



SCARE: A Case Study with Baghdad

Paulo Shakarian, V.S. Subrahmanian

University of Maryland

Maria-Luisa Sapino

Universita di Torino



Laboratory for
Computational
Cultural Dynamics

Challenge...

Given:

- **73x IED attack sites**
- **Each attack is at least 0.5 km from a cache**
- **Each attack is no more than 2 km from a cache**

Find:

Minimal number of cache sites that support each of the 73x attacks and their locations.

Challenge...

**This is an instance of a
Geospatial Abduction Problem**

**We introduce
SCARE:
The Spatio-Cultural Abductive Reasoning Engine**

**SCARE predicted cache sites within 690 m (Baghdad) and
280 m (Sadr City) on an open-source data set.**



Outline

- Countering the IED Threat
- Geospatial Abduction
- SCARE
- Experiments
- Discussion



Countering the IED Threat

As with terrorist tactics, guerrilla tactics are neither mindless nor random.

(US Army FM 3-24)



Current Analytical Approaches

I. Attack focused

- Focuses on **where** and **when** IED attacks occur
- “Hotspot” analysis to predict future attacks or driver operations
- Commanders use information to clear routes, establish forward patrol bases (Brown '07)



Current Analytical Approaches

2. Network focused

- Focused on the **IED cells** that supply and conduct attacks
- Analysts utilize intelligence information to learn about IED cells
- Specialized teams conduct forensic analysis of IED attack sites to determine where the cells operate (Moulton '09)
- Commanders use information to locate IED cell members and weapons cache sites



Countering the IED Threat

- Our hybrid approach:
 - Based on **attack** sites, find cache sites used by IED **networks**
 - Commanders can use information to either **target** or **deny** cache sites
 - Orthogonal to network and attack-based approaches



Assumptions

Intuition: The assumptions provide reasonable bounds on the behavior of the IED emplacers.

These assumptions allow us to relate the locations of cache sites to attack sites.



Assumptions

1. IED materials stored at cache site (not insurgent homes)
2. The cache site is accessed prior to the attack
3. There are constraints on cache site placement
 - i.e. it cannot be in a body of water, on a coalition base etc.



Assumptions

4. Distance between cache site and attack site must exceed a certain value
i.e. to avoid risk of compromise if too close
5. Distance between cache site and attack site must be less than a certain value
i.e. to avoid risk of compromise while transporting materials

Similar intuition to *geographic profiling*
(Rossomo and Rombouts, '08)



Geospatial Abduction

- **Geospatial abduction** (Shakarian et. al., '09) provides a framework that fits our assumptions.
- Form of *abductive reasoning* (Peirce, 1900)
- Deductive reasoning:
Stating what follows from a set of facts
- Abductive reasoning:
Finds best explanation for a set of observations



Geospatial Abduction

- Geospatial abduction problems have the following form:
 - Given two phenomena, **observations** and **partners**
 - Geospatially related
 - Constraints on the relationship
 - Observations are known, partners are not

For a given set of observations, can we infer a minimal set of partners?

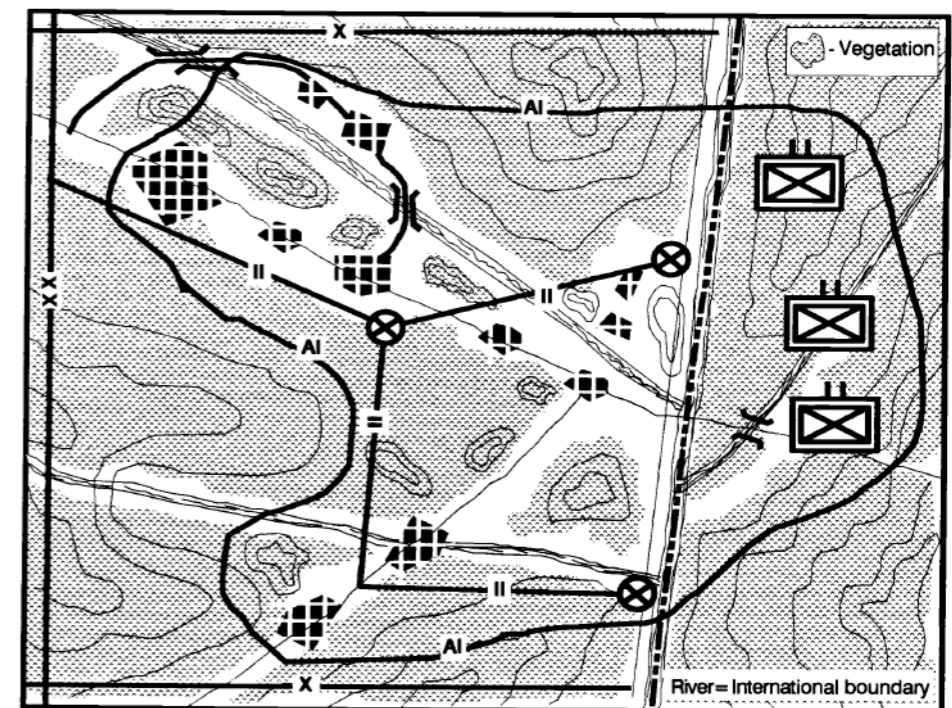
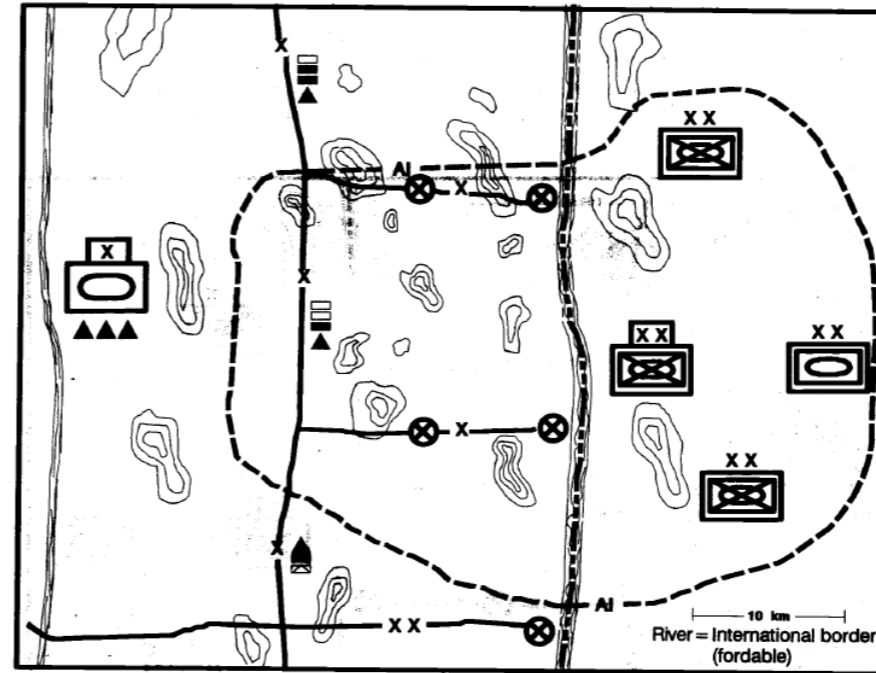


