On Predicting System Performance, System Wait Times, and Operator Workload of Human-UV teams

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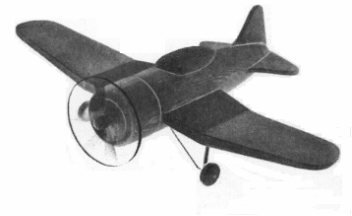
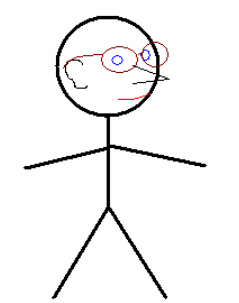
Futuristic Systems

- A few operators controlling lots of UVs





Assume one human controlling multiple homogeneous UVs

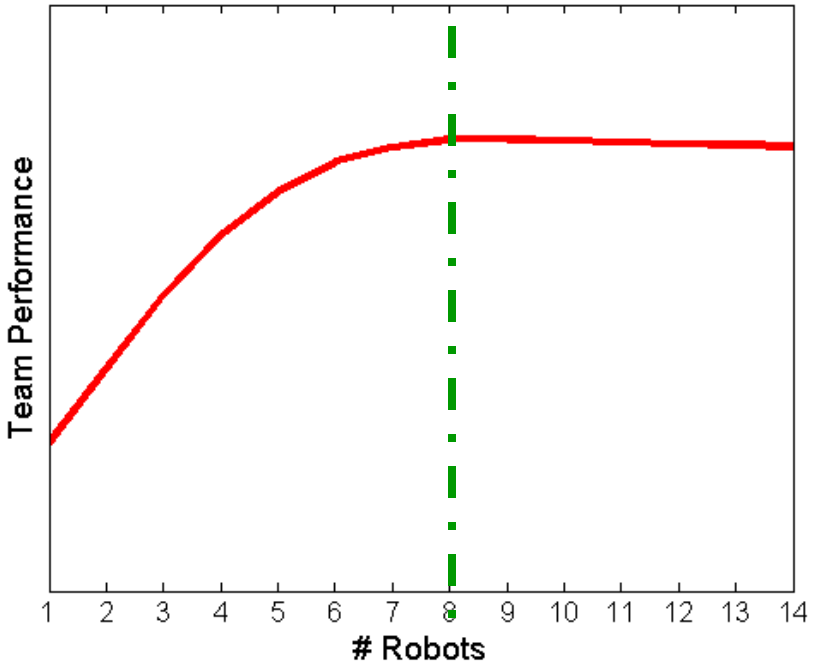
Research Objective

- Measure stuff
  - System Performance
  - Individual UV effectiveness
  - Operator Workload
- Identify key performance parameters
  - Use to improve system design
- Develop measures that predict how various factors affect system characteristics
  - e.g., What happens to system performance and operator workload when the operator is asked to control more UVs?

Fanout

- Definition:

  The number of robots a human operator(s) can *effectively* control?



Fanout can be viewed in 2 ways:

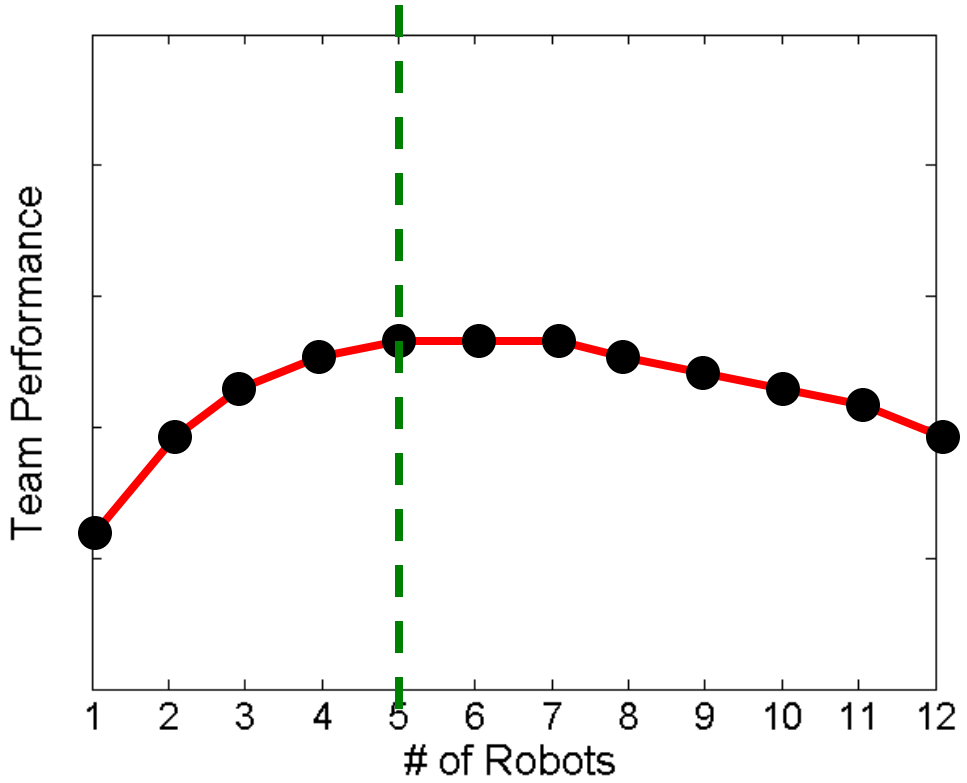
1. How many robots can we add until performance plateaus/declines?
2. How many robots are needed to obtain a desired level of performance?

Why Fanout?

- If we can construct predictive measures of fanout, we can
  - Make more informed design decisions
  - Employ adaptive automation more effectively
  - Determine what kind of team we should use to accomplish a mission

