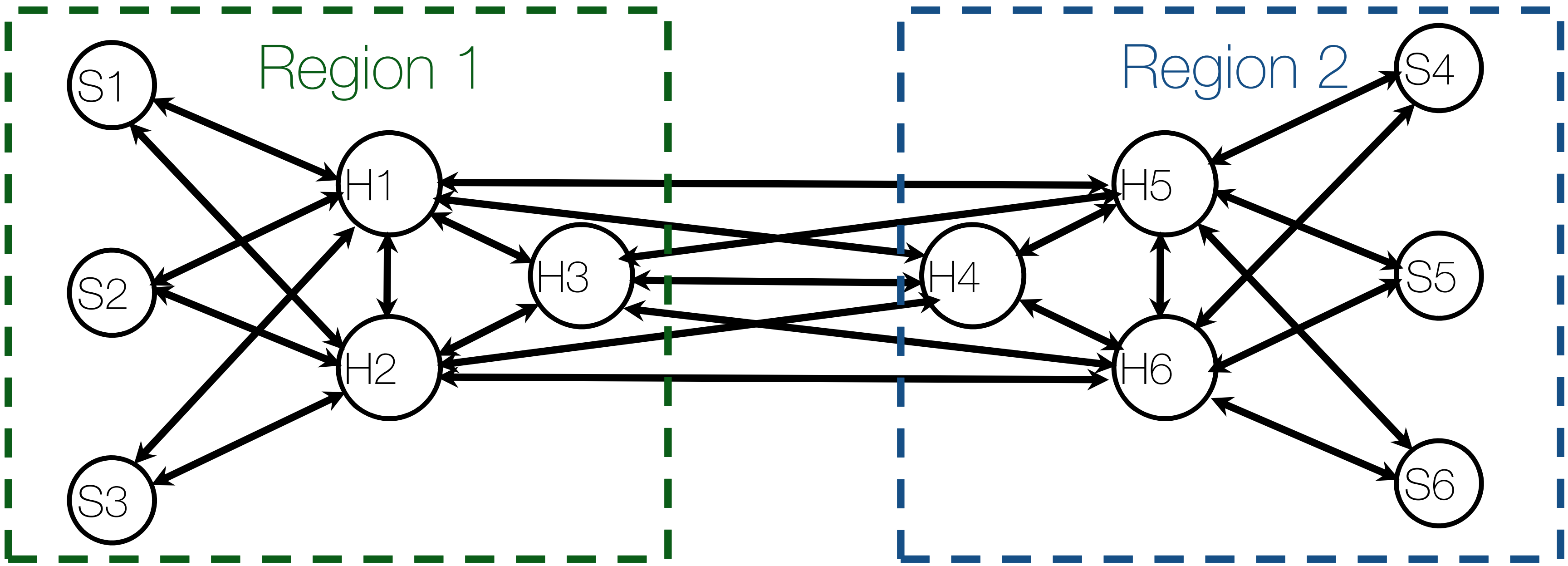
Network for initial experiments



Arcs between regions take 2 periods, all others take 1 period
Instance has 12 periods total (6-day week, 2 periods per day)

Trying to mimic hub-and-spoke structure in a network that will yield instances we can potentially solve

Computational tractability



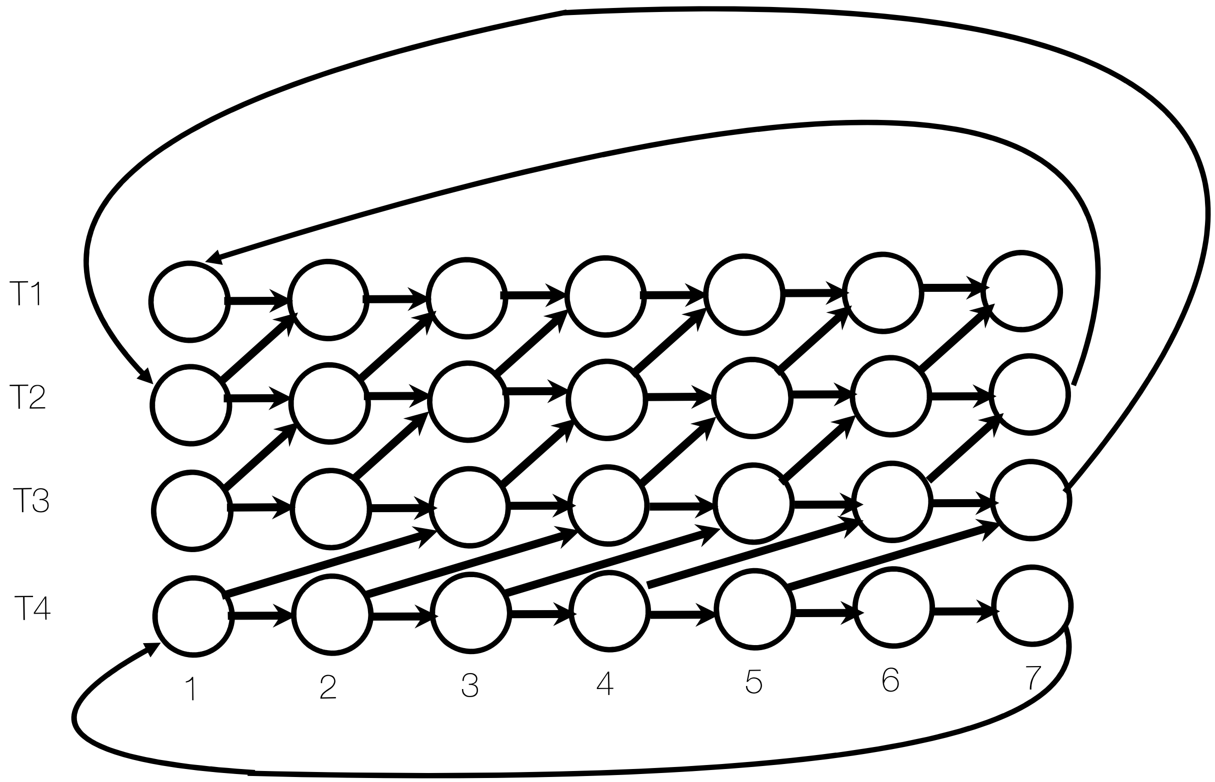
Flat network
12 nodes
50 arcs
80 commodities

