Notebook to analyze the differences between internal sensors

In [2]:
```
# Python standard library imports
import time

# Third-party imports for database connection and data manipulation
from sqlalchemy import create_engine
import pandas as pd
import matplotlib.pyplot as plt
import seaborn as sns
import matplotlib.pyplot as plt
from scipy.stats import pearsonr
# Third-party imports for mapping
import folium
```

In [3]:
```
# Database connection parameters
dbname = 'ar41'
user = 'postgres'
password = '1234'
host = 'localhost'  # localhost or the server address
port = '5432'  # default PostgreSQL port is 5432

# Establish a connection to the database
connection_str = f"postgresql://{user}:{password}@{host}:{port}/{dbname}"
engine = create_engine(connection_str)
```

1. Analysis of InAirPC1 and InAirPC2

First of all, we begin by taking a look at the data, considering some constraints:

- We do not consider NULL values (for any of the 2 sensors)
- We do not consider temperatures above 65 (above acceptable boundaries)

What should we consider as an outlier in terms of absolute difference between two sensors? Let's make buckets to analyze it:

In [4]:
```
query_buckets_inair = f"""
WITH TemperatureDifferences AS (
    SELECT
        mapped_veh_id,
        "timestamps_UTC",
        "RS_E_InAirTemp_PC2",
        "RS_E_InAirTemp_PC1",
        ABS("RS_E_InAirTemp_PC2" - "RS_E_InAirTemp_PC1") AS temp_difference
    FROM
        vehicle_data_enriched
    WHERE
        "RS_E_InAirTemp_PC1" IS NOT NULL
        AND "RS_E_InAirTemp_PC1" < 70
        AND "RS_E_InAirTemp_PC2" IS NOT NULL
        AND "RS_E_InAirTemp_PC2" < 70
)
SELECT
    bucket_range,
    COUNT(*) AS occurrences
FROM (
    SELECT
        mapped_veh_id,
```

```
        "timestamps_UTC",
        "RS_E_InAirTemp_PC2",
        "RS_E_InAirTemp_PC1",
        temp_difference,
        floor(temp_difference / 5) * 5 AS bucket_range
    FROM
        TemperatureDifferences
) AS temp_diff_buckets
GROUP BY
    bucket_range
ORDER BY
    bucket_range;
"""

df_buckets_inair = pd.read_sql_query(query_buckets_inair, engine)
print(df_buckets_inair)
```

```
    bucket_range  occurrences
0            0.0     10029485
1            5.0      4960690
2           10.0      1630787
3           15.0       527820
4           20.0       208527
5           25.0       108456
6           30.0        67708
7           35.0        47680
8           40.0        30080
9           45.0        13325
10          50.0         6785
11          55.0         3071
12          60.0         1562
13          65.0          962
```

Following this distribution of data, we choose 40 as the threshold to define an abnormal difference between sensors.

Now let's look at the data, considering what we've discussed before:

In [5]:
```
query_difference_inair = f"""
SELECT mapped_veh_id, "timestamps_UTC", "RS_E_InAirTemp_PC1", "RS_E_InAirTer
FROM vehicle_data_enriched
WHERE "RS_E_InAirTemp_PC1" IS NOT NULL AND "RS_E_InAirTemp_PC2" IS NOT NULL
AND ABS("RS_E_InAirTemp_PC1"-"RS_E_InAirTemp_PC2") >= 40
ORDER BY ABS("RS_E_InAirTemp_PC1"-"RS_E_InAirTemp_PC2") DESC;
"""

df_difference_inair = pd.read_sql_query(query_difference_inair, engine)
print(df_difference_inair)
```

```
       mapped_veh_id       timestamps_UTC  RS_E_InAirTemp_PC1  \
0              172.0  2023-02-22 23:01:19                 0.0
1              168.0  2023-07-28 20:09:00                 0.0
2              145.0  2023-06-19 19:01:42                65.0
3              136.0  2023-06-05 20:32:03                 0.0
4              117.0  2023-06-15 09:54:35                 0.0
...              ...                  ...                 ...
51621          194.0  2023-04-17 20:35:50                 0.0
51622          145.0  2023-04-20 07:59:06                22.0
51623          168.0  2023-02-18 13:39:52                17.0
51624          150.0  2023-02-24 12:09:41                25.0
51625          154.0  2023-02-15 17:23:55                 0.0

       RS_E_InAirTemp_PC2   abs
0                    65.0  65.0
1                    65.0  65.0
2                     0.0  65.0
3                    65.0  65.0
4                    65.0  65.0
...                   ...   ...
51621                40.0  40.0
51622                62.0  40.0
51623                57.0  40.0
51624                65.0  40.0
51625                40.0  40.0

[51626 rows x 5 columns]
```