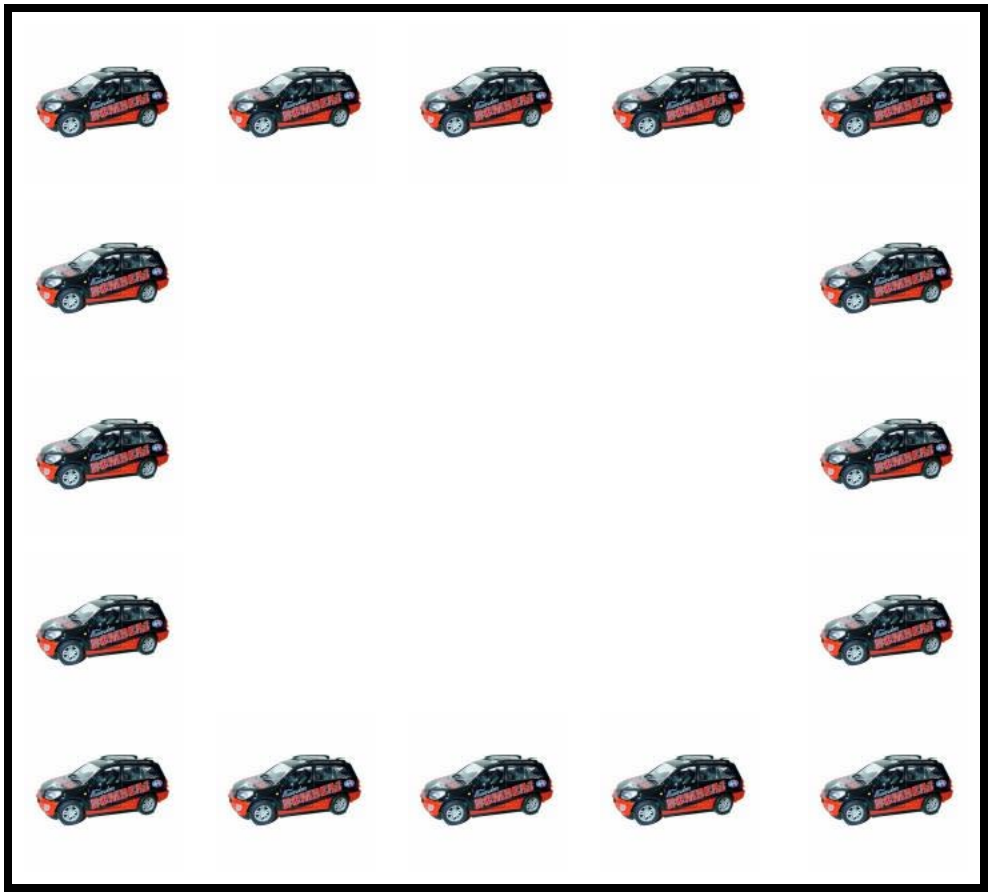
Measuring Fanout

- Methods
  - Brute Force



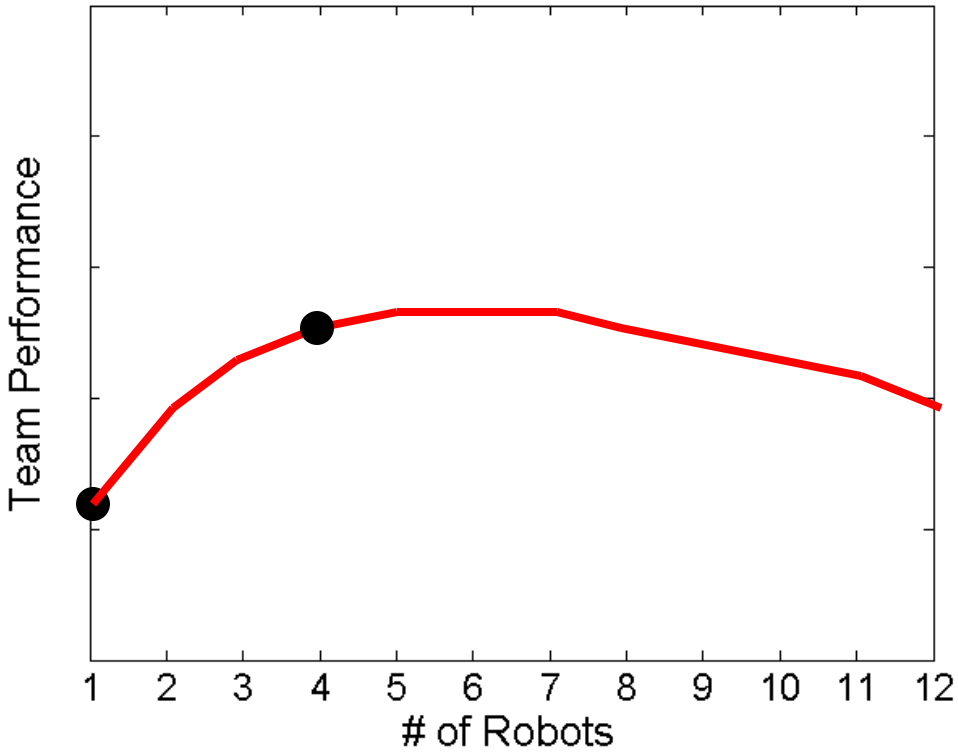
Measuring Fanout

- Methods
  - Brute Force
  - Inundate the system (Wood & Olsen, 2004)
    - See how many UVs human uses



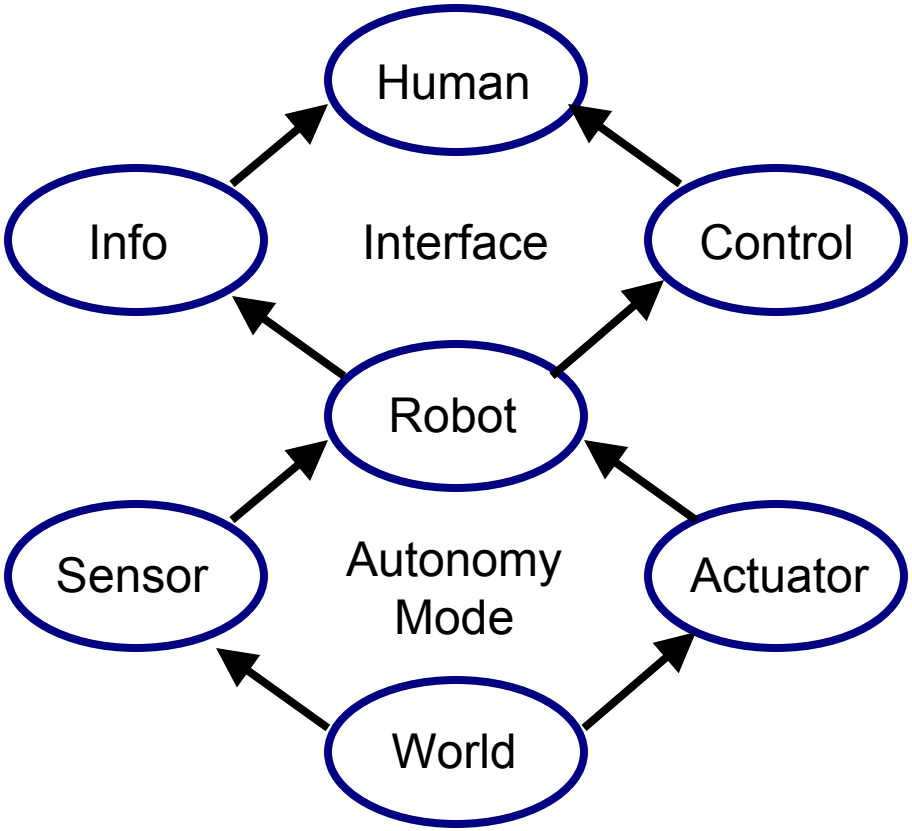
Measuring Fanout

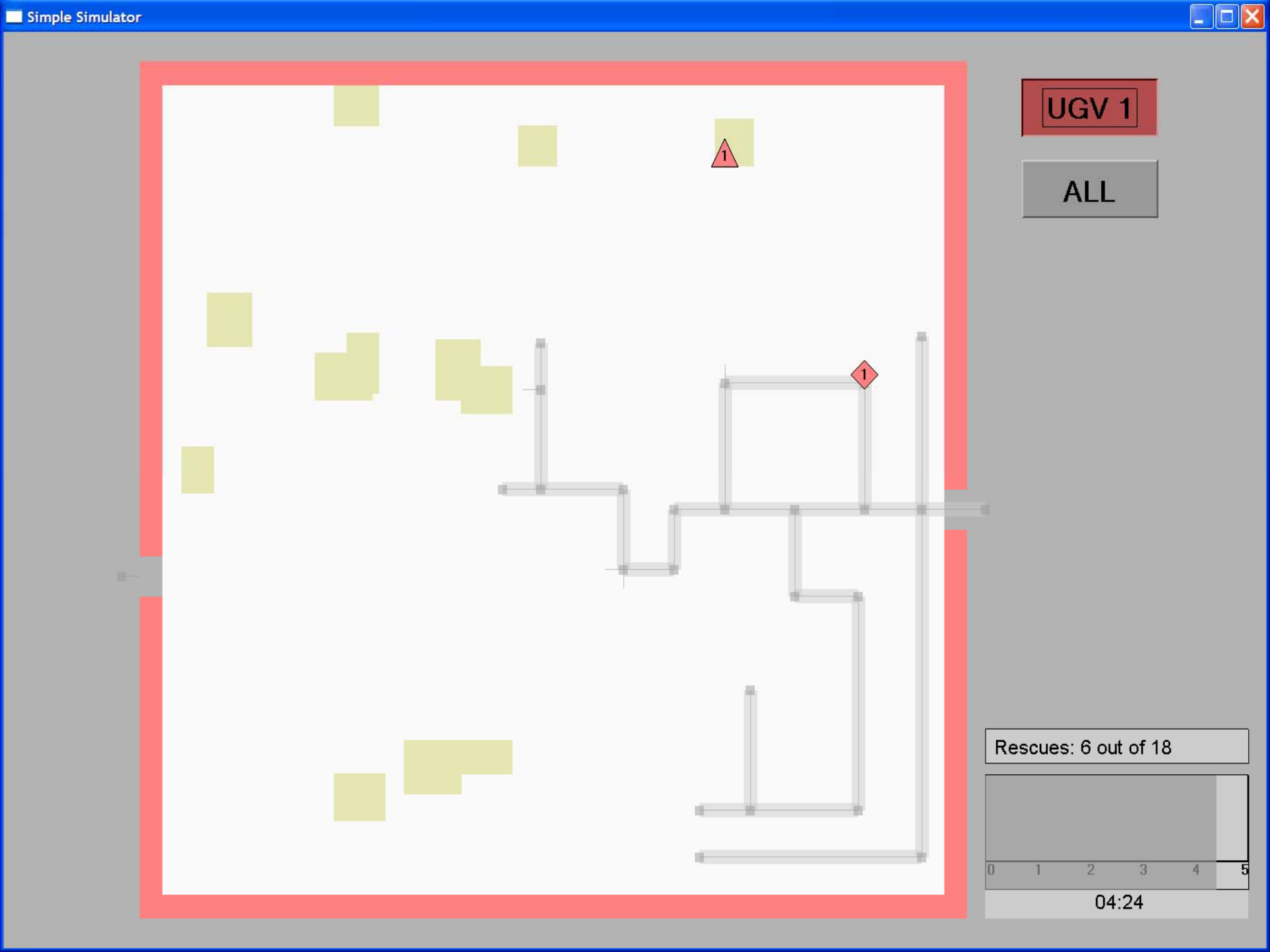
- Methods
  - Brute Force
  - Inundate the system
  - Measure a little and predict effectively

