BUS ROUTING FOR EMERGENCY EVACUATIONS: THE CASE OF THE GREAT FIRE OF VALPARAÍSO

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CONTEXT

- Natural disasters
  - Earthquakes
  - Tsunamis
  - Volcanic Activity
  - Wildfires
- There are constant efforts to improve the response to these events.

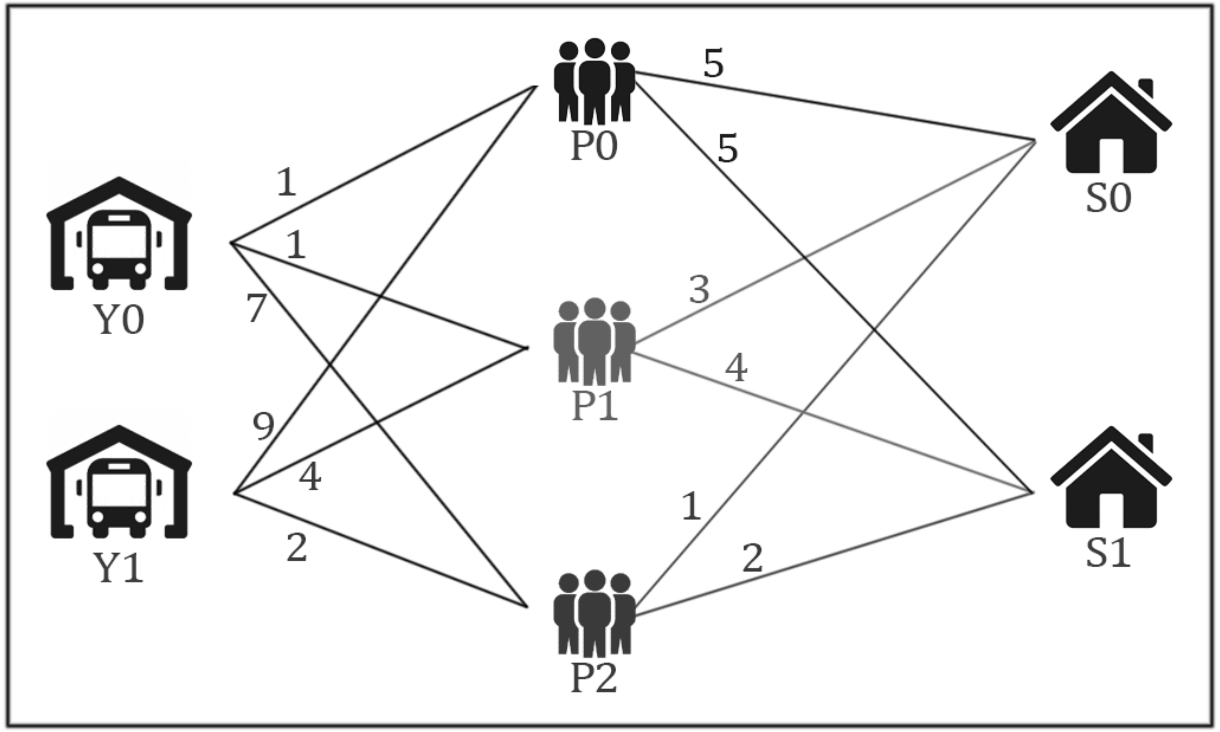
CONTEXT

- Sometimes, evacuation of a risky zone is needed
  - Self-evacuated
  - Transit dependent people

PROBLEM DESCRIPTION

- **Bus Evacuation Problem**
  - Plan the evacuation of an urban zone using public transport.

- Scenario
  - Buses
  - Yards
  - Evacuees
  - Collection points
  - Shelters



PROBLEM DESCRIPTION

- Objective
  - Generate a tour Schedule for each bus
  - Minimize the total evacuation time of the bus with the longest route (Min-Max)

- Constraints
  - All evacuees must be moved to shelters.
  - Shelters and buses has capacity contraints

- NP-Complete (Goerigk, Marc, et. al., 2012)

STATE OF THE ART

- Formally proposed by Douglas R. Bish (2011)
- Variant of the Vehicle Routing Problem
- Min-Max function proposed: minimize the evacuation duration of the bus with the longest duration
- Mixed-integer programming formulation

STATE OF THE ART

Some variants

- Robust BEP: Number of evacuees uncertain.
- Integrated BEP: Location of shelters and collection point is also planified along with the schedule.
- Two-Stage Robustness Approach: Number of evacuees, travel time and number of available buses uncertain.
- Comprehensive Evacuation Problem: Determine which shelters will be used, and how public transport interact with private transit.

