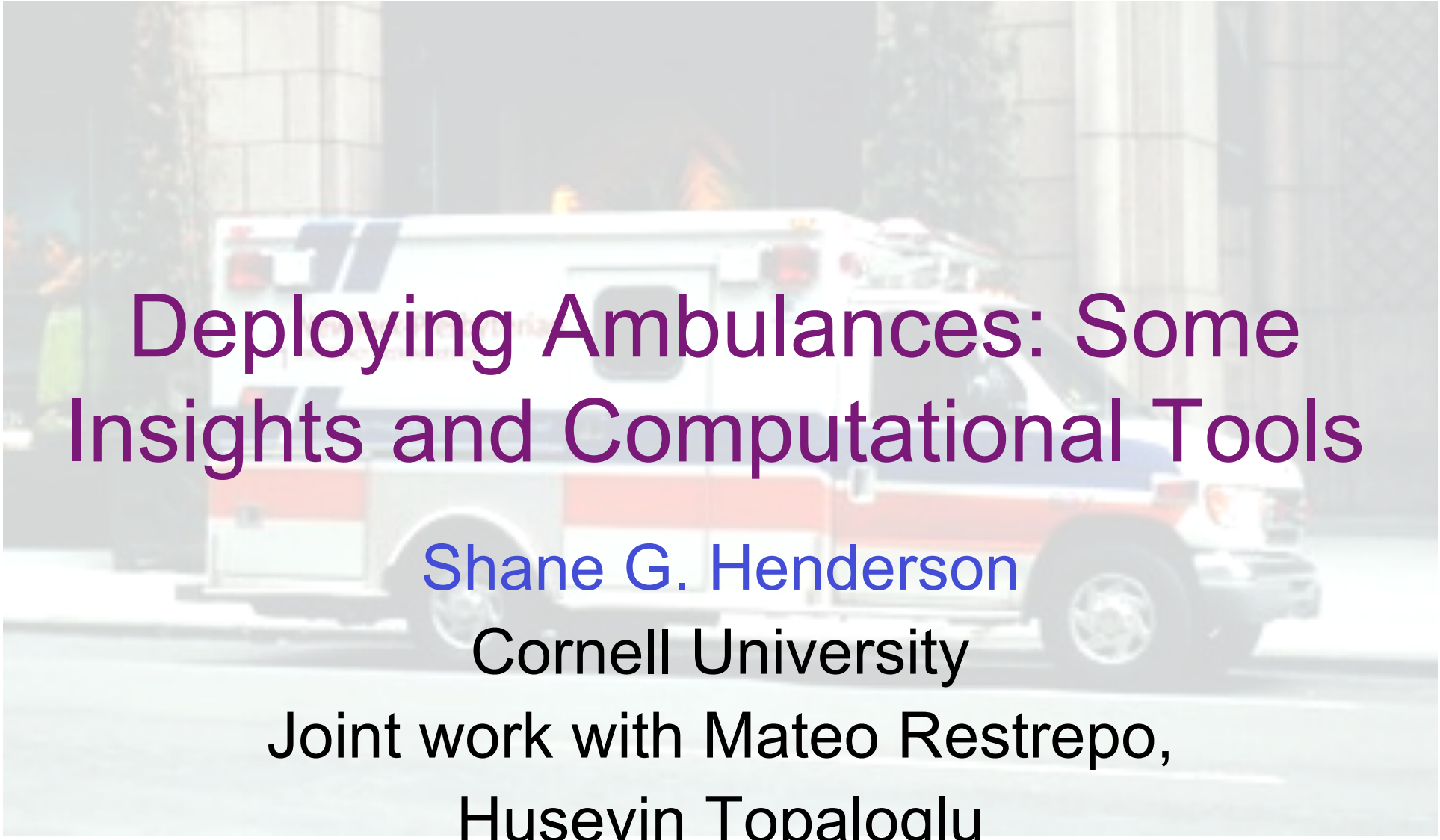


Deploying Ambulances: Some Insights and Computational Tools

Shane G. Henderson
Cornell University
Joint work with Mateo Restrepo,
Huseyin Topaloglu

