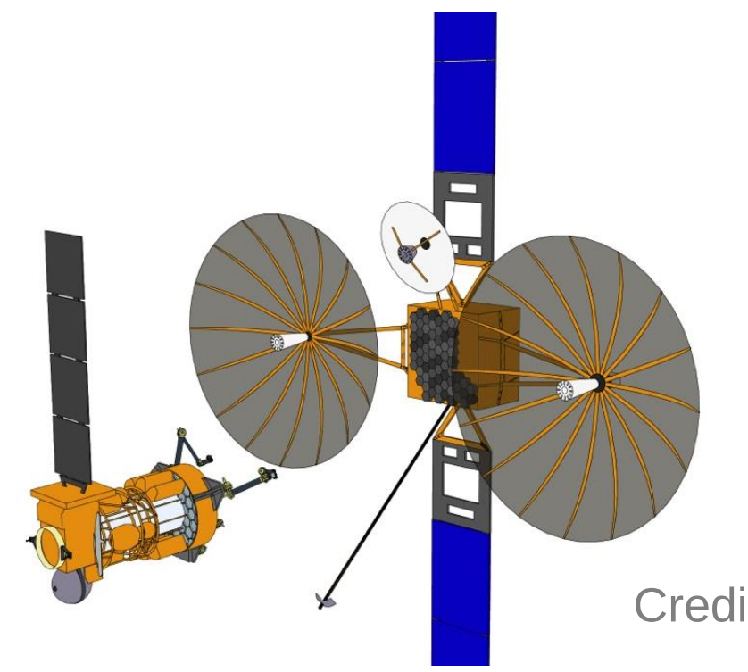
Credit: DARPA

Satellite Sequencing Optimization using a Genetic Algorithm

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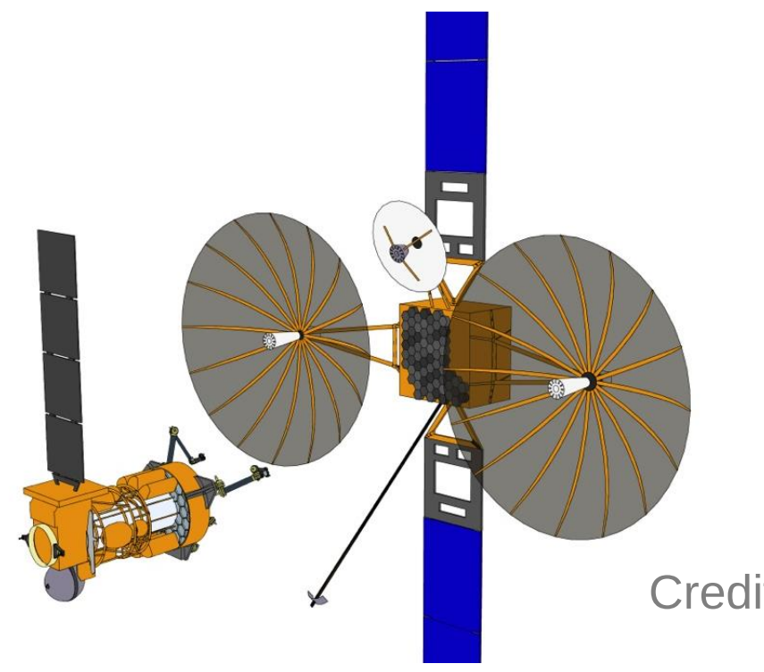

Credit: DARPA

The problem of mission design for a robotic servicing satellite in geosynchronous Earth orbit (GEO) was investigated. A representative set of potential client satellites was selected, and operational needs were randomly assigned based on the average number of GEO retirements, anomalies, and repositioning maneuvers that currently occur each year. An objective function was developed to represent the value of servicing mission sequences, including client fees, time penalties, and operational risk. A genetic algorithm was then used to find sequences of operations on the potential client set that maximized the objective function's value. Scenarios were analyzed with the database of satellites as well as with a dynamic client model. Sequences that begin with repair operations and later include refuel, observation, and retirement maneuvers were found to be the most valuable, with some differences in the optimal sequences depending on parameter values in the objective function.