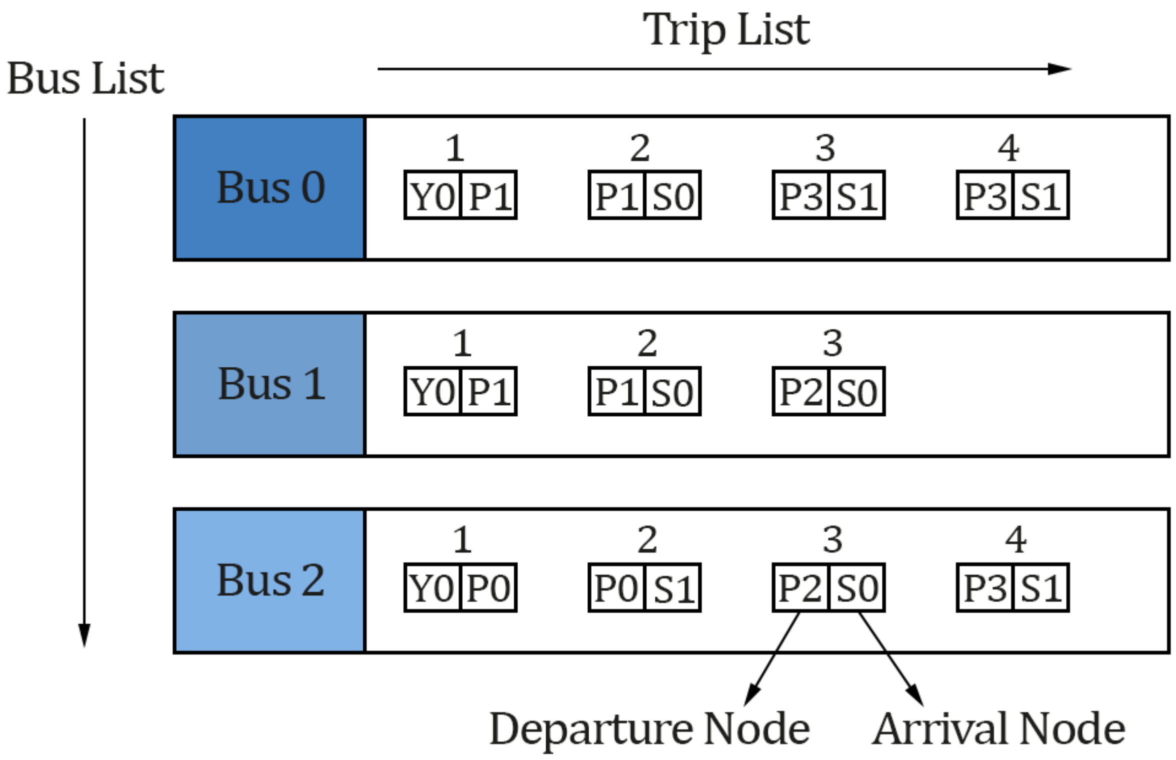
STATE OF THE ART

- Main approaches for the BEP
  - MIP solver
  - Branch and Bound

- And for the variants
  - Tabu Search
  - Branch-cut-and-Price
  - Genetic Algorithms

ALGORITHM PROPOSAL FOR THE BEP REPRESENTATION

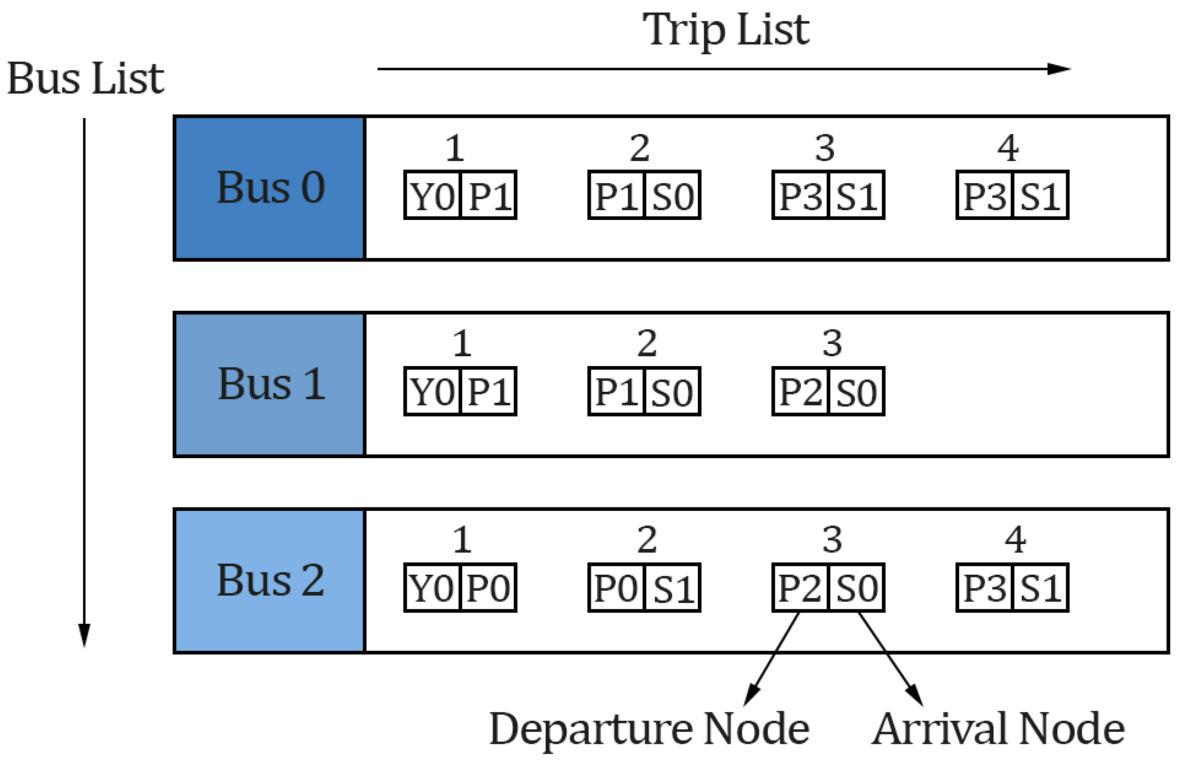
- Representation of the solutions
  - List of buses
  - List of trips
  - Trip: movement between two nodes
  - Two types of trips
    - Initial trip (Yard – Collection Point)
    - Evacuation Trip (Collection Point – Shelter)



