Support to Practical Work of ALGAV 2022/2023
Goods Delivery Planning with Electric Trucks

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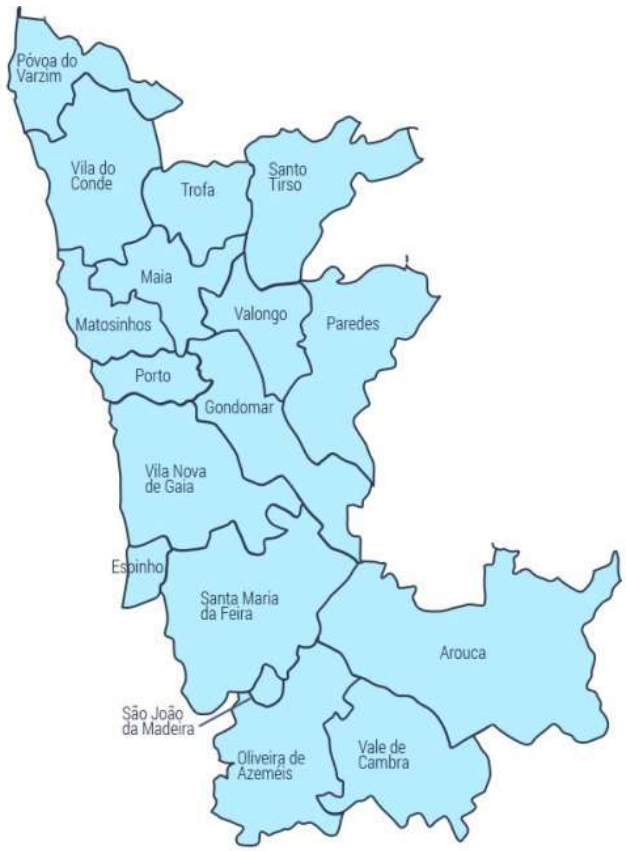
ALGAV + LAPR5 Problem

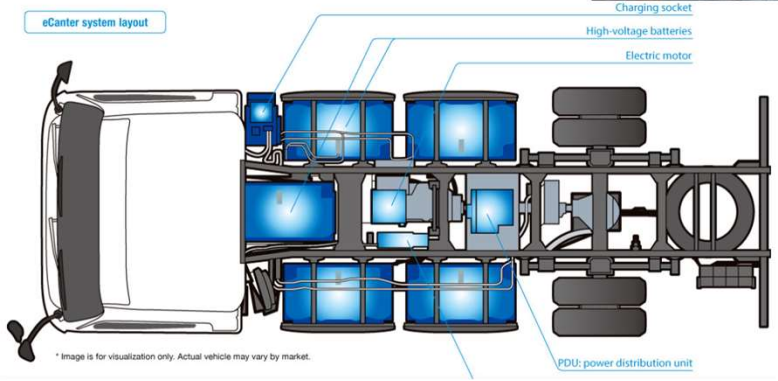
- Company with stores and warehouses in 17 municipalities (1 store/warehouse in each municipality)
- Matosinhos has the main warehouse, where all the merchandise arrives to be later distributed to the other warehouses
- Company with environmental awareness in the products it sells
- It opted for the distribution of products through the warehouses to be carried out by electric trucks



Example of na Electric Truck

Mitshubishi eCanter

- Gross Weight (weight): 7,5 ton
- load-bearing capacity of up to : 4,5 ton
- 6 ion-lithium bateries 420 V and 13.8 kWh of energy each (total 82.8 kWh)
- Autonomy 100km with the truck with the full load-bearing capacity (7,5+4,5 ton)
- Slow Electric chaging: 7 hours
- Fast Electric charging: 1 hour (till 80% of charge)