Problem statement

How to determine which satellites to service, and the sequence in which to service them for the most valuable result

Satellite Database

~450 satellites in geostationary orbit (GEO)

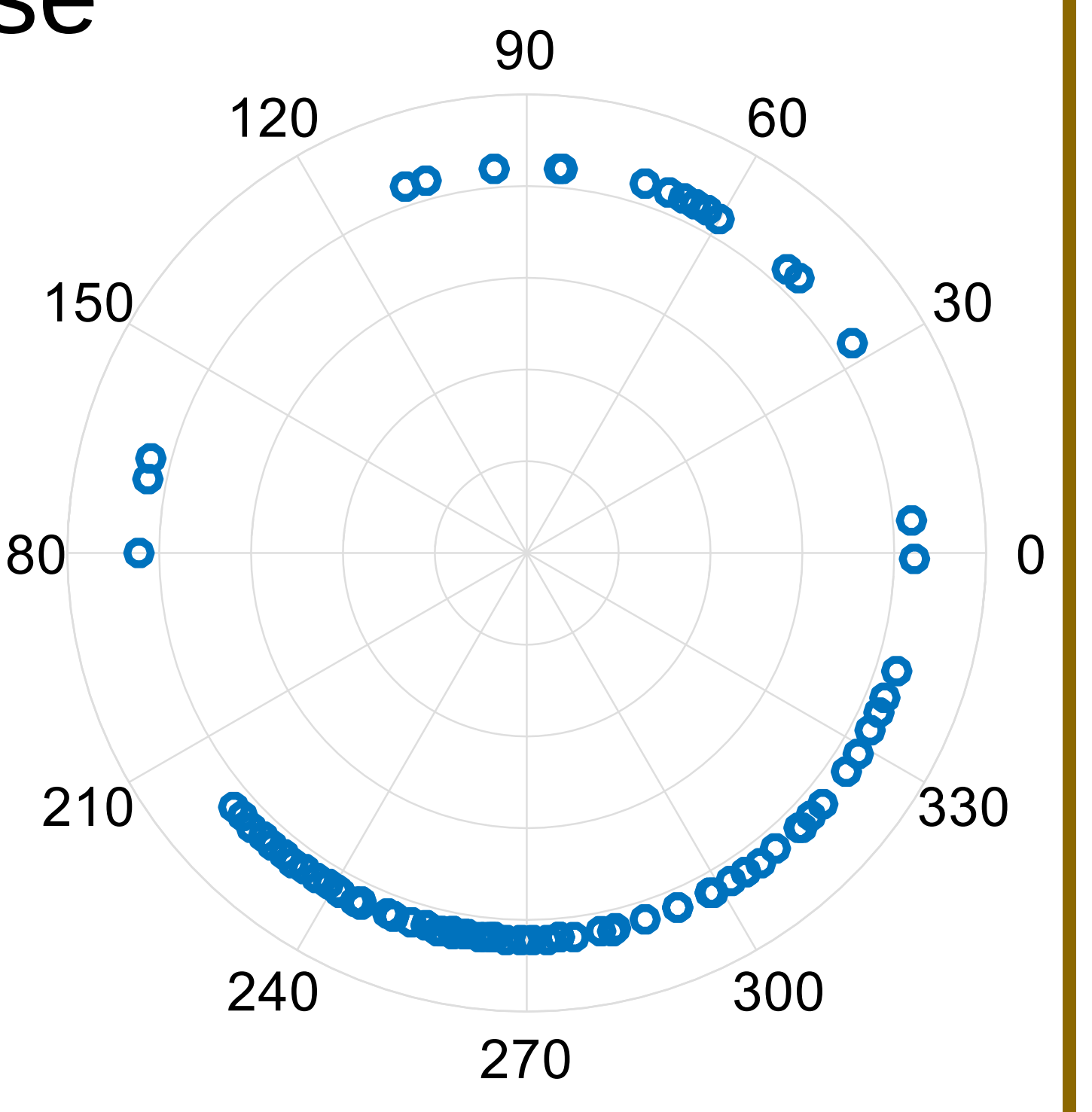
~100 useable satellites

- US owned
- US launched
- Non-inclined
- Currently active

From data about the need for satellite servicing

- 2 observations
- 5 repairs
- 14 repositions
- 15 retirements
- 17 refuels

53 client satellites in test data set



Client Data Assumptions

Operation	Revenue	Probability of Success	Operation Time	Time Penalty
Observe	\$10M	99.9%	10 days	0
