# Planning Agent Final Report

In this project we focused on the problem of solving a deterministic logistics planning problem for Air Cargo Transport System. Our search and planning agent efficiently plans a strategy for this process.

I have experimented several search algorithms and heuristics on four different types of Air Cargo problem 1, 2, 3, 4 respectively.
There are total 11 search algorithms that are used in the analysis presented below tested on 4 different problems related to Air Cargo Transportation.

**Problem Definition**
We are given three different types of planning problems that need to be solved using the same action schema.

Action(Fly(p, from,to),
    PRECOND: At(p, from) ∧ Plane(p) ∧ Airport(from) ∧ Airport(to)
    EFFECT: ¬At(p, from) ∧ At(p,to))
Action(Load(c, p, a),
    PRECOND: At(c, a) ∧ At(p, a) ∧ Cargo(c) ∧ Plane(p) ∧ Airport(a)
    EFFECT: ¬ At(c, a) ∧ In(c, p))
Action(Unload(c, p, a),
    PRECOND: In(c, p) ∧ At(p, a) ∧ Cargo(c) ∧ Plane(p) ∧ Airport(a)
    EFFECT: At(c, a) ∧ ¬ In(c, p))

**Analysis on problem 1, 2, 3, 4**

Problem 1
The optimal plan is of length 6 for this problem.

| Search Algorithm | Optimal | Expansions | Path Length | Execution Time (s) |
|---|---|---|---|---|
| Breadth First Search | Yes | 43 | 6 | 0.00594411 |
| Depth First Graph Search | No | 21 | 20 | 0.00303032 |
| Uniform cost Search | Yes | 60 | 6 | 0.00894590 |
| Greedy Best First Graph Search 1 | Yes | 7 | 6 | 0.00164158 |
| Greedy Best First Graph Search 2 | Yes | 6 | 6 | 0.41193465 |
| Greedy Best First Graph Search 3 | Yes | 6 | 6 | 0.29929283 |
| Greedy Best First Graph Search 4 | Yes | 6 | 6 | 0.50776247 |

| | | | | |
|---|---|---|---|---|
| A Star Search 1 | Yes | 50 | 6 | 0.00890677 |
| A Star Search 2 | Yes | 28 | 6 | 1.02987356 |
| A Star Search 3 | Yes | 43 | 6 | 1.05396838 |
| A Star Search 4 | Yes | 33 | 6 | 1.21358165 |

Problem 2
Optimal plan length = 9

| **Search Algorithm** | **Optimal** | **Expansions** | **Path Length** | **Execution Time (s)** |
|---|---|---|---|---|
| Breadth First Search | Yes | 3343 | 9 | 1.81303950 |
| Depth First Search | No | 624 | 619 | 2.78556195 |
| Uniform Cost Search | Yes | 5154 | 9 | 3.08115778 |
| Greedy Best First Search 1 | Yes | 17 | 9 | 0.01767745 |
| Greedy Best First Search 2 | Yes | 9 | 9 | 9.00224264 |
| Greedy Best First Search 3 | Yes | 27 | 9 | 18.50740043 |
| Greedy Best First Search 4 | Yes | 9 | 9 | 12.47610014 |
| A Star Search 1 | Yes | 2467 | 9 | 2.095102238 |
| A Star Search 2 | Yes | 357 | 9 | 227.82771191 |
| A Star Search 3 | Yes | 2887 | 9 | 1228.34163389 |
| A Star Search 4 | Yes | 1037 | 9 | 1042.03801595 |

Problem 3
Optimal plan length = 12

| Search Algorithm | Optimal | Expansions | Path Length | Execution Time (s) |
|---|---|---|---|---|
| Breadth First Search | Yes | 14663 | 12 | 8.53046281 |
| Depth First Search | No | 408 | 392 | 0.98303380 |
| Uniform Cost Search | Yes | 18512 | 12 | 11.76837428 |
| Greedy Best First Search 1 | No | 25 | 15 | 0.03065162 |
| Greedy Best First Search 2 | No | 14 | 14 | 18.51682551 |
| A Star Search 1 | Yes | 7388 | 12 | 6.90584898 |
| A Star Search 2 | Yes | 369 | 12 | 339.75939135 |

Problem 4
Optimal plan length = 14

| Search Algorithm | Optimal | Expansions | Path Length | Execution Time (s) |
|---|---|---|---|---|
| Breadth First Search | Yes | 99736 | 14 | 76.85300303 |
| Depth First Search | - | - | - | - |
| Uniform Cost Search | Yes | 113339 | 14 | 93..64420320 |
| Greedy Best First Search 1 | No | 29 | 18 | 0.04785316 |
| Greedy Best First Search 2 | No | 17 | 17 | 33.73382394 |
| A Star Search 1 | Yes | 34330 | 14 | 44.22115365 |
| A Star Search 2 | No | 1208 | 15 | 1877.04277142 |