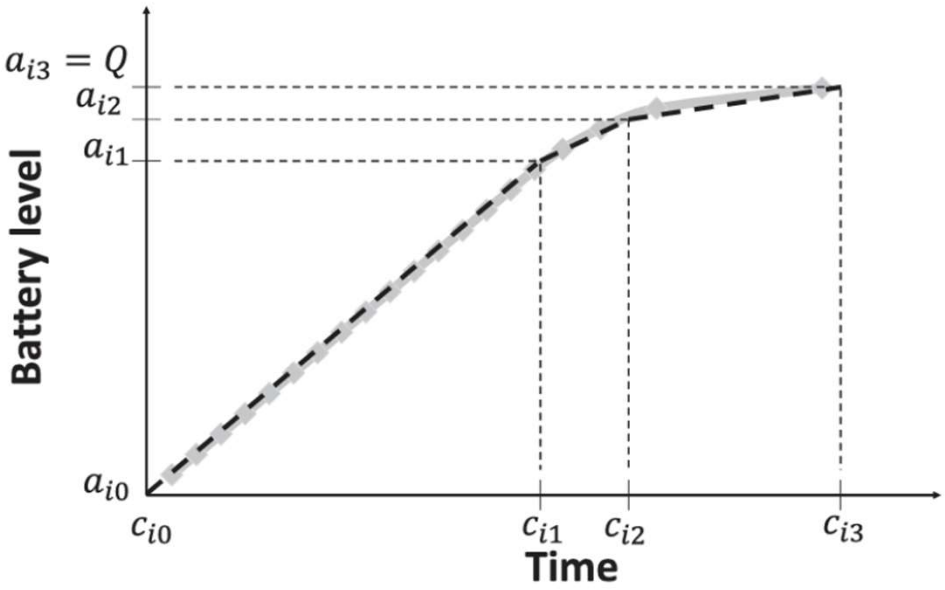
Charging Bateries

Up to about 80% battery charge is essentially linear

The remaining 20% take longer to charge, so in day-to-day use it is normal to charge up to 80%

Complete battery discharges are unhealthy for batteries, so it is advisable to stipulate a minimum charge (for example 20%) which also works as a safety measure so that the truck does not run out of charge in its battery

Manufacturers recommend battery charging cycles from a minimum (eg 20%) to a value that is not the maximum (eg 80% of the maximum)



Some (many) simplifications

- Battery charge between 20% and 80% is linear (approximation)
- The energy consumed in a given route is linearly dependent on the truck mass + transported load. Values will be given for the truck with the maximum load
- The time to travel a given route also depends linearly on the truck mass + transported load
- Time of day and traffic conditions are not considered
- The placement and removal times of the goods corresponding to the deliveries to be made in the warehouses are also estimates

Warehouse Identifiers

Armazém	Identificador
Arouca	1
Espinho	2
Gondomar	3
Maia	4
Matosinhos	5
Oliveira de Azeméis	6
Paredes	7
Porto	8
Póvoa de Varzim	9
Santa Maria da Feira	10
Santo Tirso	11
São João da Madeira	12
Trofa	13
Vale de Cambra	14
Valongo	15
Vila do Conde	16
Vila Nova de Gaia	17

Distance between Warehouses

Distância (km)	nº cidade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Arouca	1	0	53	57	67	65	30	44	57	92	37	80	29	83	22	64	85	56
Espinho	2	52	0	28	31	27	34	48	22	55	17	51	24	53	43	37	47	18
Gondomar	3	56	28	0	19	18	46	29	10	45	35	34	40	36	47	10	38	13
Maia	4	68	30	20	0	12	59	34	12	32	43	24	52	14	60	16	18	14
Matosinhos	5	64	25	18	11	0	55	35	9	30	37	32	45	25	56	18	23	9
Oliveira de Azeméis	6	29	34	47	58	55	0	60	48	83	18	70	11	73	11	55	75	47
Paredes	7	45	48	28	32	35	60	0	33	60	55	28	53	39	61	20	52	38
Porto	8	58	23	8	12	9	48	32	0	37	32	28	42	30	50	15	29	7
Póvoa de Varzim	9	90	51	44	30	29	81	59	35	0	64	36	71	24	82	42	4	35
Santa Maria da Feira	10	37	17	34	41	38	18	53	30	65	0	57	8	58	21	43	58	29
Santo Tirso	11	81	51	35	22	31	71	29	29	35	57	0	65	9	73	31	34	34
São João da Madeira	12	29	24	40	51	48	10	53	41	76	8	63	0	66	13	48	68	40
Trofa	13	81	44	36	14	25	71	38	25	25	59	9	65	0	73	21	19	27
Vale de Cambra	14	22	44	48	58	56	11	60	48	83	21	71	13	73	0	55	76	47
Valongo	15	64	38	10	15	18	55	20	16	44	45	31	48	22	56	0	36	21
Vila do Conde	16	85	46	39	20	23	75	53	29	4	58	35	65	19	76	36	0	30
Vila Nova de Gaia	17	57	18	14	16	12	47	38	8	39	30	36	37	29	48	22	31	0

