ADVANCED MODELLING FOR OPERATIONS ASSIGNMENT 2

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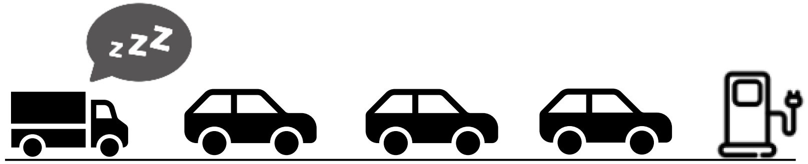
PLANNING OF EXPERIMENTS: Performance Measure of Interests

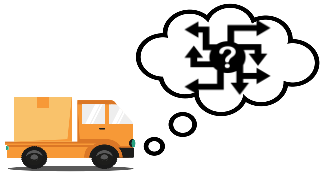
Performance Measure of Interests

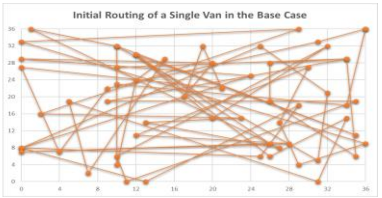
1) Minimum number of vans that satisfies 8 hours constraint to serve 60 customers: This is the most critical performance measure, due to the fact that minimizing the number of runs will impact the profitability of the business severely, and the needed number of vans must be identified by running different experiments by different system configurations. **This is the selected system performance to measure.** *(It will be explained in more detail in the next slide)*

2) Waiting times of the vans at the charging station queues: If the company wants to evaluate the **new charging policy** *(explained in Assignment 1)*, this system performance can be used to evaluate the benefits of this new charging policy. If this waiting time decreases with the new charging policy, the tour end times of the vans will be decreases consequetively.

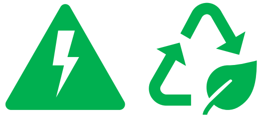


3) Maximum distance travelled by all the vans: To measure the performance of **routing,** this can be a good system performance to measure. This will have an important impact on the tour end times of vans. If the goal is to measure specifically the performance of new routing policies, this can be used.





4) The total energy consumed by the vans: With the green logistics is becoming an important aspect of sustainability, this system performance can be measured to evaluate the sustainability of the logistics operations of the company.



5) Total cost including all the aspects mentioned above: A cost function, using weighted averages of the performance measures mentioned above depending on their importance, can be used to evaluate the total performance of the last mile delivery operations. However, this function is not easy to construct, and it can vary a lot depending on the objectives of a specific company.

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PLANNING OF EXPERIMENTS: Performance Measure of Interests

How to measure minimum number of vans that satisfies 8 hours constraints to serve 60 customers:

As mentioned in the previous slide, our **system performance of interest** is **minimum number of vans that satisfy 8 hours constraint.** This system performance is chosen due to the fact that it is the most important measure to evaluate the performance of the overall last mile delivery operations, compared to other possible system performances. Because, if it can be minimized, the company will make a significant amount of saving.

How to measure minimum number of vans needed?

After each tour finishes, we will collect the data of **maximum of all tour end times of all the vans** in a single tour. For example:

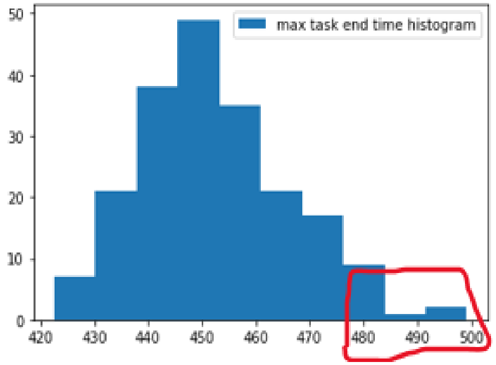
```
Tour end times of the vans:
 [352.94427962762154, 437.19967332603835,
471.74632090130325, 442.2901221109631]

Max tour end time is:
 [471.74632090130325]
```

The recorded value will be **471.75 minutes.** The main reason behind calculating only the maximum of these tour end times is the fact that the main goal is to have all our vans finishing their tours in 8 hours. Therefore, we are focusing on the maximum of them, which must be lower than 8 hours.

Statistics calculation and determining minimum number of vans needed

After recording the data of **maximum tour end times** coming from multiple runs, we can have results similar to the ones below:

```
**Max Tour End Time Statistics***
Mean= 452.5357641747609
Sample variance= 198.9365243813611
Variance of the sample mean= 2.4513515948388123
P(max throughput time>480)= 0.025755462627875536
```



The decision makers can use this data to make managerial decisions, **depending on their preferences.** In the example above, with using 4 vans, in 0.975 of the cases the tour can be completed in 8 hours by all vans. If the company is willing to accept 0.025 probability of going overtime,they can use 4 vans. If not, setting it to 5 vans will prevent overtimes almost in all cases.

To sum this part up, we can say that **maximum tour end time** statistics will be used as a **proxy** of the **minimum number of vans.** As a default setting, **4 vans** will be tried, because it is enough to satisfy 8 hours constraint in most of the cases. Whenever distribution of maximum tour end data significantly exceeds 8 hours constraint (this part depends on the **preferences of the decision maker**), we will conclude that 4 vans are not enough, so 5 vans will be used.

For example:
With the statistics are calculated for maximum throughput data:

Let P(max throughput time>8 hours)=0.09

The decision maker believes that max throughput time can exceed 8 hours constraint. **at most** 0.05

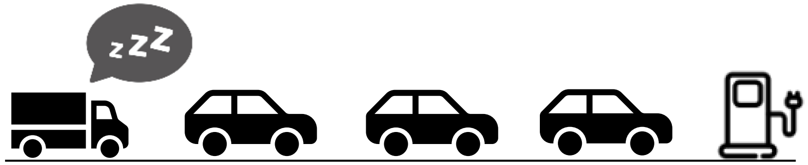
0.09>0.05

In this case, the decision will be **5 vans** instead of 4, due to the fact that the decision maker is not okay with 0.09 of the tours exceeding 8 hours constrain.

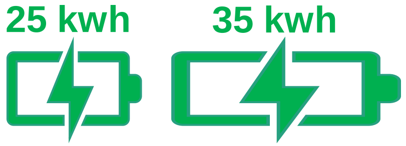
PLANNING OF EXPERIMENTS: List of Possible Factors

Possible Factors

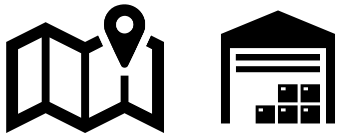
1) Charging Policy: Due to the fact that electrical vans may need charging to complete their tours, charging policy of the company may affect the performances severely. This is an important factor to use due to several reasons such as waiting times at the charging station queues may differ from one policy to another (which effects max tour end time of the vans and consequently the company may face overtime costs. (This is deeply explained in the Assignment 1). **This factor is selected to be used in our experiments** due to its significant effect on the maximum tour end time, and also due to the fact that the companies can easily try our new charging policy in the short term.



