Reconciling Flow Measurement Errors of a Gas Compression Unit

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Contents

Objective

- Objective: To carry out the data reconciliation on a compressor system
- Reconciliation literally means a process through which people with different opinions agree in a friendly manner

Cartoon Courtesy: Pixabay.org

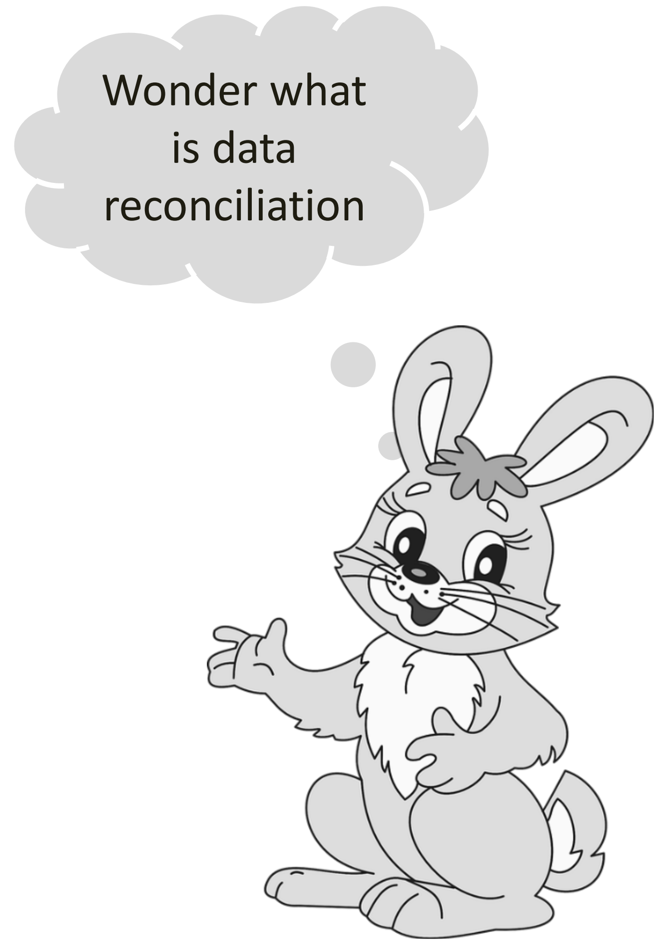
What is Data Reconciliation (DR)

Data reconciliation (DR) is a process of rectifying erroneous data

System Constraints are satisfied

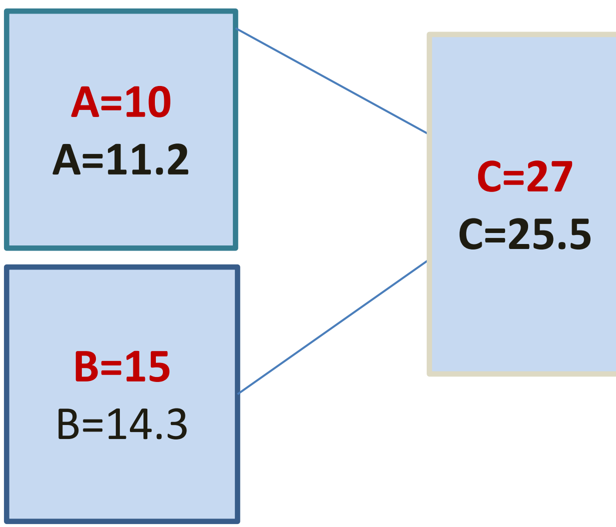
Uses mathematical modelling

Works best with Random Errors



Data Reconciliation

- Data Reconciliation is basically a constrained optimization problem
- The objective function is optimized (error minimized)
- The constraints are satisfied (A+B=C)



