P3 AIND Project (Part 3 – Written Analysis)

Table of Content

Problem: Air Cargo Problem 1

Results

	Problem 1				
	expansion	goal tests	new nodes	plan length	time elapsed
breadth first search	43	56	180	6	0.03203
breadth first search tree search	1458	1459	5960	6	1.0497
depth first graph search	21	22	84	20	0.01568
depth limited search	101	271	414	50	0.09604
uniform cost search	55	57	224	6	0.04418
recursive best first search h_1	4229	4230	17023	6	3.07277
greedy best first graph search h_1	7	8	28	6	0.00605
astar search h_1	55	57	224	6	0.04709
astar search h_ignore preconditions	41	43	170	6	0.05064
astar search h_pg_levelsum	11	13	50	6	1.50045

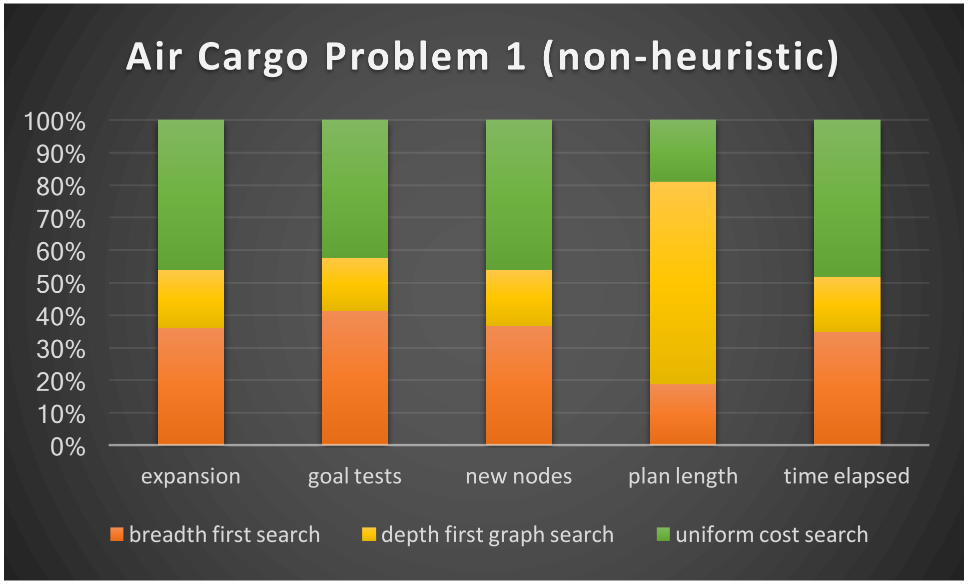
Selected methods for non-heuristic search:

1. Breadth-first search
2. Depth-first search
3. Uniform-cost search

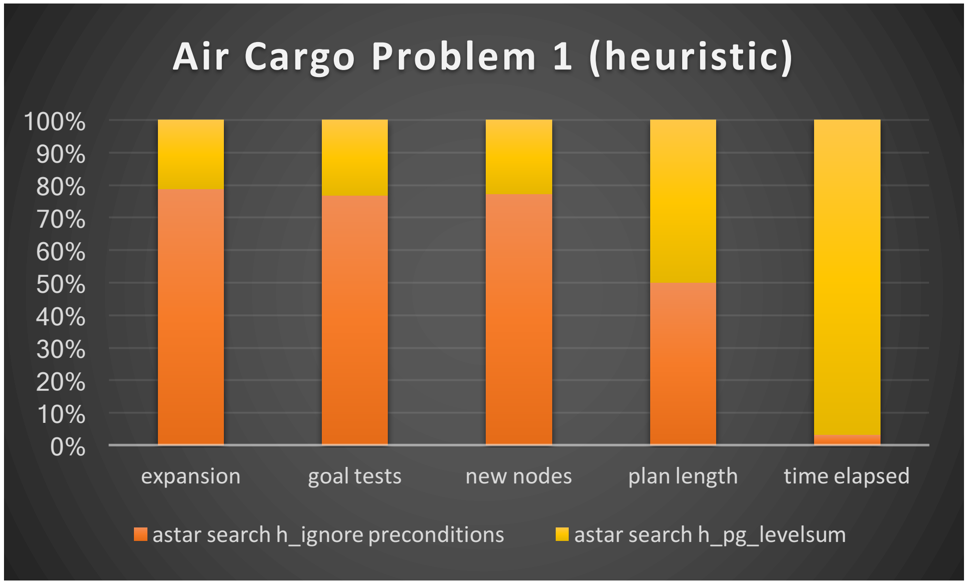
Selected methods for heuristic search:

1. A* search_ignore preconditions
2. A* search_levelsum

Stacked Bar Chart (non-heuristic search results)



Stacked Bar Chart (heuristic search results)



Optimal Plan:

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P1, SFO, JFK)
Fly(P2, JFK, SFO)
Unload(C1, P1, JFK)
Unload(C2, P2, SFO)

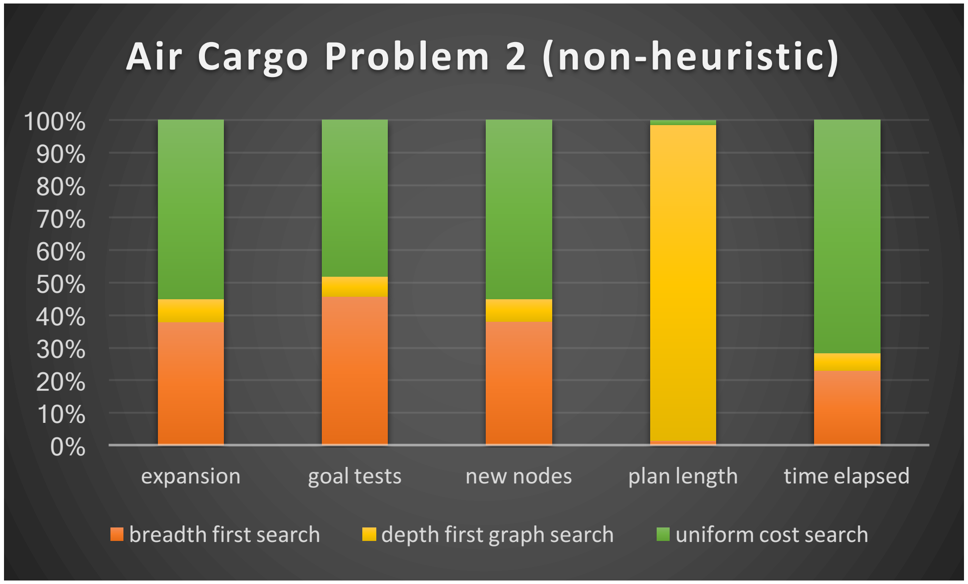
Problem: Air Cargo Problem 2

Results

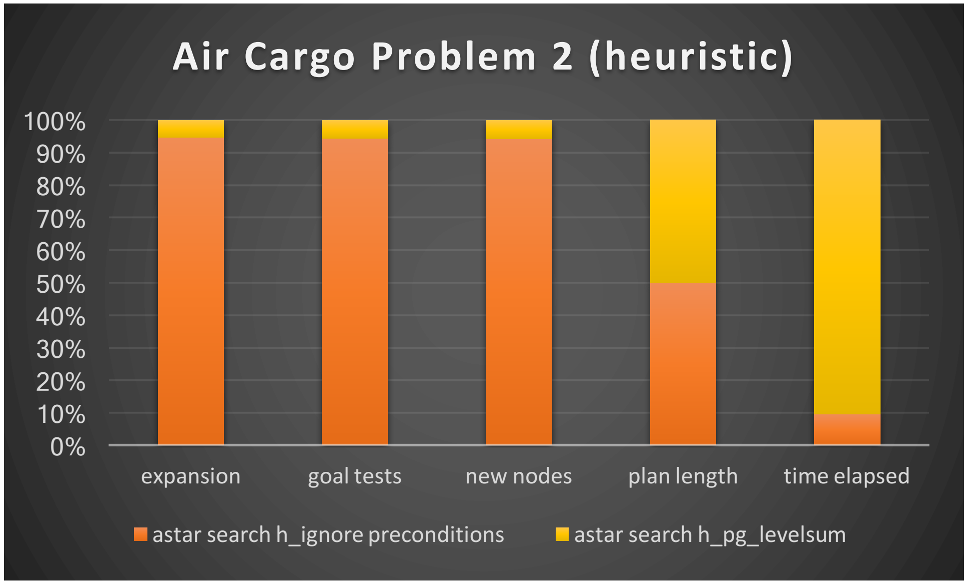
	Problem 2				
	expansion	goal tests	new nodes	plan length	time elapsed
breadth first search	3343	4609	30509	9	15.33784
breadth first search tree search	x	x	x	x	x
depth first graph search	624	625	5602	619	3.77626
depth limited search	x	x	x	x	x
uniform cost search	4853	4855	44041	9	47.89896
recursive best first search h_1	x	x	x	x	x
greedy best first graph search h_1	998	1000	8982	21	7.82641
astar search h_1	4853	4855	44041	9	48.29967
astar search h_ignore preconditions	1506	1508	13820	9	15.86626
astar search h_pg_levelsum	86	88	841	9	149.08119

