6σ

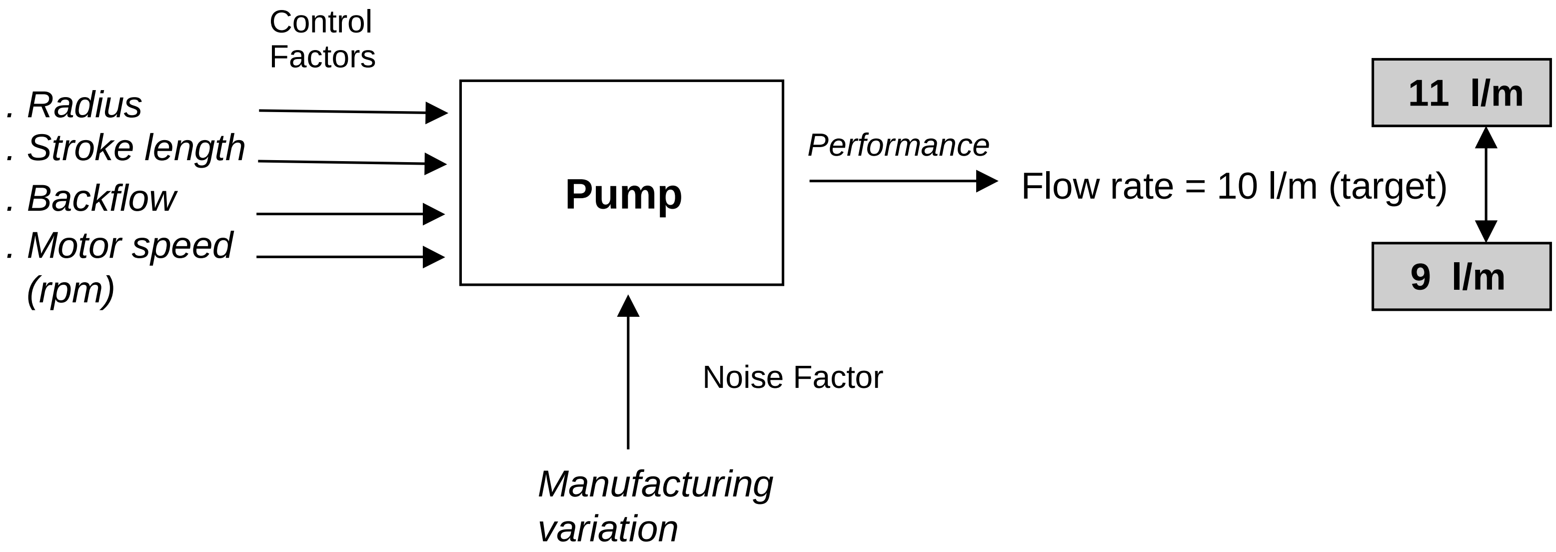
Design for Six Sigma

. Example of Robust and Tolerance Design

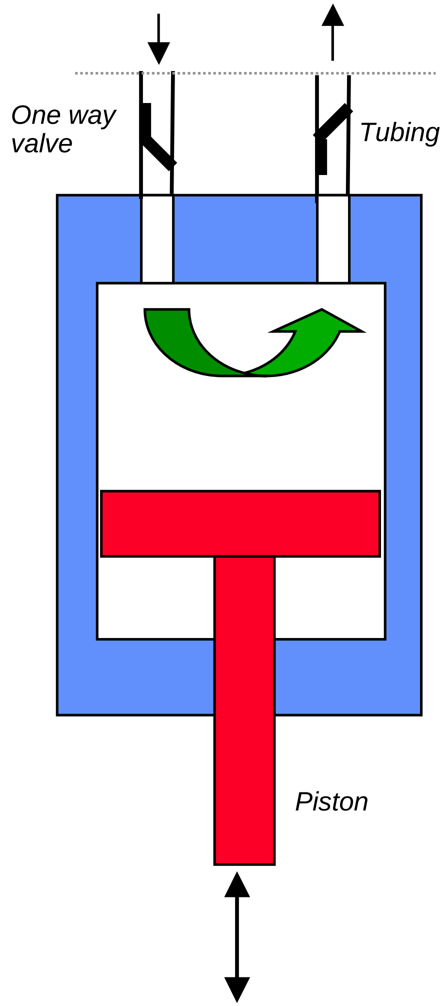
Pier Giorgio DELLA ROLE

Example of DFSS for a subsystem

We are faced with the task of designing a pump capable of delivering a constant flow rate of 10 l/min. Customer requires a pump with ‘6 sigma’ performance with a flow rate between 9 and 11 l/min.