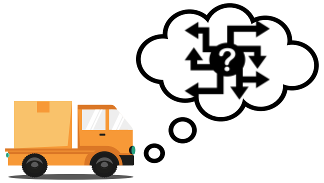
2) Battery Size: Vans with different battery sizes may have different daily costs. The vans with large batteries will have higher daily operating costs, and the ones with the smaller battery sizes will habe lower daily operating costs. Therefore, different battery sizes and their effect on the maximum tour end times are worth evaluating, depending on which the company can identify different opportunites of cost saving. **This factor is selected to be used in our experiments,** due to the fact that it has a big impact on the maximum tour end time of the vans, and also the fact that the companies which rent vans can easily adjust their fleet of vans with varying battery sizes.

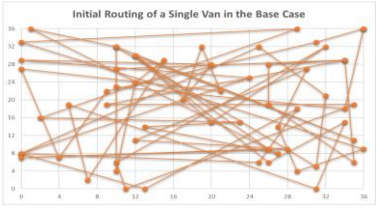


3) Warehouse Location: This factor may be investigated for long term strategic decisions, if the company is evaluating different possible locations of a warehouse to serve different areas. Different locations will have different impacts on the maximum tour end times and will change the number of vans needed to complete a tour, due to the fact that the total distance travelled needed to serve 60 customers will vary depending on the warehouse location. Moreover, the rent prices of the warehouse real estate will vary depending on the location. Therefore, this factor may be interesting to investigate for long term decisions.



4) Routing Policy: To define the routings of the vans, different policies can be used. Both optimization and also heuristic methods can used to define routings, which will have different travel distance, and consequetively different max tour end times.





PLANNING OF EXPERIMENTS: Factor Levels and Single Factor Experiments

Factor Levels

Factor 1: Charging Policy

Factor Levels: [0,1]
0: Base Case Charging Policy
1: New Charging Policy (Explained in Assignment 1)

Changing the factor level from «0» to «1», we will observe the change in the maximum tour end time of the vans. Note that this is not a numerical factor, but a factor that is referring to a policy.

Factor 2: Battery Size

For factor levels of battery size, different battery sizes for different vans can be used and this will be shown as:

Factor Levels:
[20,20,20,20]
[25,25,25,25]
[30,30,30,30]
[35,35,35,35]
[30,30,20,20]
[25,25,20,20]

NOTE:
Batery Size: [x,y,z,t] means that:
Van_0 battery = x kwh
Van_1 battery = y kwh
Van_2 battery = z kwh
Van_3 battery = t kwh

With the changing battery sizes, we will observe the change in the maximum tour end time. If with smaller batteries still the maximum tour end times can satisfy 8 hours constraint, that means an opportunity for the company to make some savings. Also, some flexible options ([30,30,20,20]) with different battery sizes for different vans will be tried, to see if a right combination can be found.

Single Factor Experiments

We will use **single factor experiments** for 2 factors just mentioned: Charging Policy and Battery Size. Our experiments will be conducted by:

1. Fixing the charging policy and conducting experiments with differing battery sizes:

In this case, we will run **2 experiments** (Experiment No: 1 and 2) and we will test if the varying battery sizes effect the maximum tour end time (which is a proxy of minimum number of vans to serve customers in 8 hours time period)

Experiment No.	Charging Policy (Fixed)	Battery Size (Changing)
1	Base Case Policy	[20,20,20,20]
		[25,25,25,25]
		[30,30,30,30]
		[35,35,35,35]
		[30,30,20,20]
		[25,25,20,20]
2	New Policy	[20,20,20,20]
		[25,25,25,25]
		[30,30,30,30]
		[35,35,35,35]
		[30,30,20,20]
		[25,25,20,20]

2. Fixing the battery size, and conducting experiments with differing charging policies:

In this case, we will run **6 experiments** (Experiments no: 3,4,5,6,7,8) and we will test if the varying charging policies effect the maximum tour end time (which is a proxy of minimum number of vans to serve customers in 8 hours time period)

Experiment No.	Battery Size (Fixed)	Charging Policy (Changing)
3	[20,20,20,20]	New Policy
		Base Case Policy
4	[25,25,25,25]	New Policy
		Base Case Policy
5	[30,30,30,30]	New Policy
		Base Case Policy
6	[35,35,35,35]	New Policy
		Base Case Policy
7	[30,30,20,20]	New Policy
		Base Case Policy
8	[25,25,20,20]	New Policy
		Base Case Policy

PLANNING OF EXPERIMENTS: Number of Runs

Due to the fact that different scenarios have different standard deviation of the sample mean, each scenario needs different number of runs to satisfy the constraint of:
Half Width of the Confidence Interval (c) < 0.005 * Mean
Therefore, we calculated number of runs for different scenarios, and selected the highest number of runs needed among all different scenarios.

The Procedure to Determine Number of Runs *(Python Script Section 11)*

1. We selected half width of the confidence interval (c)

```
if c<=0.005*statistics.mean(max_task_end_time):
    break
```

Half width is set to 0.005 of the mean of maximum tour end time, in order to have a precise estimation of the mean.

2. We chose the confidence level (1- alpha) and initial value number of runs (N)
(Python Script Section 2.5)

```
# 2.5.Statistics
alpha=0.05 # Type 1 error probability
```

alpha= 0.05
N= 50

3. We calculated the percentile of the t-distribution with N-1 degrees of freedom and 1-alpha confidence level

```
quantile=scipy.stats.t.ppf(1-alpha/2,N-1)
```

4. We run N replications to calculate half width interval

```
#calculating c
s=statistics.variance(max_task_end_time)
quantile=scipy.stats.t.ppf(1-alpha/2,N-1)
c=quantile*(s/N)**0.5
```

5. We check the condition of:
c < 0.005 * Mean of maximum tour end times

6. We start from the initial value of N=50, and increase it by 50 for the next step, if the condition is not met

```
if c<=0.005*statistics.mean(max_task_end_time):
    break
else:
    N=N+50
```

