Joanna Muras **Build a Forward Planning Agent**

This report presents search results for air cargo problem. It describes a number of algorithms used to do a search depending of complexity of the problem.

Table below presents results of running 5 types of search algorithms (search column) on 4 problem domains (problem column). 4 heuristic functions (heuristic column) were used where applicable. The results show number of actions in domain (actions column) for a problem, number of node expansions (expansions column), number of times it was tested whether node is goal node (goal tests column), number of new nodes (new nodes column), number of nodes used in solution (plan length), and time search took (time elapsed).

Problem	Search	Heuristic	Actions	Expansions	Goal Tests	New Nodes	Plan length	Time elapsed
Air Cargo Problem 1	breadth_first_search		20	43	56	178	6	0.004010400000000011
Air Cargo Problem 1	depth_first_graph_search		20	21	22	84	20	0.0022263000000000005
Air Cargo Problem 1	uniform_cost_search		20	60	62	240	6	0.0061692
Air Cargo Problem 1	greedy_best_first_graph_search	h_unmet_goals	20	7	9	29	6	0.0010278000000000093
Air Cargo Problem 1	greedy_best_first_graph_search	h_pg_levelsum	20	6	8	28	6	0.381590300000000005
Air Cargo Problem 1	greedy_best_first_graph_search	h_pg_maxlevel	20	6	8	24	6	0.2840353
Air Cargo Problem 1	greedy_best_first_graph_search	h_pg_setlevel	20	6	8	28	6	0.9514603
Air Cargo Problem 1	astar_search	h_unmet_goals	20	50	52	206	6	0.0062683000000001154
Air Cargo Problem 1	astar_search	h_pg_levelsum	20	28	30	122	6	1.0340982
Air Cargo	astar_search	h_pg_maxlevel	20	43	45	180	6	1.00873139999

Problem 1								99998
Air Cargo Problem 1	astar_search	h_pg_setlevel	20	33	35	138	6	2.3984571
Air Cargo Problem 2	breadth_first_search		72	3343	4609	30503	9	1.2863219999999993
Air Cargo Problem 2	depth_first_graph_search		72	624	625	5602	619	1.7302606999999997
Air Cargo Problem 2	uniform_cost_search		72	5154	5156	46618	9	2.1363164
Air Cargo Problem 2	greedy_best_first_graph_search	h_unmet_goals	72	17	19	170	9	0.012108200000000124
Air Cargo Problem 2	greedy_best_first_graph_search	h_pg_levelsum	72	9	11	86	9	9.9710311
Air Cargo Problem 2	greedy_best_first_graph_search	h_pg_maxlevel	72	27	29	249	9	19.825550200000002
Air Cargo Problem 2	greedy_best_first_graph_search	h_pg_setlevel	72	9	11	84	9	22.9613929
Air Cargo Problem 2	astar_search	h_unmet_goals	72	2467	2469	22522	9	1.4214759999999984
Air Cargo Problem 2	astar_search	h_pg_levelsum	72	357	359	3426	9	248.74767660000003
Air Cargo Problem 2	astar_search	h_pg_maxlevel	72	2887	2889	26594	9	2346.1939995
Air Cargo Problem 2	astar_search	h_pg_setlevel	72	1037	1039	9605	9	2021.5227873
Air Cargo Problem 3	breadth_first_search		88	14663	18098	129625	12	6.707261900000001
Air Cargo Problem 3	depth_first_graph_search		88	408	409	3364	392	0.6887592000000007