Technical Preliminaries

- Space \mathcal{S}
 - $M \times N$ grid
 - M and N not fixed – can be determined by a grid-spacing parameter
 - Integer coordinates
 - Treated as a set of discrete points

Technical Preliminaries

- Space \mathcal{S} corresponds to the first step of Intelligence Preparation of the Battlefield (IPB) known as *Define the Battlefield Environment* (FM 34-130)
- In this step, the analyst determines the Area of Interest (AI) for operations
- An AI can be represented with Space \mathcal{S}



Figures from FM 34-130, available from fas.org



Technical Preliminaries

- Feasibility predicate

$feas : \mathcal{S} \rightarrow \{TRUE, FALSE\}$

- If point $p \in \mathcal{S}$ cannot possibly be a partner,

$feas(p) = FALSE$

- i.e. if $p \in \mathcal{S}$ lies in a body of water, $feas(p) = FALSE$

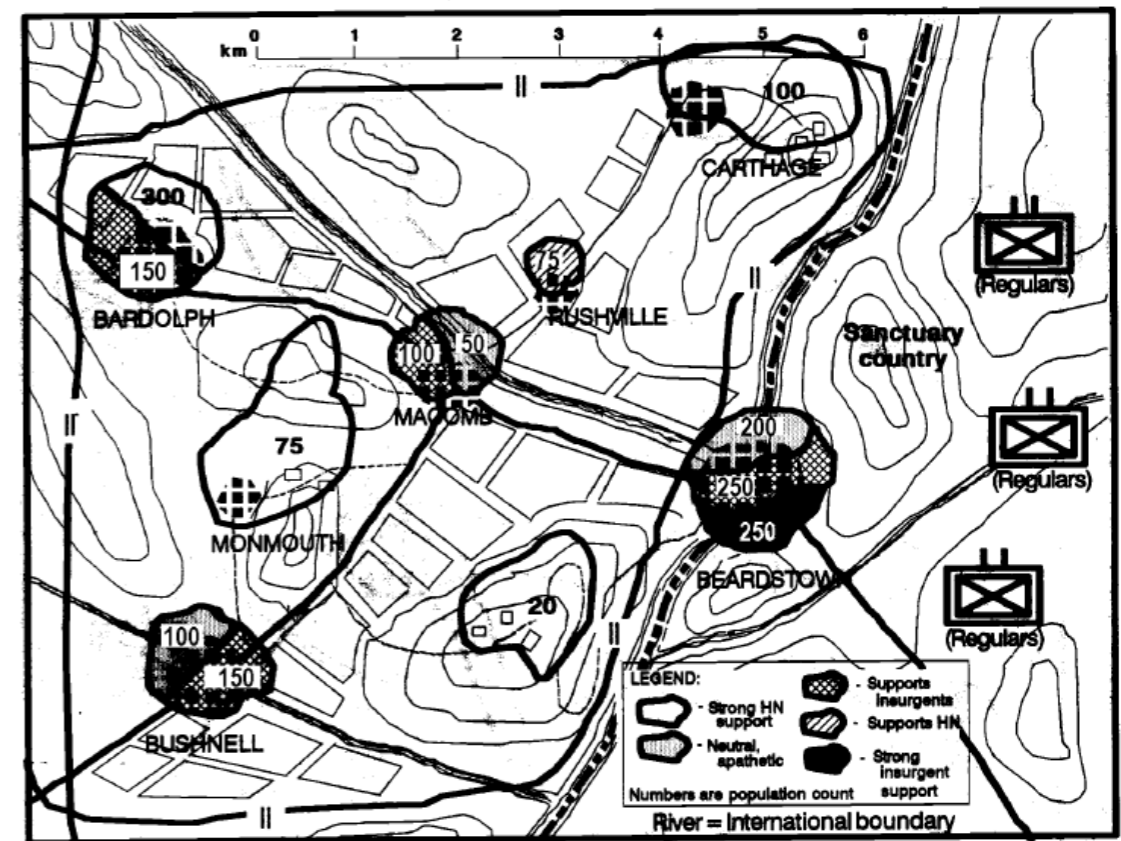
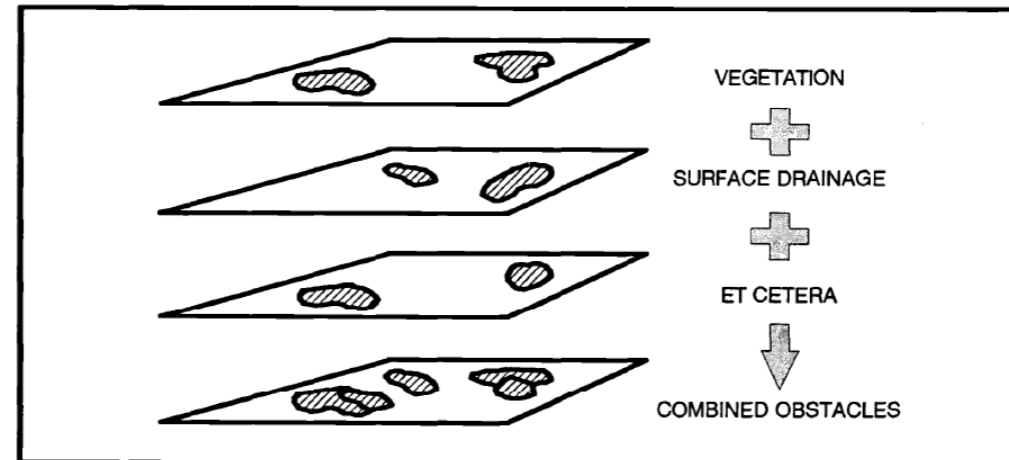
- $feas$ can be user-defined (SCARE allows user-defined $feas$)