Time-expanded network
144 nodes
600 arcs
240 commodities

SP with 9 scenarios
> 1,000,000 commodity flow variables. CPLEX bogs down solving root node LP

Generating all possible cycle variables also too time-consuming

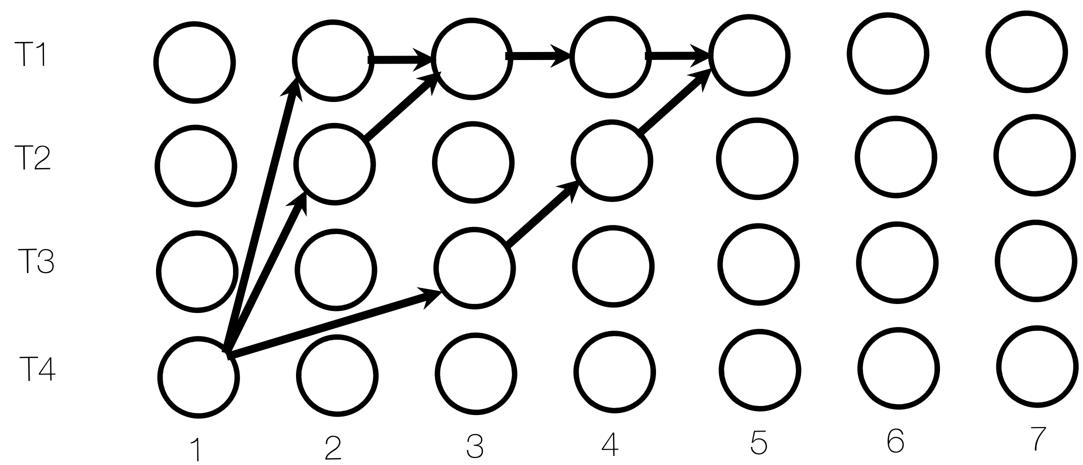
Time-space network



Not all arcs shown

Generating all possible cycle variables also too time-consuming

Time-space network



Generate paths that offer service for commodity from terminal 4 to 1

Includes direct path provided by outsourced transportation options

Reformulate to path-based model which we solve with column generation (Ext-LSND-U)

$$\text{minimize} \sum_{w \in W} \sum_{h \in N} \sum_{\tau \in \theta_h} F^{\tau}_{wh} z^{\tau}_{wh} + \sum_{(i,j) \in A} f_{ij} y_{ij} + \sum_{s \in S} p_s \sum_{k \in K} \sum_{p \in P(k,s)} c^k_p d^{ks} x^{ks}_p$$

subject to

$$y_{ij} \leq \sum_{w \in W} \sum_{h \in N} \sum_{\tau \in \theta_h} z^{\tau}_{wh} \quad \forall (i,j) \in A, \tag{1}$$

$$\sum_{h \in N} \sum_{h' \in N : h' \neq h} \sum_{\tau \in \theta_h} z^{\tau}_{hh'} \leq ub_h \quad \forall h \in N, \tag{2}$$

All of commodity k's demand must be sent

$$\sum_{p \in P(k,s)} x^{ks}_p = 1 \quad \forall k \in K, s \in S, \tag{3}$$

$$\sum_{k \in K} \sum_{p \in P(k,s) : (i,j) \in p} d^{ks} x^k_p \leq u_{ij} (y_{ij} + y^o_{ij} + y^{os}_{ij}) \quad \forall (i,j) \in A, s \in S. \tag{4}$$

$$z^{\tau}_{wh} \in \{0,1\} \;\; \forall w \in W, h \in N, \tau \in \theta_h, y_{ij} \in \{0,1\} \;\; \forall (i,j) \in A, \tag{5}$$

$$x^{ks}_p \in [0,1] \;\; \forall k \in K, s \in S, p \in P(k,s). \tag{6}$$

How much of commodity k's demand flows on path p in scenario s?

