TÉCNICO LISBOA

Waste Collection with Route Balancing Concerns: A real-world application

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WSMARTROUTE

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Context

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- Waste collection of recyclable materials has been shown to possess great potential for improvement.

Gonçalo et. al. 2014 discovered that only 40% of the recyclable waste bins collected by a waste collection company (Valorsul) presented a fill level higher than 75%.

↳ Need to improve efficiency of collection routes

Table I - Characterization of improved routes at ValorSul, on average.

	Duration (min.)	Distance (km)	# Containers
Max.	478,8	255	101
Min.	379,1	100	32
Range	99,7	155	69

↳ Highly imbalanced routes

- The improvement of the efficiency in waste collection routes frequently leads to imbalanced solutions regarding duration, distance.

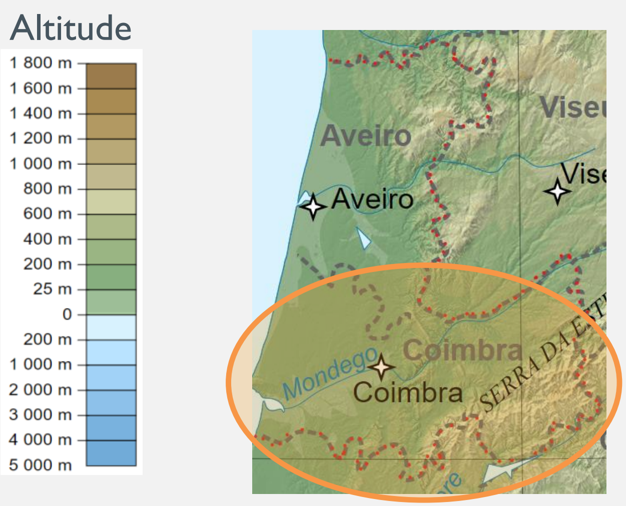
↳ How to consider balancing concerns when routing for waste collection?

Case-Study

- New Partner: ERSUC

Concerns:

- Imbalance between collection routes generates dissatisfaction amongst drivers.
  - The characteristics of the **terrain** should also be considered.



Objective

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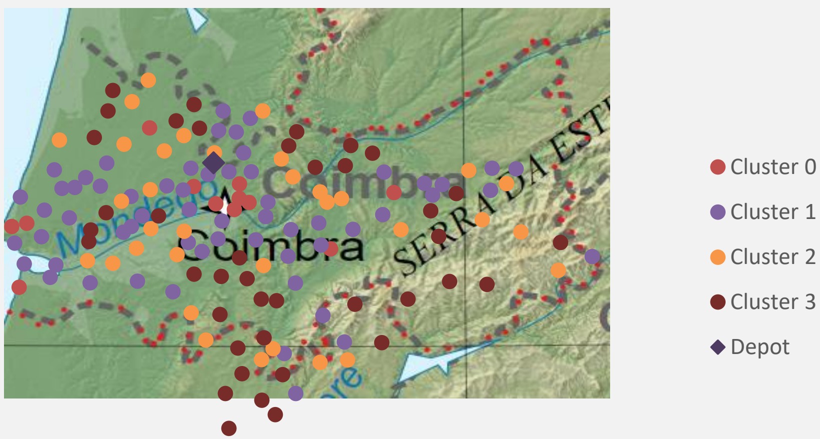
To determine static recyclable waste collection routes, considering balancing concerns.



	Time interval	# Towns
Cluster 0	< 7days	15
Cluster 1	[7-14[	59
Cluster 2	**[14-21[**	**34**
Cluster 3	>21	42

Case-Study characteristics

- **Network:** Symmetric;
- **Demand:** Containers are aggregated per town. The demand for each town is static for fixed periods of time;
  - Cluster towns by time interval between collections.
  - Material considered is Plastic/Metal;
- **Fleet:** Homogeneous of capacity 1 620 kg;
  - Capacity = 90% of full capacity, 1 800 kg.
- **Costs:** 1€/km;
- **Objectives: Minimize total distance while considering balancing concerns.**

Methodology

1) Literature Review

- What metrics can we use to measure workload balance?

2) Extend a CVRP formulation to incorporate balancing metrics.

- What impacts can we expect when we choose one metric over another?

Literature Review

Literature Review methodology

Search stage:

- Search in Web of Knowledge the key-words: Vehicle Routing Problems Route Balancing (34 articles, many irrelevant and one interesting review)
- Selection of the most relevant articles and look-up articles cited by the review and citing it.

Relevant Review articles:

[1] Jozefowiez, N., Semet, F., & Talbi, E.-G. (2008). *Multi-objective vehicle routing problems*. European Journal of Operational Research, 189(2), 293–309. https://doi.org/10.1016/J.EJOR.2007.05.055

[2] Matl, P., Hartl, R. F., & Vidal, T. (2016). *Workload Equity in Vehicle Routing Problems: A Survey and Analysis*. (September), 0–22. https://doi.org/10.1287/trsc.2017.0744

[3] Kovacs AA, Golden BL, Hartl RF, P. S. (2014). *Vehicle Routing Problems in Which Consistency Considerations are Important: A Survey*. *Networks*, *64*(3), 192–213. https://doi.org/https://doi.org/10.1002/net.21565

Literature Review

Most common routing objectives in VRP:

- **Cost;**
- **Makespan;**
- **Balance;**
- **Profit;**
- **Risk;**
- **Regionalization/Districting**

Fairness/Equity of workload distribution:

- Makespan,
- Balance,
- Regionalization/Districting

Literature Review

Fairness/Equity of workload distribution:

Objectives

- Makespan: Minimization of the maximum route length.
  - Metric: distance/duration [4,6].

- Regionalization/Districting: Creation of geographical clusters used as input for routing. [11]
  - Applicability associated with demand uncertainty [3].

- Balance: widely varied [2]
  - Metric: Length (**distance**, **duration**), **Demand** (weight, #customers)
  - Function: Range, Min-Max, Standard Deviation, Absolute Deviation to the mean.

Literature Review

Modeling Approaches

Single-Objective

- Primary objective, PO
- Constraint, C

Multi-Objective

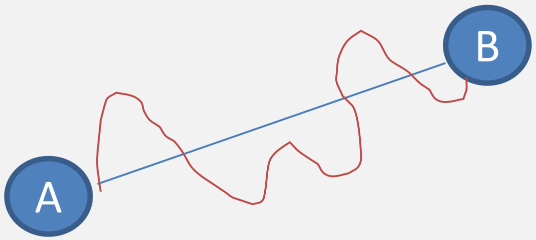
- Weighted Sum, WS
- Multiobjective methods, MOm (ε-constraint method)

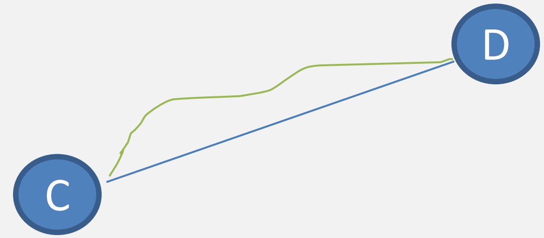
In Matl, P. et. al. 2016 it is possible to conclude that, when modeling balancing concerns:

- Many more works with heuristics (50 heuristic methods to 11 exact)
- The most frequent functions are: min-max and range.