Air Cargo Problem 3	uniform_cost_search		88	18510	18512	161936	12	9.2006677
Air Cargo Problem 3	greedy_best_first_graph_search	h_unmet_goals	88	25	27	230	15	0.022696599999999734
Air Cargo Problem 3	greedy_best_first_graph_search	h_pg_levelsum	88	14	16	126	14	22.382877300000004
Air Cargo Problem 3	greedy_best_first_graph_search	h_pg_maxlevel	88	21	23	195	13	26.8393283
Air Cargo Problem 3	greedy_best_first_graph_search	h_pg_setlevel	88	35	37	345	17	127.15152259999999
Air Cargo Problem 3	astar_search	h_unmet_goals	88	7388	7390	65711	12	5.367039199999994
Air Cargo Problem 3	astar_search	h_pg_levelsum	88	369	371	3403	12	413.32678769999995
Air Cargo Problem 4	breadth_first_search		104	99736	114953	944130	14	62.4931047
Air Cargo Problem 4	depth_first_graph_search		104	25174	25175	228849	24132	2255.6572815
Air Cargo Problem 4	uniform_cost_search		104	113339	113341	1066413	14	73.28962670000055
Air Cargo Problem 4	greedy_best_first_graph_search	h_unmet_goals	104	29	31	280	18	0.036879499999948614
Air Cargo Problem 4	greedy_best_first_graph_search	h_pg_levelsum	104	17	19	165	17	42.10260199999999993
Air Cargo Problem 4	greedy_best_first_graph_search	h_pg_maxlevel	104	56	58	580	17	97.1335939999999
Air Cargo Problem 4	greedy_best_first_graph_search	h_pg_setlevel	104	107	109	1164	23	596.4100717000001
Air Cargo	astar_search	h_unmet_go	104	34330	3433	32850	14	34.6832

Problem 4		als			2	9		168000 0008
Air Cargo Problem 4	astar_search	h_pg_levels um	104	1208	1210	12210	14	2331.99 5729

Table and chart below present number of nodes expanded against number of actions in the domain. For all algorithms but one number of expanded nodes grows with domain size. For four following algorithms the difference is the biggest: uniform cost search, breadth first search, A* search with unmet goals heuristic function, and depth first search. However, for depth first search number of expanded nodes for 88 actions (408) was smaller than for 72 actions (624). This is rather unusual, but might be related to the fact that problems and goals were different for the domains. All greedy searches had the smallest amount of expanded nodes and their grow with domain size was the smallest as well.

	20	72	88	104
breadth_first_search	43	3343	14663	99736
depth_first_graph_search	21	624	408	25174
uniform_cost_search	60	5154	18510	113339
greedy_best_first_graph_search, h_unmet_go	7	17	25	29
greedy_best_first_graph_search, h_pg_levels	6	9	14	17
greedy_best_first_graph_search, h_pg_maxle	6	27	21	56
greedy_best_first_graph_search, h_pg_setlev	6	9	35	107
astar_search, h_unmet_goals	50	2467	7388	34330
astar_search, h_pg_levelsum	28	357	369	1208
astar_search, h_pg_maxlevel	43	2887		
astar_search, h_pg_setlevel	33	1037		

