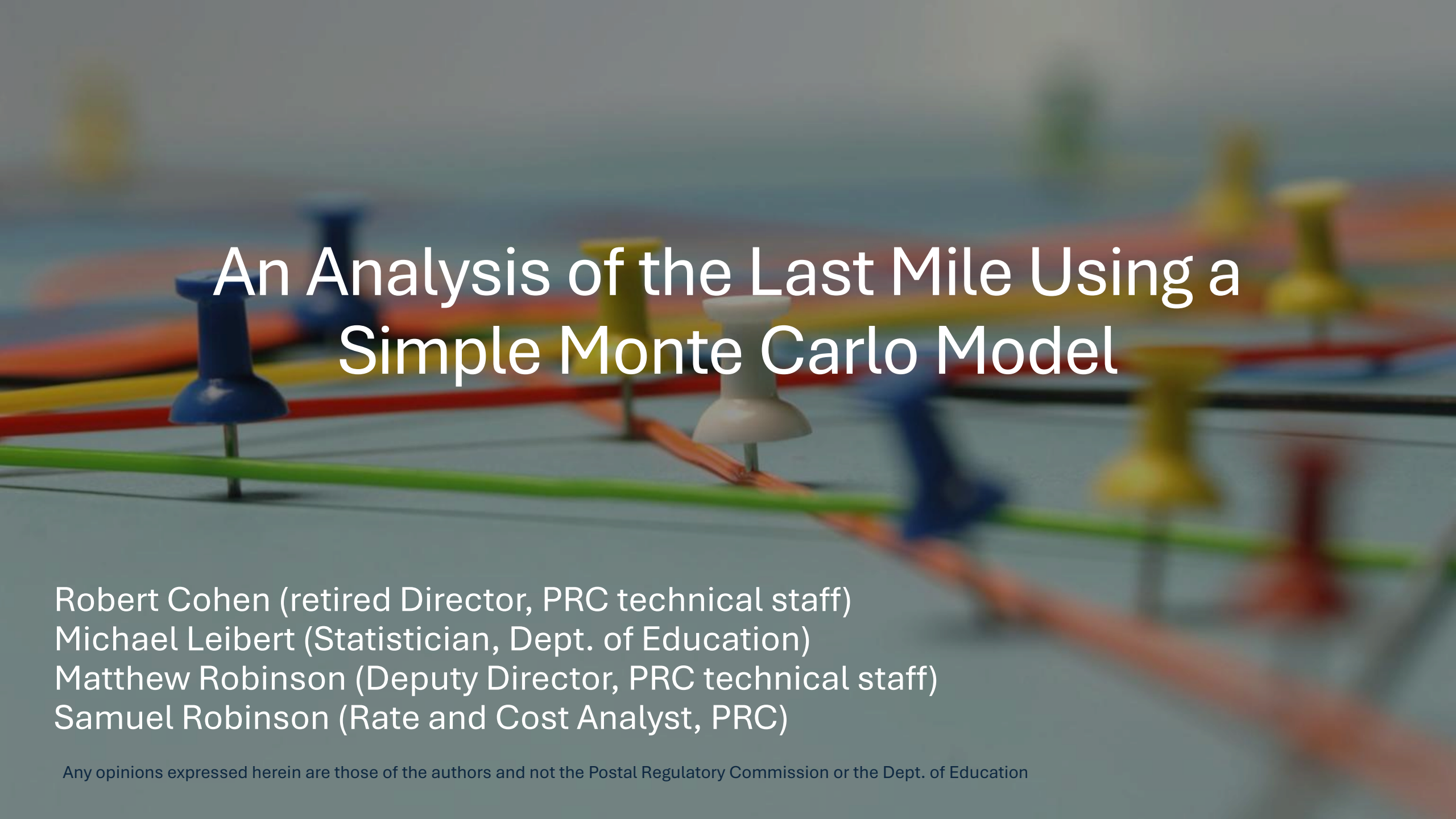

An Analysis of the Last Mile Using a Simple Monte Carlo Model

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Model Design and Applications