Distances were estimated using a route planner and indicate the actual distance traveled between warehouses, which will be greater than minimum arc distance (not straight line)

The table considers the distance from the city of the line to the city of the column, for example, the distance from Arouca to Espinho is 53 km while the distance from Espinho to Arouca is 52 km

The main diagonal has zeros (distance to the warehouse itself)

Time of the truck on the way carrying the maximum load (associated with the maximum weight)

Tempo (minutos) Camião c/ peso máxim nº cidade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Arouca	1	0	122	122	151	147	74	116	141	185	97	164	76	174	59	132	181	128
Espinho	2	116	0	55	74	65	69	74	61	103	36	88	61	95	78	69	99	46
Gondomar	3	120	50	0	46	46	74	63	38	84	59	61	67	67	82	34	80	36
Maia	4	149	65	46	0	27	103	55	36	50	78	42	97	44	111	32	53	38
Matosinhos	5	141	55	48	25	0	97	55	29	48	69	53	95	63	105	34	46	27
Oliveira de Azeméis	6	69	71	74	103	99	0	88	92	134	42	116	23	126	25	84	132	80
Paredes	7	116	71	61	53	53	88	0	59	88	84	74	82	76	97	29	84	69
Porto	8	134	59	32	34	32	88	57	0	69	65	53	82	61	97	36	65	32
Póvoa de Varzim	9	181	95	86	55	48	134	95	69	0	109	61	132	67	143	71	15	67
Santa Maria da Feira	10	97	34	59	78	71	40	82	65	109	0	92	32	99	63	74	105	53
Santo Tirso	11	164	88	65	42	55	118	74	59	63	97	0	111	25	126	53	59	67
São João da Madeira	12	76	61	67	97	92	19	82	86	128	32	109	0	120	40	78	126	74
Trofa	13	174	107	74	46	67	128	80	76	67	105	27	122	0	137	67	59	78
Vale de Cambra	14	59	80	80	109	105	27	97	99	143	61	122	42	132	0	90	139	86
Valongo	15	132	74	34	36	36	86	34	42	71	82	53	80	69	95	0	69	53
Vila do Conde	16	179	92	84	57	46	132	92	67	15	105	57	130	61	141	69	0	65
Vila Nova de Gaia	17	128	42	40	42	34	82	74	29	69	55	69	80	82	90	53	67	0

Times were estimated using a route planner for a light vehicle and multiplied by a constant factor
It is an average estimate, it does not consider the time of day (another simplification)
The table considers the time from the city of the line to the city of the column, for example, the time from Arouca to Espinho is 122 minutes while from Espinho to Arouca is 116 minutes
The main diagonal has zeros (time for own warehouse)

Energy to make a trip with the maximum load (associated with the maximum weight)