Red Colour- Measured Values
Brown Colour- Reconciled Values

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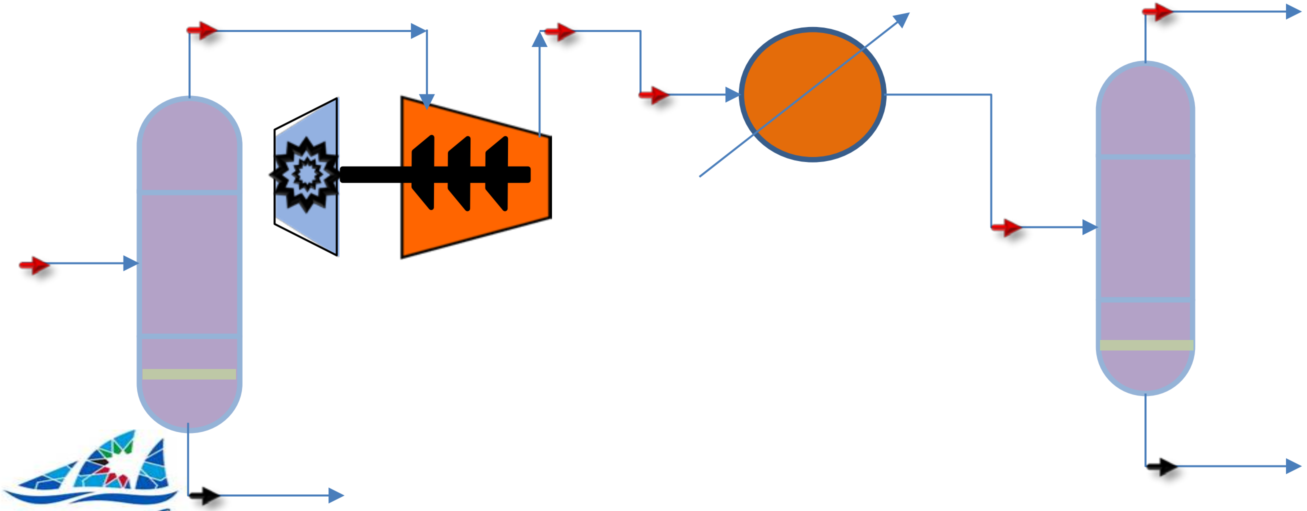
Need for Data Reconciliation

- Measured Data may contain errors
- Such data is often non repeatable
- Some data may be missing or has not been measured
- Data may not satisfy Process Constraints