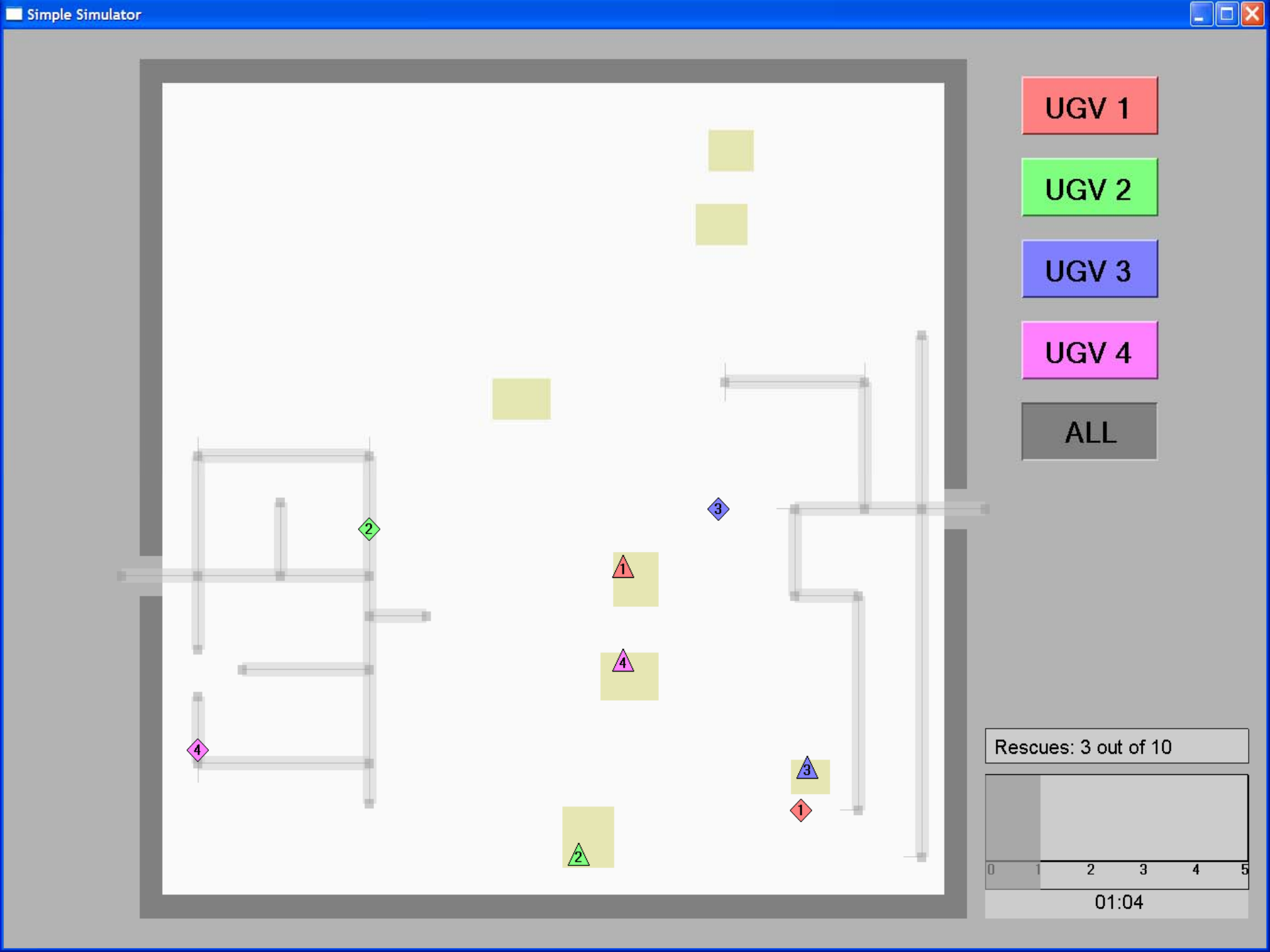


Develop a Theory

- Interaction scheme
  - Human
  - Robot
    - Autonomy Mode, etc.
  - Interface
- Team Configuration
  - Combination of interaction schemes
- Improve fanout by improving
  - interaction scheme
  - the interaction between the interaction schemes

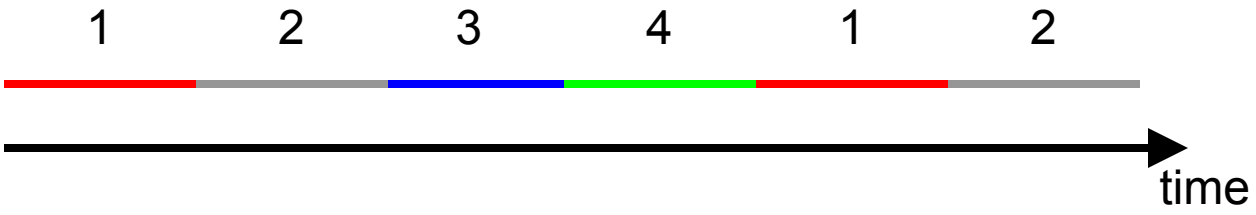



Simple Simulator
UGV 1
ALL
1
1
Rescues: 6 out of 18
0
1
2
3
4
5
04:24


Simple Simulator
UGV 1
UGV 2
UGV 3
UGV 4
ALL
Rescues: 3 out of 10
0
1
2
3
4
5
01:04

Theory of Fanout

- Operator switches her/his attention between robots



- Each robot's time is divided in to
  - Interaction time (IT) when human gives it its attention
  - Neglect time (NT) when human ignores (neglects) it