Repair	\$25M	99.0%	30 days	\$100,000
Reposition	\$10M	99.5%	20 days + transfer time	\$100,000
Retire	\$10M	99.5%	20 days + transfer time	0
Refuel	\$15M	99.0%	30 days	\$100,000

Objective Function

$$C = \sum_{i=1}^{s}\left[c_1 \frac{V_i}{2-\prod_{k=1}^{i} p_k} - c_2 \beta_i max\left(0, T_i - T_{i,allow}\right)\right]$$

where

b = Lost revenue per day of customer non-operation

C = Total value of a chromosome

c_{1-2} = Scaling factors for relative values of terms

p = Probability of success for each servicing operation type

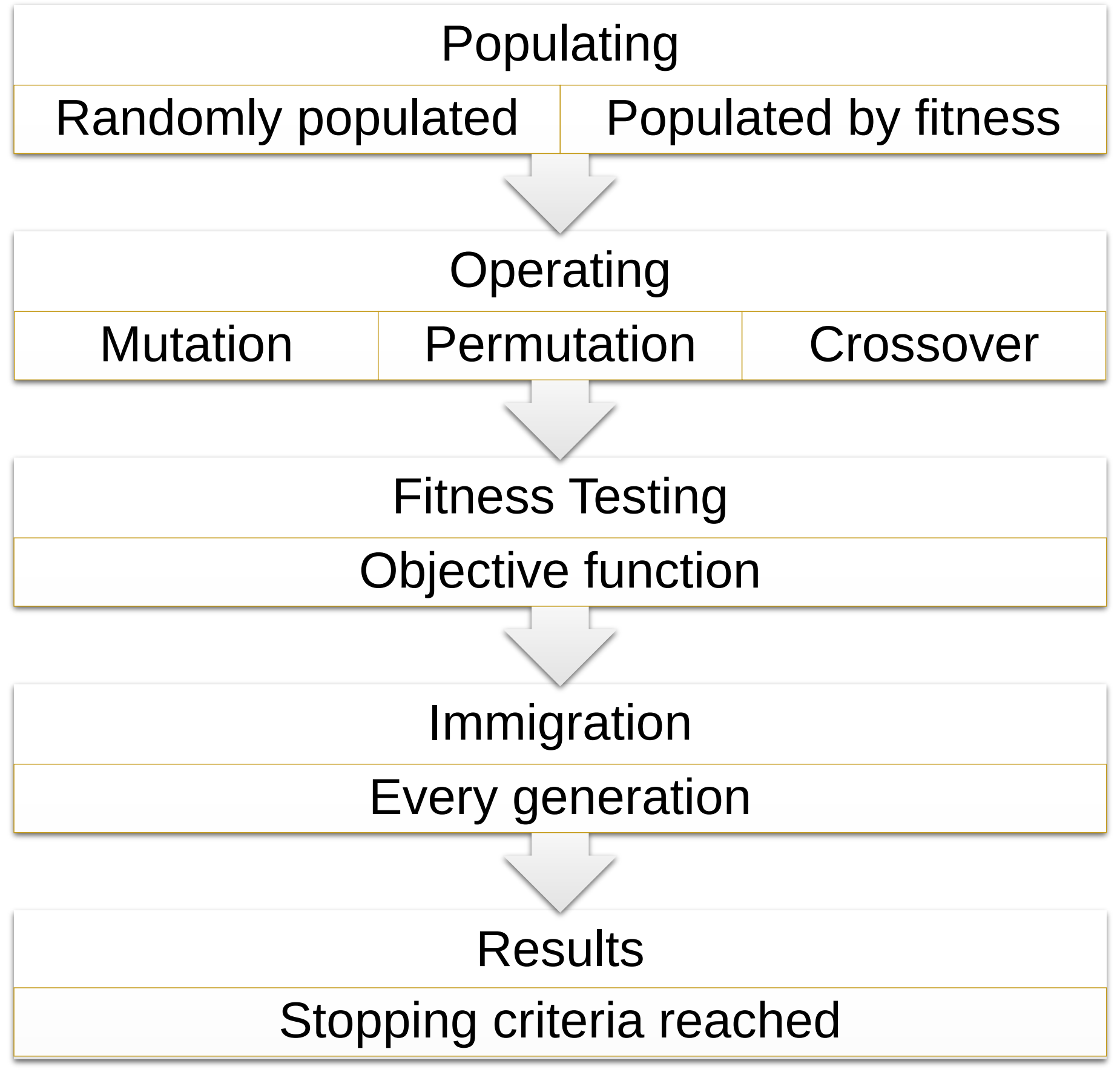
s = Number of satellites in a mission sequence

