Air Cargo Planning Heuristic Analysis

# Test Results

Air cargo planning search was run for each problem set and the results are given below. The optimal solutions are marked with yellow highlights.

The table below gives the result for problem set 1

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search Type** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Elapsed Time (s)** |
| Breadth First Search | 43 | 56 | 180 | 6 | 0.02524 |
| Breadth First Tree Search | 1458 | 1459 | 5960 | 6 | 0.755732638 |
| Depth First Graph Search | 21 | 22 | 84 | 20 | 0.01363713 |
| Depth Limited Search | 101 | 271 | 414 | 50 | 0.07997 |
| Uniform Cost Search | 55 | 57 | 224 | 6 | 0.0276881 |
| Recursive Best First Search h\_1 | 4229 | 4230 | 17023 | 6 | 2.0938 |
| Greedy Best **First** Graph Search h\_1 | 7 | 9 | 28 | 6 | 0.0036352699 |
| A\* Search h\_1 | 55 | 57 | 224 | 6 | 0.029 |
| A\* Search h\_ignore\_preconditions | 41 | 43 | 170 | 6 | 0.03 |
| A\* Search h\_pg\_levelsum | 11 | 13 | 50 | 6 | 0.974229 |

Below is the result for problem set 2. Search types Breadth First Tree Search, Depth Limited Search, Recursive Best First Search with h\_1 and A\* Search with h\_pg\_levelsum took too long to complete and had to be manually terminated.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search Type** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Elapsed Time (s)** |
| Breadth First Search | 3343 | 4609 | 30509 | 9 | 11.435519 |
| Breadth First Tree Search | N/A | N/A | N/A | N/A | Too long |
| Depth First Graph Search | 624 | 625 | 5602 | 619 | 2.82175 |
| Depth Limited Search | N/A | N/A | N/A | N/A | Too Long |
| Uniform Cost Search | 4853 | 4855 | 44041 | 9 | 9.174799 |
| Recursive Best First Search h\_1 | N/A | N/A | N/A | N/A | Too Long |
| Greedy Best First Graph Search h\_1 | 998 | 1000 | 8982 | 15 | 1.8444889 |
| A\* Search h\_1 | 4853 | 4855 | 44041 | 9 | 9.22 |
| A\* Search h\_ignore\_preconditions | 1450 | 1452 | 13303 | 9 | 3.34161512 |
| A\* Search h\_pg\_levelsum | N/A | N/A | N/A | N/A | Too Long |

Below is the result for problem set 3. Search types Breadth First Tree Search, Depth Limited Search, Recursive Best First Search with h\_1, A\* Search with h\_1 and A\* Search with h\_pg\_levelsum took too long to complete and had to be manually terminated.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Search Type** | **Expansions** | **Goal Tests** | **New Nodes** | **Plan Length** | **Elapsed Time (s)** |
| Breadth First Search | 14663 | 18098 | 129631 | 12 | 82.59431 |
| Breadth First Tree Search | N/A | N/A | N/A | N/A | Too Long |
| Depth First Graph Search | 408 | 409 | 3364 | 392 | 1.5093 |
| Depth Limited Search | N/A | N/A | N/A | N/A | Too Long |
| Uniform Cost Search | 18223 | 18225 | 159618 | 12 | 40.8363 |
| Recursive Best First Search h\_1 | N/A | N/A | N/A | N/A | Too Long |
| Greedy Best First Graph Search h\_1 | 5578 | 5580 | 49150 | 22 | 12.41854 |
| A\* Search h\_1 | N/A | N/A | N/A | N/A | Too Long |
| A\* Search h\_ignore\_preconditions | 5040 | 5042 | 44944 | 12 | 13.745888 |
| A\* Search h\_pg\_levelsum | N/A | N/A | N/A | N/A | Too Long |