Data Reconciliation (DR) for Compressor

- Differences between true and measured values need to be minimized
- Constraints of mass and energy balances need to be fulfilled



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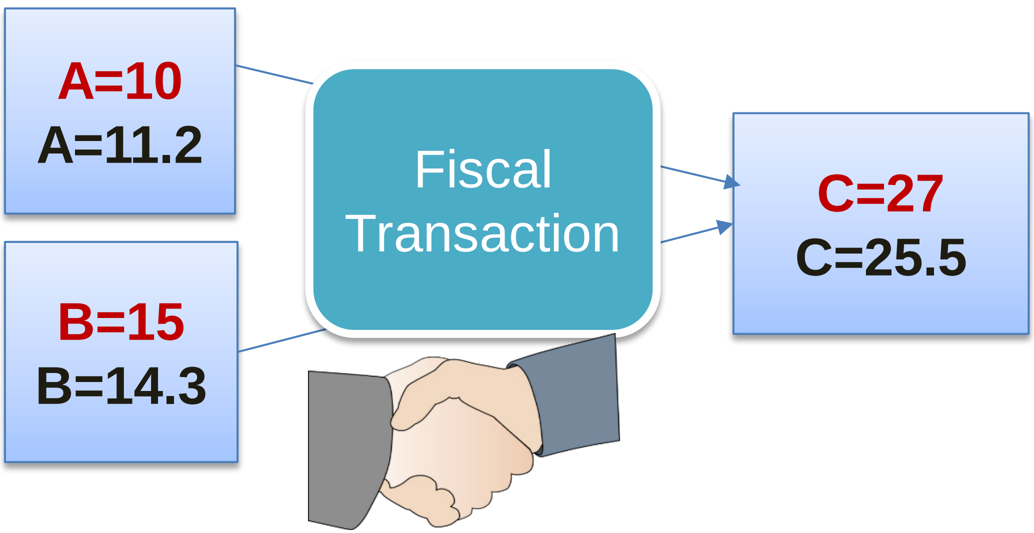
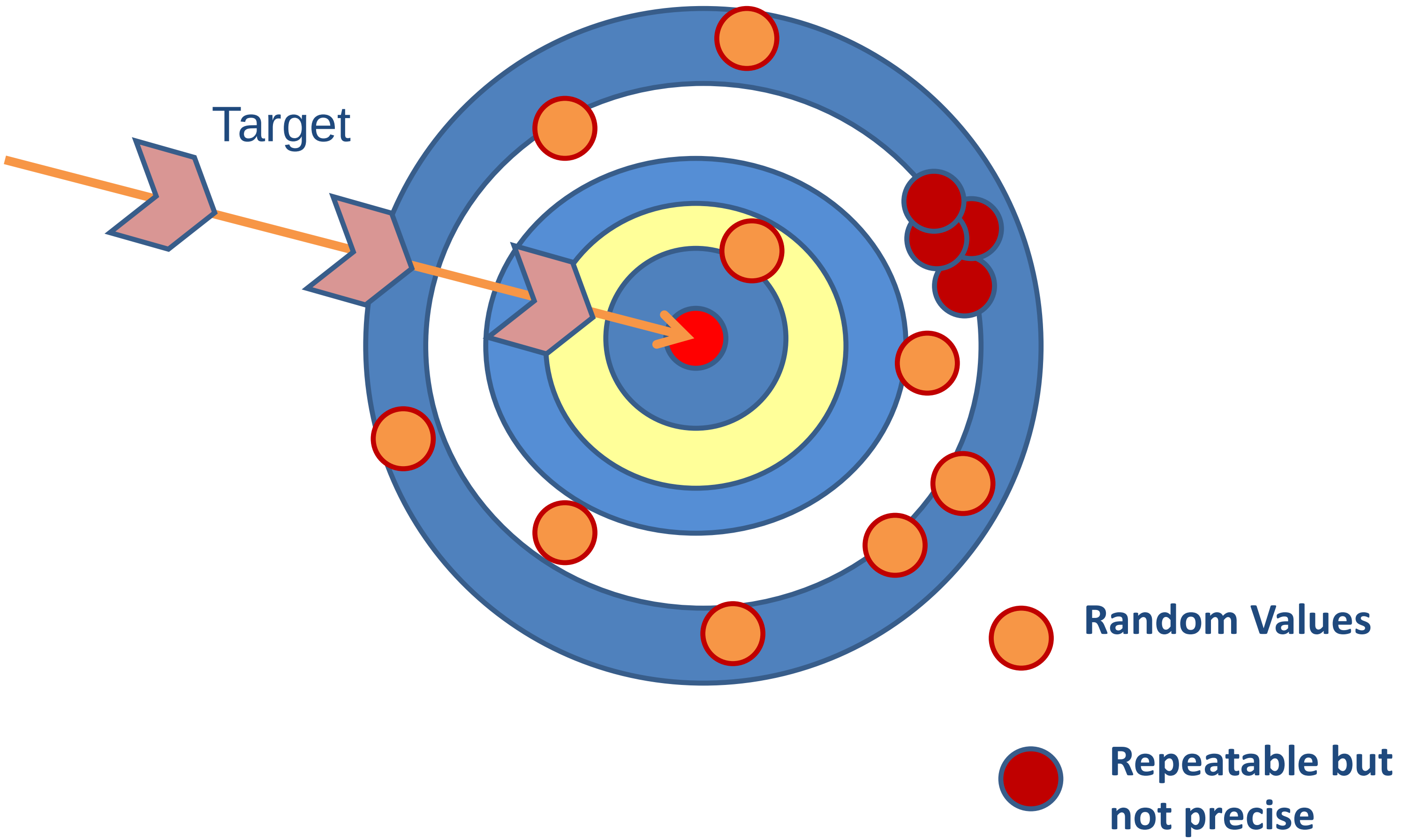
Custody Transfer