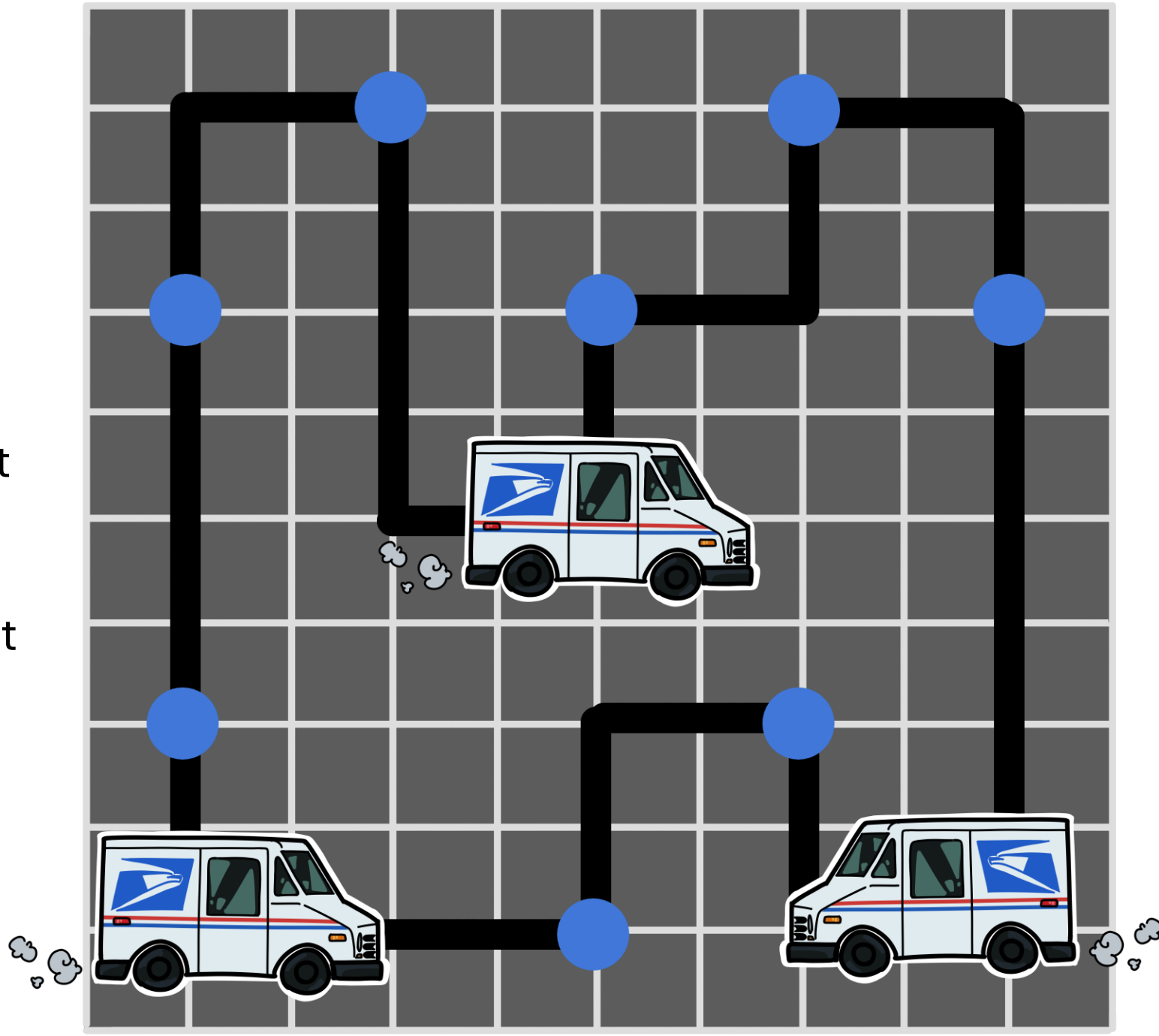
- Size and shape of delivery area and number of points to be randomly assigned as stops are defined as input parameters
  - E.g., 100 x 100 grid (with 10,000 potential points) with 100 delivery stops
- By altering the parameters, we examine various scenarios
  - Merging routes
  - Different locations of entry point
  - E-commerce vs. Retail Shopping
  - Rectangular shaped delivery areas
  - Barrier with a single crossing point
  - Deferring Delivery

From a specified entry point, a greedy algorithm is used to calculate the total distance traveled (TDT) to reach each stop and return to the entry point

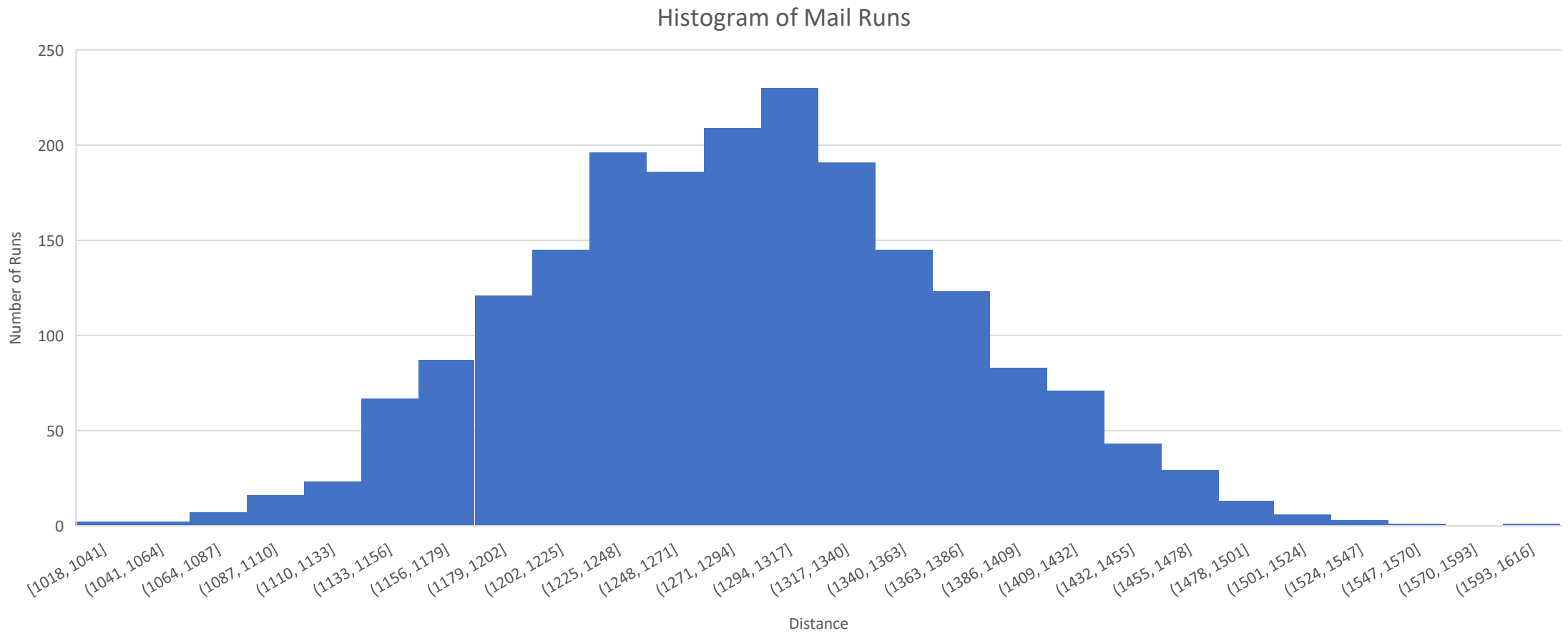
Travel is vertical or horizontal, but not diagonal