T = Time required for orbit transfer and servicing operation

T_{allow} = Wait time allowed before customer starts deducting daily fee

V = Revenue from servicer operation

Genetic Algorithm (GA) Structure



Populating

Randomly populated | Populated by fitness

Operating

Mutation | Permutation | Crossover

Fitness Testing

Objective function

Immigration

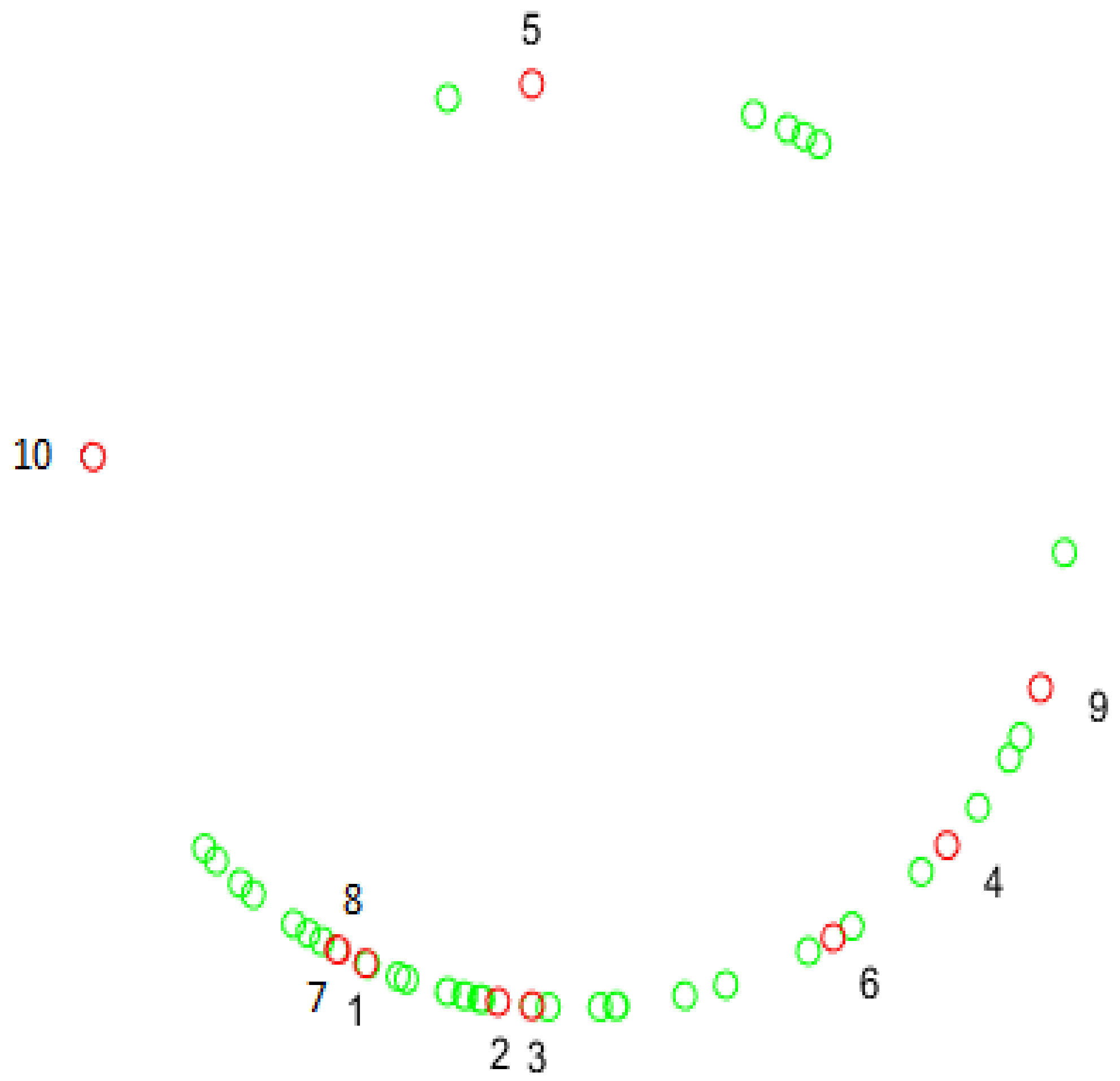
Every generation

Results

Stopping criteria reached

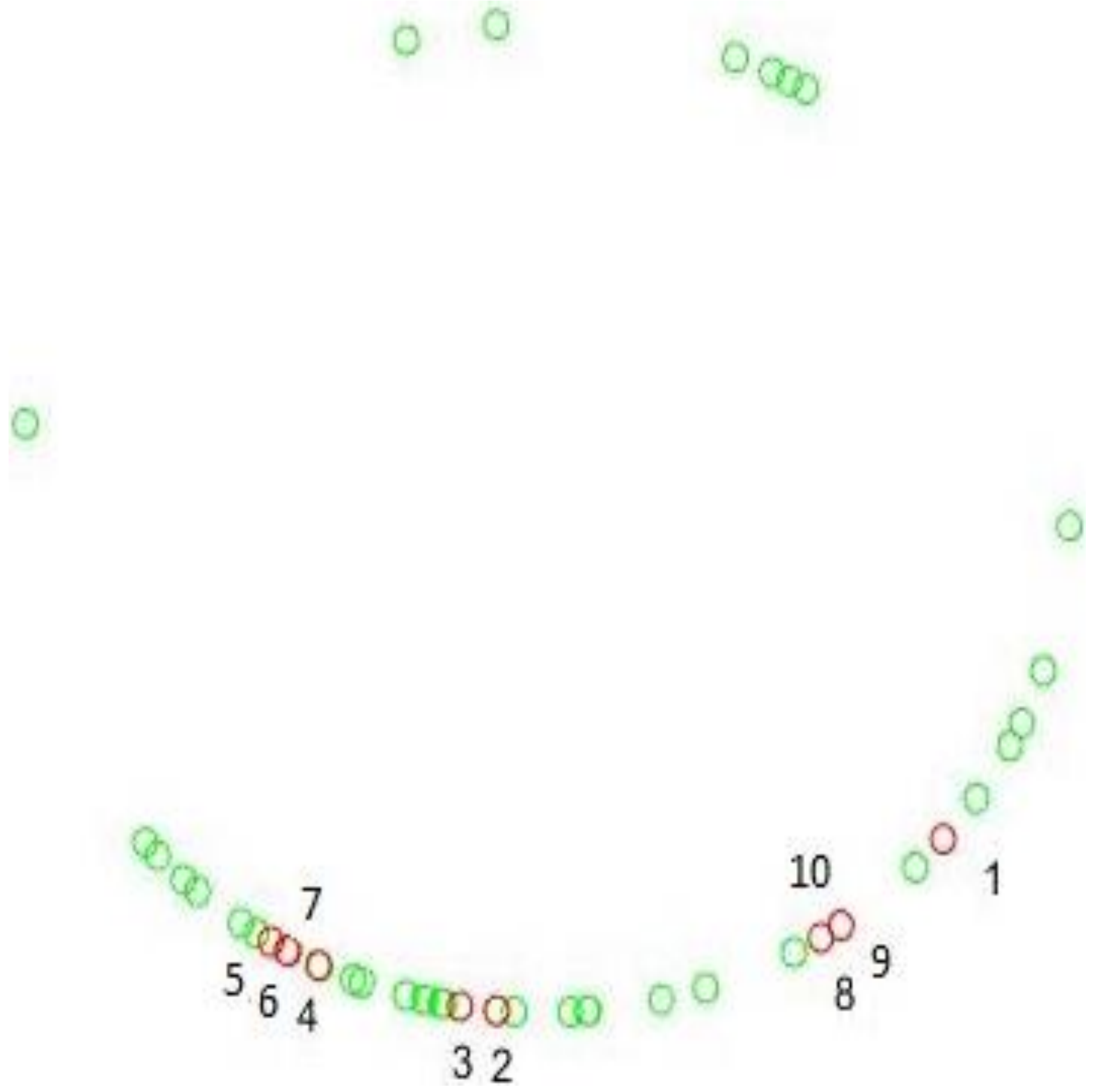
120 Day Time Allowance from Client Perspective

