

Supporting Innovations in Transportation: Research Opportunities

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The birth of the vehicle routing problem

THE TRUCK DISPATCHING PROBLEM*

G. B. DANTZIG¹ AND J. H. RAMSER²

The paper is concerned with the optimum routing of a fleet of gasoline delivery trucks between a bulk terminal and a large number of service stations supplied by the terminal. The shortest routes between any two points in the system are given and a demand for one or several products is specified for a number of stations within the distribution system. It is desired to find a way to assign stations to trucks in such a manner that station demands are satisfied and total mileage covered by the fleet is a minimum. A procedure based on a linear programming formulation is given for obtaining a near optimal solution. The calculations may be readily performed by hand or by an automatic digital computing machine. No practical applications of the method have been made as yet. A number of trial problems have been calculated, however.

Research motivated by a real-life application

Outline

- Innovations in Transportation
 - Passenger Transportation
 - Freight Transportation
- Research in Support of Innovations in Transportation
 - Passenger Transportation
 - Freight Transportation
- Final Remarks

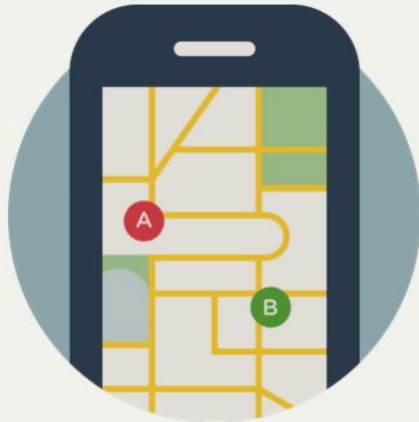
Innovations in Transportation

- Driving forces
 - Digital connectivity
 - Automotive advances
 - Sharing economy
 - Sustainability
 - Electric VRP, Green VRP, ...

Passenger Transportation

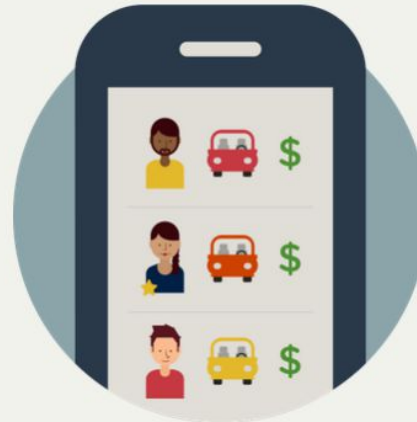


HOW IT WORKS



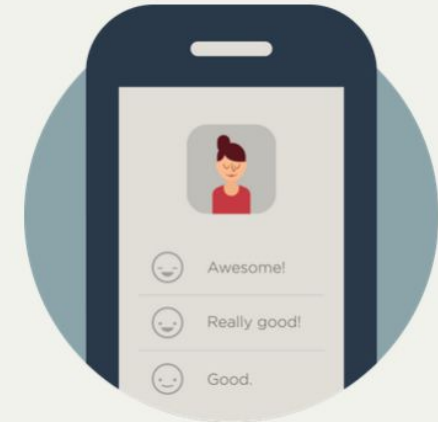
Enter your destination.

Type in where you're headed and get your price up front. Your driver will take you there quickly and safely.



Choose from a list of rides.

Sort available drivers by lowest price, shortest ETA and your favorites. How your ride is up to you!



Pay & rate through the app.

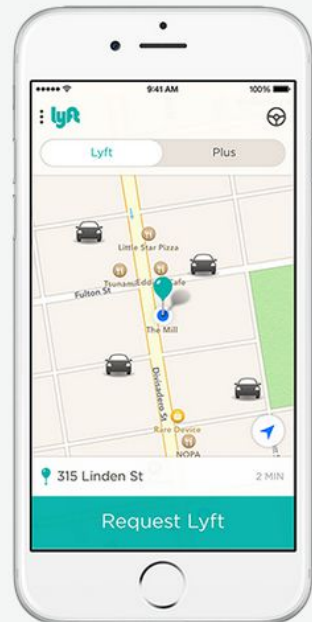
No cash, no hassle. When you've arrived, pay your driver and rate your experience with the tap of a button.



How Lyft Works

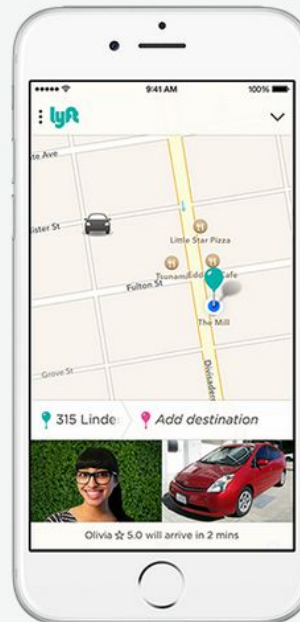
1. Request a ride

With just one tap, get matched with a friendly, background-checked driver.



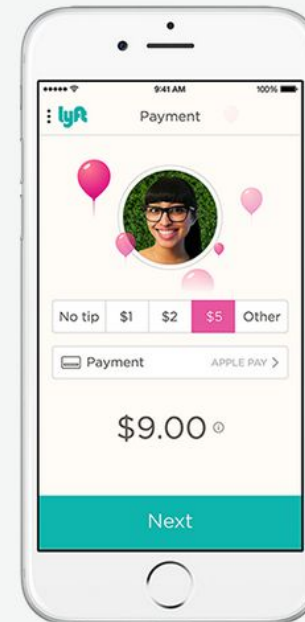
2. Get picked up

Track your driver's ETA in the app. You'll see their photo so you know who you're riding with.



3. Get there fast

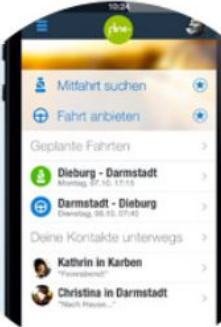
When the ride ends, just pay with your phone.
Done!





The flinc principle:

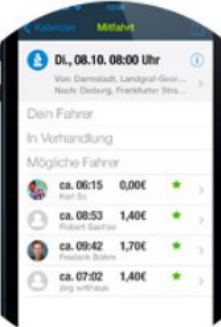
1



Create a ride search or ride offer.

The image shows a smartphone screen with the flinc app interface. The top bar has "flinc" and a green car icon. Below are buttons for "Mitfahrt suchen" and "Fahrt anbieten". A section titled "Geplante Fahrten" lists two trips: "Dieburg - Darmstadt" and "Darmstadt - Dieburg". Below that is "Deine Kontakte unterwegs" with two entries: "Kathrin in Karben" and "Christina in Darmstadt".

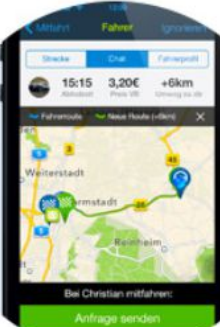
2



flinc automatically suggests suitable drivers or passengers.

The image shows a smartphone screen with the flinc app interface. The top bar has "flinc" and a green car icon. Below are buttons for "Mitfahrt suchen" and "Fahrt anbieten". A section titled "Geplante Fahrten" lists two trips: "Dieburg - Darmstadt" and "Darmstadt - Dieburg". Below that is "Deine Kontakte unterwegs" with two entries: "Kathrin in Karben" and "Christina in Darmstadt".


3



You send requests to the flincers.

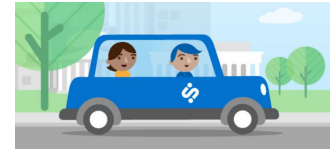
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4



After receiving confirmation, you share your ride!

The image shows a smartphone screen with the flinc app interface. The top bar has "flinc" and a green car icon. Below are buttons for "Mitfahrt suchen" and "Fahrt anbieten". A section titled "Geplante Fahrten" lists two trips: "Dieburg - Darmstadt" and "Darmstadt - Dieburg". Below that is "Deine Kontakte unterwegs" with two entries: "Kathrin in Karben" and "Christina in Darmstadt".

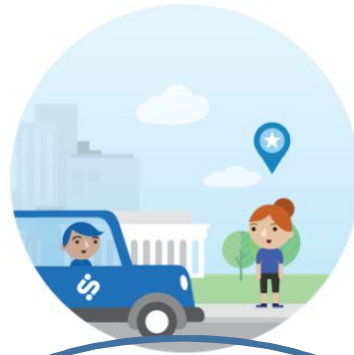


how to ride



1. Request a Ride

Our technology instantly finds the best ride for you and shows you the price before you book.



2. Walk to Your Pickup

Just a block or so away.



3. Grab a Seat

We'll pickup and dropoff other people along the way.

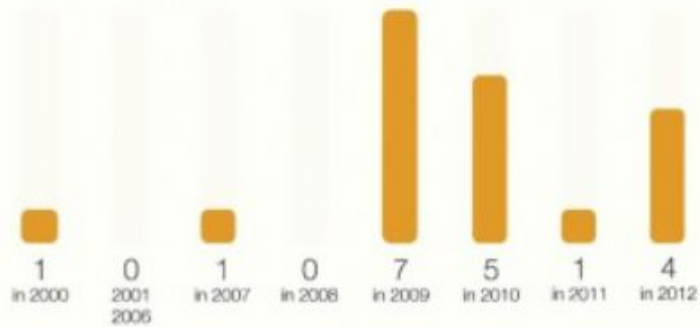


4. Share & Save

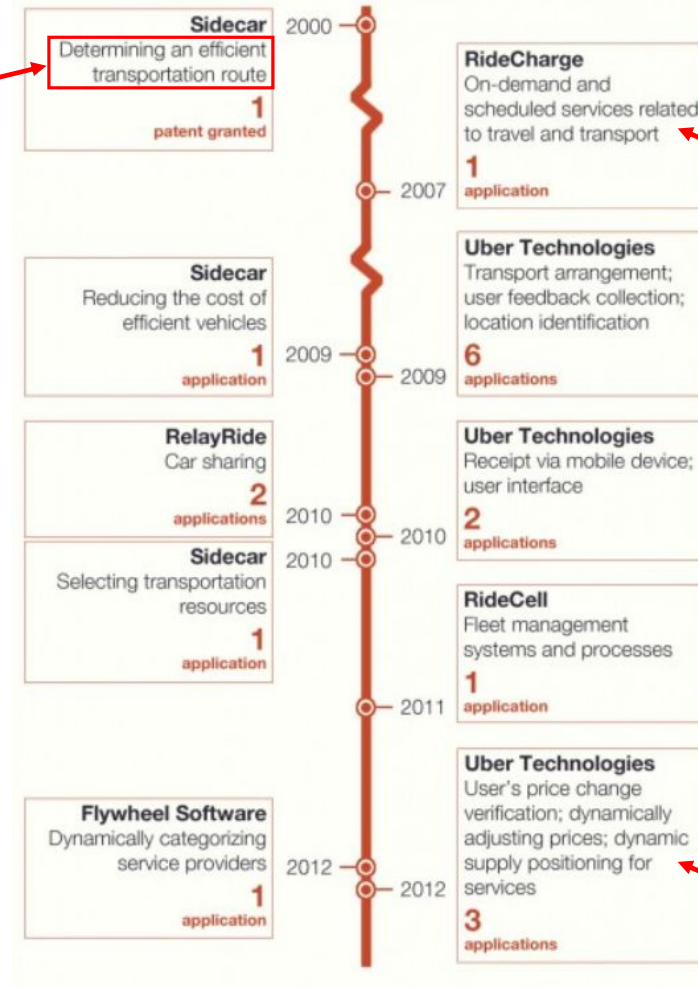
Save money every time, no matter how many people ride.

Ridesharing patents

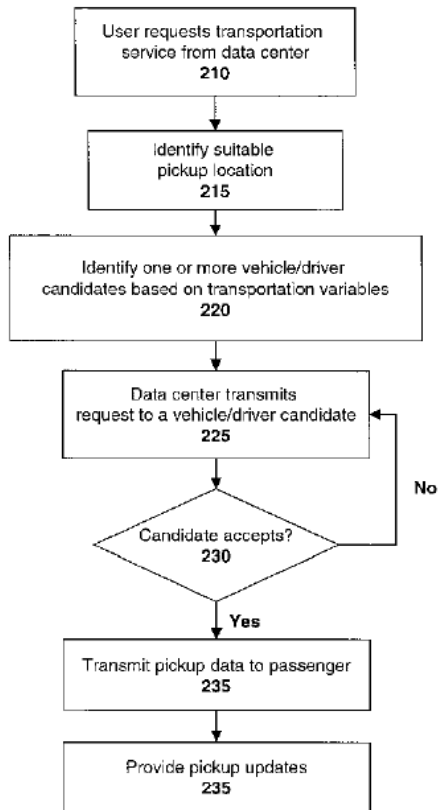
NUMBER OF RIDESHARING PATENT APPLICATIONS
by priority dates



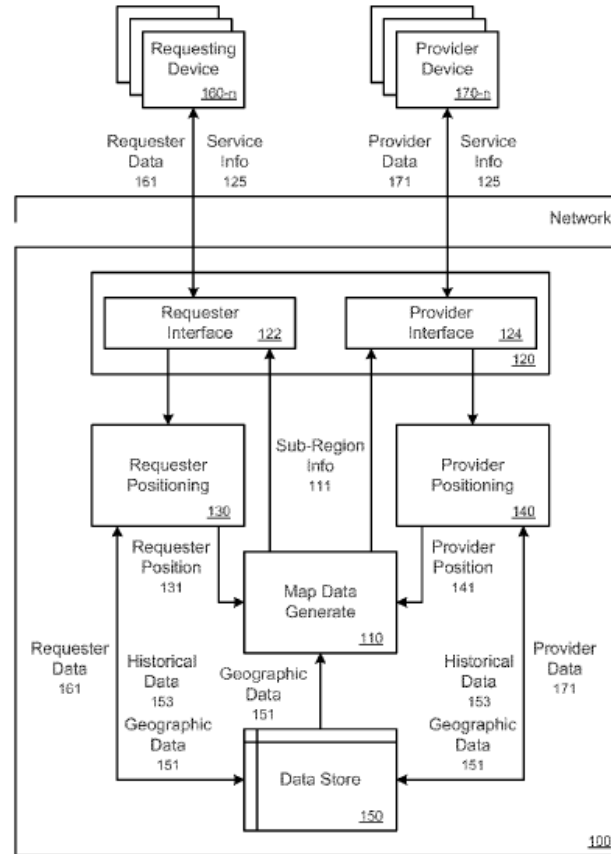
PATENTING TIMELINE
by priority dates



Sidecar patent



Uber patent



Transport innovation



Freight Transportation

Business | Thu Mar 28, 2013 1:01am EDT

Exclusive: Wal-Mart may get customers to deliver packages to online buyers

SAN FRANCISCO | BY ALISTAIR BARR AND JESSICA WOHL

Amazon's Next Delivery Drone: You

Move would help Web retailer manage the shopping experience, rising shipping costs

By **GREG BENSINGER**

June 16, 2015 11:00 a.m. ET

In its ceaseless quest to speed delivery, Amazon.com Inc. wants to turn the U.S. into a nation of couriers.