ALGORITHM PROPOSAL FOR THE BEP REPRESENTATION

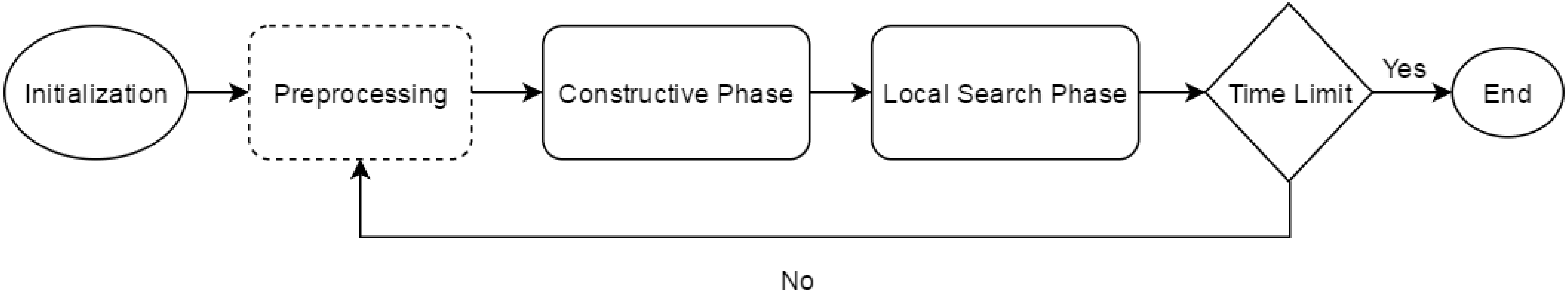
Advantages

- Incorporates many constraints
  - Flow-balance for collection points
  - Flow-balance for shelter nodes
  - Bus can only make one trip at a time
  - Each bus leaves the yard on first trip
- Easy to manipulate to generate other solutions
- Easy to evaluate the objective function
- Other constraints are handled on the process…