Each scenario is repeated at least 1,000 times to obtain mean distances

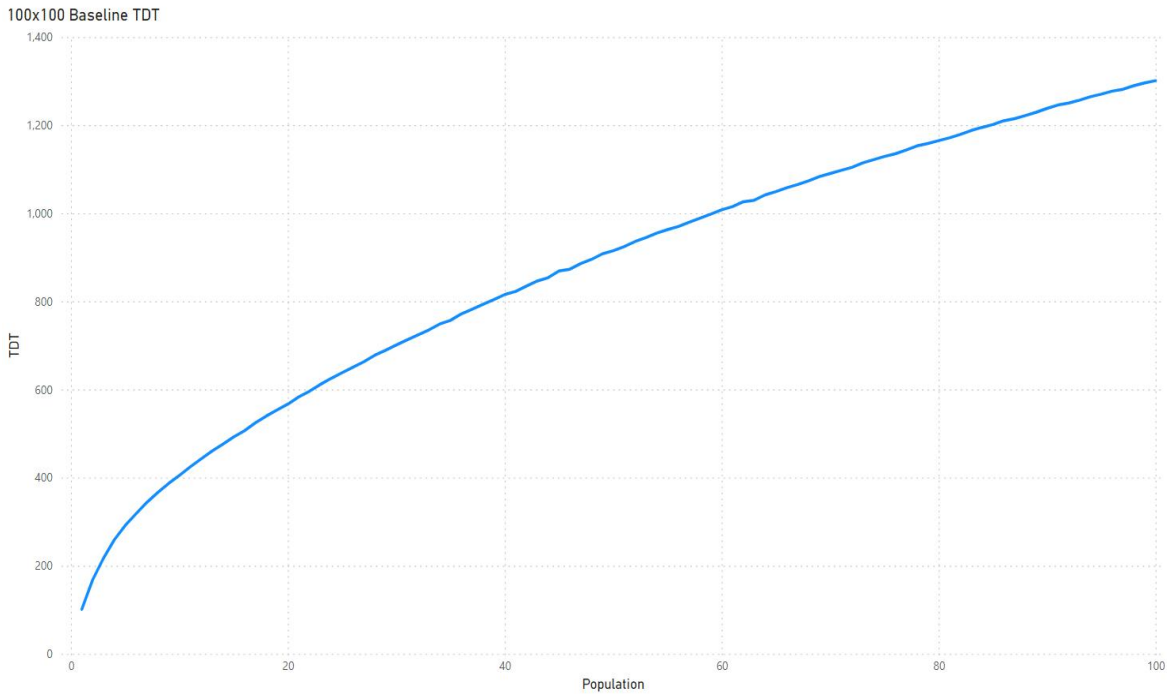
Total Distance Traveled (TDT) divided by stops = Average Distance Traveled (ADT)