No metrics for terrain concerns → MILP of CVRP

New Metric - Ruggedness





Highly rugged area

Normal area

Ruggedness Coefficient calculation:

$$coef_{ij} = \frac{RealDistance_{ij}}{EucledianDistance_{ij}} \times 100$$

- Associates, on average, higher coefficients to regions the company believes to have more ruggedness.

Scenarios

Workload function

Workload Metric

1. Demand
   - A. min-max
   - B. Range
2. Distance
   - A. min-max
   - B. Range
3. Duration
   - A. min-max
   - B. Range
4. Ruggedness
   - A. min-max
   - B. Range

→ 8 Scenarios

Objective Function: Minimize total route length, while balancing the workload.

↳ Objective function as a weighted sum

Workload metrics

1. Demand : Number of containers to collect

$$\text{Workload}_k = \sum_i b_{ik} \times NbContainers_i$$

2. Distance : Distance inter-towns and intra-towns

$$\text{Workload}_k = \sum_{ij} x_{ijk} \times d_{ij} + \sum_i b_{ik} \times NbContainers_i \times DBC$$

3. Duration : Time to travel inter and intra-towns + plus container collection time

$$\text{Workload}_k = \sum_{ij} x_{ijk} \times d_{ij} \times InvInter + \sum_i b_{ik} \times NbContainers_i \times DBC \times InvIntra + \sum_i b_{ik} \times NbContainers_i \times ACT$$

4. Ruggedness : To associate each arc with a “terrain difficulty” measure

$$\text{Workload}_k = \sum_{ij} x_{ijk} \times coef_{ij}$$

Scenarios (I)

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1.Demand

A. Max $\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_i b_{ik} \times NbContainers_i \right)$

B. Range $\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_i b_{ik} \times NbContainers_i \right) - \min_k \left(\sum_i b_{ik} \times NbContainers_i \right)$

Total Distance

2. Distance

A. Max $\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_{ij} x_{ijk} \times d_{ij} + \sum_i b_{ik} \times NbContainers_i \times DBC \right)$

B. Range

$$\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_{ij} x_{ijk} \times d_{ij} + \sum_i b_{ik} \times NbContainers_i \times DBC \right)$$
$$- \min_k \left(\sum_{ij} x_{ijk} \times d_{ij} + \sum_i b_{ik} \times NbContainers_i \times DBC \right)$$

Scenarios (II)

3. Duration

A. Max $\sum_{ijk} x_{ijk} \times d_{ij} \times IInterv$

$$+ \max_k \Big(\sum_{ij} x_{ijk} \times d_{ij} \times IInterv + \sum_i b_{ik} \times NbContainers_i \times DBC \times IIntrav + \sum_i b_{ik} \times NbContainers_i \times ACT\Big)$$

B. Range

$$\sum_{ijk} x_{ijk} \times d_{ij} \times IInterv$$

$$+ \max_k \Big(\sum_{ij} x_{ijk} \times d_{ij} \times IInterv + \sum_i b_{ik} \times NbContainers_i \times DBC \times IIntrav + \sum_i b_{ik} \times NbContainers_i \times ACT\Big)$$

$$- \min_k \Big(\sum_{ij} x_{ijk} \times d_{ij} \times IInterv + \sum_i b_{ik} \times NbContainers_i \times DBC \times IIntrav + \sum_i b_{ik} \times NbContainers_i \times ACT\Big)$$

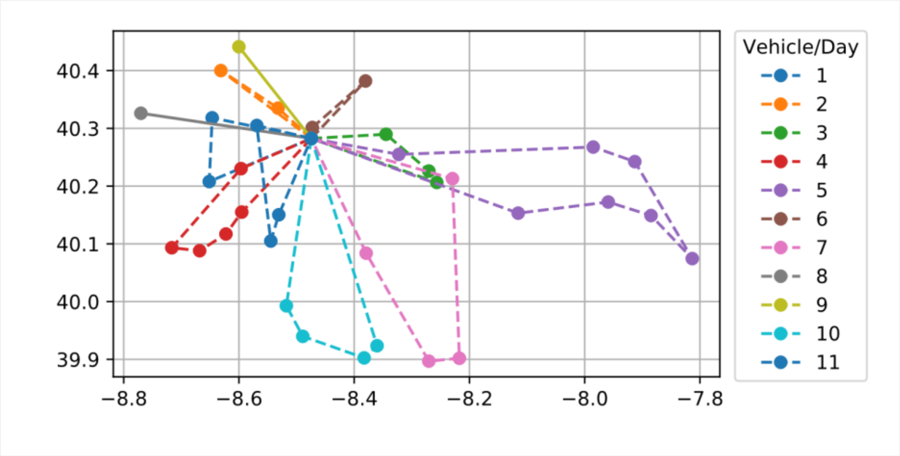
4. Ruggedness Coefficient

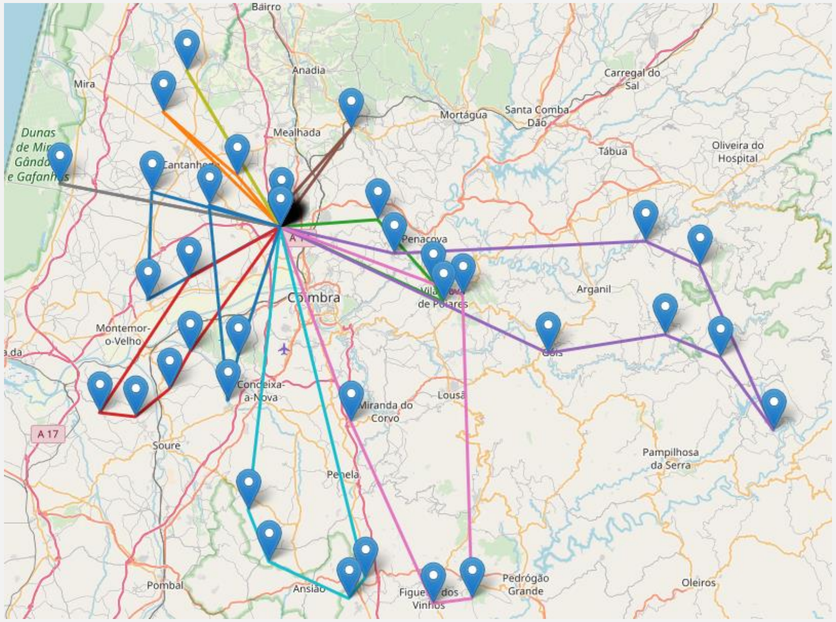
A. Max $\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_{ij} x_{ijk} \times coef_{ij}\right)$

B. Range $\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_{ij} x_{ijk} \times coef_{ij}\right) - \min_k \left(\sum_{ij} x_{ijk} \times coef_{ij}\right)$