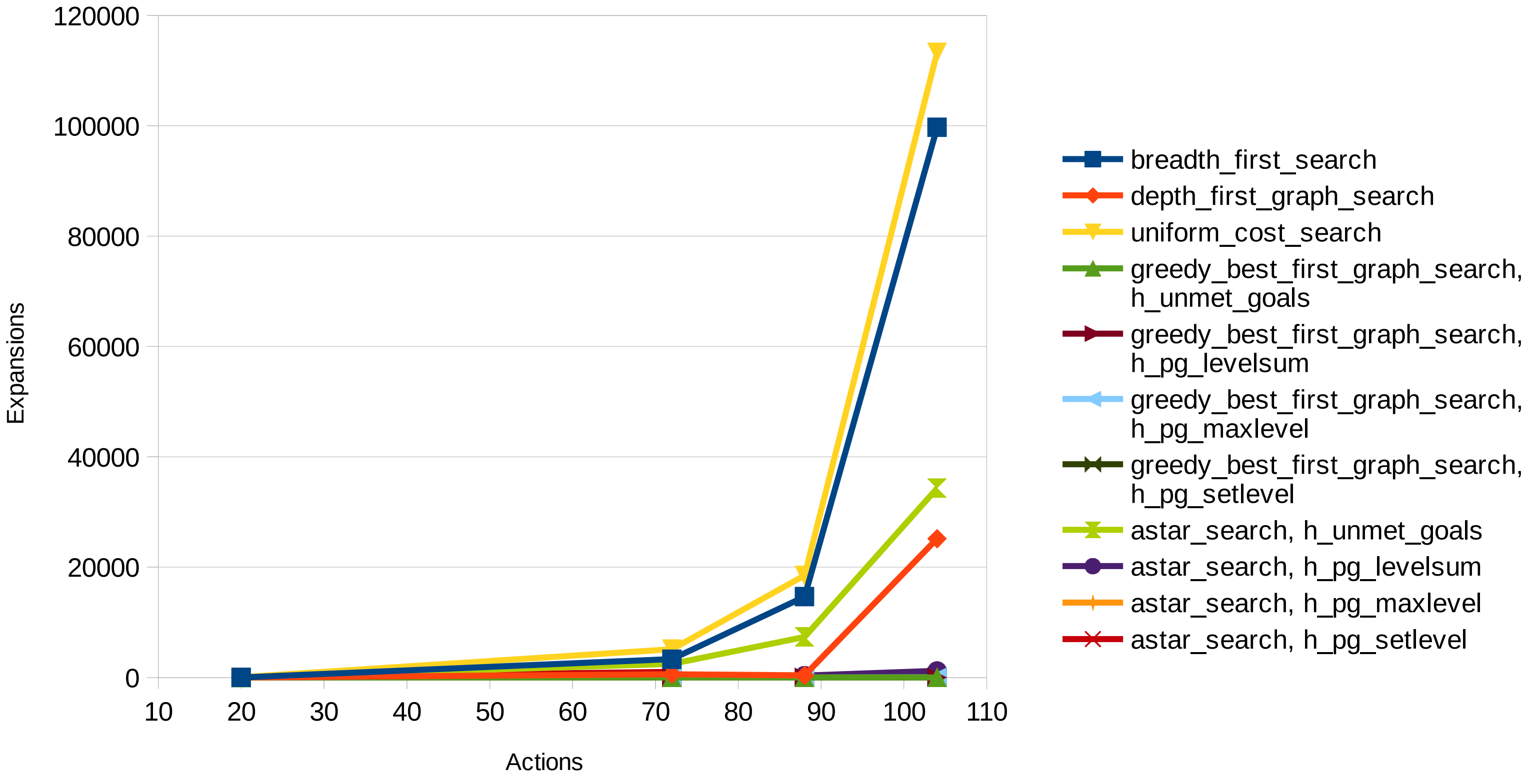
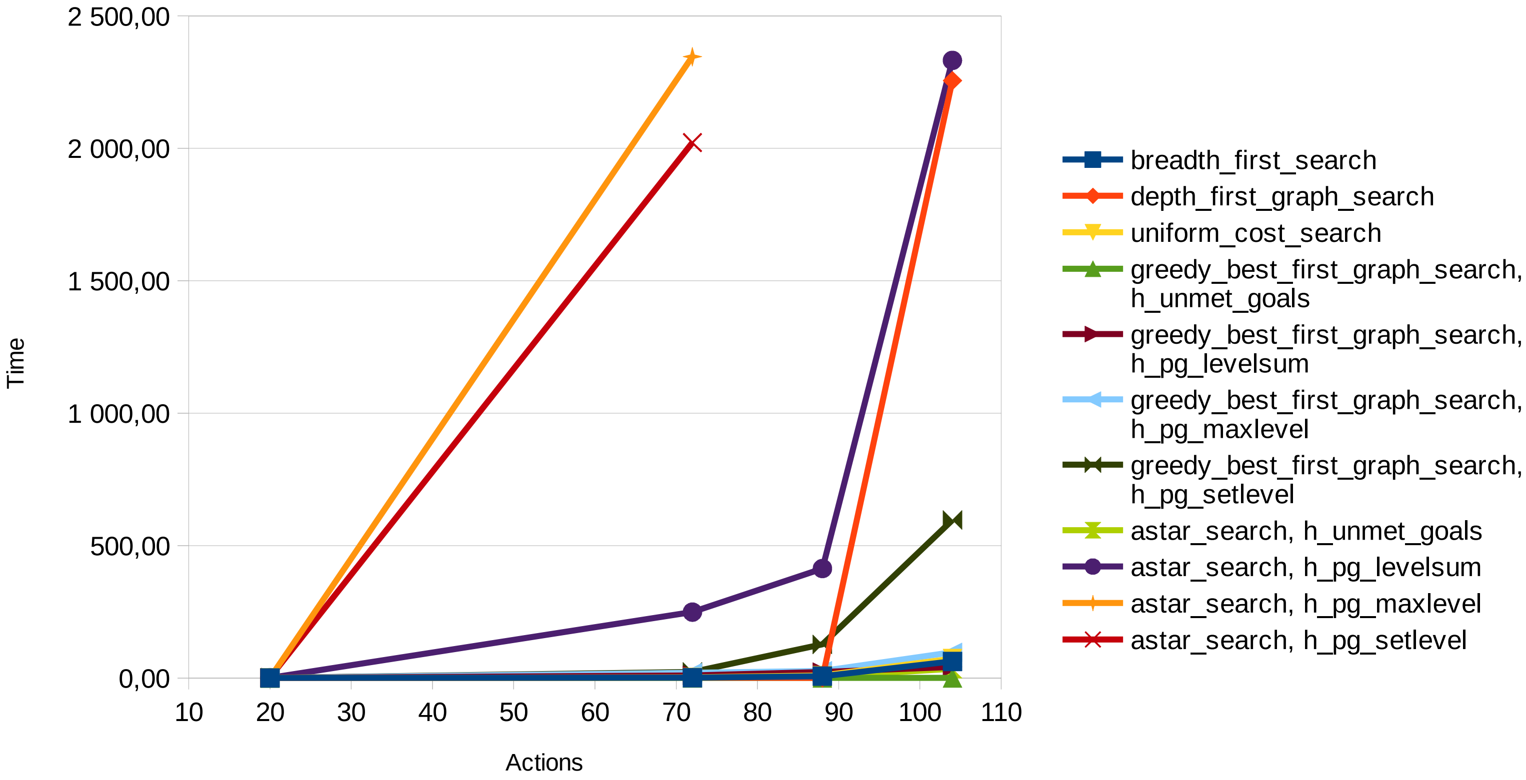


