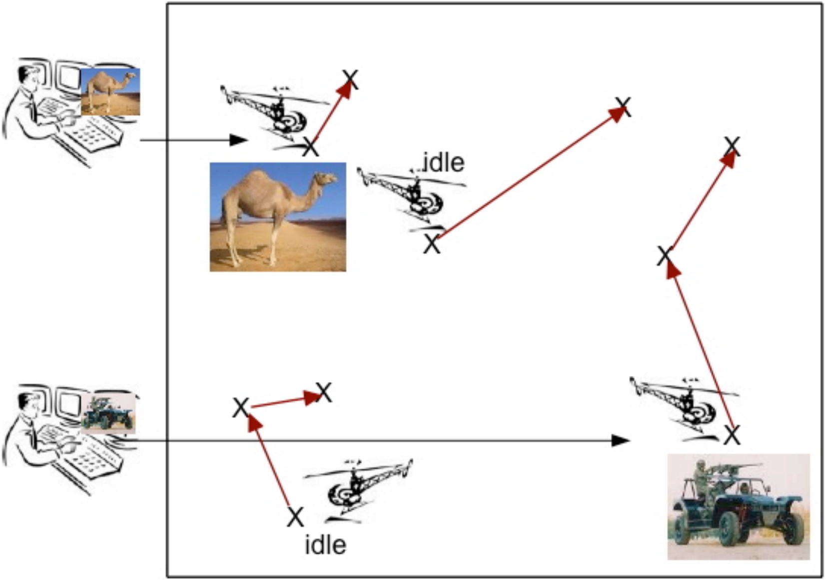
Humans-in-the-Loop Target Classification

Mid-Year Review, Department of Aerospace Engineering,
University of Michigan, April 3, 2008.

Presenter **Tom Temple**
Joint work with **Ketan Savla and Emilio Frazzoli**

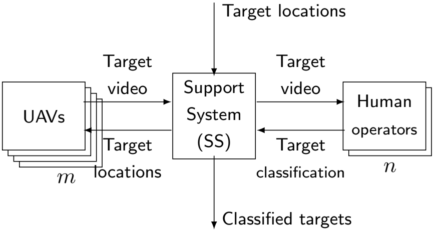
Laboratory for Information and Decision Systems,
Massachusetts Institute of Technology

Motivation



Problem Formulation

- The surveillance of a region $\mathcal{Q}$ is entrusted to n human operators and m UAVs.
- **Targets** arrive randomly in $\mathcal{Q}$ at a rate λ with uniform distribution over $\mathcal{Q}$.
- The UAVs are routed to visit targets and record video.



- A target is **classified** when a human operator has seen enough video of the target to decide whether it is “lethal” or “benign.”

Objective

Goals

(i) Design joint motion coordination and operator task allocation policies

(ii) Characterize the quality of service as a function of n and m.

Quality of Service

The average time between the arrival of a target and its classification.

Approach

Theoretical lower bounds, efficient policy design.

Assumptions

- The humans watch video at a real time rate.
- Operators can stop and resume where they left off.
- Another operators can also resume where a *different* operator left off.
- The an operator's belief states about a target is not interpretable by the decision support system.

The Blame Game

- Imagine that a customer is waiting for service at a particular instant blames either the UAVs or the humans for having to wait.

- Specifically, if all the human operators are busy at that instant they blame the humans and otherwise they blame the UAVs.

- Define W_v, W_h as the expected integrals of blame for the UAVs and humans, respectively.