- Allows for analyst input

- Allows for the consideration of socio-cultural variables

Technical Preliminaries

- The feasibility predicate *feas* corresponds with step 2 of IPB known as *Describe the Battlefield Effects*.
- In this step, the analyst examines geographic and cultural effects on the battlefield and produces a Modified Combined Obstacle Overlay (MCOO)
- The MCOO can be expressed with *feas*.



Figures from FM 34-130, available from fas.org



Technical Preliminaries

- Set of observations \mathcal{O} – a subset of \mathcal{S}
- α – minimum distance between an observation and a partner
- β – maximum distance between an observation and a partner

Technical Preliminaries

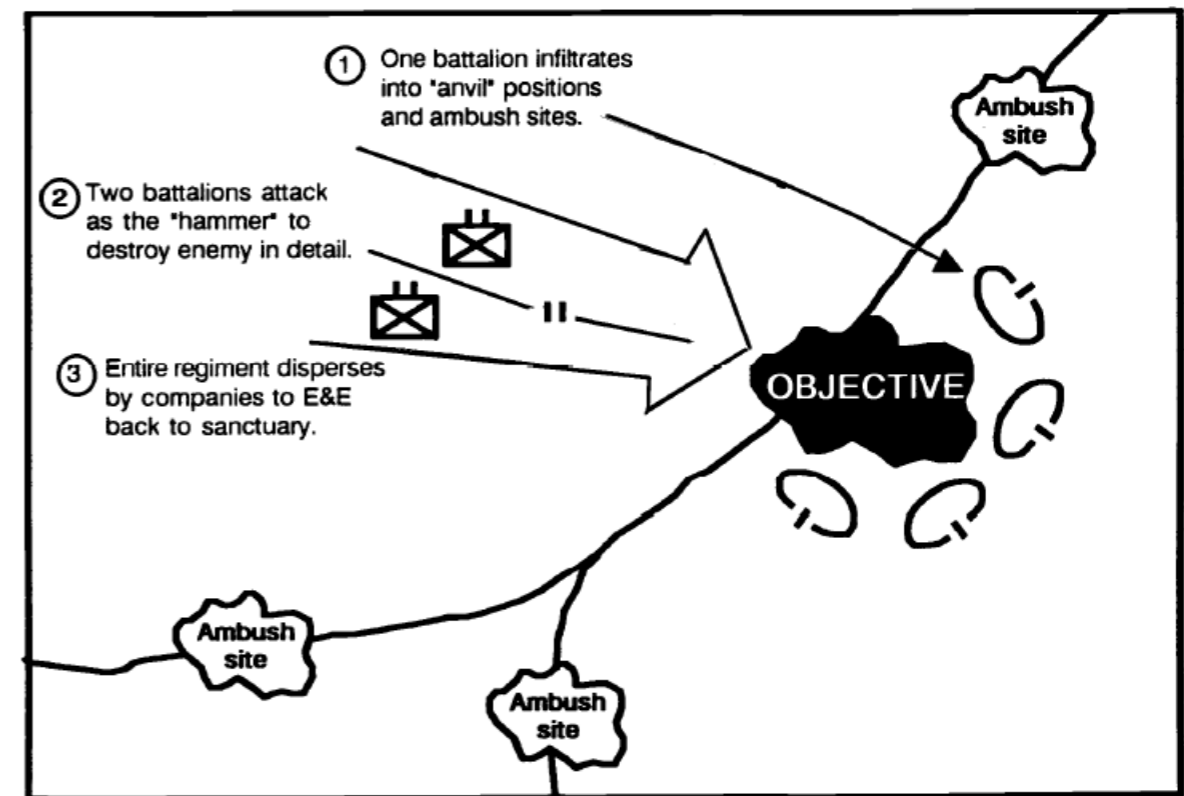
- α, β corresponds with step 3 of IPB known as *Evaluate the Threat*.
- In this step, the analyst examines how the enemy normally conducts operations using a DOCTEMP (doctrinal template).
- α, β can be based on historical enemy activity, or expert data (such as rate of march tables in FM 34-130)
- Future work: more constraints beyond distance.

FOOT MARCHES

BASIC DATA TABLE, FOOT MARCHES

	Visibility	*Rate of March (km/h)	Normal March (8 hours) (km)	Forced March (12 hours) (km)
ROADS	Day	4	32	48
	Night	3	24	36
CROSS-COUNTRY	Day	2	16	24
	Night	1	8	12

*NOTE: Computed on a 50-minute hour, allowing for 10-minute halt each hour.