With this data we can observe that there are many timestamps that have one working sensor and the other one on 0, which just means that one sensor is off, and it shouldn't be considered an outlier in terms of difference between PC1 and PC2

With that in mind, we create a new query:

In [6]:
```
query_difference_inair2 = f"""
SELECT mapped_veh_id, "timestamps_UTC", "RS_E_InAirTemp_PC1", "RS_E_InAirTer
FROM vehicle_data_enriched
WHERE "RS_E_InAirTemp_PC1" IS NOT NULL AND "RS_E_InAirTemp_PC2" IS NOT NULL
AND ABS("RS_E_InAirTemp_PC1"-"RS_E_InAirTemp_PC2") >= 40
ORDER BY ABS("RS_E_InAirTemp_PC1"-"RS_E_InAirTemp_PC2") DESC;
"""

df_difference_inair2 = pd.read_sql_query(query_difference_inair2, engine)
print(df_difference_inair2)
```

```
       mapped_veh_id       timestamps_UTC  RS_E_InAirTemp_PC1  \
0              159.0  2023-02-13 22:56:38                65.0
1              162.0  2023-03-08 20:12:26                 6.0
2              159.0  2023-02-13 22:55:37                65.0
3              162.0  2023-03-08 20:11:26                 7.0
4              161.0  2023-01-27 09:29:01                 7.0
...              ...                  ...                 ...
19781          142.0  2023-02-23 12:04:06                55.0
19782          116.0  2023-02-03 12:31:31                52.0
19783          196.0  2023-03-05 17:44:19                11.0
19784          192.0  2023-03-11 04:07:21                 7.0
19785          170.0  2023-03-14 05:35:51                15.0

       RS_E_InAirTemp_PC2   abs
0                     6.0  59.0
1                    65.0  59.0
2                     7.0  58.0
3                    65.0  58.0
4                    65.0  58.0
...                   ...   ...
19781                15.0  40.0
19782                12.0  40.0
19783                51.0  40.0
19784                47.0  40.0
19785                55.0  40.0

[19786 rows x 5 columns]
```

Now we have around 20,000 values that could be considered outliers. Now let's take a look at the trains that normally have this case happening:

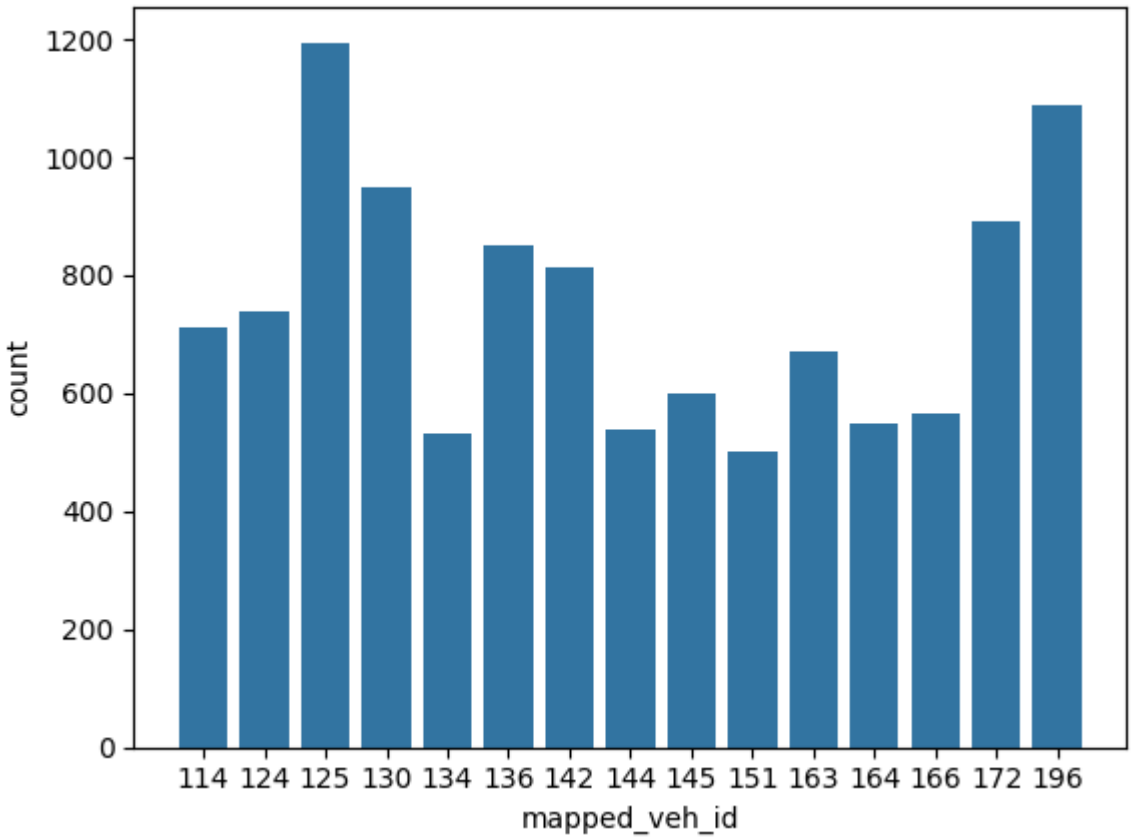
In [7]:
```
query_difference_inair3 = f"""
WITH absdiffinair AS (
    SELECT mapped_veh_id, "timestamps_UTC", "RS_E_InAirTemp_PC1", "RS_E_InAi
    FROM vehicle_data_enriched
    WHERE "RS_E_InAirTemp_PC1" IS NOT NULL AND "RS_E_InAirTemp_PC2" IS NOT N
    AND ABS("RS_E_InAirTemp_PC1"-"RS_E_InAirTemp_PC2") >= 40
    ORDER BY ABS("RS_E_InAirTemp_PC1"-"RS_E_InAirTemp_PC2") DESC
)
SELECT mapped_veh_id, count(*)
FROM absdiffinair
GROUP BY mapped_veh_id
ORDER BY count(*) DESC;
"""

df_difference_inair3 = pd.read_sql_query(query_difference_inair3, engine)

#Keep only trains with more than 500 cases
df_difference_inair3 = df_difference_inair3[df_difference_inair3['count']>50
df_difference_inair3['mapped_veh_id'] = df_difference_inair3['mapped_veh_id

sns.barplot(x='mapped_veh_id', y='count', data=df_difference_inair3)
plt.plot()
```

Out[7]:
```
[]
```



Now the question is: are this ocurrences happening at different times of the year, or during an extended continous period?

