Metaheuristic-Based Multi-Objective Scheduling of Rescue Units to Control Wildfires

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Introduction

- Multiple studies have found that climate change has already led to an increase in wildfire season length, wildfire frequency, and burned area.

Problem: Extinguish fires in multiple locations using multiple fire stations and a limited number of vehicles at each station.

OBJECTIVES

Minimize the total time until all fire points are extinguished.

Minimize the total number of used rescue vehicles.

CONSTRAINTS

Number of rescue units sent from a fire station cannot exceed its own capacity.

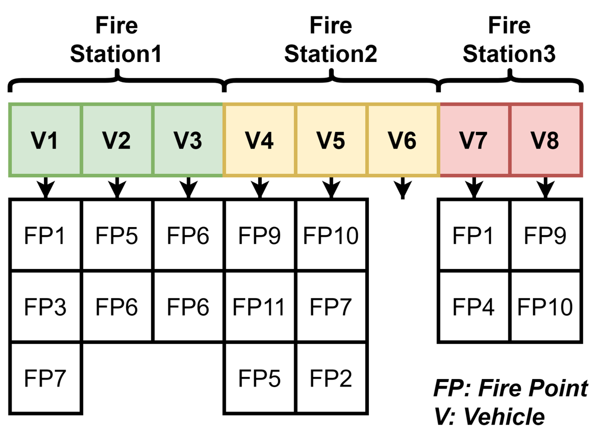
The combined extinguishing speed of vehicles at a fire point must surpass the fire spread speed.

All fire points should be extinguished in a finite time.

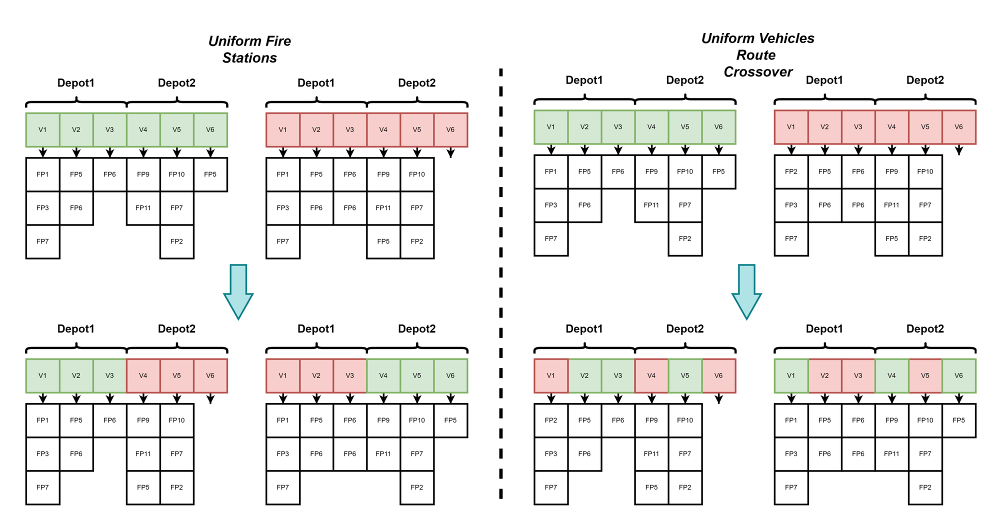
Solution: To design a new multi-depot NSGA II based algorithm for extinguishing fires quickly while using small number of rescue units. To the best of our knowledge, it is the first NSGA II based model to include multiple fire stations and allow vehicles to visit multiple fire points.