- Most critical requirement of Data Reconciliation is for custody transfer application
- It may benefit and mutually satisfy both parties involved as custody transfer often is linked to fiscal transactions



Repeatability & Accuracy



Errors in Measurement

- Gross Errors: Caused by errors in reading , remembering 87.46 as 78.46
- Measurement Errors
  - Random Instrument Errors
    Cause is not fully clear
  - Systematic Errors
    - Require Corr.Factor
    - Env. Factors Temp, Humidity
    - Parallax errors

Random Errors

- Random errors are the Instrument indicated error as no Instrument is perfect
- Expected to be scattered in a Normal or Gaussian Distribution
- DR is best applicable to random errors

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Instrument Accuracy

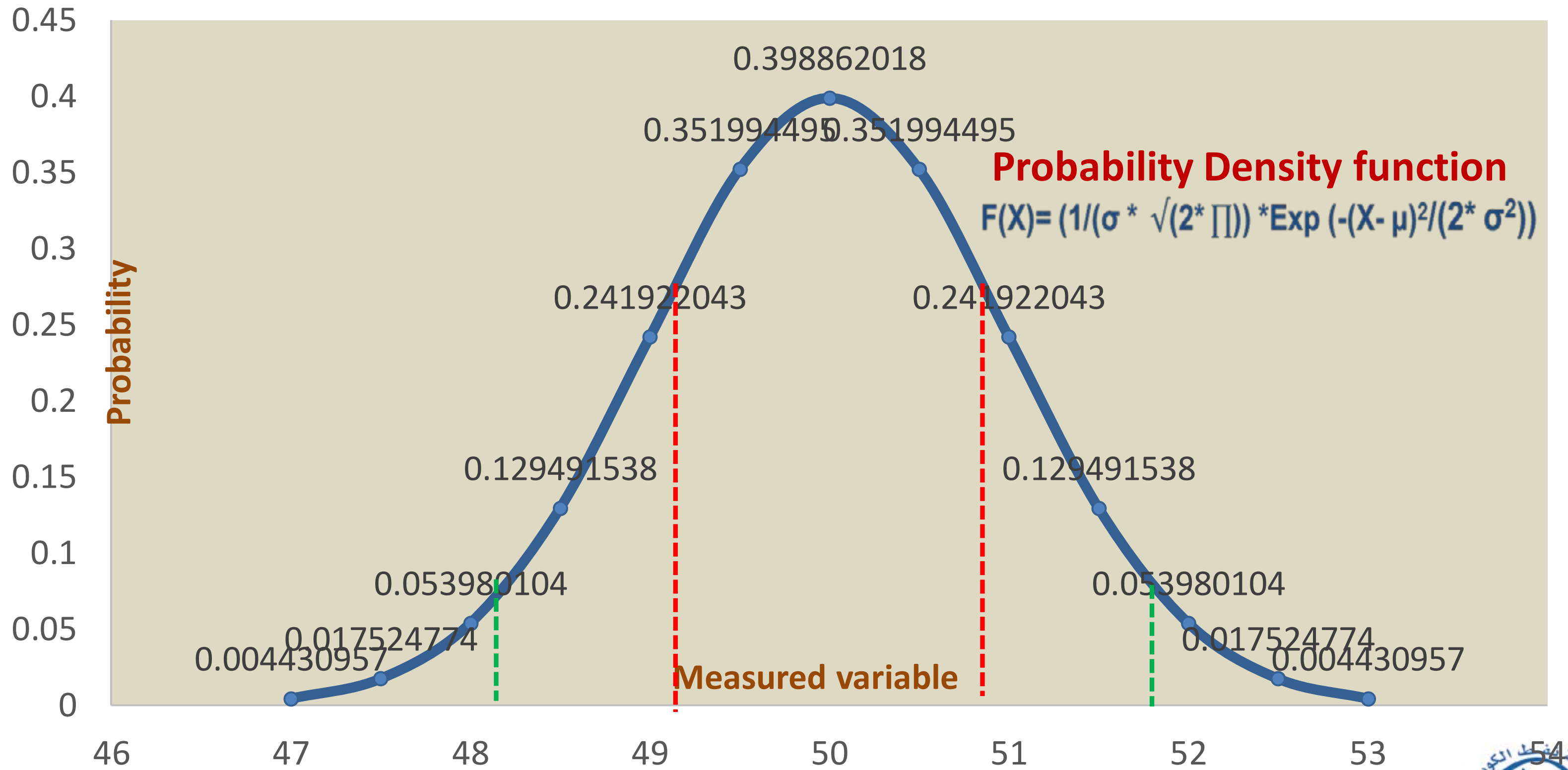
Accuracy of a meter is often defined to be +/- 1-3% (avg +-2%) as a percentage of full scale reading with a confidence level of 95%

If the full scale reading which the Instrument can read is 1500 kg, and its error is +/-1%, then it can be said with a 95% confidence that the true value shall lie within +/- 15 kgs of the measured value

The accuracy may sometimes also be specified in terms of the actual reading.

Probability Density Function-Bell Curve

- Horizontal axis is the range of possible numeric outcomes
- Vertical axis is the probability of outcome