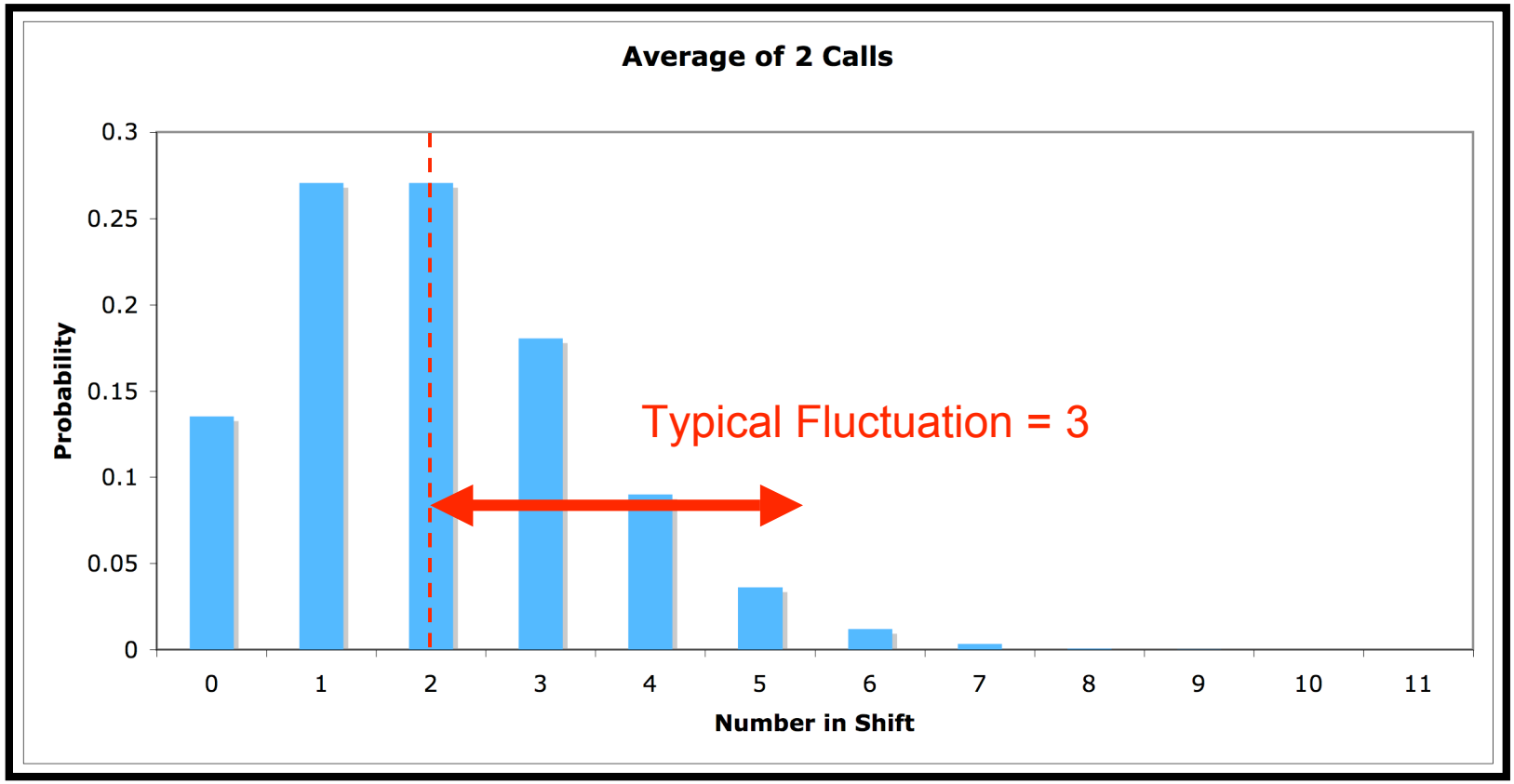
Thanks to NSF DMI 0400287

Goal and Outline

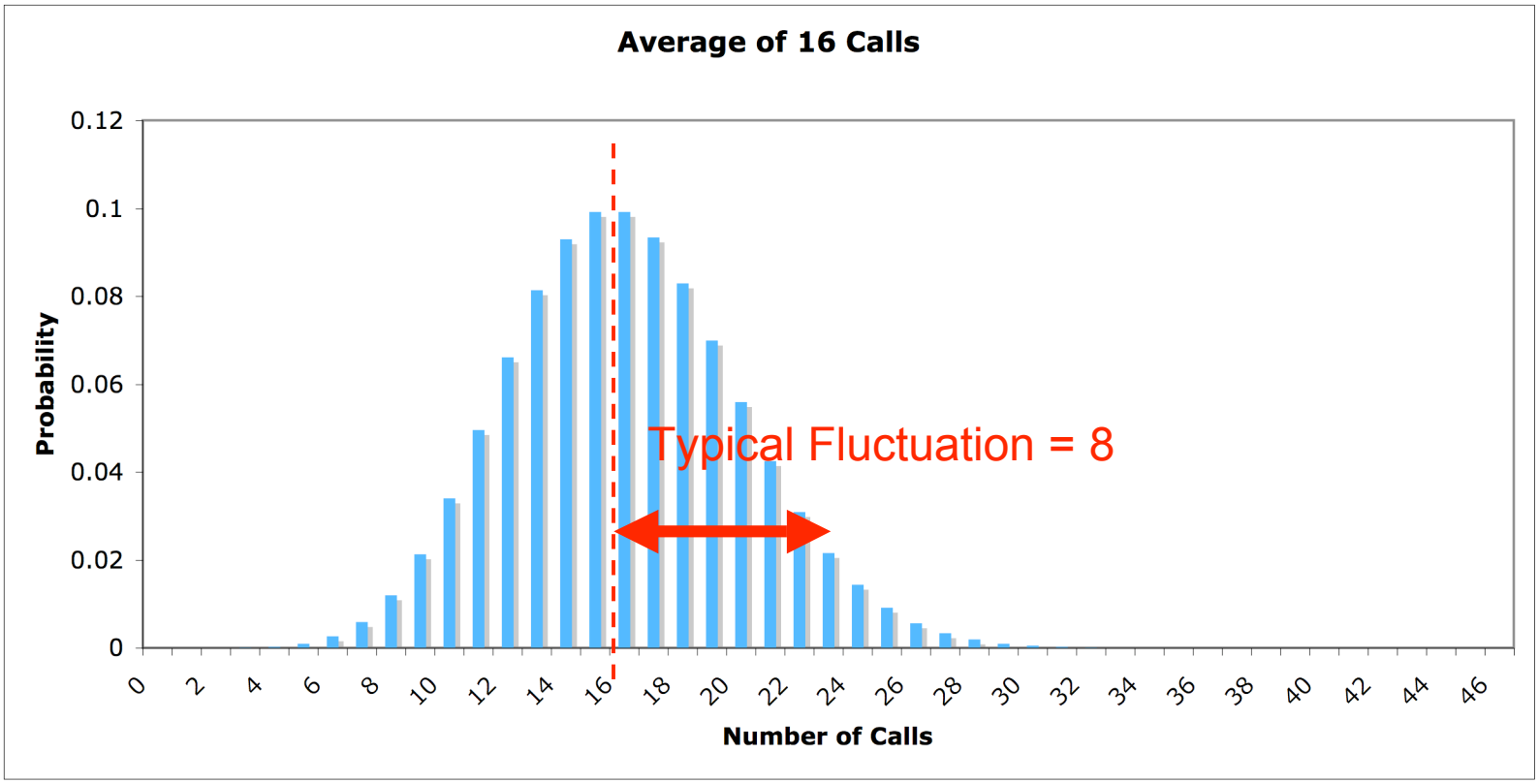
- Goal: Develop insight and computational tools for ambulance-deployment questions
- Why do small towns have to run ambulances at lower utilizations than cities?
- Should the number of ambulances in separate regions be proportional to the number of calls?
- A New Approach to System-Status Management

Why do small towns have to run ambulances at lower utilizations than cities?

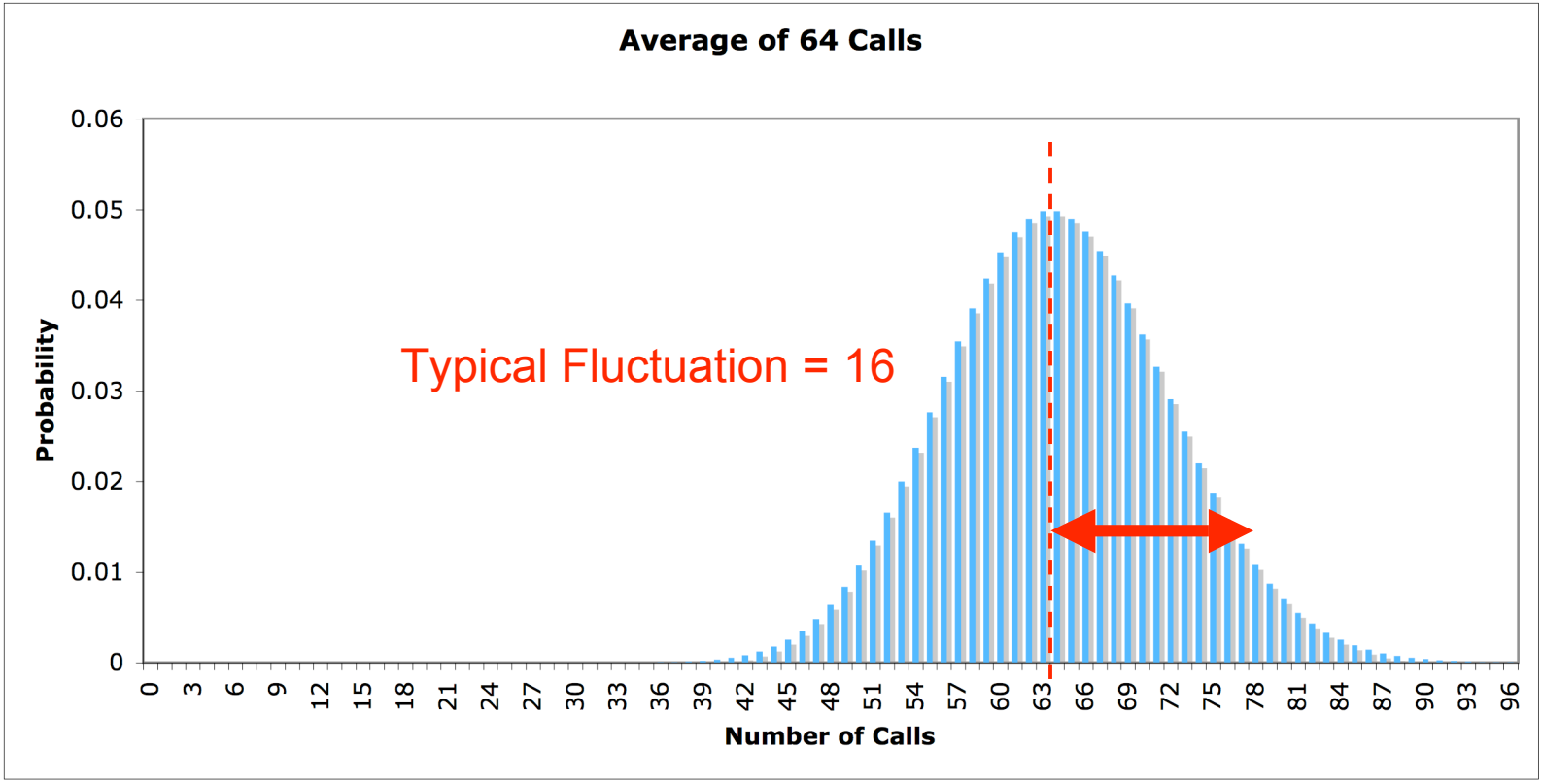
Number of Calls in a Shift



Number of Calls in a Shift



Number of Calls in a Shift



Number of Calls in a Shift

Average Num of Calls	Fluctuations
2	3
16	8
64	16
N	$2\sqrt{N}$

- Theory predicts #calls is roughly distributed as Poisson(mean)
- For Poisson, std dev = √average
- As average gets big, relative fluctuations get small

