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# Heuristic Analysis

## Optimal plan for Problems 1, 2, and 3.

### Non-heuristic search result metrics

I present non-heuristic search result metrics in the following tables for Air Cargo Problems 1, 2 and 3. Used Breath First Search, Depth First Search, Uniform Cost Search algorithms.

#### Air Cargo Problem 1

Search Algorithm	breadth_first_search	depth_first_graph_search	uniform_cost_search
Node Expansions	43	21	55
Goal Tests	56	22	57
New Nodes	180	84	224
Plan length	6	20	6
Time elapsed, seconds	0.036	0.019	0.040

#### Air Cargo Problem 2

Search Algorithm	breadth_first_search	depth_first_graph_search	uniform_cost_search
Node Expansions	3343	624	4853
Goal Tests	4609	625	4855
New Nodes	30509	5602	44041
Plan length	9	619	9
Time elapsed, seconds	10.670	2.922	9.782

#### Air Cargo Problem 3

Search Algorithm	breadth_first_search	depth_first_graph_search	uniform_cost_search
Node Expansions	14663	408	18151
Goal Tests	18098	409	18153
New Nodes	129631	3364	159038
Plan length	12	392	12
Time elapsed, seconds	83.889	1.422	45.970

According the metrics, the most performant non-heuristic planning solution is Depth First Search algorithm. Depth First Search takes significantly shorter execution time, along with lowest node expansions, goal tests and new nodes for Air Cargo Problems. In the same time, Depth First Search doesn't give us optimal solution with minimal plan length.

Breath First Search and Uniform Cost Search algorithms give us much better results for plan length. Both algorithms gives relatively equal results on time elapsed, node expansions, goal tests and new nodes. But Uniform Cost Search took half of time on execution Air Cargo Problem 3. We can chose Uniform Cost Search as the best non-heuristic solution for Air Cargo Problems.

## Heuristic search result metrics

Tables below contain result metrics for A\* Search algorithm with constant number, ignore preconditions, level sum heuristics.

### Air Cargo Problem 1

Search Algorithm	astar_search with h_1	astar_search with h_ignore_preconditions	astar_search with h_pg_levelsum
Node Expansions	55	41	11
Goal Tests	57	43	13
New Nodes	224	170	50
Plan length	6	6	6
Time elapsed, seconds	0.034	0.030	0.570

### Air Cargo Problem 2

Search Algorithm	astar_search with h_1	astar_search with h_ignore_preconditions	astar_search with h_pg_levelsum
Node Expansions	4853	1450	86
Goal Tests	4855	1452	88
New Nodes	44041	13303	841
Plan length	9	9	9
Time elapsed, seconds	9.226	2.731	50.103

### Air Cargo Problem 3

Search Algorithm	astar_search with h_1	astar_search with h_ignore_preconditions	astar_search with h_pg_levelsum
Node Expansions	18151	5038	314
Goal Tests	18153	5040	316
New Nodes	159038	44926	2894
Plan length	12	12	12
Time elapsed, seconds	45.361	12.862	270.045

## The best heuristic

As we see in tables, A\* Search algorithm with all presented heuristic functions gave out the same plan length in frame of solving Air Cargo Problem 1, 2 or 3. A\* Search with ignore preconditions solved the problem most quickly. Ignore preconditions heuristic estimates the minimum number of actions that must be carried out from the current state in order to satisfy all of the goal conditions by ignoring the preconditions required for an action to be executed.

Constant number heuristic is not a true heuristic, and it has not good results with comparison with other heuristics.

Level sum heuristic uses a planning graph representation of the problem state space to estimate the sum of all actions that must be carried out from the current state in order to satisfy each individual goal condition. Level sum has longest execution time,

but the best results for node expansions, goal tests, new nodes. So level sum heuristics is a good fit for those cases when the size of RAM matters.

Heuristic approach is not guaranteed to be optimal or perfect, but sufficient for the immediate goals. Heuristic methods can be used to speed up the process of finding a satisfactory solution.

According all result metrics (heuristic and non-heuristic), Breath First Search, Uniform Cost Search algorithms, A\* Search with ignore preconditions and A\* Search with level sum solved the Air Cargo problems with equal length of plan. Choosing from these 4 algorithms, A\* Search with ignore preconditions has the best execution time and A\* Search with level sum is optimized for memory usage.

So heuristic search algorithms are the better planners than non-heuristics for Air Cargo Problem on deterministic, fully observable, static environment.