Table and chart below present search time against the number of actions in the domain. For all algorithms but one time needed to finish the search grows with domain size. For five following algorithms the difference is the biggest: A* search with all heuristic function but unmet goals, depth first search, and greedy algorithm with set level heuristic function. However, for depth first search time needed to finish for 88 actions (0.69s) was smaller than for 72 actions (1.73s). This is rather unusual, but might be related to the fact that problems and goals were different for the domains. Noticeable smallest amount of time to find solution is required by greedy search with unmet goals heuristic function. A* search with the same heuristic function (unmet goals) obtained better results than other algorithms as well.

	20	72	88	104
breadth_first_search	0,00	1,29	6,71	62,49
depth_first_graph_search	0,00	1,73	0,69	2 255,66
uniform_cost_search	0,01	2,14	9,20	73,29
greedy_best_first_graph_search, h_unmet_go	0,00	0,01	0,02	0,04
greedy_best_first_graph_search, h_pg_levels	0,38	9,97	22,38	42,10
greedy_best_first_graph_search, h_pg_maxle	0,28	19,83	26,84	97,13
greedy_best_first_graph_search, h_pg_setlev	0,95	22,96	127,15	596,41
astar_search, h_unmet_goals	0,01	1,42	5,37	34,68
astar_search, h_pg_levelsum	1,03	248,75	413,33	2 332,00
astar_search, h_pg_maxlevel	1,01	2 346,19		
astar_search, h_pg_setlevel	2,40	2 021,52		



The chart below presents time needed to finish search for different algorithms depending on the domain size. As presented the differences in times between algorithms grew with domain size. The biggest differences were noticed for greedy search with set level heuristic function, and A* search for all heuristic functions but unmet goals.