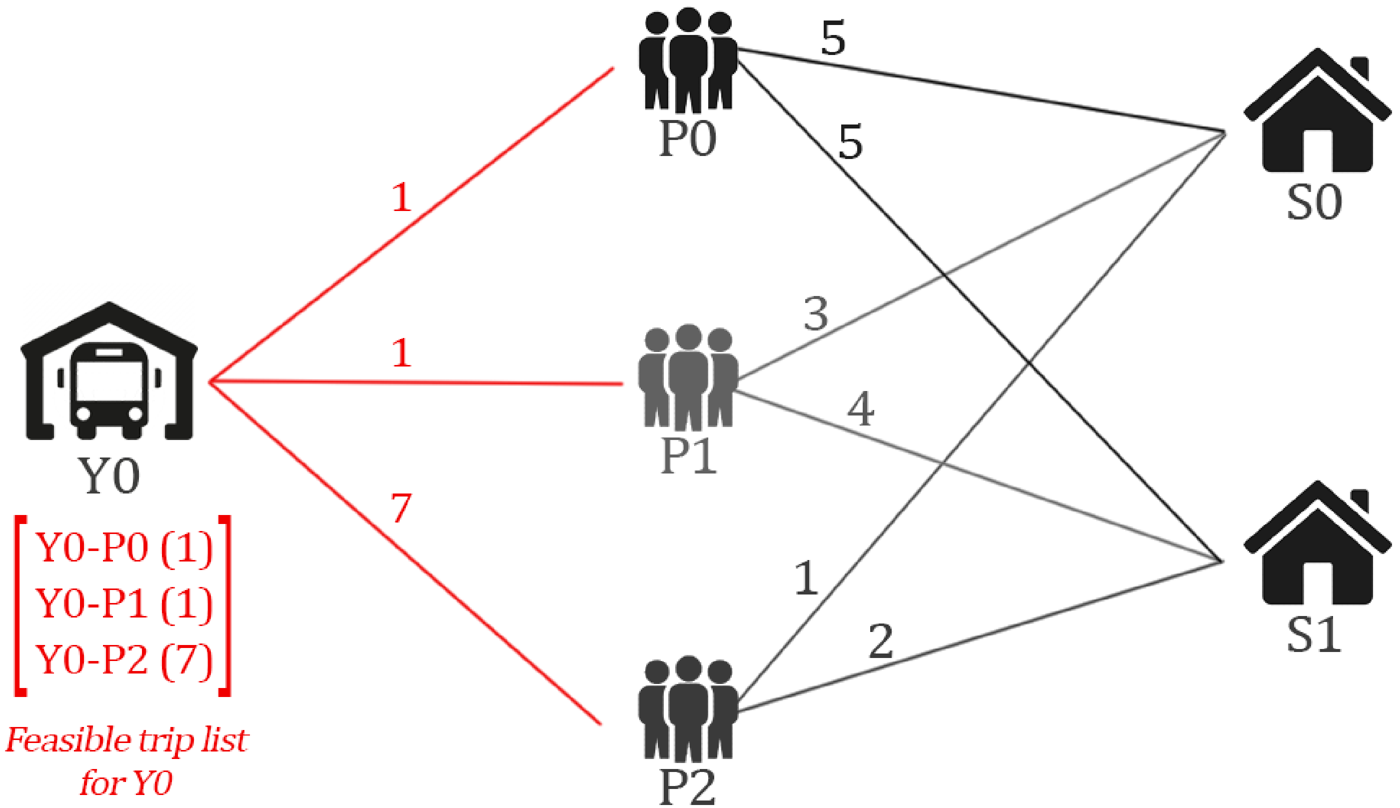


ALGORITHM PROPOSAL FOR THE BEP

GREEDY RANDOMIZED ADAPTIVE SEARCH PROCEDURE (GRASP) METAHEURISTIC

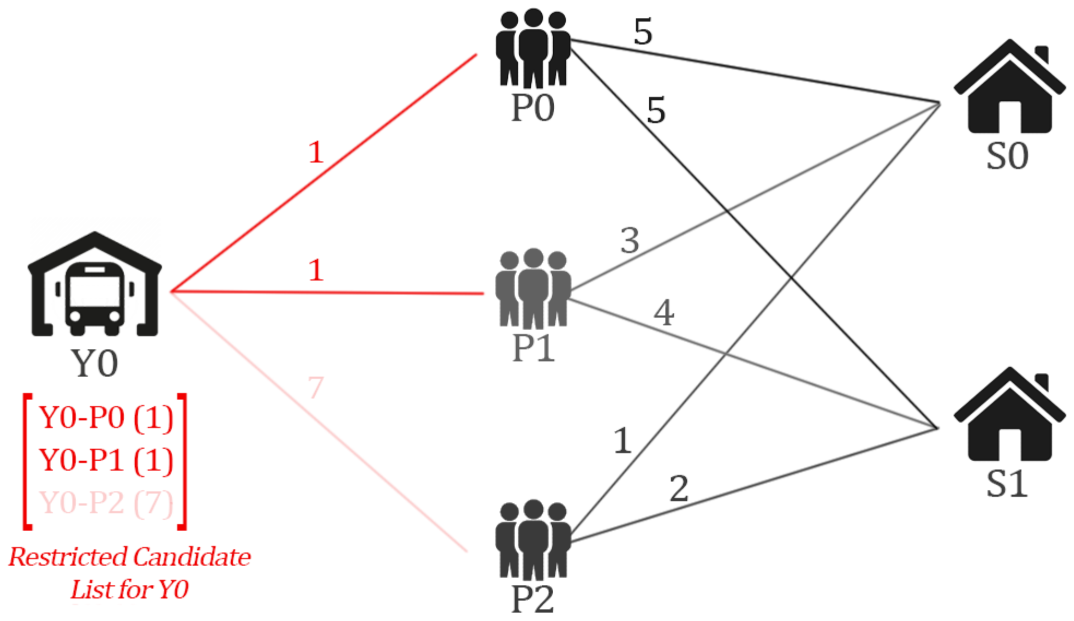


ALGORITHM PROPOSAL FOR THE BEP
INITIALIZATION PHASE



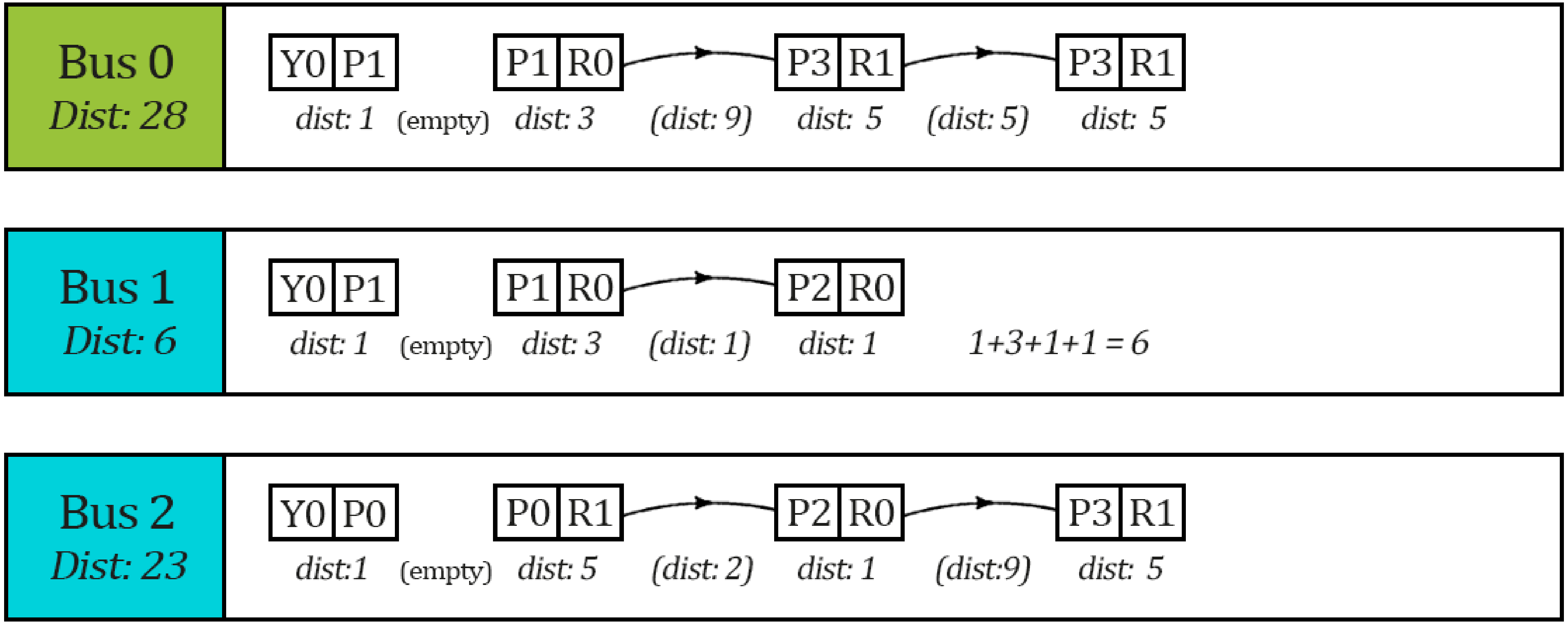
ALGORITHM PROPOSAL FOR THE BEP CONSTRUCTION PHASE