Fanout Equation

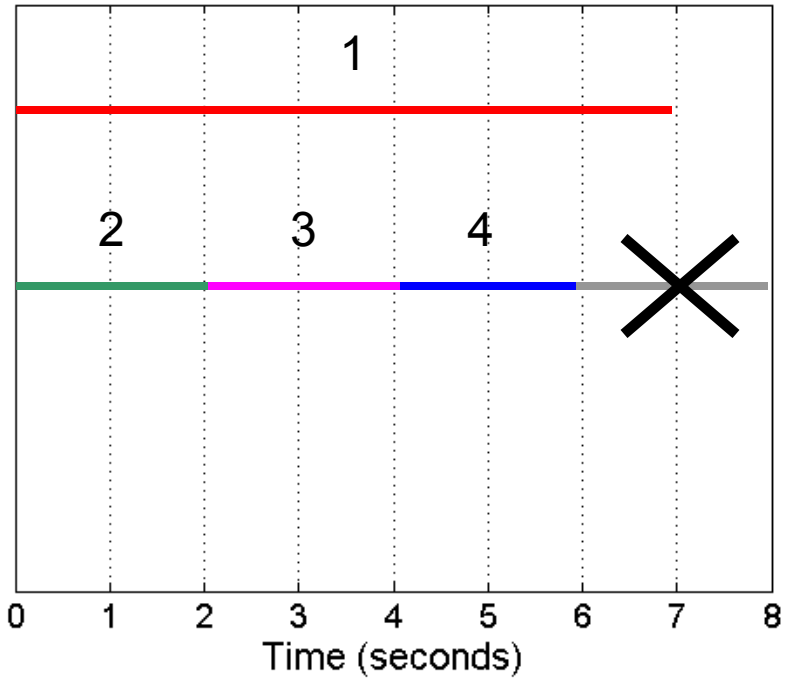
(Olsen & Goodrich, 2003)

$$FO = \left\lfloor \frac{NT}{IT} \right\rfloor + 1 = \left\lfloor \frac{NT + IT}{IT} \right\rfloor$$

Example

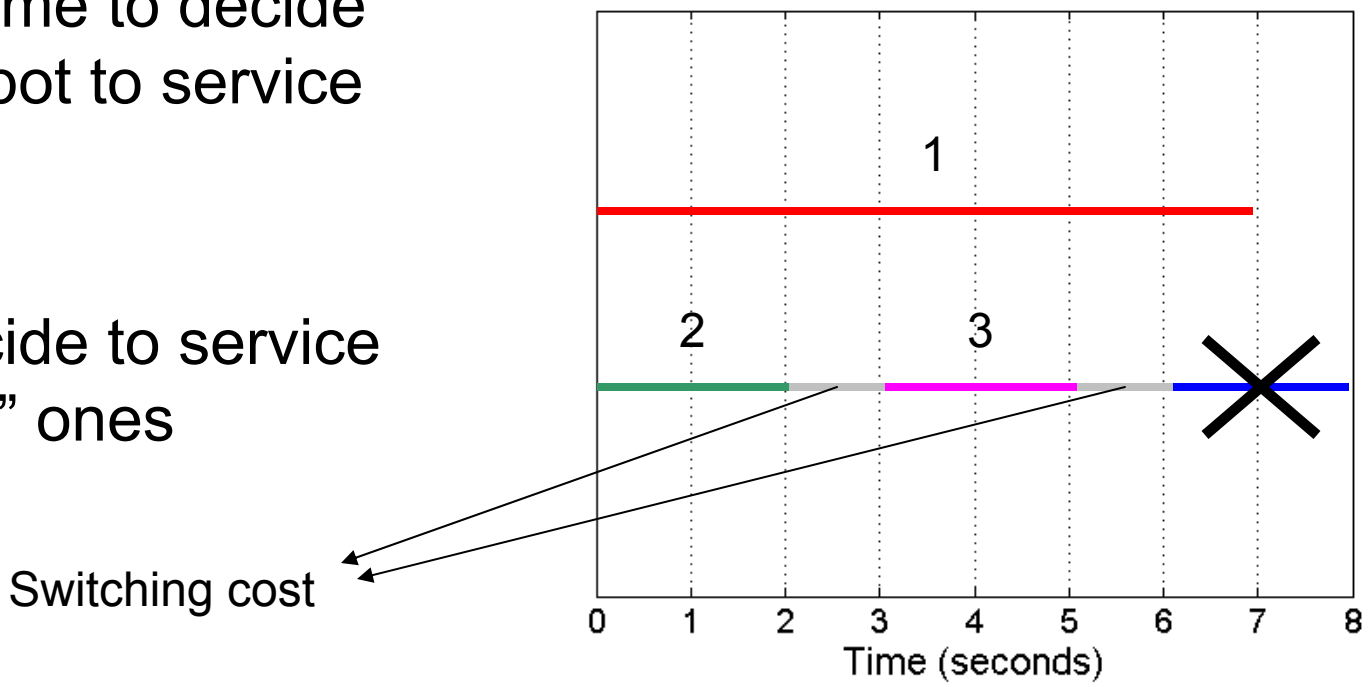
NT = 7 seconds
IT = 2 seconds

$$FO = \left\lfloor \frac{NT}{IT} \right\rfloor + 1 = \left\lfloor \frac{7}{2} \right\rfloor + 1 = 4$$



Switching Costs

- It takes time to decide which robot to service next
- Must decide to service the “right” ones



We can assume switching costs are part of IT

- IT changes with the number of robots

Fanout Equation

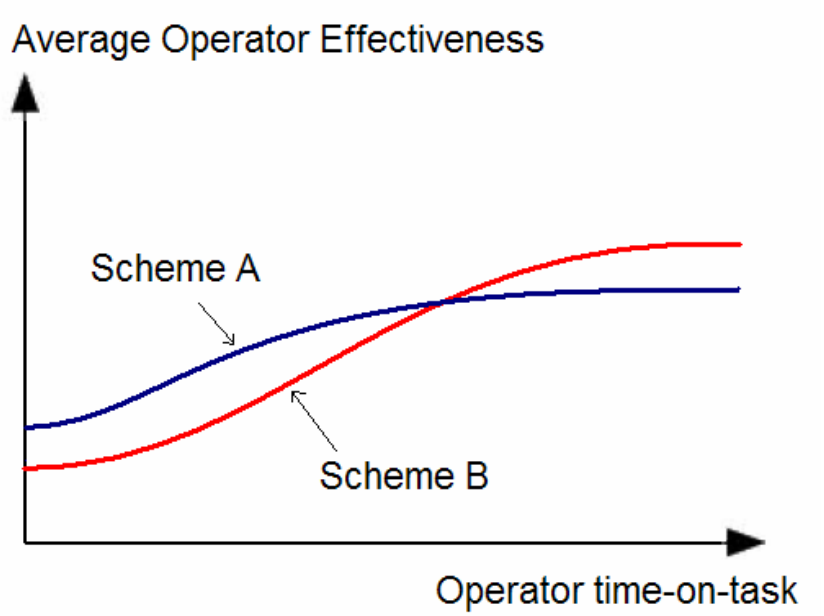
(Olsen & Goodrich, 2003)

$$FO = \left\lfloor \frac{NT}{IT} \right\rfloor + 1 = \left\lfloor \frac{NT + IT}{IT} \right\rfloor$$

- To increase fanout, increase NT or decrease IT
  - Do this improving aspects of the interaction scheme
    - Interface
    - Robot autonomy (may need to switch to different level of automation)
  - Or, increase training
- So IT and NT must be tied to performance