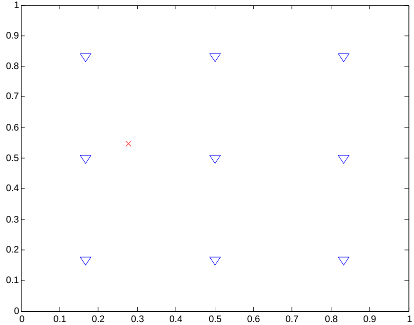
$$W_q = W_v + W_h$$

The Light Load case

- $\rho_h \to 0$
- $W_h \to 0$

W_v is simply the travel time

$$W_q \propto \frac{1}{\sqrt{m}}$$

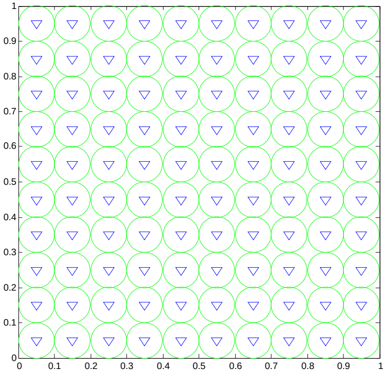


Heavy Load: Many UAVs

- $\rho_h \rightarrow 1$
- $m \rightarrow \infty$

The resulting system is a M/G/n queue

$$W_q = W_h = \frac{\lambda(\lambda^{-2} + \sigma_s^2/n^2)}{2(1-\rho_h)}$$

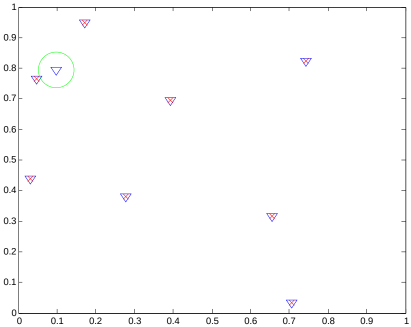


Heavy Load: Few UAVs

- $\rho_h \rightarrow 1$
- $m = n$

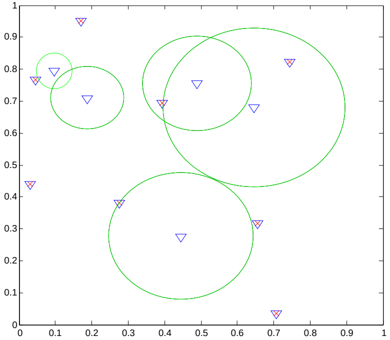
Reduces to the multi-agent Dynamic Traveling Repair-person Problem (mDTRP)

$$W_q \propto \frac{\lambda}{n^2(1-\rho_h)^2}$$



Heavy Load: general number of UAVs

- $\rho_h \to 1$
- Let $k = m - n$, and hold n fixed.
- For the UAVs to be blamed, all k free UAVs must to be en-route to targets when an operator becomes free.

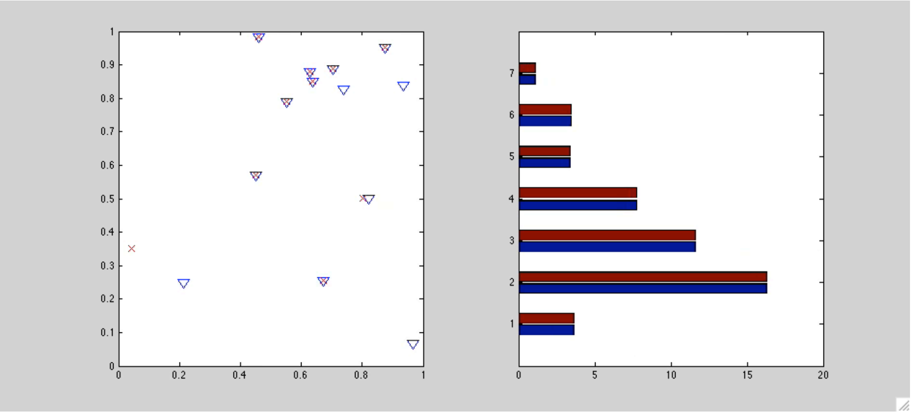


$$W_v = \frac{\lambda}{a_o n^2 (1-\rho_h)^2 + a_1 k n (1-\rho_h) + a_2 k^2}$$ **Bounded!**