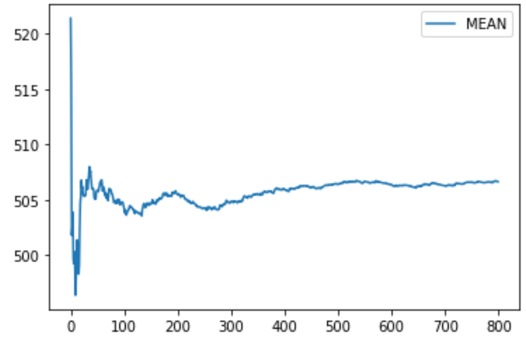
```
N= 50 c/mean= 0.019321739256514633
N= 100 c/mean= 0.012950004787220571
N= 150 c/mean= 0.011179982670747409
N= 200 c/mean= 0.009544561366754
N= 250 c/mean= 0.008442683107399945
N= 300 c/mean= 0.007537564537622274
N= 350 c/mean= 0.007382052201342089
N= 400 c/mean= 0.006812449017072641
N= 450 c/mean= 0.006439579911789212
N= 500 c/mean= 0.006154238789619457
N= 550 c/mean= 0.005930046311164598
N= 600 c/mean= 0.005701439879007538
N= 650 c/mean= 0.005476752811073421
N= 700 c/mean= 0.005192123021291277
N= 750 c/mean= 0.005037474617018722
N= 800 c/mean= 0.004856121421105277
```

N=**800** IS SELECTED

This procedure is followed for all configurations (12 scenarios) considering the 2 factors of: Charging Policy and Battery Size. In the case of:

Battery Size: [20,20,20,20]
Charging Policy=0

We needed 800 runs to satisy the condition of half width. This was the case in which we needed the biggest number of runs. Therefore, we decided to use **800 runs,** for our experiments to measure **the maximum tour end time**, which is a **proxy** of **minimum number of vans to serve 60 customers in 8 hours** (explained in slide 4) to be used ,which is our system performance measure of interest.



DOE Python Script

Anova_num=0: Fixed charging policy, varying battery sizes experiments
Anova_num=1: Fixed battery size, varying charging policy experiments

Anova_num=1 : How does the code work? (Same logic for Anova_num=0)
Python Script Section 11

1. The user sets anova_num=1

```
anova_num=1
```

2. The user fixes the battery size and runs the code

```
battery_size = [30,30,30,30]
```

3. The code performs Anova Test with fixed battery size and changing charging policies. (*Detailed explanation is provided in Python Script Assignment_2_Anova Section 11)*

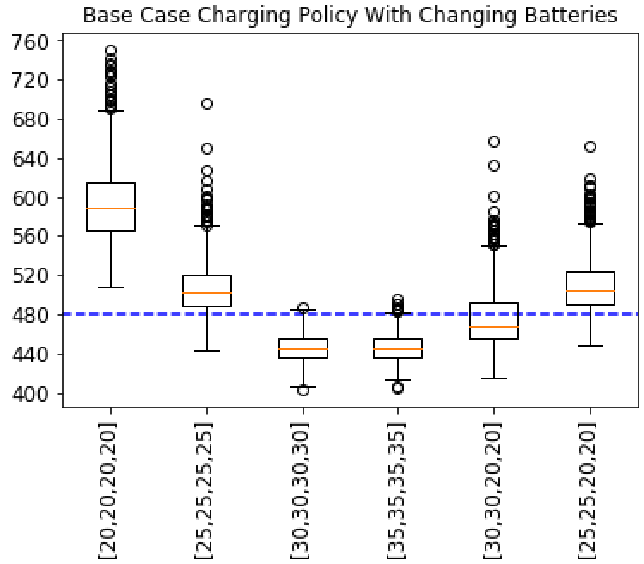
```
elif anova_num==1:
    while True:
        if charging_policy_change==0:
            charging_policy=0
        elif charging_policy_change==1:
            charging_policy=1
        if charging_policy_change==1:
            y1=np.array(max_task_end_time[:N])
            y2=np.array(max_task_end_time[N:N*2])
            print(f_oneway(y1,y2))
        else:
            charging_policy_change+=1
```

Charging_policy_change parameter is used to change the charging policy until both of them used in the experiment.

Varying Battery Sizes, Fixed Charging Policy

Experiment 1

Charging policy= Base Case Charging Policy
Battery Size= Changing



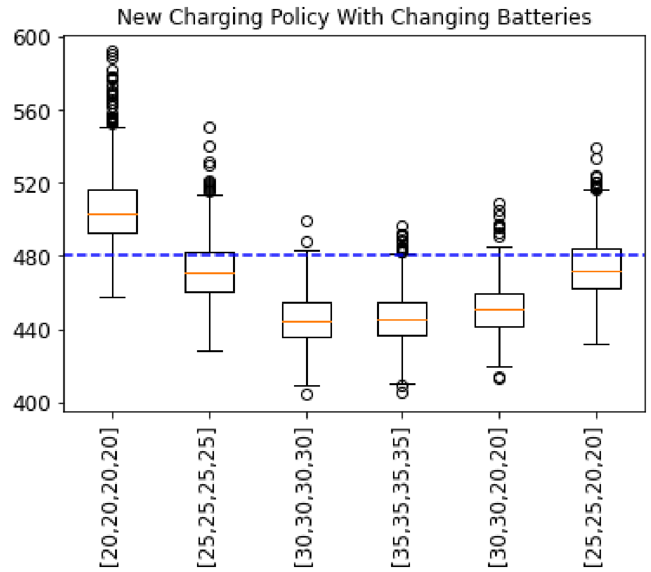

```
f_oneway(y1,y2,y3,y4,y5,y6)
F_onewayResult(statistic=3095.379020656219, pvalue=0.0)
```

With the Base Case charging policy and varying battery sizes, we can conclude that:

- The change in the battery size significantly effects the maximum tour end time with the p-value 0
- Battery sizes [30,30,30,30] and [35,35,35,35] giving very similar results. This is because the van does not need any charging to complete the tour in both of these battery sizes.
- With these 2 battery sizes, Base Case charging policy and 4 vans, the tour can be completed in 8 hours.