Baseline Results

CVRP

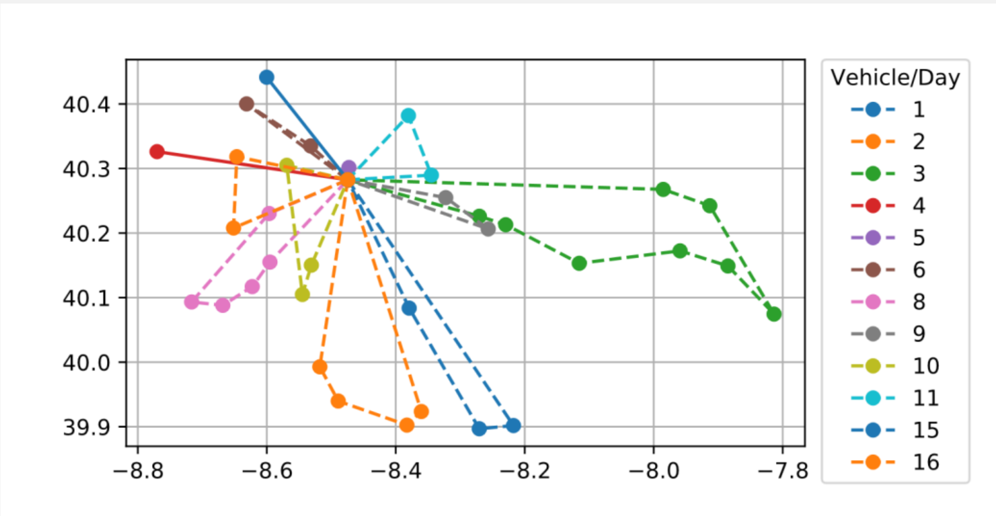


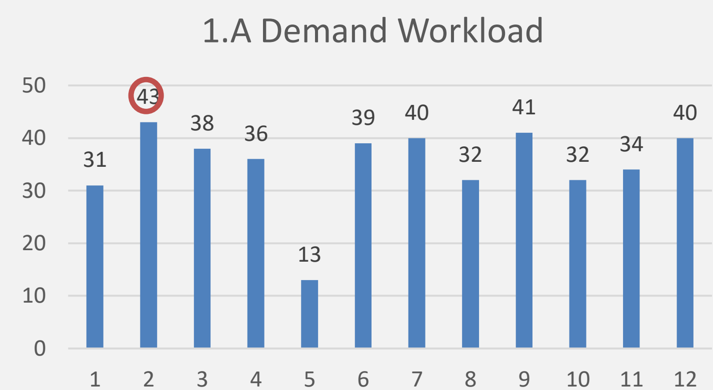


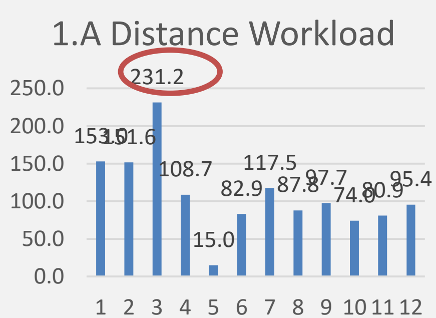
# Routes	Total Distance (km)	Total Duration (h)	Av. Route Demand (#Containers)	Av. Ruggedness
11	1 295,5	53,1	38	468

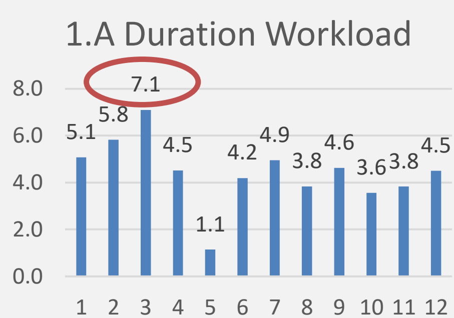
Results 1.A (Demand, min-max)

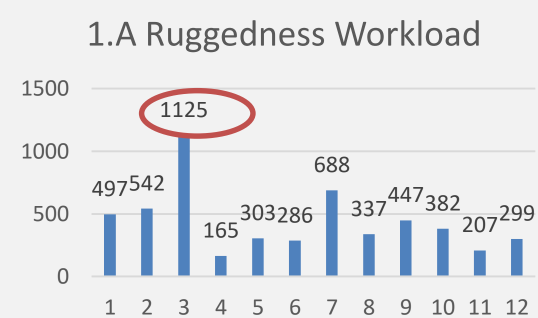
$$\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_i b_{ik} \times NbContainers_i \right)$$