If the sensors eventually return to have normal differences, should we care about these differences? Probably not

So let's make a query to understand differences that persist over a long period of time:

- This query looks for continous differences of more than 40°C in the same train, and makes groups
- We can see the starting and ending timestamps, the count of timestamps considered and the duration in minutes

In [14]:
```
query_difference_inair4 = f"""
WITH selected_data AS (
    SELECT
        mapped_veh_id,
        "timestamps_UTC"::TIMESTAMP,
        "RS_E_InAirTemp_PC1",
        "RS_E_InAirTemp_PC2",
        ABS("RS_E_InAirTemp_PC1" - "RS_E_InAirTemp_PC2") AS temp_difference,
        LAG("timestamps_UTC"::TIMESTAMP) OVER (PARTITION BY mapped_veh_id OR
    FROM
        vehicle_data_enriched
    WHERE
        "RS_E_InAirTemp_PC1" IS NOT NULL
        AND "RS_E_InAirTemp_PC2" IS NOT NULL
        AND "RS_E_InAirTemp_PC1" <= 65
        AND "RS_E_InAirTemp_PC2" <= 65
        AND ("RS_E_InAirTemp_PC1" != 0 AND "RS_E_InAirTemp_PC2" != 0)
        AND ABS("RS_E_InAirTemp_PC1" - "RS_E_InAirTemp_PC2") >= 40
)
, grouped_data AS (
```

```
    SELECT
        mapped_veh_id,
        "timestamps_UTC",
        temp_difference,
        SUM(CASE WHEN "timestamps_UTC" - prev_timestamp > INTERVAL '10' MINU
    FROM
        selected_data
)
SELECT
    mapped_veh_id,
    new_group AS group,
    COUNT(*) AS count,
    MIN("timestamps_UTC") AS starting_timestamp,
    MAX("timestamps_UTC") AS ending_timestamp,
    EXTRACT(EPOCH FROM (MAX("timestamps_UTC") - MIN("timestamps_UTC"))) / 60
FROM
    grouped_data
GROUP BY
    mapped_veh_id,
    new_group
HAVING
    COUNT(*) > 1
ORDER BY
    duration_minutes DESC;
"""

df_difference_inair4 = pd.read_sql_query(query_difference_inair4, engine)
print(df_difference_inair4)
df_difference_inair4.to_csv('InAirSensorDiff.csv', sep=',', index=False, enc
```

```
     mapped_veh_id  group  count  starting_timestamp    ending_timestamp  \
0            125.0      1    592 2023-01-23 08:29:46 2023-01-23 13:40:45
1            196.0      1    404 2023-03-05 17:37:09 2023-03-05 21:00:04
2            136.0     11    287 2023-02-21 21:22:20 2023-02-21 23:51:28
3            168.0     10    283 2023-03-31 10:03:11 2023-03-31 12:31:18
4            163.0      8    256 2023-02-20 21:28:55 2023-02-20 23:49:24
..             ...    ...    ...                 ...                 ...
868          173.0      3      2 2023-02-09 04:04:31 2023-02-09 04:04:32
869          128.0      6      2 2023-04-28 20:34:14 2023-04-28 20:34:15
870          142.0     46      2 2023-05-19 13:23:23 2023-05-19 13:23:24
871          142.0     42      2 2023-04-18 19:28:07 2023-04-18 19:28:08
872          181.0      3      2 2023-02-07 07:09:48 2023-02-07 07:09:49

     duration_minutes
0          310.983333
1          202.916667
2          149.133333
3          148.116667
4          140.483333
..                ...
868          0.016667
869          0.016667
870          0.016667
871          0.016667
872          0.016667

[873 rows x 6 columns]
```

There are many groups of consecutive temperature differences that go on for more than 2 hours, which is something strange considering that we are excluding the records when either one of the sensors is off.

The average duration of this absolute difference is of 13 minutes.