Note: (x) sign means aborted due to process takes longer than 10 minutes

Stacked Bar Chart (non-heuristic search results)



Stacked Bar Chart (heuristic search results)



Optimal Plan:

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Load(C3, P3, ATL)
Fly(P2, JFK, SFO)
Unload(C2, P2, SFO)
Fly(P1, SFO, JFK)
Unload(C1, P1, JFK)
Fly(P3, ATL, SFO)
Unload(C3, P3, SFO)

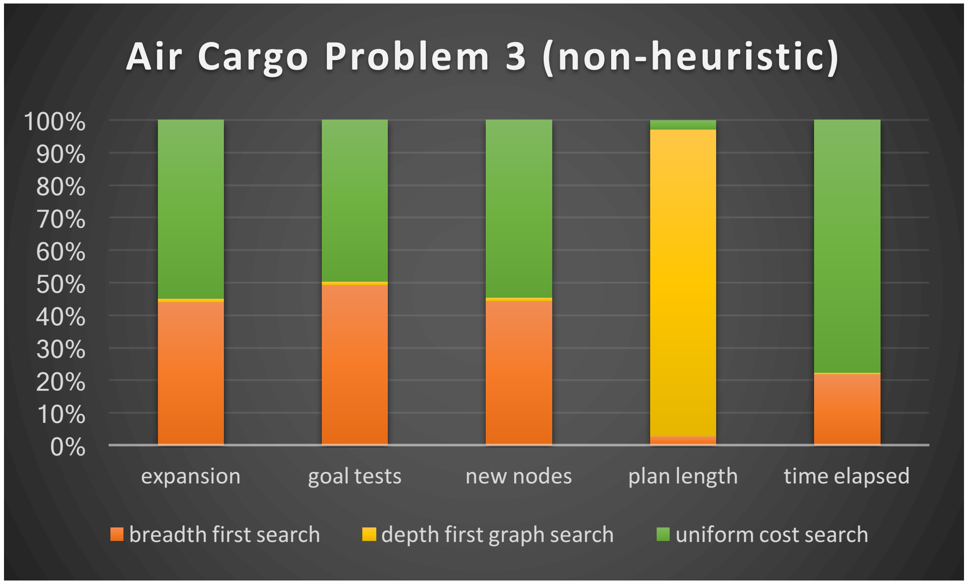
Problem: Air Cargo Problem 3

Results

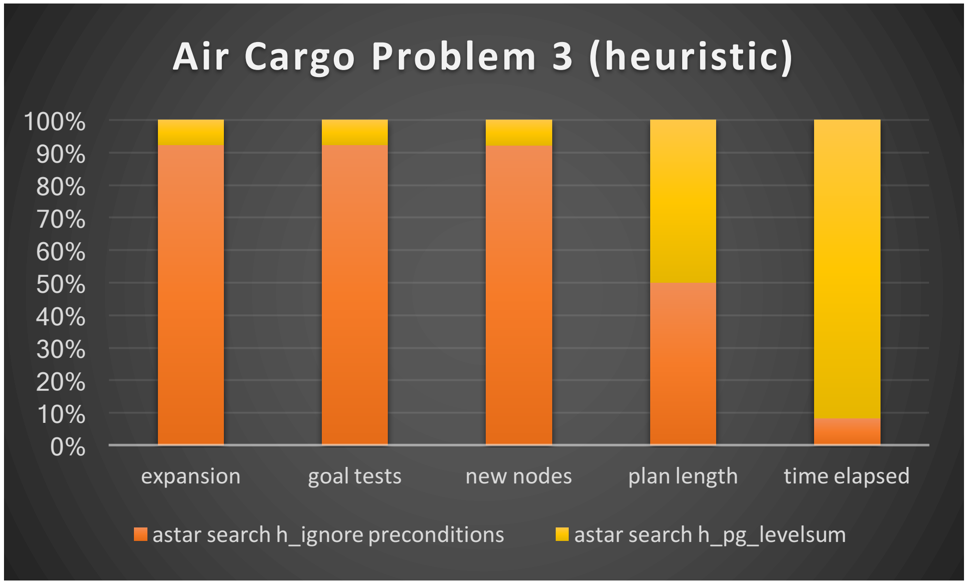
	Problem 3				
	expansion	goal tests	new nodes	plan length	time elapsed
breadth first search	14663	18098	129631	12	116.91748
breadth first search tree search	x	x	x	x	x
depth first graph search	408	409	3364	392	2.00041
depth limited search	x	x	x	x	x
uniform cost search	18234	18236	159707	12	415.145045
recursive best first search h_1	x	x	x	x	x
greedy best first graph search h_1	5605	5607	49360	22	113.16541
astar search h_1	18234	18236	159707	12	436.51399
astar search h_ignore preconditions	5118	5120	45650	12	89.38996
astar search h_pg_levelsum	414	416	3818	12	973.30732