Proposed Algorithm

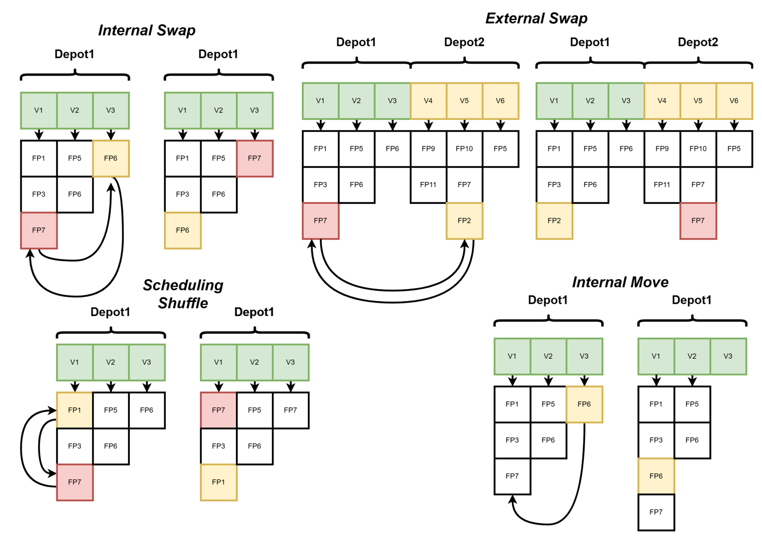
- In our genetic algorithm, each chromosome, i.e., individual will have the following solution representation:
- We have enhanced the NSGA II Algorithm with new problem specific operators, including 2 crossover operators and 4 mutation operators.



Crossover



Mutation



Reference Algorithms

In our comparison study, we have implemented and tested all the following algorithms below.

Multi-Objective Algorithms:

- E-Constraint Method [1]
- Greedy Heuristic [1]
- Multi-Objective GA

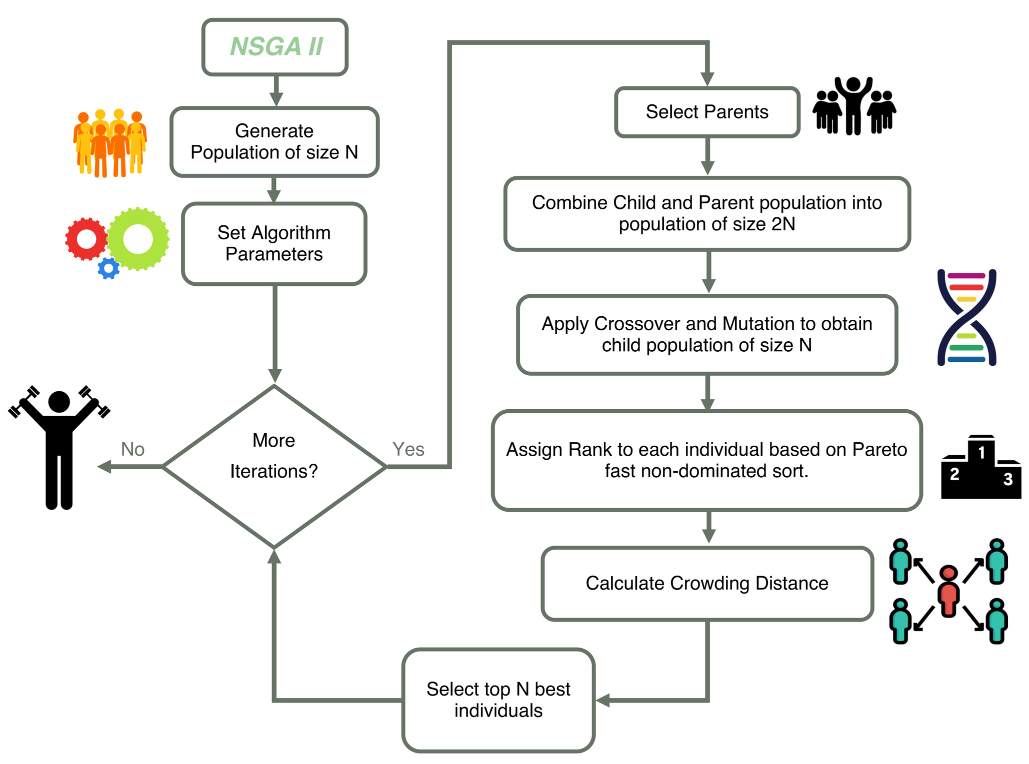
Single Objective Algorithms:

- Unified Objective GA
- Mixed Integer Programming

Multi-Objective solutions are very rare.