Figures from FM 34-130, available from fas.org



Technical Preliminaries

- Explanation \mathcal{E} - subset of \mathcal{S} that are partners for \mathcal{O}
 - *The result of to a Geospatial Abduction problem*

Technical Preliminaries

- The production of an *explanation* aides with step 4 of IPB known as *Determine Enemy Courses of Action (COA's)*.
- Elements of \mathcal{E} - constitute High-Value Targets (HVT's) as they are necessary for the enemy to successfully conduct attacks. (i.e. Network Focus)
- Elements of \mathcal{E} - can also be considered High Payoff Targets (HPT's) – as the denial of cache sites can lead to the success of friendly COA's. (i.e. Attack Focus)

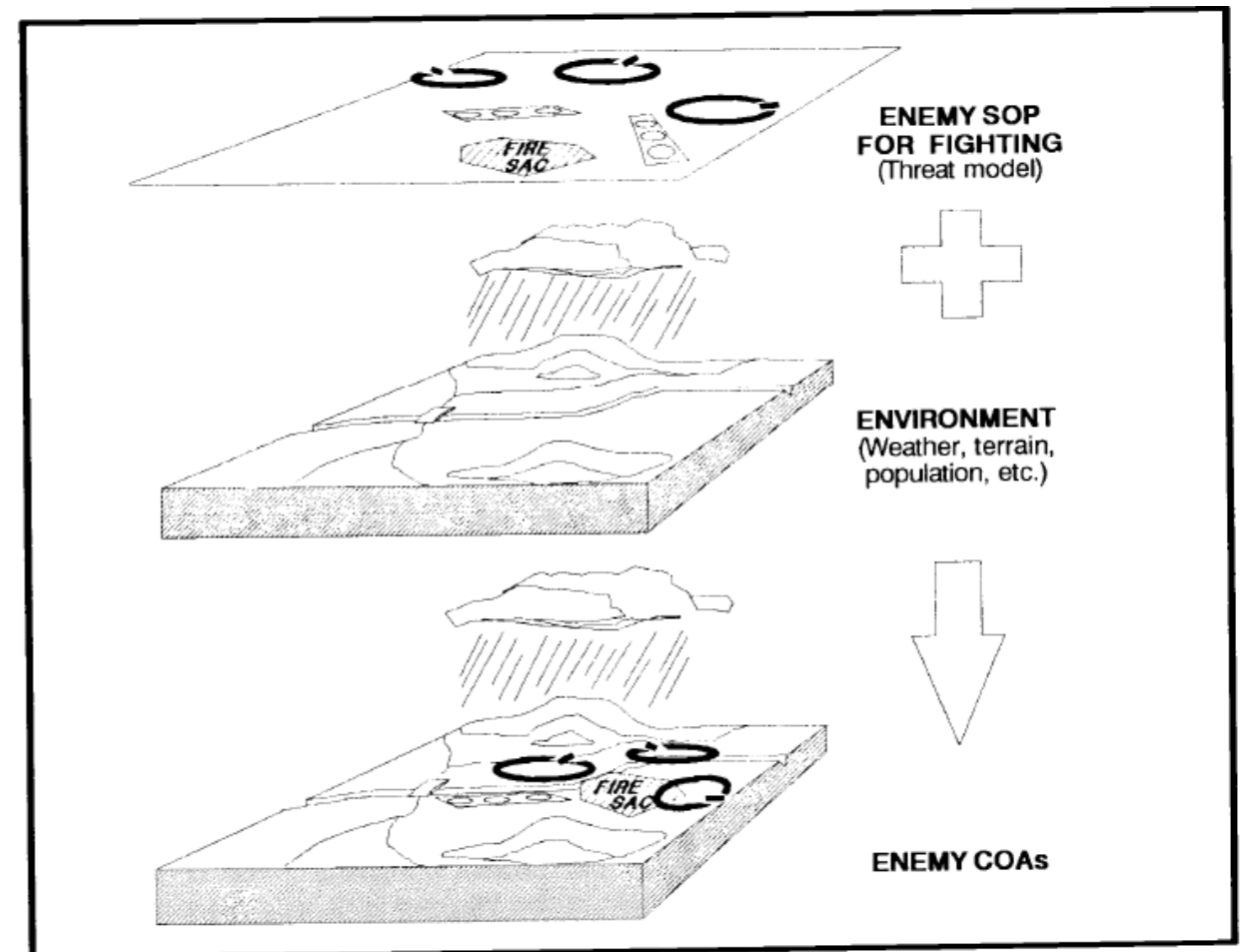


Figure from FM 34-130, available from fas.org



Complexity

- **k-SEP: k Spatial Explanation Problem**
 - Given $\langle \mathcal{S}, \mathcal{O}, \alpha, \beta, \text{feas} \rangle$, find \mathcal{E} of size k or less
- *Related decision problem is **NP-complete** based on a reduction from geometric covering by discs (Masuyama et al, 1981)*
 - *Exact algorithm based on enumeration is exponential in k*



