Optimizing London Fire Station Resources to Better Serve the Community

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Motivation

By simulating real-world emergency scenarios, fire station resources can be efficiently deployed to each incident while minimizing overall travel distance for the fire engines. This analysis also showed the impact of adding additional resources to existing fire stations in order to better serve the community.

Data

Using data provided by the London Fire Brigade as well as information from Kaggle, we were able to obtain a historical database for over 85,000 fire incidents for 2017 (from January to October).

Key Methods

Integer Programming Optimization, Simulation, Great Circle distance and R

Optimization Model

Inputs

Distance Matrix, D

d_{ij} = distance between i[th] incident and j[th] fire station

Delay Factor Matrix, F

f_{ij} = randomly generated factor (between 0 and 1) to simulate arrival delays due to traffic conditions, road blocks, etc.

Effective Distance Matrix, E

$e_{ij} = d_{ij} + f_{ij}d_{if} = (1 + f_{ij})d_{if}$

Availability Vector, A

a_j = number of fire engines available at j[th] station

Decision Variable

Sent Matrix, S

$$s_{ij} = \begin{cases} 1, & \text{if fire engine is dispatched to incident i to station j} \\ 0, & \text{if fire engine is not sent to incident i from staion j} \end{cases}$$

Constraints

$\sum_i s_{ij} = 1$, one fire engine is dispatched to each incident

$\sum_j s_{ij} \leq a_j$, the total number of fire engines dispatched from a station cannot exceed the available number

Output

$$\sum_i \sum_j s_{ij} e_{ij}$$

Results

Sample Result Output for Select Simulation Periods

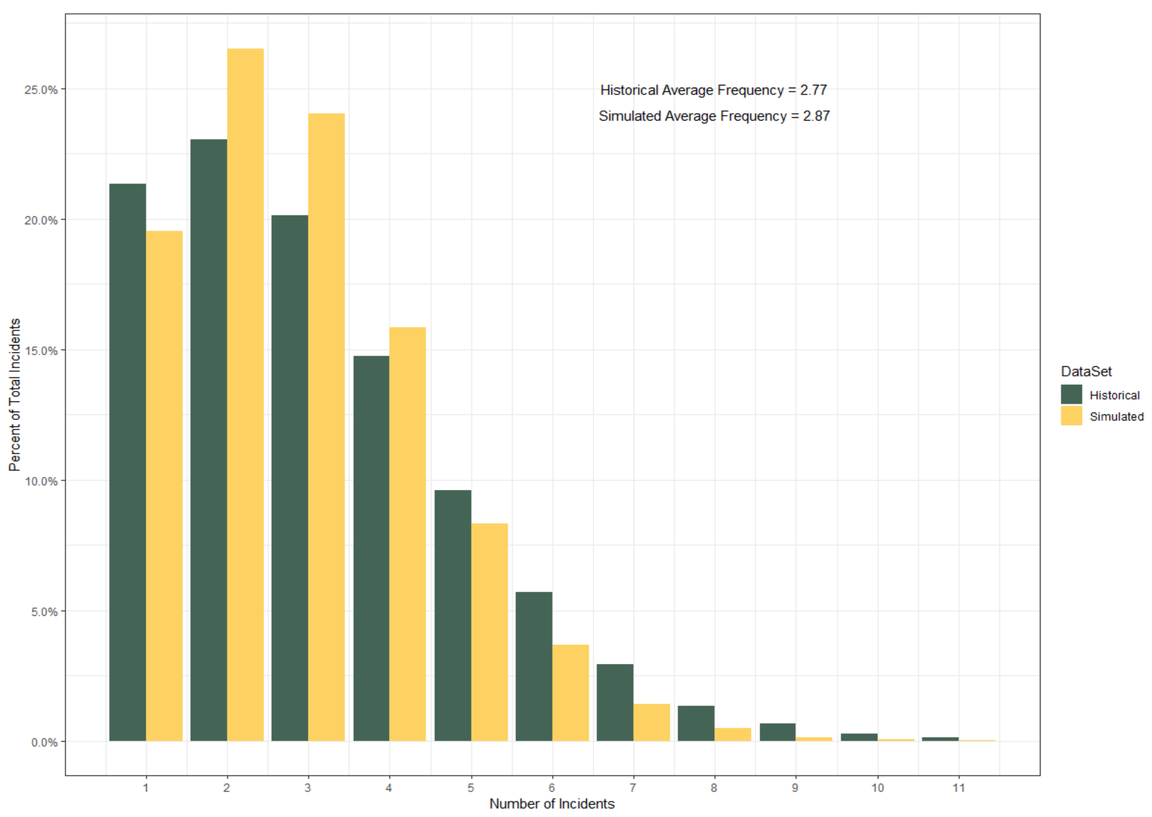
Period ID	Incident Number	Incident Fire Engine Deployment							
		Dowgate	Euston	Holloway	Islington	Kentish Town	Paddington	Soho	West Hampstead
26	071065-03062017	0	0	1	0	0	0	0	0
26	111710-18082017	0	0	0	0	0	0	0	1
26	079544-18062017	0	0	0	0	0	1	0	0
26	141792-21102017	0	0	0	0	0	0	1	0
27	061388-16052017	0	1	0	0	0	0	0	0
27	024617-27022017	0	0	0	0	0	0	1	0
27	116856-29082017	0	0	0	0	1	0	0	0
28	026377-03032017	0	0	0	0	0	1	0	0
28	070188-02062017	1	0	0	0	0	0	0	0
28	039442-02042017	0	0	0	1	0	0	0	0
29	082627-23062017	0	0	0	0	1	0	0	0
29	142806-23102017	0	0	1	0	0	0	0	0
30	026696-04032017	0	0	0	0	1	0	0	0