NSGA II

NSGA II provides fast convergence, elitism strategy and diversity preservation. Elitist approach keeps valuable individuals for the next generations [2].



Discussions and Future Work

- Extended the single station solutions in the literature to multiple stations.
- Provided more diverse behaviors for rescue units.
- Developed a highly parameterized testing framework and benchmarking.
- Tuned our algorithm to obtain promising parameters and improved our results.
- As a future work, fire points can spread dynamically.

References

[1] P. Wu, F. Chu, A. Che and M. Zhou, "Bi–objective scheduling of fire engines for fighting forest fires: New optimization approaches", IEEE Trans. Intell. Transp. Syst., vol. 19, no. 4, pp. 1140-1151, Apr. 2018.

[2] K. Deb, A. Pratap, S. Agarwal and T. Meyarivan, "A fast and elitist multi-objective genetic algorithm: NSGA-II," in IEEE Transactions on Evolutionary Computation, vol. 6, no. 2, pp. 182-197, April 2002.

Testing Framework

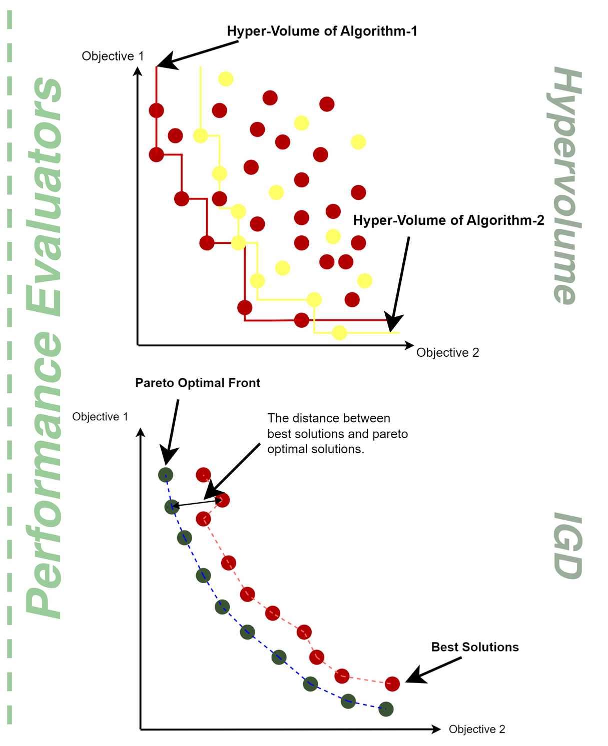
- There are countless forms of algorithms available against wildfire disasters.
- In order to make comparisons, we need to adapt our model to these algorithms.

PARAMETER	VALUE
fitness type	hypervolume, igd, score
number_of_fire_points	10
number_of_fire_stations	10
fire_point_generator	grid or random,
rescue_unit_generator	grid or random,
fiee_station_generator	grid or random,
environment_size	100x100
spread_speed_boundry	[5, 19]
gridiness	3
traveling_speed_boundry	[30, 80]
fire_fighting_speed_boundry	[20,30]
unique_vehicles	unique_over_stations
vehicles_per_station_boundry	[6, 8]
job_type	single_objective
job_type	multi_objective
job_type	e_constraint
size_of_population	100
downgrade	true

Crossover	Mutation	Hypervolume	IGD	Unified
external_cut_and_crossfill	–	113860	9574	350
uniform_vehicles_route	–	66940	1491	277
uniform_fire_stations	–	65011	**1364**	**256**
best_fire_stations_first	–	**162856**	19305	409

Crossover	Mutation	Hypervolume	IGD	Unified
best_fire_stations_first	internal_swap	315262	24029	303
best_fire_stations_first	external_swap	337842	22171	370
best_fire_stations_first	scheduling_shuffle	98493	6758	340
best_fire_stations_first	internal_move	133715	**6374**	**268**
best_fire_stations_first	score_based_mutation	**369297**	8324	395