Experiment 2

Charging policy= New Charging Policy
Battery Size= Changing




```
f_oneway(y1,y2,y3,y4,y5,y6)
F_onewayResult(statistic=1644.7579182514457, pvalue=0.0)
```

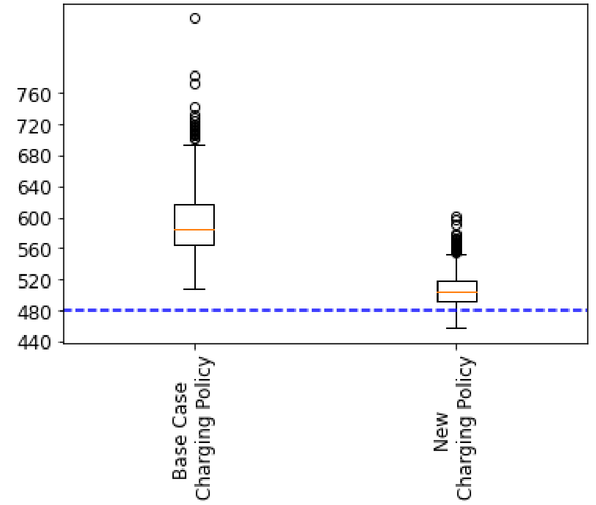
With the New Charging policy and varying battery sizes, we can conclude that:

- The change in the battery size significantly effects the maximum tour end time with the p-value 0
- Battery sizes [30,30,30,30] and [35,35,35,35] giving very similar results. This is because the van does not need any charging to complete the tour in both of these battery sizes.
- With the new charging policy, battery size [30,30,20,20] also gives promising results

Varying Charging Policy, Fixed Battery Size

Experiment 3

Battery Size: battery_size = [20,20,20,20]
Charging policy= Changing




```
f_oneway(y1,y2)
F_onewayResult(statistic=2674.372158085168, pvalue=0.0)
```

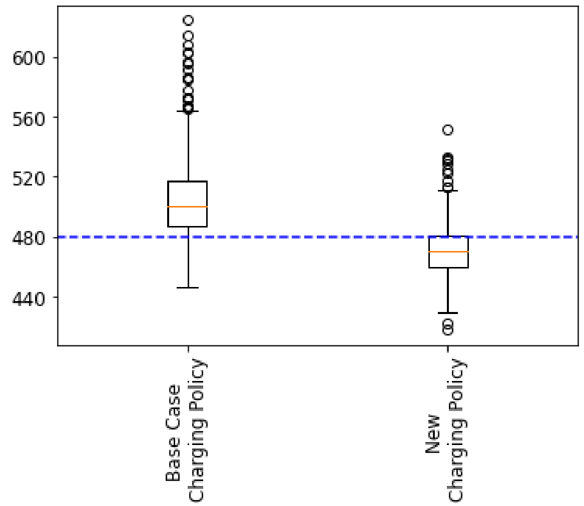
With the battery size [20,20,20,20] and varying charging policy, we can conclude that:

- The change of the charging policy significantly impact the maximum tour end time with the p-value 0

- Even though new charging policy improves the results, with the battery size [20,20,20,20], it seems that the tour cannot be completed in 8 hours

Experiment 4

Battery Size: battery_size = [25,25,25,25]
Charging policy= Changing




```
f_oneway(y1,y2)
F_onewayResult(statistic=967.699242946174, pvalue=1.6361436862069064e-166)
```

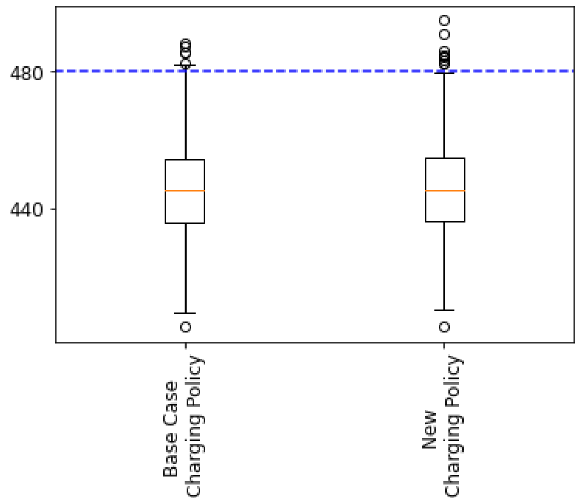
With the battery size [25,25,25,25] and varying charging policy, we can conclude that:

- The change of the charging policy significantly impact the maximum tour end time with the p-value 1.63e-166

- The new charging policy improves the results and the maximum tour end time seems to be under 8 hours in most of the cases

Experiment 5

Battery Size: battery_size = [30,30,30,30]
Charging policy= Changing




```
f_oneway(y1,y2)
F_onewayResult(statistic=0.08526507828728475, pvalue=0.7703
```

With the battery size [30,30,30,30] and varying charging policy, we can conclude that:

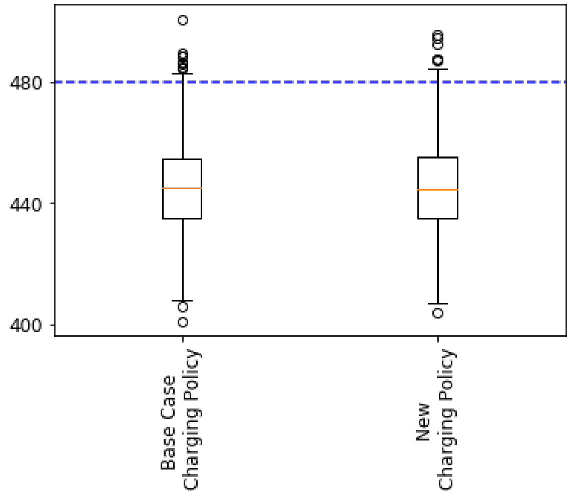
- The change of the charging policy has no significant impact on the tour end time with the p-value 0.7703

- This result is due to the fact that the vans do not need any charging with this battery size, because it is large enough to complete a tour. Therefore, no impact of the new charging policy can be seen with this large battery size.

Varying Charging Policy, Fixed Battery Size

Experiment 6

Battery Size: battery_size = [35,35,35,35]
Charging policy= Changing



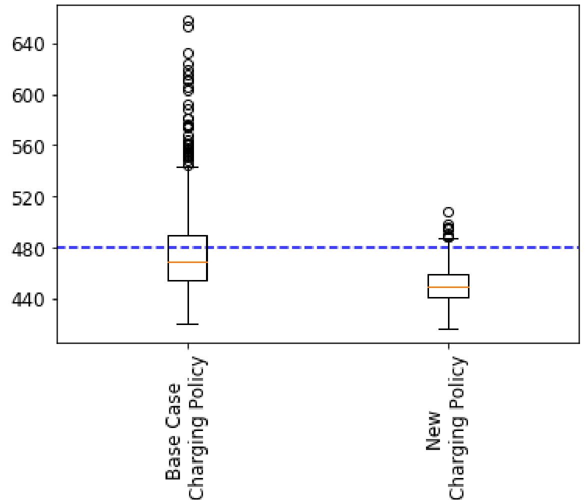

```
f_oneway(y1,y2)
F_onewayResult(statistic=0.2250522545085426З, pvalue=0.63528184
```

With the battery size [35,35,35,35] and varying charging policy, we can conclude that:

- The change of the charging policy has no significant impact on the tour end time with the p-value 0.6352
- This result is due to the fact that the vans do not need any charging with this battery size, because it is large enough to complete a tour. Therefore, no impact of the new charging policy can be seen with this large battery size.