Algorithms

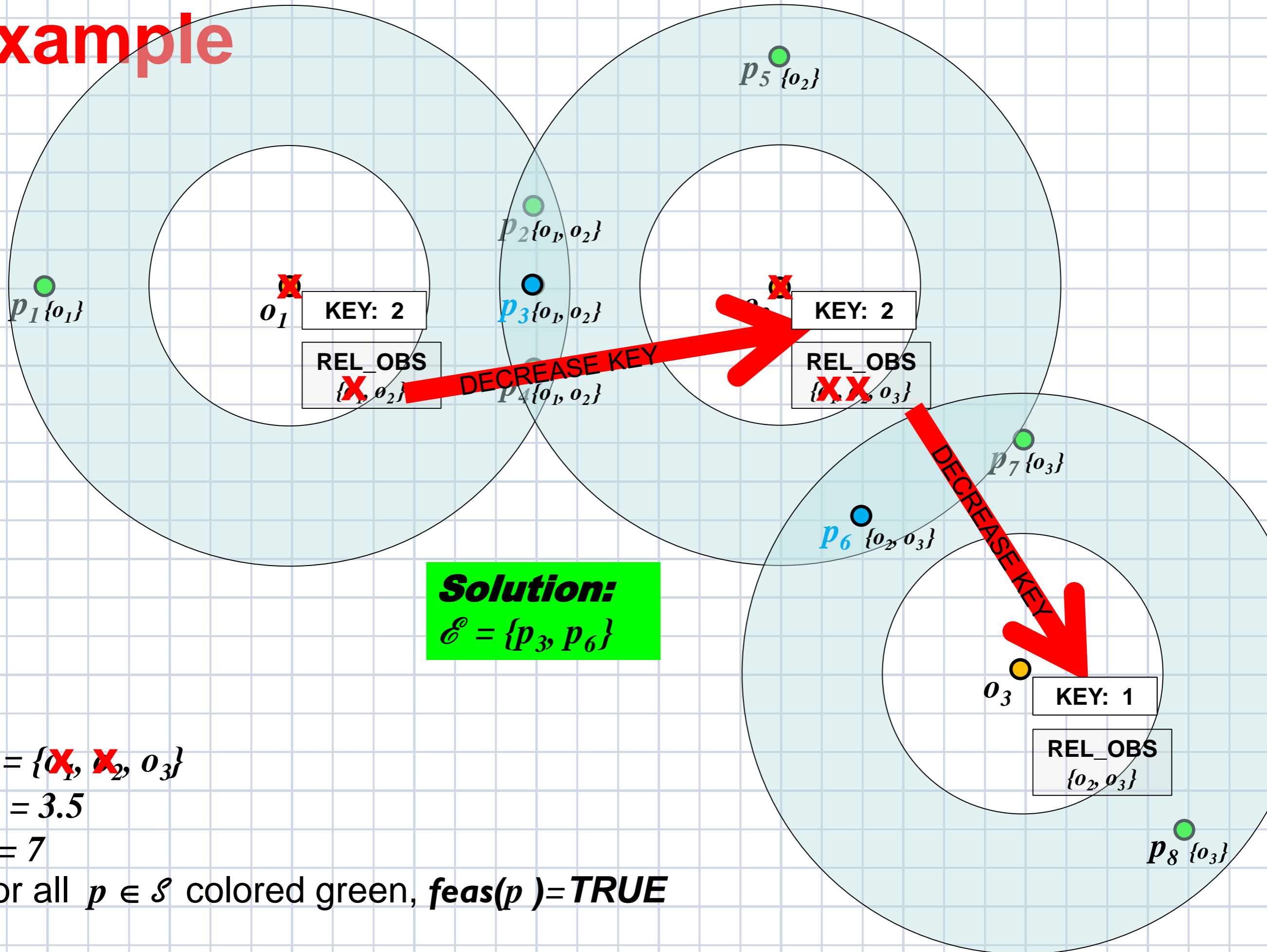
- *k-Sep* reduces to *DOMSET* and *SET-COVER*
- *Shakarian et. al. '09* provides 2 other greedy approaches that use different heuristics
- **GREEDY-KSEP-OPT2:**
2-part greedy algorithm
 - First, selects an observation
 - Then greedily selects an partner to cover that observation



GREEDY-KSEP-OPT₂

- Observation selected based on “least in common” heuristic
 - Picks observations that share partners with the fewest other observations first
 - Reduces non-determinism
 - Reduces cardinality
 - Increases accuracy
 - Modest increase in cost (still less than straightforward greedy approach)

Example



Solution:
 $\mathcal{E} = \{p_3, p_6\}$

$$O = \{\cancel{o_1}, \cancel{o_2}, o_3\}$$

$$\alpha = 3.5$$

$$\beta = 7$$

For all $p \in \mathcal{S}$ colored green, $feas(p) = TRUE$



GREEDY-KSEP-OPT₂

- Complexity:
 - $O(n)$ time for greedy selection
 - Additional $O(n \lg n)$ time to maintain “least in common” heuristic using Fibonacci heap
 - Total: $O(n + n \lg n)$

N.B.: $n = |\mathcal{O}|$ (cardinality of the set of observations)



SCARE

- Implementation of GREEDY-KSEP-OPT2
 - Written in Java
 - Outputs results to Google Earth
 - Able to run on stand-alone Intel-based computer
 - Access to web-based version available by request



Experimental Set-Up

- **Given:**
 - Given 14 months of IED attack for Iranian-backed “special groups” (Cochrane ‘08)
 - Distances between IED attacks and cache sites (calculated from 7 months of historical data)
 - Areas restricted from use by the “special groups” for cache sites
 - religious data for neighborhoods (from non-government parties) and locations of major US facilities (from non-government parties)
- **Find IED cache sites**
 - Compare to ground truth based on Cochrane ‘08

Feasibility Overlay

Coalition Facilities
Bodies of Water
Sunni Neighborhoods

For all points p inside
that are inside a
polygon,
 $feas(p)=FALSE$

Image © 2009 DigitalGlobe

11.9 km

©2008 Google

Eye alt 41.13 km

lat 33.295147° lon 44.386178°



“Special Groups”

- Shi'ite militant groups believed to be Iranian-sponsored
- Attacks attributed based on weapon systems
 - Explosively Formed Projectiles (EFP's)
 - Iranian-manufactured small arms/munitions
- Jaysh al-Mahdi (JAM) most widely known such group