DHL launched the unique MyWays platform to facilitate last-mile deliveries throughout Stockholm by involving the city's residents. With the pilot, individuals now have the opportunity to deliver packages with products ordered online directly to other end consumers. Using a specifically developed mobile app, the service connects individuals who ask for flexible deliveries with those offering to transport parcels along their daily routes for a small fee. MyWays is being facilitated through DHL Freight's network of service points in Stockholm.





SAME DAY DELIVERY IS NOT A NEW CONCEPT

Hundreds of millions of dollars have been spent by companies trying to solve this challenge, but past attempts have failed miserably. We analyzed their failures and asked ourselves

"WHY NOW?"

CUSTOMER EXPECTATIONS

Fast delivery is the last battleground for the customer experience. This battle actually puts omni-channel retailers in the catbird seat as they all have stores and inventory within five miles of 90% of their customers. With Deliv, they can now deliver on the same day promise better and faster than anyone else—even better than the e-commerce juggernaut in the Pacific Northwest!

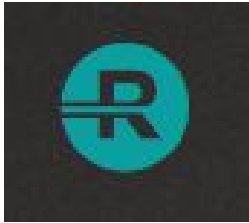
TECHNOLOGY

Deliv uses the technology advancements of omni-channel platforms and GPS-enabled smartphones to mobilize our crowd of drivers. For the first time in history, the fastest and most flexible same-day delivery is now also the cheapest shipping option. [Learn more](#) about how easy it is to integrate Deliv.

PARTNERSHIPS

Deliv partners join our national crowdsourced delivery network, leveraging their brick and mortar assets as well as their e-commerce technology. Together, we are able to out-Amazon Amazon. [See our partnerships.](#)

TIMING IS EVERYTHING. AND THE TIMING IS NOW.



Say hello
to the first neighbor-to-neighbor shipping network.

How it works

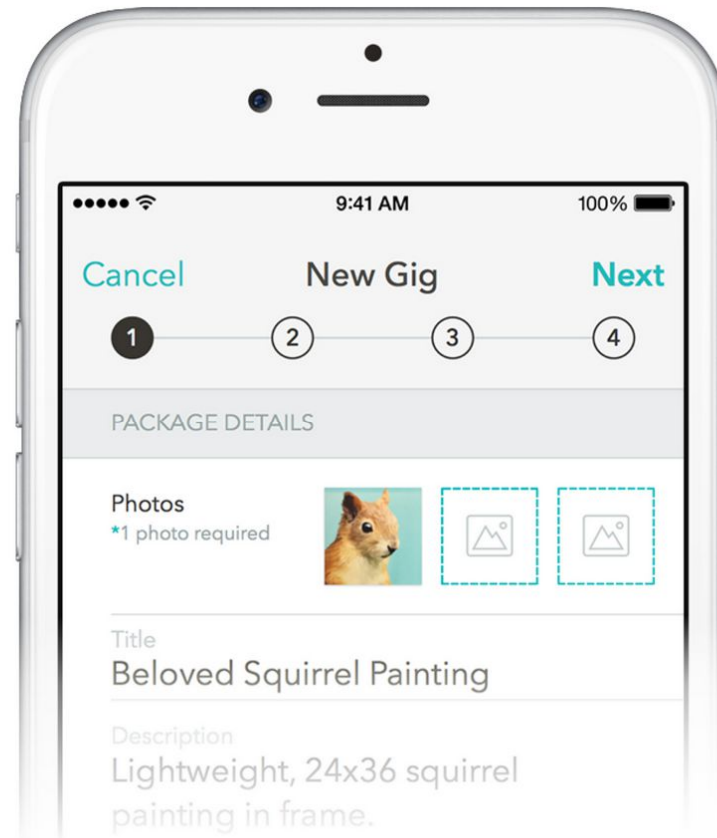


Create a Gig

A Gig is what we call a shipment or delivery.

Just create a Gig and we'll match you with a Roadie driver who's headed that direction.

Think of it as carpooling for cargo. The Roadie mobile app makes it safe, easy and fun!





Audi, DHL and Amazon Partner Up for Trunk Delivery Service

This could be the future of online shopping

It was revealed that Amazon is working on a new program which will deliver convenience to your car's trunk, but only if you fulfil three conditions: you must be an Amazon Prime customer, own an Audi and live in Germany.

This new project was revealed by Audi in a press release on their official website, claiming that "With comprehensive connectivity, we are transforming the car into a service device and integrating it even more closely into the everyday lives of our customers."



CARDROPS

SHOP



ORDER YOUR PHONE ONLINE.

Simply select Cardrops as your shipment method during checkout.

SHIP



WHILE YOU SLEEP WE LOCATE YOUR CAR.

Cardrops opens your trunk remotely the moment our trusted delivery partner arrives. We securely lock your car and keep you updated via SMS. No hassle, no worries.

SHINE



WE MAKE YOU SHINE!

Driving around to pickup points and postal offices is so nineties, don't you think? With Cardrops we want you to just enjoy your new goodies.



Groceries Delivered in an Hour

— What is Instacart?

Instacart is a grocery delivery service that delivers in as little as an hour! We connect you with Personal Shoppers in your area who pick up and deliver your groceries from your favorite local stores.

— What are your hours?

We deliver from 9am to Midnight every day, depending on local store hours. On holidays, our delivery hours are subject to store holiday hours. You can view available delivery times for your area from the shopping cart.

Our fastest delivery was just 12 minutes! Most customers choose to have delivery in the next 2 hours, and you can also schedule for a later date or time during checkout.

— What is Instacart Express?

Instacart Express is a grocery delivery membership. With Instacart Express, you get free delivery on 2 hour & scheduled grocery deliveries over \$35. Instacart Express begins with a 14-day free trial. After that, Express is just \$99/year.



Grocery Shopping

Give us your shopping list and we'll stock your pantry with the groceries you need for the week.

Select Task



Delivery Service

Need something delivered across town? We'll safely transport anything from couches to documents to take-out food.

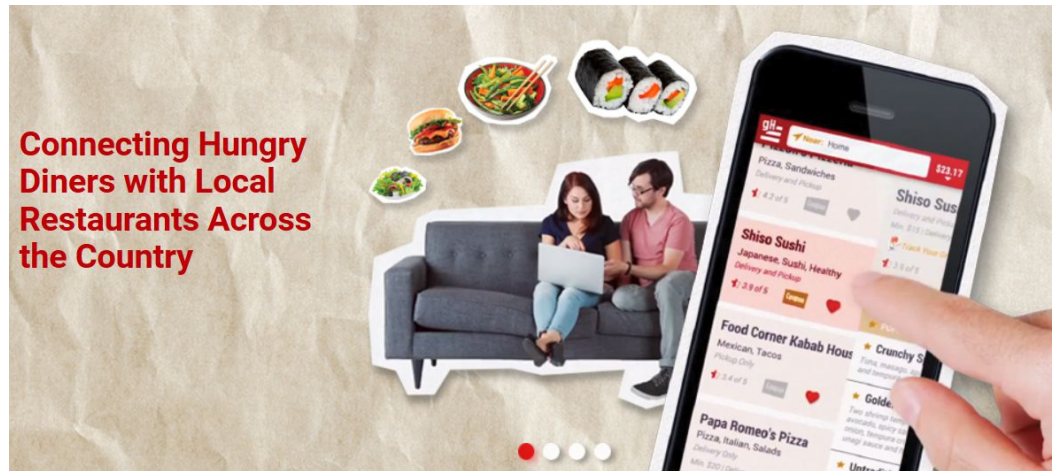
Select Task

How TaskRabbit works

- 1 Select your Task**
Choose from one of the tasks recommended, or create your own custom task.
- 2 Describe your Task**
Describe your tasks so that our qualified Taskers can get a clear idea of the details.
- 3 Choose a Tasker**
Select from a variety of taskers with specific specialities and price points.

Walgreens Uses Crowdsourced Delivery Service To Get Cold Medicine To Sufferers

A new partnership with TaskRabbit facilitates the home delivery of over-the-counter remedies.



Connecting Hungry
Diners with Local
Restaurants Across
the Country

What is GrubHub?

GrubHub Inc. is the nation's leading online and mobile food ordering company dedicated to connecting hungry diners with local takeout restaurants. The company's online and mobile ordering platforms allow diners to order directly from approximately 30,000 takeout restaurants in more than 800 U.S. cities and London. Every order is supported by the company's 24/7 customer service teams. GrubHub Inc. has offices in Chicago, New York and London.

THE WALL STREET JOURNAL.

The nearly 11-year-old online food-ordering company connects home-and-office diners with some 35,000 restaurants. GrubHub's average daily orders in the latest quarter rose 30% to 234,700. Its gross food sales grew 36% to \$590 million.



amazonPrime

FREE Two-Day
Shipping on over
20 million items

When you want it, when you need it

FREE Two-Day shipping with Amazon Prime

Need a last minute gift? Can't get out of the house? Realize you forgot to pick up something? With FREE Two-Day Shipping from Amazon Prime, your shopping problems are solved. You get unlimited deliveries with no minimum order size, and with 20 million eligible items, the options are practically limitless. From big to small, A to Z, home to office, and everywhere in between, satisfying that shopping itch—or need—is just two days away.

Prime^{now}

SKIP THE TRIP. ONE-HOUR DELIVERY.

Exclusively for Amazon Prime Members.

The image shows a smartphone in the center displaying the PrimeNow app interface. The app screen has an orange header with the PrimeNow logo. Below the header, the text reads: "When would you like your order delivered?" followed by "You, or someone else, must be available to receive your order." Under the heading "Today", there are four delivery time slots: "Within one hour" for \$7.99, and three "FREE" slots for 6:00 - 8:00 PM, 8:00 - 10:00 PM, and 10:00 PM - 12:00 AM. Under the heading "Tomorrow", there is one "FREE" slot for 6:00 - 8:00 AM. The phone is surrounded by various products: headphones, Aveeno lotion, Pellegrino water, a white t-shirt, a box of Cheerios cereal, a roll of Bounty paper towels, a bottle of Tide detergent, a tablet displaying "The 4-Hour Workweek" by Ferriss, and a jar of Skippy peanut butter.



What is AmazonFresh?

AmazonFresh offers same-day and early morning delivery of a broad selection of items, including fresh grocery and local products.

How does delivery work?

AmazonFresh offers two delivery options -- Doorstep Delivery or Attended Delivery.

Doorstep Delivery

Most customers use our Doorstep Delivery option. With Doorstep Delivery, you choose a 3-hour time window that works best for your schedule -- you don't even have to be home. We will leave your items on your doorstep in temperature-controlled tote bags and pick them up with your next delivery. To be eligible for Doorstep Delivery, your driver must have unrestricted access to your doorstep without having to call you.

Attended Delivery

With Attended Delivery, you select a 1-hour appointment when you will be home to receive the delivery. Some of the benefits of Attended Delivery are:

- Shorter 1-hour delivery windows
- In-person delivery straight to your kitchen
- No totes or other shipping supplies to store in your home
- Delivery to buildings with secure entry or limited access

At AmazonFresh, the quality of your food is our biggest concern. We carefully control the conditions in which your products are stored, right up until the moment you receive them, so that fresh items stay chilled and frozen items remain frozen. To keep all of your products at their proper temperatures, Doorstep Deliveries will be packed with frozen water bottles. The water is safe to consume, and the bottles are yours to keep, dispose of, or recycle. While we encourage you to retrieve your groceries as soon as possible once delivered, this packaging is designed to maintain the correct temperature of your products for up to 1 hour after the end of your delivery window.

Introducing Prime Pantry

Low-priced everyday essentials in everyday sizes, delivered to your home.



Prime Pantry is a new shopping experience on Amazon.com. Prime members can shop popular household essentials and have them conveniently delivered.

Adding your first Prime Pantry item to Cart starts a Prime Pantry box. As you shop, you see that each Pantry item tells you what percentage of a Pantry box it fills based on its size and weight. Pantry boxes are large and can hold up to 45 pounds or four cubic feet of household products. As you check items off your list, we continuously track and show you how full your box is.

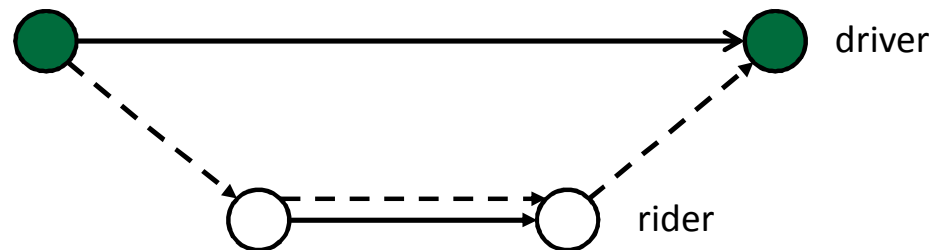
Transport innovation



Innovations in Passenger Transportation

Dynamic ridesharing

- Match people with “similar” itineraries and let them travel together



The sharing economy: Physical assets as services

Technology makes sharing assets cheaper and easier than ever—and therefore possible on a large scale. Especially useful for expensive items that are not fully used by those who own them. The “collaborative consumption” allows owners to make money from underused assets.

