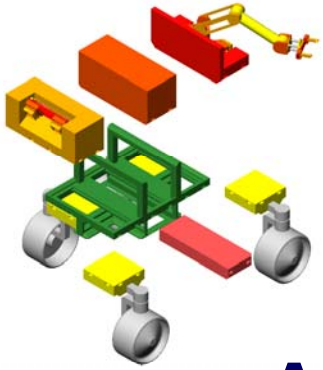

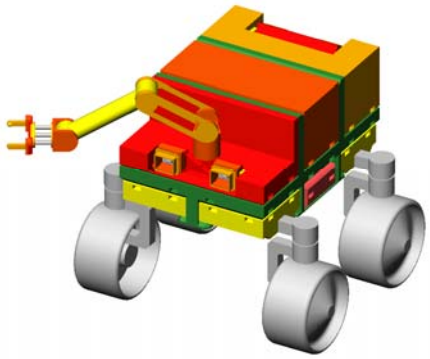

An Analytical Tool for Robot Mission Reliability Prediction

AISR PI Workshop
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THE ROBOTICS INSTITUTE

Overview

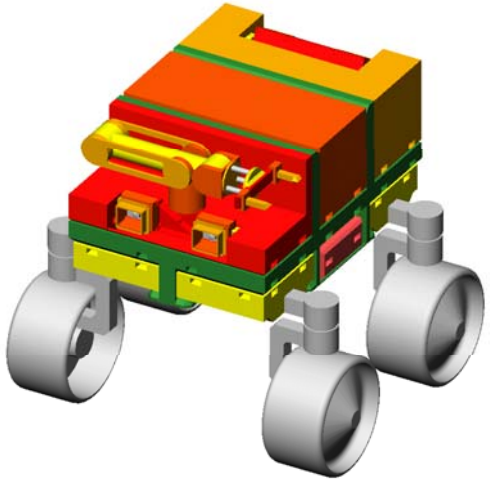
- Motivation
- Approach
- Initial result for solar-panel assembly mission
- Current work
  - Mission taxonomy
  - Application to multirobot task allocation
- Conclusions

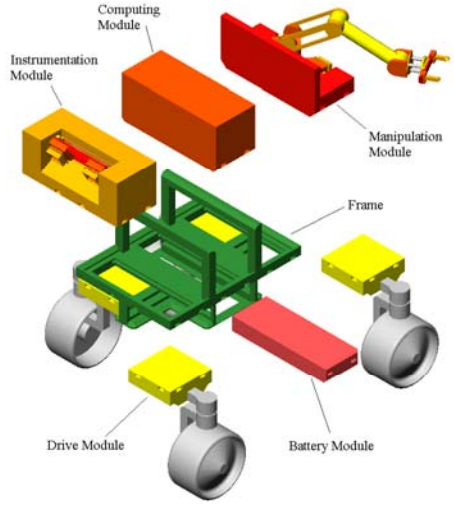
Motivation

- Statements about superior robustness of a greater number of robots are qualitative
- Minimal prior work [Bererton02] on reliability modeling for multirobot missions
- Cost, time, and reliability are interdependent:
  - Team size increase ➔ time reduced **&** *cost higher*
  - Time reduced ➔ reliability requirement lower
  - Reliability lower ➔ *cost lower*
- Be able to answer questions such as:
  - How does team size affect mission cost, duration, and reliability?
  - Is it better to use a larger team of less reliable (cheaper), or a smaller team of more reliable (costlier) robots?
  - How is task allocation affected by considering reliability?

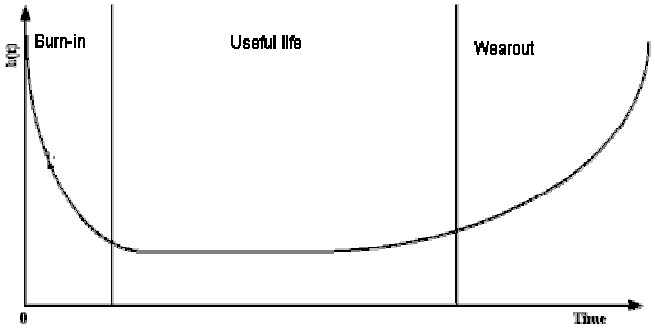
Approach

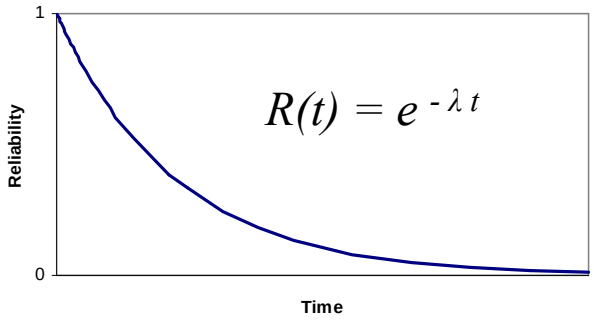
- Robots in remote or harsh environments
- Robots considered in terms of subsystems:





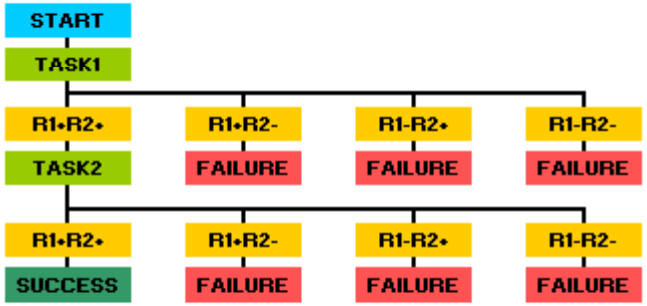
- Hardware failures



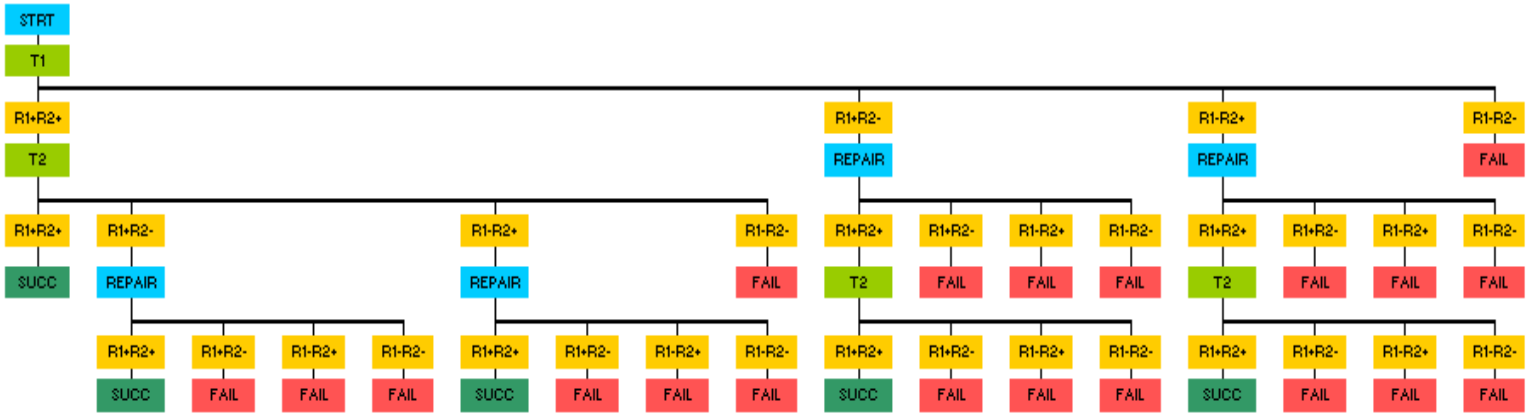


Approach

- Explicit enumeration for a simple mission:



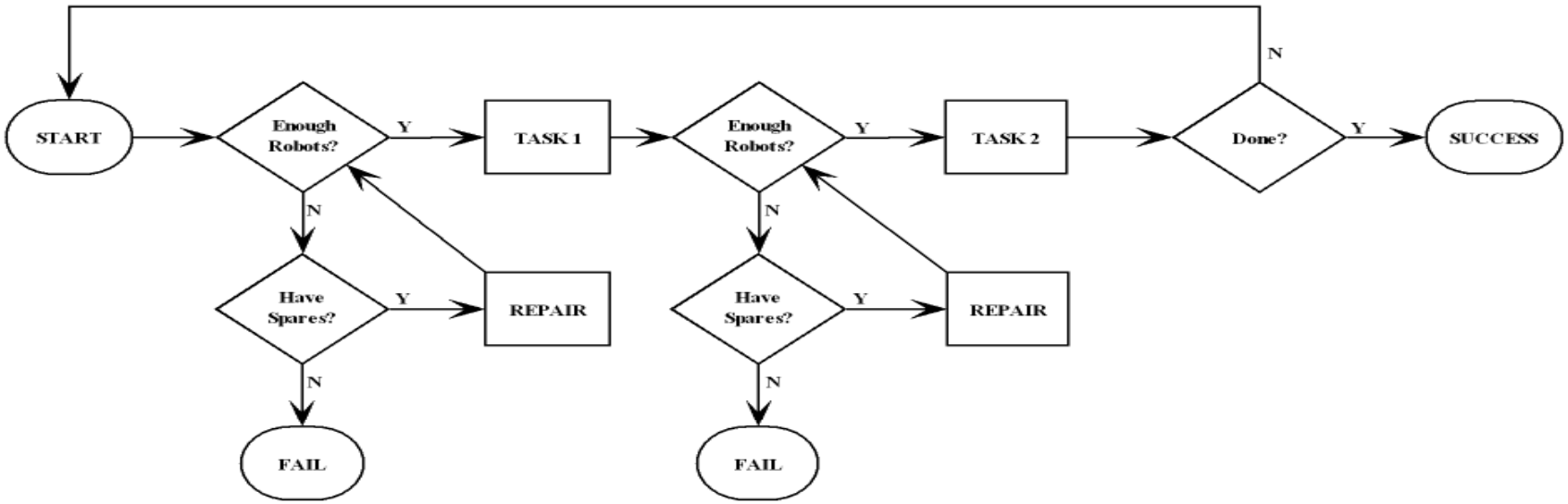
- A slightly more complicated mission:



→ *Combinatorial explosion for missions of any real complexity.*

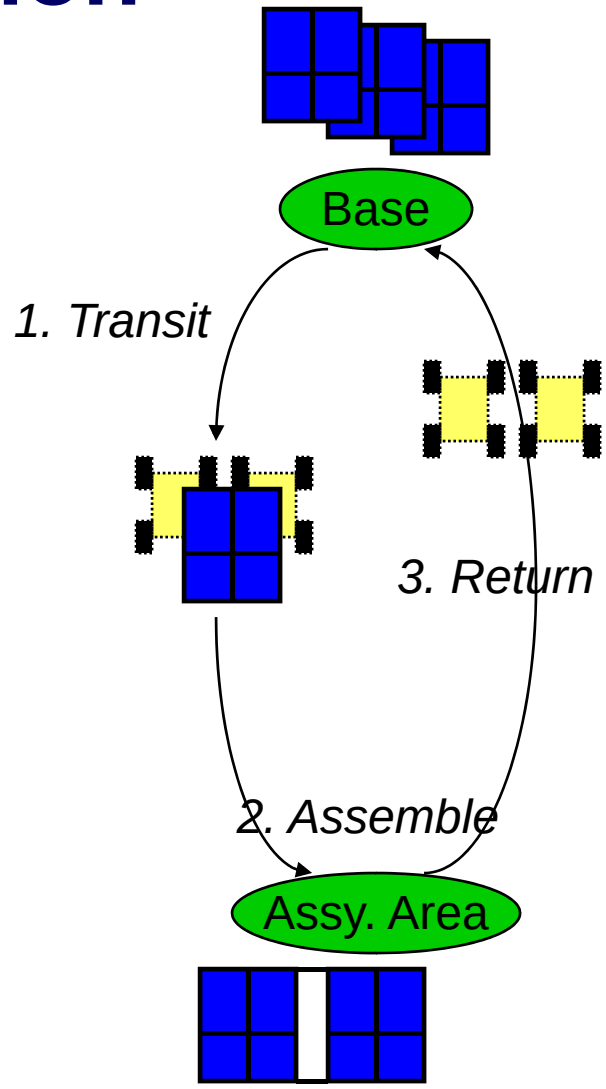
Approach

- Stochastic simulation for more complex missions:



Solar Panel Mission

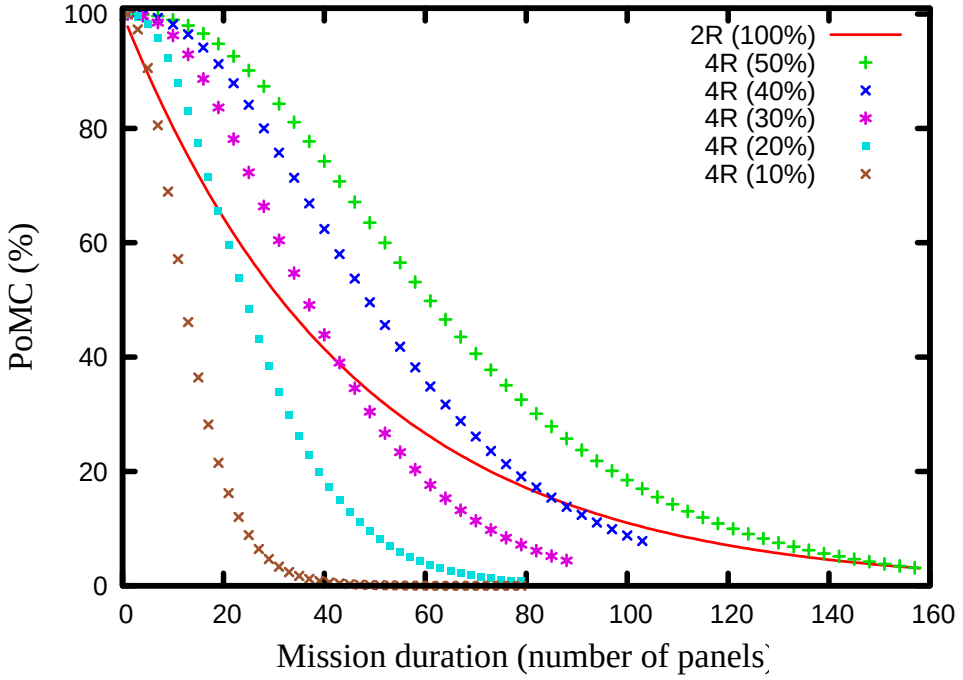
- Solar panel array installation
- Three subtasks
  - Carry the panel to the assembly area
  - Assemble the panel
  - Return to the base
- Mission-design variables
  - Mission duration (number of panels to install)
  - Number of robots
  - Component reliabilities