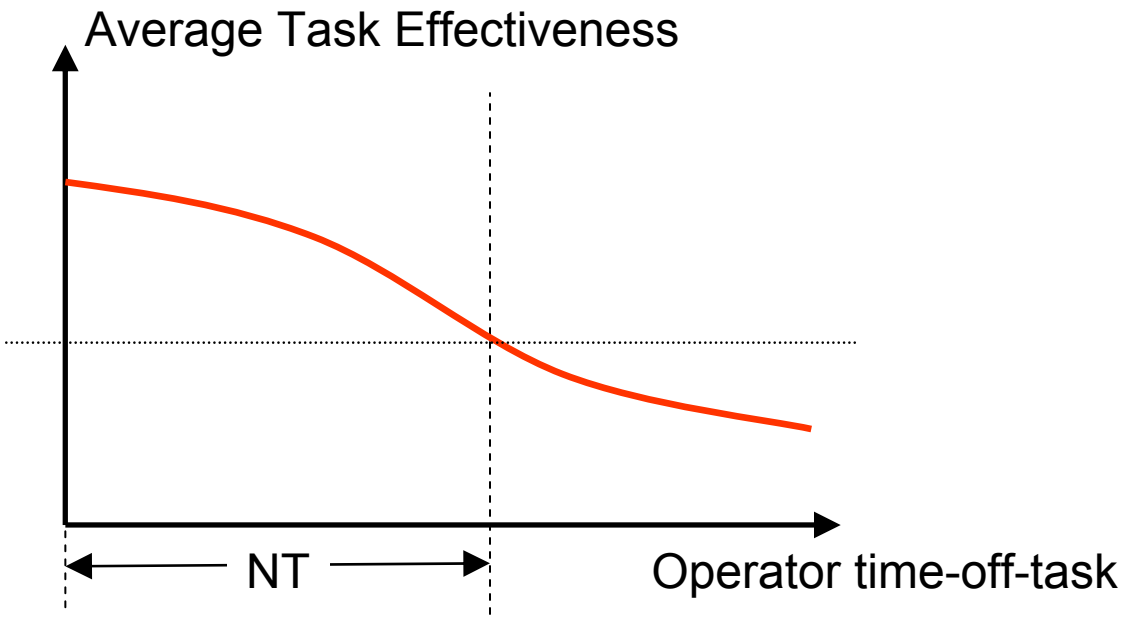
Interface Efficiency (IE)

- Describes a robot's effectiveness as the operator interacts with it.
  - Function of *Operator time-on-task*
- Helps determine interaction time (IT)?



Neglect Impact (NI)

- Describes how the robot's effectiveness changes as the operator *neglects* it.
  - Function of operator time-off-task
- Determines "acceptable" NT



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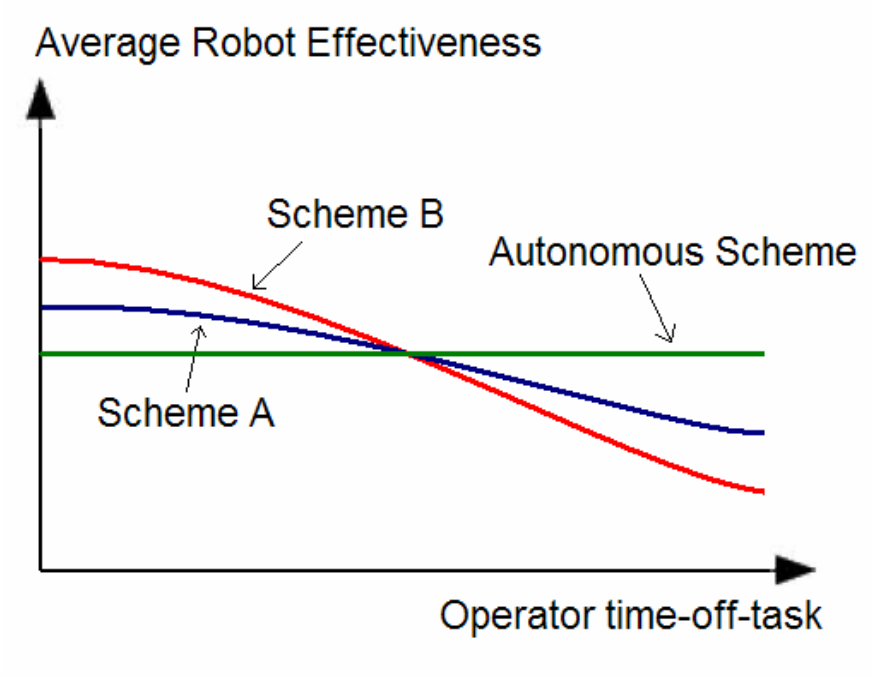
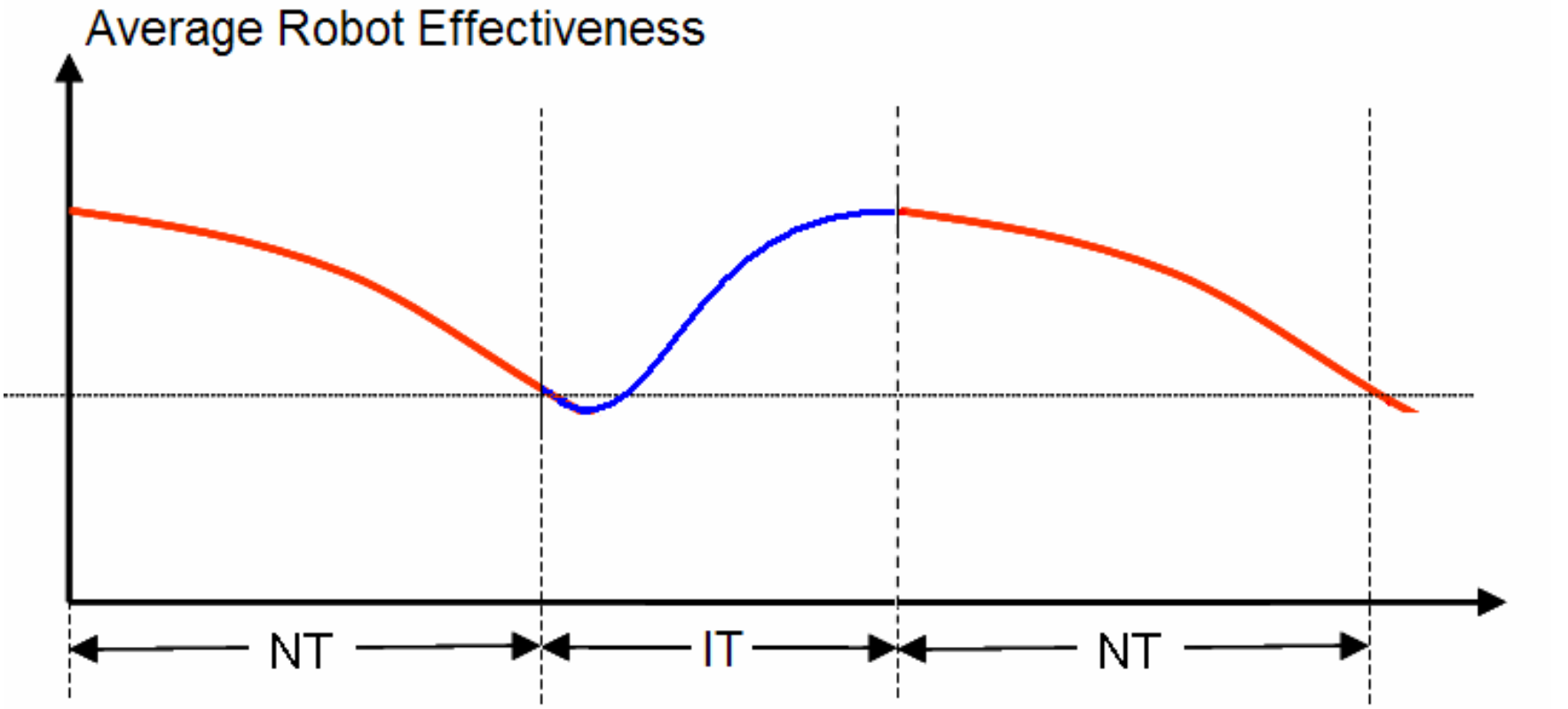


Putting It Together



Attention Allocation Efficiency

- What is the proper NT?

