Identification of critical steps in semiconductor manufacturing process for yield management

The methodology and data analysis

Project Report

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(Duration: June 2020)

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Acknowledgement

I would like to express my deepest appreciation to all those who provided me the possibility to complete this project and report. A special gratitude I give to my mentor, **Mr. Vikas Kumar**, whose contribution in stimulating suggestions and encouragement, helped me to coordinate my project especially in writing this report.

Furthermore, I would like to acknowledge with much appreciation the crucial role of **Mr. Ashwani K Tuknayat, Group Head PPG** at SCL who gave the permission to use all required data and the necessary materials to complete the project. I would also like to acknowledge with much appreciation, the role of the department concerned with data handling to provide me with the data at the required times, even during the hard times of the epidemic, helping me do a major part of the methodology (to be proposed in the following sections).

Also, I would like to present my gratitude to my institute **Indian Institute of Technology**, **Mandi**. I am thankful to the **faculty members** associated with the department of Computer Science who have always motivated me to stride forward and gain new skills.

Abstract

Increasing the yield efficiency is a requirement that is very difficult to pursue manually, as it requires manual effort and a considerable time window to see the results. Hence, we try to build a model (based on Deep Learning) that can carry out the process many times faster and without the involvement of any real time queries on the processes. All we require is the data collected, pertaining to parameters and objects, prior to carrying out the processes/unit steps. However, the proposed model can only be applied on a single process for its optimisation.

For the purpose of data storage, the tool SQL Management Server 2014 was used. The data analysis was carried out in a python environment with some of the very helpful python3 libraries to carry out data science algorithms in an elegant and efficient manner.

Contents

Description

Increasing the yield effeciency is a requirement that is very difficult to pursue manually, as it requires manual effort and considerable time window to see the results. Hence, we try to build a model (based on DeepLearning) that can carry out the process many times faster and without the involvemnet of any real time queries on the processes. All we require is the data collected,pertaining to parameters and objects , prior to carrying out the processes/unit steps. However, the proposed model can only be applied on a single process for its optimisation

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Methodology proposed

The following steps were proposed to carry out the research on the data

1. **Finding** out the process on which the optimisation has to be applied
2. **Fetching the data** from sql table into csv format, (as python is very comfortable with csvs')
3. **Analysing** the selected process to find:

    - the mean and the standard deviations for each parameter id
    - the expected distribution of the parameters for the process (assuming the process parameters to follow a gaussian distribution).
    - Graphing the results as histograms/line_curves to outline the presence of outliers
    - from the above insights, finding out outlier data pertaining to the measured values of the given data.
4. Removing the outliers. normalising the data and other **preprocessing** techniques to clean data. Finally, learning the effect of input parameters on the ouput.
5. From the weights and relation obtained varying the input parameters through a range of LSL to USL and **find its value for optimal output** (best yield)
6. **output the final values** that should be applied for the process.

The following points will cover the above mentioned methodology in a greater detail.

<u>Note: environment</u>

the code presumes you have python3 installed on your machine. The following python3 libraries are required to execute the cells.

- pandas
- numpy
- scipy
- matplotlib

you may simply run `pip install requirements.txt` to ensure the libraries are installed.

1. Process for carrying out research

The process chosen to carry out this research was "Product Flow 1.8V/3.3V w". As this process was quite useful and had the scope to be imporved our further analysis assumes all other data is only related to this process.

2. Fetching data from sql database

The following command on executing fetches the required data for further analysis. The output of the data is stored in `data/data.csv`

```sql
SELECT A.LotID,A.DeviceID,A.ProcessID , C.OperationID, C.ParameterId, C.M
easuredValue as MV, C.WaferNo, E.UpperHoldValue as USL, E.LowerHoldValue
as LSL, E.UpperControlLimit as UCL, E.LowerControlLimit as LCL
FROM
  LLotStart A
  inner join LOperationMeasuredValueRaw C on C.LotID = A.LotID
  inner join ParameterIdForRnQA1 B on B.ParameterId  = C.ParameterId
  inner join LOperationLimits E on E.OpParameterID = B.ParameterId and E.
OperationID = C.OperationID
  inner join LOperationParameterUnit F on F.OpParameterId = B.ParameterId
and F.OperationID = C.OperationID
WHERE A.LotID like 'F%' and ProcessID = 'Product Flow 1.8V/3.3V w'
order by C.ParameterId, LotID desc
```

In [ ]:

```python
#-----processing the spacing error in the fetched data------
#-----extracting data-------
file = open('data/data.csv','r')
data = file.read()
file.close()

#-------formatting data------------
data = data.split('\n')
for i in range(0,len(data)):
    data[i]=data[i].split(',')
    for j in range(len(data[i])):
        data[i][j]=data[i][j].strip()
data[0][0]='lotid'

#----writing to the final file for csv--------
file=open('data/processed_data.csv','w')
s=''
for i in range(0,len(data)-1):
    s+=data[i][0]
    for j in range(1,len(data[i])):
        s+=','+data[i][j]
    s+='\n'
file.write(s)
file.close()
```

3. Analysing

The above cell would result in `data/processed_data.csv` . As mentioned above we follow the steps indicated below to further analyse the so created data.