Solar Panel Mission - Results

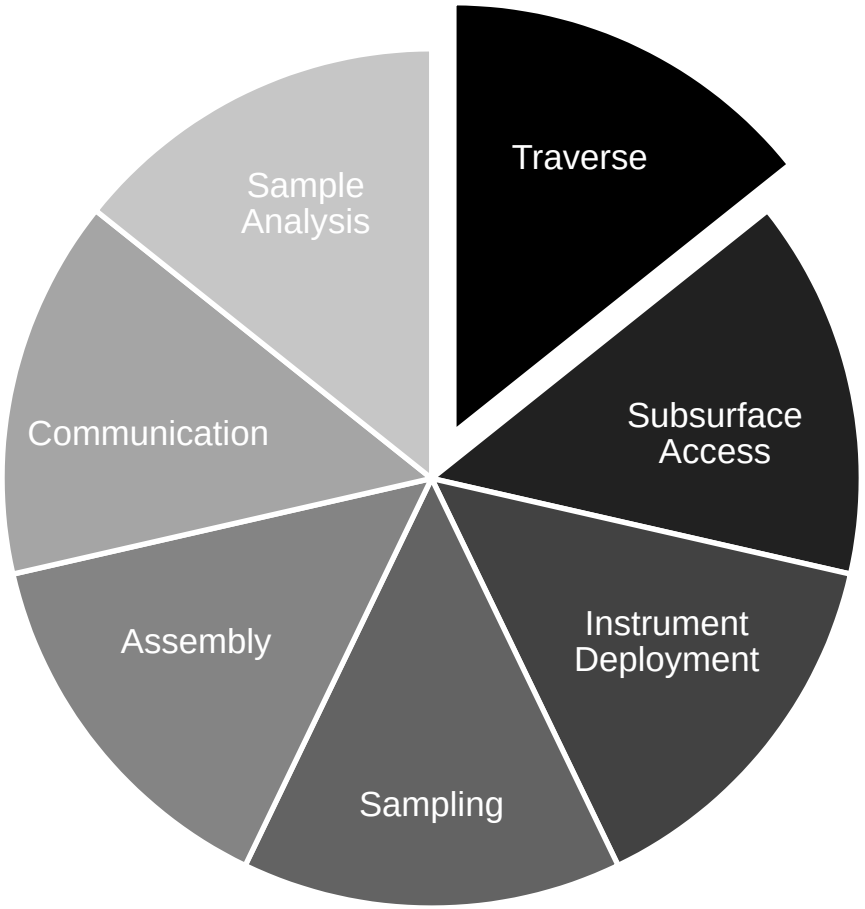
- What's better, more robots with low reliability or fewer robots with high reliability?

→ Lower-reliability 4-robot team has higher PoMC than 2-robot team for mission duration < crossover w/ 2-robot (red) line



Mission Taxonomy

"Basic Activities"

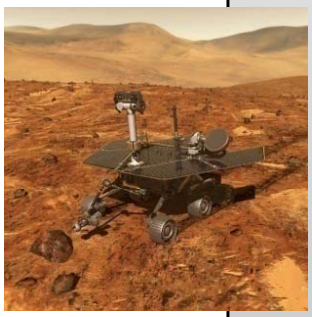


- Different proportions
- Missions with different characteristics
- Different mission class
- Not a fixed boundary

Based on analysis of missions in:
Solar System Exploration Roadmap
(SSER) Mars Exploration Program (MEP)