Dynamic ridesharing: Societal benefits



- *Effective use of empty car seats can*
 - *Reduce congestion (and emissions)*
 - *Reduce costly infrastructure expansions*

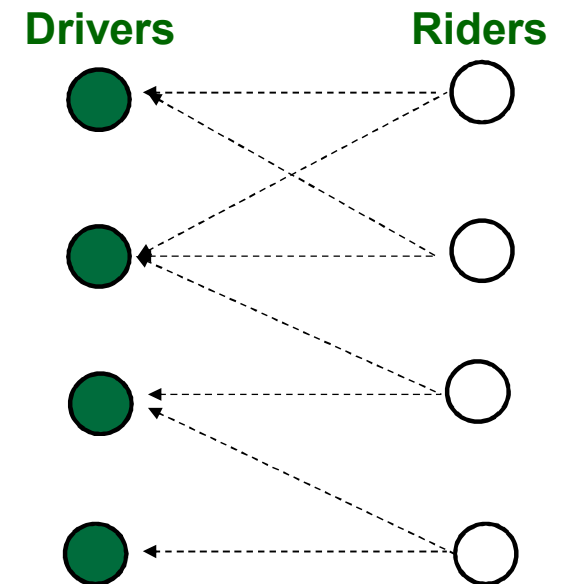
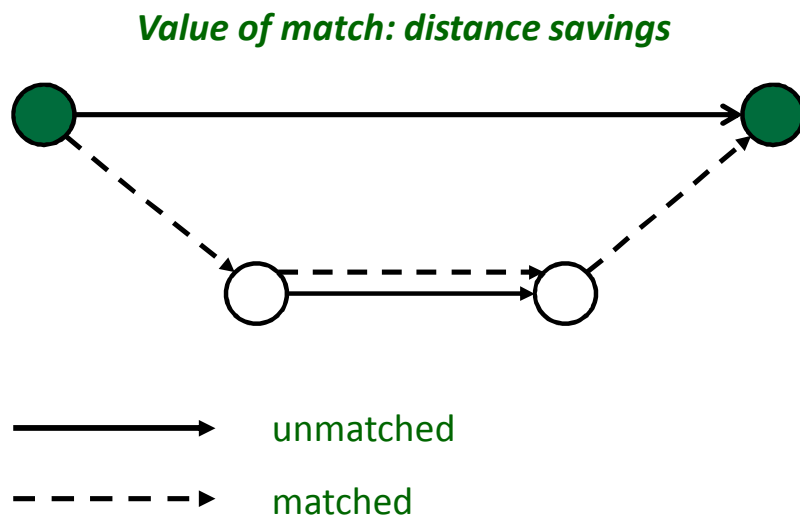


Dynamic Ridesharing

- Matching of participants with similar travel plans
- Non-recurring, dynamic trips :
 - One - off trips established on short-notice
- Automated process:
 - Algorithms match participants and generate routes
- Cost-sharing:
 - fare paid by rider < trip cost
- Participants benefits:
 - Cost savings, use of HOV lanes, environmental concerns
- Provider benefits:
 - Takes a commission from matches generated

Dynamic ridesharing: Basics

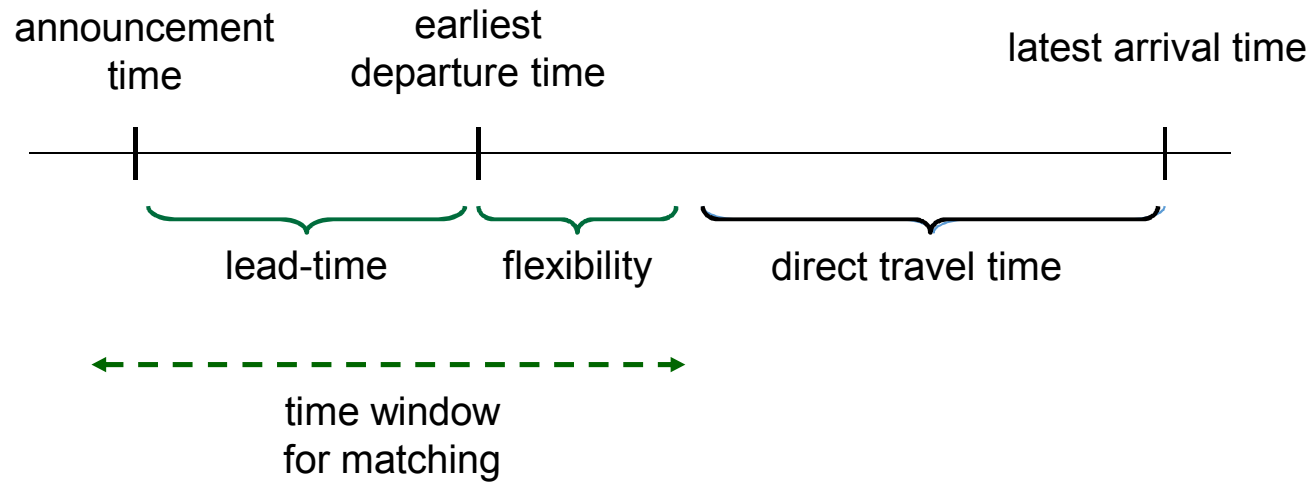
Note: It appears that most rideshare companies use a greedy assignment procedure



We assume that the rider drives him/herself if no match can be found, but this could easily be changed to, for example, the rider using public transportation

***Finding an optimal set of matches:
Matching problem***

Dynamic ridesharing: Time



Dynamic ridesharing: Variants

- Rider return trips
- Flexible roles (driver or rider)
- Multiple drivers (transfers)
- Multiple riders

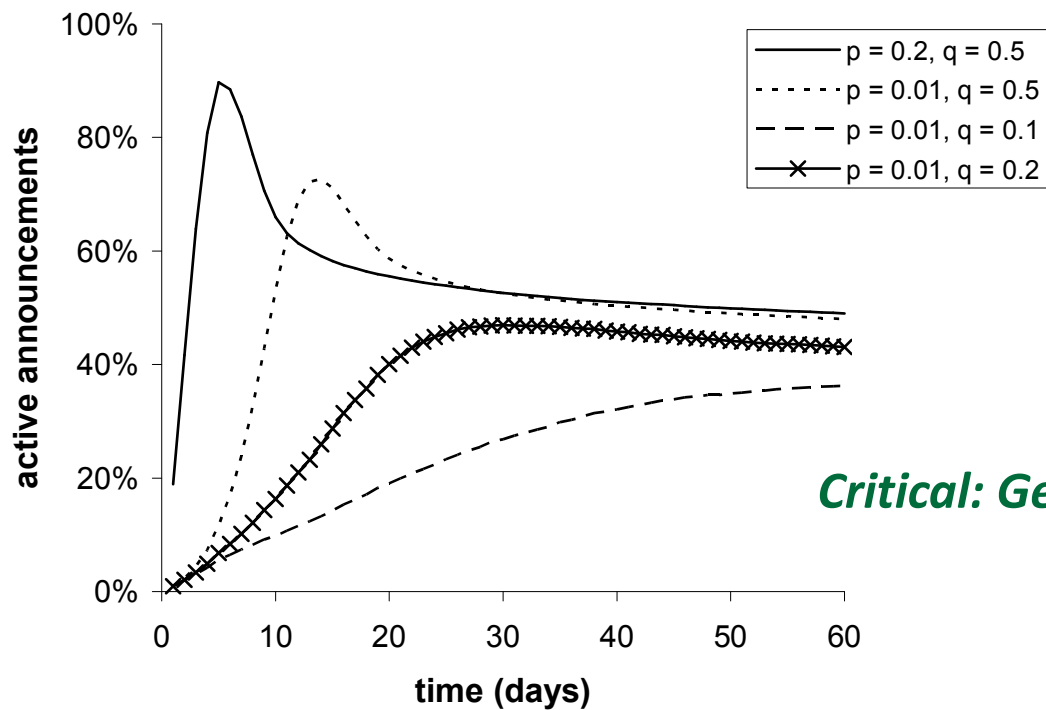
Optimization problem is no longer a
pure matching problem

Dynamic ridesharing: Success factors

Critical success factor for dynamic ridesharing:

- ***Matching rate – number of participants that find a match***

Simulation Study Metro Atlanta



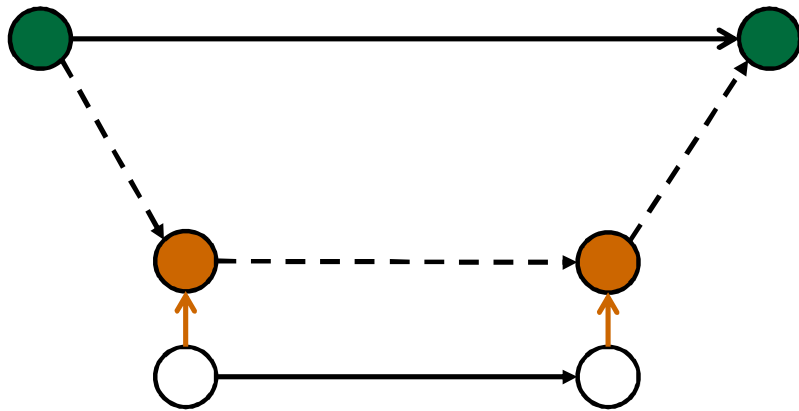
different models of adoption
(Bass diffusion model)

Critical: Get Large Fast!

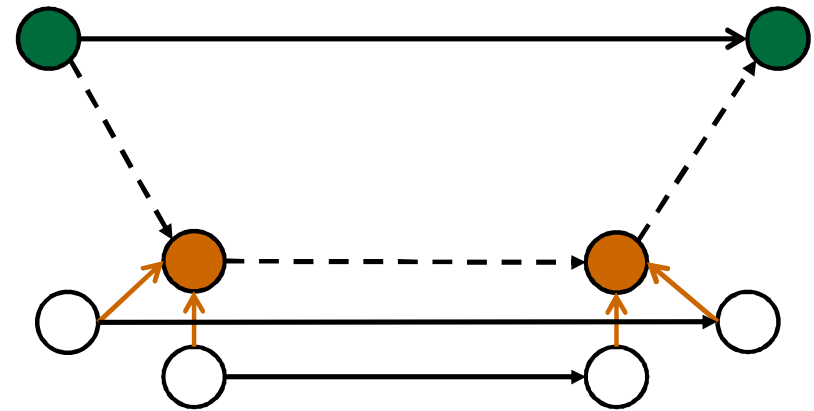
Dynamic ridesharing: How to increase matching rate?

- *Meeting points – increase number of feasible matches*
- *Dedicated drivers – supplement the driver pool*

Dynamic ridesharing: Meeting points



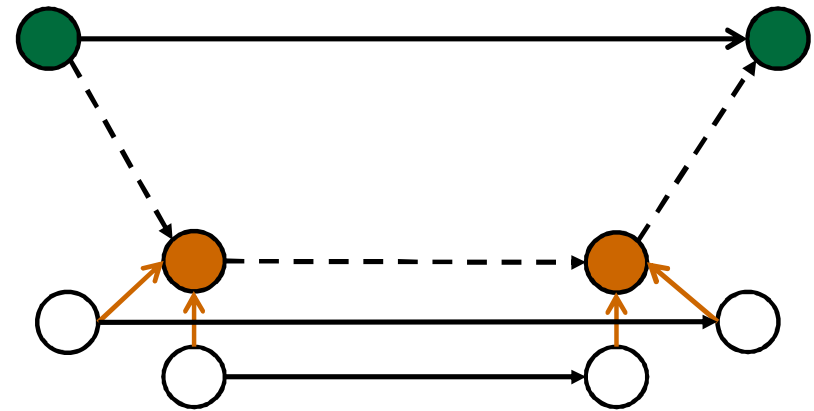
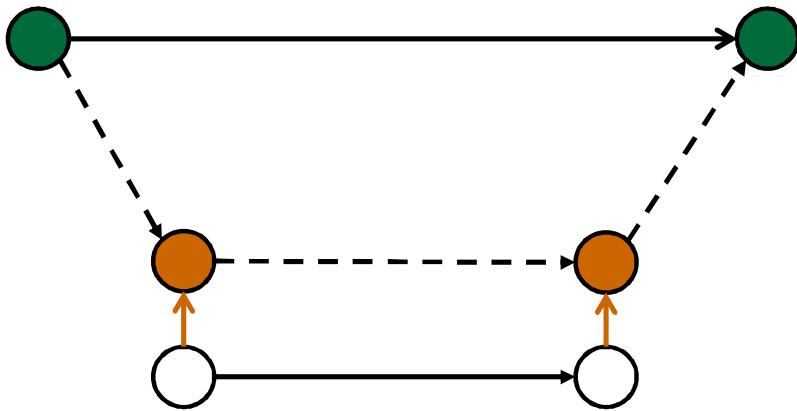
Matches that were previously infeasible may now be feasible



Matching multiple riders without introducing transfers is now possible

Side benefit: True origin and destination of a rider may be hidden, giving the rider more security

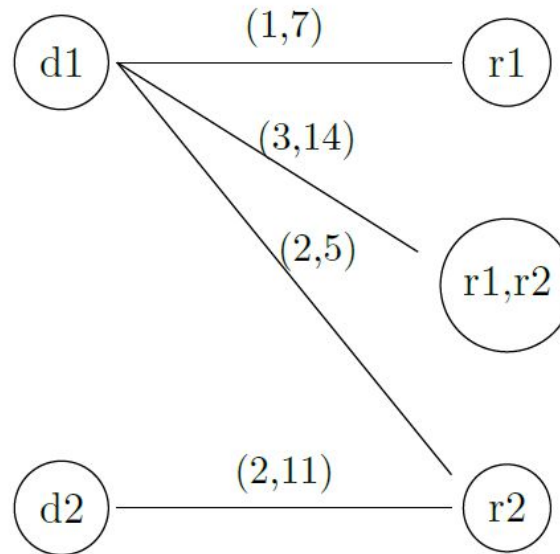
Dynamic ridesharing: Meeting points



Research Challenge: How to identify feasible matches efficiently?