Sequence No.	Longitude (°)	Time Penalty (\$/day)	Operation	Operation Time (days)	Total Time (days)
1	245	100,000	Repair	30	30
2	261	100,000	Repair	38	68
3	265	100,000	Repair	32	100
4	320	100,000	Repair	58	158
5	95	100,000	Repair	98	256
6	302	0	Observe	87	343
7	241	0	Observe	41	384
8	241	0	Retire	20	404
9	342	0	Retire	49	454
10	169	0	Retire	75	528



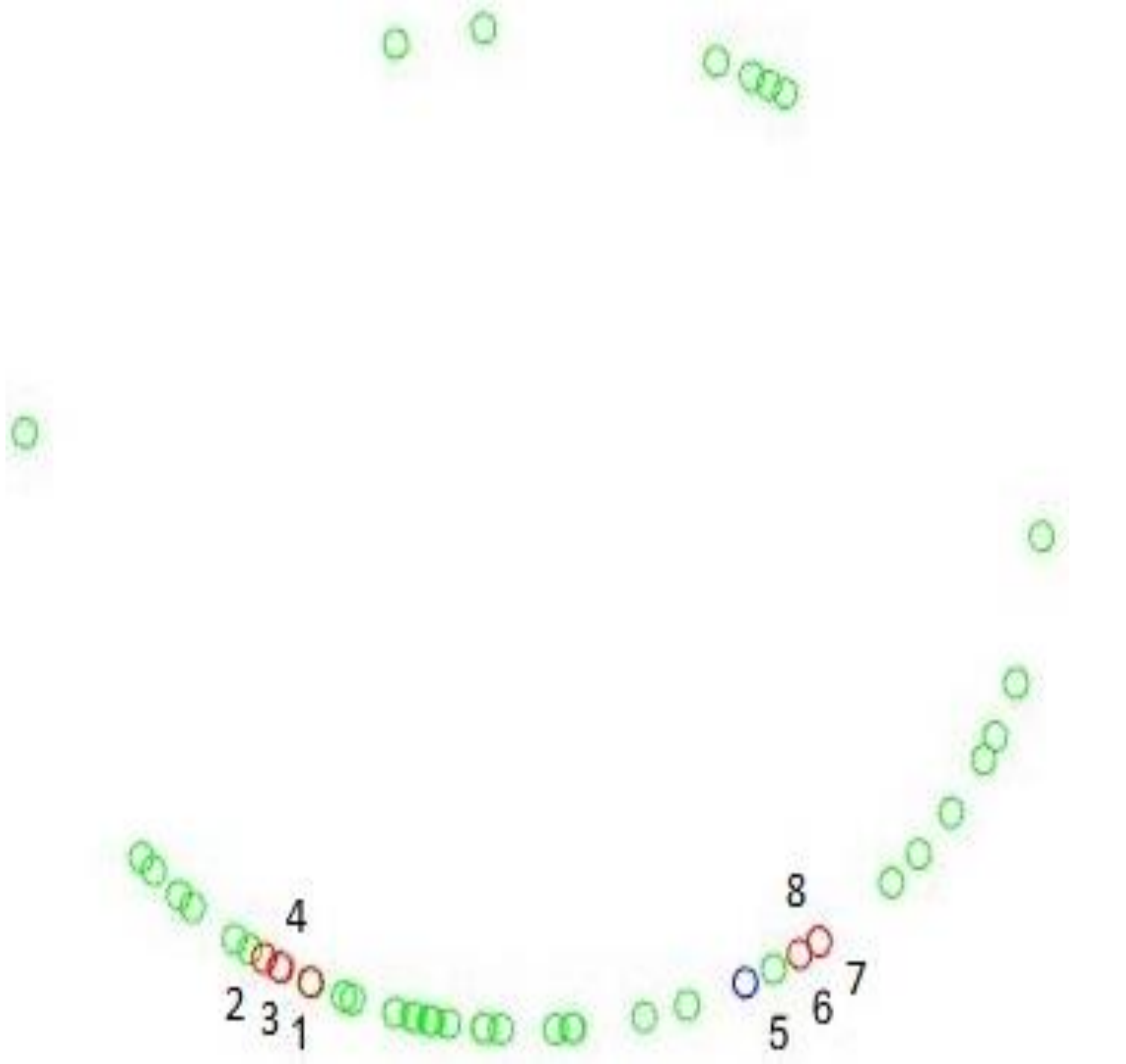
120 Day Time Allowance from Servicer Perspective

Sequence No.	Longitude (°)	Time Penalty (\$/day)	Operation	Operation Time (days)	Total Time (days)
1	320	100,000	Repair	30	30
2	265	100,000	Repair	58	88
3	261	100,000	Repair	32	120
4	245	100,000	Repair	38	158
5	239	100,000	Refuel	33	191
6	241	5,000	Observe	11	202
7	241	5,000	Retire	20	222
8	302	5,000	Observe	28	250
9	305	5,000	Retire	22	272
10	304	5,000	Retire	21	293



Dynamic Client Model

Sequence No.	Longitude (°)	Operation	Total Time (days)
i	320	Repair	30
ii	265	Repair	88
iii	261	Repair	120
ADD NEW SATELLITE	255	--	--
1	245	Repair	155
2	239	Refuel	188
3	241	Observe	199
4	241	Retire	219
5	295	Refuel	265
6	302	Observe	279
7	304	Retire	301
8	305	Retire	321



Conclusions

Technological advances and an economic analysis indicate that multi-satellite GEO servicing will become a reality in the near future. The results achieved in this study demonstrate that the order of a servicing sequence can greatly impact the profit of a mission as well as the general safety of the robotic servicer. The genetic algorithm and objective function proved to be effective in identifying high-value mission designs.

The highest value sequences will begin operations with the highest revenue satellites. Once all the highest revenue satellites are exhausted, or the time delay of service grows too large to make the operation profitable, the servicer should move on to the lowest risk operations. From there, the servicer should end its mission with retirement operations so that it can dispose of itself in the graveyard orbit along with its last client.