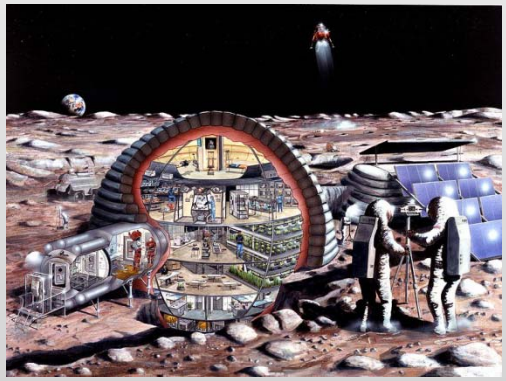
3 Mission Classes

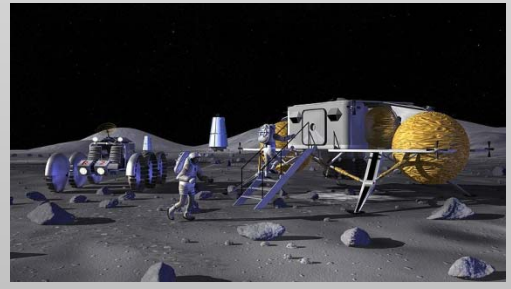
Search & Exploration



Sample Acquisition & Composition Analysis

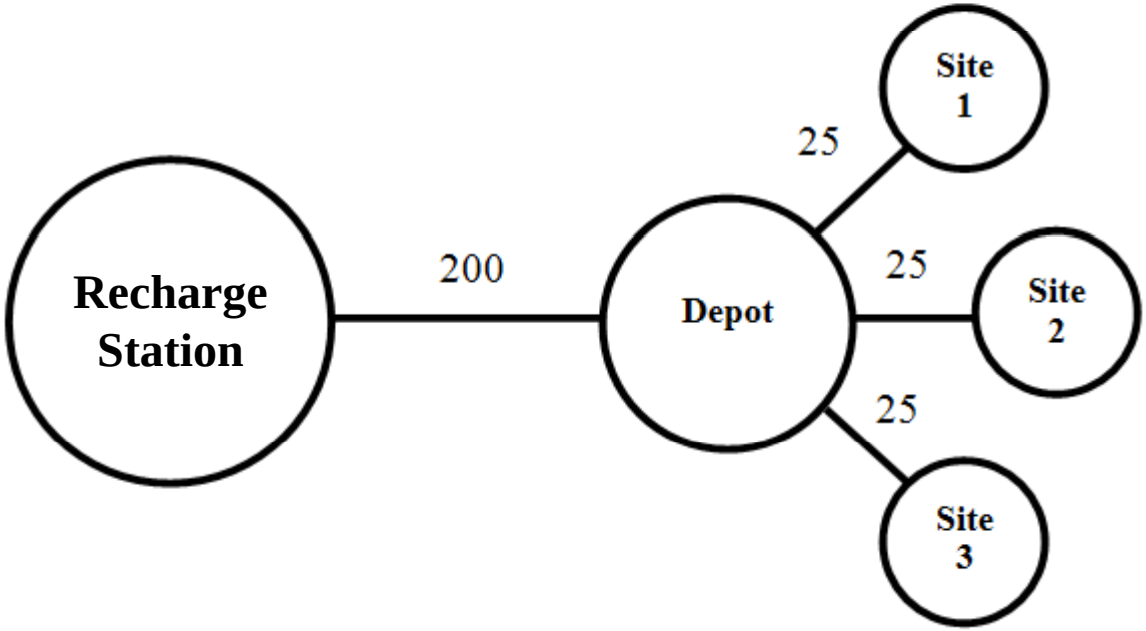
Construction





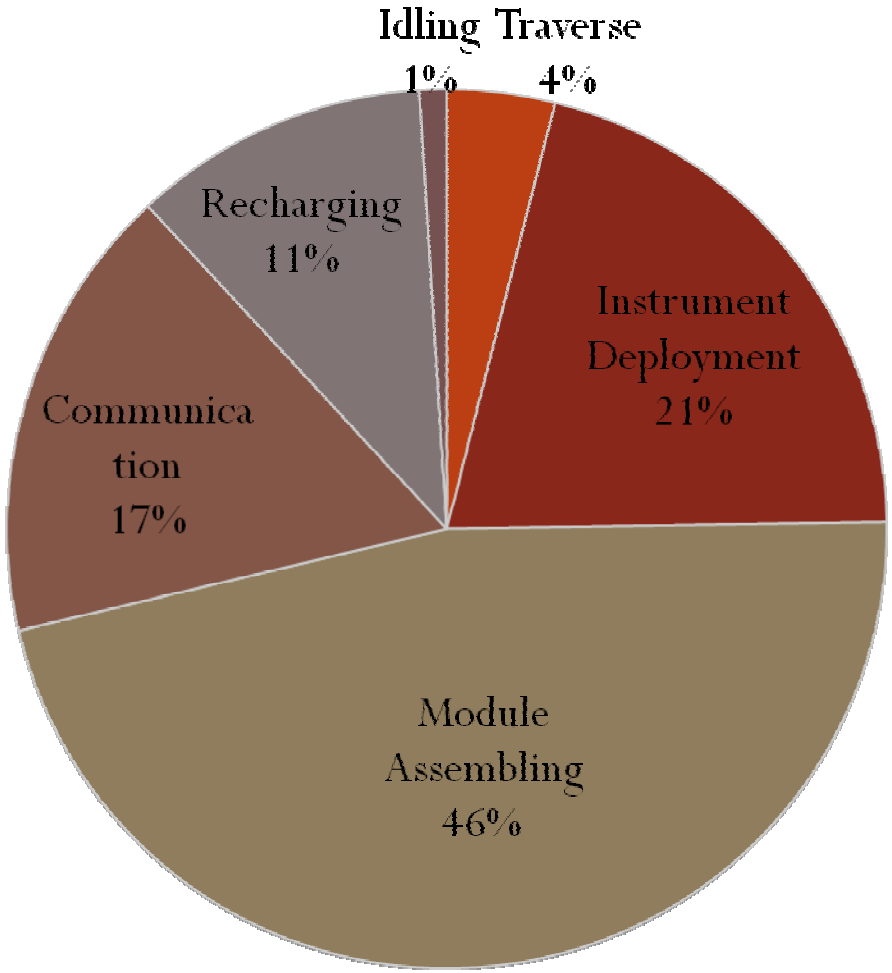
Construction Mission Scenario

- An example:



  - Communicate with other robots after every task
  - Return and replenish battery when needed

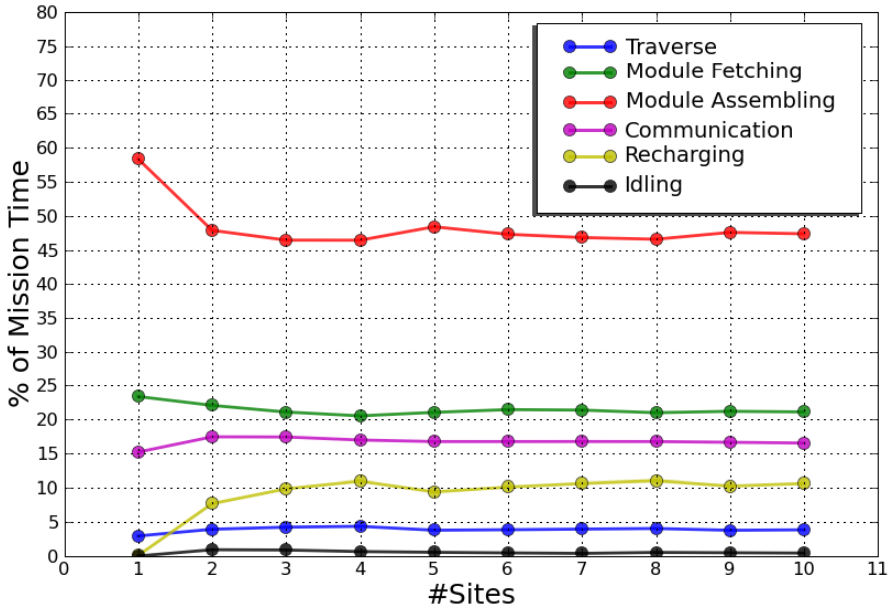
Stability of Construction Mission

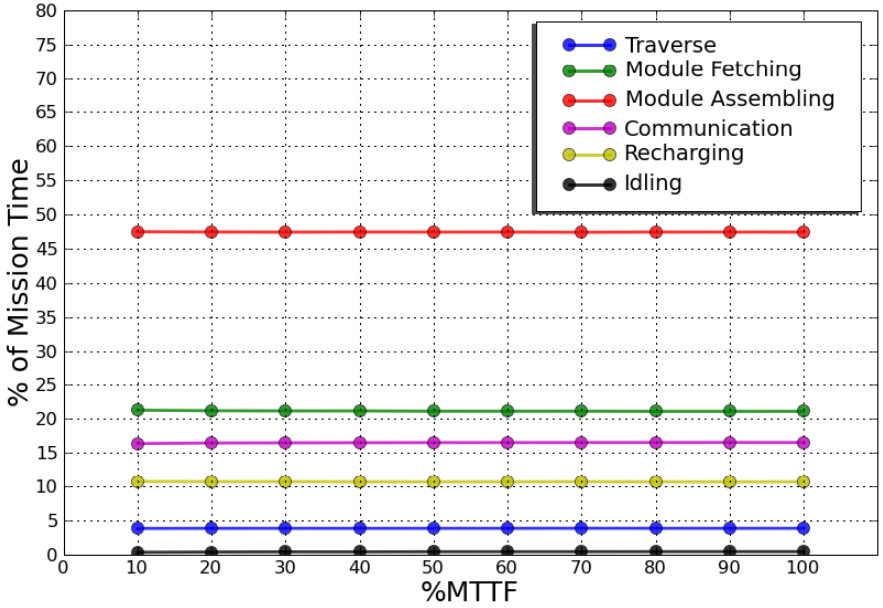


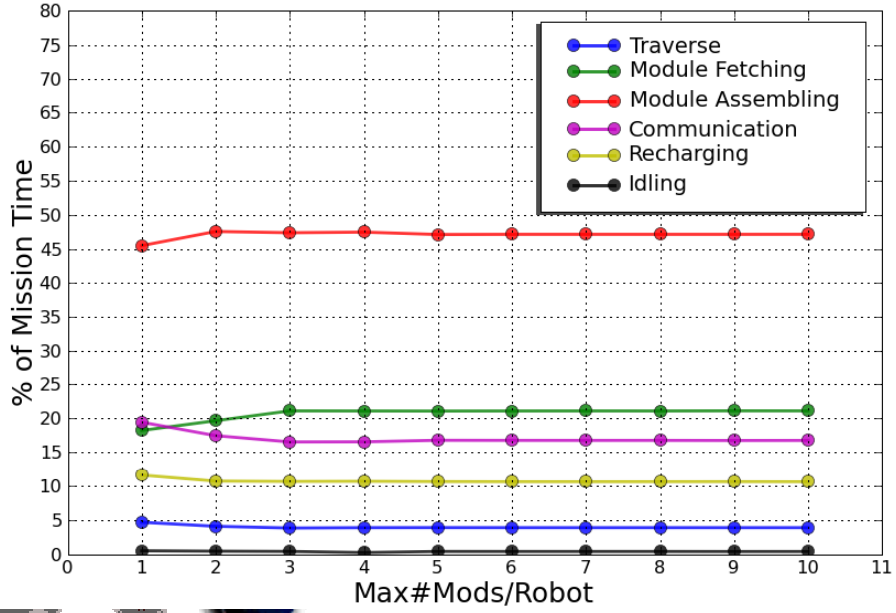
% of Mission Time (±2%)