One of these paths models outsourcing transportation at the shipment level

Reformulate to path-based model which we solve with column generation (Ext-LSND-U)

$$\text{minimize} \sum_{w\in W}\sum_{h\in N}\sum_{\tau\in\theta_h} F^{\tau}_{wh} z^{\tau}_{wh} + \sum_{(i,j)\in A} f_{ij} y_{ij} + \sum_{s\in S} p_s \sum_{k\in K}\sum_{p\in P(k,s)} c^k_p d^{ks} x^{ks}_p$$

subject to

$$y_{ij} \le \sum_{w\in W}\sum_{h\in N}\sum_{\tau\in\theta_h} z^{\tau}_{wh} \quad \forall (i,j)\in A, \tag{1}$$

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$$x^{ks}_p \in [0,1] \ \ \forall k\in K, s\in S, p\in P(k,s). \tag{6}$$

Price path variables out for each commodity and each scenario with same shortest path-type problem seen in path-based formulations of capacitated network design problems

First CG-based heuristic (CG-Solve)

- Solve LP relaxation of Ext-LSND-U via column generation
- Choose all paths and cycles generated (including those not in final LP solution)
- Solve Ext-LSND-U with a MIP solver

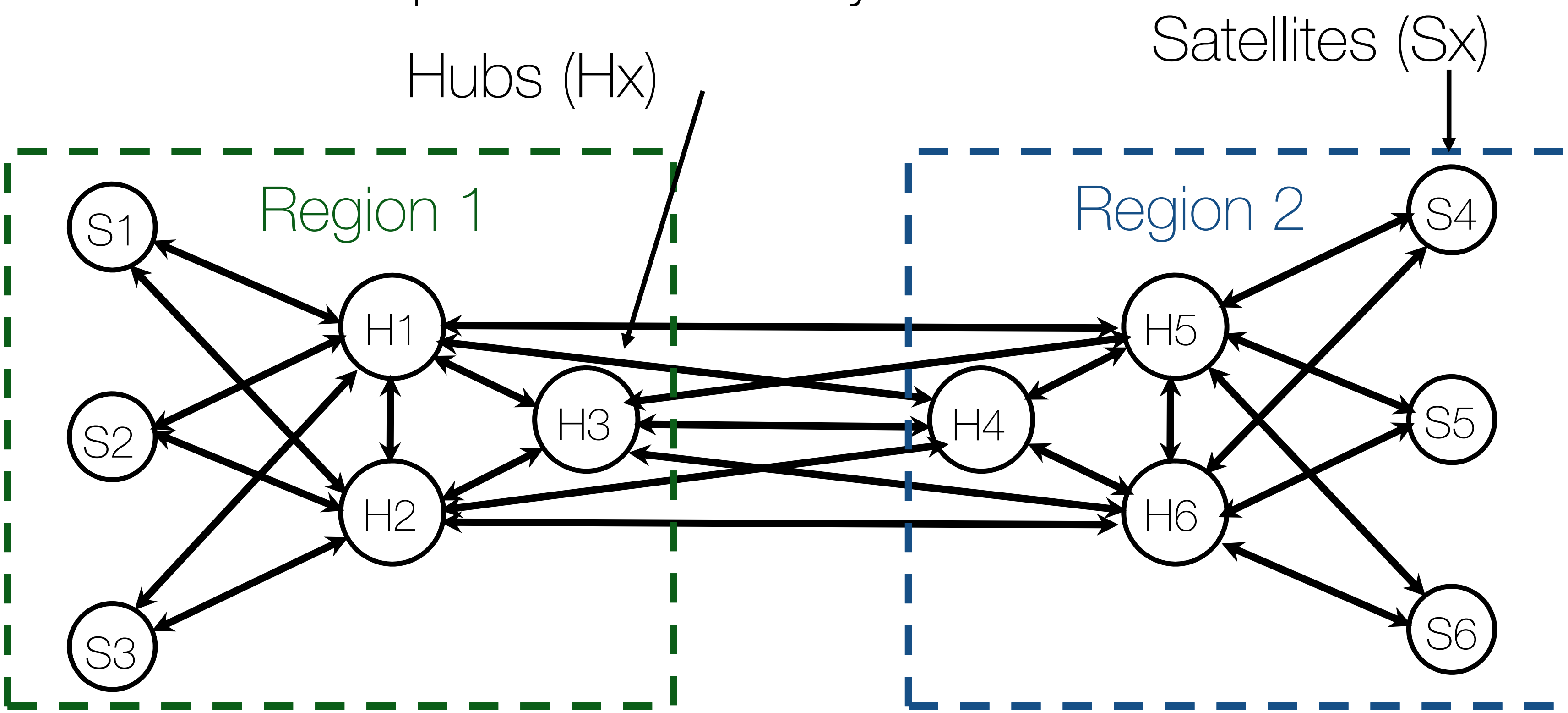
A CG-based Mathheuristic (IPS)

- Solve LP relaxation Ext-LSND-U via column generation for cycles C* and paths P*
- Solve Ext-LSND-U(C*,P*) to produce solution sol*
- Let C_{sol}, P_{sol} represent cycles and paths used in sol*
- Set $C_{cand} = C^*$, $P_{cand} = P^*$
- Determine neighborhood operator
  - if operator generates new cycles and paths then
    - Use operator to generate new cycles, C_{new} and paths, P_{new}
    - Set $C_{cand} = C_{cand} \cup C_{new}$; $P_{cand} = P_{cand} \cup P_{new}$
- Use operator to determine cycles, $C_{nbhd} = C_{cand} \cup C_{sol}$ defining neighborhood
- Use operator to determine paths, $P_{nbhd} = P_{cand} \cup P_{sol}$ defining neighborhood
- Solve Ext-LSND-U($C_{nbhd} \cup C_{sol}$, $P_{nbhd} \cup P_{sol}$) for solution sol