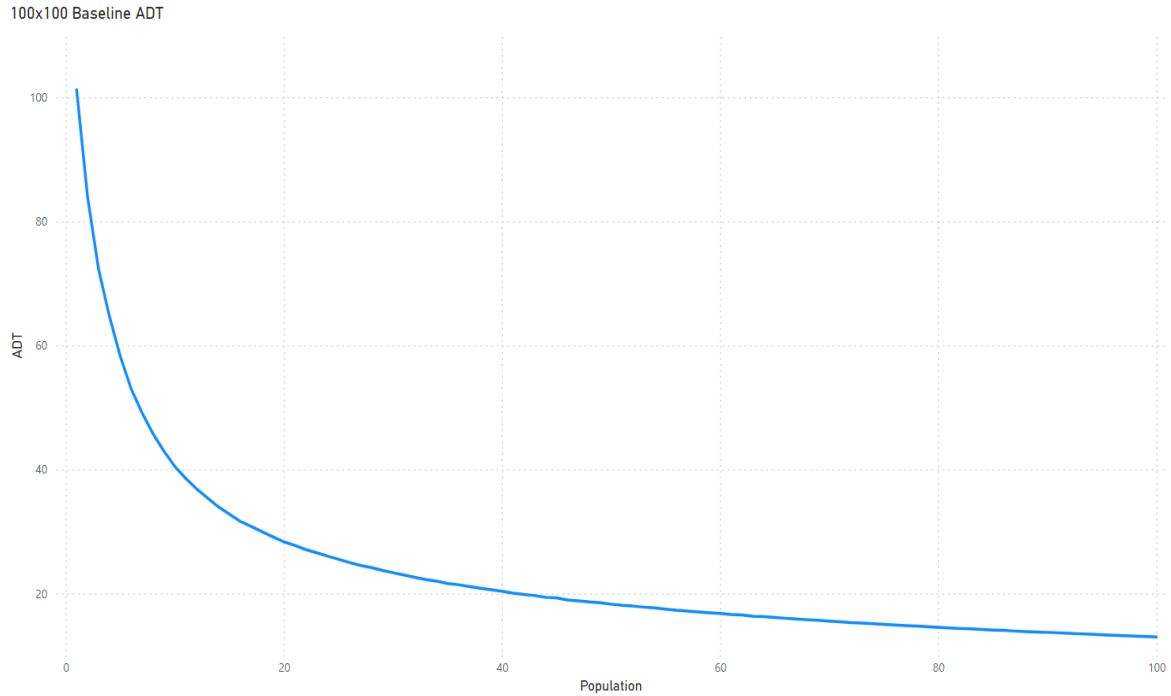


Total Distance Traveled (TDT) for 1,000 Iterations of 100 Randomized Stops in a 100x100 Grid



Relationship Between Distance Traveled and Stops





Initial Observations

- TDT curve approaches linear at higher numbers of stops
- ADT drops rapidly until approximately 40 stops
- Improvement in ADT flattens at relatively low coverage
  - May explain why Amazon often has multiple vans delivering to the same neighborhood
  - Demand effects of improved speed and reliability of delivery may outweigh cost of slightly higher ADT

Distance Saved by Merging Routes

	TDT	ADT
2 Routes of 10	803	40.1
1 Route of 20	563	28.1
Savings	240	12.0
Percent Savings	29.9%	29.9%
2 Routes of 50	1,817	18.2
1 Route of 100	1,289	12.9
Savings	528	5.3
Percent Savings	29.1%	29.1%

Merging Routes

- Percentage change in both ADT and TDT equal for merger of any two routes of equal volume
- For low volume routes, TDT savings is small but ADT savings is relatively large
- For higher volume routes, TDT savings is larger but ADT savings is smaller
  - For delivery of own products, faster and/or more reliable service from two routes may allow higher prices and/or more sales, offsetting small cost increase

Effect of Entry Point on TDT

Stops	Y=50, X=50 Center	Y=1, X=50 Mid-Edge	Y=1, X=1 Corner
50	908	928	948
100	1,289	1,309	1,328
200	1,744	1,760	1,777

Effect of Entry Point on TDT

- Entry Point has relatively small effect on travel distance
- At higher numbers of stops, the effect is smaller
- Results are consistent with location of distributions centers on edges of metro areas
  - Higher cost of central location likely outweighs travel distance savings