Impact on Deployment

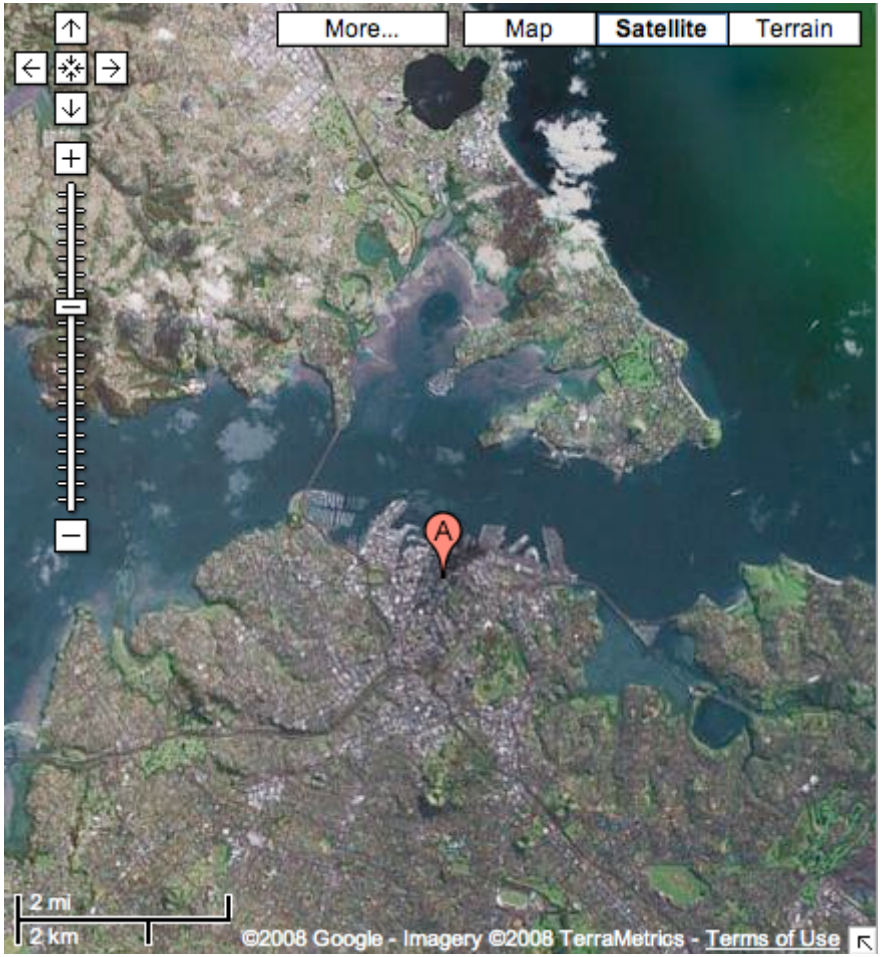
- Need to plan for $N + 2\sqrt{N}$ calls, where N = average
- When N is small this is much bigger than the mean
- When N is big, not much difference
- Disclaimer: Assumes all ambulances on shift can cooperate. Not always true in large areas

Should the number of ambulances in separate regions be proportional to the number of calls?

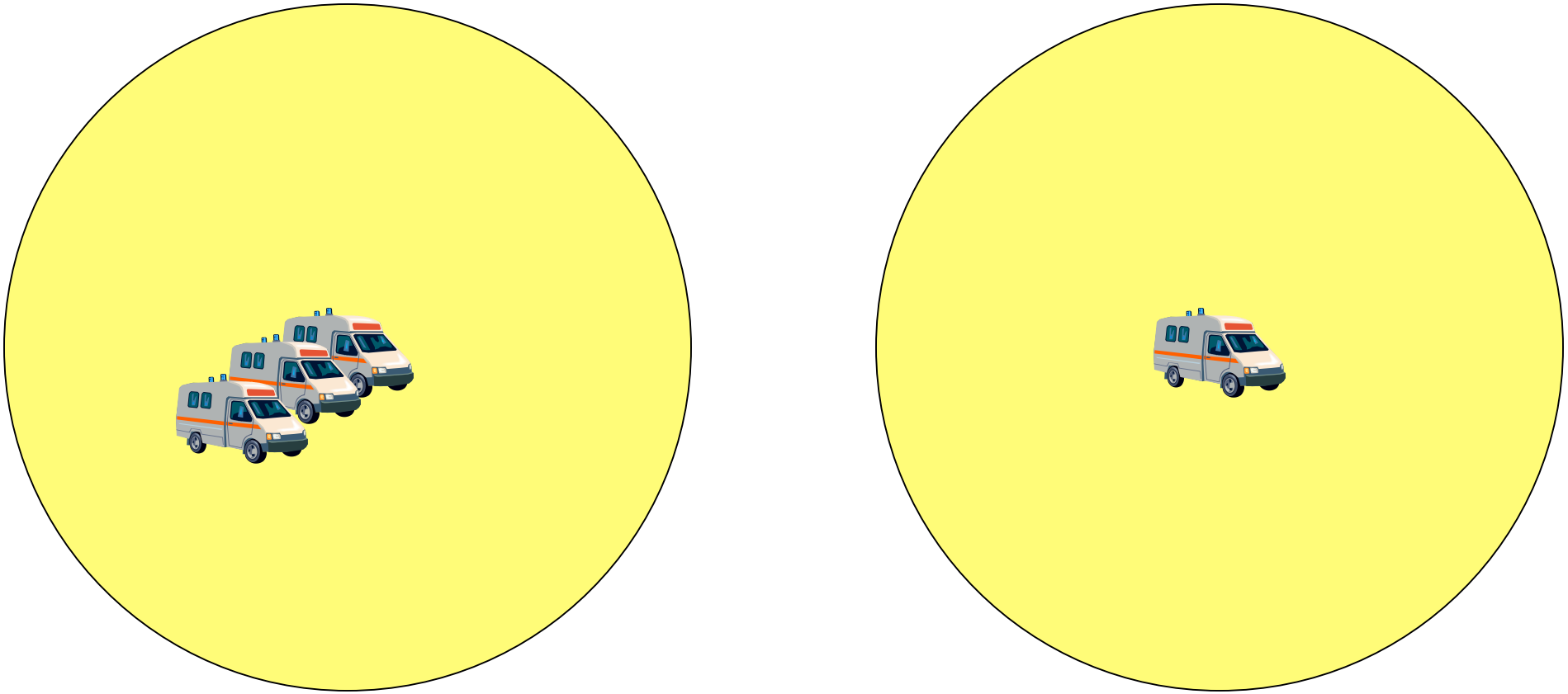
Allocating Ambulances

Provincial or regional planning

Traffic congestion disconnects city



Shane G.



- Two regions, no communication
- Calls that arrive when all ambulances in the region are busy are “lost”
- What arrangment of *c* ambulances minimizes lost calls?