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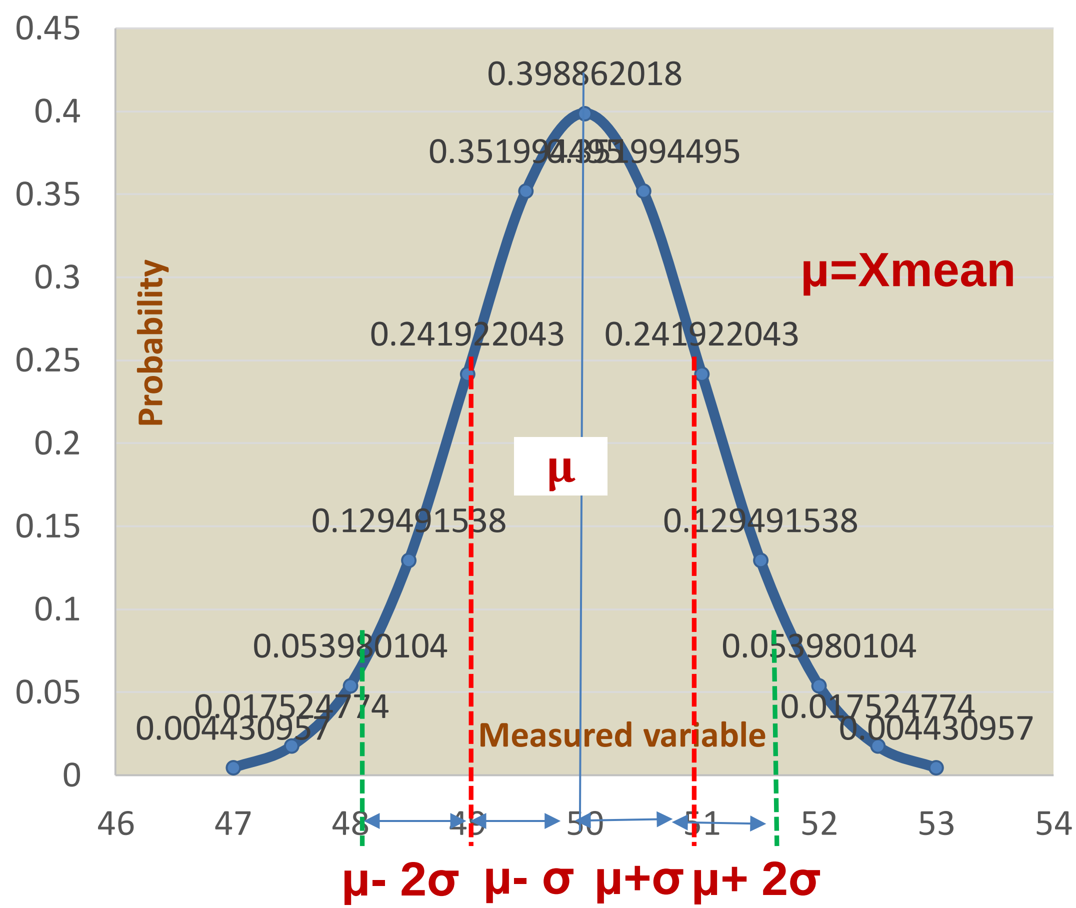
Probability Density Function & Confidence Levels

$$F(X) = \left(1/\left(\sigma * \sqrt{2*\prod}\right)\right) * Exp\left(-(X-\mu)^2/(2*\sigma^2)\right)$$

- 95% Confidence Level: 95% probability for which P(X1<X<X2) =0.95
  X= measured value

In gaussian distribution curve

- X1= μ -1.96σ (~2σ)
- X2= μ +1.96σ(~2σ)



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Standard Deviation

The Weight of a block is measured as follows:	
S.No	**Weight, in gms, Xi**
1	50.8
2	51.4
3	49.6
4	48.7
5	50.2
6	49.4
7	49.9
Sum= $\sum Xi$ =	**350**
Mean =μ= $\sum Xi /n$ =	**50**
Std. Dev=σ= $\sqrt{\sum(Xi-\mu)^2 /(n-1)}$	**0.9000**

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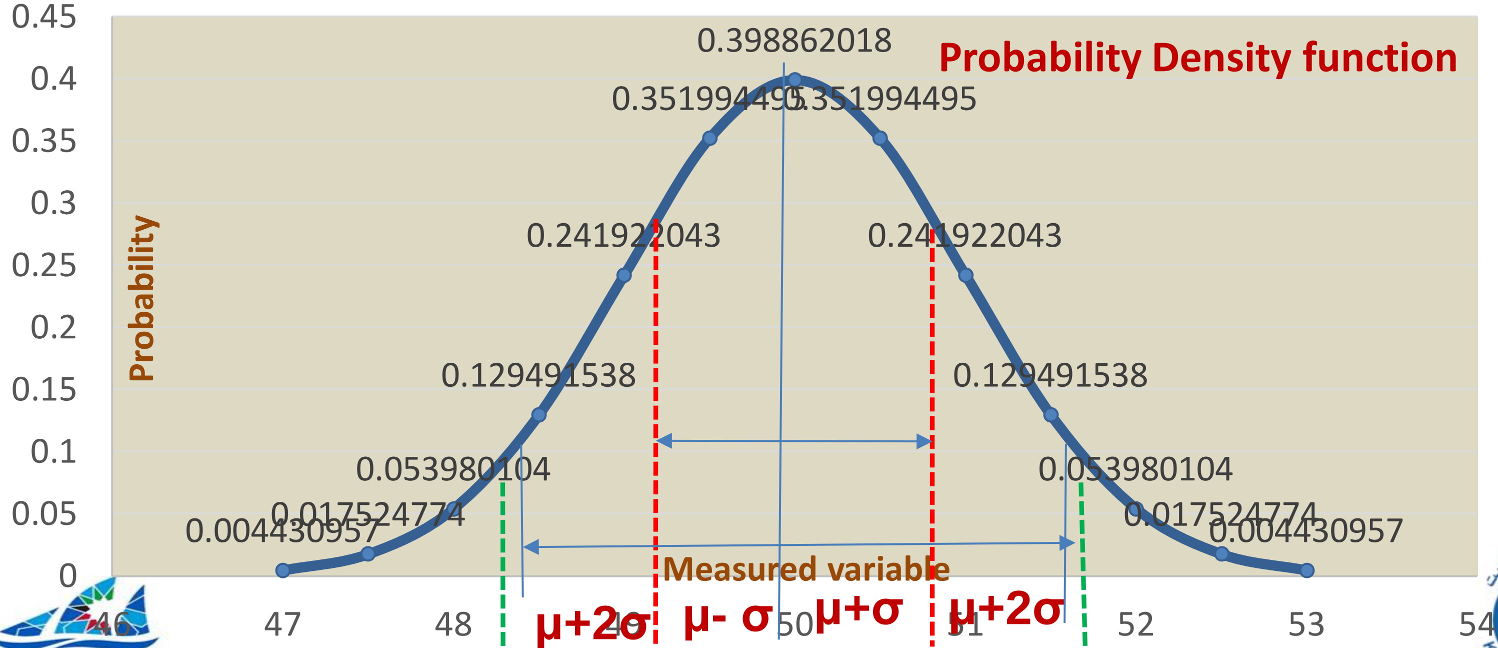
The Probability Function Values