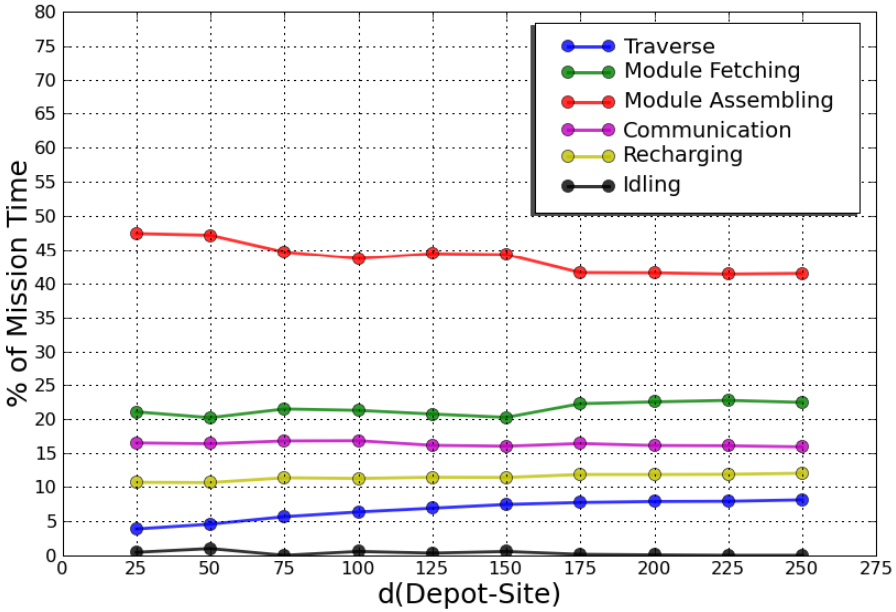
Variable	Value
#Sites	1 – 10
#Mods/site	1 – 10
#Robots	2
#Spare robots	0 – 10
%MTTF	10% – 100%
#Mods/robot	1 – 10
d(RS – depot)	0 – 500
d(depot – site)	25 – 150

Sensitivity Analysis: (#Robots = 2)



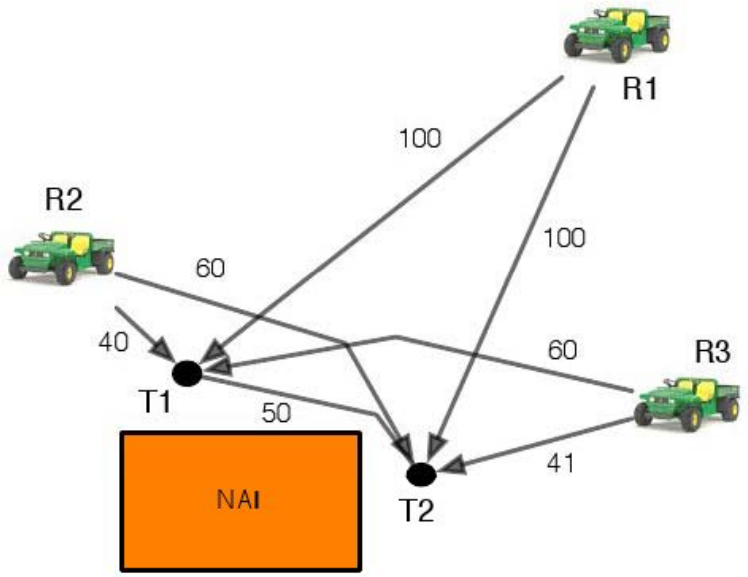






Mission Planning

Multirobot Task Allocation



(d) Example area coverage task.

- Hypothesis - improve plan selection by considering probability of failure *a priori*
- Related work focuses on failure detection and replanning

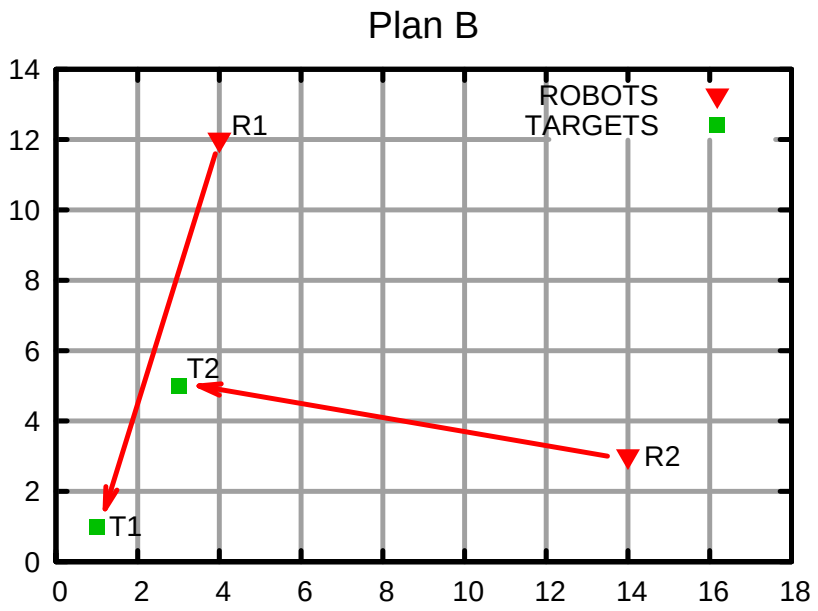
Image from Zlot (2006)

Mission Planning

Task Allocation Example

- Find the plan with the shortest mission duration:
- Homogeneous robots with uniform speed (duration = distance)

Plan		D (R_1)	D (R_2)	D_{max}
A	$R_1T_1 + R_1T_2$	15.9	0	15.9
B	$R_1T_1 + R_2T_2$	11.4	11.2	**11.4**
C	$R_2T_1 + R_1T_2$	7.1	13.2	13.2
D	$R_2T_1 + R_2T_2$	0	17.6	17.6
E	$R_1T_2 + R_1T_1$	11.5	0	11.5
F	$R_2T_2 + R_2T_1$	0	15.7	15.7