Now let's make a query so we can see the original records belonging to a group that has temperature differences for more than the average duration (13 minutes):

In [12]:
```
query_difference_inair5 = f"""
WITH selected_data AS (
    SELECT
        mapped_veh_id,
        "timestamps_UTC"::TIMESTAMP,
        "RS_E_InAirTemp_PC1",
        "RS_E_InAirTemp_PC2",
        ABS("RS_E_InAirTemp_PC1" - "RS_E_InAirTemp_PC2") AS temp_difference,
        LAG("timestamps_UTC"::TIMESTAMP) OVER (PARTITION BY mapped_veh_id OR
        lat,
        lon,
        "RS_E_OilPress_PC1",
        "RS_E_OilPress_PC2",
        rs_e_rpm_pc1,
        rs_e_rpm_pc2,
        "RS_E_WatTemp_PC1",
        "RS_E_WatTemp_PC2",
        "RS_T_OilTemp_PC1",
        "RS_T_OilTemp_PC2",
        timestamps_floor,
        nearest_point_id,
        "Lat",
        "Lon",
        "Time",
        "Temperature",
        "Humidity",
        "Rain"
    FROM
        vehicle_data_enriched
    WHERE
        "RS_E_InAirTemp_PC1" IS NOT NULL
        AND "RS_E_InAirTemp_PC2" IS NOT NULL
        AND "RS_E_InAirTemp_PC1" <= 65
        AND "RS_E_InAirTemp_PC2" <= 65
        AND ("RS_E_InAirTemp_PC1" != 0 AND "RS_E_InAirTemp_PC2" != 0)
        AND ABS("RS_E_InAirTemp_PC1" - "RS_E_InAirTemp_PC2") >= 40
),
grouped_data AS (
    SELECT
        mapped_veh_id,
        "timestamps_UTC",
        temp_difference,
        SUM(CASE WHEN "timestamps_UTC" - prev_timestamp > INTERVAL '10' MINU
    FROM
        selected_data
)
, group_durations AS (
    SELECT
        mapped_veh_id,
        new_group AS group,
        MIN("timestamps_UTC") AS starting_timestamp,
        MAX("timestamps_UTC") AS ending_timestamp,
        EXTRACT(EPOCH FROM (MAX("timestamps_UTC") - MIN("timestamps_UTC")))
    FROM
        grouped_data
    GROUP BY
        mapped_veh_id, new_group
    HAVING
        COUNT(*) > 1
)
```

```
, average_duration AS (
    SELECT
        AVG(duration_minutes) AS avg_duration
    FROM
        group_durations
)
SELECT
    sd.mapped_veh_id,
    sd."timestamps_UTC" AS timestamp,
    sd."RS_E_InAirTemp_PC1",
    sd."RS_E_InAirTemp_PC2",
    sd.temp_difference,
    sd.lat,
    sd.lon,
    sd."RS_E_OilPress_PC1",
    sd."RS_E_OilPress_PC2",
    sd.rs_e_rpm_pc1,
    sd.rs_e_rpm_pc2,
    sd."RS_E_WatTemp_PC1",
    sd."RS_E_WatTemp_PC2",
    sd."RS_T_OilTemp_PC1",
    sd."RS_T_OilTemp_PC2",
    sd.timestamps_floor,
    sd.nearest_point_id,
    sd."Lat",
    sd."Lon",
    sd."Time",
    sd."Temperature",
    sd."Humidity",
    sd."Rain"
FROM
    selected_data sd
JOIN
    grouped_data gd ON sd.mapped_veh_id = gd.mapped_veh_id AND sd."timestamp
JOIN
    group_durations gdd ON gd.mapped_veh_id = gdd.mapped_veh_id AND gd.new_g
JOIN
    average_duration ad ON 1=1
WHERE
    gdd.duration_minutes > ad.avg_duration
ORDER BY
    sd.mapped_veh_id,
    sd."timestamps_UTC";
"""

df_difference_inair5 = pd.read_sql_query(query_difference_inair5, engine)
df_difference_inair5['outlier_flag'] = 'Outside Temperature'
print(df_difference_inair5)
df_difference_inair5.to_csv('R10-1.csv', sep=',', index=False, encoding='ut
```

```
       mapped_veh_id           timestamp  RS_E_InAirTemp_PC1  \
0              102.0 2023-04-26 23:43:58                58.0
1              102.0 2023-04-26 23:44:08                58.0
2              102.0 2023-04-26 23:44:57                58.0
3              102.0 2023-04-26 23:45:08                58.0
4              102.0 2023-04-26 23:45:58                58.0
...              ...                 ...                 ...
14822          197.0 2023-04-03 07:10:52                64.0
14823          197.0 2023-04-03 07:11:50                64.0
14824          197.0 2023-04-03 07:11:51                64.0
14825          197.0 2023-04-03 07:12:50                64.0