$$F(X)= (1/(\sigma * \sqrt{(2*\prod)}) *Exp (-(X- \mu)^2/(2* \sigma^2))$$

X	μ	σ	F(X)
48	50	0.9	**0.05398**
48.5	50	0.9	**0.129492**
49	50	0.9	**0.241922**
49.5	50	0.9	**0.351994**
50	50	0.9	**0.398862**
50.5	50	0.9	**0.351994**
51	50	0.9	**0.241922**
51.5	50	0.9	**0.129492**
52	50	0.9	**0.05398**

Probability of measured variables

- Our interest: Probability of finding measured variables in a range (between an X1 & X2)
- $P(X_1 < X < X_2) = (1/(\sigma^* \sqrt{(2^*\pi)})) ^* \int_{x1}^{x2} \text{Exp}(-(X-\mu)^2/(2^* \sigma^2))$



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Probability-Measured values

- If Mean of X measured values =μ=50, σ =0.9

- The probability that a measured value will fall between +/-1σ of the mean i.e between 49.1 & 50.9

$$(1/(\sigma^* \sqrt{(2^*\prod)}) * \int_{49.1}^{50.9} \text{Exp}\,(-(X-\mu)^2/(2^* \sigma^2)) = 0.6827=68.27\%$$

- Likewise, Probability that the measured value will fall between +/- 2σ i..e. between 48.2 and 51.8= **95.45%**
- Likewise, Probability that the measured value will fall between +/- 3σ i..e. between 47.3 and 52.7= **99.7%**

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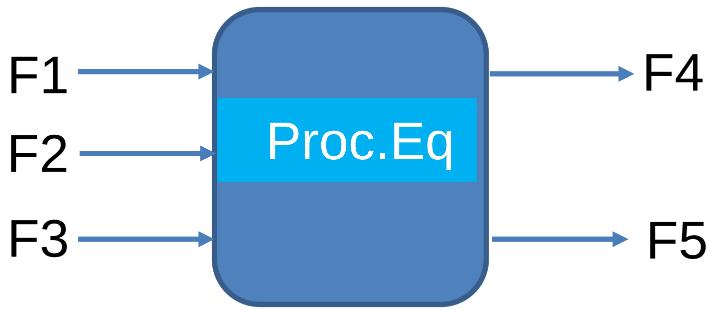
Data Reconciliation – Basic Concept

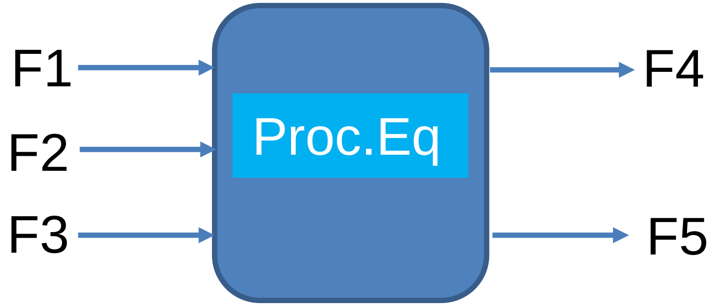


Reconc. Total=593.46

Stream	Std Dev	Measured Flow, kg/Hr	Reconc . Flow
F1	5	100	98.69
F2	8	150	146.65
F3	6	350	348.12
F4	9	291	295.23
F5	10	293	298.23
Obj Fn	**0.83660**	**Epsilon**	**3.6E-11**