Dynamic ridesharing: Meeting points

Side-constrained matching problem



Dynamic ridesharing: Meeting points

Metro Atlanta: 229 Travel Analysis Zones

Max extra drive time: 20 minutes

Max walking: 11 minutes

#Drivers: ~1500

#Riders: ~1500

Avg. trip duration: 30 minutes

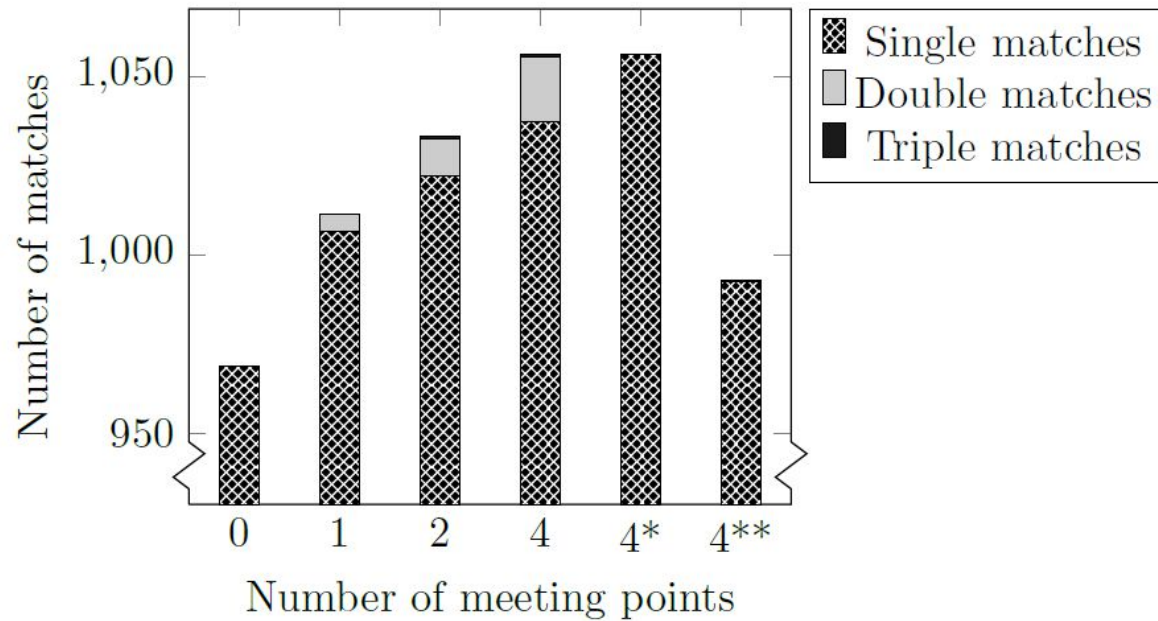
Table 2: Results for different numbers of meeting points and types of matches.

	0	1	2	4	4*	4**
<i>System:</i>						
<i>Matching rate (%)</i>	68.00	71.14	72.90	74.83	74.13	69.71
<i>Mileage savings (%)</i>	27.39	28.36	28.93	29.63	29.24	27.59
<i>Drivers:</i>						
<i>Matching rate (%)</i>	67.96	70.93	72.45	74.08	74.08	69.65
<i>Trip time increase (%)</i>	25.45	25.98	26.31	26.41	26.19	25.77
<i>Riders:</i>						
<i>Matching rate (%)</i>	68.11	71.43	73.43	75.65	74.26	69.84
<i>Trip time increase (%)</i>	13.09	19.27	22.74	26.54	16.43	16.42
<i>Walk time (min:sec)</i>	-	8:06	8:28	8:56	8:45	5:06

4: Single driver – single rider only*

*4**: Closest meeting point only*

Dynamic ridesharing: Meeting points



Dynamic Ridesharing: Dedicated Drivers

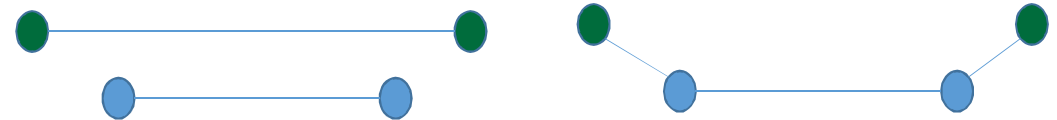
- Idea: Employ (a few) dedicated drivers to ensure that a certain service level is guaranteed, e.g., 95% of **riders** served
- Goal:
 - Attract new participants
 - Make sure existing participants continue to be participants

Issues

- What should riders who travel with dedicated drivers pay?
- How should the cost of dedicated drivers be covered?

Dedicated Drivers: Fare paid

- *Premise: Riders who travel with dedicated drivers should not be advantaged or disadvantaged, but pay about the same as riders who travel with regular drivers*



(Earlier proposed scheme: proportional based on cost-savings)

- Riders pay
 - A fee per mile traveled
 - Use (historical) data from riders traveling with regular drivers to determine the fee. Possibly stratifying by distance traveled, time of day, origin and destination location, ...

Dedicated Drivers: Who pays?

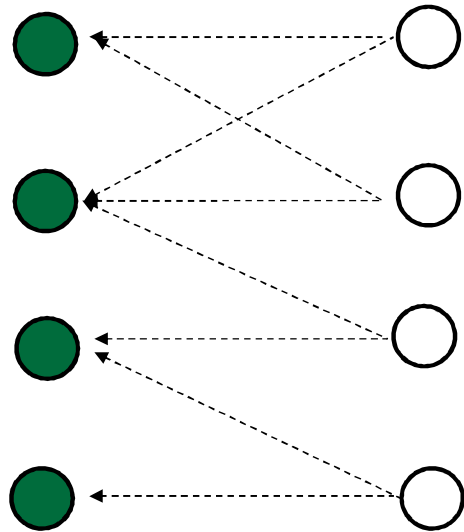
- Service provider:
 - Uses dedicated drivers to attract participants so as to increase revenue from commissions
 - Many companies accept initial losses to build user base

Possible other revenue generation mechanism: adds in app

- Public institution (government, local council):
 - As part of a sustainability initiative
 - Cost small compared to building new infrastructure
 - One-off payment
- Riders & Regular Drivers:
 - Improved service in everyone's interest

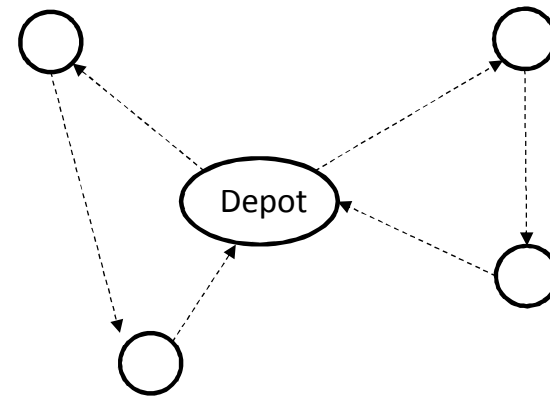
Dedicated drivers: Solution Approach

Pairing Riders with Ad-hoc Drivers



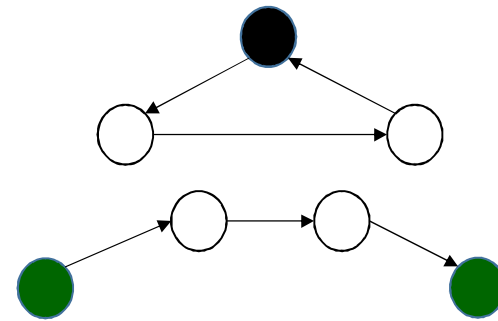
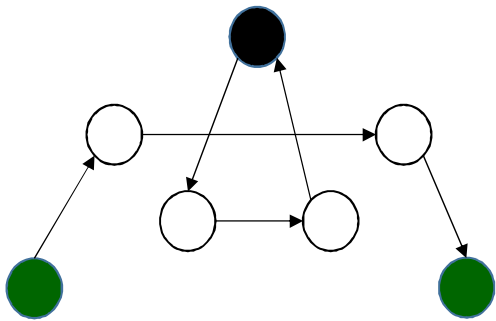
Matching Problem: Easy

Pairing Riders with Dedicated Drivers




VRP with Profits: Hard

Dedicated drivers: Custom neighborhoods



Dedicated drivers: Dedicated drivers

Uniform Distribution									
	Total Cost (Per-rider Cost)			# Ded Drivers			% Served by Ded Drivers		
	90 %	95%	98%	90 %	95%	98%	90 %	95%	98%
100	527.11 (18.90)	622.21 (20.15)	658.27 (20.65)	5.90	6.90	7.10	62.00%	64.38%	65.10%
200	631.92 (16.73)	769.00 (17.97)	862.89 (18.85)	7.30	9.10	10.10	42.00%	45.05%	46.73%
300	728.62 (15.56)	942.18 (17.20)	1059.62 (18.02)	8.60	10.90	12.20	34.59%	38.25%	39.93%
400	759.99 (14.62)	991.33 (16.00)	1158.35 (17.04)	8.60	11.50	13.70	28.78%	32.53%	34.59%
500	754.09 (13.84)	1037.52 (15.37)	1246.87 (16.74)	8.90	12.10	14.00	24.13%	28.28%	30.33%


Five Hubs

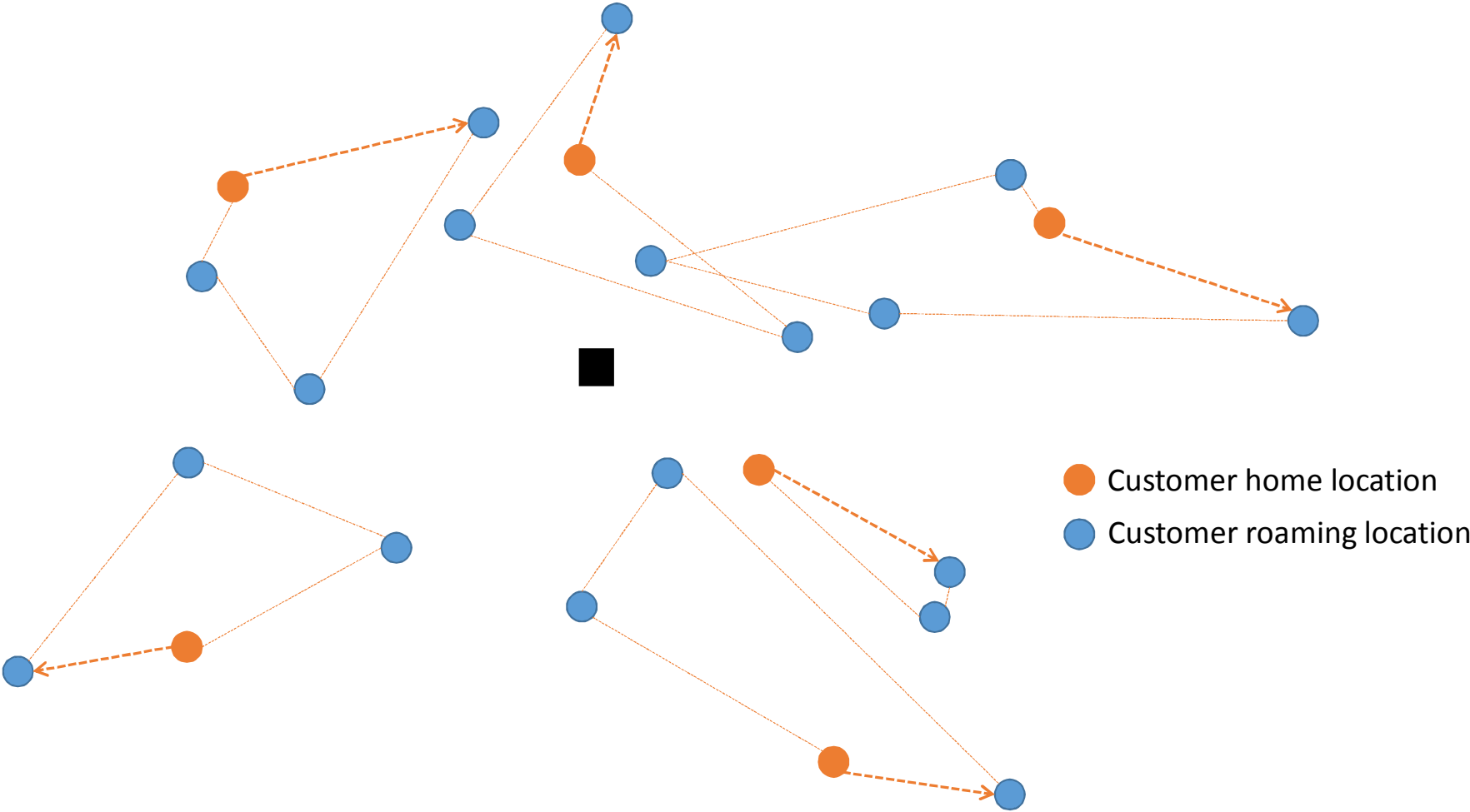
	Total Cost			# Ded Drivers			% Served by Ded Drivers		
	90 %	95%	98%	90 %	95%	98%	90 %	95%	98%
100	224.59 (14.32)	289.70 (15.55)	312.83 (15.94)	3.10	4.00	4.30	34.67%	38.75%	40.00%
200	193.16 (12.56)	279.21 (13.74)	336.72 (14.45)	3.00	4.00	5.00	17.00%	21.37%	23.78%
300	120.15 (11.74)	244.67 (13.53)	323.63 (14.68)	2.00	4.00	5.00	1.33%	12.52%	14.90%
400	58.51 (12.13)	169.73 (12.40)	276.56 (14.14)	1.29	2.80	4.80	2.11%	7.16%	10.00%
500	47.08 (10.56)	121.46 (11.40)	229.76 (13.08)	1.50	2.10	3.90	0.40%	4.50%	7.22%