Experiments

- **Baghdad**
 - 27 x 25 km area
 - 73 attacks considered
- **Sadr City**
 - 7 x 7 km area
 - 40 attacks considered

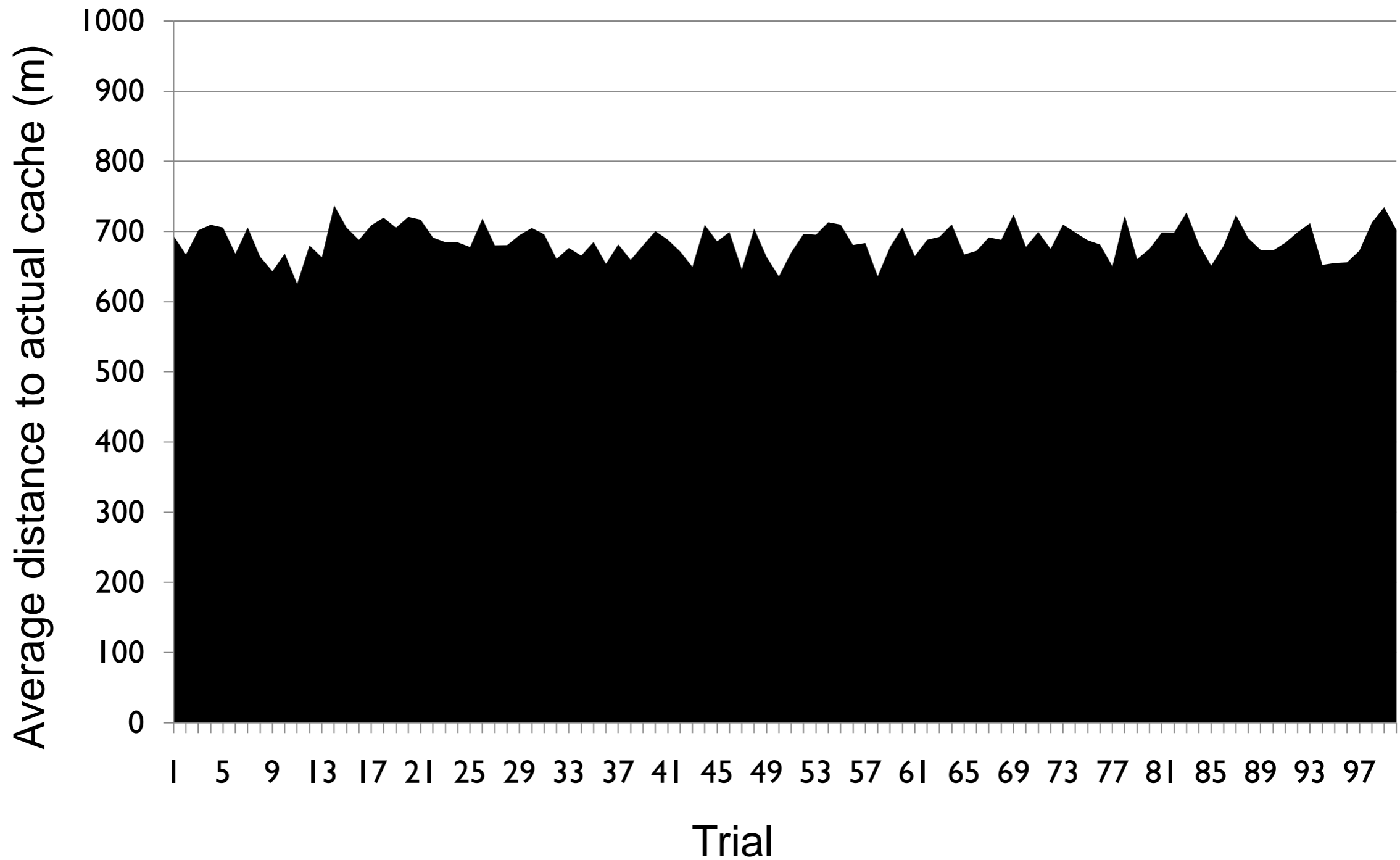


Findings – Baghdad

- Overall:
 - Each run provided 14 possible cache sites with an average run-time of 201.4 ms.
 - In each trial, at least **7** (on average, 7.9) predictions were less than **500 m** from an actual cache
 - Overall average distance to actual cache: **690 m**