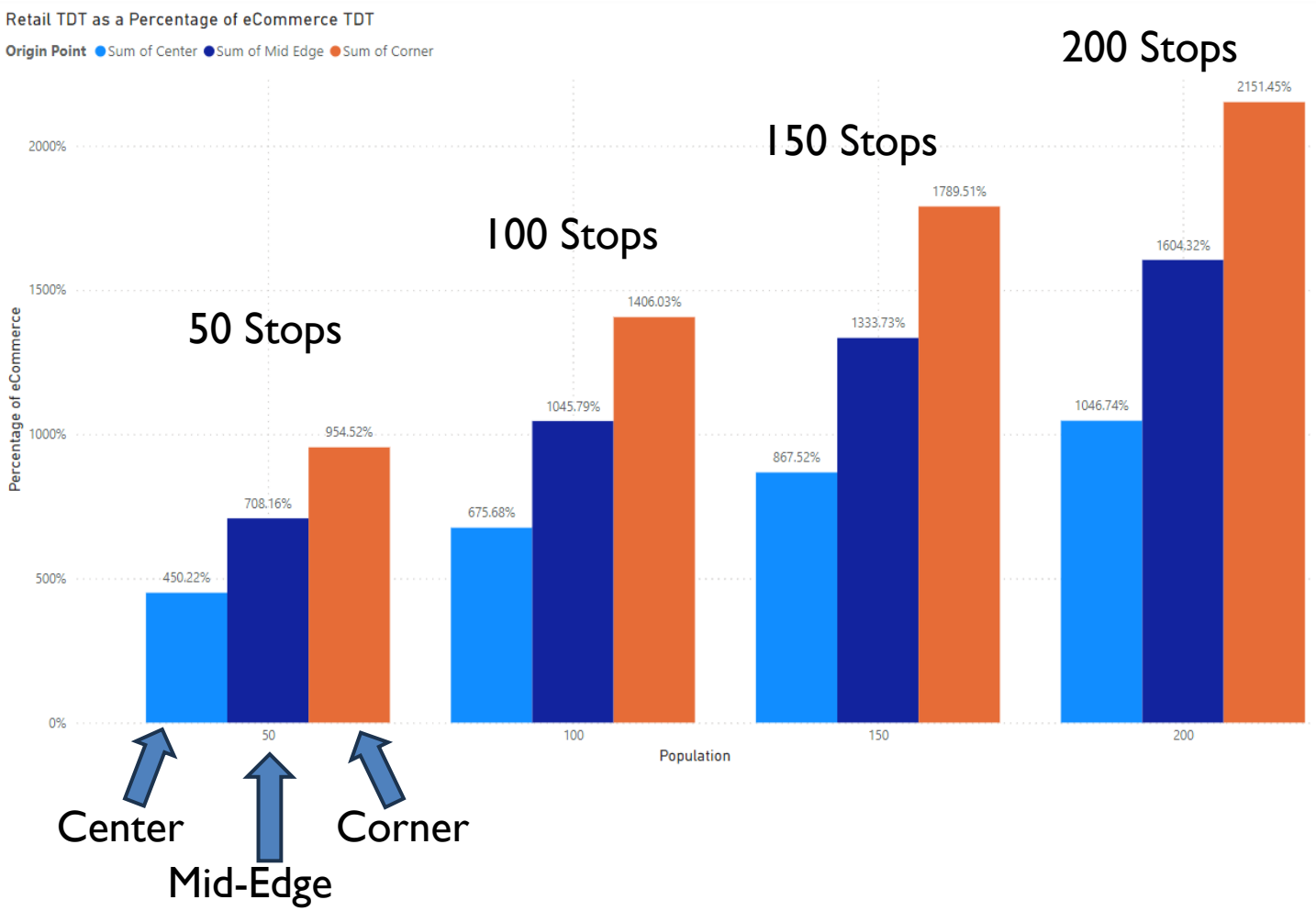
E-commerce vs. Physical Shopping

- Distance traveled by delivery van is compared to sum of distances traveled (round trip) if each package is picked up individually
- The number of packages and the location of the entry point/retail location are varied to examine effects on TDT savings

E-commerce vs Physical Shopping

TDT Savings from E-commerce

	Starting Point	Starting Point	Starting Point
# of stops	Center	Mid-Edge	Corner
50	81.8%	87.6%	90.5%
100	87.1%	91.3%	93.4%
200	91.3%	94.1%	95.6%



E-commerce vs. Retail Shopping

- Even for low volumes, total distance travelled by delivery van far less than physical shopping distances

- Unlike delivery, total distance for retail shopping is sensitive to location of entry point/retail location
  - For savings from e-commerce, location is as important as volume

TDT of Rectangular Areas

# stops	100x100 (Base)	200x50	% from Base	400x25	% from Base	800x12.5	% from Base
50	929	951	2.3%	1172	26.2%	1338	44.0%
100	1309	1329	1.5%	1491	13.9%	2947	25.1%

Effect of Narrower Rectangles on TDT

- More constrained shapes result in higher travel distances
  - Fewer opportunities for "short-cuts" between stops
- The effect is more pronounced at lower numbers of stops

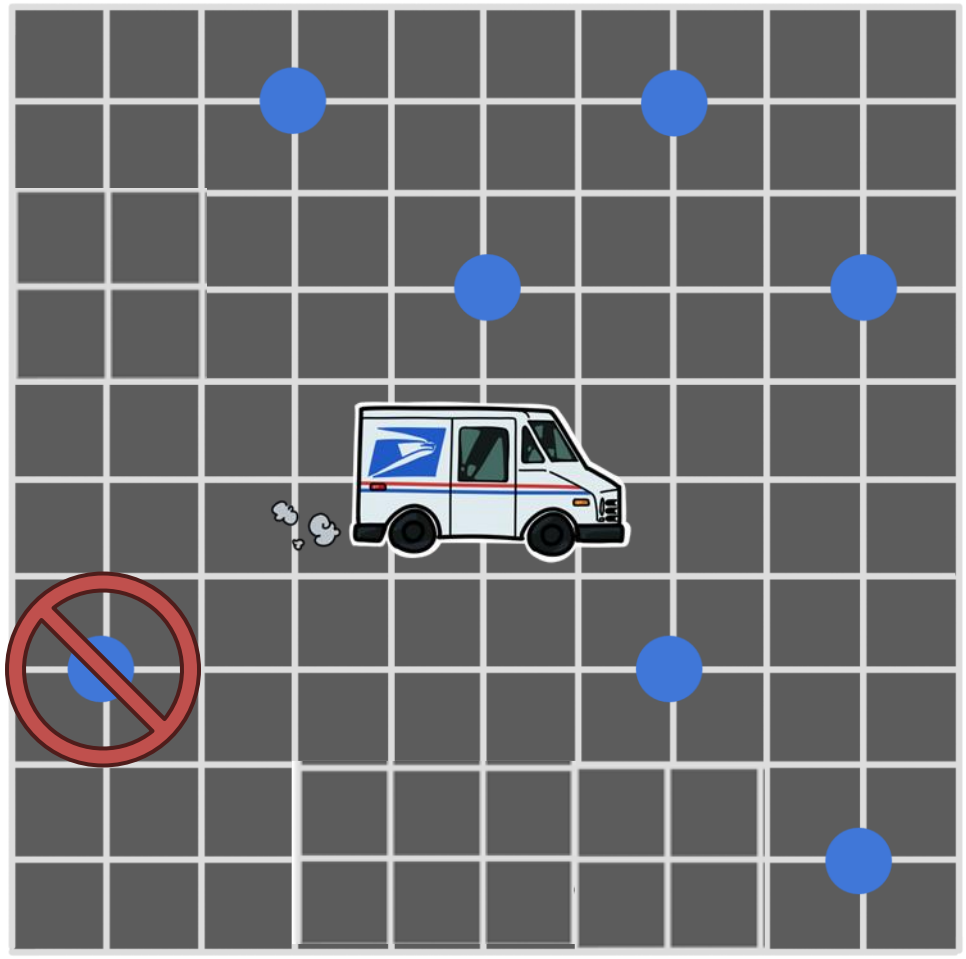
Effect on TDT of Barrier with Central or Edge Crossing Point