Four Elements

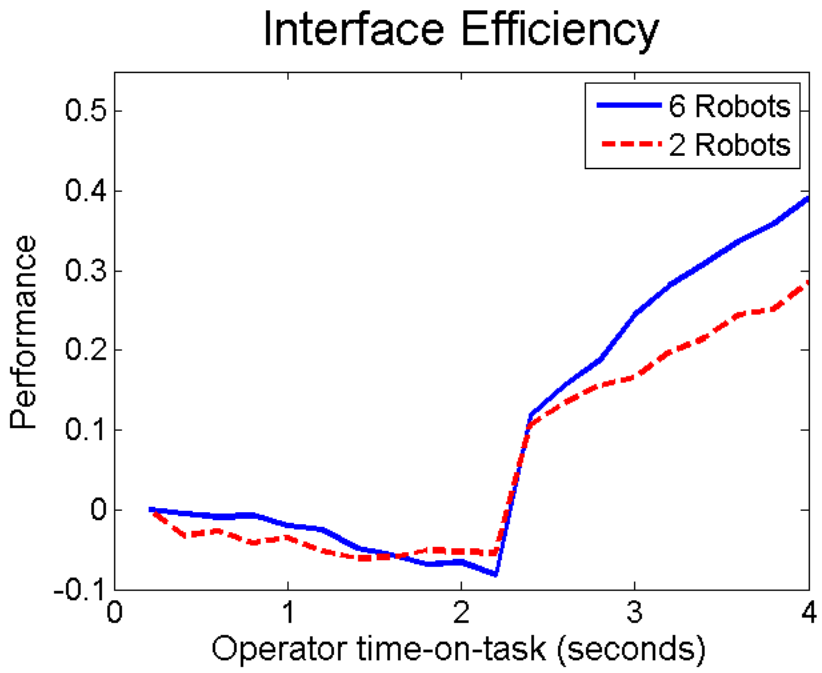
- Interface Efficiency
- Neglect Impact
- Attention Allocation Efficiency
- Task Allocation Efficiency

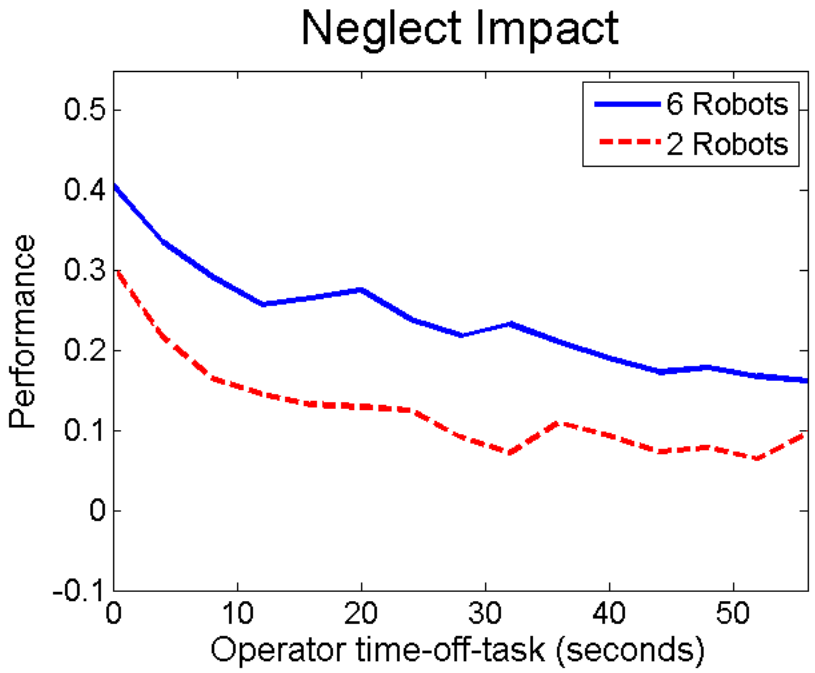
If we have accurate measures of these elements, we can construct the fanout curve

How is each component affected by increasing number of UVs?

Information

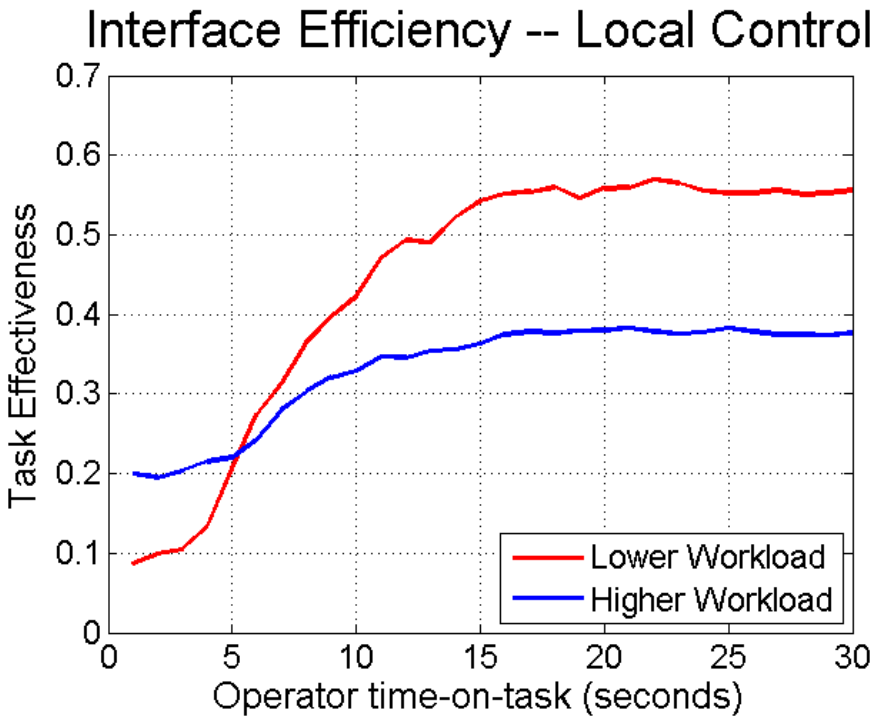
Robots shares discovered map of the “building”, so increasing number of robots can increase interface efficiency and neglect impact

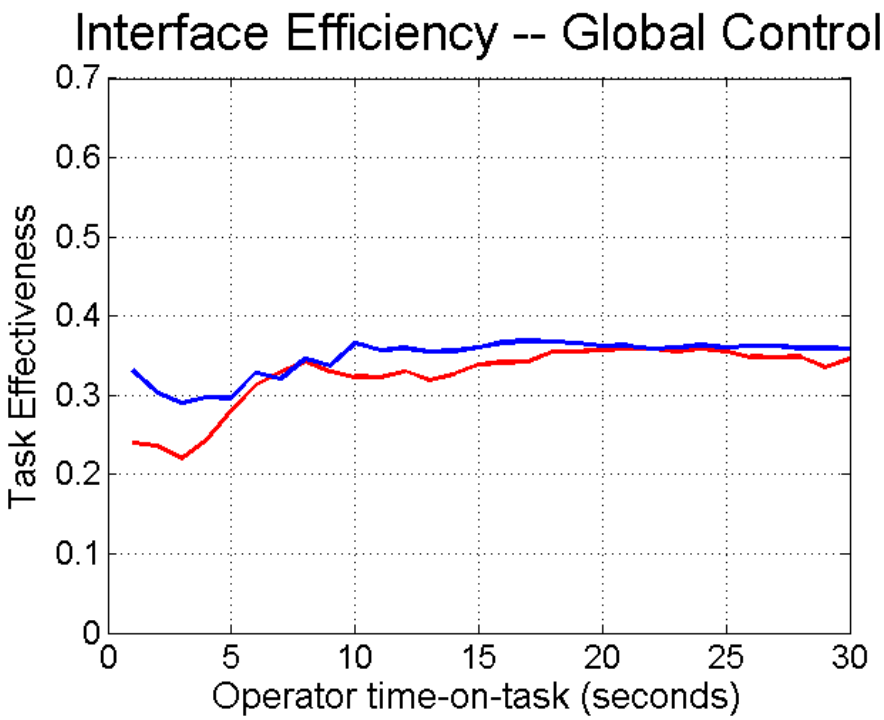




IT and NT change as # of robots changes. Must predict change.