- Non-deterministic Greedy
- Create a solution where all evacuees are taken to shelters
- Movement of buses and transport of evacuees is simulated
- Restricted Candidate List (RCL) is a fraction of the feasible trips
- Domain filtering ⟶ RCL gets smaller



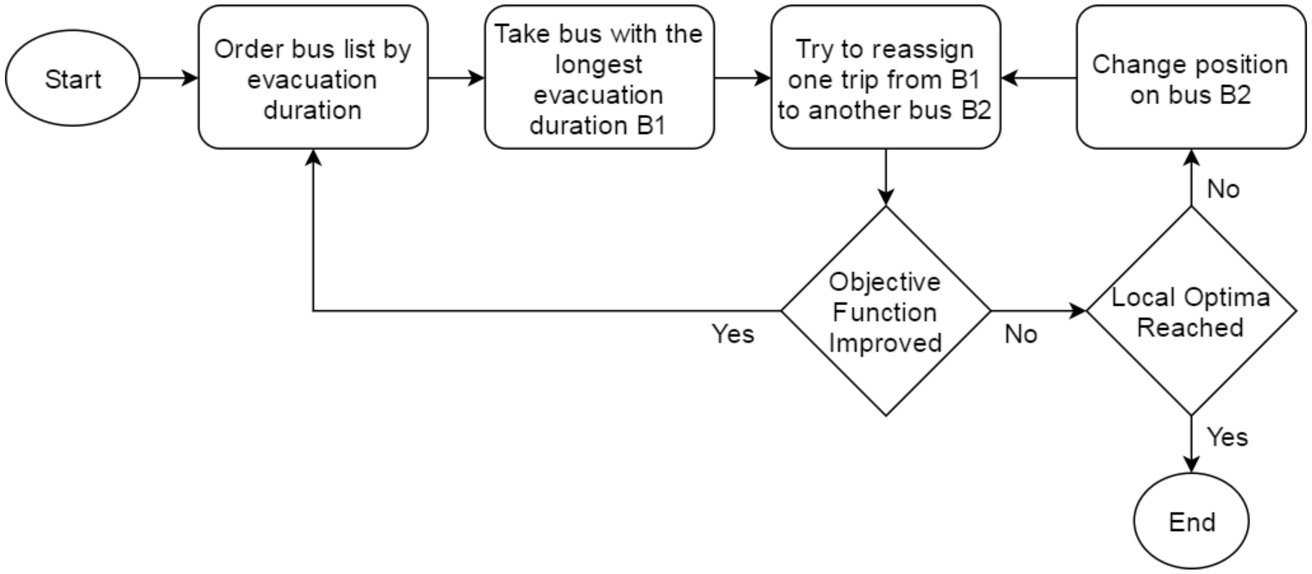
ALGORITHM PROPOSAL FOR THE BEP

CONSTRUCTION PHASE – SOLUTION EXAMPLE



ALGORITHM PROPOSAL FOR THE BEP
LOCAL SEARCH PHASE

- First Improvement Hill Climbing
- Same representation
- Only the variation on the OF is calculated

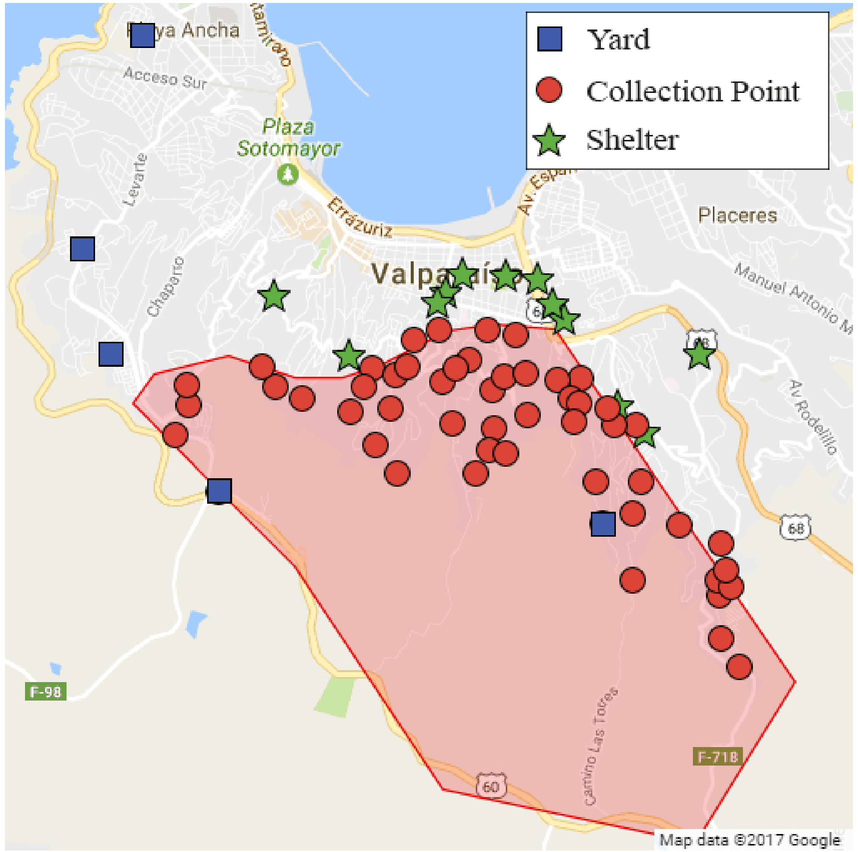


EXPERIMENTS AND RESULTS
EXPERIMENT ENVIROMENT – DATASET 1

- Dataset of instances based on a real case scenario
- Great Fire of Valparaíso, Chile (2014)
- Biggest urban fire in Chile