Stops	No Barrier	Crossing at x=50 and Y=50	% change from no barrier	Crossing at y=0 and x=50	% change from no barrier
50	928	985	6.2%	1,075	15.8%
100	1,309	1,364	4.2%	1,451	10.8%
200	1,760	1,863	5.9%	1,954	11.0%

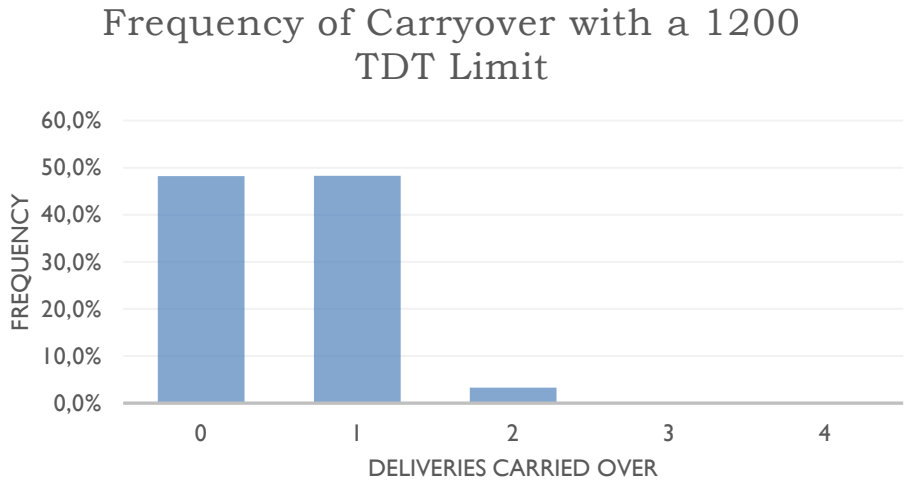
Effect of Barrier with Single Crossing Point

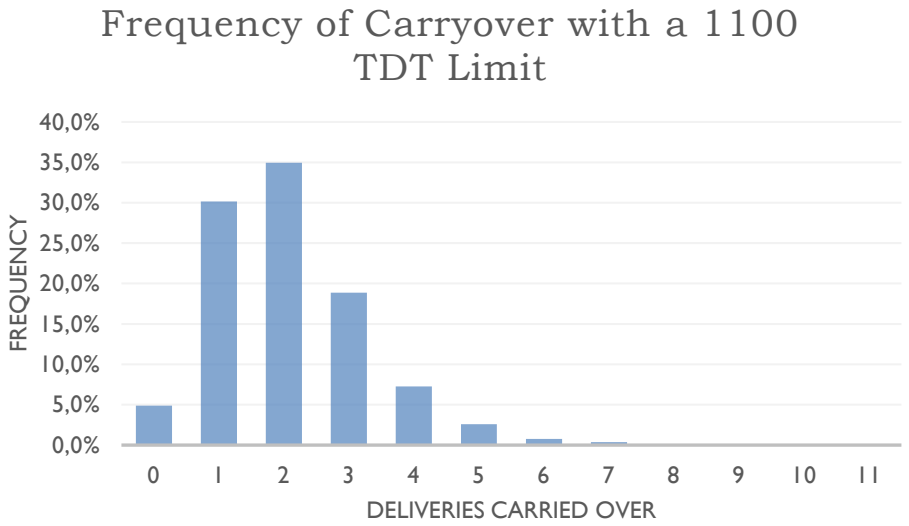
- Addition of barrier through center of grid increases TDT
- Location of crossing point has substantial impact
  - Central crossing point reduces TDT compared to crossing point on edge
- Higher numbers of stops appears to reduce the effect of a barrier
  - However, model begins to produce counterintuitive results as volume increases
  - Apparent effect of weakness in greedy algorithm – lack of "foresight" can result in paths requiring backtracking to cross barrier