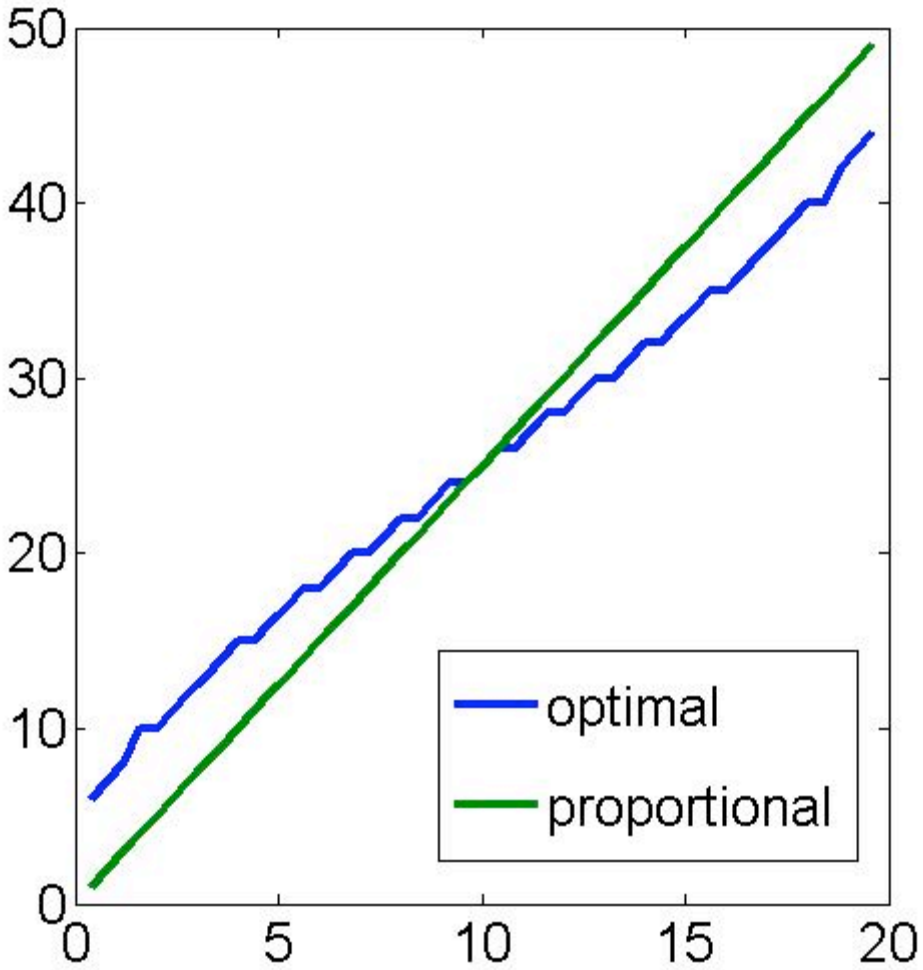
Two Locations, No Interaction

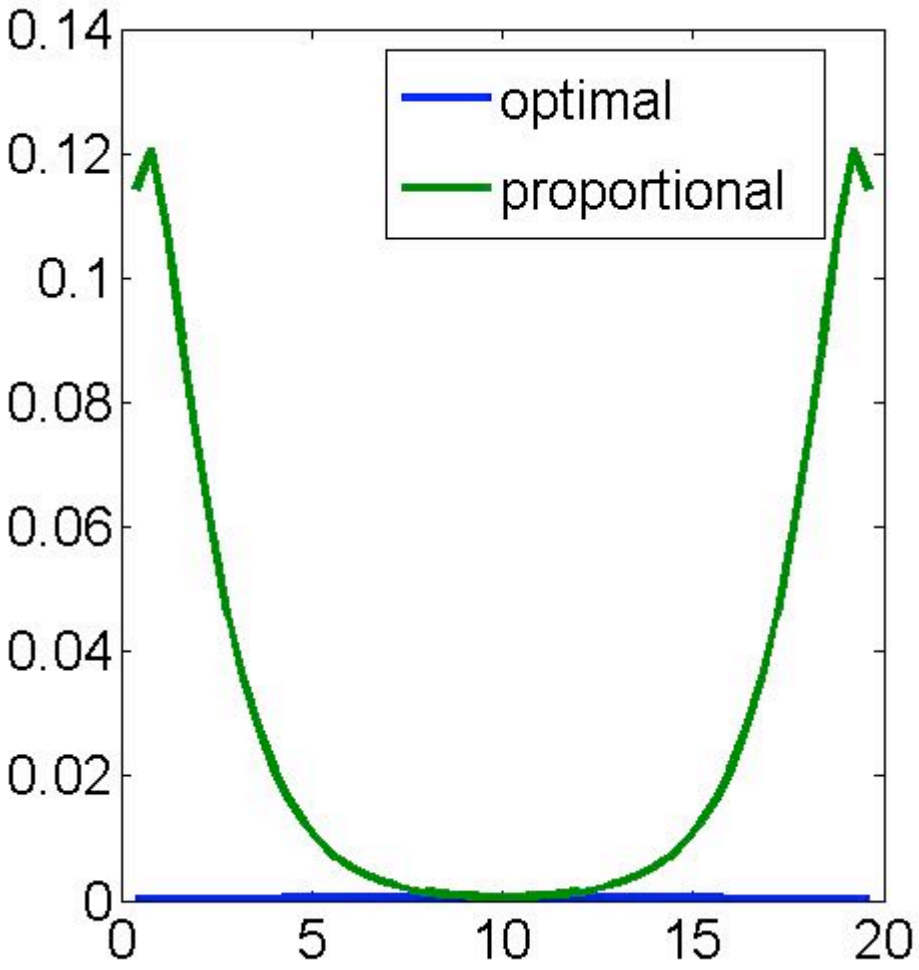
- Arrival rates λ_1 and λ_2
- Minimize $\lambda_1 L(\lambda_1, c_1) + \lambda_2 L(\lambda_2, c_2)$
- s/t $c_1 + c_2 = c$

- Q: Should c_i^* be proportional to λ_i ?