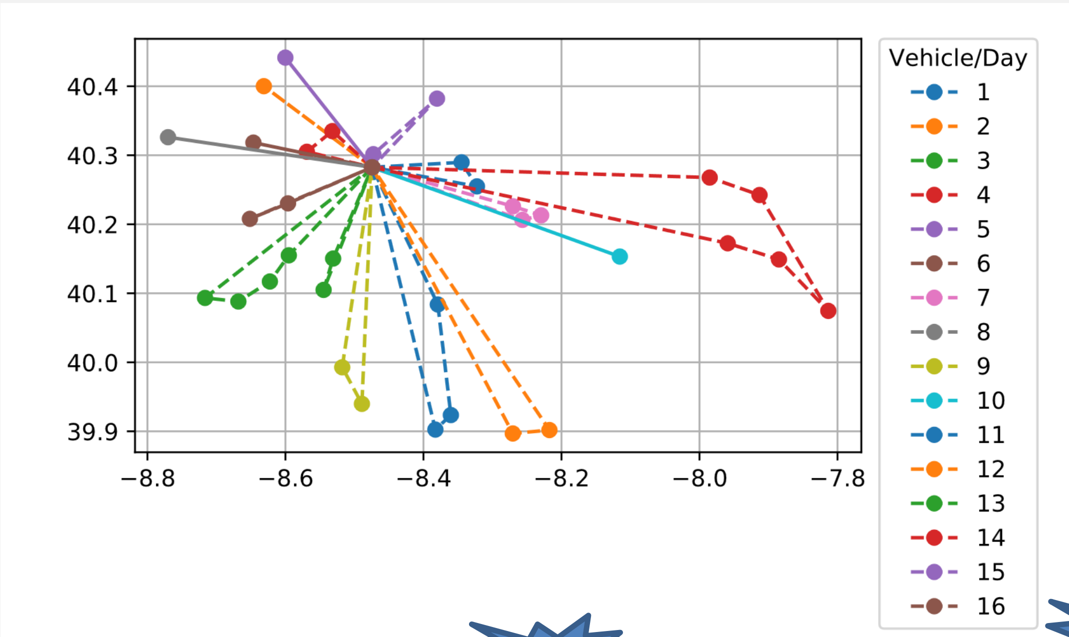


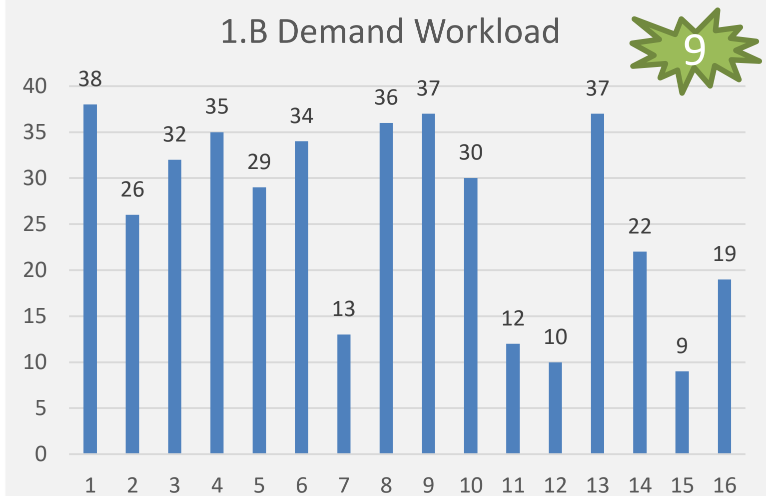


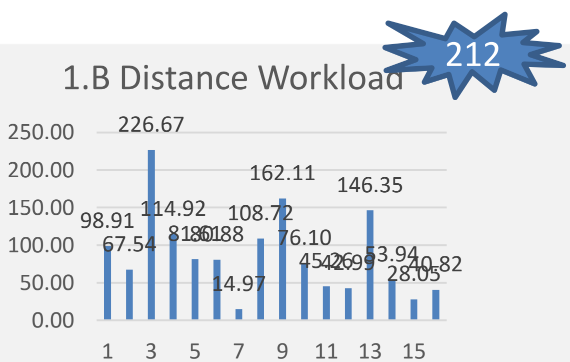


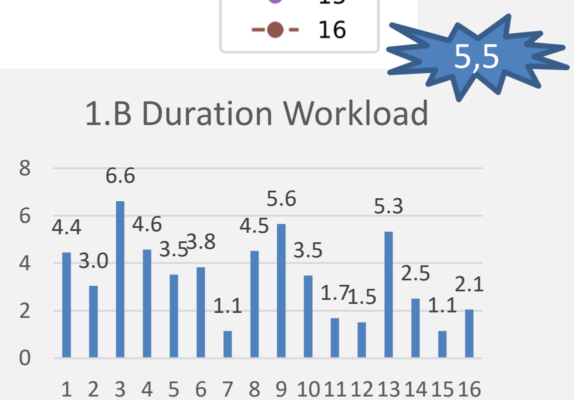
Results 1. B (Demand, Range)

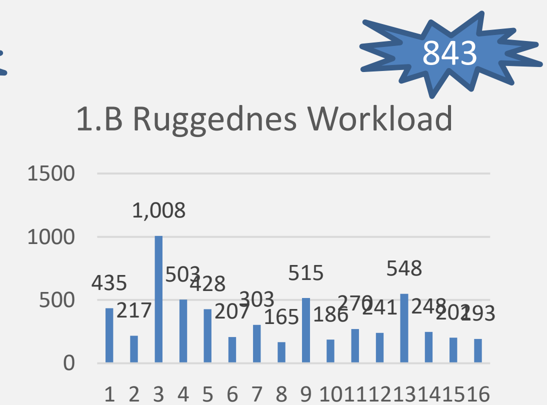
$$\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_i b_{ik} \times NbContainers_i \right) - \min_k \left(\sum_i b_{ik} \times NbContainers_i \right)$$





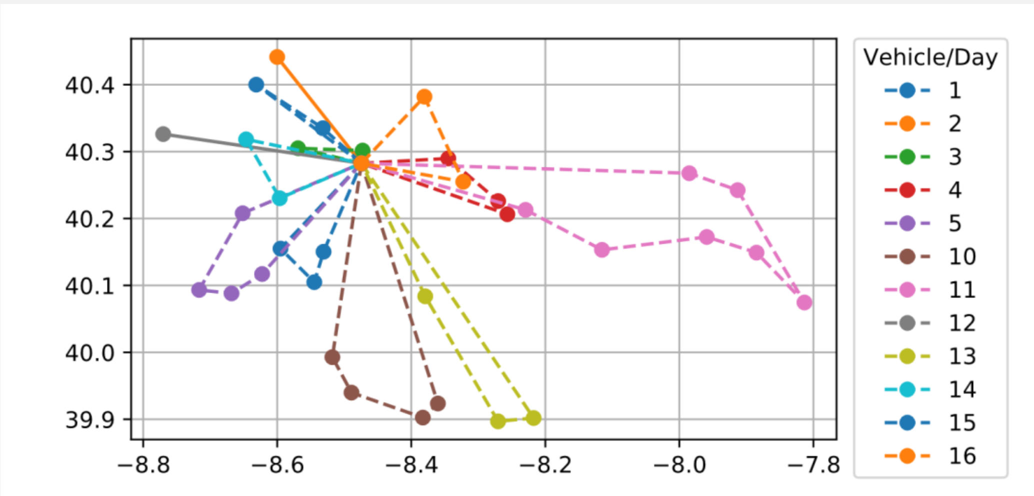


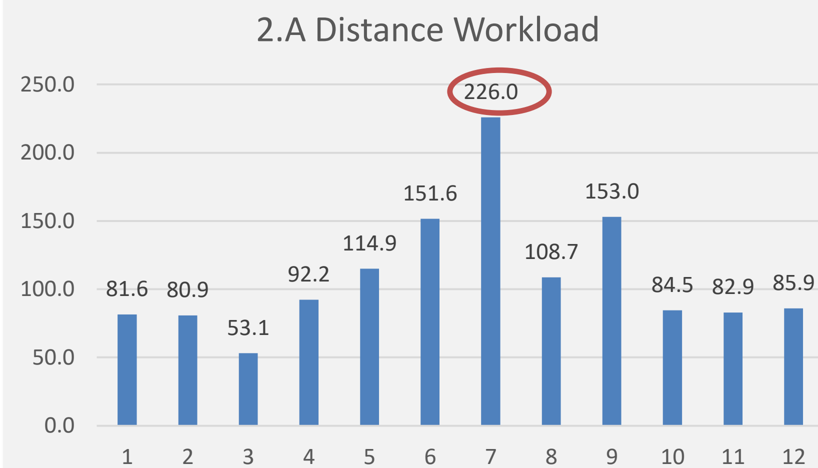


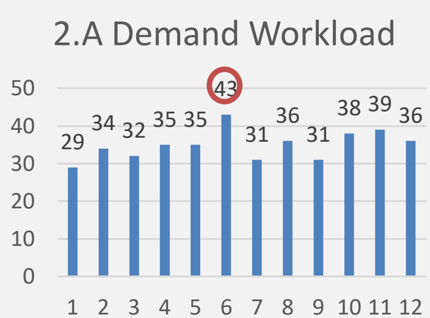


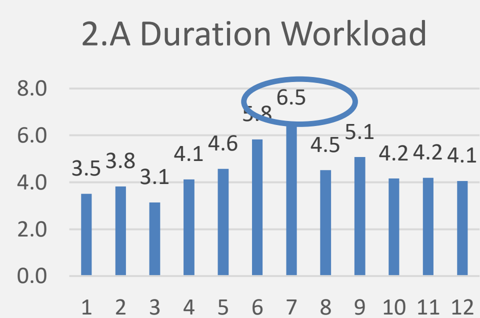
Results 2.A (Distance, min-max)

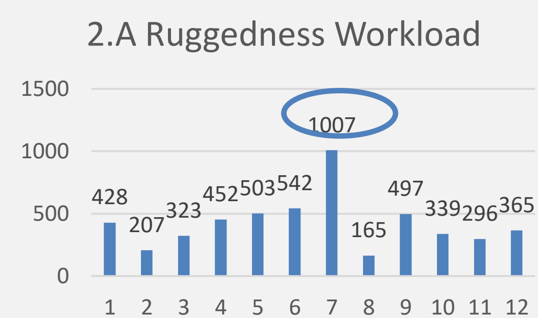
$$\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_{ij} x_{ijk} \times d_{ij} + \sum_i b_{ik} \times NbContainers_i \times DBC \right)$$