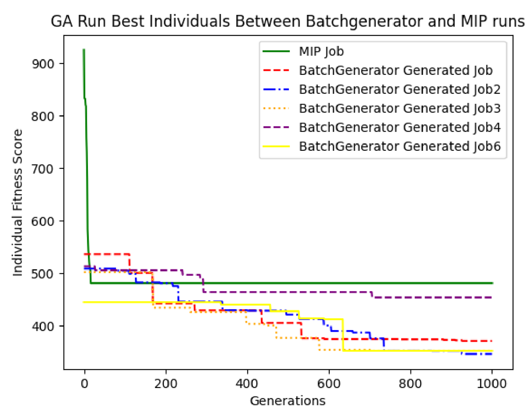
Performance Evaluators



Experimental Results

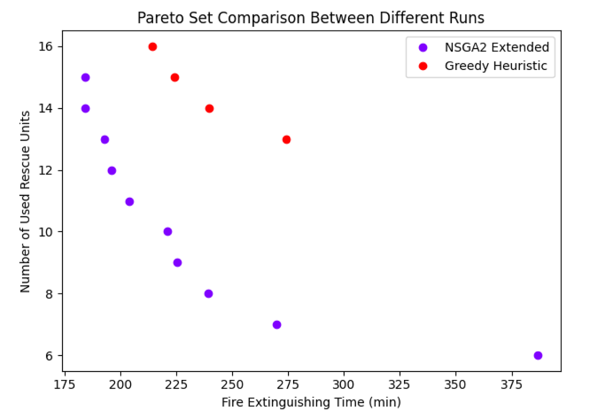
- *Limited NSGA2:* Mutations involve 'move' are not allowed, vehicles visiting only one point as in reference [1]
- *Extended NSGA2:* All Mutation and Crossover operators are allowed.

Unified Objective GA *VS* MIP



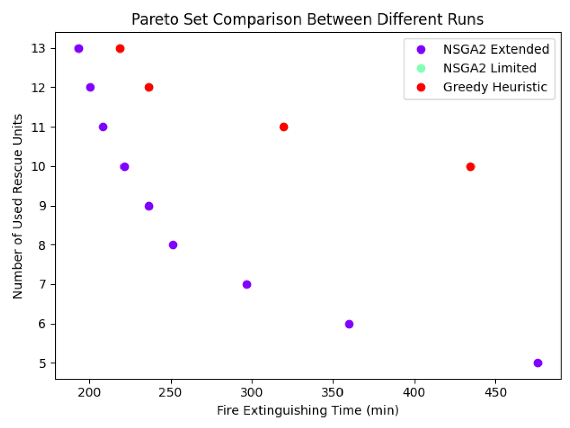
- The Batch Generator runs algorithms with various parameter values, and tuning is used to identify the best job generated.

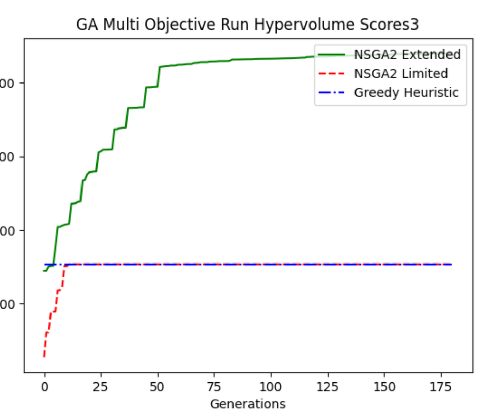
Our Multi-Objective GA *VS* Greedy Heuristic [1]



Our Multi-Objective GA *VS* Greedy Heuristic [1] (Single Depot)