**Number of nodes expanded vs Number of Actions**

| Algorithm | Action- problem 1 | Nodes-problem 1 | Action-problem 2 | Action-problem 2 |
|---|---|---|---|---|
| BFS | 20 | 43 | 72 | 3343 |
| DFS | 20 | 21 | 72 | 624 |
| UCS | 20 | 60 | 72 | 5154 |
| GBFS 1 | 20 | 7 | 72 | 17 |
| GBFS 2 | 20 | 6 | 72 | 9 |
| GBFS 3 | 20 | 6 | 72 | 27 |
| GBFS 4 | 20 | 6 | 72 | 9 |
| A* Search 1 | 20 | 50 | 72 | 2467 |
| A* Search 2 | 20 | 28 | 72 | 357 |
| A* Search 3 | 20 | 43 | 72 | 2887 |
| A* Search 4 | 20 | 33 | 72 | 1037 |

| Algorithm | Action-problem 3 | Nodes-problem 3 | Action-problem 4 | Nodes-problem 4 |
|---|---|---|---|---|
| BFS | 88 | 14663 | 104 | 99736 |
| DFS | 88 | 408 | 104 | - |
| UCS | 88 | 18512 | 104 | 113339 |
| GBFS 1 | 88 | 25 | 104 | 29 |
| GBFS 2 | 88 | 14 | 104 | 17 |
| A* Search 1 | 88 | 7388 | 104 | 34330 |
| A* Search 2 | 88 | 369 | 104 | 1208 |

**Analysis -** The amount of nodes expanded increases as the number of actions for the problem increases. The number of nodes expand for each next problem. However the increase is observed to be different depending on search algorithms and heuristics. In case of uninformed search like BFS, UCS, DFS and A* search, the amount of nodes significantly increases as the number of actions increases. However the  amount of increase in case of Greedy Best First Search algorithms is slightly slow but it also increases with actions.

**Search Time vs Number of Actions**

| Algorithm | Search Time 1 | Actions Problem 1 | Search Time 2 | Actions Problem 2 |
|---|---|---|---|---|
| BFS | 0.00594411 | 20 | 1.81303950 | 72 |
| DFS | 0.00303032 | 20 | 2.78556195 | 72 |
| UCS | 0.00894590 | 20 | 3.08115778 | 72 |
| GBFS 1 | 0.00164158 | 20 | 0.01767745 | 72 |
| GBFS 2 | 0.41193465 | 20 | 9.00224264 | 72 |
| GBFS 3 | 0.29929283 | 20 | 18.50740043 | 72 |
| GBFS 4 | 0.50776247 | 20 | 12.47610014 | 72 |
| A* Search 1 | 0.00890677 | 20 | 2.095102238 | 72 |
| A* Search 2 | 1.02987356 | 20 | 227.82771191 | 72 |
| A* Search 3 | 1.05396838 | 20 | 1228.34163389 | 72 |
| A* Search 4 | 1.21358165 | 20 | 1042.03801595 | 72 |

| Algorithm | Search Time 3 | Actions Problem 3 | Search Time 4 | Actions Problem 4 |
|---|---|---|---|---|
| BFS | 8.53046281 | 88 | 76.85300303 | 104 |
| DFS | 0.98303380 | 88 | - | 104 |
| UCS | 11.76837428 | 88 | 93..64420320 | 104 |
| GBFS 1 | 0.03065162 | 88 | 0.04785316 | 104 |
| GBFS 2 | 18.51682551 | 88 | 33.73382394 | 104 |
| A* Search 1 | 6.90584898 | 88 | 44.22115365 | 104 |
| A* Search 2 | 339.75939135 | 88 | 1877.04277142 | 104 |

**Analysis -** Search time also increase as the number of actions increases corresponding to the different problems. The number of actions for each problem increases as the complexity of the problem increases. Run time increases greatly for A* search which is way more than other algorithms like BFS, DFS, UCS, GBFS etc.

### Complexity Analysis

Greedy Best First Search 1, 2 uses less memory than Depth first Search. BFS uses less memory than Uniform Cost Search. In case of larger domains A* search uses less memory than BFS and DFS..

### Search Time Analysis

Of all the strategies, Breadth first search always finds the optimal path with quite less search time. However as the size of the problem domain increases, Greedy Best first search 1 algorithm outperforms BFS with lesser search time. Depth First Search also needs less time to search however the path planning is not optimal just like Greedy best first search 1.

### Questions

Ques 1. Which algorithms are suitable for planning in restricted domains?
=> From the above 4 problems, an example of restricted domain problem would be similar to Air Cargo problem 1. So lesser time taken to solve the problem means better the algorithm. Using this idea Greedy Best First Search and Depth First Search are suitable for planning in such domains.

Ques 2. Which algorithms are suitable for planning in large domains?
=>An example of larger domain would be Air Cargo problem 4. In this case Greedy Best First Search performs much better than other algorithms..

Ques 3. Which algorithms are better in case of optimal plans?
=> Breadth First Search outperforms other algorithms in case of planning the optimal path. Uniform Cost search and A star search are also able to find the optimal path in all four cases however the time taken by both is more than BFS. While Depth First Search on the other hand never finds the optimal plan but is able to achieve the goal in all cases.