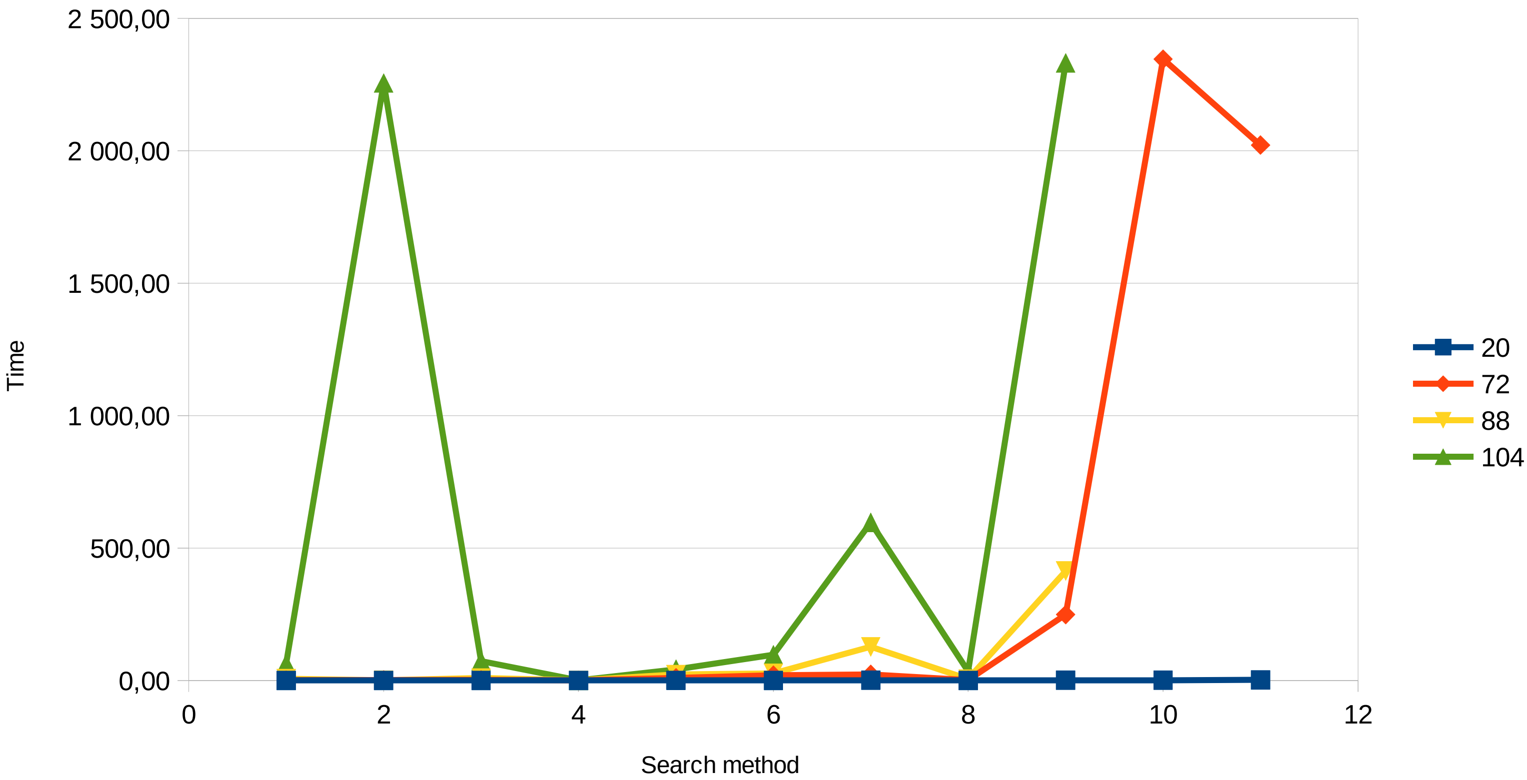
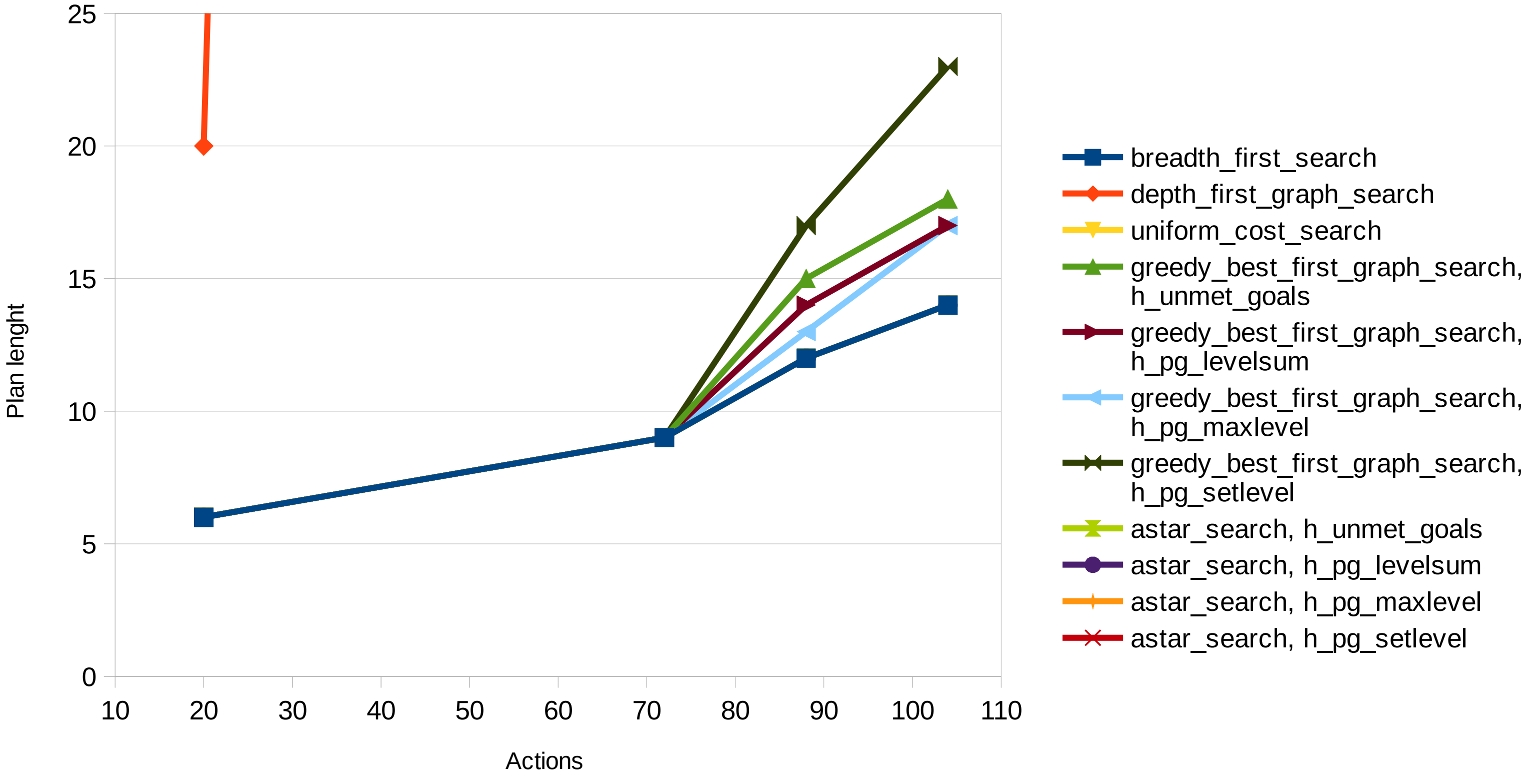