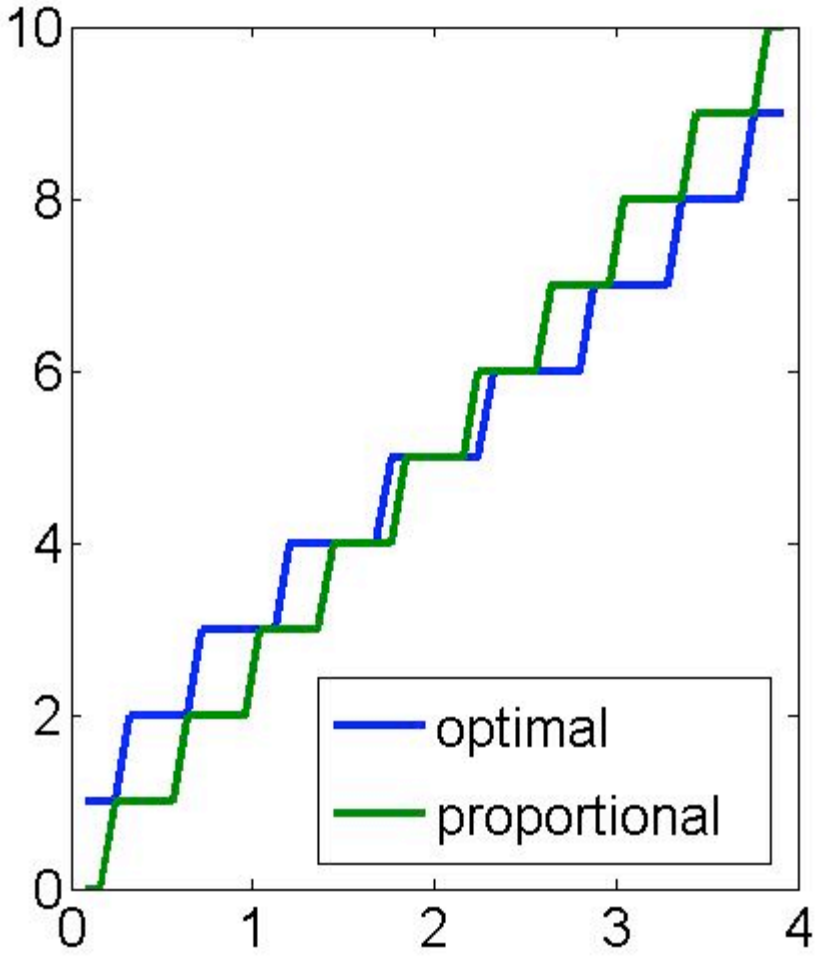
- A: No…

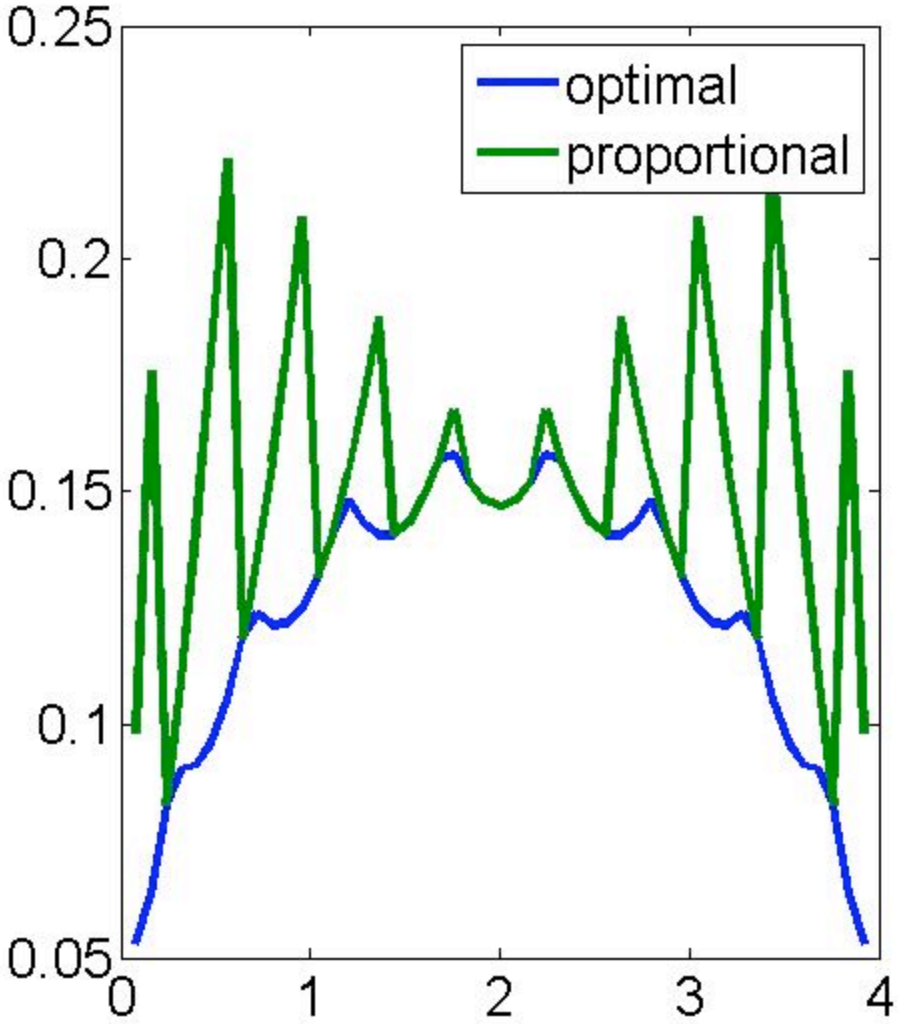
50 ambulances, 20 calls/hr





10 ambulances, 4 Calls Per Hr





So Where are We?

- Allocating in proportion to demand is not always best
- Better to boost allocation to smaller location slightly
- Limitation: Assumes all ambulances at a location share the total load

A New Approach to System-Status Management

Relocation

AKA

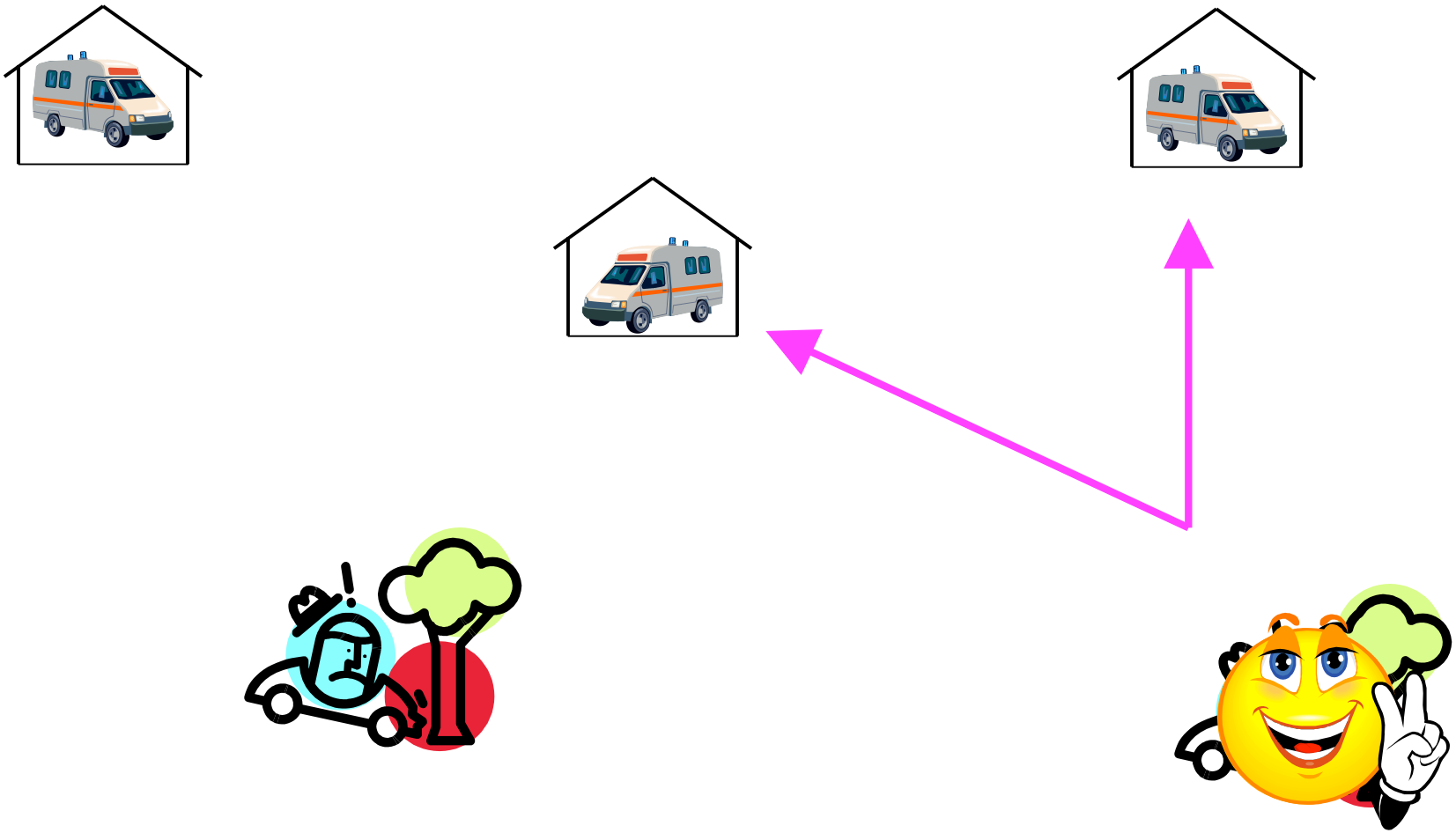
- Relocation
- Redeployment
- System status management
- Move up

Existing SSM Methods

- Have lookup table: Ideal ambulance locations given number available
- Dispatch available ambulances to keep those locations full
- Issues:
  - Potentially many “cold” moves
  - Crew prefers base to street corners
  - How do we know it’s better?