EXPERIMENTS AND RESULTS
EXPERIMENT ENVIROMENT – DATASET 1

- Instances
  - 12 shelters
  - 52 collection points located on bus stops and open spaces
  - 5 yards
  - 2,250 evacuees
  - Bus capacity of 30 evacuees
  - Distance between points from Google Maps Distance Matrix API



EXPERIMENTS AND RESULTS
EXPERIMENT ENVIROMENT – DATASET 2

- Dataset of randomly generated instances
  - 9 sets of instances, 10 instances each
  - Random distances in {1,…,10}
  - Random collection point demands in {1,…5}
  - Random shelter capacities in {1,…,10}
- Total of 90 instances of increasing size

Set	Y	P	S	B
S_2	1	2	2	2
S_3	1	3	3	2
S_4	1	4	4	3
S_5	1	5	5	3
S_6	1	6	6	4
S_7	1	7	7	4
S_8	1	8	8	5
S_9	1	9	9	5
S_{10}	1	10	10	6

RANDOMLY GENERATED INSTANCES DETAIL.

EXPERIMENTS AND RESULTS
EXPERIMENT ENVIROMENT

- Additional considerations (Goerigk, Marc, et. al., 2013)
  - Demand on each point is a multiple of the bus capacity
  - Capacity on each shelter is a multiple of the bus capacity
  - Collection points are not connected to each other
  - Shelters are not connected to each other

EXPERIMENTS AND RESULTS
EXPERIMENT ENVIROMENT

- Additional considerations
  - All distances are symmetric, i.e. $d_{ij} = d_{ji}$
  - Total shelter capacity is always greater or equal to the demand
  - Buses are evenly distributed among yards

EXPERIMENTS AND RESULTS
EXPERIMENTAL SETUP – DATASET 1

1. Parameter testing
   - RCL Size: 0.1, 0.3, 0.5
   - Maximum HC iterations: 20, 50, 100, 500
   - Execution time: 3 and 5 minutes
   - 8 seeds
   - Total of 192 executions
2. Evacuation times changing number of buses

EXPERIMENTS AND RESULTS
RESULTS FOR PARAMETER TESTING – DATASET 1

RCL size proportion α	Avg distance [mts]	Standar dev. [mts]	Best result [mts]
0.1	12,407	215.36	12,086
0.3	12,286	338.83	11,873
0.5	12,347	386.75	11,879

RESULTS FOR DIFFERENT RCL SIZES ON DATASET 1.

- Best results for 0.3
  - Best average distance
  - Best result
- Enough exploration of the search space, while maintaining quality

EXPERIMENTS AND RESULTS

RESULTS FOR PARAMETER TESTING – DATASET 1

Max. HC It.	Avg distance [mts]	Standard dev. [mts]	Best result [mts]
20	12,799	250.60	12,305
50	12,221	156.70	11,873
100	12,185	170.95	11,873
500	12,181	168.77	11,873

RESULTS FOR DIFFERENT HC MAXIMUM ITERATIONS ON DATASET 1.

- Best average with more iterations
- Best result is the same since 50 iterations
- Local optimum or movement nature

EXPERIMENTS AND RESULTS
RESULTS FOR PARAMETER TESTING – DATASET 1

Time limit [s]	Avg distance [mts]	Standard dev. [mts]	Best result [mts]
180	12,382	331.54	11,873
300	12,312	314.00	11,873

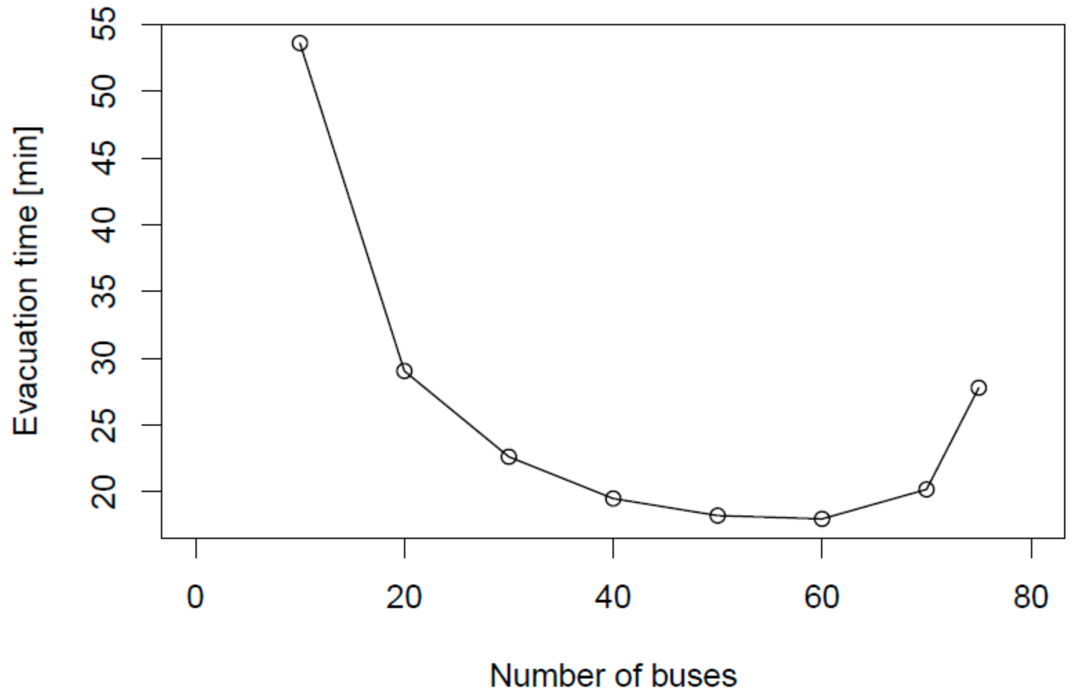
RESULTS FOR DIFFERENT TIME LIMITS ON DATASET 1.