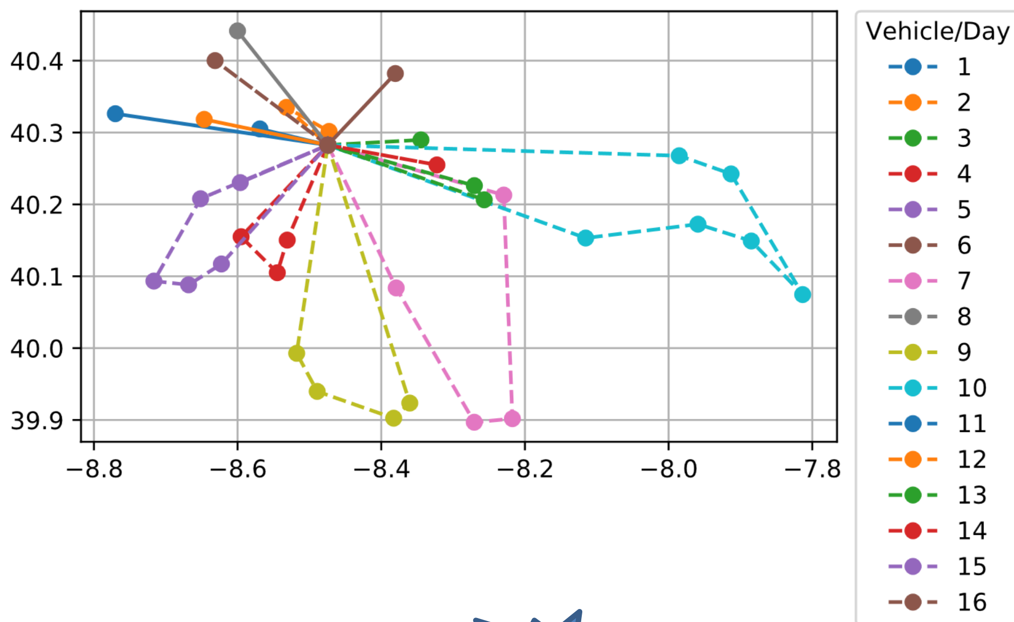


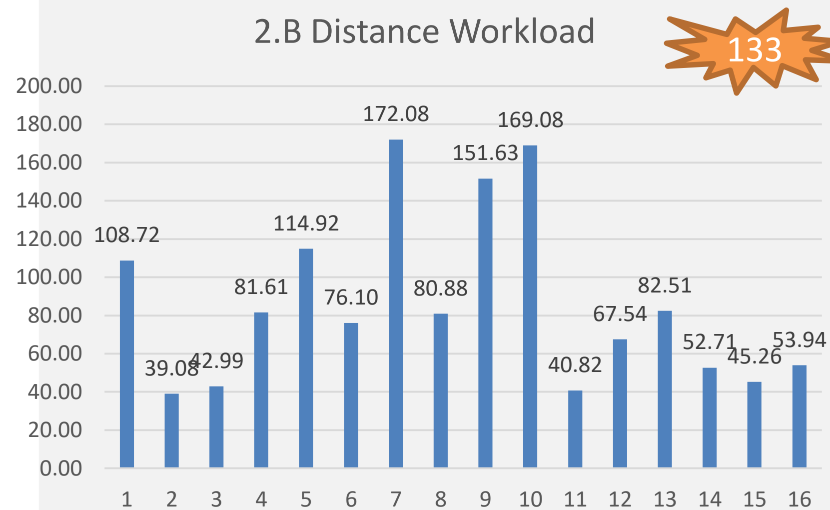


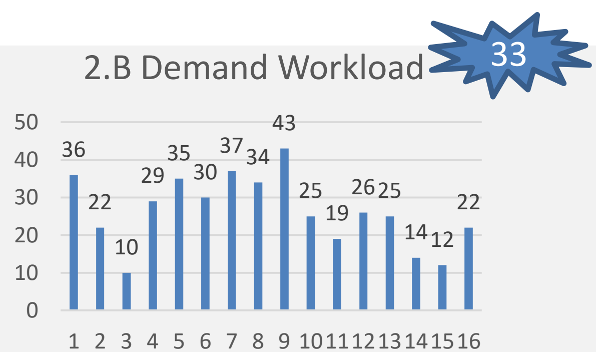


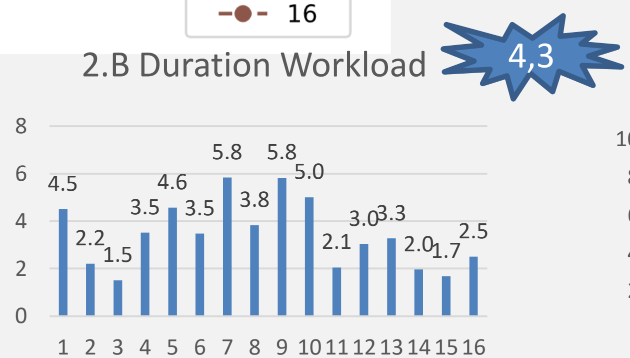
Results 2. B (Distance, Range)

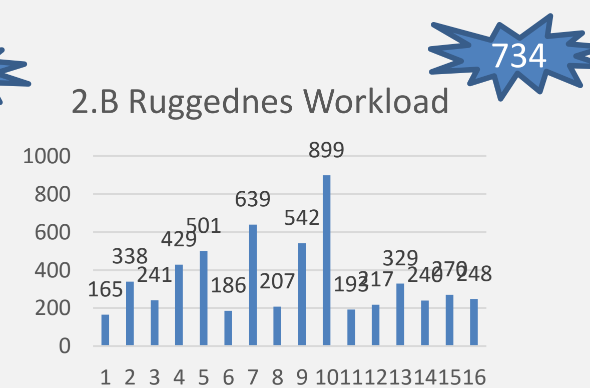
$$\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_{ij} x_{ijk} \times d_{ij} + \sum_i b_{ik} \times NbContainers_i \times DBC\right) - \min_k \left(\sum_{ij} x_{ijk} \times d_{ij} + \sum_i b_{ik} \times NbContainers_i \times DBC\right)$$