Effects of Workload





Workload Tolerant

Other Factors

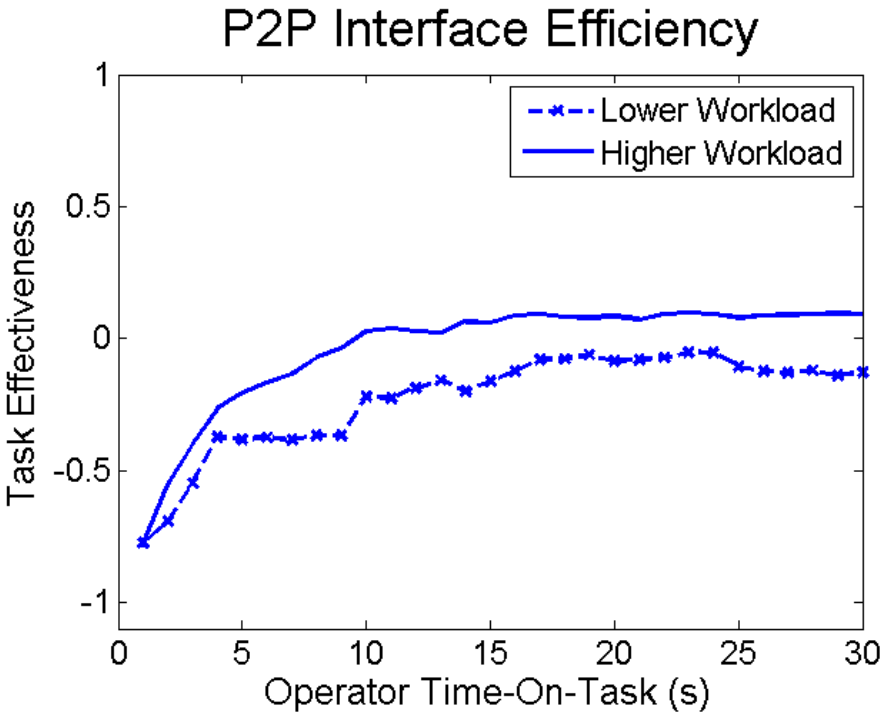
- Other factors that change measures
  - Complexity
    - World, display
  - Task priority
  - Operator skill and training
  - Nature of other tasks

Summary

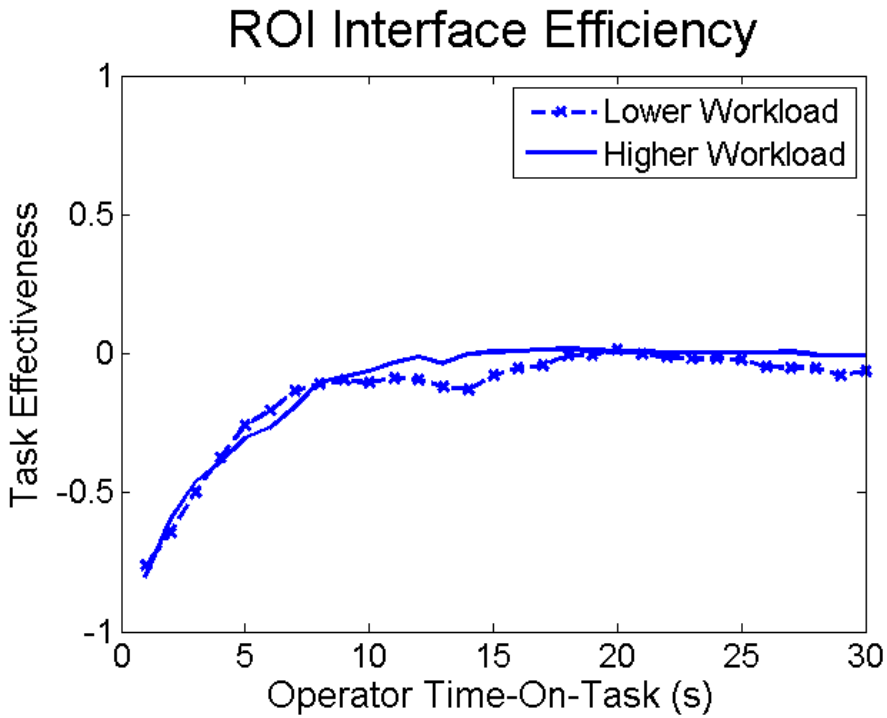
- Started on path to measure fanout efficiently
  - Book chapter to further work coming shortly
- Future Work
  - Investigate *wait times*
  - Lots more

Cost of Workload

When robot performance was “low”



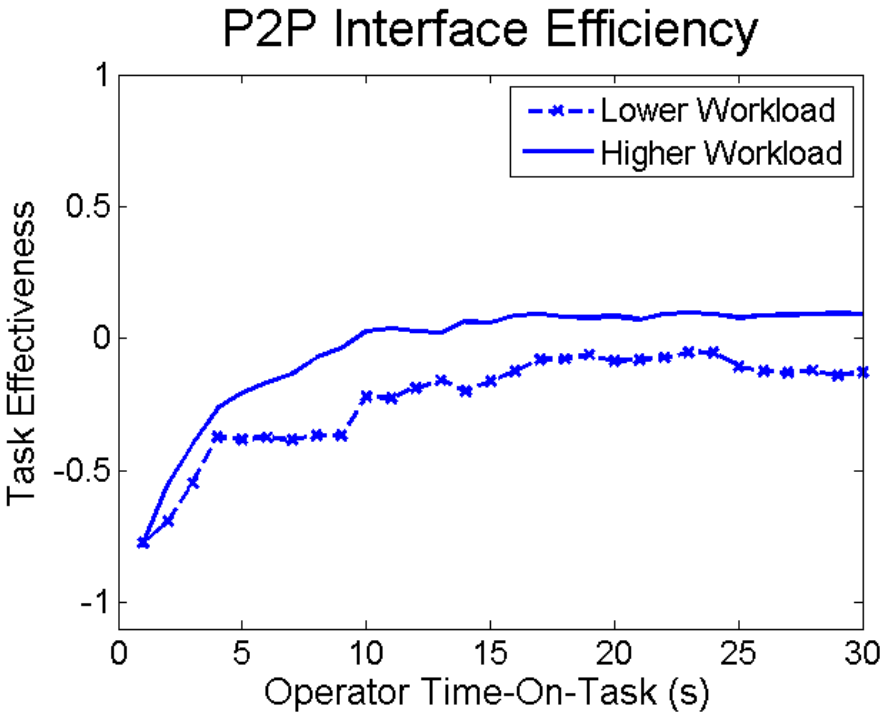
Local Control

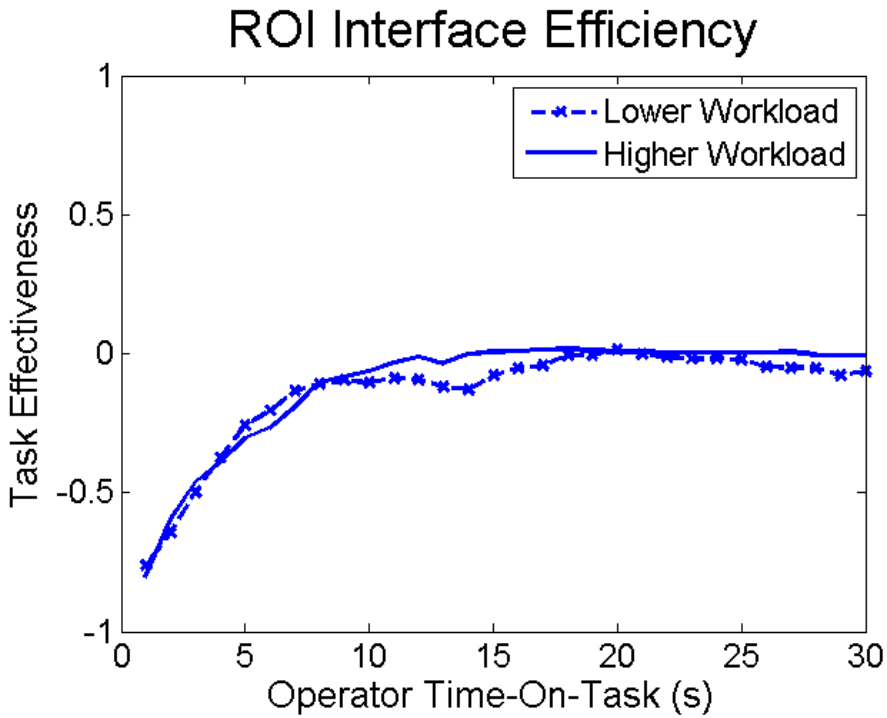


Global Control

Cost of Workload

When robot performance was “low”