Methods for choosing cycles to define neighborhood

- Neighborhoods that don't generate new cycles or paths
  - RandomCycle: Choose set of cycles randomly
  - RandomHome: Choose set of cycles with same home terminal randomly
  - CoverFlow: Choose cycles that cover flows on arcs in current solution, based on scoring mechanism
  - CoverOutsource: Choose cycles that cover arcs that are outsourced in current solution, based on scoring mechanism
- Neighborhoods that do generate new cycles and paths
  - Each generates new cycles and paths using skeleton solution of selected cycles and paths, excluding certain ones
  - SolCG: Use cycles that are most used in current solution
  - CoverPathCG: Only uses paths of current solution, with no consideration for cycles
  - ScenCoverPathCG: Only uses paths from subset of scenarios, with no consideration for cycles

Factors in experimental study



Model a planning horizon of 12 periods

144 nodes in the network
600 Time-indexed service arcs
228 commodities

Schedule guidelines:
Each Sx has one shipment a week to 3 Sx
Each Sx has two shipments a week to 5 Hx
Each Hx has two shipments a week to 5 Sx
Each Hx has three shipments a week to each Hx

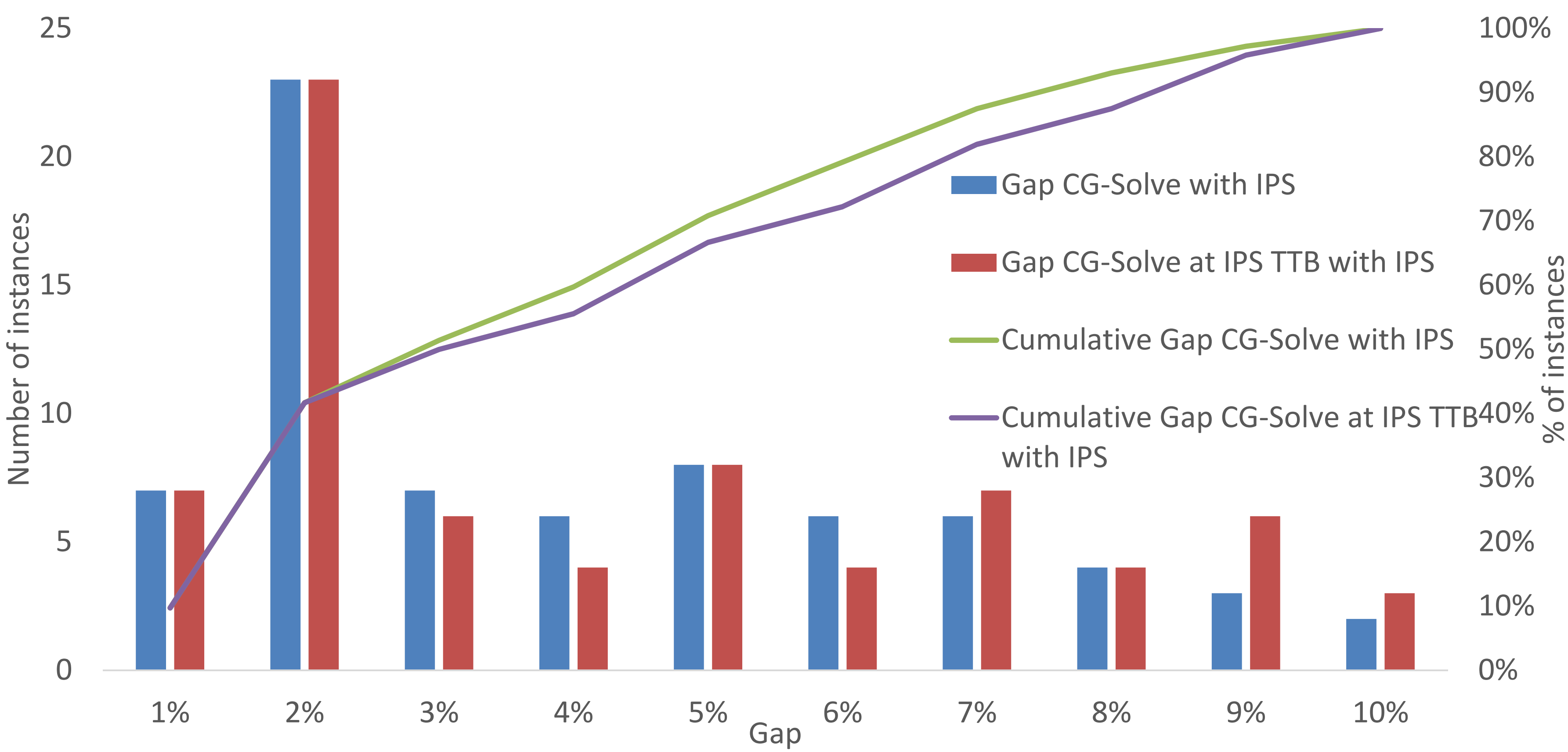
Scenarios

- Fit a distribution to trucking data from a large US LTL carrier
- Assumed one distribution for all commodities (means and standard deviations weren't that different)
- 24 demand scenarios per instance
- Six demand distributions tested
  - Variance
    - Original data
    - 2*original variance
    - 3*original variance
  - Mean
    - Original data
    - 5*original mean

Generated scenarios with code implementing "A Heuristic for Moment-matching Scenario Generation," Kjetil Høyland, Michal Kaut and Stein W. Wallace, published in *Computational Optimization and Applications*, 24 (2-3), pp. 169–185, 2003.