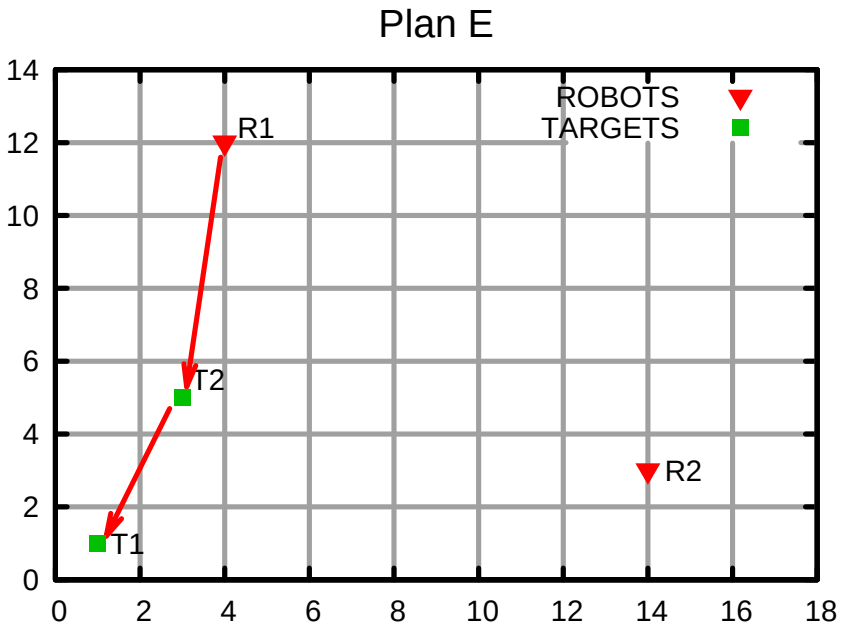
Mission Planning

Expected Value

- Comparison of expected duration with "naive" duration:

$$D_{\text{exp}} = \frac{\sum_i P_i D_i}{\sum_i P_i}$$

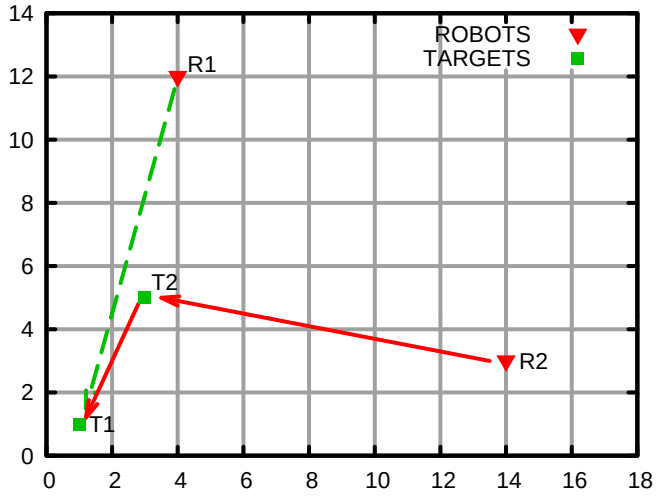
Plan		D	D_{exp}
A	$R_1T_1 + R_1T_2$	15.9	15.9
B	$R_1T_1 + R_2T_2$	**11.4**	12.2
C	$R_2T_1 + R_1T_2$	13.2	13.4
D	$R_2T_1 + R_2T_2$	17.6	17.4
E	$R_1T_2 + R_1T_1$	11.5	**11.9**
F	$R_2T_2 + R_2T_1$	15.7	15.2

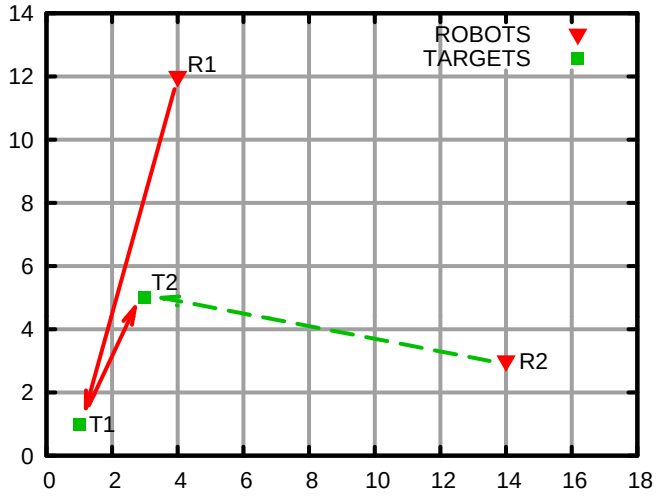


Mission Planning

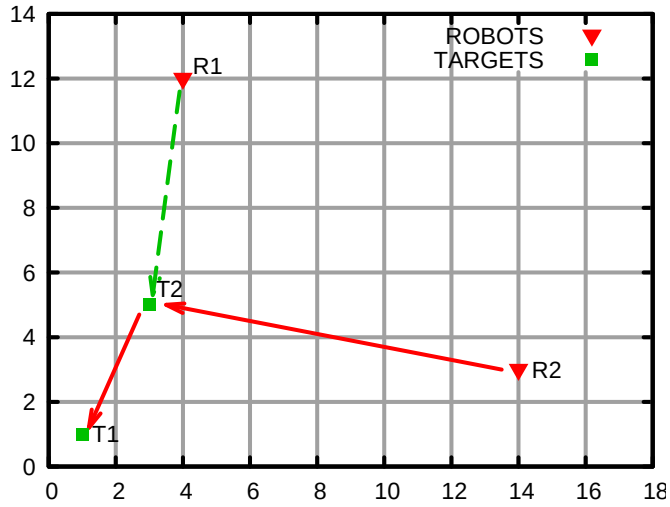
When Failure Occurs

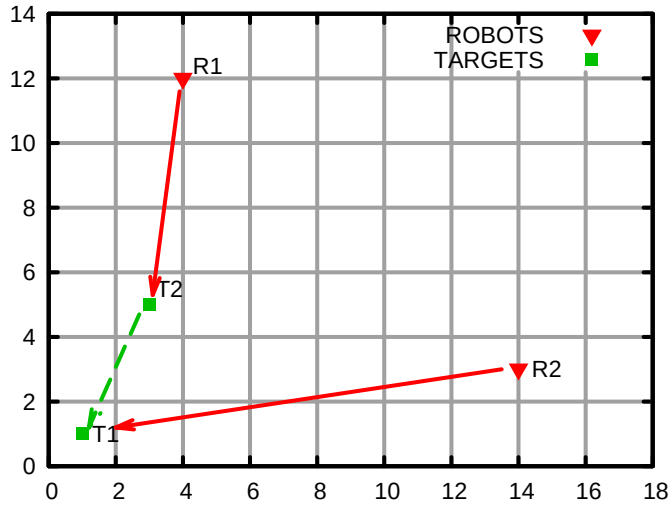
- Backup plans for (naïve) plan B ($R_1T_1 + R_2T_2$):





- Backup plans for (expected value) plan E ($R_1T_2 + R_1T_1$):