- **Let reconciled flow rates =F1*, F2*,F3*, F4*& F5***
- **Minimize (((100-F1*)/5)^2)+ (((150-F2*)/8)^2)+ (((350-F3*)/6)^2) + (((291-F4*)/9)^2)+ (((293-F5*)/10)^2)**
- **Subject to the constraints: ((F1*+F2*+F3*-F4*-F5*)^2)< (1*e-06)**

Data Reconciliation –Effect of Std. Dev.



Stream	Std Dev	Measured Flow, kg/Hr	Reconc . Flow
F1	10	100	94.77
F2	9	150	145.76
F3	8	350	346.66
F4	5	291	292.31
F5	6	293	294.88
Obj Fn	**0.83660**	**Epsilon**	**3.43E-10**

Reconc. Total=587.19

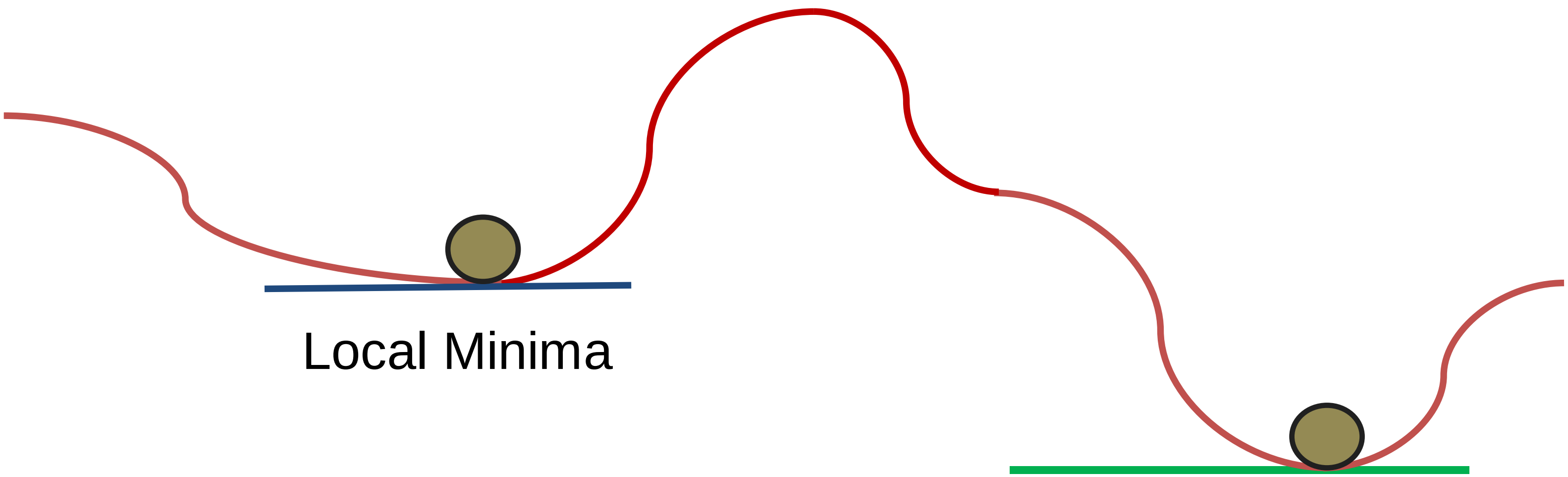
- **Let reconciled flow rates =F1*, F2*,F3*, F4*& F5***
- **Minimize (((100-F1*)/10)^2)+ (((150-F2*)/9)^2)+ (((350-F3*)/8)^2) + (((291-F4*)/5)^2)+ (((293-F5*)/6)^2)**
- **Subject to the constraints: ((F1*+F2*+F3*-F4*-F5*)^2)< (1*e-06)**

Weighted Least squares method

- Monitors the gradient or slope of the objective function as the input values (or decision variables) change
- an optimum solution is obtained when the partial derivatives are equal to zero.
- input values (or decision variables) change to final reconciled values
- Can get trapped into a local minima-depending on initial conditions
- Global Minima is achieved only when epsilon $<10^{-6}$

Data Reconciliation- Process Software Solver

- The mass and energy balances were ensured
- Achieves convergence (global minima) with any random initial conditions