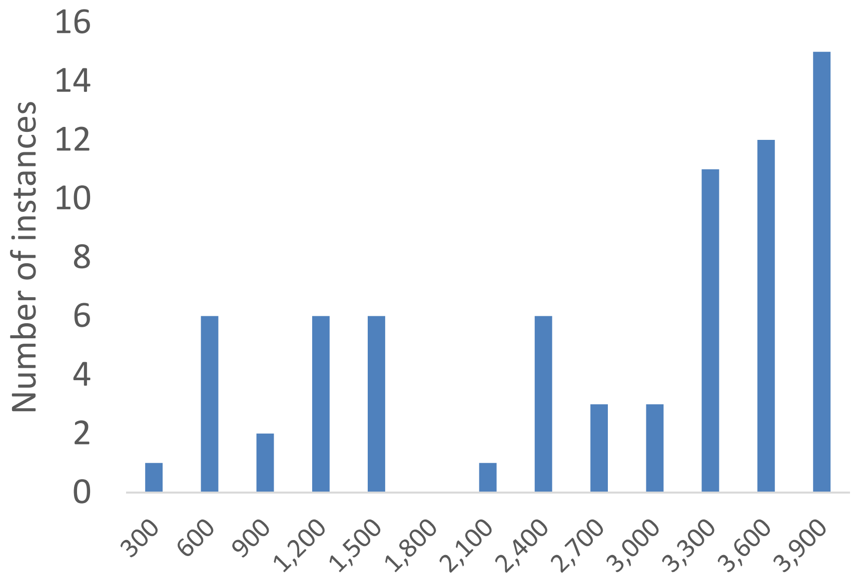
Comparing two heuristics

- Ran CG-Solve for 5 hours
- IPS was better in all 72 instances
- Ran IPS heuristic for 75 minutes
- TTB= Time to Best IPS Solution

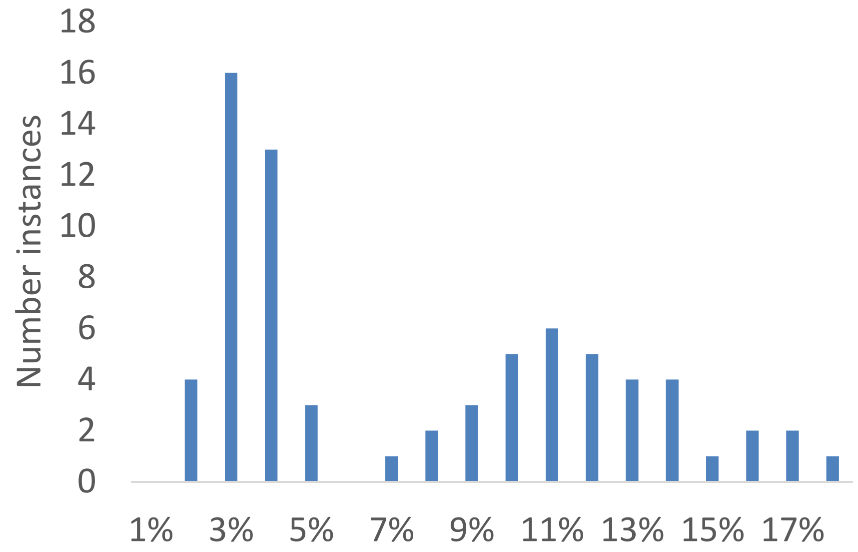


IPS Improvement

- IPS finds best solution in 42 minutes on average
- Best solution is 7.2% better than first solution on average