Functional Scheme and Transfer Function Y = f (x)



Flow rate (l/min)

$$F = (3.141 \times R^{2} \times L - B)\, N$$

R = Piston radius
L = Stroke length
B = Back flow
N = Motor speed (rpm)

PROCEDURE FOR SETTING TARGETS and TOLERANCES

1. It may be possible to reduce the output's variation by adjusting the average of the inputs

(non linear relationship between inputs and output)

Adjusting the averages can make the pump less sensitive or more ROBUST to the variations of the inputs.
Since it is generally less costly to adjust targets than tighten tolerances, this step has the highest priority.

2. If the desired performance has not been achieved, the next step would be to tighten tolerances.

The question is which tolerances and by how much?

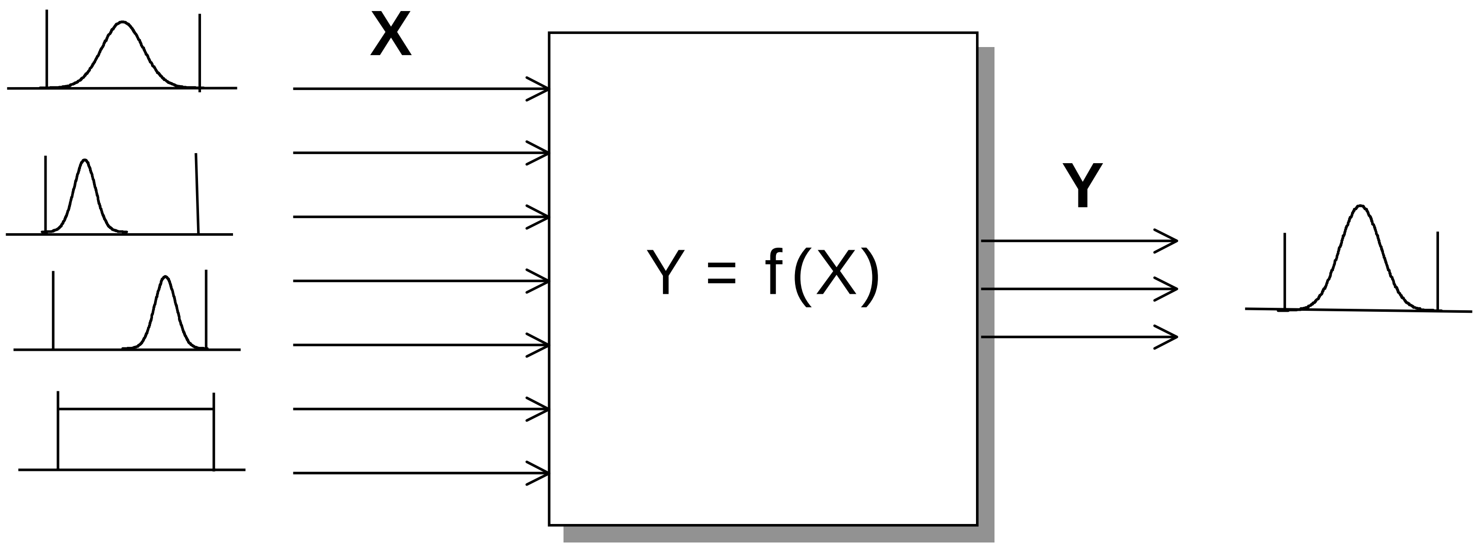
In deciding which tolerances to tighten, you should consider both the cost and the effect of change.