Experiment 7

Battery Size: battery_size = [30,30,20,20]
Charging policy= Changing



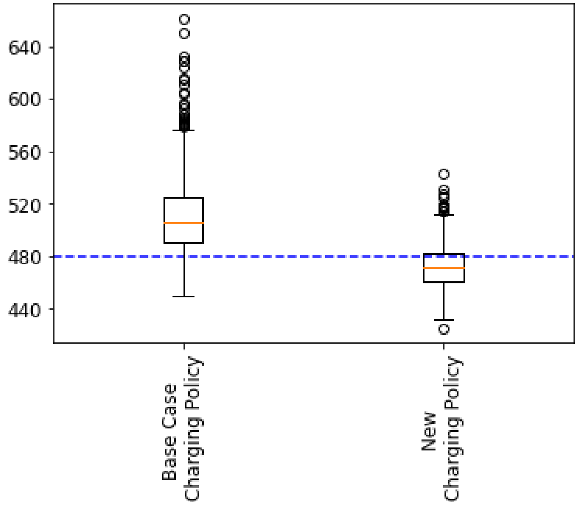

```
f_oneway(y1,y2)
F_onewayResult(statistic=394.64539820085366,
               pvalue=1.158403216437761e-78)
```

With the battery size [30,30,20,20] and varying charging policy, we can conclude that:

- The change of the charging policy significantly impact the maximum tour end time with the p-value 1.15e-78
- The new charging policy improves the results and the maximum tour end time seems to be under 8 hours in most of the cases.

Experiment 8

Battery Size: battery_size = [25,25,20,20]
Charging policy= Changing




```
f_oneway(y1,y2)
F_onewayResult(statistic=1069.6266943104683,
               pvalue=4.808948287681991e-180)
```

With the battery size [25,25,20,20] and varying charging policy, we can conclude that:

- The change of the charging policy significantly impact the maximum tour end time with the p-value 4.80e-180
- The new charging policy improves the results and the maximum tour end time seems to be under 8 hours in most of the cases.

A Hypothetical Business Case

Below, we will be explaning a hypothetical business case, in which the decision maker is trying to identify the **number of vans** to use depending on varying **battery sizes** for different vans and also **the charging policy** to use. In the following slides, the decisions about the number of vans will be made depending on the preferences of the decision makers described in this hypothetical business case.

EXPRESS COURIER X is an express courier, operating in Europe. They are transforming their traditional last mile delivery operations to be performed by electric vans. With the city infrastructures are developing to support charging of the electric vehicles more and more, last mile delivery with electric vans has become a viable option in the last years for the courier companies.

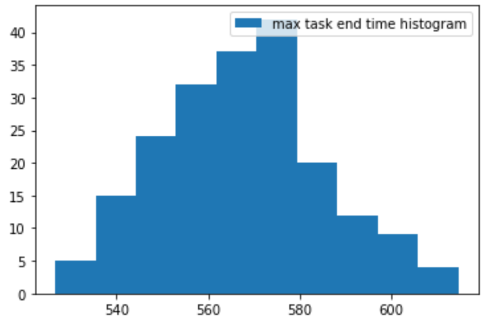
The challange for the company contains 3 aspects:

- Evaluating the number of vans needed to serve the areas
- Evaluating different vans with different battery size options, which have different daily costs
- Evaluating a new charging policy, which is believed to have a good chance of improving the performances

The operations manager believes that evaluating different battery sizes may be an opportunity for cost saving, due to daily costs of those batteries vary. The daily costs of the vans are rougly as below:
35 kwh battery vans= 150 €/day
30 kwh battery vans= 135 €/day
25 kwh battery vans= 120 €/day
20 kwh battery vans= 105 €/day

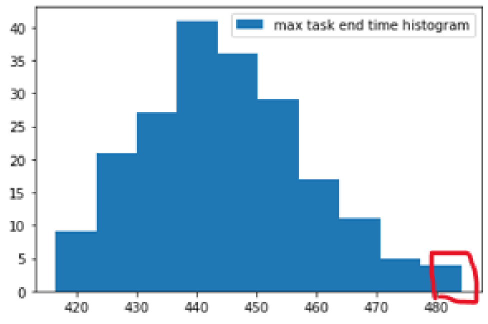
The operations manager wants to have **all the vans** serving to the **same area** complete their tours **in 8 hours** in **95%** of the cases (**only 5%** of the tours are allowed to exceed 8 hours constraint). They already know from previous simulations that **3 vans are not possible** to serve 60 customers in 8 hours. Specifically, they are evaluating an area, to which they can **easily serve with 4 vans all having 35 kwh batteries**. However, evaluating the options with **different battery sizes** can lead to big **cost savings** for the company. Moreover, having a new charging policy considered to be introduced for the last mile delivery operations, the operations manager believes that they have a good chance of doing the last mile deliveries with vans having smaller battery sizes.

Max Tour End Time: 3 vans



Not possible to serve 60 customers in 8 hours with 3 vans, even with biggest batteries

Max Tour End Time: 4 vans



60 customers can easily be served in 8 hours by 4 vans using 35kwh batteries

Therefore, 3 vans and 5 vans will not be tried, and we will try to identify only in which cases 4 vans would not be enough. (You will see that with changing battery sizes 4 vans may not be enough in some cases, due to the **trade-off** of choosing smaller batteries increasing the maximum tour end time)

Summarizing the challange

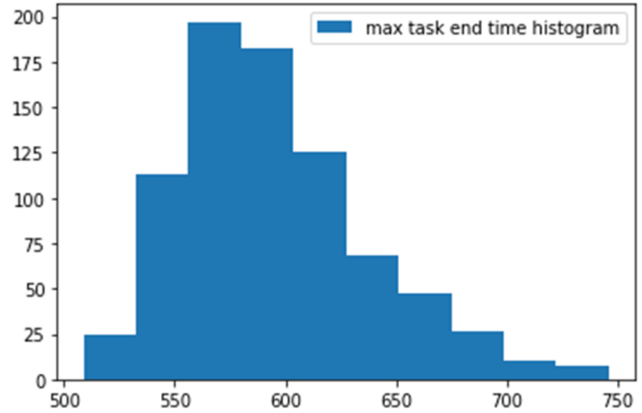
Find the right combination of :

- Battery sizes for different vans
- Charging policy

To achieve cost savings, and still being able to serve 60 customers with 4 vans in 8 hours with 95% confidence level.

