## Optimal Plan

The optimal plans for each problem are described below.

Optimal Plan 1

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

Optimal Plan 2

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

Optimal Plan 3

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(C1, P1, JFK) => Unload(C2, P2, SFO)

## Comparison of Non-heuristic searches

For Problem 1, both breadth first search and uniform cost searches produced a solution with the smallest plan length, which is 6. Because the complexity of the problem is small where we have two airports, two cargos and two airplanes, breadth first search had the shortest time elapsed. The depth limited search and depth first search had longer plan lengths, 12 and 50 respectively.

For Problem 2, the number of expansions increased a lot compared with that for problem 1. The breadth first search achieved the shortest plan length 9, although the computation time was 14.4 seconds and was longer than that for depth first search. The uniform cost search had a similar result with the breadth first search. It had a plan length of 9, and the time elapsed was almost the same as the breadth first search at 14.1 seconds.

For Problem 3, the number of expansions increased too for the breadth first search, and the breadth first search achieved the shortest plan length 12. The depth first search had a similar level of the expansions for problem 2, but the plan length was very high at 596.

Table 1: Comparisons of Non-heuristic search results

| | | Expansions | Goal Tests | New Nodes | Plan Length | Time Elapsed |
|---|---|---|---|---|---|---|
| **P1** | **breadth first search** | 43 | 56 | 180 | 6 | 0.03 |
| | **depth first graph search** | 12 | 13 | 48 | 12 | 0.02 |
| | **uniform cost search** | 55 | 57 | 224 | 6 | 0.04 |
| **P2** | **breadth first search** | 3343 | 4609 | 30509 | 9 | 14.4 |
| | **depth first graph search** | 582 | 583 | 5211 | 575 | 3.4 |
| | **uniform cost search** | 4852 | 4854 | 44030 | 9 | 14.1 |
| **P3** | **breadth first search** | 14663 | 18098 | 129631 | 12 | 107.4 |
| | **depth first graph search** | 627 | 628 | 5176 | 596 | 3.3 |
| | **uniform cost search** | 18235 | 18237 | 159716 | 12 | 64.6 |

## Comparison of heuristic searches

The result of the heuristic searches is summarized in the table 1 below. The ignore preconditions heuristic tended to perform better than the level sum heuristic. In all of the three problems, both heuristic searches were able to find the plan of the same length. The ignore preconditions heuristic had shorter computation time for all of the three problems, and the elapsed time for the ignore preconditions is nearly a quarter for the level sum heuristic.

To solve Problem 1, it did not matter too much whether you use non-heuristic search or heuristic search result. Because the size of the problem is small in terms of the complexity, both methods produced similar results. In particular, breadth first search achieved the same plan length with the shortest computation time.

To solve Problem 2 and 3, it appears heuristic searches tend to perform better than non-heuristic searches. Both of the heuristic searches found the plan of the shortest length. With the non-heuristic searches, the depth first search did not find the optimal plan in that it found longer plan length. With the heuristic searches, we can expect both would be able to find the optimal plan. When it comes to the computation time, the uniform cost search achieved almost as fast as the ignore preconditions heuristic and was faster than the level sum heuristic. From these results, we can expect that the ignore preconditions heuristic would give rise to the best performance.

Table 2: Comparisons of heuristic search results

| | | Expansions | Goal Tests | New Nodes | Plan Length | Time Elapsed |
|---|---|---|---|---|---|---|
| **P1** | **ignore preconditions** | 55 | 57 | 224 | 6 | 0.05 |
| | **level sum** | 11 | 13 | 50 | 6 | 0.6 |
| **P2** | **ignore preconditions** | 4852 | 4854 | 44030 | 9 | 13.7 |
| | **level sum** | 86 | 88 | 841 | 9 | 53.2 |
| **P3** | **ignore preconditions** | 18235 | 18237 | 159716 | 12 | 60.7 |
| | **level sum** | 318 | 320 | 2934 | 12 | 261.8 |