- More time allows finding better average results
- Best value is the same

EXPERIMENTS AND RESULTS
RESULTS FOR BUS VARIATION – DATASET 1

Buses	Avg distance [m]	Avg duration [min]
10	35730.50	53.6
20	19371.50	29.1
30	15092.25	22.6
40	13008.50	19.5
50	12157.25	18.2
60	11992.50	18.0
70	13463.00	20.2
75	18534.00	27.8

OBJECTIVE VALUE AND EVACUATION TIME FOR DIFFERENT NUMBER OF BUSES.



EXPERIMENTS AND RESULTS
EXPERIMENTAL SETUP – DATASET 2

1. Parameter testing
   - RCL Size: 0.1, 0.3, 0.5
   - Maximum HC iterations: 20, 50, 100
   - Execution time: 30 seconds
2. Performance testing
   - GRASP vs CPLEX
   - Execution time: 15 minutes

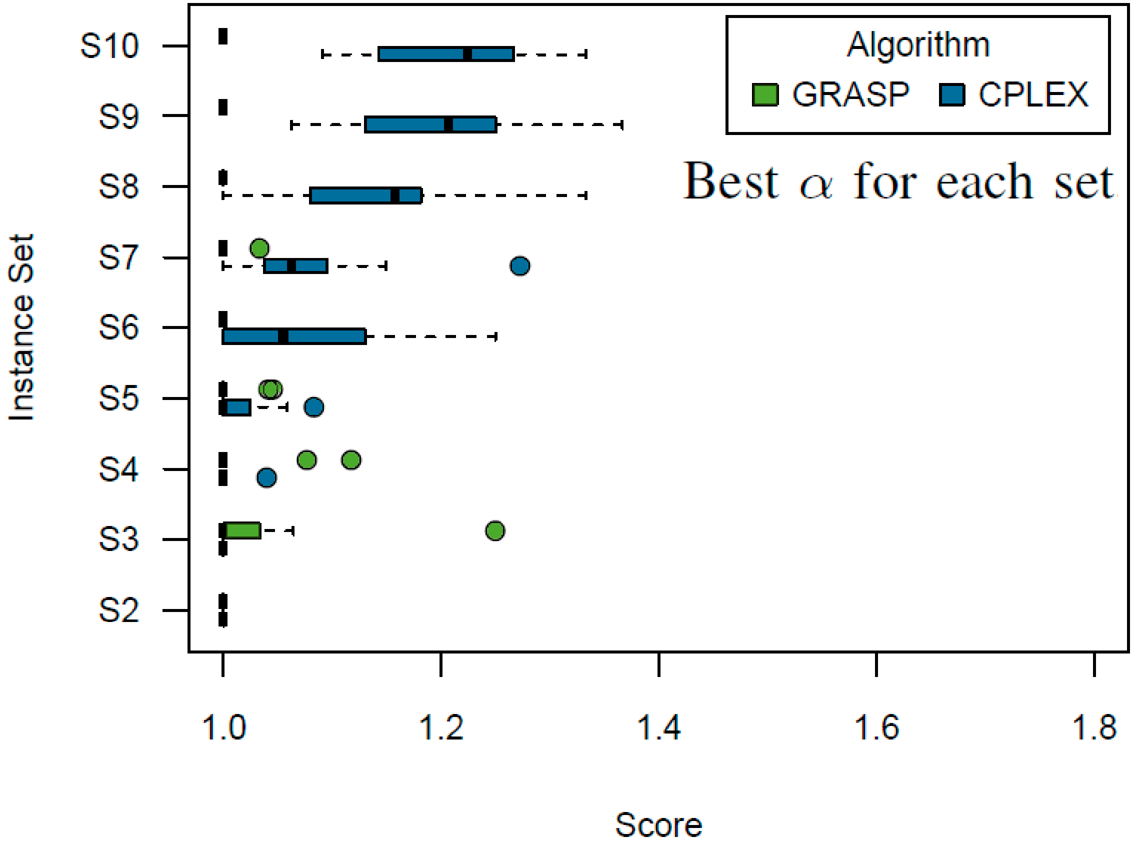
- 4 seeds for each experiment
- Normalized values