Base Case Charging Policy, Varying Battery Sizes, 4 vans

battery_size = [20,20,20,20]
Charging policy= Base Case




```
**Max Tour End Time Statistics***
Mean= 594.8086615421698
Sample variance= 1800.13811068236
Variance of the sample mean= 15.040292096469393
P(max throughput time>480)= 0.9965946610722104
```

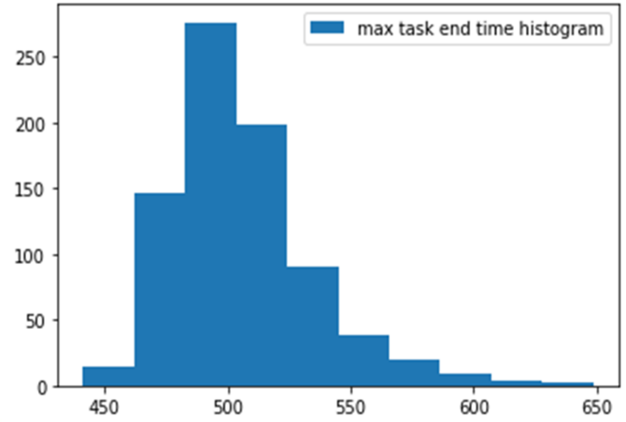
With the probability of **0.9965**, 4 vans cannot satisfy 8 hours constraint since the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.9965 > 0.05

So, 4 vans are **NOT** enough with this battery size and charging policy

Note: The sample variance is very huge in this case, which shows unreliability of the base case charging policy

battery_size = [25,25,25,25]
Charging policy= Base Case




```
**Max Tour End Time Statistics***
Mean= 505.74972756054325
Sample variance= 853.8506866243287
Variance of the sample mean= 2.795998438444576
P(max throughput time>480)= 0.810899154449179
```

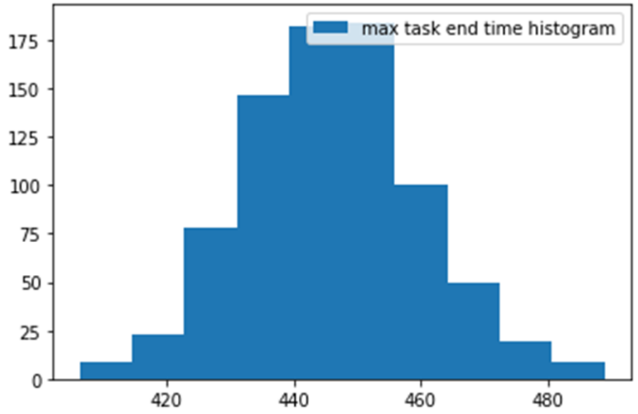
With the probability of **0.81**, 4 vans cannot satisfy 8 hours constraint since the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.81 > 0.05

So, 4 vans are **NOT** enough with this battery size and charging policy

Note: The sample variance is very huge in this case, which shows unreliability of the base case charging policy

battery_size = [30,30,30,30]
Charging policy= Base Case




```
**Max Tour End Time Statistics***
Mean= 446.01307021320355
Sample variance= 193.26377271224655
Variance of the sample mean= 0.36268283837152504
P(max throughput time>480)= 0.007247374200513468
```

With the probability of **0.00724**, 4 vans cannot satisfy 8 hours constraint since the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

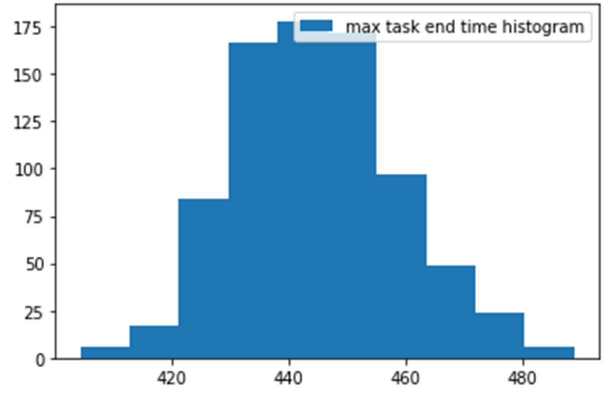
0.00724 < 0.05

So, 4 vans are **enough** with this battery size and charging policy

Note: The sample variance decreases, because with this battery size the van does not need any charging to complete the tour, so the variability is mainly caused by speed and unloading time stochasticity

Base Case Charging Policy, Varying Battery Sizes, 4 vans

battery_size = [35,35,35,35]
Charging policy= Base Case



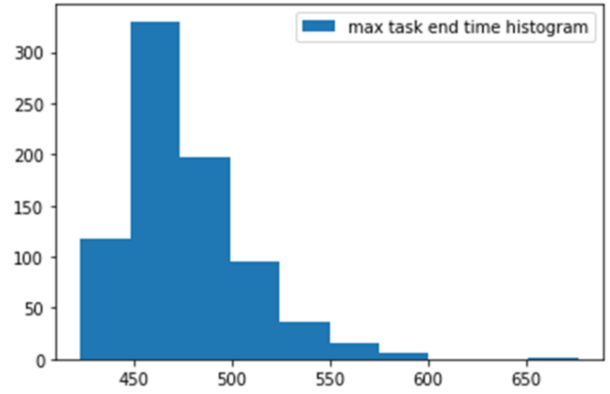
Max Tour End Time Statistics*
Mean= 444.84338367627026
Sample variance= 194.5502792826776
Variance of the sample mean= 0.9967615537864837
P(max throughput time>480)= 0.005858983068188772

With the probability of **0.0058**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.0058<0.05

So, **4 vans** are **enough** with this battery size and charging policy

battery_size = [30,30,20,20]
Charging policy= Base Case



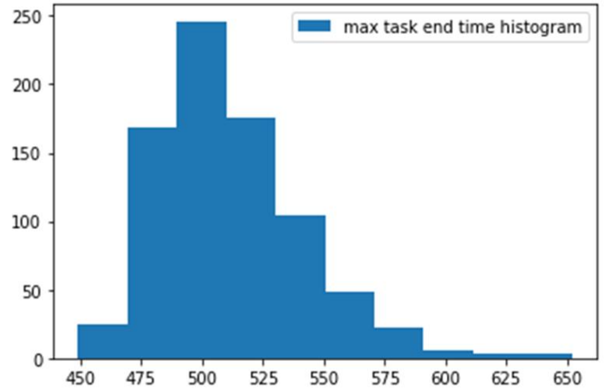
Max Tour End Time Statistics*
Mean= 476.277663567117
Sample variance= 932.0666890773848
Variance of the sample mean= 11.229551446393227
P(max throughput time>480)= 0.45147927866614335