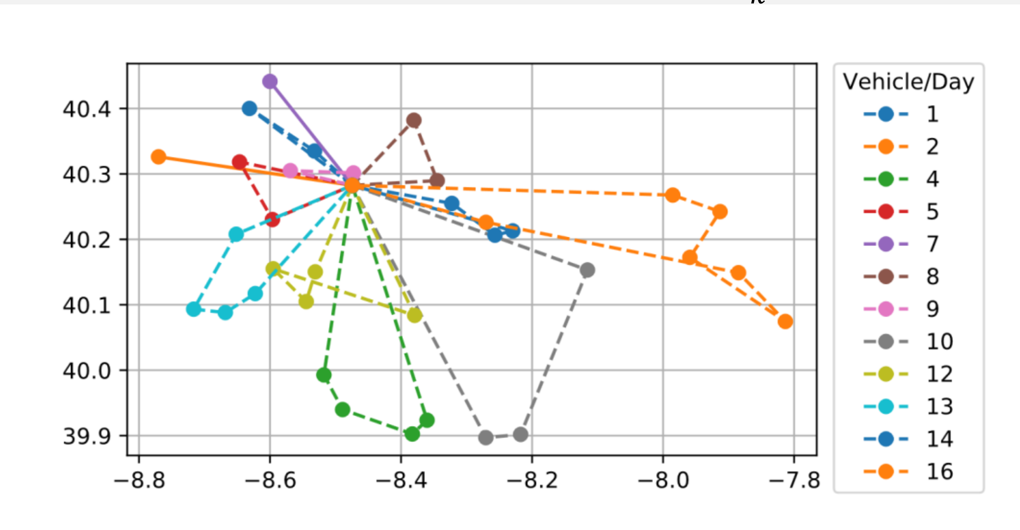


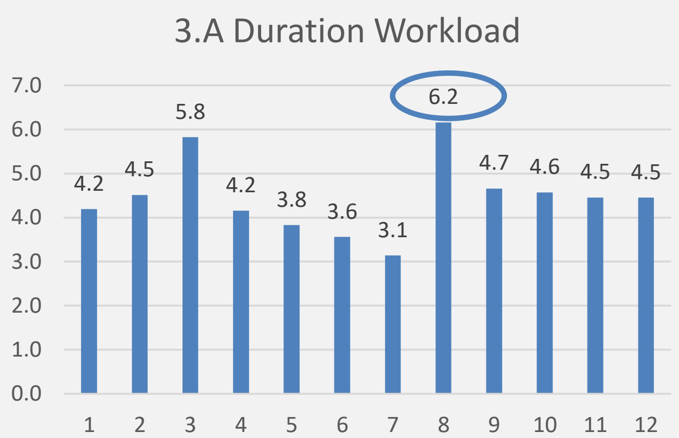


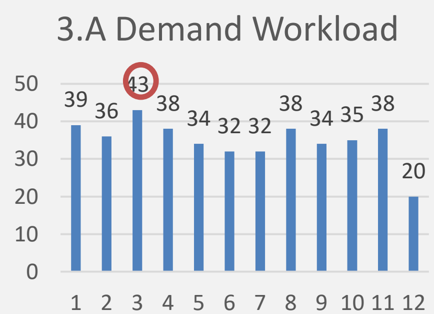


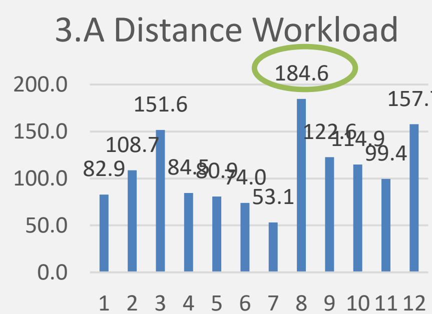
Results 3.A (Duration, min-max)

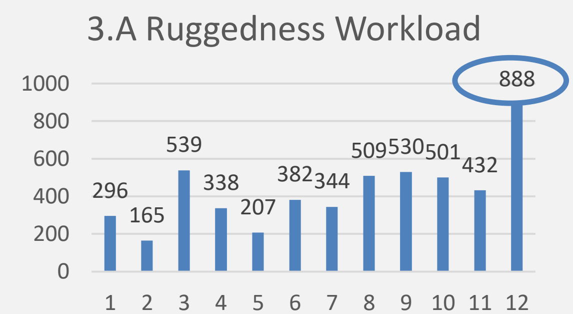
$$Inter\ Distance\ TT + \max_k(Inter\ TT + IntraTT + Container\ \text{Colection Time})$$











Results 3. B (Duration, Range)

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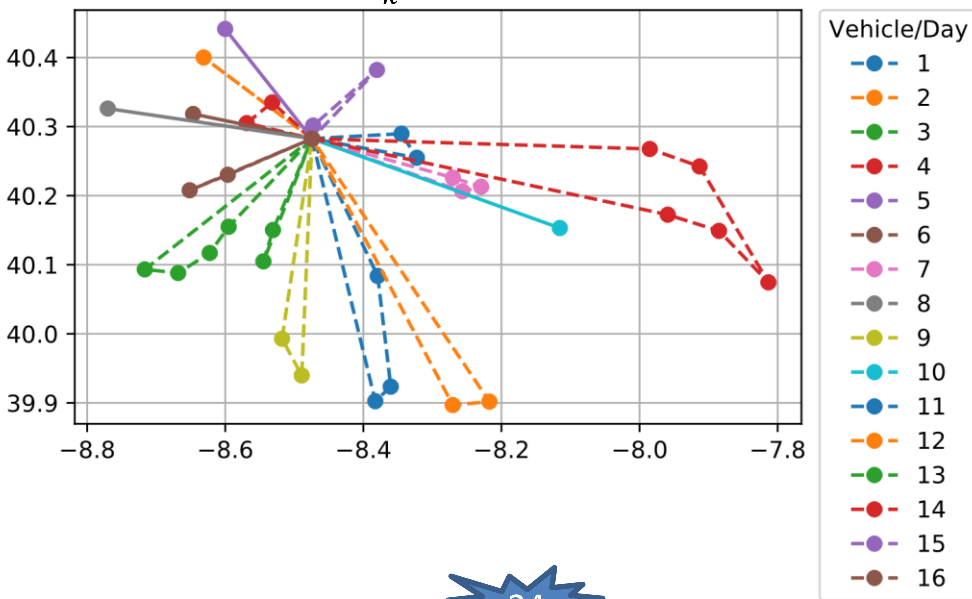
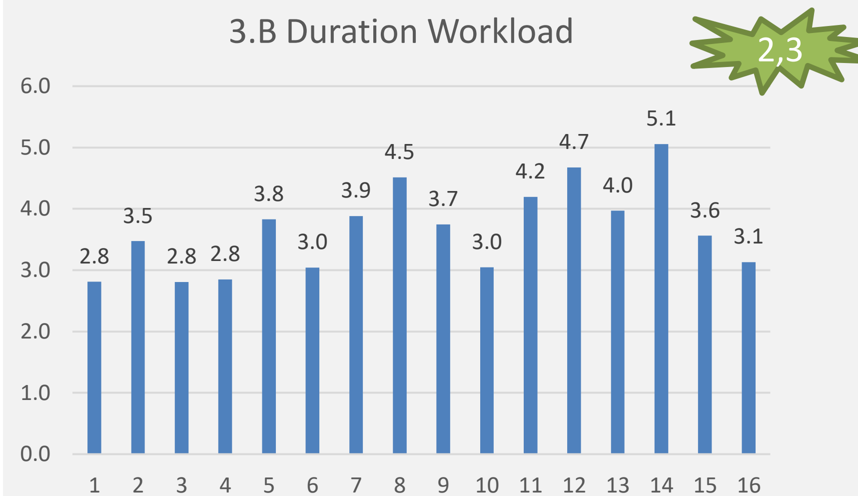
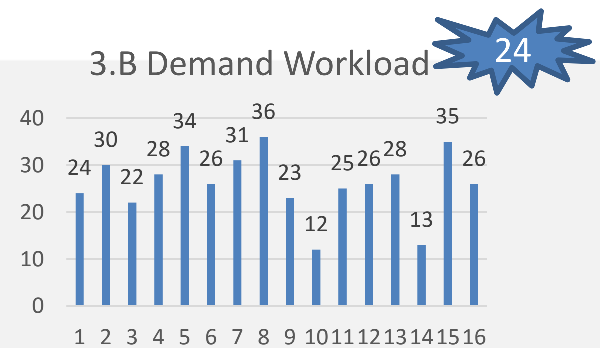
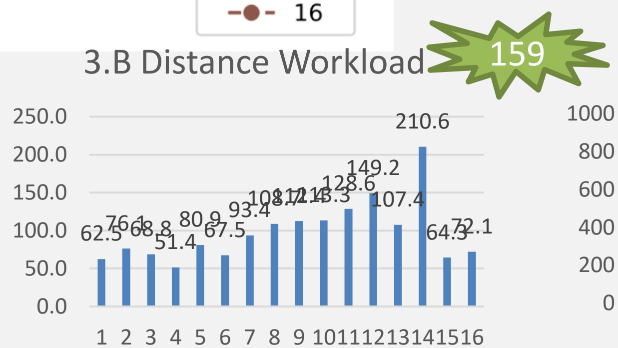
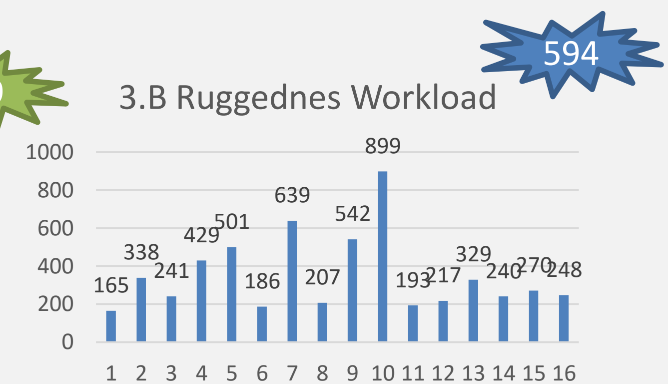
$$Inter\ Distance\ TT + \max_k(Inter\ TT + IntraTT + Container\ \text{Colection Time}) - \min_k(Inter\ TT + IntraTT + Container\ \text{Colection Time})$$