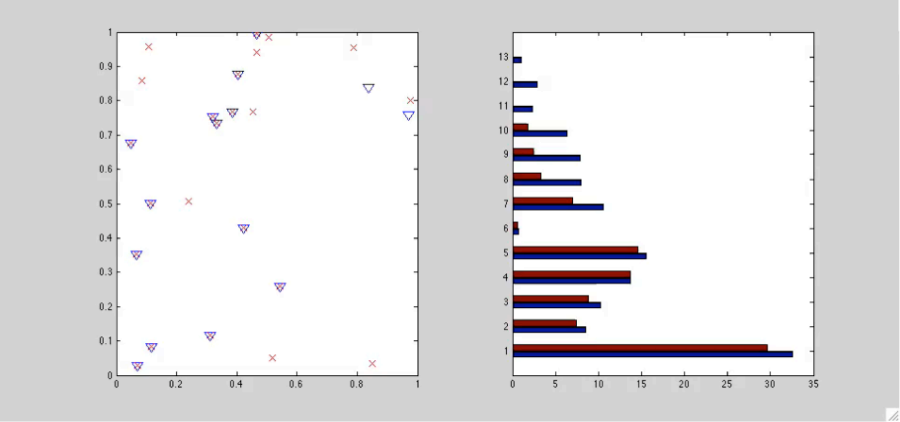
Simulations: Heuristics

- A UAV receives a reward whenever a classification is made using video that they have collected.
- UAVs always maximize their expected reward rate for their current and immediate next target.
- When a new target appears, the UAVs bid on it.
- A UAV is allowed to leave a target whenever doing so gives a higher rate of reward. This allows for the use of offline information collection.

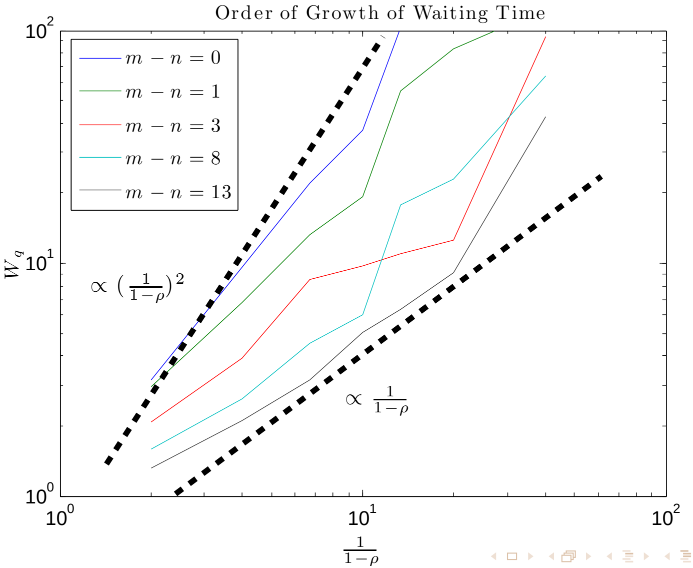
Simulation



Simulation


0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
1
2
3
4
5
6
7
8
9
10
11
12
13
0
5
10
15
20
25
30
35

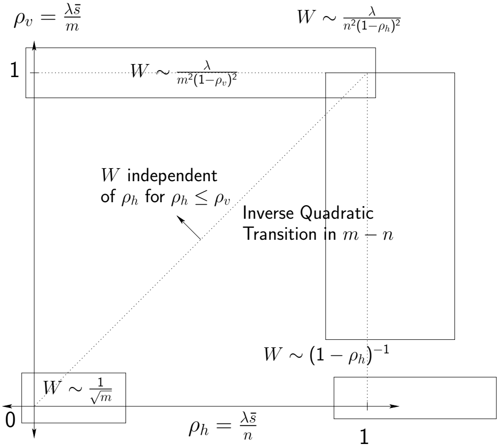
Empirical Results



Summary

"Human-in-the-loop vehicle routing policies for dynamic environments," *IEEE CDC*, Dec 2008.

- Provable optimality for simple algorithms
- Provide an analytical foundation for general algorithms
- Addressed how "situational awareness" affects system performance



What if the human operators' decision time is affected by their load factor?

Situational Awareness

For the moment, consider a single operator,

- We include "Situational Awareness" by letting $s = s_0\chi(\rho)$
- We can arbitrarily scale s_0 such such that the minimum of χ is 1, without loss of generality.
- We assume χ is convex, bounded and differentiable on $[0, 1]$
- Since ρ is itself a function of s, the steady state values are the solution to the coupled equations,

$$\bar{s} = \bar{s_0}\chi(\rho)$$
$$\rho = \frac{1}{\lambda \bar{s}}$$

Multiple Operators

- With multiple operators we are free to choose a solution.