With the probability of **0.45**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.45>0.05

So, **4 vans** are **NOT** enough with this battery size and charging policy

battery_size = [25,25,20,20]
Charging policy= Base Case



Max Tour End Time Statistics*
Mean= 511.3323503375433
Sample variance= 870.5249109788921
Variance of the sample mean= 2.3190182955459275
P(max throughput time>480)= 0.8558698657403163

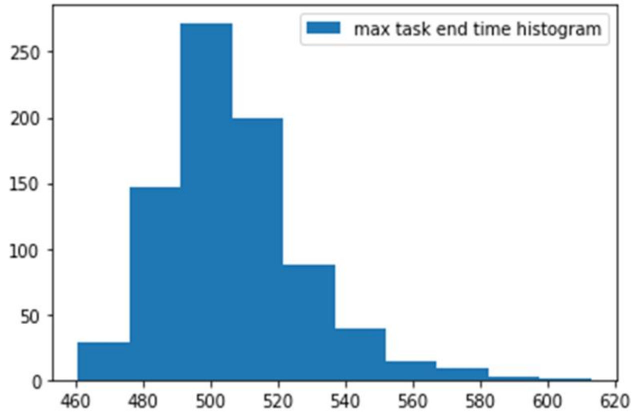
With the probability of **0.855**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.855>0.05

So, **4 vans** are **NOT** enough with this battery size and charging policy

New Charging Policy, Varying Battery Sizes, 4 vans

battery_size = [20,20,20,20]
Charging Policy= New Charging Policy



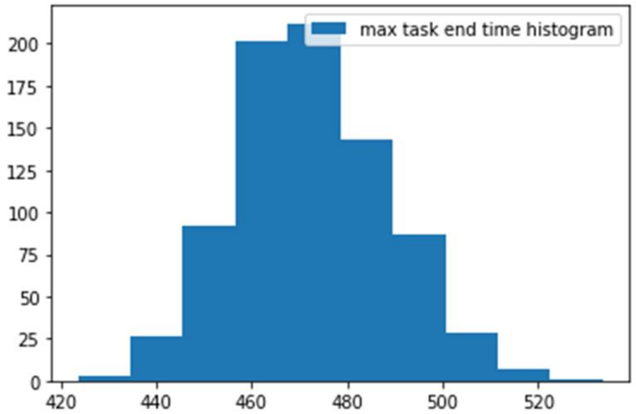

```
**Max Tour End Time Statistics***
Mean= 506.6326562624113
Sample variance= 437.27751931940884
Variance of the sample mean= 1.8377446820613321
P(max throughput time>480)= 0.8985988798722102
```

With the probability of **0.8985**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.8985>0.05

So, **4 vans** are **NOT** enough with this battery size and charging policy

battery_size = [25,25,25,25]
Charging Policy= New Charging Policy



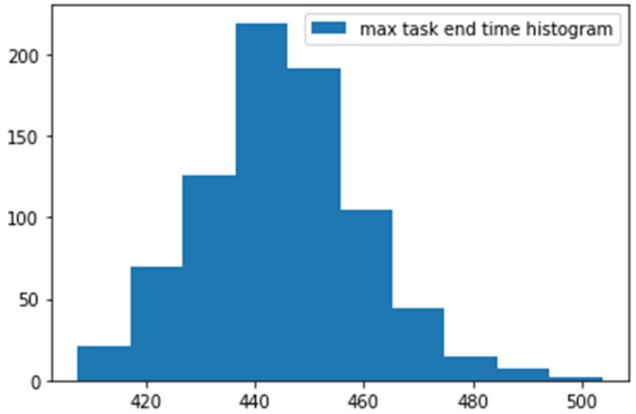

```
**Max Tour End Time Statistics***
Mean= 472.6006870529591
Sample variance= 249.9676289508499
Variance of the sample mean= 0.5847127202430403
P(max throughput time>480)= 0.31989088563757373
```

With the probability of **0.3198**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.3198>0.05

So, **4 vans** are **NOT** enough with this battery size and charging policy

battery_size = [30,30,30,30]
Charging Policy= New Charging Policy




```
**Max Tour End Time Statistics***
Mean= 444.87243776961225
Sample variance= 226.2028005828362
Variance of the sample mean= 1.406979587228828
P(max throughput time>480)= 0.0097559712378269
```

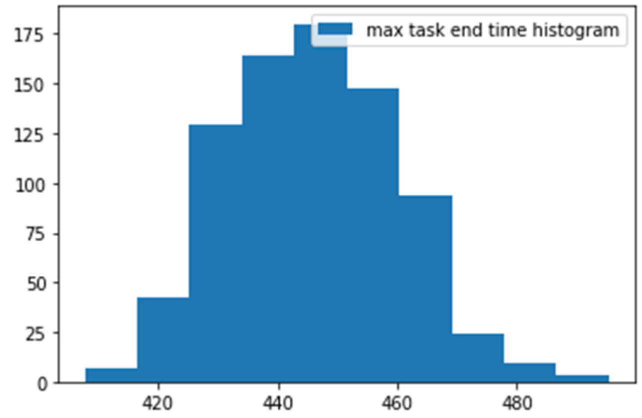
With the probability of **0.0097**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.0097<0.05

So, **4 vans** are **enough** with this battery size and charging policy

New Charging Policy, Varying Battery Sizes, 4 vans

battery_size = [35,35,35,35]
Charging Policy= New Charging Policy



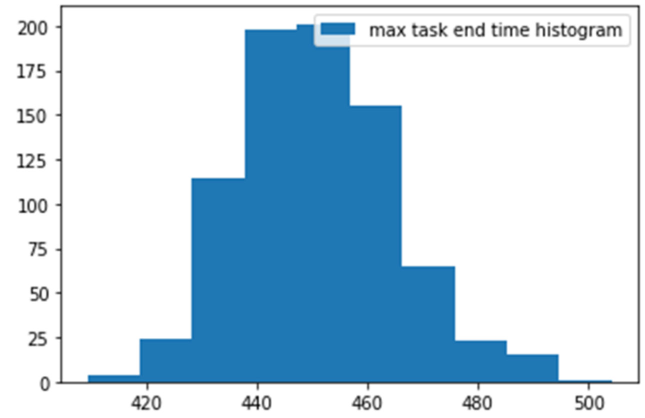

```
**Max Tour End Time Statistics***
Mean= 445.7425629972084
Sample variance= 201.31201885641377
Variance of the sample mean= 0.6713961580586564
P(max throughput time>480)= 0.007879276488607867
```

With the probability of **0.0078**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.0078<0.05