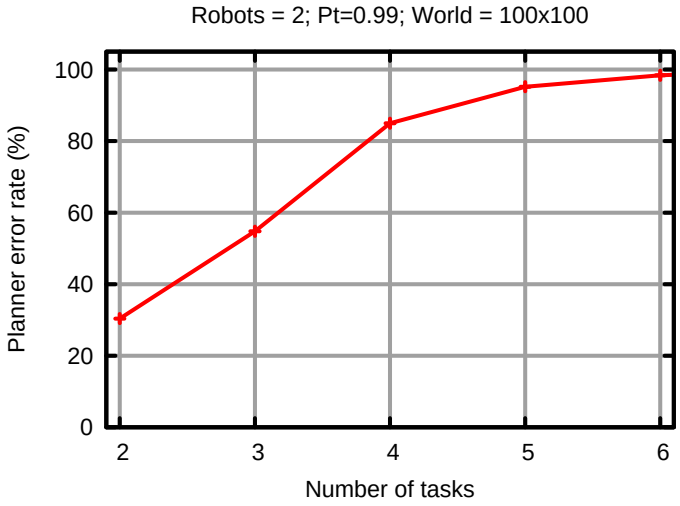


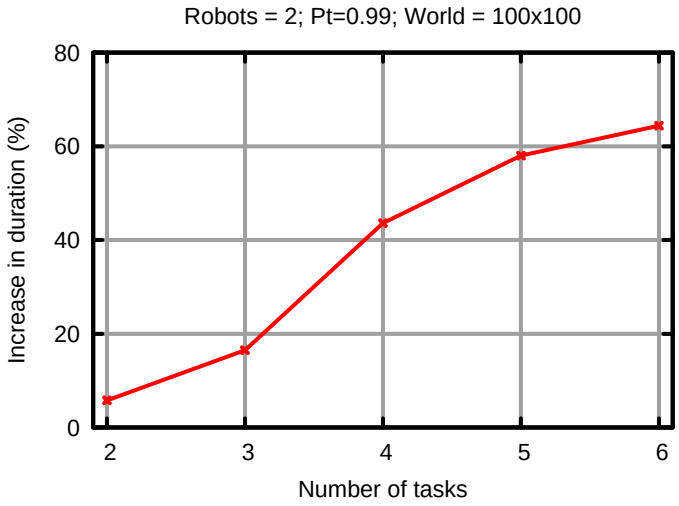
Simulation

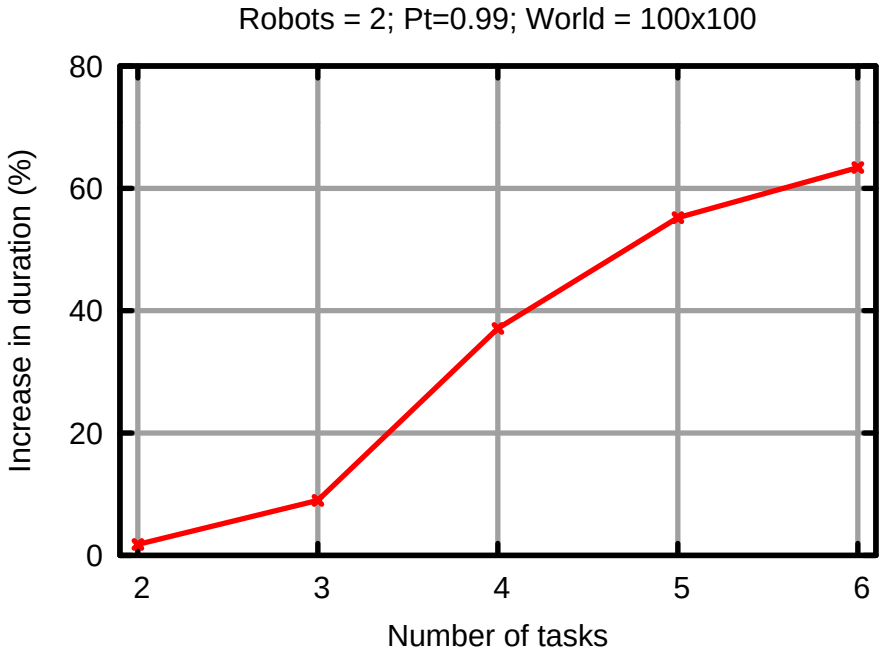
- Implement this process in software
- Randomize robot and target locations
- Compare chosen (naive) plan against best (expected value) plan and evaluate average differences over large number of runs
- Investigate effect of mission parameters (task count, team size, robot reliability, world size) on results

Mission Planning

Simulation



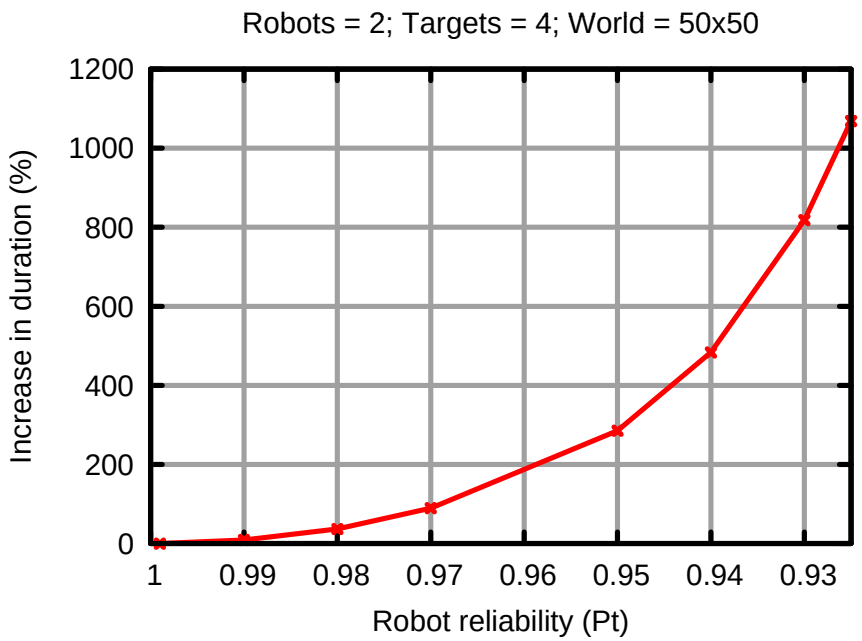


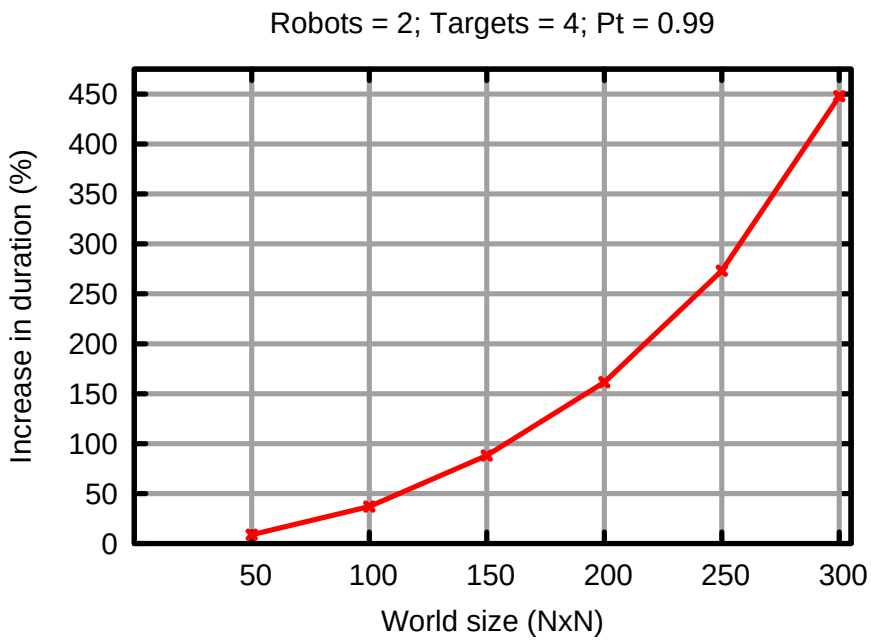


Mission Planning

Simulation

- Similar results with respect to other mission parameters:





Heuristic planners

- So... if we have complete knowledge of all plans and backup plans, using reliability improves plan selection
- But... complete planners not useful for many (most?) real-world problems
- Can reliability information also improve incomplete planners?