Finding mean,standard deviations for each parameter id

The following python snippet does the entire work of finding

Some essential points to note:

- Since the provided data does not contain the target value we assume target value to be around the mean for that will remain same throughout for a given parameter under the process.
- The mean calculated is only wrt to the given process so it includes all the sum of all the values of measured value for a given parameter and dividing by total occurances, but the scope of domain is only the process included, as the same parameter might have been used for other process too, but will not be considered in these means. The same goes for the calculated standard deviations.

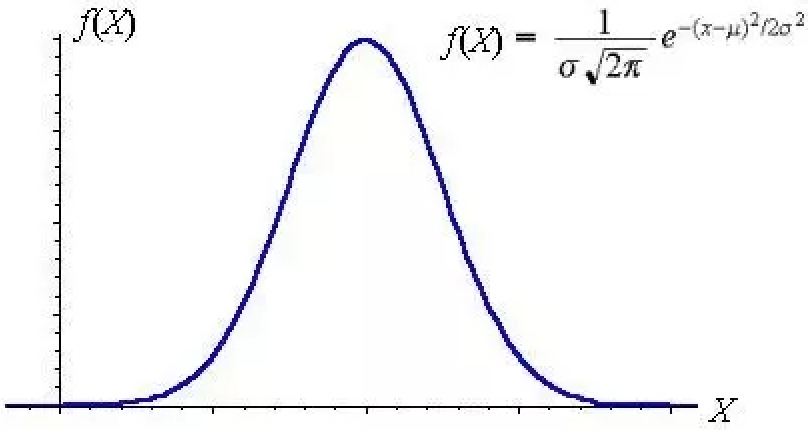
In [ ]:

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Wed Jun 17 21:06:59 2020

@author: dipanshu
"""
import pandas as pd
import numpy as np

data = pd.read_csv('data/processed_data.csv')

parameter_grouped_data = data.groupby('parameterid')
mv_stdev = parameter_grouped_data.mv.std()
mv_mean = parameter_grouped_data.mv.mean()

for i in range(len(data)):
    data.at[i,'mean']=mv_mean[data.loc[i]['parameterid']]
    data.at[i,'standard_dev']=mv_stdev[data.loc[i]['parameterid']]
    data.at[i,'target_value']=int(mv_mean[data.loc[i]['parameterid']])

data.to_csv('data/data_w_mean_std.csv', index=False)
```

Expected distribution of the parameters for the process

Some essential points to note:

- we have assumed the data to follow a gaussian distribution for each parameter. The gaussian distribution has a mean and a standard deviation as its parameters. (Also called bell shaped curve)
- The distribution has the following distribution, where mu=mean and sigma=standard_deviation



Graphing the results as histograms/line_curves to outline the presence of outliers

The following python snippet does the entire work of graphing the various plots

Some essential points to note:

- Some parameters have a very large value of USL inserted. These values are dummy values and hence do not occur in the provided artist for the graph. the graph covers a range on the x axis from (mean-10*stdev) to (mean+10*stdev)

In [ ]:

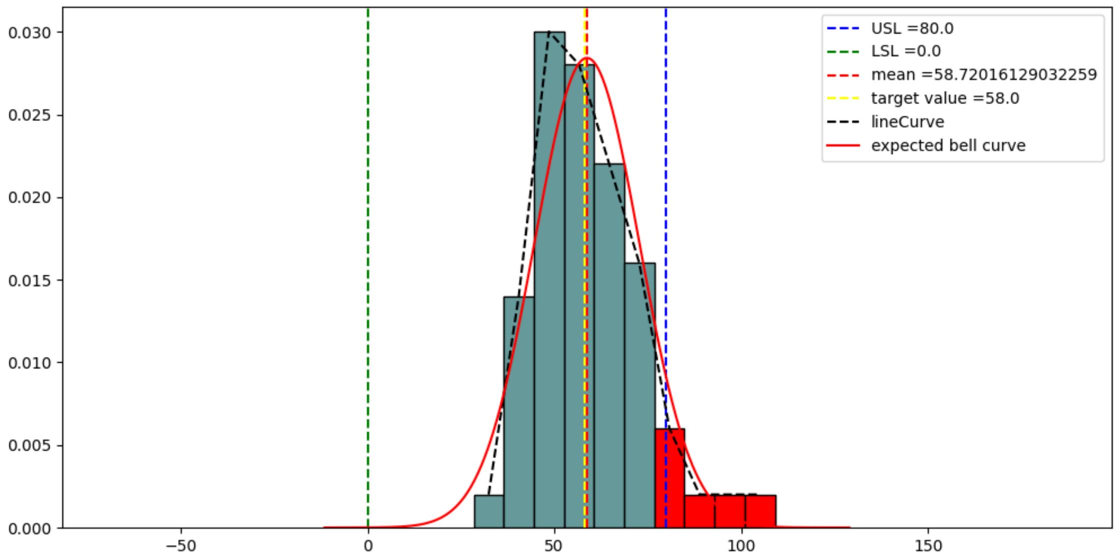
```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Sat Jun 20 11:35:16 2020