Time to best solution

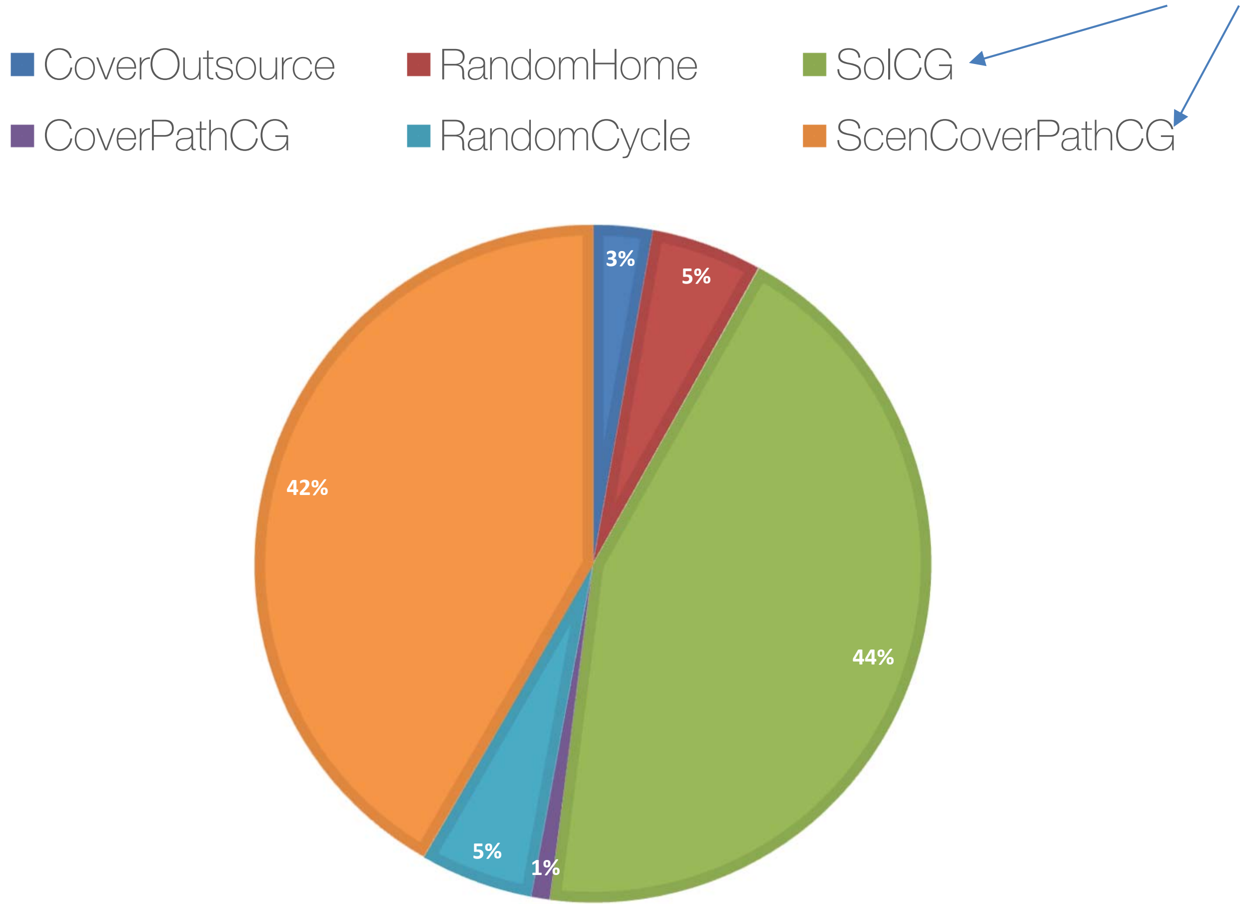


Improvement over first solution

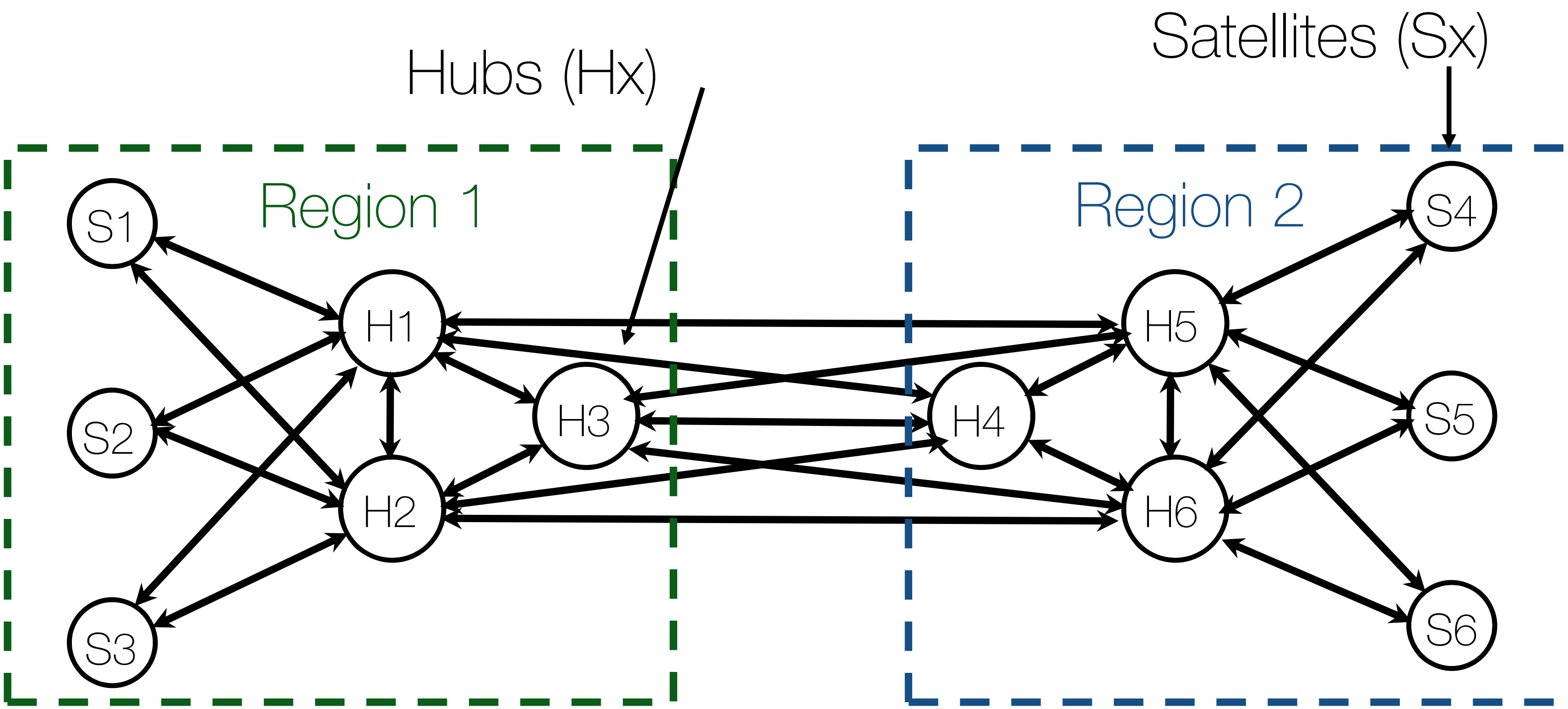
Best neighborhoods to improve solutions

- Proportion of improvements between first and best solution attributed to each neighborhood generating mechanism