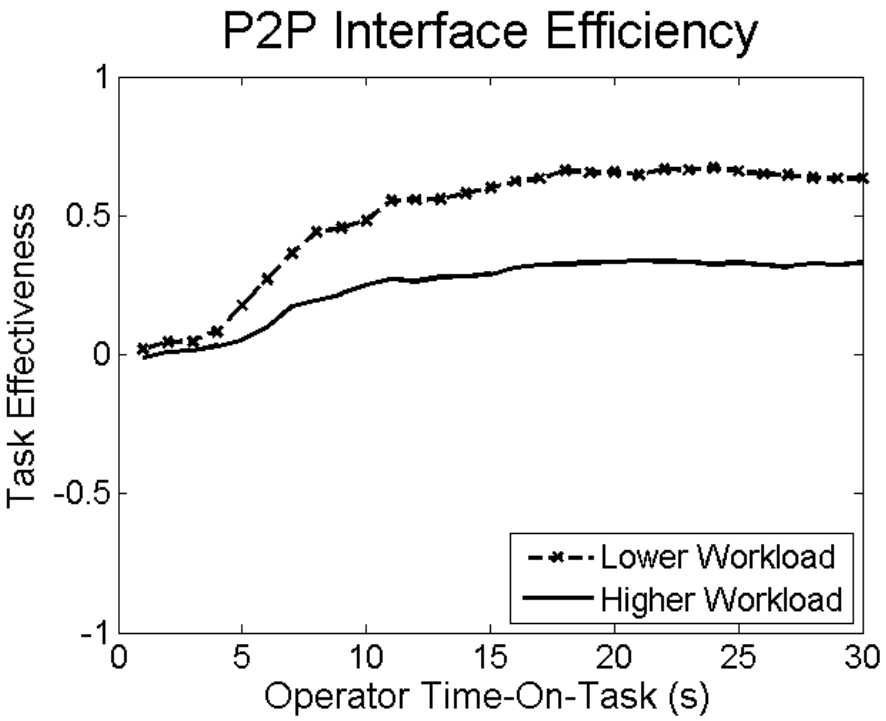




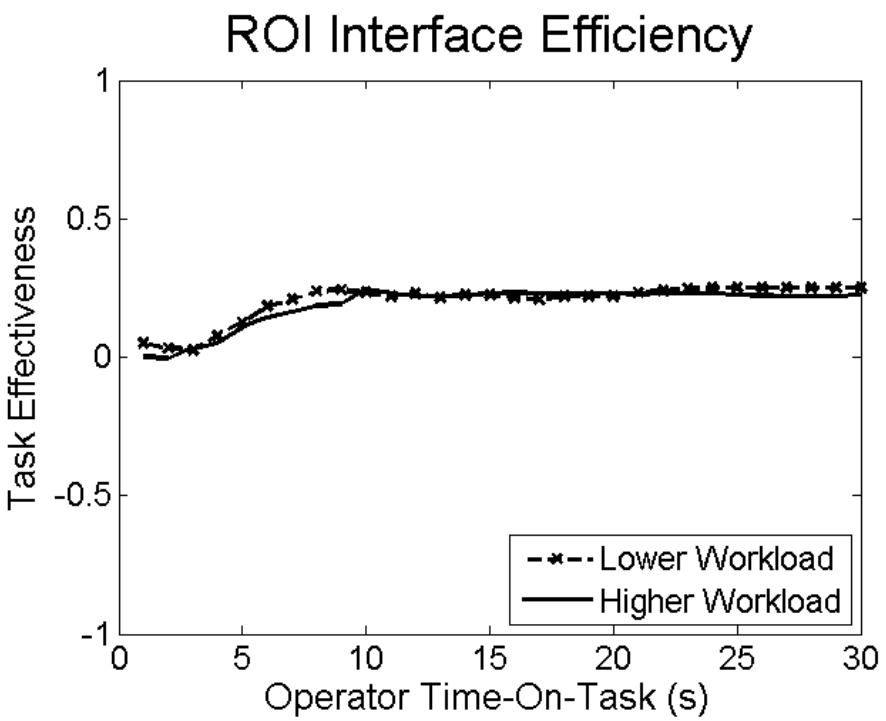
Workload Tolerant Interaction Schemes

Cost of Workload

When robot performance was “medium”



Local Control



Global Control

Value of Adding a Robot

- Value of adding a UV to a system:

$$V_{Add} = V_{Work} + V_{Information} - Cost_{Workload} - Cost_{Complexity}$$

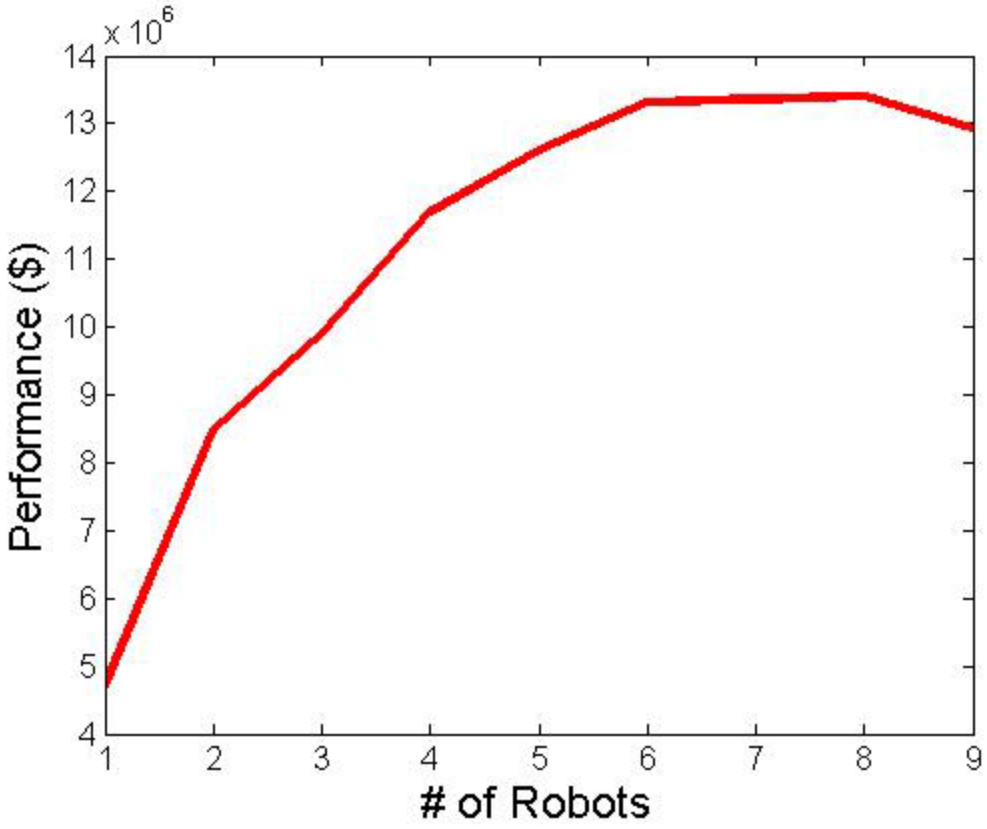
V_{Work} - Work done by the added UV

$V_{Information}$ - Increased performance of other UVs due to the information gathered by added UV

$Cost_{Workload}$ - Decrease in performance of other UVs due to increased neglect times, etc

$Cost_{Complexity}$ - Decrease in performance due to increases in complexity (display and world)

Fanout



Performance = 1M * numRescues – 1M * LostRobots