Heuristic planner

- Greedy planner:
  - Consider one task ordering at a time, N total task orderings
  - Assign robots greedily
  - Ex: For two robots (R1,R2) and two tasks (T1,T2)
    - Evaluate:
      - T1R1
      - T1R2
    - If T1R1 was chosen, then evaluate:
      - T1R1 + T2R1
      - T1R1 + T2R2
    - Repeat for each task ordering, choose best overall

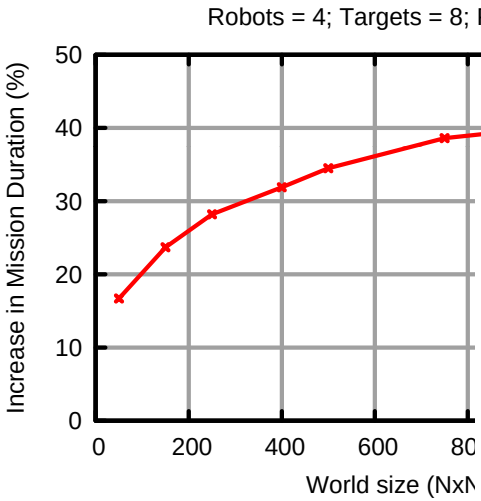
Heuristic planner

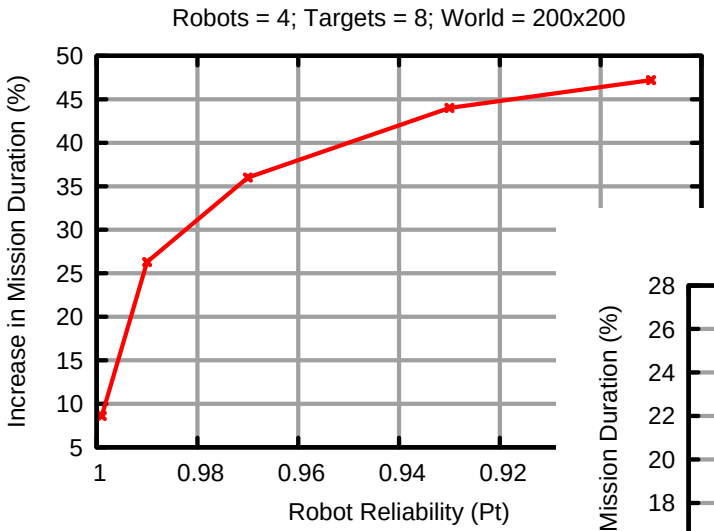
- Incorporating reliability:
  - Use expected value when evaluating complete plans. e.g.:
  - Evaluate:
    - val(T1R1)
    - val(T1R2)
  - If T1R1 was chosen, then evaluate:
    - expval(T1R1 + T2R1)
    - expval(T1R1 + T2R2)

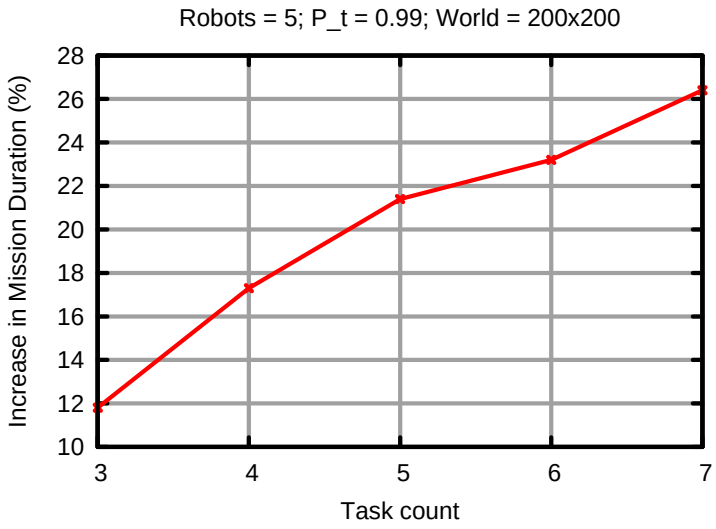
Mission Planning

Heuristic Planner Results

- Using N=1k (out of 40k possible orderings)

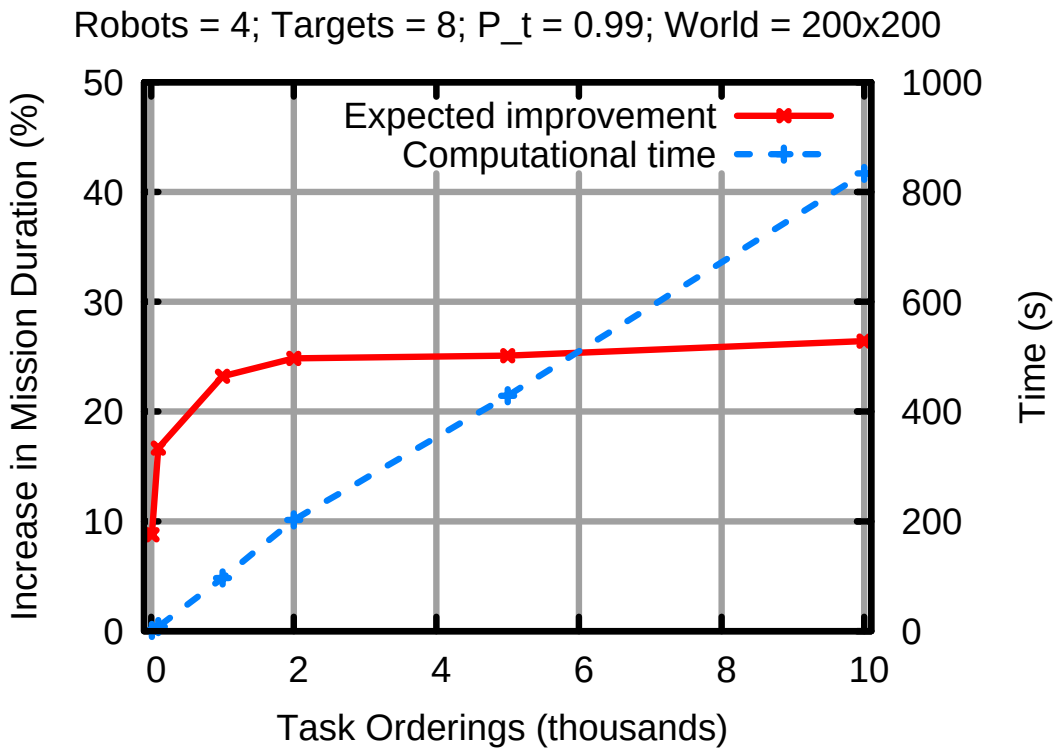






Heuristic planners

- Effect of N on effectiveness of reliability information, and on computational time:



Conclusions

- Analytical method developed for trading off reliability, cost, and time in configuring multirobot teams
- Three mission classes identified based on “basic activities” analysis of NASA mission docs
- Ignoring robot failure in multirobot task allocation plans → suboptimal plans for complete *and* heuristic planners

Future Work

- Comparison of cost-reliability tradeoff characteristics over the three mission classes
- Incorporation of different failure models & modalities
- Consider model for performance degradation rather than binary failure for components and robots