Table and chart below present the length of the plans returned by each algorithm on all search problems. In terms of finding optimal solution we can see that depth search performs definitively the worst for all domain sizes. For larger domains all greedy algorithms seem to find solution very close to optimal, but slightly bigger. The algorithms that find optimal solution in all domain sizes are: breath search, uniform cost search, and A* search.

	20	72	88	104
breadth_first_search	6	9	12	14
depth_first_graph_search	20	619	392	24132
uniform_cost_search	6	9	12	14
greedy_best_first_graph_search, h_unmet_go	6	9	15	18
greedy_best_first_graph_search, h_pg_levels	6	9	14	17
greedy_best_first_graph_search, h_pg_maxle	6	9	13	17
greedy_best_first_graph_search, h_pg_setlev	6	9	17	23
astar_search, h_unmet_goals	6	9	12	14
astar_search, h_pg_levelsum	6	9	12	14
astar_search, h_pg_maxlevel	6	9		
astar_search, h_pg_setlevel	6	9		



The algorithm that definitively performed the best time wise (almost real time) for all domain sizes is greedy search with unmet goals heuristic function. A* search with unmet goals heuristic function performed pretty good as well, however for larger domains time needed to finish was definitively larger. For small domains basic algorithms (breadth search, depth search, and uniform cost search) and ones using unmet goals heuristic function performed noticeably better than other algorithms. The optimal plans were found by breath search, uniform cost search, and A* search.