# Optimal Sequence

The table below gives optimal sequence for each problem

|  |  |  |
| --- | --- | --- |
| **Problem** | **Optimal Search Type** | **Sequence** |
| Problem Set 1 | Greedy Best First Graph Search with h\_1 | Load(C1, P1, SFO)  Load(C2, P2, JFK)  Fly(P1, SFO, JFK)  Fly(P2, JFK, SFO)  Unload(C1, P1, JFK)  Unload(C2, P2, SFO) |
| Problem set 2 | Greedy Best First Graph Search h\_1 | Load(C1, P1, SFO)  Load(C2, P2, JFK)  Load(C3, P3, ATL)  Fly(P1, SFO, ATL)  Fly(P2, JFK, ATL)  Fly(P3, ATL, SFO)  Fly(P2, ATL, SFO)  Unload(C2, P2, SFO)  Load(C2, P3, SFO)  Fly(P2, SFO, ATL)  Fly(P1, ATL, JFK)  Unload(C1, P1, JFK)  Fly(P1, JFK, ATL)  Unload(C3, P3, SFO)  Unload(C2, P3, SFO) |
| Problem Set 3 | Depth First Graph Search | Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Fly(P2, ATL, SFO)  Load(C2, P1, JFK)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, SFO)  Unload(C2, P1, SFO)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Fly(P2, ATL, SFO)  Load(C2, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Load(C3, P1, ATL)  Fly(P1, ATL, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, SFO)  Fly(P2, ORD, ATL)  Fly(P1, SFO, JFK)  Fly(P2, ATL, SFO)  Unload(C3, P1, JFK)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, SFO)  Unload(C2, P2, JFK)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Fly(P2, ATL, SFO)  Load(C3, P1, JFK)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, SFO)  Fly(P2, ATL, JFK)  Unload(C3, P1, SFO)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Fly(P2, ATL, SFO)  Load(C3, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, SFO)  Load(C1, P1, SFO)  Fly(P2, ATL, ORD)  Fly(P1, SFO, ORD)  Fly(P2, ORD, SFO)  Fly(P1, ORD, ATL)  Fly(P2, SFO, JFK)  Fly(P1, ATL, JFK)  Unload(C3, P2, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, SFO)  Unload(C1, P1, ATL)  Fly(P1, ATL, ORD)  Fly(P2, SFO, ORD)  Fly(P1, ORD, SFO)  Fly(P2, ORD, ATL)  Fly(P1, SFO, JFK)  Fly(P2, ATL, JFK)  Load(C3, P2, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Unload(C3, P2, ATL)  Fly(P2, ATL, ORD)  Fly(P1, ATL, ORD)  Fly(P2, ORD, SFO)  Fly(P1, ORD, SFO)  Fly(P2, SFO, JFK)  Fly(P1, SFO, JFK)  Load(C2, P2, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, SFO)  Fly(P1, ATL, SFO)  Unload(C2, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, SFO, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Load(C3, P1, ATL)  Fly(P1, ATL, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, SFO)  Fly(P2, ORD, ATL)  Fly(P1, SFO, JFK)  Fly(P2, ATL, SFO)  Unload(C3, P1, JFK)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, SFO)  Load(C3, P2, JFK)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, SFO)  Fly(P1, ATL, JFK)  Fly(P2, SFO, ATL)  Load(C1, P2, ATL)  Fly(P2, ATL, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, SFO)  Fly(P1, ORD, ATL)  Fly(P2, SFO, JFK)  Fly(P1, ATL, SFO)  Unload(C3, P2, JFK)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, SFO)  Fly(P1, ATL, JFK)  Load(C3, P1, JFK)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, SFO)  Unload(C3, P1, SFO)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Fly(P2, ATL, SFO)  Unload(C1, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, SFO)  Load(C3, P1, SFO)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, JFK)  Fly(P2, ORD, ATL)  Unload(C3, P1, JFK)  Fly(P2, ATL, JFK)  Fly(P1, JFK, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Load(C4, P2, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ATL, ORD)  Fly(P2, ATL, SFO)  Fly(P1, ORD, SFO)  Fly(P2, SFO, JFK)  Fly(P1, SFO, JFK)  Unload(C4, P2, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, SFO)  Fly(P1, ATL, SFO)  Load(C2, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, SFO, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, JFK)  Unload(C2, P2, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, SFO)  Fly(P1, ATL, SFO)  Load(C1, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, SFO, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, JFK)  Unload(C1, P2, JFK)  Fly(P2, JFK, ORD)  Load(C4, P1, JFK)  Fly(P2, ORD, ATL)  Fly(P1, JFK, ORD)  Fly(P2, ATL, SFO)  Fly(P1, ORD, ATL)  Fly(P2, SFO, JFK)  Fly(P1, ATL, SFO)  