Note: (x) sign means aborted due to process takes longer than 10 minutes

Stacked Bar Chart (non-heuristic search results)



Stacked Bar Chart (heuristic search results)



Optimal plan:

Load(C1, P1, SFO)
Load(C2, P2, JFK)
Fly(P2, JFK, ORD)
Load(C4, P2, ORD)
Fly(P1, SFO, ATL)
Load(C3, P1, ATL)
Fly(P1, ATL, JFK)
Unload(C1, P1, JFK)
Unload(C3, P1, JFK)
Fly(P2, ORD, SFO)
Unload(C2, P2, SFO)
Unload(C4, P2, SFO)

Analysis and Discussions

Non-heuristic search results

For non-heuristic search results, we are comparing three methods as follows:

1. Breadth-first search
2. Depth-first search
3. Uniform-cost search

The result metrics that we are measuring include expansion, goal tests, new nodes, plan length, and time elapsed.

Based on the table and charts, we can see the result metrics are very consistent among the three search methods. We can generalize our findings as follows:

1. In terms of being the quickest algorithm to get an optimal plan, depth-first search is the winner.
    a. This algorithm solves problem 1 within 0.01568 seconds (vs 0.03203 seconds using breadth-depth first and 0.04418 seconds using uniform-cost search),
    b. problem 2 within 3.77626 seconds (vs 15.33784 seconds using breadth-depth first and 47.89896 seconds using uniform-cost search), and
    c. problem 3 within 2 seconds (vs 116.91748 seconds using breadth-depth first and 415.14505 seconds using uniform-cost search).

2. However, we can argue that being the quickest may not be the most important metric. Instead, one should look into the shortest plan length because each trip is costly and one should try to minimize the length to get the lowest total cost to get an optimal plan. As it turns out, both breadth first search and uniform cost search perform equally well to solve
    a. problem 1 with plan length of 6 (vs 20 with depth-first search),
    b. problem 2 with plan length of 9 (vs 619 with depth-first search), and
    c. problem 3 with plan length of 12 (vs 392 with depth-first search).

3. Rationale:
    a. depth-first search is quick because it uses brute-force to find a plan. However, it fails to explore broader plans that may be more efficient. We can draw this conclusion based on the expansion, goal tests, and new nodes metrics. In the case of depth-first search, these metrics are much lower than breadth-first search or uniform-cost search.

b. Breadth-first depth and uniform cost depth performed almost equally. Both algorithms are able to find the most effective optimal plan (ie. shortest plan length). The similar results reflect much similarity between the two algorithms. The little difference is when the goal test is applied, where in uniform-cost search, the goal test is applied to a node when it is selected for expansion rather than when it is first generated as in breadth-first search.

Heuristic search methods

For heuristic search results, we are comparing three methods as follows:

1. A* search_ignore preconditions
2. A* search_levelsum

Similar to non-heuristic search methods, we use the same performance metrics, ie. expansion, goal tests, new nodes, plan length, and time elapsed.

Our observation between the two heuristic method finds that both “ignore preconditions” and “levelsum” heuristics are able to find the most efficient plan. The plan lengths for problem 1, 2, and 3 are equal to non-heuristics breadth-first and uniform-cost search methods.

When we compare the speed, “ignore preconditions” performed about up to 10x faster than “levelsum” heuristics, depending the complexity of the problem.

- In problem 1, “ignore precondition” took 0.05064 seconds vs “levelsum” 1.50045 seconds,
- In problem 2, “ignore precondition” took 15.86626 seconds vs “levelsum” 149.08119 seconds, and
- In problem 3, “ignore precondition” took 89.38996 seconds vs “levelsum” 973.30732 seconds,

Rationale: by ignoring the preconditions, this heuristic works much faster as any goal conditions can be achieved in one step.

Heuristic vs non-heuristic search methods

When we compare the results between heuristic and non-heuristic search methods, we can observe heuristic algorithms in general perform faster, while still giving the optimal plan. Non-heuristic forward search methods can be inefficient and require large state space. Backward search can help to expedite solution findings. However, it is hard to come up the heuristics with backward search.

As we learned from this exercise, forward search with heuristics perform better as heuristics allow to define a relaxed problem which is easier to solve.