Energia (kWh) Camião c/ peso máximo	nº cidade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Arouca	1	0	42	46	54	52	24	35	46	74	30	64	23	66	18	51	68	45
Espinho	2	42	0	22	25	22	27	38	18	44	14	41	19	42	34	30	38	14
Gondomar	3	45	22	0	15	14	37	23	8	36	28	27	32	29	38	8	30	10
Maia	4	54	24	16	0	10	47	27	10	26	34	19	42	11	48	13	14	11
Matosinhos	5	51	20	14	9	0	44	28	7	24	30	26	36	20	45	14	18	7
Oliveira de Azeméis	6	23	27	38	46	44	0	48	38	66	14	56	9	58	9	44	60	38
Paredes	7	36	38	22	26	28	48	0	26	48	44	22	42	31	49	16	42	30
Porto	8	46	18	6	10	7	38	26	0	30	26	22	34	24	40	12	23	6
Póvoa de Varzim	9	72	41	35	24	23	65	47	28	0	51	29	57	19	66	34	3	28
Santa Maria da Feira	10	30	14	27	33	30	14	42	24	52	0	46	6	46	17	34	46	23
Santo Tirso	11	65	41	28	18	25	57	23	23	28	46	0	52	7	58	25	27	27
São João da Madeira	12	23	19	32	41	38	8	42	33	61	6	50	0	53	10	38	54	32
Trofa	13	65	35	29	11	20	57	30	20	20	47	7	52	0	58	17	15	22
Vale de Cambra	14	18	35	38	46	45	9	48	38	66	17	57	10	58	0	44	61	38
Valongo	15	51	30	8	12	14	44	16	13	35	36	25	38	18	45	0	29	17
Vila do Conde	16	68	37	31	16	18	60	42	23	3	46	28	52	15	61	29	0	24
Vila Nova de Gaia	17	46	14	11	13	10	38	30	6	31	24	29	30	23	38	18	25	0

The energy took into account the previously indicated distances and the characteristics of the truck (100km with the maximum Load in terms of weight carried out and with batteries at 100% energy at the start)

It is an average estimate, it does not consider the time of day, traffic, speed at which the truck is moving

The table considers the energy from the city of the line to the city of the column, for example, the energy to go from Arouca to Gondomar is 46 kWh while from Gondomar to Arouca it is 45 kWh

The main diagonal has zeros (energy for the warehouse itself)

And if the truck isn’t full?

We can apply some rules of 3, for example, let's admit the route from Arouca to Espinho. In the 2 previous tables, with the truck loaded with 4300 kg transported (remembering that the truck itself weighs 7500 kg, so the total is 11800 kg) we have a travel time of 122 minutes and an energy consumption of 42 kWh.

Let's assume that the load is 1000 kg and not 4300 kg, so the total weight of the truck with the load is 7500 kg+1000 kg = 8500 kg. So the rules of 3 are:

11800 kg ↔ 122 minutes

8500 kg ↔ T

T = 122*8500/11800 = 87.88 minutes

11800 kg ↔ 42 kWh

8500 kg ↔ E

E = 42*8500/11800 = 30.25 kWh

Therefore, with less load in kg, the truck travels in less time and consumes less energy.

It should be noted that this is a simplification, but sufficient for our purposes.

Extra time for intermediate loads

Tempo extra carga intermédia (min)	nº cidade	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Arouca	1	0	0	0	25	25	0	0	0	53	0	40	0	45	0	24	45	0
Espinho	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gondomar	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maia	4	25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Matosinhos	5	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Oliveira de Azeméis	6	0	0	0	0	0	0	0	0	45	0	30	0	33	0	0	35	0
Paredes	7	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0
Porto	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Póvoa de Varzim	9	50	0	0	0	0	42	0	0	0	24	0	31	0	45	0	0	0
Santa Maria da Feira	10	0	0	0	0	0	0	0	0	25	0	0	0	0	0	0	0	0
Santo Tirso	11	42	0	0	0	0	31	0	0	0	0	0	25	0	33	0	0	0
São João da Madeira	12	0	0	0	0	0	0	0	0	37	0	23	0	26	0	0	28	0
Trofa	13	42	0	0	0	0	31	0	0	0	0	0	25	0	33	0	0	0
Vale de Cambra	14	0	0	0	0	0	0	0	0	45	0	31	0	35	0	0	37	0
Valongo	15	24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vila do Conde	16	45	0	0	0	0	35	0	0	0	0	0	25	0	37	0	0	0
Vila Nova de Gaia	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

When the truck leaves a warehouse where it made a delivery to go to another, it must have enough energy to reach the Destination with at least 20% of its electrical charge.

If this is not possible, charge the battery in the warehouse where you are till reach 80% of the electrical charge.

But there are journeys between warehouses that are so long that they do not allow this charge to beenough to get there with 20% electrical charge.

In such cases an intermediate charge is required which should allow the truck arrives at the target warehouse with 20% of its electrical load.

For example, between Póvoa de Varzim and Arouca (remember that the distance is 90 km) it takes another 50 minutes for an intermediate load.