Unload(C4, P1, SFO)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Fly(P2, ATL, SFO)  Load(C4, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, SFO)  Load(C3, P2, JFK)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Fly(P2, ATL, SFO)  Unload(C4, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Load(C2, P2, JFK)  Fly(P1, ATL, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, SFO)  Fly(P2, ORD, ATL)  Fly(P1, SFO, JFK)  Fly(P2, ATL, SFO)  Unload(C3, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, SFO)  Unload(C2, P2, JFK)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Load(C2, P1, JFK)  Fly(P2, ATL, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, SFO)  Fly(P1, ORD, ATL)  Fly(P2, SFO, JFK)  Fly(P1, ATL, SFO)  Unload(C2, P1, SFO)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Load(C1, P1, JFK)  Fly(P2, ATL, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, SFO)  Fly(P1, ORD, ATL)  Fly(P2, SFO, JFK)  Fly(P1, ATL, SFO)  Unload(C1, P1, SFO)  Fly(P1, SFO, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, JFK)  Fly(P2, ATL, SFO)  Load(C4, P2, SFO)  Fly(P2, SFO, ATL)  Fly(P1, JFK, ORD)  Fly(P2, ATL, JFK)  Fly(P1, ORD, ATL)  Fly(P2, JFK, ORD)  Fly(P1, ATL, SFO)  Load(C3, P1, SFO)  Fly(P2, ORD, ATL)  Fly(P1, SFO, ORD)  Fly(P2, ATL, SFO)  Fly(P1, ORD, ATL)  Fly(P2, SFO, JFK)  Unload(C4, P2, JFK)  Fly(P1, ATL, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, SFO)  Fly(P2, ORD, ATL)  Fly(P1, SFO, JFK)  Fly(P2, ATL, SFO)  Load(C4, P1, JFK)  Fly(P2, SFO, ORD)  Fly(P1, JFK, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, ORD)  Unload(C3, P1, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ATL, ORD)  Fly(P1, ATL, SFO)  Fly(P2, ORD, SFO)  Fly(P1, SFO, JFK)  Fly(P2, SFO, JFK)  Unload(C4, P1, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, ORD)  Fly(P2, ATL, SFO)  Fly(P1, ORD, SFO)  Load(C2, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, SFO, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, JFK)  Unload(C2, P2, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, SFO)  Fly(P1, ATL, SFO)  Load(C1, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, SFO, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, JFK)  Unload(C1, P2, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Load(C3, P1, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ATL, ORD)  Fly(P1, ATL, SFO)  Fly(P2, ORD, SFO)  Fly(P1, SFO, JFK)  Load(C4, P1, JFK)  Fly(P2, SFO, JFK)  Fly(P1, JFK, ORD)  Fly(P2, JFK, ORD)  Fly(P1, ORD, ATL)  Fly(P2, ORD, ATL)  Fly(P1, ATL, SFO)  Unload(C4, P1, SFO)  Fly(P2, ATL, ORD)  Fly(P1, SFO, ORD)  Fly(P2, ORD, SFO)  Fly(P1, ORD, ATL)  Fly(P2, SFO, JFK)  Fly(P1, ATL, JFK)  Load(C2, P2, JFK)  Fly(P2, JFK, ORD)  Fly(P1, JFK, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, SFO)  Fly(P1, ATL, SFO)  Unload(C2, P2, SFO)  Fly(P2, SFO, ORD)  Fly(P1, SFO, ORD)  Fly(P2, ORD, ATL)  Fly(P1, ORD, ATL)  Fly(P2, ATL, JFK)  Fly(P1, ATL, JFK)  Unload(C3, P1, JFK) |

# Conclusion

For simpler case like problem 1, greedy best first graph search with h\_1 gave the most optimal solution, with fewest expansions and taking least time, followed by breadth first search. As complexity increased in problem 2 greedy best first graph search with h\_1 still gave the best result but now A\*Search with h\_ignore\_preconditions gave much better solution than breadth first search. In Problem 3 Depth First Graph search gave the fastest solution followed by Greedy best first Graph search with h\_1.

Depth first search can find solution quickly, but it lacks optimality, because it does not consider all nodes. In problem 3 we saw depth first search find solution fastest, because luckily fastest path was explored first. Breadth first search generally is very close to optimal solution, because it considers all nodes to find the shortest path. Greedy best first search with h\_1 is able to optimize breadth first search even further by using heuristic. When it comes to heuristic based search it should be noted that A\* Search with h\_ignore\_precondition performs better in more complex scenarios, but A\* Search with h\_1 and A\* Search with h\_pg\_levelsum don’t, because they suffer from increasingly complex heuristic.