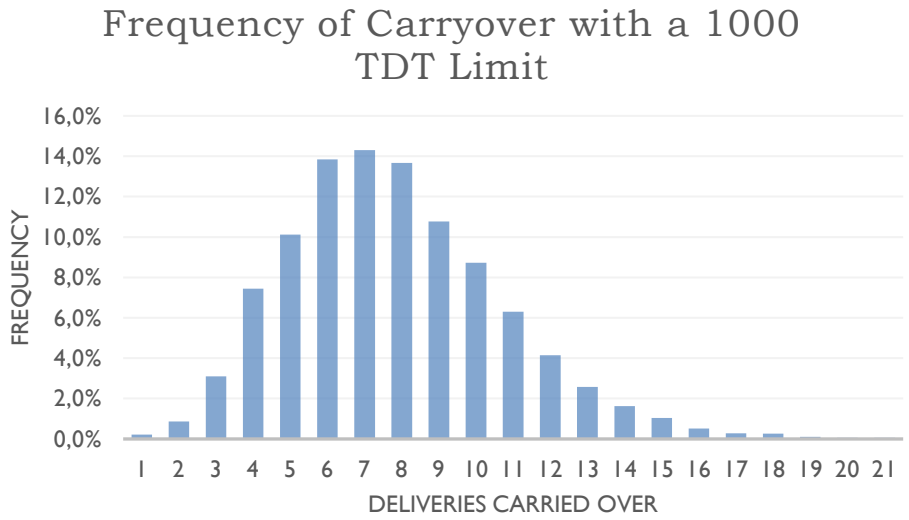
Effects of Delivery Deferral

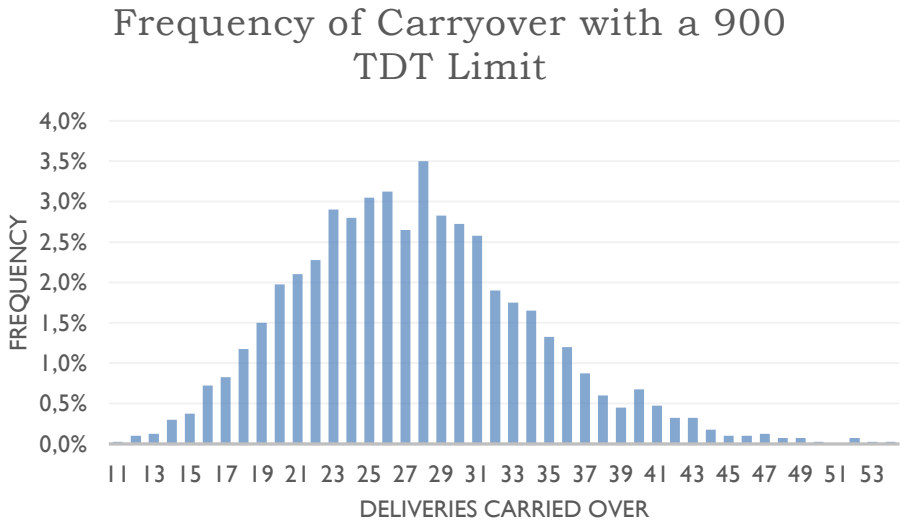


Imposing Delivery Deferral Through a TDT Limit





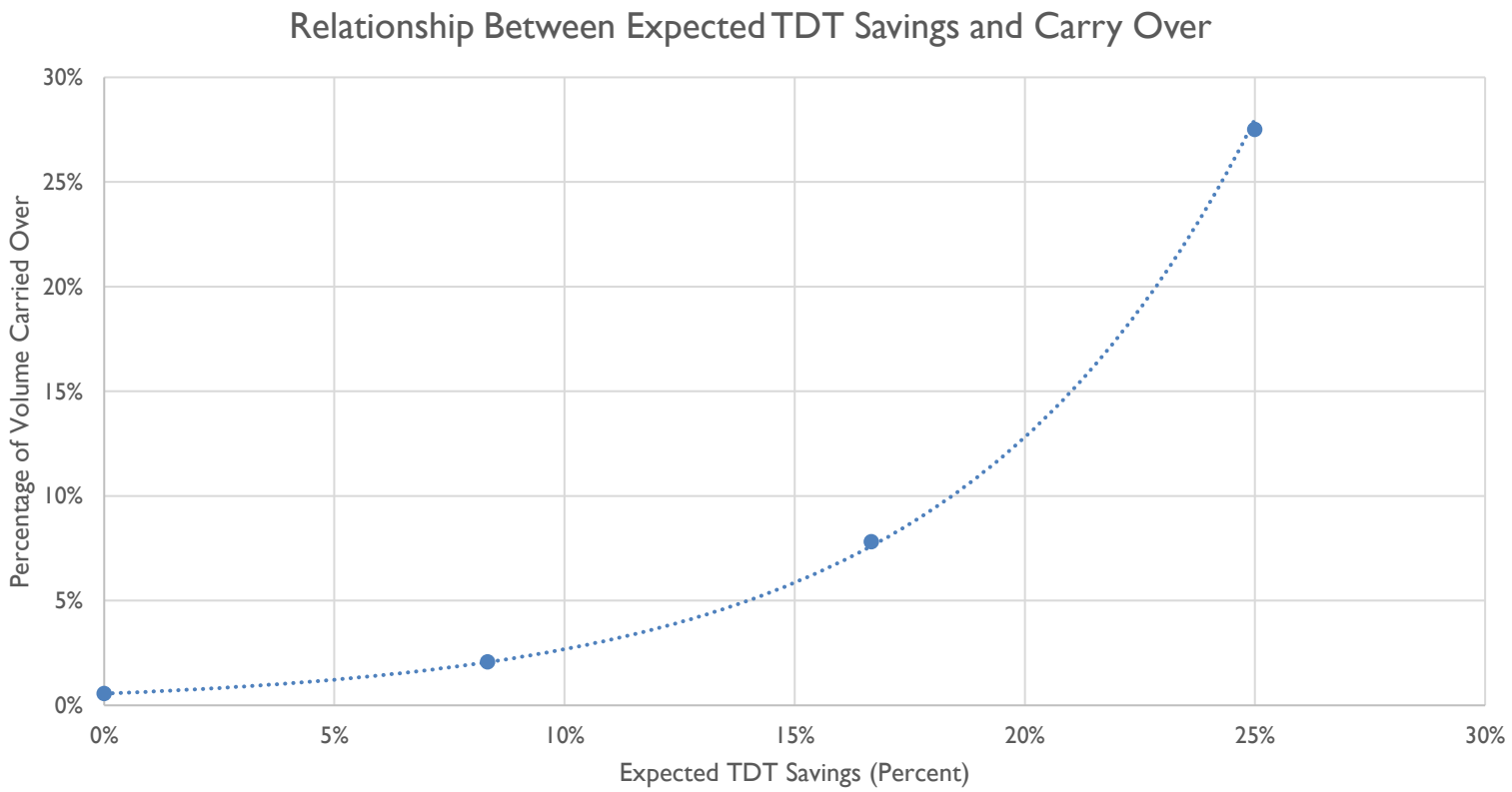




Expectations for Impact on TDT Savings

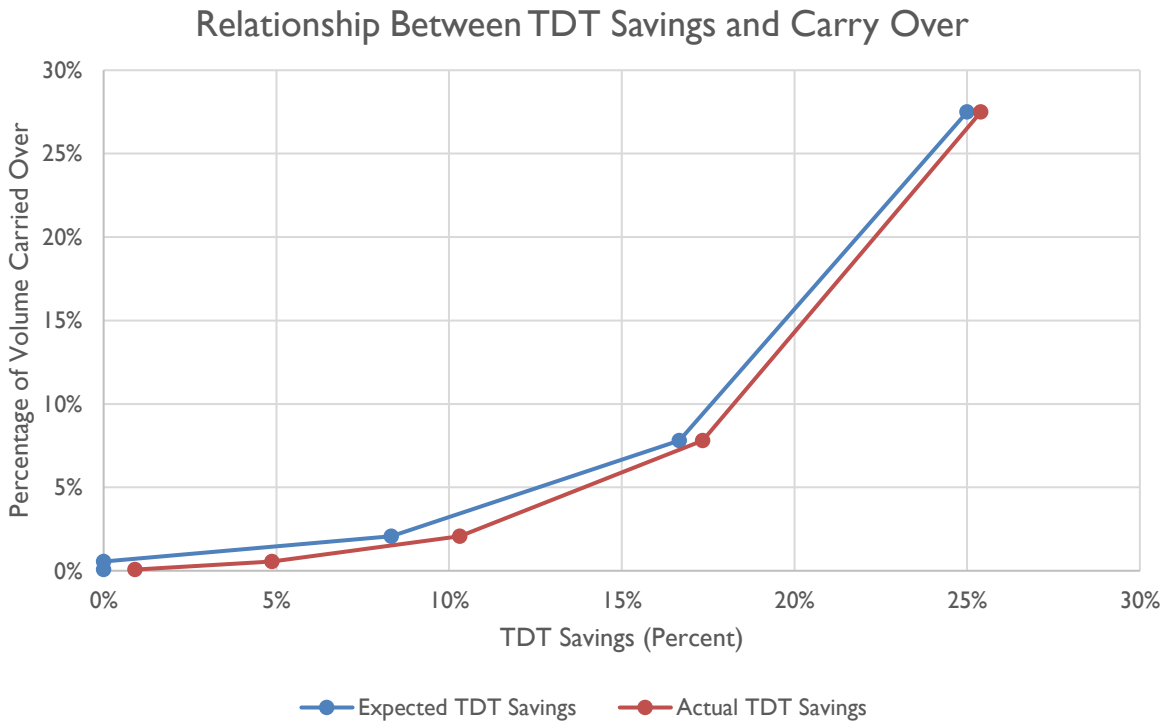
- A higher number of TDT savings requires exponentially increasing amounts of deferrals.
- The first deliveries deferred are the most impactful.

Relationship Between Expected TDT Savings and Carry Over



Relationship Between Actual TDT Savings and Carry Over

TDT Limit	Average Percentage Deferred	Expected TDT Savings	Actual TDT Savings
900	27.5%	25.0%	25.4%
1000	7.8%	16.7%	17.3%
1100	2.1%	8.4%	10.3%
1200	0.6%	0.0%	4.9%
1300	0.1%	0.0%	0.9%



Actual Impact on TDT Savings

- Actual TDT Savings are better than expected even with a high number of deferrals.
  - The "final" cut delivery point frequently provides some TDT savings leftover from the goal. These additional savings are likely correlated with the population density of the grid.