Two Hubs

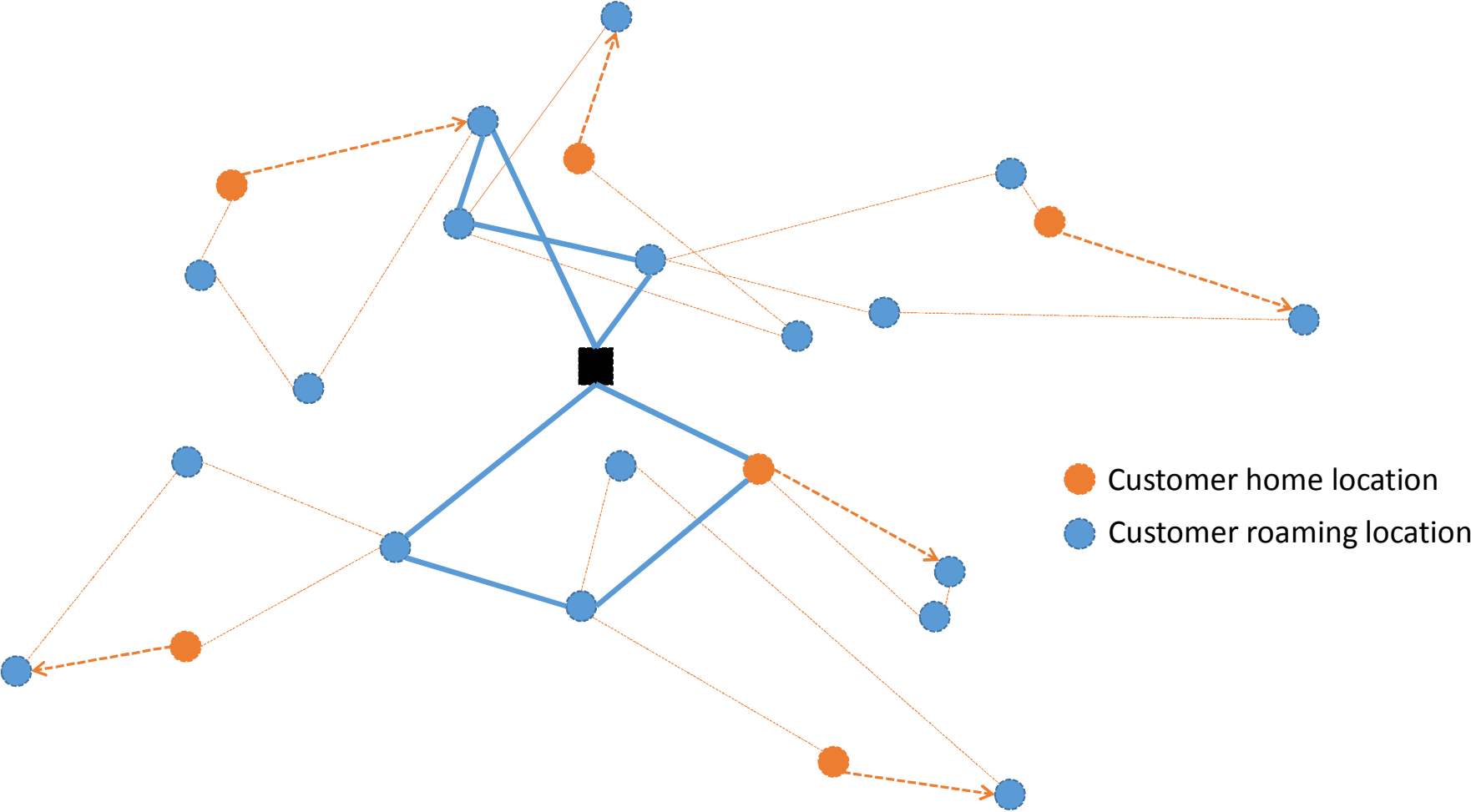
	Total Cost			# Ded Drivers			% Served by Ded Drivers		
	90 %	95%	98%	90 %	95%	98%	90 %	95%	98%
100	49.62 (22.03)	110.31 (20.23)	137.97 (21.47)	1.10	1.90	2.60	5.33%	11.25%	13.06%
200	140.35 (23.39)	130.55 (23.57)	184.51 (22.96)	1.67	1.89	3.00	2.00%	5.26%	8.06%
300	122.07 (26.76)	179.29 (24.06)	191.47 (23.38)	1.50	2.33	2.80	0.67%	2.94%	5.31%
400	107.59 (26.90)	136.17 (24.12)	195.89 (24.47)	1.00	1.83	2.60	0.22%	1.74%	4.03%
500	25.52 (25.52)	237.39 (23.00)	176.43 (24.03)	1.00	3.00	2.22	0.04%	0.80%	2.65%

Innovations in Freight Transportation

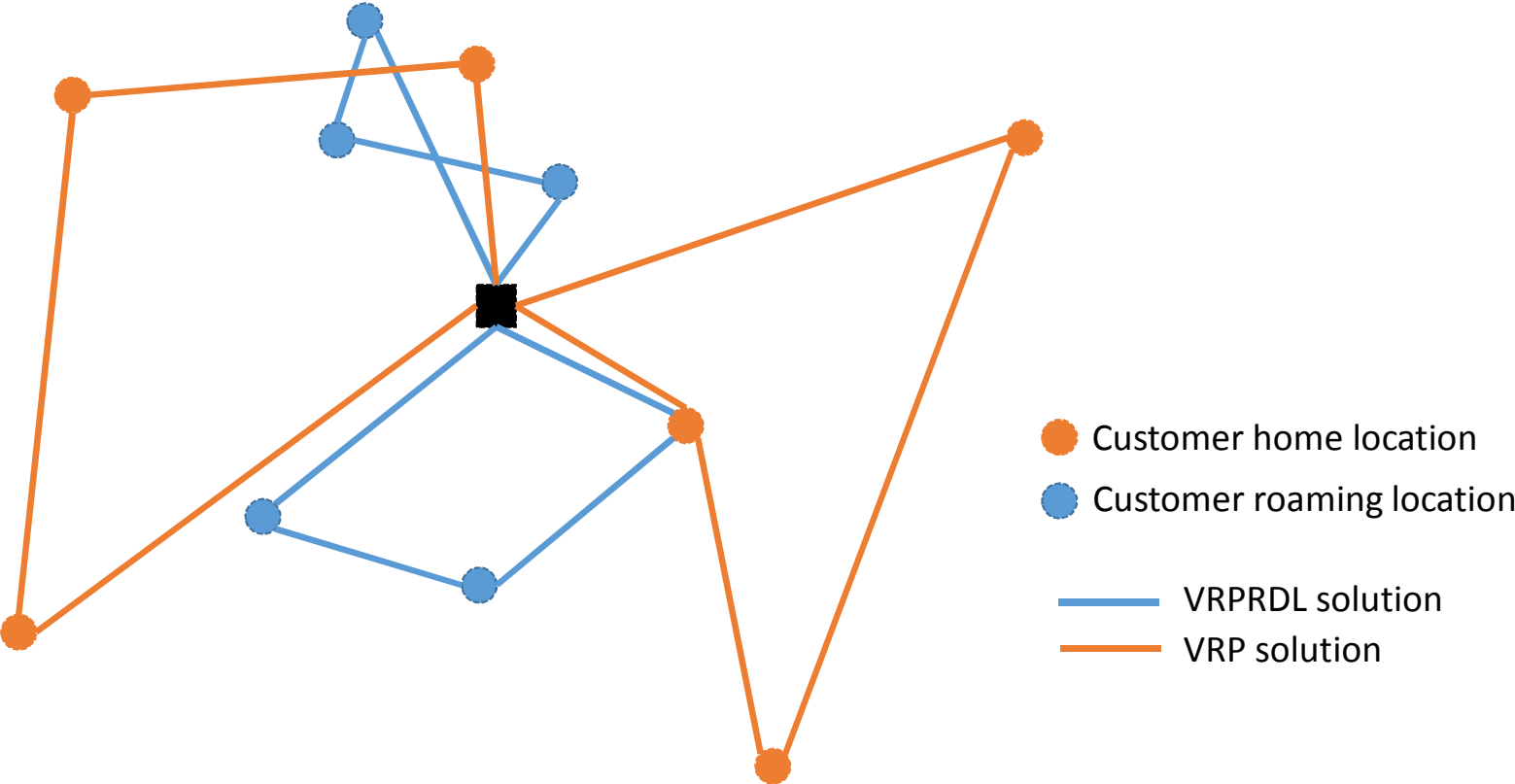
Vehicle Routing Problem with Roaming Delivery Locations



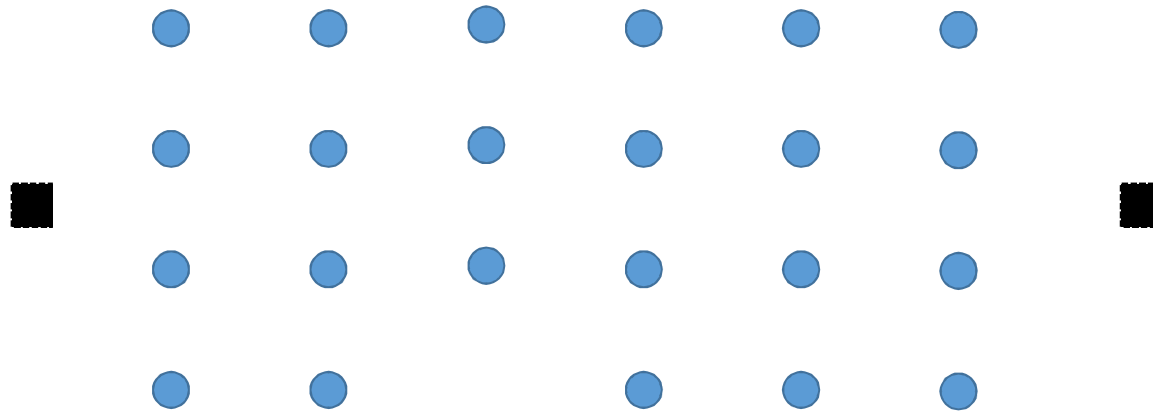
Vehicle Routing Problem with Roaming Delivery Locations



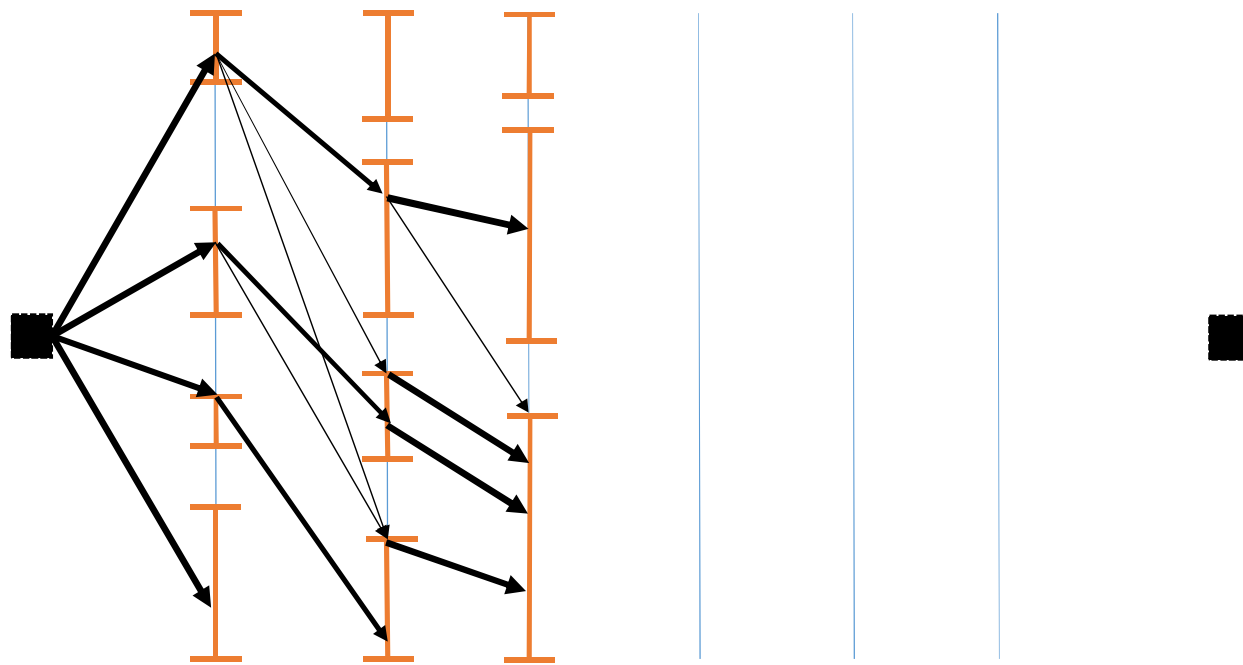
Vehicle Routing Problem with Roaming Delivery Locations



Optimizing for a Given Delivery Sequence



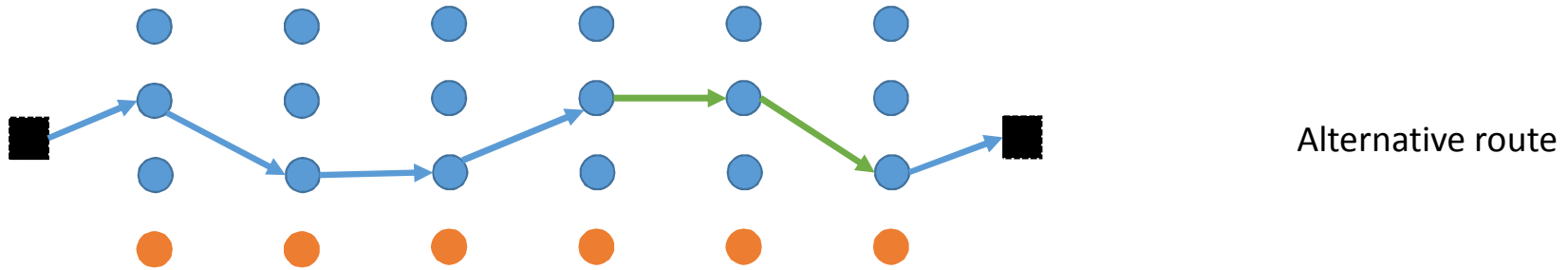
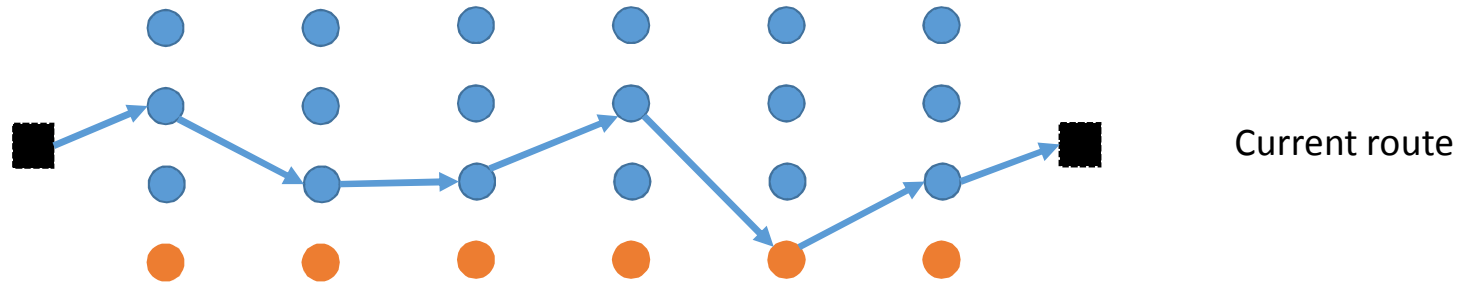
Optimizing for a Given Delivery Sequence



Observe: Each departure creates at most one new additional time point.

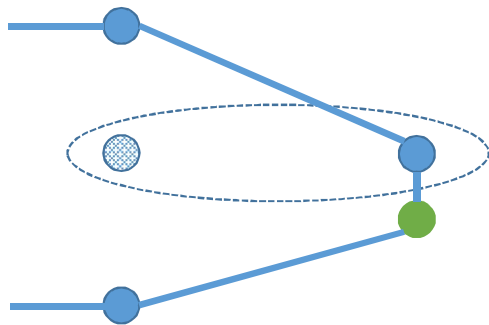
Consequence: Can be solved efficiently by dynamic programming.