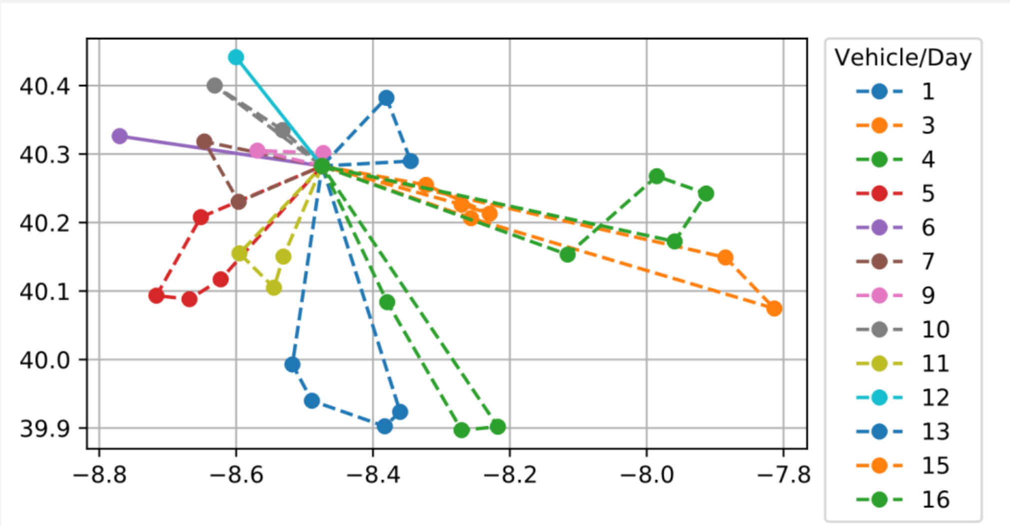


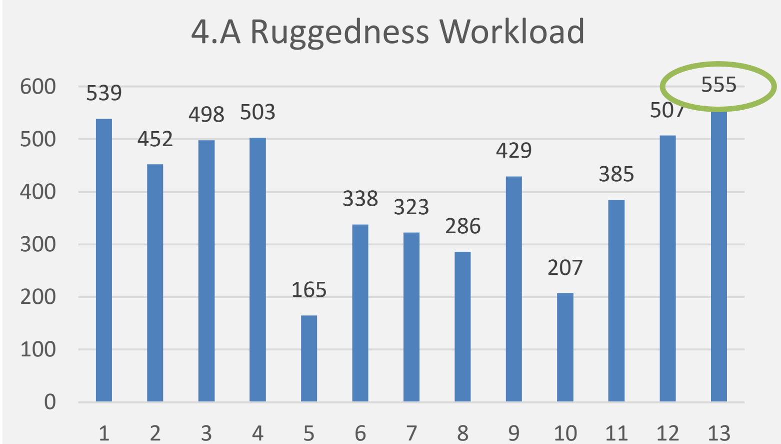


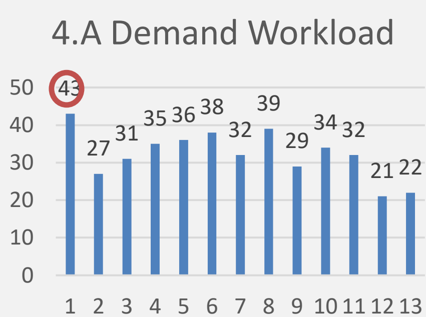


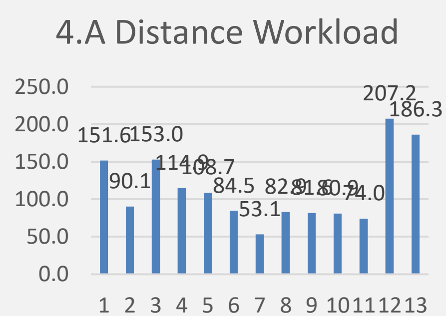
Results 4.A (Ruggedness, min-max)

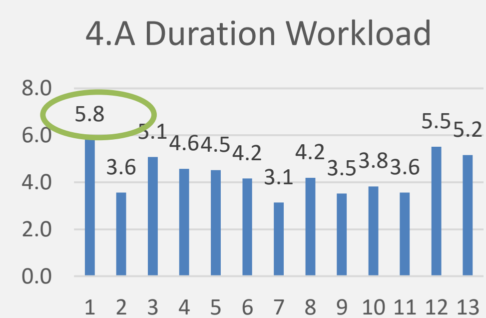
$$\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_{ij} x_{ijk} \times coef_{ij} \right)$$