DATA for DESIGN and MANUFACTURING PROCESSES

	Factors	Nominal value		Dev. Standard	
MAKE	**Radius**	**0.4 dm**	**0.2 dm**	**0.001**	From the actual manufacturing process
	Stroke length	**0.4 dm**	**0.8 dm**	**0.002**	
BUY	**Back flow** *(Inlet Valve)*	**0.002 l**	**0.002 l**	**0.00005**	**0.00002**
	N (rpm) *(Electrical motor)*	**50**	**100**	**2**	**1**
				Low cost	High cost
		Solution 1	*Solution 2*		

MonteCarlo Simulation

How much variation in Y (output) is created by variation in X (inputs) and the system function Y = f (X)

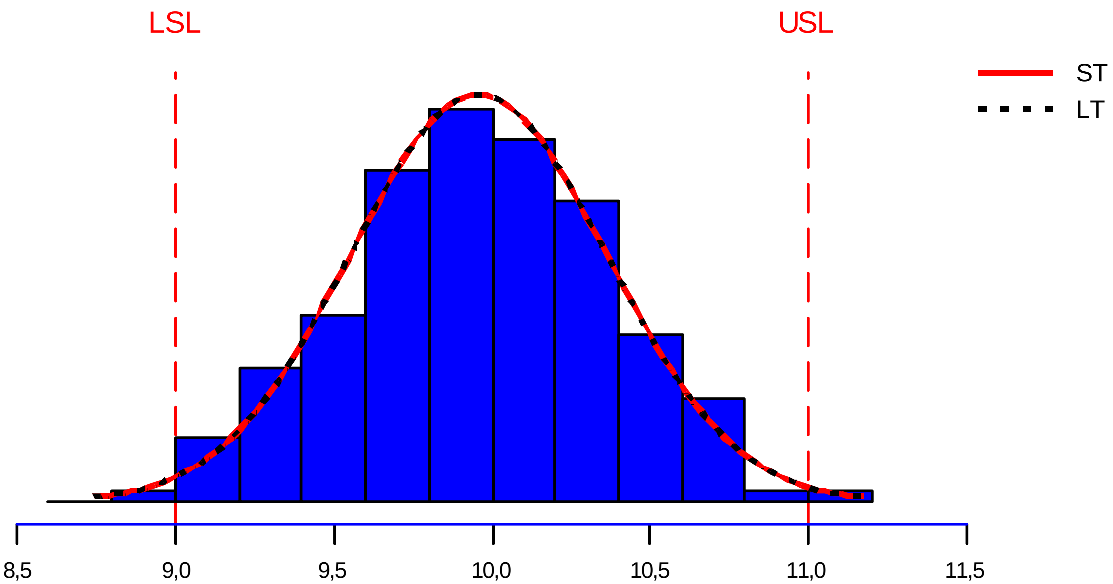


. Random values of X are generated and applied to function Y = f (X) to predict the variation of Y
. Transfer function Y = f(X) can be non-linear
. X's can be any distribution
. May require a lot of trials (~1000) and results are not repeatable

Flow rate - Solution 1

Process Capability Analysis for Flow rate

Process Data	
USL	11,0000
Target	*
LSL	9,0000
Mean	9,9572
Sample N	200
StDev (ST)	0,406053
StDev (LT)	0,406053