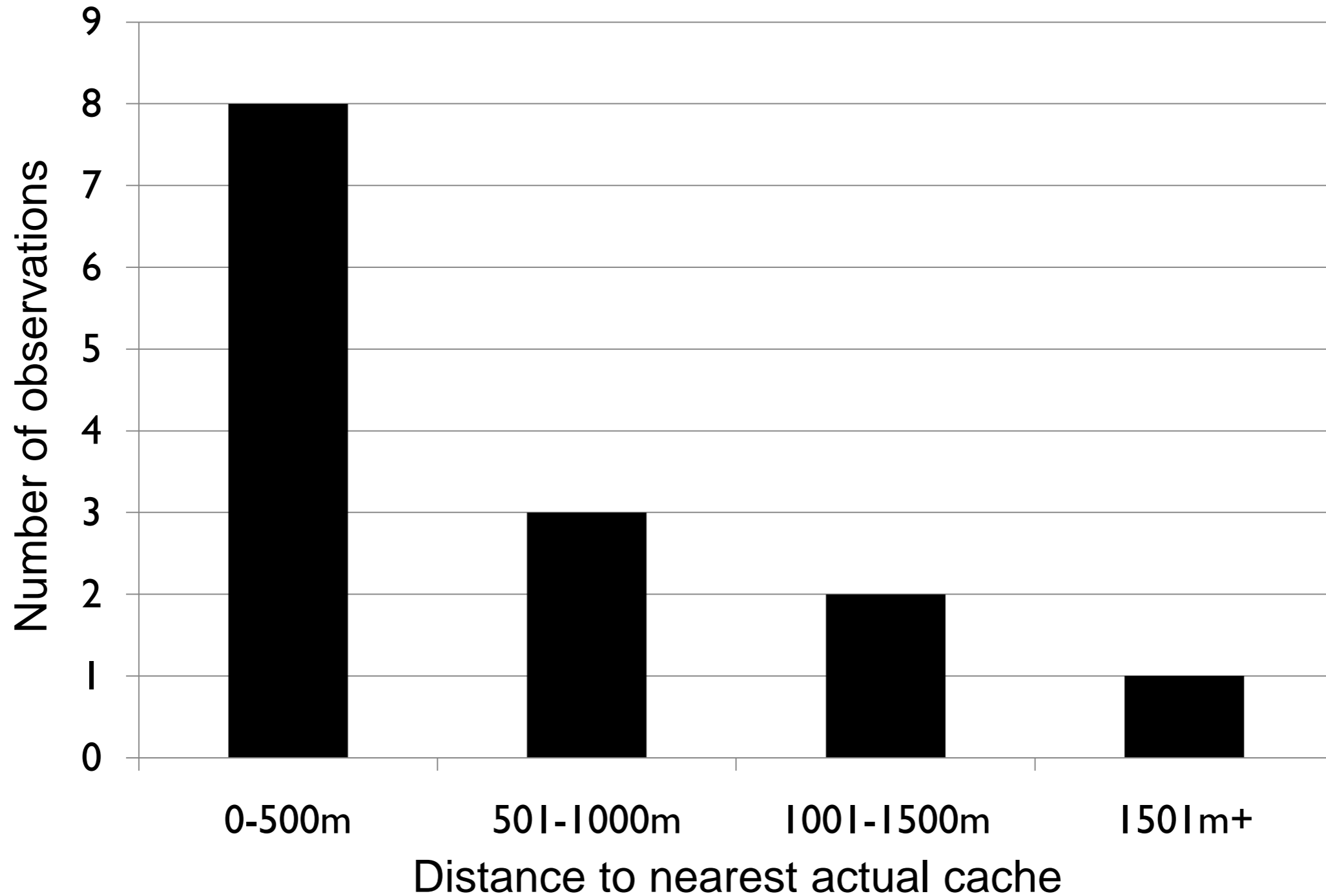


Findings - Baghdad





Findings – Baghdad



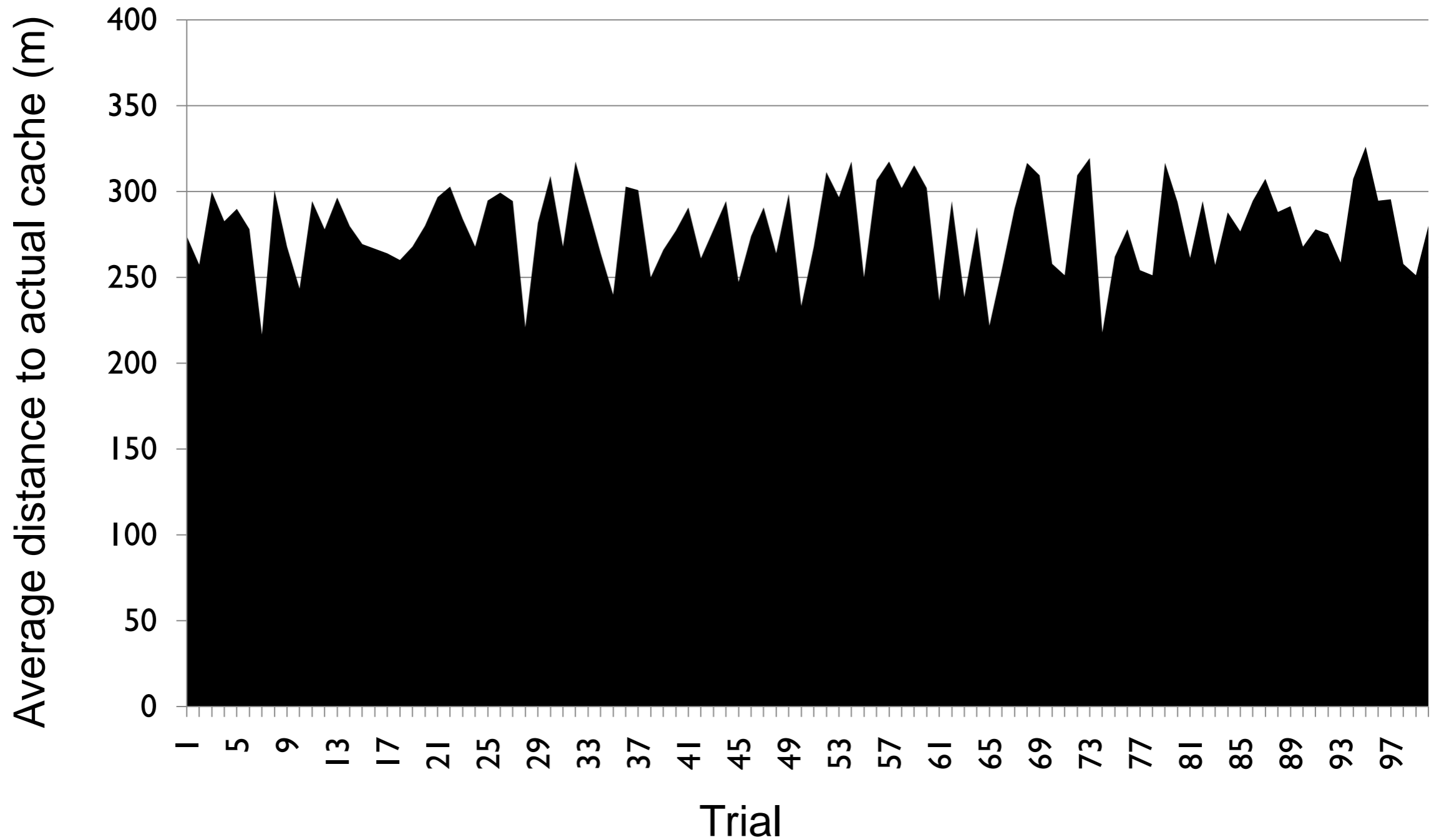


Findings – Sadr City

- Overall:
 - Each run provided 6 possible cache sites with an average run-time of 24.6 ms.
 - In each solution, **all** possible caches were less than **500 m** from an actual cache
 - Overall average distance to actual cache:
280 m