In our planning problem, as we aim to minimize the time, solutions that require intermediate loads will tend not to be chosen, but if, for example, there are only 2 deliveries exactly to Arouca and Póvoa de Varzim, there is no way to avoid it!

Truck Characteristics

Caraterística do Camião	Tara (kg)	Capacidade Carga (kg)	Carga Total Baterias (kWh)	Autonomia com Carga Máx. (km)	Tempo recarregamento baterias 20%a80% (minutos)
eTruck01	7500	4300	80	100	60

- The eTruck01 truck (model) has a gross weight of 7500 kg, a load capacity of 4300 kg (the maximum it can carry)
- Its batteries allow a total of 80 kWh and when fully charged (electrical charge) allow the truck to travel fully loaded (in terms of mass, i.e. carrying 4300 kg) for 100 km (this is the truck's autonomy)
- A quick charge of batteries from 20% to 80% of their electrical charge takes 60 minutes (let's assume that this charge is linear, for example if we go from 50% to 80% it will be 30 minutes)
- In terms of characteristics this truck is very similar to the eCarter presented earlier

First exemple of Deliveries

Id. Entrega	Data(AAAAMMDD)	Massa Entrega (kg)	Armazém Entrega	Tempo Colocação (min)	Tempo retirada (min)
4439	20221205	200	1	8	10
4438	20221205	150	9	7	9
4445	20221205	100	3	5	7
4443	20221205	120	11	6	8
4449	20221205	300	8	15	20

- Delivery 4439 must be made on December 5, 2022 weighing 200 kg and must be delivered to Arouca (warehouse nº 1)
- It takes 8 minutes to place the load on the truck and 10 minutes to remove it. Placement and withdrawal times are also estimates (actually would depend on many factors)
- The placement time will not be very important because it is assumed that the trucks already leave with the load placed, which was previously placed by a work team before the truck leaves in the morning
- The pick-up time is important because it adds to the travel time. Note that unloading can be done while the truck is charging in a quick charge system
- This example involves 5 deliveries, so it is not subject to a combinatorial explosion that makes a solution impossible to generate all possible trajectories and choose the one with the shortest duration. That's where we'll start

Second exemple of Deliveries

Id. Entrega	Data(AAAAMMDD)	Massa Entrega (kg)	Armazém Entrega	Tempo Colocação (min)	Tempo retirada (min)
4439	20221206	200	1	8	10
4438	20221206	150	9	7	9
4445	20221206	100	3	5	7
4443	20221206	120	11	6	8
4449	20221206	300	8	15	20
4398	20221206	310	17	16	20
4432	20221206	270	14	14	18
4437	20221206	180	12	9	11
4451	20221206	220	6	9	12
4452	20221206	390	13	21	26
4444	20221206	380	2	20	25
4455	20221206	280	7	14	19
4399	20221206	260	15	13	18
4454	20221206	350	10	18	22
4446	20221206	260	4	14	17
4456	20221206	330	16	17	21

- We now have 16 deliveries, so the solution of generating them all and choosing the best one gets more complicated. For a better sensitivity we will start with the first 6 deliveries, then we will include them one by one and see how far we can go with the approach of generating all the solutions and choosing the best one (less time)

Third exemple of Deliveries

Id. Entrega	Data(AAAAMMDD)	Massa Entrega (kg)	Armazém Entrega	Tempo Colocação (min)	Tempo retirada (min)
4512	20221207	340	16	18	21
4517	20221207	130	11	6	9
4513	20221207	270	4	14	18
4506	20221207	160	9	8	10
4526	20221207	280	14	15	19
4510	20221207	360	10	19	22
4542	20221207	300	8	15	20
4536	20221207	180	12	9	11
4532	20221207	220	6	9	12
4549	20221207	280	7	14	19
4522	20221207	380	2	20	25
4533	20221207	410	13	22	26
4538	20221207	260	15	13	18
4511	20221207	310	17	16	20
4544	20221207	100	3	5	7
4539	20221207	200	1	8	10

- This is another example of 16 deliveries, it is advisable to test with several different examples to be able to draw conclusions (for example, if a heuristic is good or not, this is because the example can condition the evaluation of the heuristic)