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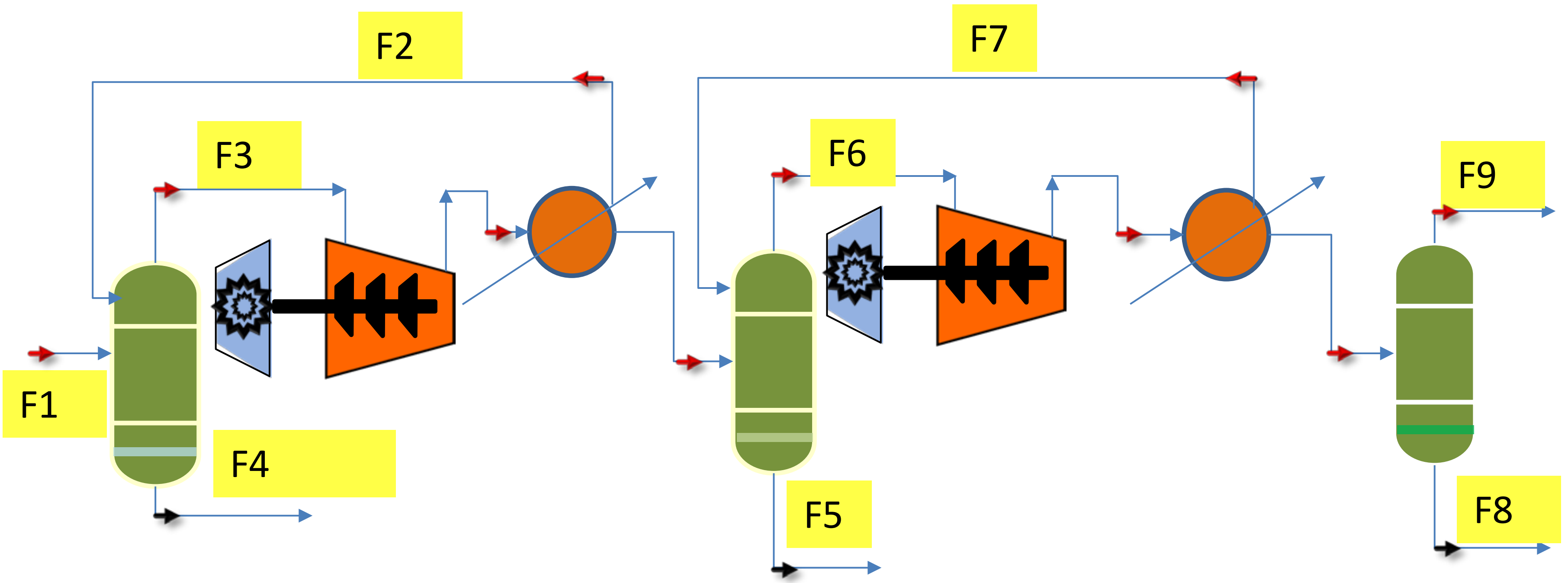
Compressor System-Blind data used



Material Balance:

F1+F2-F3-F4-=0

F3-F2+F7-F6-F5=0

F6-F7-F8-F9=0

Data Reconciliation-Weighted Least Squares

- **The weights are used as the inverse of variances ($w=1/\sigma^2$)**
- **Minimize: $\sum ((\text{Measured value} - \text{Reconciled Value})/\sigma)^2$**
- **Constraints:**

$(F1+F2-F3-F4)^2 < \text{Epsilon (typically } 10^{-6})$

$(F3-F2+F7-F6-F5)^2 < \text{Epsilon}$

$(F6-F7-F8-F9)^2 < \text{Epsilon}$

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Comparison of Excel Solver results vs Software

Parameters Reconciled		Excel Solver	Process Software
F1	Feed	5142	5176
F2	Recycle-1	569	569
F3	Feed to 1st Comp	5711	5745
F4	1st Stg.Suc Scrub Liq	0	0
F5	1st Stg Disch Scrub Liq	77.3	76.1
F6	Feed to 2nd Comp	5626	5660
F7	2nd stg. Recycle	561	561
F8	2nd Stg Scrubber Liq	101	130
F9	Export Gas	4963	4970
	Constraint	$<10^{-8}$	$<10^{-10}$

Observations & Conclusions

- It can be seen that the results of weighted least squares method are based only on material balances and ignores the energy balances (i.e.purely on measured flow data)

- The Process Solver carries out the reconciliation with the both mass and energy Balances

- Though the weighted least squares method results are based only on measured flow rates, measured data is based on heat & material balance.

- Hence the difference between the weighted least squares method and the Process Software reconciliation software is not significant (within 2-3 standard deviations) of any measured variable

Thank You