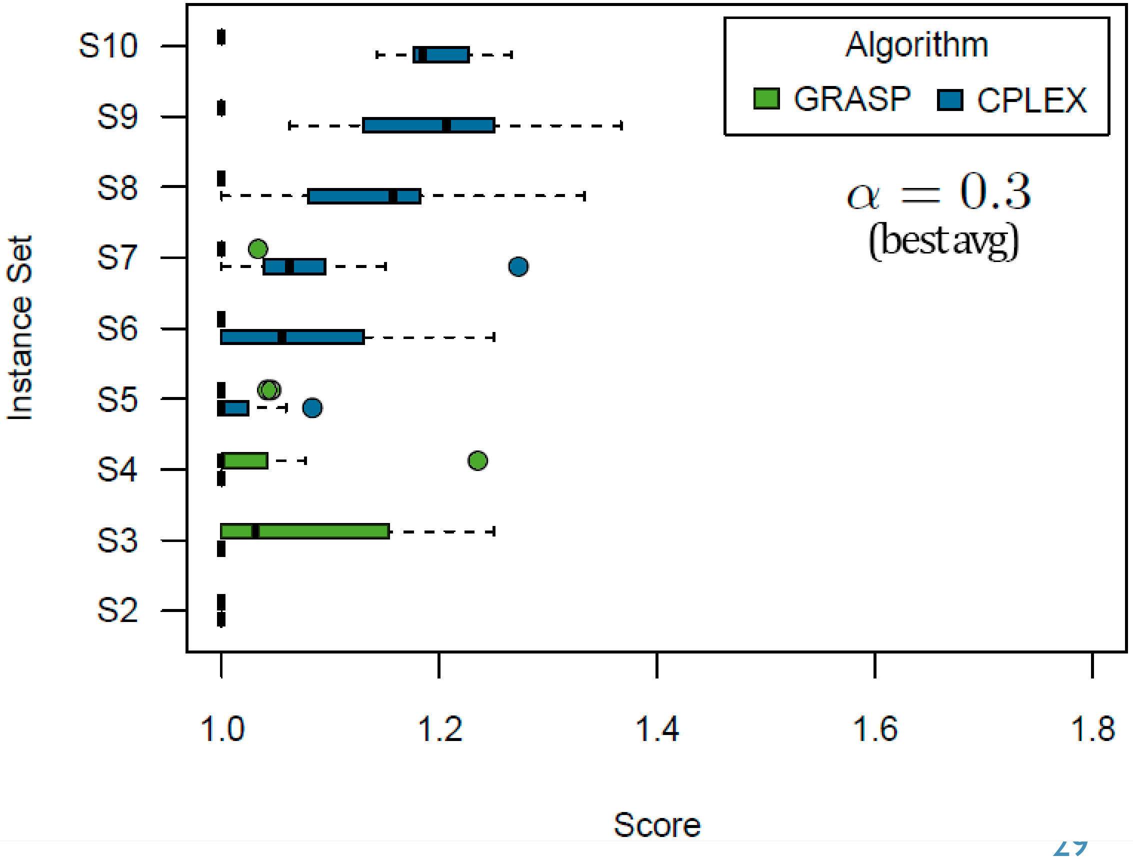
EXPERIMENTS AND RESULTS
RESULTS FOR PARAMETER TESTING – DATASET 2

	RCL size proportion α			Max. HC It.		
	0.1	0.3	0.5	20	50	100
S_2	**1.000**	**1.000**	**1.000**	1.000	1.000	1.000
S_3	1.046	1.046	**1.000**	1.031	1.031	1.031
S_4	1.161	1.020	**1.005**	1.062	1.062	1.062
S_5	1.090	**1.006**	1.028	1.041	1.041	1.041
S_6	1.167	**1.011**	1.076	1.085	1.085	1.085
S_7	1.114	**1.021**	1.124	1.086	1.086	1.086
S_8	1.051	**1.030**	1.129	1.070	1.070	1.070
S_9	1.062	**1.047**	1.212	1.107	1.107	1.107
S_{10}	**1.003**	1.077	1.257	1.112	1.112	1.112
Mean Rank	2.170	1.590	2.240	-	-	-

AVERAGE RESULTS FOR DIFFERENT PARAMETER VALUES ON DATASET 2 (NORMALIZED)

EXPERIMENTS AND RESULTS
RESULTS FOR PERFORMANCE TESTING– DATASET 2





EXPERIMENTS AND RESULTS

RESULTS FOR PERFORMANCE TESTING– DATASET 2

	CPLEX - GRASP	N	Mean Rank	Sum of Ranks
$a.\ cplex < grasp$	Negative Ranks	13^a	20.35	264.50
$b.\ cplex > grasp$	Positive Ranks	46^b	32.73	1505.50
$c.\ cplex = grasp$	Ties	30^c		
	Total	89		

RANKS ON WILCOXON SIGNED-RANK TEST FOR ALL SETS.

		$cplex - grasp$
a. Based on negative ranks.	Z	-4.684^a
b. Wilcoxon Signed Ranks Test.	Asymp. Sig. (2-tailed)	.000

TEST STATISTICS.[b]

CONCLUSIONS AND FUTURE WORK

- GRASP for BEP
  - Simple structure and easy to implement
  - Just a few parameters
- Contributions
  - Able to find different solutions for one instance
  - Solutions are well balanced
  - Effective to solve real-world size problems

CONCLUSIONS AND FUTURE WORK

- Performance against MIP solver
  - Less time to find the best solution possible
  - Less memory consumption
- Future work
  - Solve more complex variants (cycles in graphs, asymmetric costs)
  - Apply different strategies (detect patterns, satisfy demands in order)
  - Try different moves for the local search phase
  - Dynamic version of the problem

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