Environment		Extended NSGA2			Limited NSGA2			Greedy Heuristic		
FP	FPG	Hypervolume	IGD	Unified Score	Hypervolume	IGD	Unified Score	Hypervolume	IGD	Unified Score
5	G	**34376,8**	**287,3**	**114**	32101	544,2	115,9	32101	544,2	115,9
5	R	**33898**	**243**	**107,7**	32140,8	465,6	110,5	32140,8	465,6	110,5
10	G	**32918,9**	**251,6**	**83,3**	29366,8	519	91,5	29366,8	519	91,5
10	R	**32302**	**300,7**	**91**	29372,2	493,4	**91**	29372,2	493,4	**91**
20	G	**26857,5**	**1150**	353,5	21979,9	3295,7	**351,1**	21979,9	3295,7	**351,1**
20	R	**29780,1**	**363**	**109,8**	23381,3	875,4	114,1	23381,3	875,4	114,1
50	G	**16667,6**	**1716,1**	**265,5**	5228	14230,5	437	5228	14230,5	437
50	R	**29121,9**	**1370,7**	**243,5**	11553,7	7796,6	276,3	11553,7	7796,6	276,3

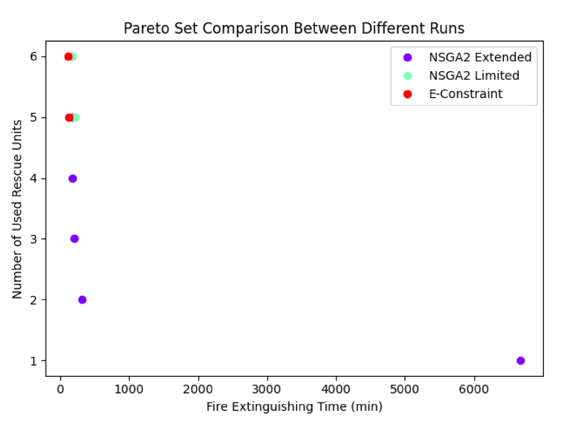


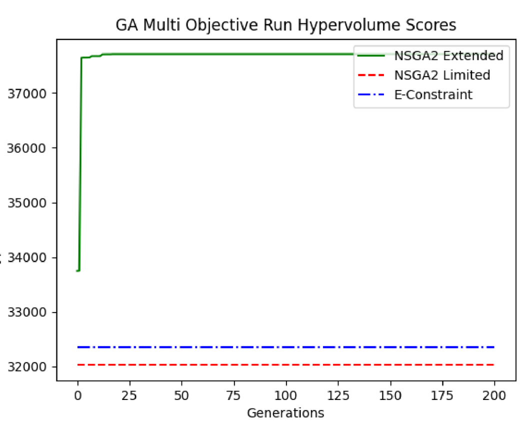


- Limited NSGAII and Greedy share the identical Pareto Front points.
- They couldn't find a solution for fewer than 10 vehicles.

Our Multi-Objective GA *VS* E-Constraint [1] (Multi Depot)

Environment		Extended NSGA2			Limited NSGA2			E-Constraint		
FS	FP	Hypervolume	IGD	Unified Score	Hypervolume	IGD	Unified Score	Hypervolume	IGD	Unified Score
3	5	**37708,3**	1283,6	117,9	32025,1	**627,7**	125,3	32359,0	366,2	**83,2**
5	5	**33772,4**	**299,8**	**123,3**	31667,6	781,7	171	31370,4	1135,8	135,2
3	10	**32835,2**	**700,7**	**150,1**	28776,6	1015,8	173,2	*Timeout*		
5	10	**108648,2**	5754,3	**96,9**	29244,8	**718,7**	108,7			
3	20	**29822**	**674,2**	184,4	23190,5	1393,1	**146,7**			
5	20	**40442,5**	7278,2	136,2	23413,3	**876**	**109,3**			
3	50	**41345,3**	**933,9**	138,7	11848	1257,6	**116,7**			
5	50	**37525,2**	**833,1**	200,8	11730,4	2736,1	**198,1**			





- Extended NSGAII finds a solution with one vehicle but with a low score.

Technologies Used

python NumPy matplotlib git GitHub