New cycle and path generating neighborhoods



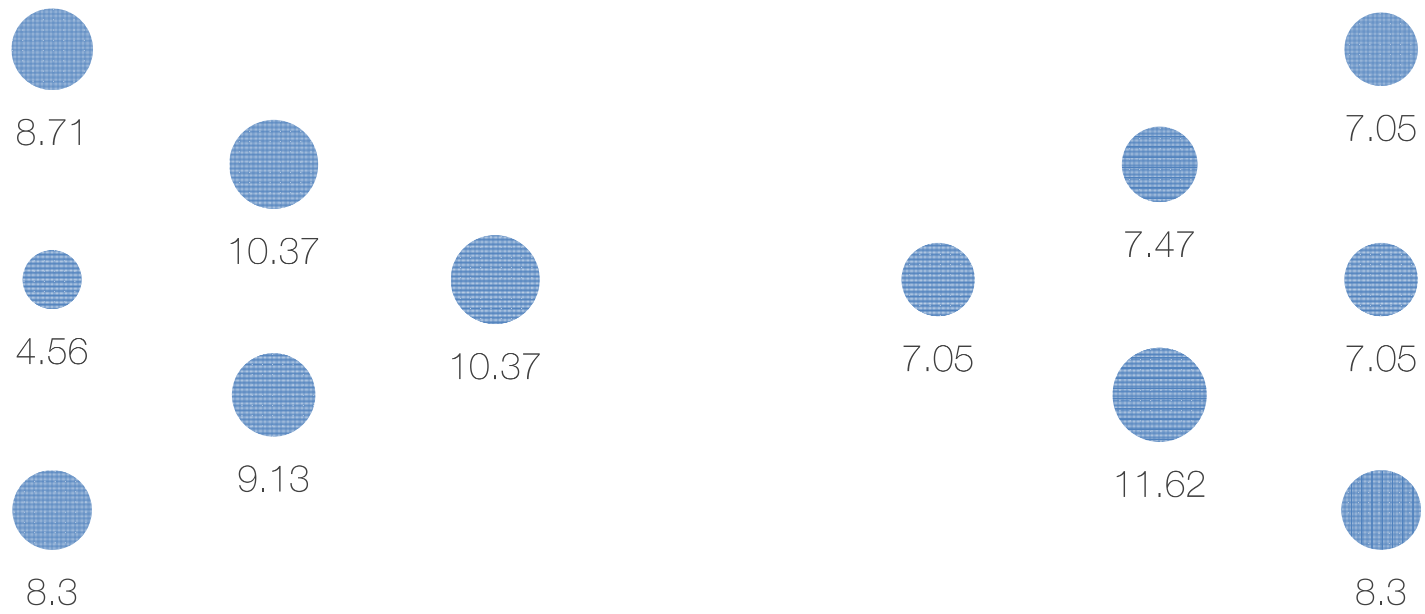
Model Validation



Resource acquisition costs by terminal

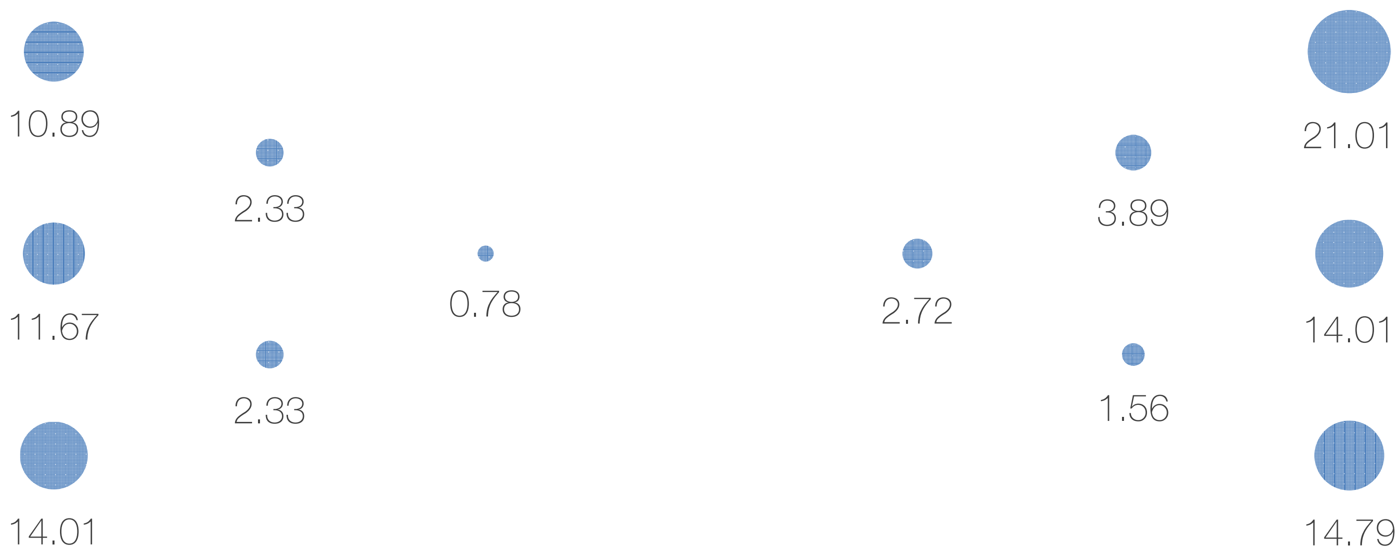
Cost 1: All nodes $1,800 to acquire resource
Cost 2: Satellites @ $1,800, Hubs @ $2,000
Cost 3: Satellites @ 2,000, Hubs @900
Cost 4: S1,H1,H3,S6 @ 1,800
S2,H6,S4 @ 1,900
Others @ 2,000