Heuristic Solution

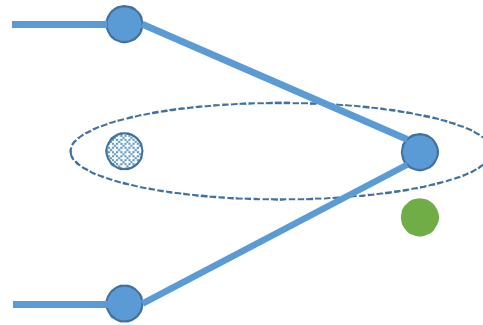


Idea: Maintain all routes that differ in one customer location

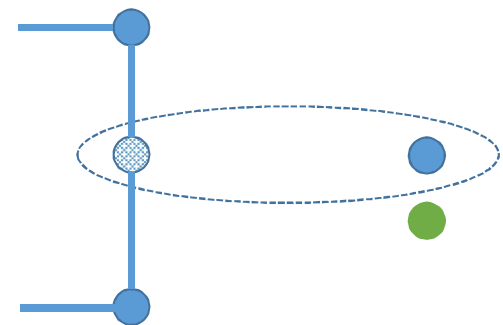
Deletion with alternative routes



standard deletion operation

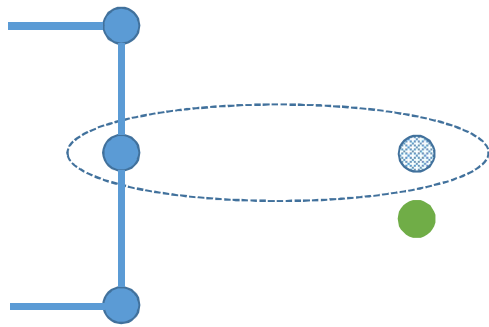


deletion operation with an alternative route option

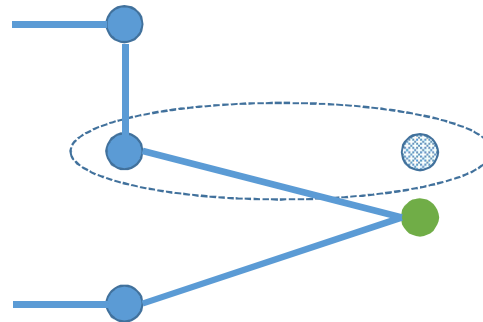


- location to be deleted
- alternative customer location

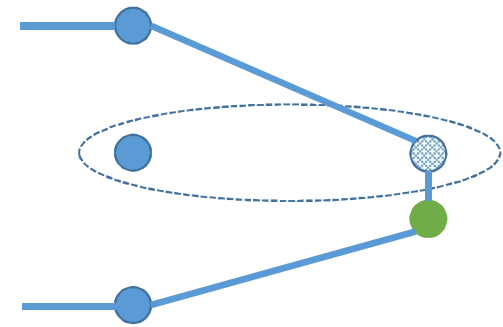
Insertion with alternative routes



standard insertion operation



Insertion operation with an alternative route option



- location to be inserted
- alternative customer location

Heuristic Solution

- Construct a feasible solution
 - GRASP
 - restricted candidate list size: 2
 - number of iterations: 100
- Iterative improvement
 - Random destroy – Greedy recreate
 - number of customers to remove depends on instance size: $0.2 \times \text{\#customers}$
 - Randomized greedy destroy – Randomized greedy recreate
 - number of customers to remove depends on instance size: $0.2 \times \text{\#customers}$
 - chose randomly among the best
 - Switch neighborhoods after 10 iterations without improvement
 - When switching neighborhoods after destroy optimize sequences before recreating
 - Diversify by splitting the route with most customers into two routes after 750 iterations
 - Total number of improvement steps: 1000

Vehicle Routing Problem with Roaming Delivery Locations

- Factors impacting success/benefit
 - Setting:
 - Home delivery only (HD)
 - Roaming locations only (RDL)
 - Home and roaming locations (HRDL)
 - Roaming location characteristics
 - Relatively close to home location
 - Relatively far from home location
 - Impacts where delivery can be made (possibly closer to the depot or other customers)
 - Impacts available time for delivery (cannot deliver when vehicle is driving)

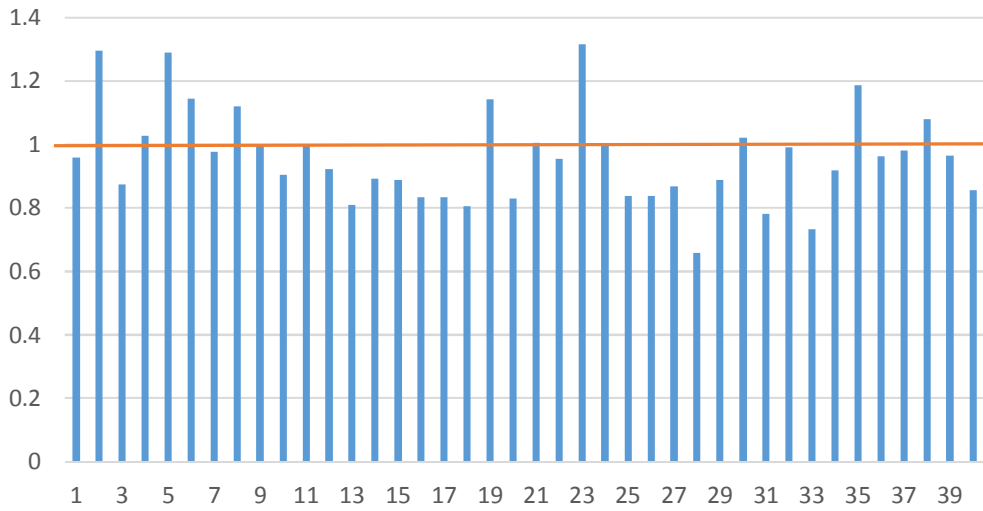
Vehicle Routing Problem with Roaming Delivery Locations

- Experimental setting
 - Number of instances: 40
 - Number of customers: 15, 30, 60, 120
 - Number of locations per customer: up to 5
 - Roaming location distances: 100%, 50%, 25%, 12.5%

Vehicle Routing Problem with Roaming Delivery Locations

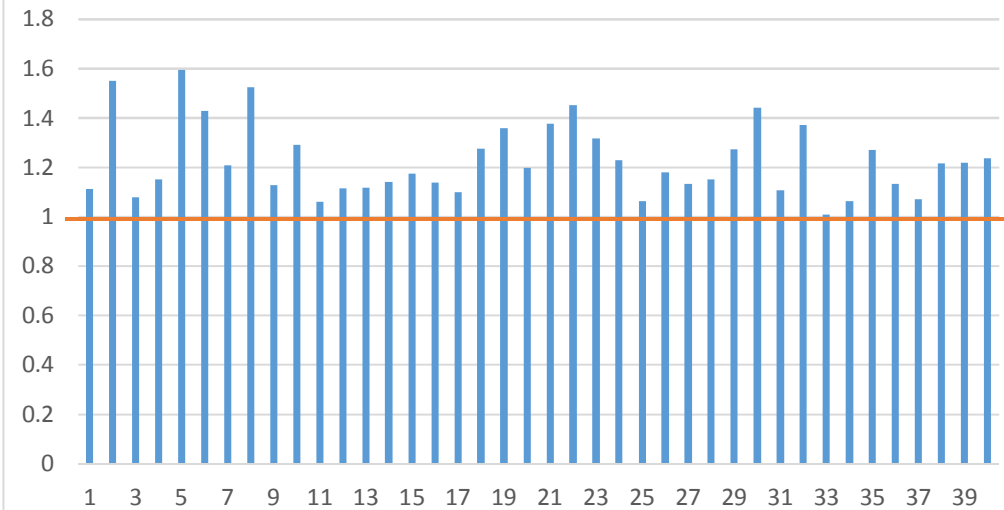
- Algorithmic observations:
 - Heuristic almost always produces the same solution as Gurobi (with 2 hours time limit and starting from GRASP solution) on small instances
 - Heuristic finds solution that is 4% better than the one found by Gurobi (with 2 hours time limit and starting from GRASP solution) on medium instances (on average)
 - Heuristic finds solution that is 22% better than the one found by Gurobi (with 2 hours time limit and starting from GRASP solution) on large instances (on average)
- “Automatic route changes” occur in about 4% of the destroy and repair operations of improving moves
- Reoptimizing sequences rarely leads to an improvement

Cost ratio HD to RDL

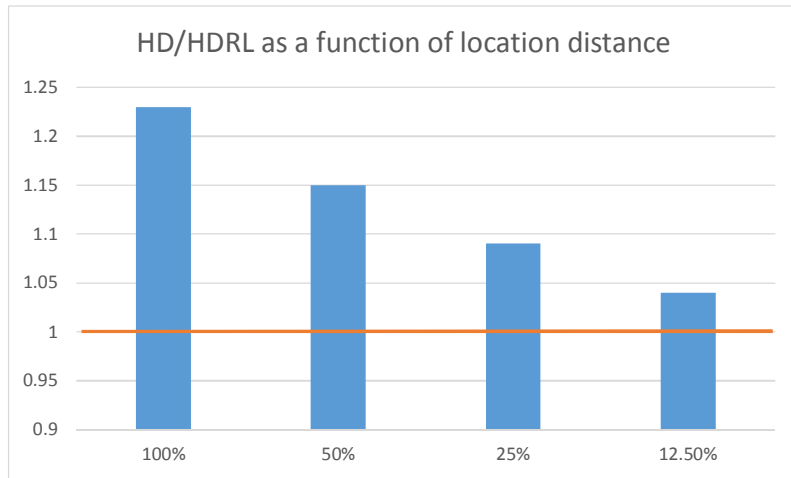


Whether RDL-only improves over HD-only depends strongly on the instance characteristics

Cost ratio HD to HRDL



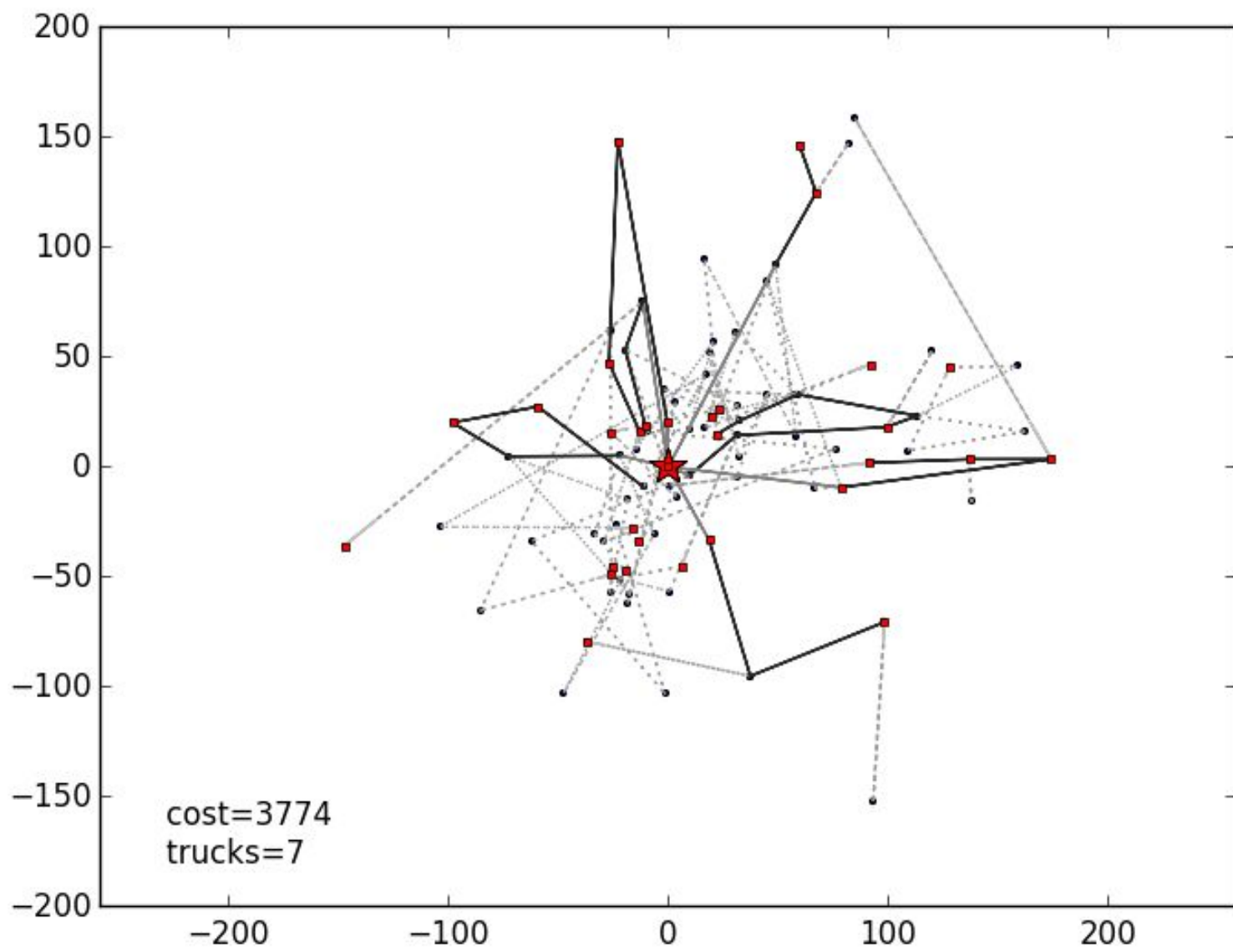
HRDL always improves over HD-only, but the benefits depends strongly on the instance characteristics



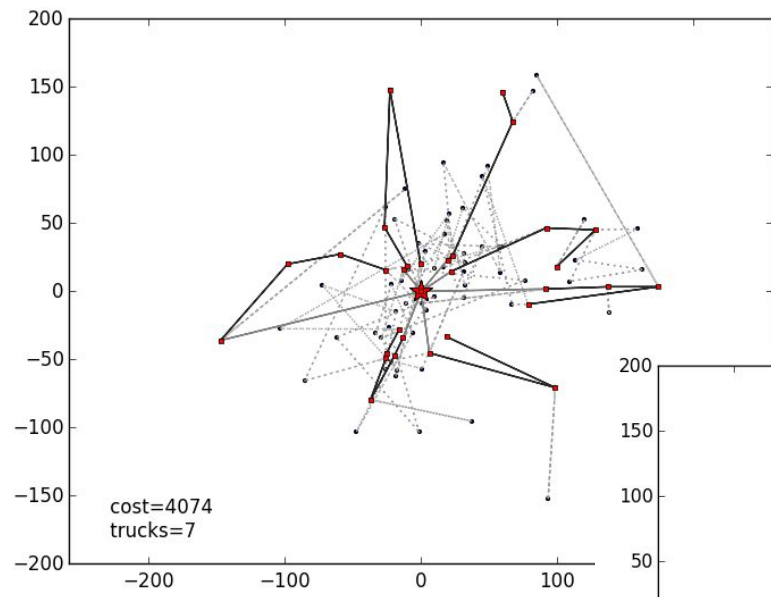
HRDL improvement over HD-only depends on the location distances

