Heuristic Analysis

1. Optimal Plan for Each Problem

- air_cargo_p1:

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

- air_cargo_p2:

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

- air_cargo_p3:

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

2. Comparison of Non-Heuristic Search

Three different non-heuristic strategies, namely breadth_first_search, depth_first_graph_search and uniform_cost_search, are applied on the air cargo planning problems. The results metrics (time elapsed, number of node expansion, plan length and optimality) are recorded in Table 1 to Table 3.

air_cargo_p1				
Search Type	**Execution Time (s)**	**Node Expansions**	**Plan Length**	**Optimal?**
breadth_first_search	0.0570	43	6	Yes
depth_first_graph_search	0.0432	21	20	No
uniform_cost_search	0.0646	55	6	Yes

Table 1: Non-Heuristic Search Results of Problem 1

air_cargo_p2				
Search Type	**Execution Time (s)**	**Node Expansions**	**Plan Length**	**Optimal?**
breadth_first_search	22.9516	3343	9	Yes
depth_first_graph_search	5.8516	624	619	No
uniform_cost_search	20.9909	4852	9	Yes

Table 2: Non-Heuristic Search Results of Problem 2

air_cargo_p3				
Search Type	**Execution Time (s)**	**Node Expansions**	**Plan Length**	**Optimal?**
breadth_first_search	186.1302	14663	12	Yes
depth_first_graph_search	3.0333	408	392	No
uniform_cost_search	89.9561	18223	12	Yes

Table 3: Non-Heuristic Search Results of Problem 3

Among the three strategies, only breadth_first_search and uniform_cost_search found optimal solutions. uniform_cost_search is slightly faster than breadth_first_search at the expense of higher number of node expansions. Depth_first_graph_search found the solution plan for all three problems at very short time with least number of node expansions. However, none of its solutions is optimal. This is due to the nature that it searches as deep as possible in the graph until it finds a solution.

3. Comparison of Heuristic Search

The results of A* planning searches with three different heuristics (h_1, h_ignore_preconditions and h_pg_levelsum) are shown in Table 4 to Table 6.

air_cargo_p1				
Search Type	**Execution Time (s)**	**Node Expansions**	**Plan Length**	**Optimal?**
astar_search with h_1	0.0804	55	6	Yes
astar_search with h_ignore_preconditions	0.0696	41	6	Yes
astar_search with h_pg_levelsum	1.7115	11	6	Yes

Table 4: Heuristic Search Results of Problem 1

air_cargo_p2				
Search Type	**Execution Time (s)**	**Node Expansions**	**Plan Length**	**Optimal?**
astar_search with h_1	23.0311	4852	9	Yes
astar_search with h_ignore_preconditions	7.7015	1450	9	Yes
astar_search with h_pg_levelsum	165.6839	86	9	Yes

Table 5: Heuristic Search Results of Problem 2

air_cargo_p3				
Search Type	**Execution Time (s)**	**Node Expansions**	**Plan Length**	**Optimal?**
astar_search with h_1	100.1680	18223	12	Yes
astar_search with h_ignore_preconditions	29.1645	5040	12	Yes
astar_search with h_pg_levelsum	953.2761	325	12	Yes

Table 6: Heuristic Search Results of Problem 3

All three heuristic A* search found optimal plans for all cargo planning problems. h_ignore_preconditions heuristic provides the fastest solution and has less number of node expansions than h_1 heuristic. While h_pg_levelsum heuristic has least number of node expansions, it is also significant slower than the other two heuristics.

4. Comparison of Heuristic and Non-Heuristic Search

Search Type	**Execution Time (s)**	**Node Expansions**	**Plan Length**	**Optimal?**
air_cargo_p1				
uniform_cost_search	0.0646	55	6	Yes
astar_search with h_ignore_preconditions	0.0696	41	6	Yes
air_cargo_p2				
uniform_cost_search	20.9909	4852	9	Yes
astar_search with h_ignore_preconditions	7.7015	1450	9	Yes
air_cargo_p3				
uniform_cost_search	89.9561	18223	12	Yes
astar_search with h_ignore_preconditions	29.1645	5040	12	Yes

Table 7: Comparison of Heuristic and Non-Heuristic Search

Table 7 depicts side by side comparison of the fastest optimal uninformed search and the fastest heuristic A* search. A* search with "ignore conditions" heuristic defines a relaxed problem from the original problem by ignoring the preconditions required for an action to be executed. It then uses this cost estimate to more intelligently determine the search direction. Therefore, it outperforms uniform_cost_search in terms of speed and number of node expansions in all three planning problems. Its advantage is more significant in complex problems like Problem 2 and Problem 3 where ~3x of performance improvement is observed. We can conclude that A* search with the "ignore conditions" heuristic is the best search heuristic for the air cargo transportation planning problem.