Ingredients for our Method

- Real-time information on ambulances
  - GPS coordinates
  - Status, e.g., at hospital for 12 minutes
- A simulation model of ambulance dynamics
- A function, V say, that gives the value or quality of a configuration
- Managerial decisions on when and where to consider redeployment
  - E.g., Upon call completion only, or other times too
  - E.g., Only to bases, or to other locations too



Assume send ambulance to 1

Do 10 times:

Simulate immediate future, and look up V for final ambulance positions, status

Compute average of V values

= 50.1 say

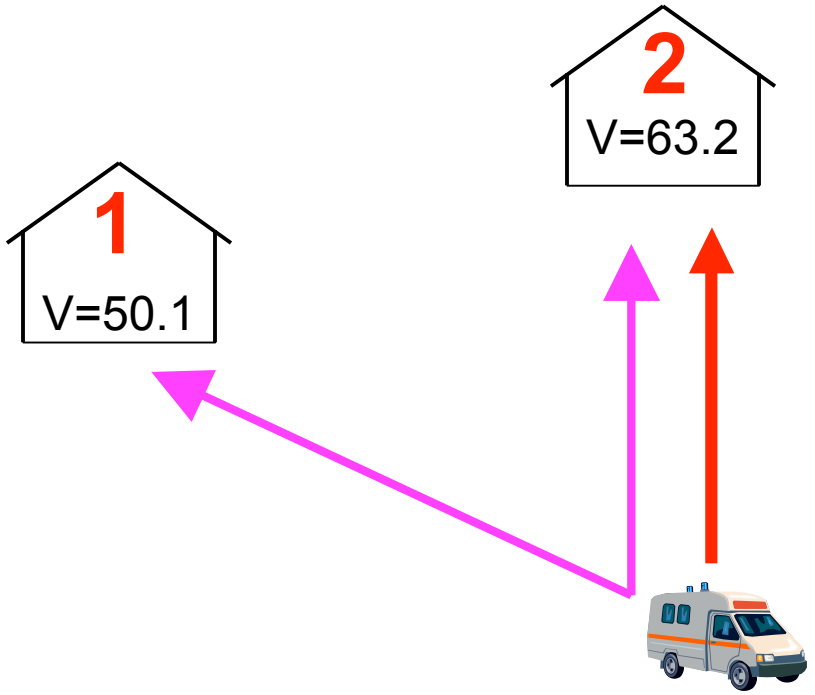
Assume send ambulance to 2

Do 10 times:

Simulate immediate future, and look up V for final ambulance positions, status

Compute average of V values

= 63.2



Some Features

- Super-fast simulations in real time
- Exploits upcoming information, e.g., Ambulance 2 should be free shortly
- Can limit potential moves
  - To ambulances completing a call, or
  - To ambulances already on the road, or
  - To small set of destinations
- Dispatcher can intervene - override, query
- Can restrict relocations to “high benefit” ones

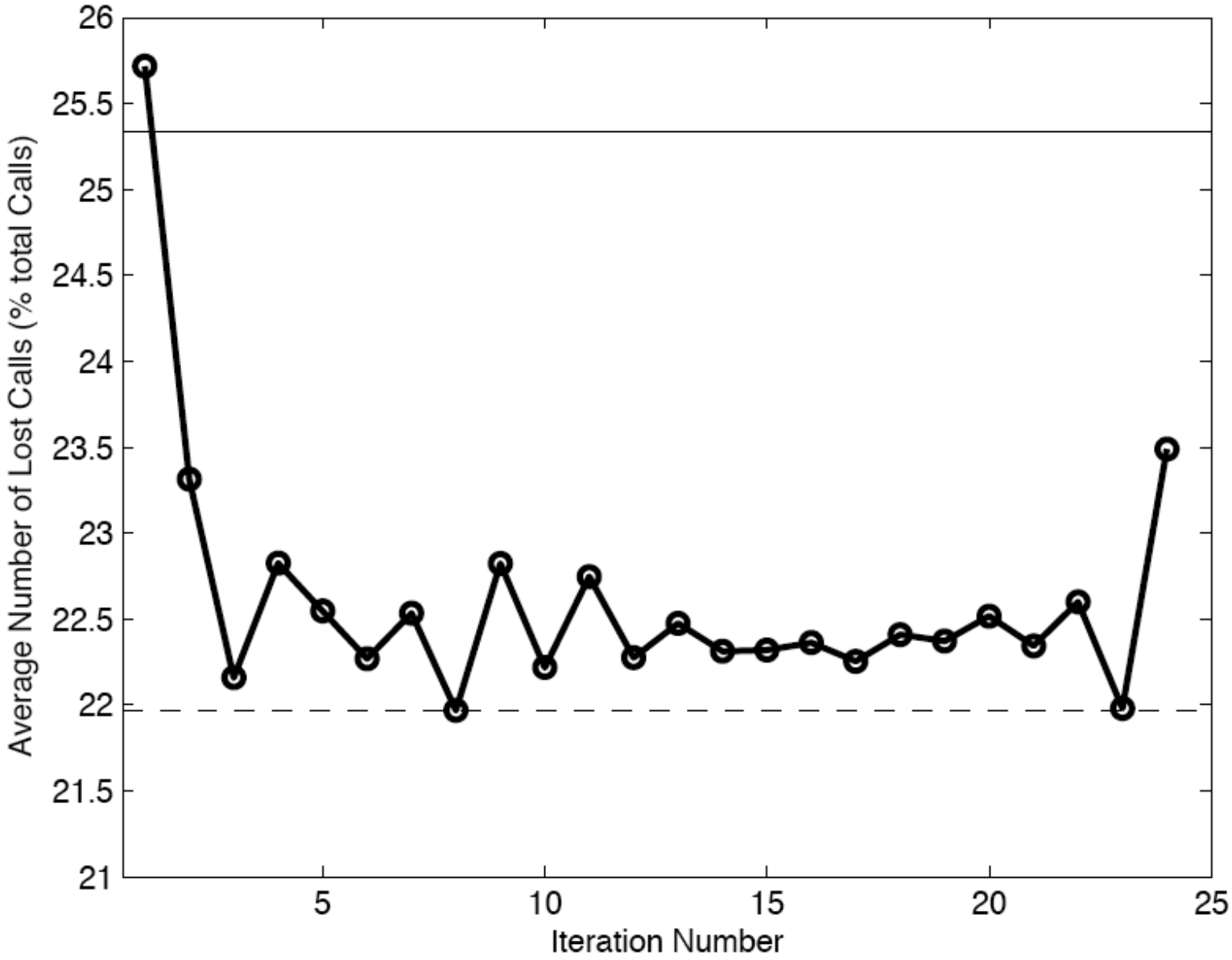
Where Did V Come From?

- Selected in initial training phase - not in real time
- Use “Approximate Dynamic Programming” methods in conjunction with simulation: “computer learning”
- Guess V - simulate it - improve it
- Computationally intensive!