Interesting observations:

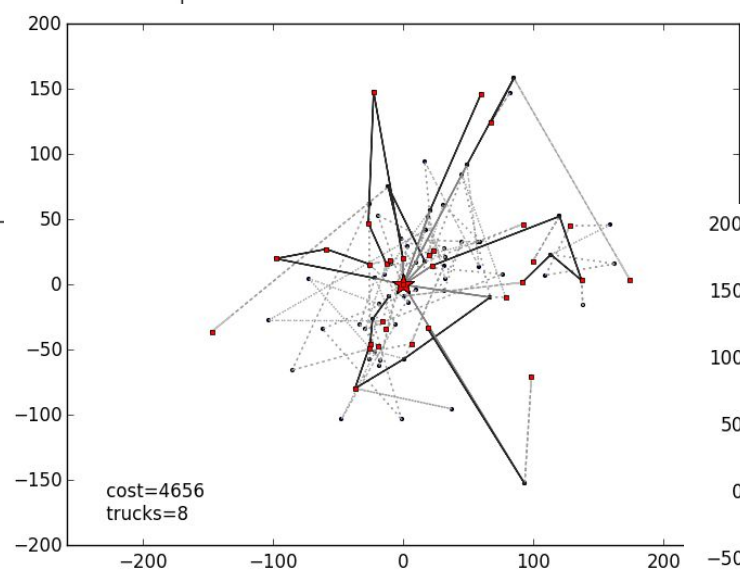
- RDL-only can be infeasible even when HD-only is feasible
- RDL-only can be infeasible for 50% location distance even when RDL-only is feasible for 100% location distance



HRDL

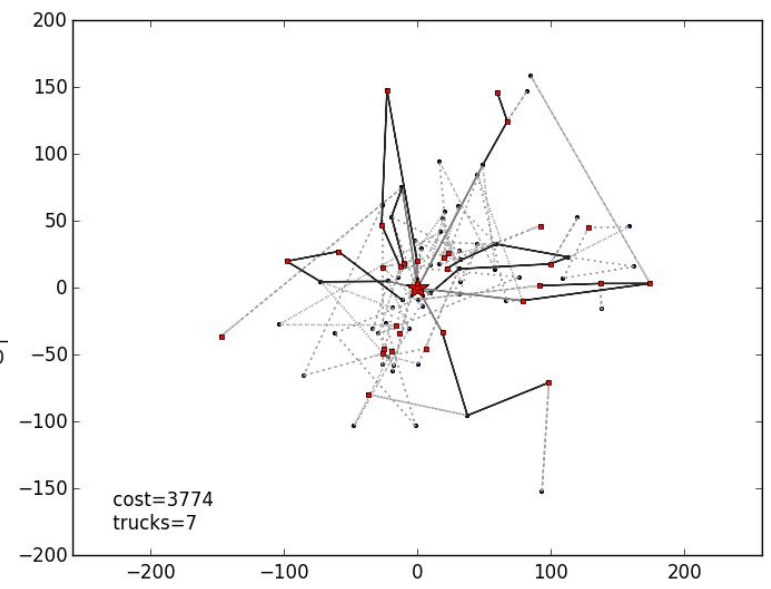


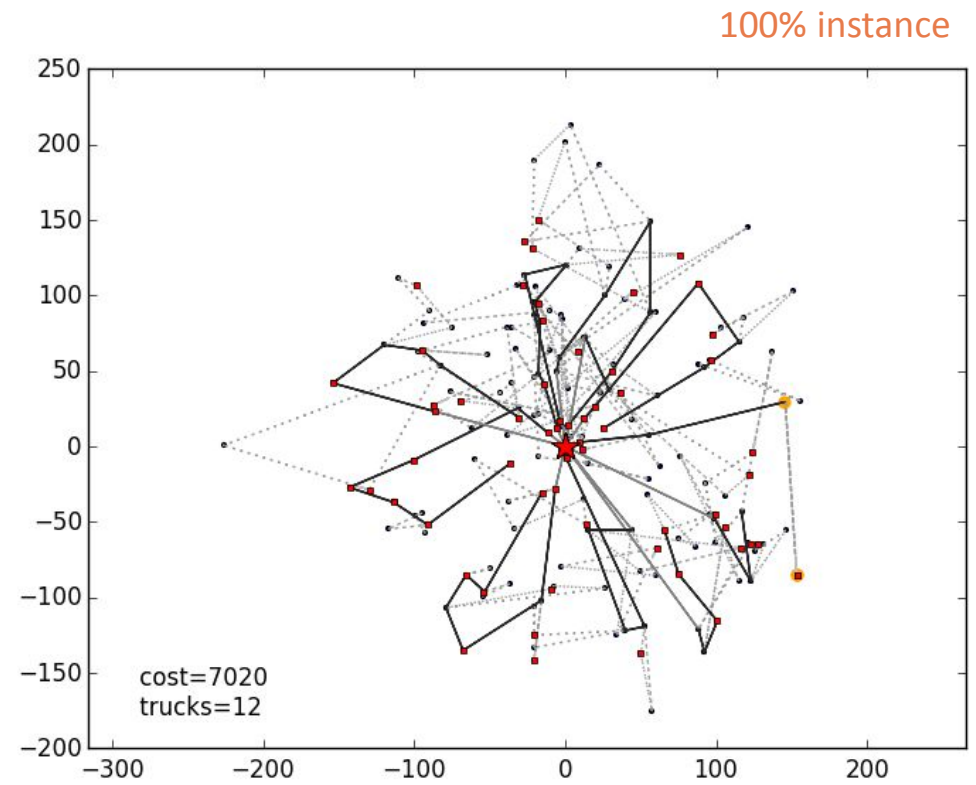
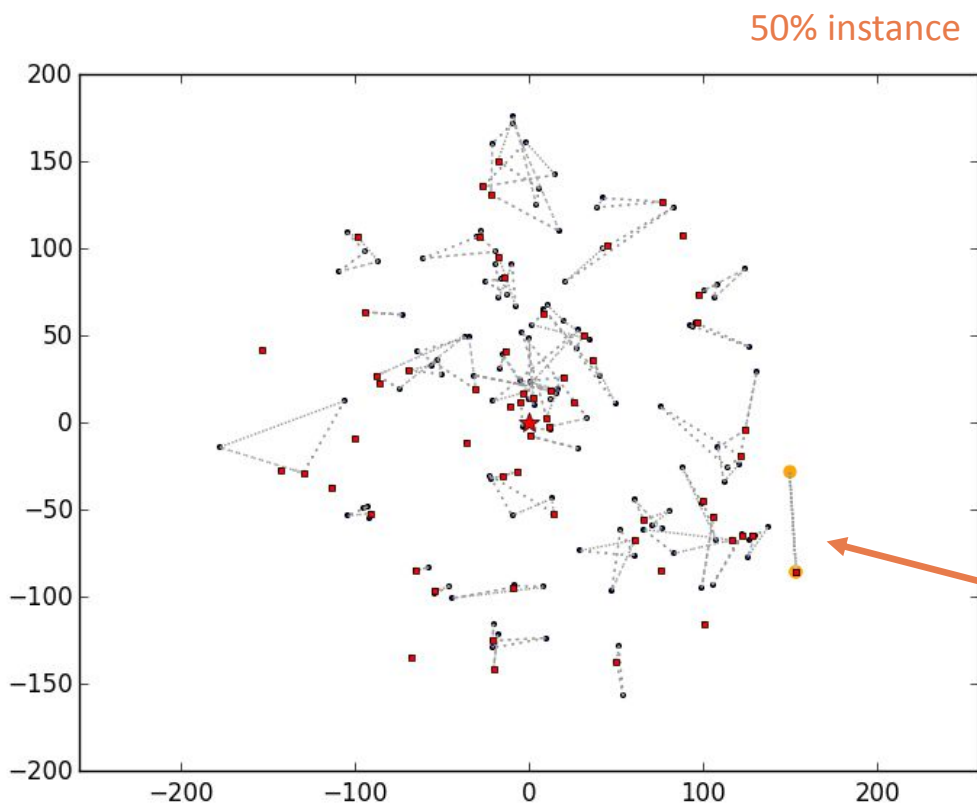
HD