14826          197.0 2023-04-03 07:12:52                64.0

       RS_E_InAirTemp_PC2  temp_difference        lat       lon  \
0                    17.0             41.0  51.016234  3.772886
1                    17.0             41.0  51.016019  3.773479
2                    15.0             43.0  51.016256  3.772875
3                    15.0             43.0  51.016017  3.773477
4                    13.0             45.0  51.016259  3.772912
...                   ...              ...        ...       ...
14822                24.0             40.0  50.403815  4.439004
14823                24.0             40.0  50.403722  4.439648
14824                24.0             40.0  50.403787  4.439017
14825                24.0             40.0  50.403726  4.439646
14826                24.0             40.0  50.403822  4.439007

       RS_E_OilPress_PC1  RS_E_OilPress_PC2  rs_e_rpm_pc1  ...  \
0                    3.0              282.0           0.0  ...
1                    3.0              286.0           0.0  ...
2                    3.0              279.0           0.0  ...
3                    3.0              276.0           0.0  ...
4                    3.0              279.0           0.0  ...
...                  ...                ...           ...  ...
14822                3.0              234.0           0.0  ...
14823                3.0              238.0           0.0  ...
14824                3.0              231.0           0.0  ...
14825                3.0              234.0           0.0  ...
14826                3.0              234.0           0.0  ...

       RS_T_OilTemp_PC2     timestamps_floor  nearest_point_id        Lat
\
0                  63.0  2023-04-26 23:00:00               208  51.016234
1                  63.0  2023-04-26 23:00:00               208  51.016019
2                  63.0  2023-04-26 23:00:00               208  51.016256
3                  63.0  2023-04-26 23:00:00               208  51.016017
4                  63.0  2023-04-26 23:00:00               208  51.016259
...                 ...                  ...               ...       ...
14822              83.0  2023-04-03 07:00:00               449  50.403815
14823              81.0  2023-04-03 07:00:00               449  50.403722
14824              82.0  2023-04-03 07:00:00               449  50.403787
14825              81.0  2023-04-03 07:00:00               449  50.403726
14826              81.0  2023-04-03 07:00:00               449  50.403822

           Lon                 Time  Temperature  Humidity  Rain  \
0      3.772886  2023-04-26 23:00:00          3.1      85.0   0.0
1      3.773479  2023-04-26 23:00:00          3.1      85.0   0.0
2      3.772875  2023-04-26 23:00:00          3.1      85.0   0.0
3      3.773477  2023-04-26 23:00:00          3.1      85.0   0.0
4      3.772912  2023-04-26 23:00:00          3.1      85.0   0.0
...         ...                  ...          ...       ...   ...
14822  4.439004  2023-04-03 07:00:00          1.5      85.0   0.0
14823  4.439648  2023-04-03 07:00:00          1.5      85.0   0.0
14824  4.439017  2023-04-03 07:00:00          1.5      85.0   0.0
14825  4.439646  2023-04-03 07:00:00          1.5      85.0   0.0
```

```
14826  4.439007  2023-04-03 07:00:00          1.5      85.0   0.0

              outlier_flag
0      Outside Temperature
1      Outside Temperature
2      Outside Temperature
3      Outside Temperature
4      Outside Temperature
...                    ...
14822  Outside Temperature
14823  Outside Temperature
14824  Outside Temperature
14825  Outside Temperature
14826  Outside Temperature

[14827 rows x 24 columns]
```

And with that, we can conclude the analysis. There are ~15000 values that have a strange continous difference between their internal air temperature sensors.