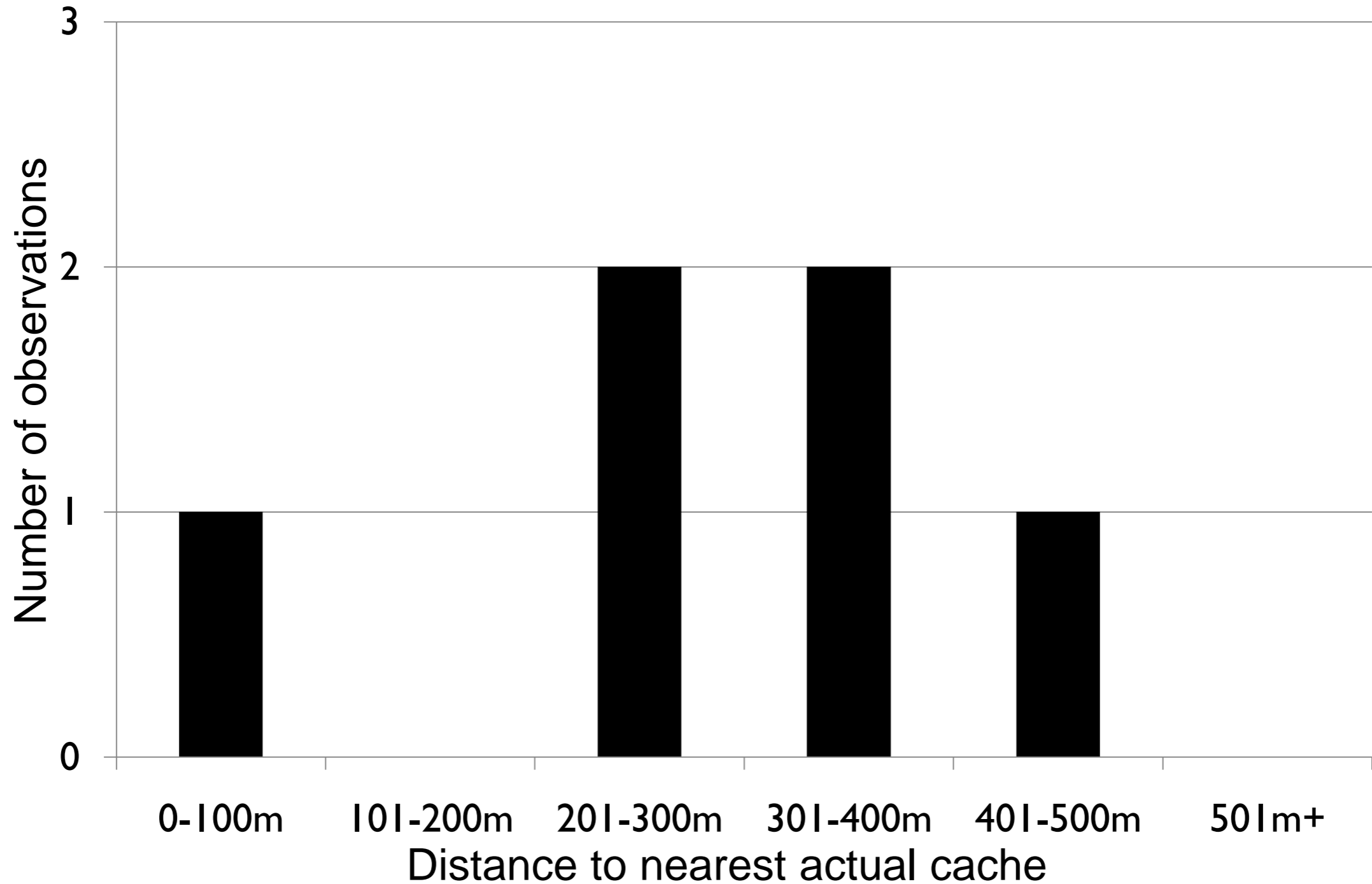


Findings – Sadr City





Findings – Sadr City





Discussion

- SCARE shows viability as a system for predicting IED cache locations.
- SCARE may need to consider different constraints for different areas based on physical and cultural geography.
- Our experimental results indicate that there is use in our model of IED cell behavior and that Geospatial Abduction is a good formalism for this model.



Tactical Utility

- Based on our tests, SCARE may already have some tactical utility
 - SCARE predictions can be used to help cue other assets.
 - SCARE predictions can be used to deny enemy operations.
- Current results are promising, but further testing on other datasets is needed



Concluding Remarks

- Use of Geospatial Abduction to counter the IED threat by locating cache sites that support specific attacks
- Implemented a greedy approach to Geospatial Abduction with SCARE
- Tested SCARE on Iraq “Special Groups” data
- Returned cache sites less than 700 m from actual sites for Baghdad (less than 300 m for Sadr City)
- Possible current tactical use



SCARE Demo

- <http://scare.umiacs.umd.edu/>



Questions