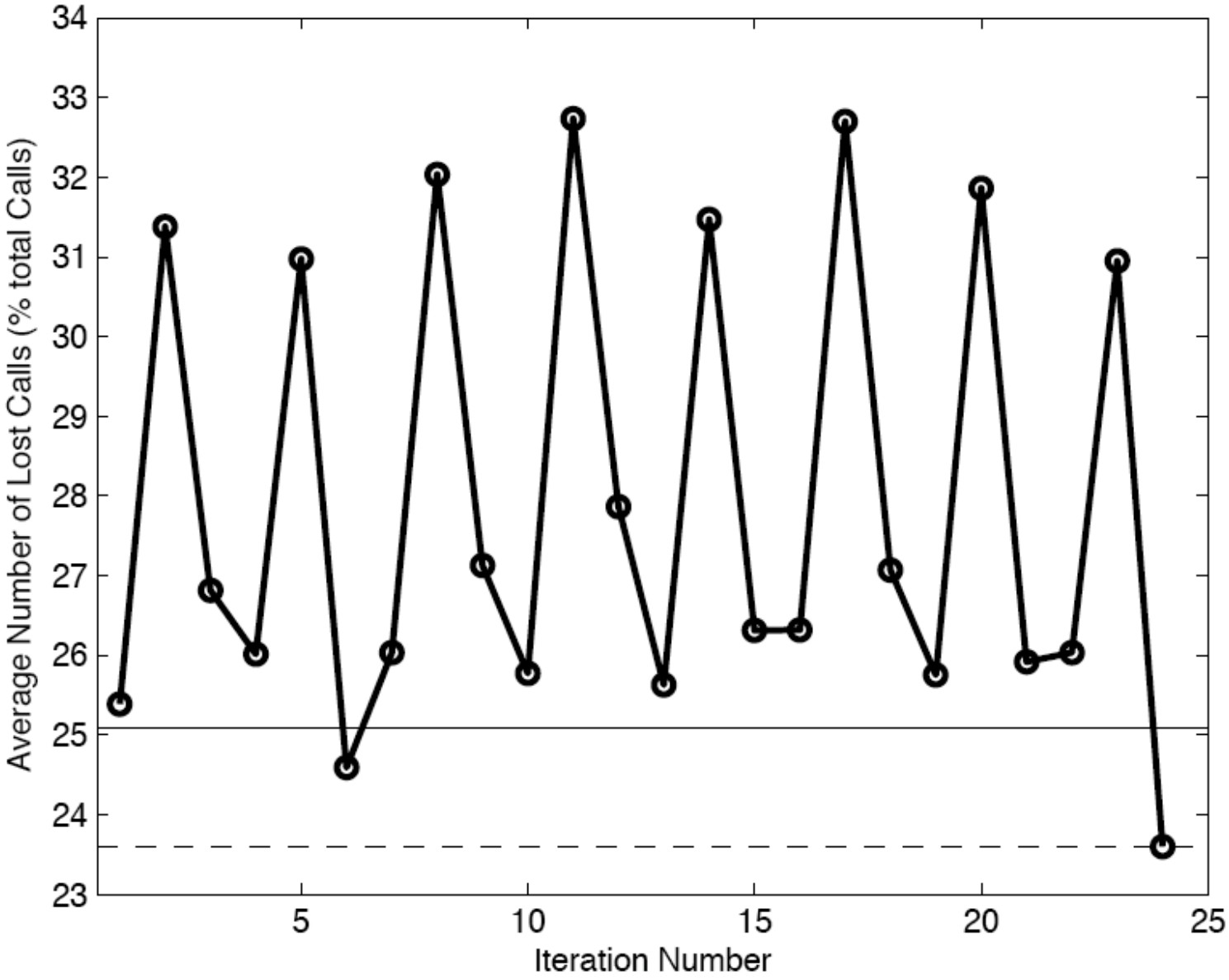
Shortcomings

- Need a simulation model
  - Must be maintained
  - Be careful to use right model for right day
- Need to customize for each installation
- Doesn't work well with "large scale events" like 9/11
- Haven't yet tried multiple levels of care

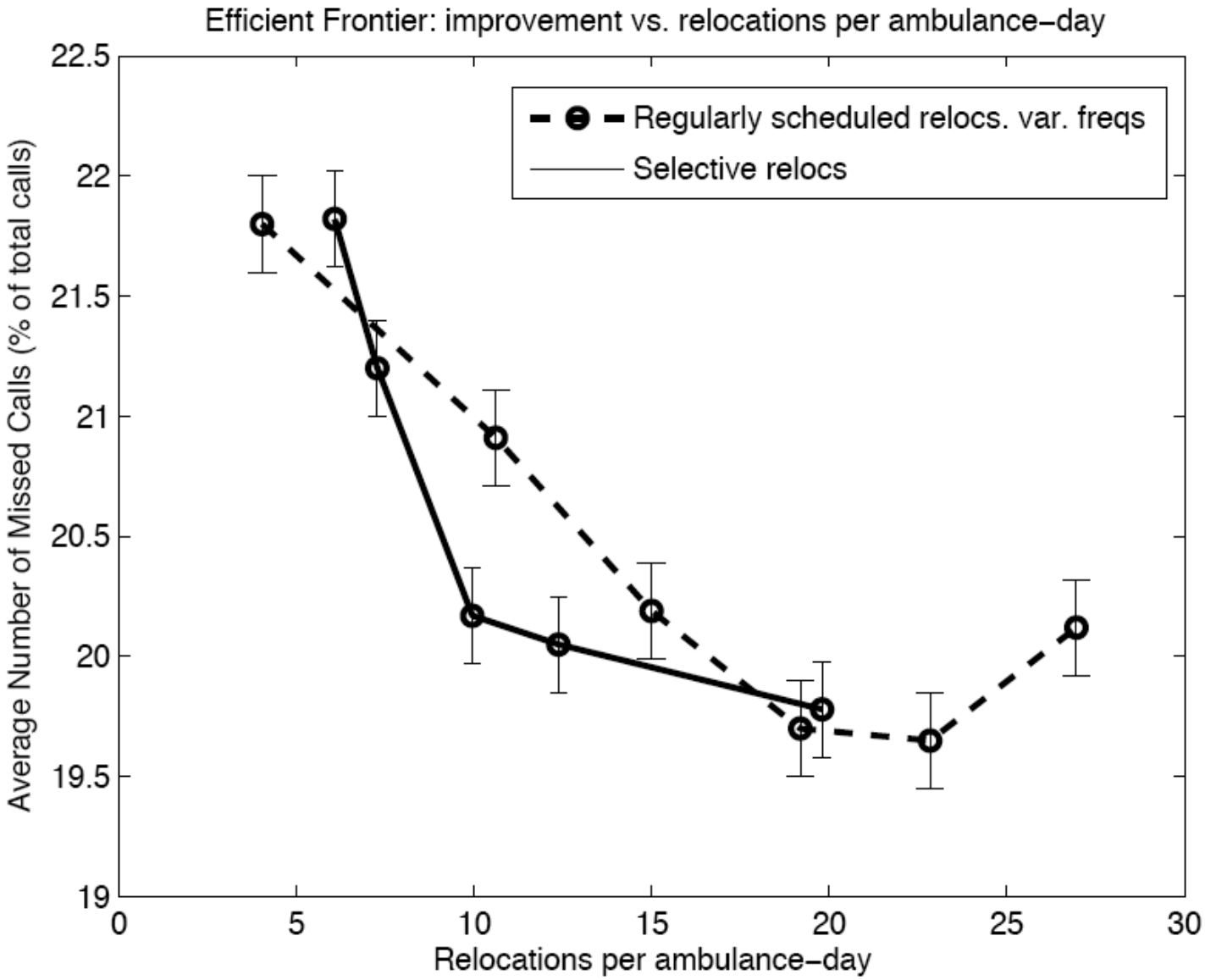
“Convergence”
(Edmonton – Thanks Armann)



“Convergence” (Edm)