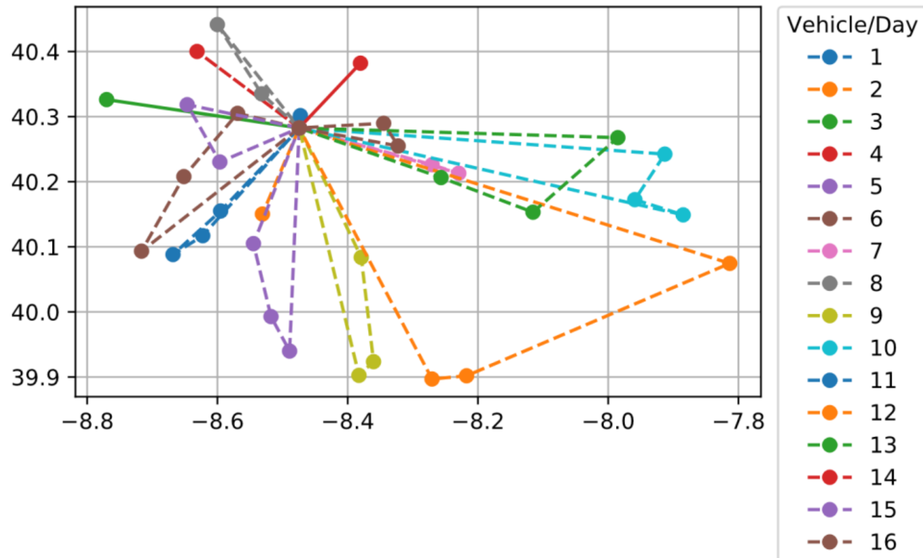


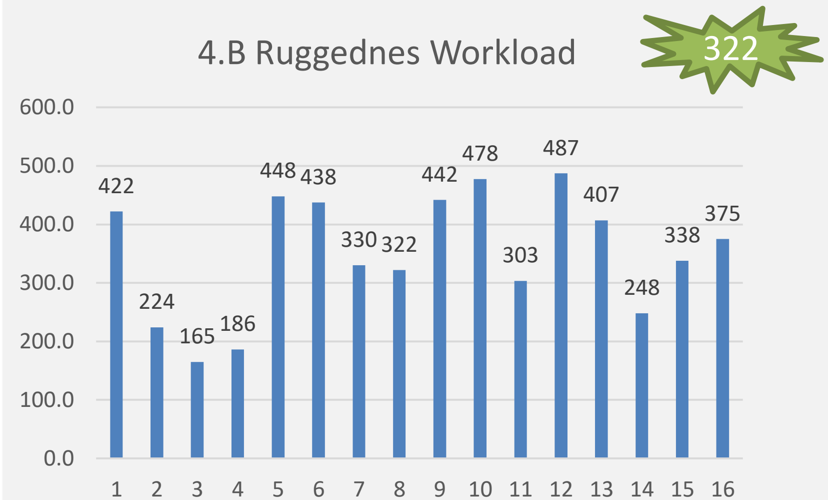


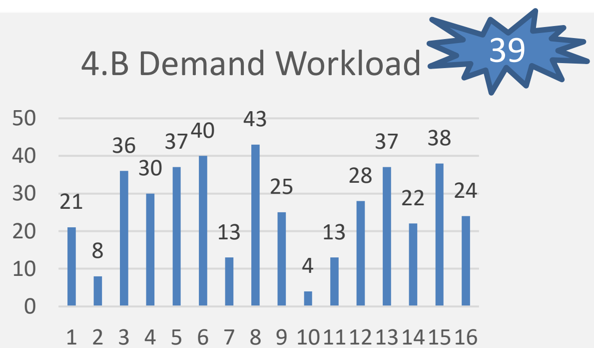


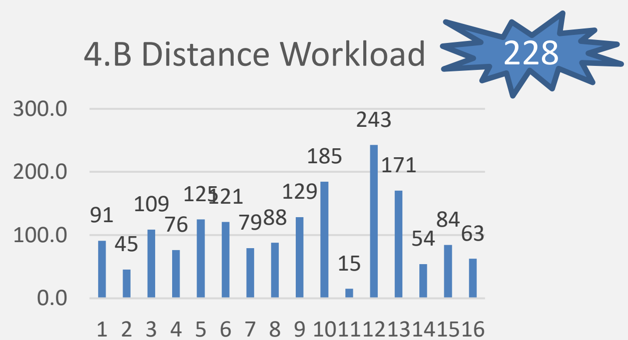
Results 4. B (Ruggedness, Range)

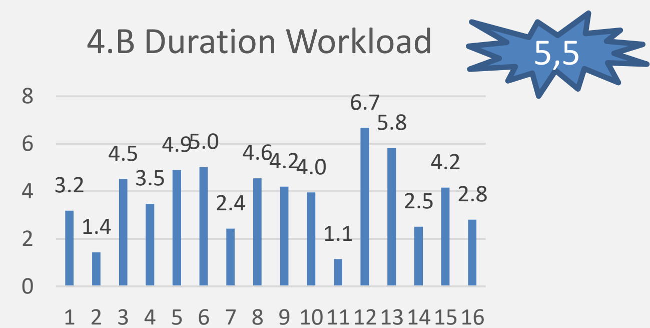
$$\sum_{ijk} x_{ijk} \times d_{ij} + \sum_{ik} b_{ik} \times NbContainers_i \times DBC + \max_k \left(\sum_{ij} x_{ijk} \times coef_{ij} \right) - \min_k \left(\sum_{ij} x_{ijk} \times coef_{ij} \right)$$











Scenarios comparison to Baseline

	Total Distance (km)	Variation
Baseline	1 295,5	-
1.A	1 295,8	0%
1.B	1 389,8	7%
2.A	1 315,4	2%
2.B	1 379,9	6%
3.A	1 315,0	1%
3.B	1 567,2	17%
4.A	1 468,9	12%
4.B	1 676,2	23%

	#Routes	Variation
Baseline	11	-
1.A	12	8%
1.B	16	31%
2.A	12	8%
2.B	16	31%
3.A	12	8%
3.B	16	31%
4.A	13	15%
4.B	16	31%

Total Distance: Best results in terms of total distance associated to scenarios with function max and metric demand.

Number of routes: Range function always used the full set of routes (16). Scenario 4.A requires one more route to perform the collection.

Scenarios comparison to Baseline

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	Total Duration (h)	Variation
Baseline	53,1	-
1.A	53,2	0%
1.B	55,0	3%
2.A	53,5	1%
2.B	54,8	3%
3.A	53,5	1%
3.B	58,6	9%
4.A	56,6	6%
4.B	60,8	13%

	Ruggedness			
	Max	Variation	Range	Variation
Baseline	1037	-	872	-
1.A	1125	8%	960	-8%
1.B	1008	-3%	843	-23%
2.A	1007	-3%	842	-23%
2.B	899	-15%	734	-41%
3.A	888	-17%	723	-43%
3.B	759	-37%	594	-75%
4.A	555	-87%	390	-166%
4.B	487	-113%	322	-222%

Total Duration: Best total duration associated to scenarios with metrics demand and distance. However, the duration workload is mire balanced.

Ruggedness: There is a compromise – Despite having the worst results in terms of cost, has a very high improvement in both workload functions.

Conclusions

- In the literature, there are much more works with balancing concerns when heuristics are applied.
- The new metric, Ruggedness, associates, on average, higher coefficients to regions the partners empirically believe to have more ruggedness.
- Best results in terms of total distance/cost are associated to scenarios with function max and metric demand.
- Balancing newly introduced metric seems to have a great impact in the solution, implying a trade-off (scenarios that represent the greatest increase in cost but seem to have potential to improve social acceptance of routes)

Future Work

- To solve the whole problem.
  - At this moment it is impossible to solve all of the scenarios for all of the clusters.
- Incorporate some of the workload into a VRPP model already published in the project.
- Add balancing functions associated with dispersion.
  - Absolute Deviation to the mean

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Waste Collection with Route Balancing Concerns: A real-world application

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