- The optimum can be expressed as a straightforward convex optimization problem

$$\begin{aligned} \min_{\{\rho_1,\ldots,\rho_n\}} \quad & \textstyle\sum_{i=1}^{n} \rho_i \chi(\rho_i) \bar{s_0} \\ \text{s.t.} \quad & \textstyle\sum_{i=1}^{n} \frac{\rho_i}{\bar{s_0}\chi(\rho_i)} = \lambda \\ & 0 \le \rho_i \le 1, i = 1, \ldots, n. \end{aligned}$$

Situational Awareness under Heavy Load

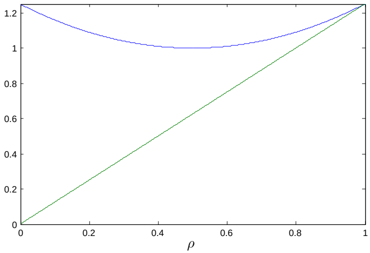
The results presented for the heavy load case are based on queuing arguments that require system stability and do not necessarily carry over.

- For fixed $\bar{s}$, stability is equivalent to $\rho_h < 1$.
- With variable $\bar{s}$, this is not necessarily sufficient

Two Cases for Real-World χ

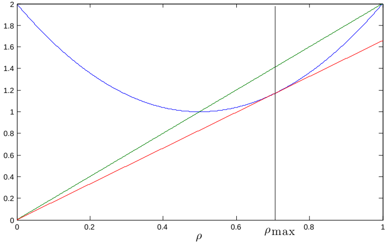
If $\frac{d\chi(1)}{d\rho} \leq \chi(1)$

- $\rho_h < 1$ is sufficient for stability
- previous heavy load results hold



If $\frac{d\chi(1)}{d\rho} > \chi(1)$

- $\rho_h = 1$ is not optimally productive
- there exists some $\rho_{\text{max}} < 1$ such that $\rho_h \leq \rho_{\text{max}}$ is necessary for stability

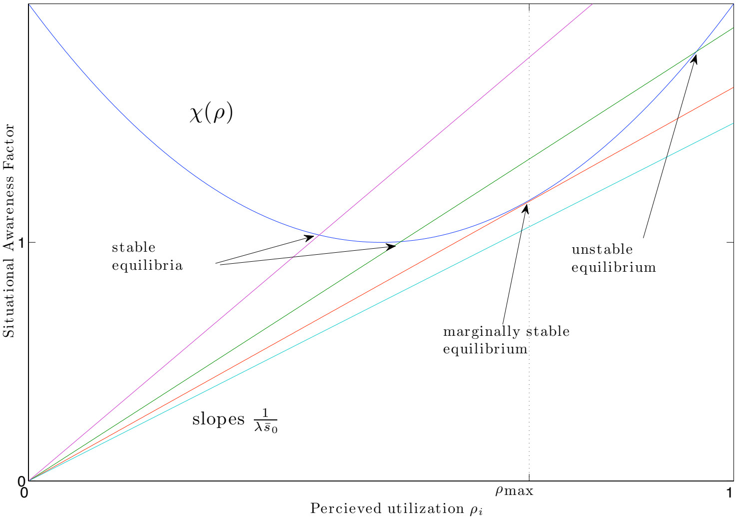


Perceived load, $\tilde{\rho}$

- Defining Situational Awareness in terms of average load, assumes that the operators know the average load a priori.
- A more realistic model would define Situational Awareness in terms of *perceived* load, $\tilde{\rho}_i$ which is estimated by operator i.
- The "error" in this estimation is another potential source of instability.

Estimation Stability

Equilibrium Conditions for Operator i



Decision Support Implications

- We need to carefully manage the perceived operator loads if we are to guarantee system stability.
- If for operator i, $\tilde{\rho}_i > \rho_{\text{max}}$, then we need to give him a break, even if there are outstanding targets.
- Corresponds to previous results with

$$n' \leftarrow n\rho_{\text{max}} \text{ and,}$$
$$\rho'_h \leftarrow \rho/\rho_{\text{max}}.$$

Summary

"Efficient routing of multiple vehicles for human-supervised services in a dynamic environment," *AIAA GNC*, Aug 2008.

- Addressed how "situational awareness" affects system performance
- Identified queue stability conditions in heavy load
- Determined how and when previous results can be used.

Future Work

- Vanishing targets (customer impatience).
- Vehicles with finite capacity e.g. fuel, range, memory.
- Alternate support system architectures allowing more involvement by human operators in the mission tasks.