So, **4 vans** are **enough** with this battery size and charging policy

battery_size = [30,30,20,20]
Charging Policy= New Charging Policy



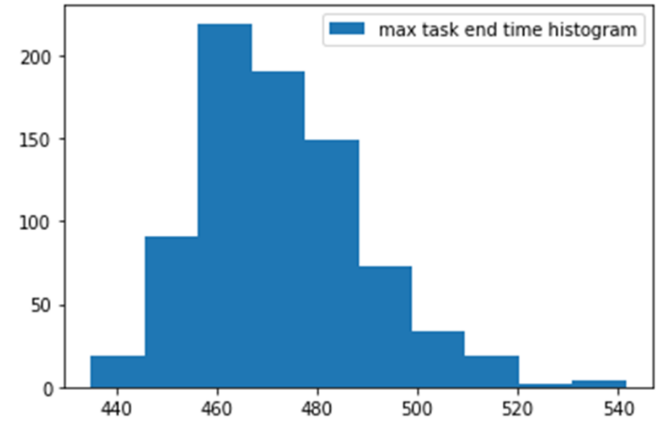

```
**Max Tour End Time Statistics***
Mean= 450.86853863534964
Sample variance= 198.2330184180292
Variance of the sample mean= 2.568199382607052
P(max throughput time>480)= 0.01926996246678714
```

With the probability of **0.019**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.019<0.05

So, **4 vans** are **enough** with this battery size and charging policy

battery_size = [25,25,20,20]
Charging Policy= New Charging Policy




```
**Max Tour End Time Statistics***
Mean= 473.1018084576387
Sample variance= 280.3734124873272
Variance of the sample mean= 1.8911310284248635
P(max throughput time>480)= 0.3401802736221284
```

With the probability of **0.34**, 4 vans cannot satisfy 8 hours constraint. Since, the company set the threshold for probability of maximum tour end time exceeding 8 hours as **0.05:**

0.34>0.05

So, **4 vans** are **NOT** enough with this battery size and charging policy

DECISION MAKING USING SIMULATION OUTPUT ANALYSIS: Solving the Business Case

Having analyzed 12 possible scenarios with changing battery sizes and charging policies, the summary table is constructed, which can be seen on the right.

It can be summarized that:

- New charging policy leads to significant improvements in the last mile delivery performance. In fact, if you compare the **scenario 5** and **scenario 11,** the battery size of [30,30,20,20] can satisfy the 8 hours tour end time constraint for all 4 vans **only** when **the new charging policy** is used ,with the confidence of 98% (1-0.0193). Moreover, the New Charging Policy also dominates the Base Case Charging Policy in terms of the mean of the maximum tour end times of 4 vans, and also the probability of exceeding 8 hours tour end time.

- Due to the success of the new charging policy, vans with smaller batteries can be used, which will lead to significant cost savings for the company.

Scenarios	Battery Size	Charging Policy	Mean of Max Tour End Times (Minutes)	P(Max Tour End Time >480)	4 Vans are enough?	Daily Cost of 4 Vans
1	[20,20,20,20]	Base Case Policy	594.8	0.9966	No	420 €
2	[25,25,25,25]	Base Case Policy	505.7	0.8109	No	480 €
3	[30,30,30,30]	Base Case Policy	446	0.007	Yes	540 €
4	[35,35,35,35]	Base Case Policy	444.8	0.0058	Yes	600 €
5	[30,30,20,20]	Base Case Policy	476.3	0.4515	No	480 €
6	[25,25,20,20]	Base Case Policy	511.3	0.8559	No	450 €
7	[20,20,20,20]	New Policy	506.6	0.8986	No	420 €
8	[25,25,25,25]	New Policy	472.6	0.3199	No	480 €
9	[30,30,30,30]	New Policy	444.9	0.0098	Yes	540 €
10	[35,35,35,35]	New Policy	445.7	0.0079	Yes	600 €
11*	[30, 30,20,20]*	New Policy*	450.9	0.0193	Yes*	480* €
12	[25,25,20,20]	New Policy	473.1	0.34	No	450 €

Cost Savings

Battery Size= [35,35,35,35] (Previous Setting)
Charging Policy= Base Case Charging Policy
Daily Cost of 4 vans = 4 vans * 150€/(van*day)=600€/day

Battery Size= [30,30,20,20] (New Setting)
Charging Policy= New Charging Policy
Daily Cost of 4 vans = 2 vans * 135€/(van*day) + 2 vans * 105€/(van*day) = 480€/day

Saving= 600€/day – 480€/day = **120€/day**
Saving Ratio= 120/600= **20%**

Conclusion to the Case Study

Considering the simulation outputs and the preferences of the company:

- The charging policy will be changed to the New Charging Policy
- Battery sizes of the vans will be set to [30,30,20,20], meaning that Van_0 and Van_1 will have 30 kwh batteries, Van_2 and Van_3 will have 20 kwh batteries.
- In this setting, the company will have 120 €/day saving, which is a 20% saving compared to the inital system configuration

Further Considerations

We can see that, in the scenario 12, 4 vans can complete the tour in 8 hours with 66% confidence. The decision maker may consider the tradeoff between paying overtime to delayed vans and saving 30€/day. If overtime is an option for the company, this aspect is also worth considering.

CONCLUSION

In the second assignment, we determined the most important system performance to measure which is the minimum number of vans to serve all customers under 8 hours. As the **proxy** of the minimum number of vans necessary, we chose the **maximum of tour end times,** which is used to identify if the given number of vans are enough to satisfy 8 hours maximum tour end time constraint with a confidence level. Depending on the preference of the decision maker on the probability of going overtime, the number of vans can vary (e.g. In the business case we introduced it was 95%).

We determined the two most important factors which are **charging policy** and **battery sizes** of vans that have significant effects on the chosen system performance measure. For 12 different configurations of the system considering the two factors, we determined the number of runs required to have a more reliable result and we selected the highest number of runs (800 runs) needed among these 12 different configurations. We conducted **single factor experiments** to prove the impacts of the chosen factors on the system performance measure are significant. We fixed one of the chosen factors while changing the level of the other factor. For each experiment, we conducted one-way ANOVA test and proved that the change in charging policy and battery size significantly affect maximum tour end time.

Finally, we formulated a hypothetical business case in which the decision-maker is trying to find the optimal number of vans to use depending on different system configurations considering charging policy and battery size. In the business case, the decisionmaker can observe the benefit of using the new charging policy over the base case policy. Considering tradeoff between vans with smaller battery sizes which are cheaper and having smaller max tour end times by using the vans with bigger battery sizes. The decisionmaker can save costs by choosing the right combination of battery sizes and charging policies while the van fleet still can serve all the customers in 8 hours with a little risk of overtime (under 5%).