RDL

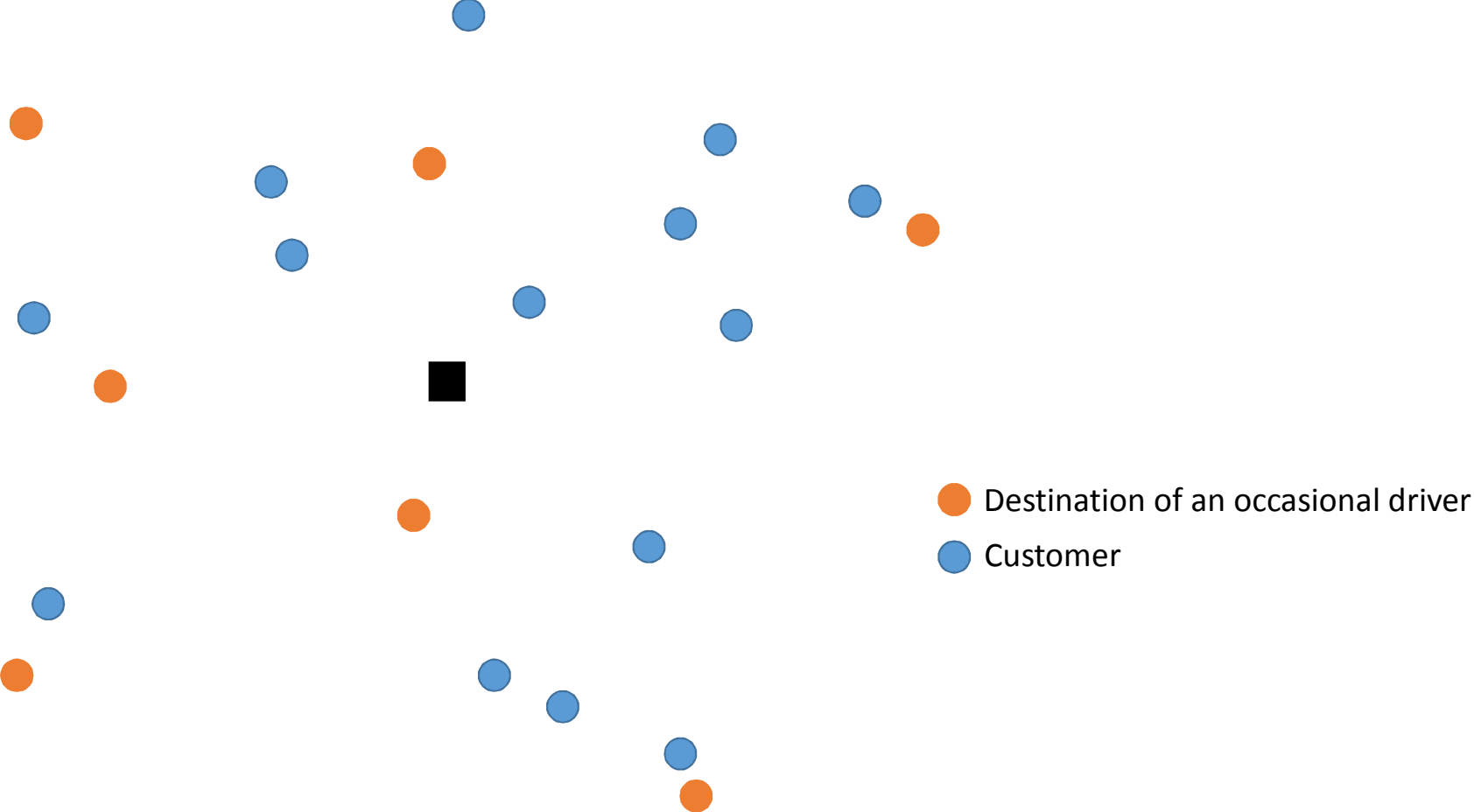
HRDL



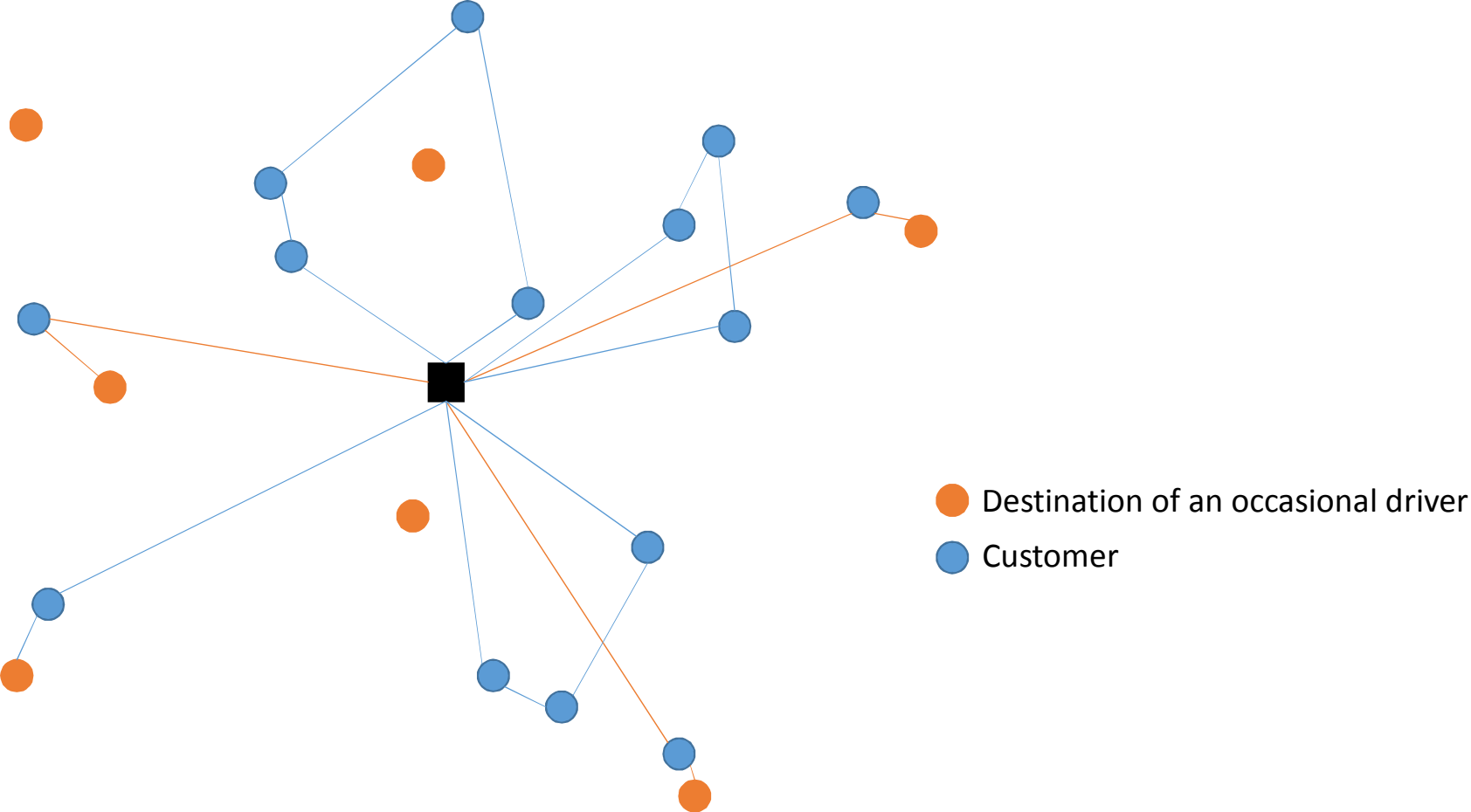


Customer can no longer be served due to time windows at both locations

Vehicle Routing Problem with Occasional Drivers



Vehicle Routing Problem with Occasional Drivers



A Multi-Start Heuristic

- Initial solutions:
 - All customers served by regular drivers
 - Serve as many customers as possible by occasional drivers giving preference to customers far away from the depot
 - Solve an IP formulation of the problem in which all but the binary variables indicating whether or not a customer is served by an occasional driver or by a regular driver are relaxed
 - Serve as much demand as possible by occasional drivers

A Multi-Start Heuristic

while stopping criterion not met **do**

JUMP(s,k)

INTERNAL-TABU-SEARCH(s)

if s better than s-best **then**

s-best = s, k = 1

else

k = k+1 mod k-max

A Multi-Start Heuristic

JUMP(s,k):

- Randomly assign k customers served by occasional drivers to regular drivers (creating new routes if necessary)
- Randomly reassign customers served by occasional drivers

INTERNAL-TABU-SEARCH(s)

- 1-move: move customer to a different route
- swap-move: swap customers served on different routes
- in-move: force customer served by occasional driver to be served by a regular driver
- out-move: force customer served by a regular driver to be served by an occasional driver

Vehicle Routing Problem with Occasional Drivers

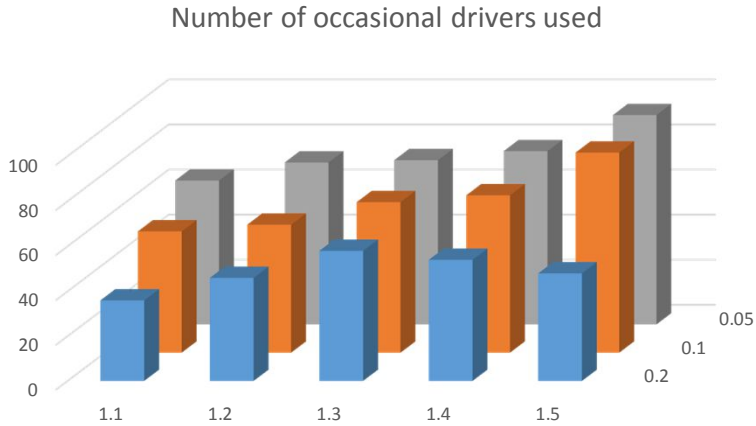
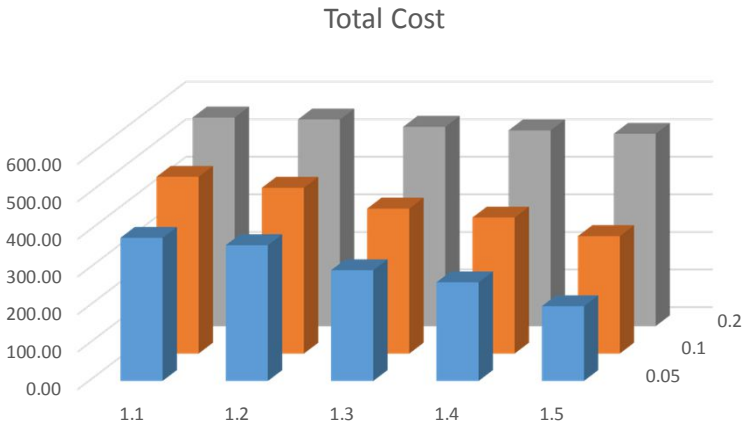
- Factors impacting success/benefit
 - Number of occasional drivers
 - Willingness of occasional drivers to deviate from direct route to destination
 - Compensation of occasional drivers

Both the number of occasional drivers and their willingness to deviate from the direct route to their destination are a function of the compensation

Vehicle Routing Problem with Occasional Drivers

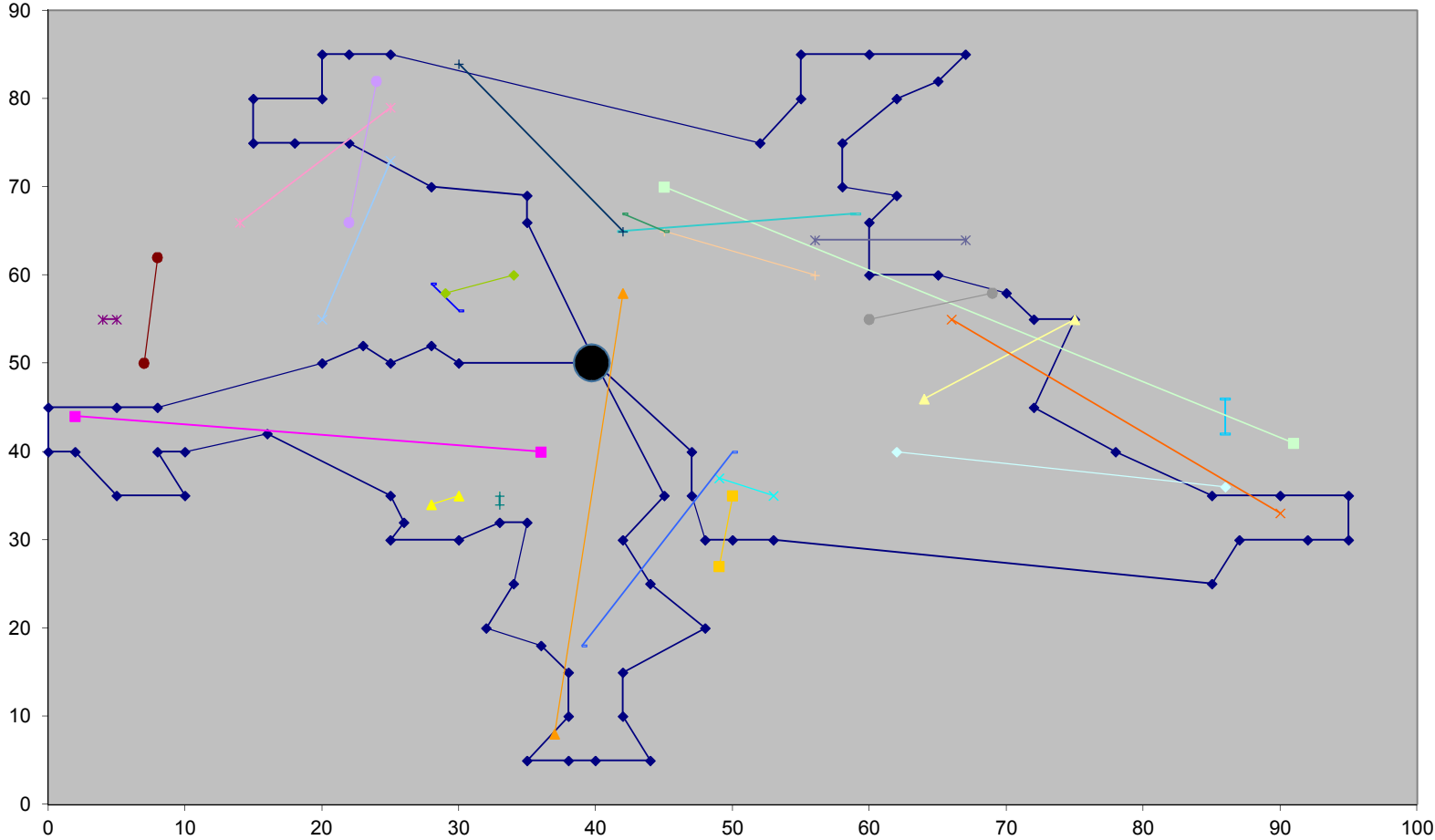
- Experimental setting
 - Number of occasional drivers: 100
 - Willingness of occasional drivers to deviate from direct route to destination (ζ): extra mileage less 0.1, 0.2, 0.3, 0.4, or 0.5 times direct distance to destination
 - Compensation of occasional drivers (ρ): distance to customer at 0.05 or 0.2 times the per-mile cost of regular driver

Vehicle Routing Problem with Occasional Drivers

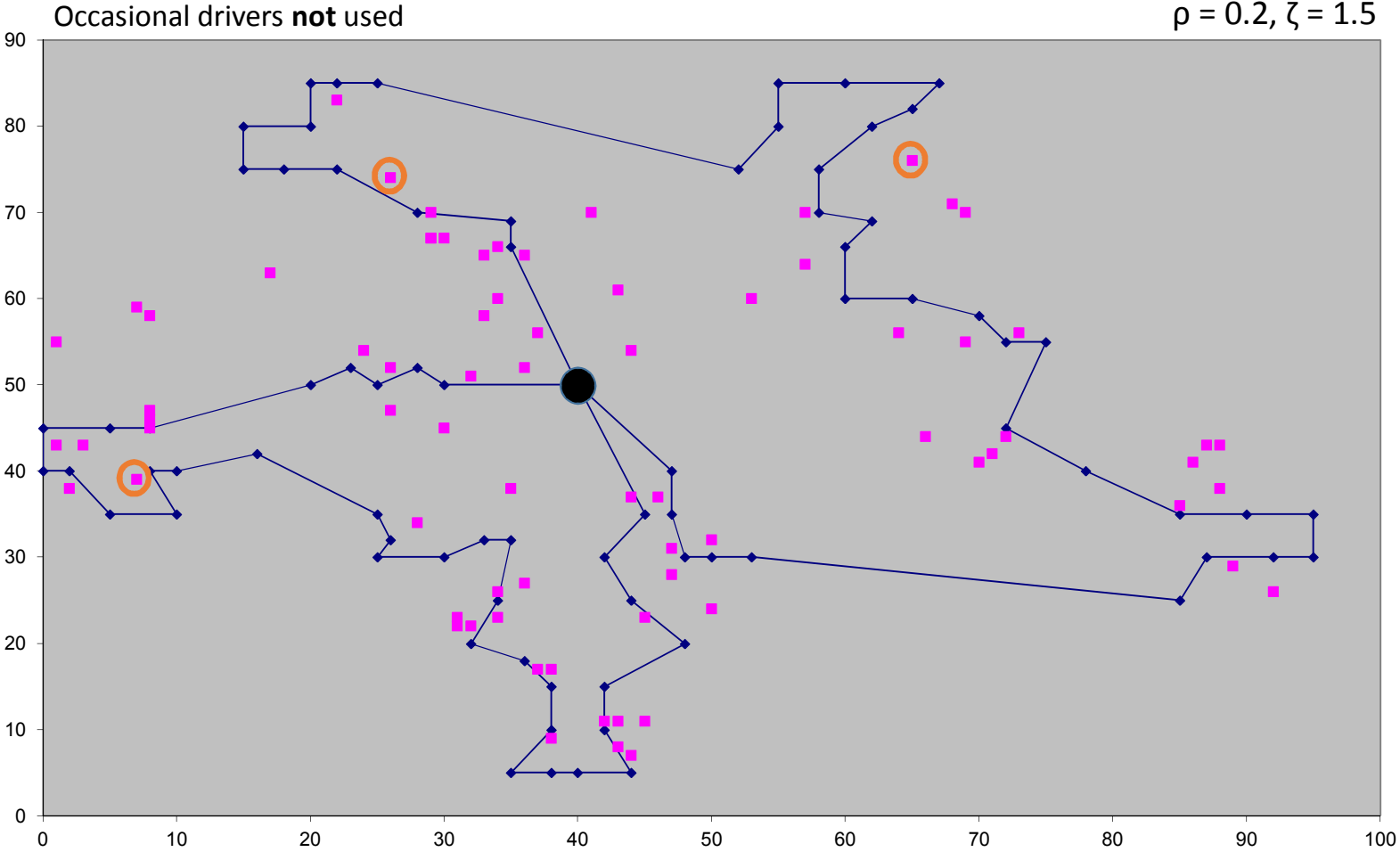


Vehicle Routing Problem with Occasional Drivers

$\rho = 0.2, \zeta = 1.5$



Vehicle Routing Problem with Occasional Drivers



Vehicle Routing Problem with Occasional Drivers

- Observation: Compensation scheme does not accomplish goal (encourage occasional drivers to serve far-away customers)
 - Alternative scheme: extra distance traveled at a per-mile compensation greater than per-mile cost (driver dependent)
 - Alternative scheme: compensation based on cost-to-serve of a customer (driver independent)

Future Research

- Pricing for flexibility
- Opportunity costs
- Transfers
- Scale / real-time

And there are many more such research opportunities ...

MailOnline

Amazon trolleys take a ride on New York subway

David Crow in New York

Keep on truckin': Automated 'road trains' of lorries controlled by just one driver are coming to Britain next year

ATRI Study Says Truck Platooning Feasible in Some Operations

Commercial Carrier Journal

May 27, 2015

Freightliner Launches First-Ever Road-Legal North American Autonomous Truck

Commercial Carrier Journal

May 5, 2015

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- Xing Wang
- Claudia Archetti
- Damian Reyes
- Grazia Speranza
- Alejandro Toriello