Percentage of resources per terminal



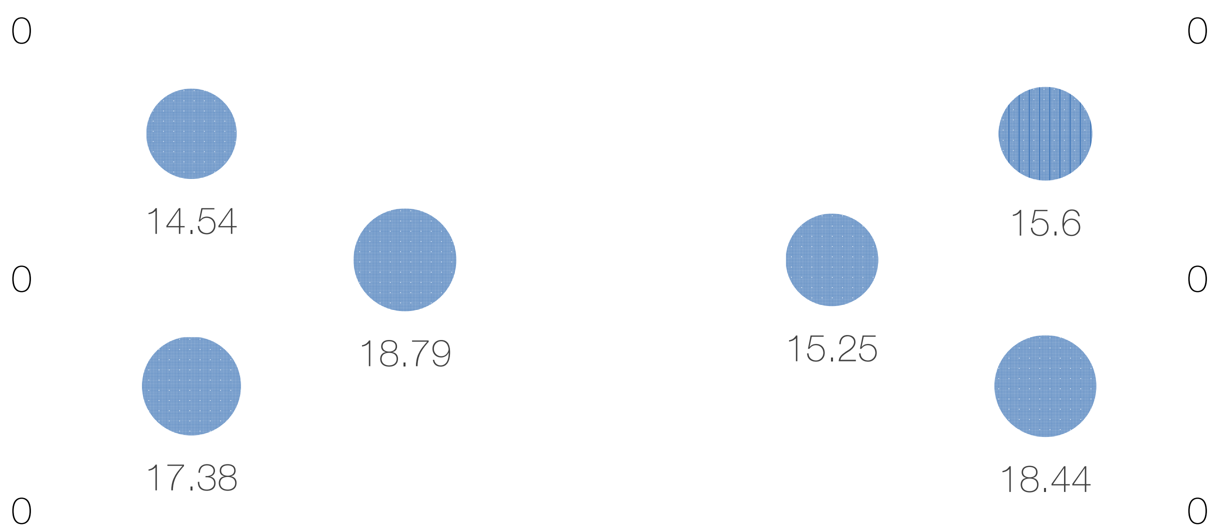
Cost 1: All $1,800 to acquire resource

Percentage of resources per terminal



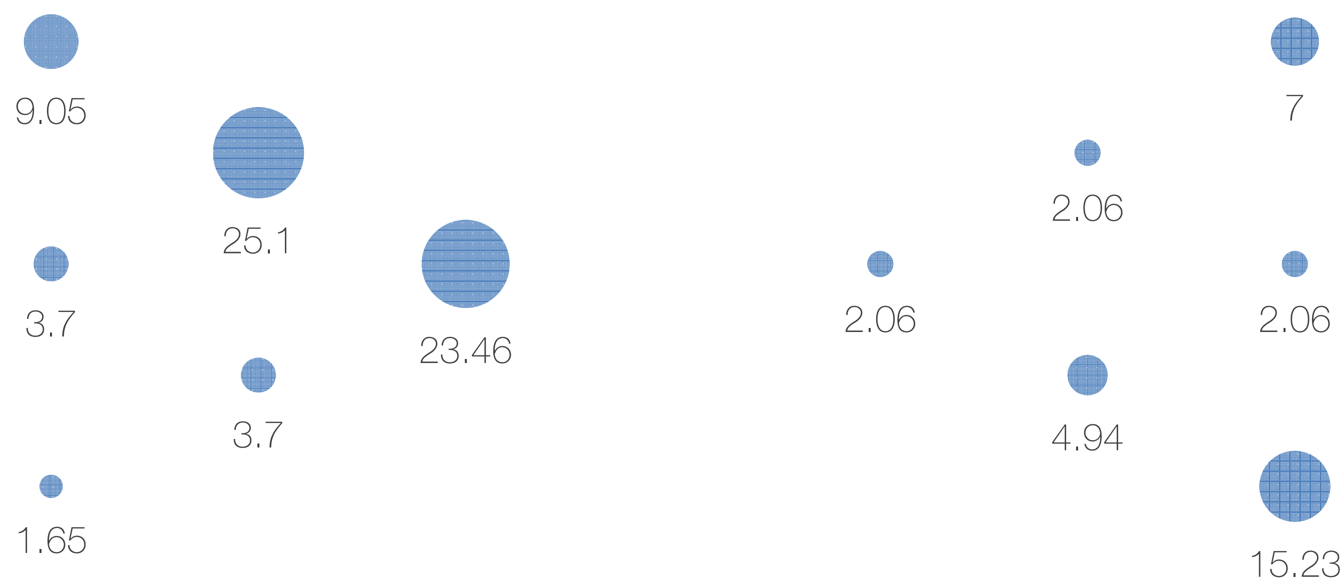
Cost 2: Satellites @ $1,800, Hubs @ $2,000

Percentage of resources per terminal



Cost 3: Satellites @ 2,000, Hubs @900

Percentage of resources per terminal



Cost 4: S1,H1,H3,S6 @ 1,800
S2,H6,S4 @ 1,900
Others @ 2,000

Up Next

- Adapt algorithm for Polish Post
  - Very similar network, on larger scale
  - Approximately 190 Satellites and 15 Hubs
  - Resource costs vary by region
  - Outsource via contracts and spot market

Questions?