Period ID	Total Fire Engine Deployment								Total Incidents	Total Effective Distance (km)
	Dowgate	Euston	Holloway	Islington	Kentish Town	Paddington	Soho	West Hampstead		
26	0	0	1	0	0	1	1	1	4	11.43
27	0	1	0	0	1	0	1	0	3	32.46
28	1	0	0	1	0	1	0	0	3	11.23
29	0	0	1	0	1	0	0	0	2	18.08
30	0	0	0	0	1	0	0	0	1	0.41

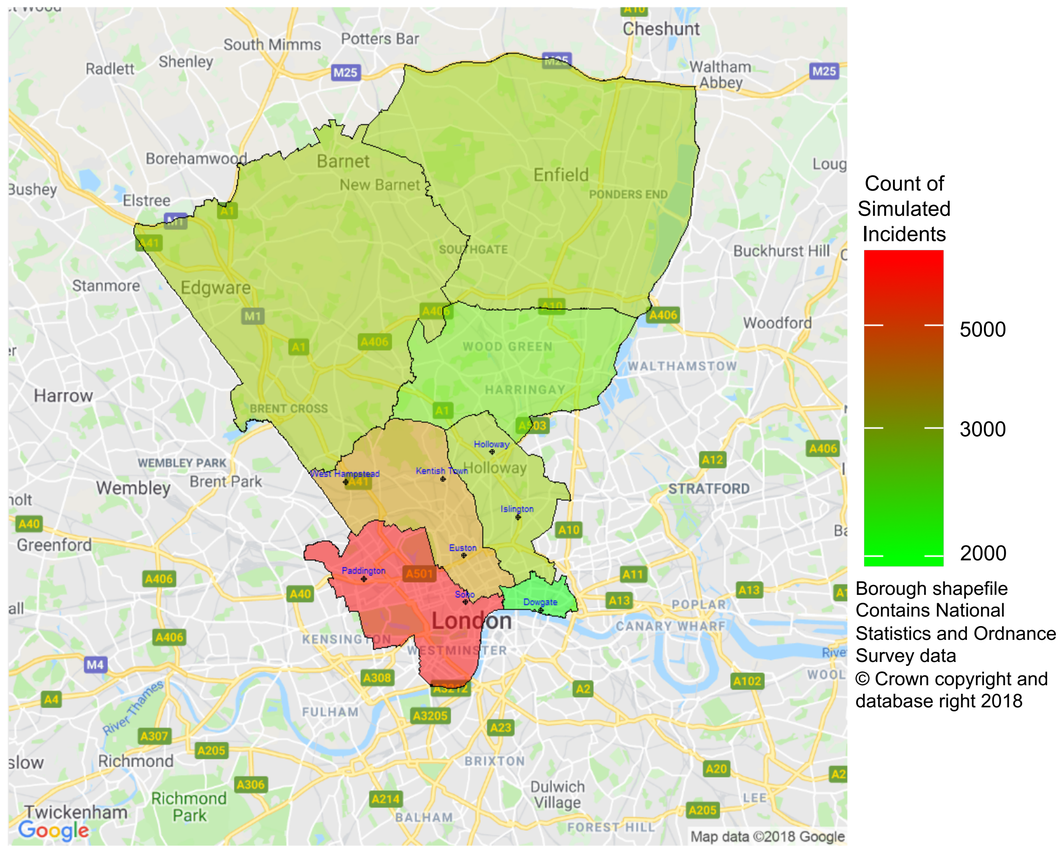
Simulation

- 9,600 simulated time periods (15-minute intervals over 100 days)
- A zero-truncated Poisson distribution was used to determine number of incidents in each simulation period were optimized using integer programming (IP)
- Incidents for each time period were selected using a random draw of a subset of the historical data
- The model assumes fire engines are deployed at the end of each 15-minute period and do not return for 30 minutes (i.e., a fire engine deployed in the previous two simulation periods cannot be used in the current period

Incidents Per 15-Minute Period for Historical Data and Simulation Set



Concentration of Simulated Incidents Over 100 Days and Fire Stations Included in Analysis



Sensitivity Analysis

Fire Engine Availability

	Dowgate	Euston	Holloway	Islington	Kentish Town	Paddington	Soho	West Hampstead	Total Fire Engines
Base Model	1	1	1	1	2	2	2	2	12
Sensitivity +1	2	2	2	2	3	3	3	3	20
Sensitivity +2	3	3	3	3	4	4	4	4	28

- The base analysis was performed using actual fire engine counts from London Fire Brigade's fleet list (as of September 2017).
- Two sensitivity analyses were performed by adding 1 fire engine and 2 fire engines to the starting fleet of each fire station.
- For the base analysis, slightly over 400 simulation periods (about 4.4%) did not have a sufficient number of fire engines available to deploy to all incidents for that time period (i.e., there was no feasible solution for the optimization problem).
- When increasing the starting number of fire engines at each station by 1, there was only one simulation without a feasible solution.
- The sensitivity analysis with two additional fire engines per station had no infeasible solutions.