@author: dipanshu
"""

import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
import scipy.stats as st

data = pd.read_csv('data/data_w_mean_std.csv')

parameter_grouped_data = dict(list(data.groupby('parameterid')))
parameters = list(parameter_grouped_data.keys())
for index,parameter in enumerate(parameters):
    plt.figure(figsize=[12,6])

    mean=parameter_grouped_data[parameter]['mean'].mean()
    standard_dev=parameter_grouped_data[parameter].standard_dev.mean()
    target = parameter_grouped_data[parameter].target_value.mean()
    if(mean==target):
        target+=1

    if(standard_dev==0):
        print('data not enough... aborting for',parameter)
        continue

    usl = parameter_grouped_data[parameter].usl.mean()
    lsl = parameter_grouped_data[parameter].lsl.mean()

    plt.axvline(usl,linestyle='dashed',label='USL ='+str(usl),color='b')
    plt.axvline(lsl,linestyle='dashed',label='LSL ='+str(lsl),color='g')
    plt.axvline(mean,linestyle='dashed',label='mean ='+str(mean),color='red')
    plt.axvline(target,linestyle='dashed',label='target value ='+str(target),col
or='yellow')

    n,bins,patches = plt.hist(parameter_grouped_data[parameter].mv, align='mid',
\
                              color=(0.4, 0.6, 0.6, 1), edgecolor='black',densit
y=True)
    for i in range(len(bins)-1):
        bar_val = (bins[i]+bins[i+1])/2
        if(bar_val<lsl or bar_val>usl):
            patches[i].set_fc('r')

    bell_x = [(bins[i]+bins[i+1])/2 for i in range(len(bins)-1)]
    bell_y = n
    expected_x = np.linspace(mean-standard_dev*5,mean+standard_dev*5,1000)
    expected_y = st.norm(mean,standard_dev).pdf(expected_x)

    plt.plot(bell_x,bell_y,linestyle='dashed',color='black',label='lineCurve')
    plt.plot(expected_x,expected_y,color='red',label='expected bell curve')
    plt.xlim([mean-10*standard_dev,mean+10*standard_dev])

    plt.legend()
    plt.savefig('graphs/'+str(parameter)+'.png')
```

```
    plt.close()
    print('progress: ',round((index/len(parameters))*100,2),'graphed',parameter,
'...')

print('process has completed... thank you for your patience =)')
```

one of the graphs with correct data looks as follows

Key points to note

- where the x axis is the measured values while the y axis is the distribution (fraction of the occurence of that bin)
- the bars in green represent that these are acceptable values, while those in red represent non-acceptable values



Finding out outlier data pertaining to the measured values of the given data.

The following python snippet does the entire work of outputing the csv containing info related to those outliers

In [ ]:

```
#!/usr/bin/env python3
# -*- coding: utf-8 -*-
"""
Created on Sun Jun 21 12:32:11 2020

@author: dipanshu
"""

import pandas as pd
import matplotlib.pyplot as plt
import numpy as np
import scipy.stats as st

data = pd.read_csv('data/data_w_mean_std.csv')

parameter_grouped_data = dict(list(data.groupby('parameterid')))
parameters = list(parameter_grouped_data.keys())

outliers = pd.DataFrame(columns=data.columns)

for parameter in parameters:
    df = parameter_grouped_data[parameter]
    mean=parameter_grouped_data[parameter]['mean'].mean()
    standard_dev=parameter_grouped_data[parameter].standard_dev.mean()
    usl = parameter_grouped_data[parameter].usl.mean()
    lsl = parameter_grouped_data[parameter].lsl.mean()
    outlier_df = df.loc[(df.mv>usl) | (df.mv<lsl)]
    outliers=pd.concat([outliers,outlier_df],ignore_index=True)

outliers.to_csv('data/outlier_data.csv',index=False)
```

In [5]:

```
#-------displaying few above rows of the created dataset with outlier values----
-------
import pandas as pd
data = pd.read_csv('data/outlier_data.csv')
data.head(3)
```

Out[5]:

	lotid	deviceid	processid	operationid	parameter
0	F19320003.F1	SCL19MP0021_Process_R4	Product Flow 1.8V/3.3V w	MDF_YEDR1.033	CP_Pad_NIT_0.2_De
1	F18190003.F1	SCL18MP0015	Product Flow 1.8V/3.3V w	MWE_YEDR1.041	CP_Pad_Scan_0.
2	F18190003.F1	SCL18MP0015	Product Flow 1.8V/3.3V w	MWE_YEDR1.041	CP_Pad_Scan_0.

Future Goals

Due to a very small amount of "VALID" data for each parameter the future activites depend on the availablity of better amounts of data with correct information implanted. However the above piece of the report would go same once a cleaner version of data is available.

It would be essential to again list down the activities we seek for the future provided we get the valid forms of the required data

- Removing the outliers. normalising the data and other **preprocessing** techniques to clean data. Finally, learning the effect of input parameters on the ouput.
- From the weights and relation obtained varying the input parameters through a range of LSL to USL and **find its value for optimal output** (best yield)
- **output the final values** that should be applied for the process.

References

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