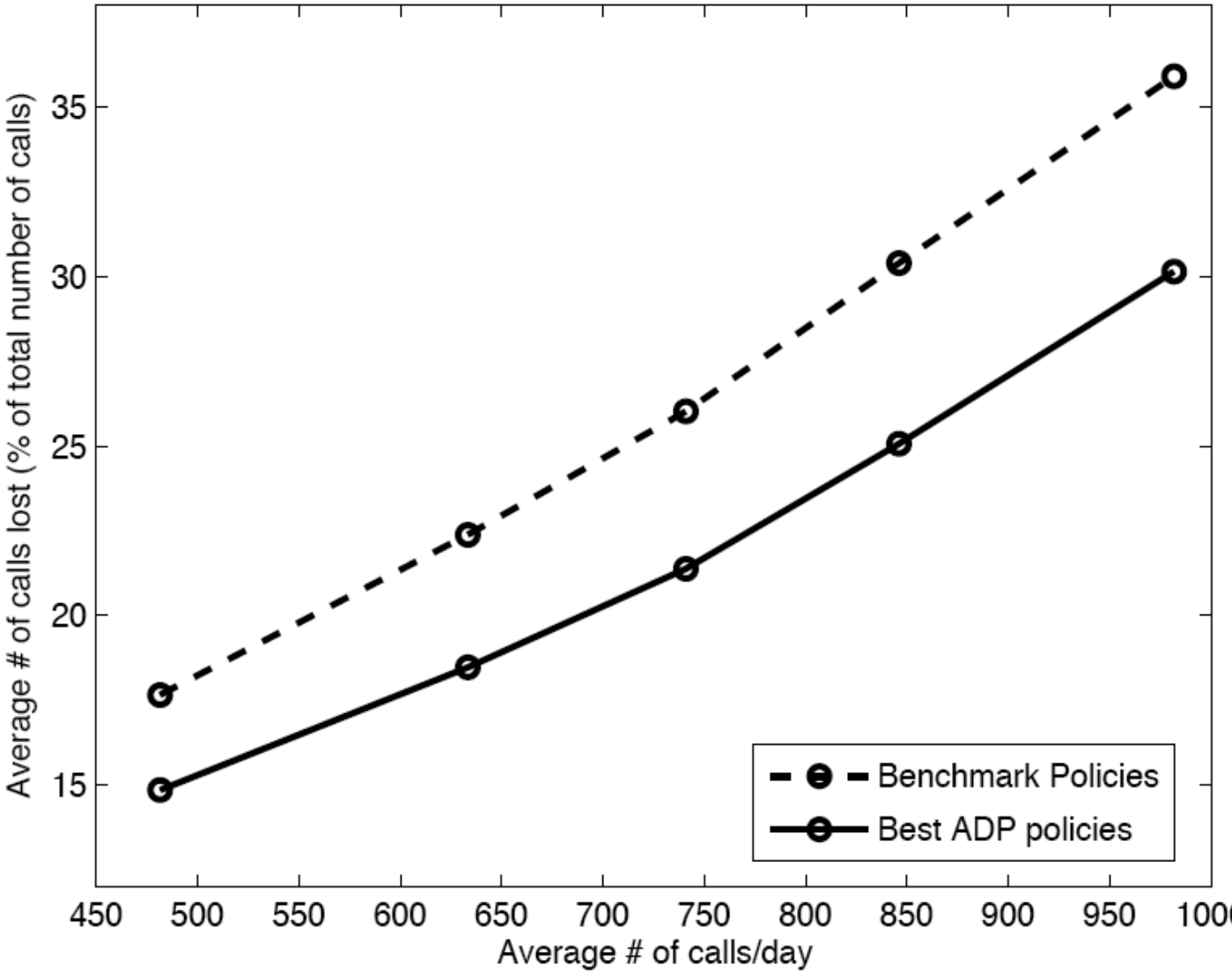


Extra Redeployments? (Edm)

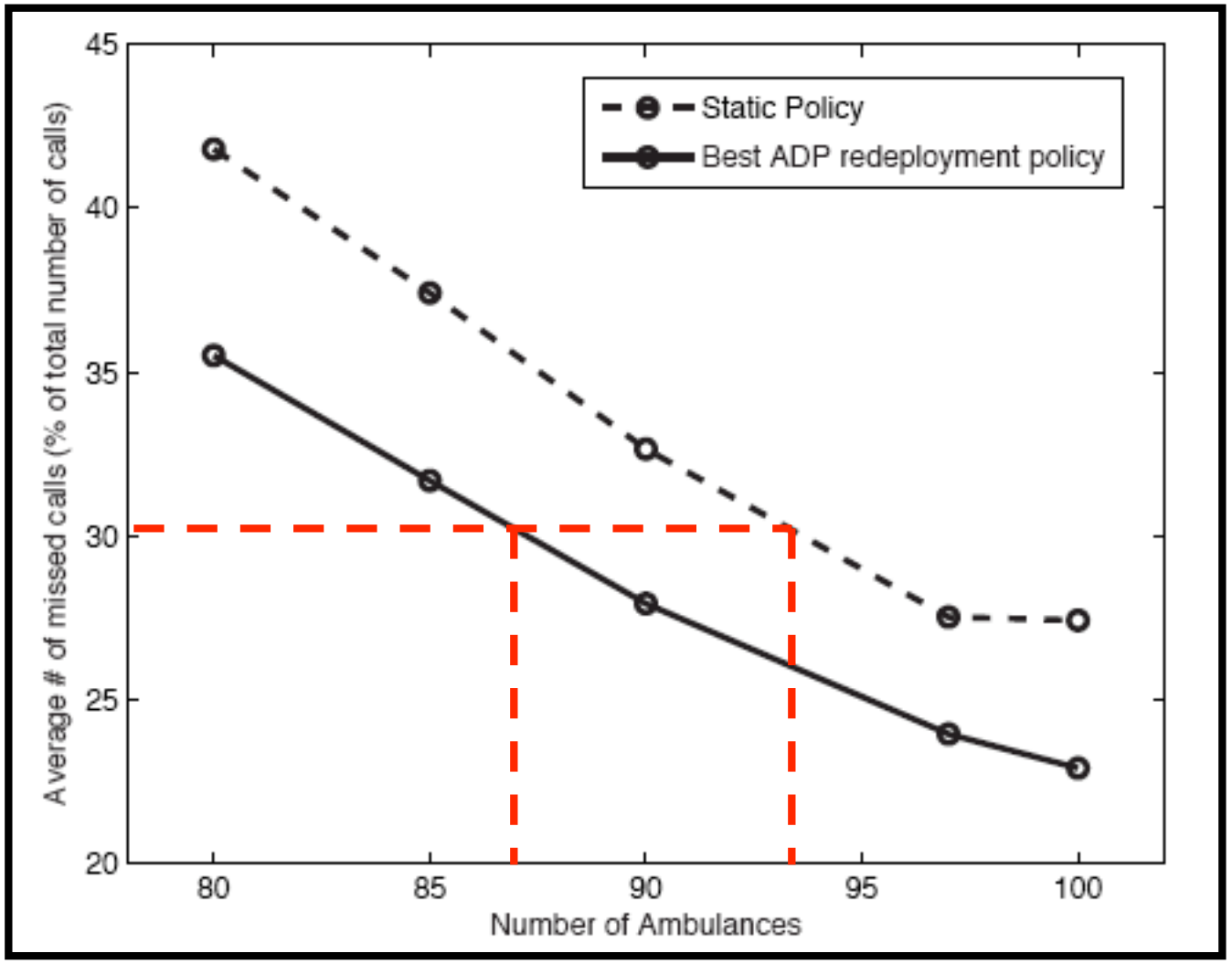


Other Call Volumes?

(Certain City - Thanks Alex, Andrew)



Varying # Ambulances



What is Next For Us?

- Multiple levels of care
- How much better are street corners than bases?
- Interaction with large-scale events
- Testing on high-resolution simulation software

References

- Andersson and Värband. 2006. Decision support tools for ambulance dispatch and relocation. *Journal of Operational Research Society*
- Berman, O. 1981. Dynamic repositioning of indistinguishable service units on transportation networks. *Transportation Science*, 15:115-136.
- Bertsekas and Tsitsiklis 1996. *Neuro-Dynamic Programming*. Athena Scientific.
- Brotcorne, Laporte and Semet. 2003. Ambulance location and relocation models. *European Journal of Operational Research*, 147: 451-463.
- Goldberg. 2004. Operations research models for the deployment of emergency services vehicles. *EMS Management Journal*, 1:20-39.
- Henderson and Mason. 2004. Ambulance service planning: simulation and data visualization. In M. L. Brandeau, F. Sainfort, and W. P. Pierskalla, eds, Operations Research and Health Care: A Handbook of Methods and Applications, 77-102. Kluwer Academic, Boston.
- Ingolfsson and coauthors at Edmonton – many papers
- Kolesar and Walker. 1974. An algorithm for the dynamic relocation of fire companies. *Operations Research*, 22:249-274.
- Laporte, Gendreau and Semet. 2001. A dynamic model and parallel tabu search heuristic for real-time ambulance relocation. *Parallel Computing* 27:1641-1653.
- Rajagopalan, Saydam and Xiao. 2006. A multiperiod expected covering location model for dynamic redeployment of ambulances. *Manuscript*.
- Restrepo, Henderson and Topaloglu. 2008. Erlang loss models for the static deployment of ambulances. *Health Care Management Science*. To appear.
- Restrepo, Henderson and Topaloglu. 2008. Approximate dynamic programming for ambulance redeployment. *Manuscript.*

Wrap-up

- Rural areas have higher ratio of variability to average load
- Should increase resources to lower-loaded areas beyond proportional
- Dynamic relocation can substantially improve day-to-day performance
- Approximate DP: some art required

Some Basis Functions

- Expected # missed calls over remaining horizon
- # waiting calls that will be missed
- Rate of calls arriving to uncovered areas
- Rate of calls arriving to covered areas, that will likely (Erlang loss) be missed
- If ambulances are not diverted from present paths, future locations are also important. Future versions of last 2 basis functions