Potential (ST) Capability	
Cp	0,82
CPU	0,86
CPL	0,79
Cpk	0,79
Cpm	*

Overall (LT) Capability	
Pp	0,82
PPU	0,86
PPL	0,79
Ppk	0,79

Observed Performance	
PPM < LSL	5000,00
PPM > USL	5000,00
PPM Total	10000,00

Expected ST Performance	
PPM < LSL	9200,66
PPM > USL	5114,07
PPM Total	14314,73

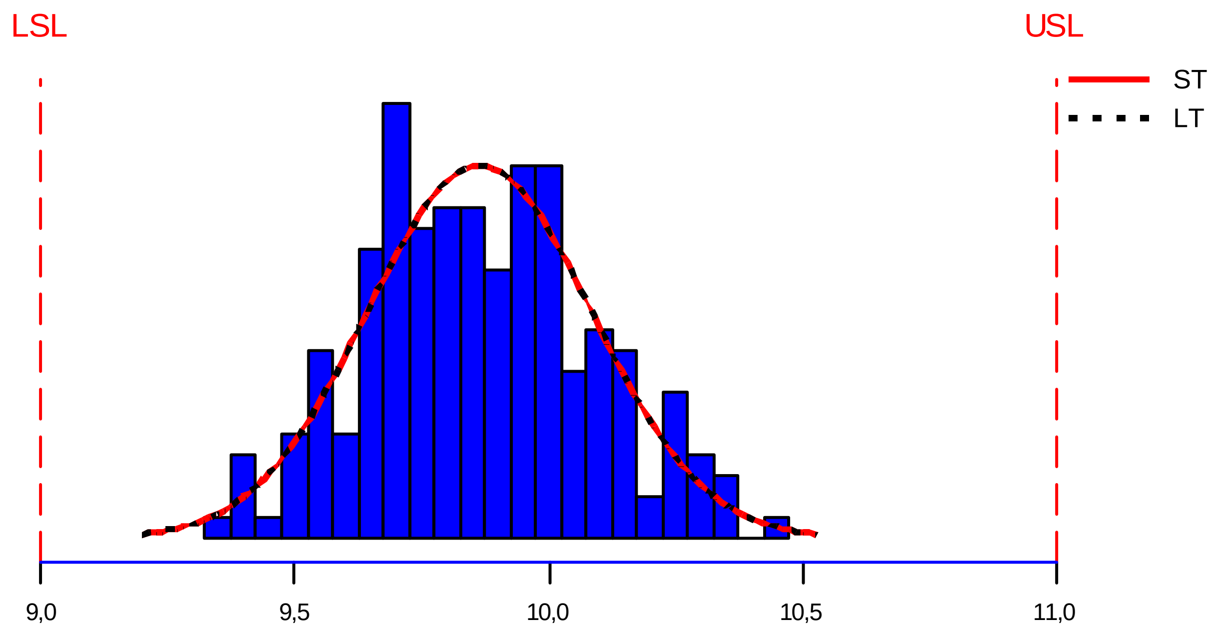
Expected LT Performance	
PPM < LSL	9200,66
PPM > USL	5114,07
PPM Total	14314,73

Flow rate - Solution 2

Process Capability Analysis for Flow rate2

Process Data	
USL	11,0000
Target	*
LSL	9,0000
Mean	9,8638
Sample N	200
StDev (ST)	0,221539
StDev (LT)	0,221539

Potential (ST) Capability	
Cp	1,50
CPU	1,71
CPL	1,30
Cpk	1,30
Cpm	*

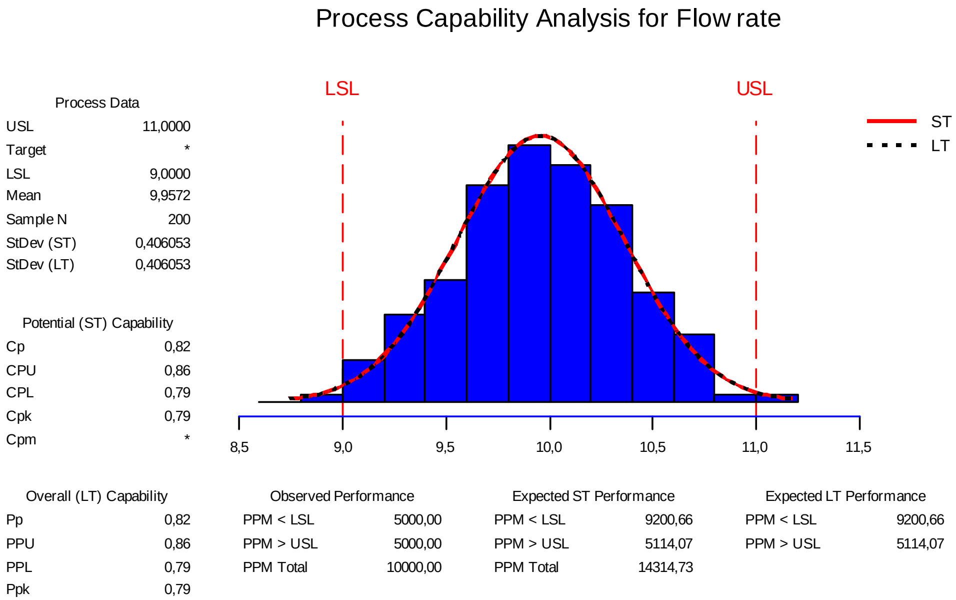


Overall (LT) Capability	
Pp	1,50
PPU	1,71
PPL	1,30
Ppk	1,30

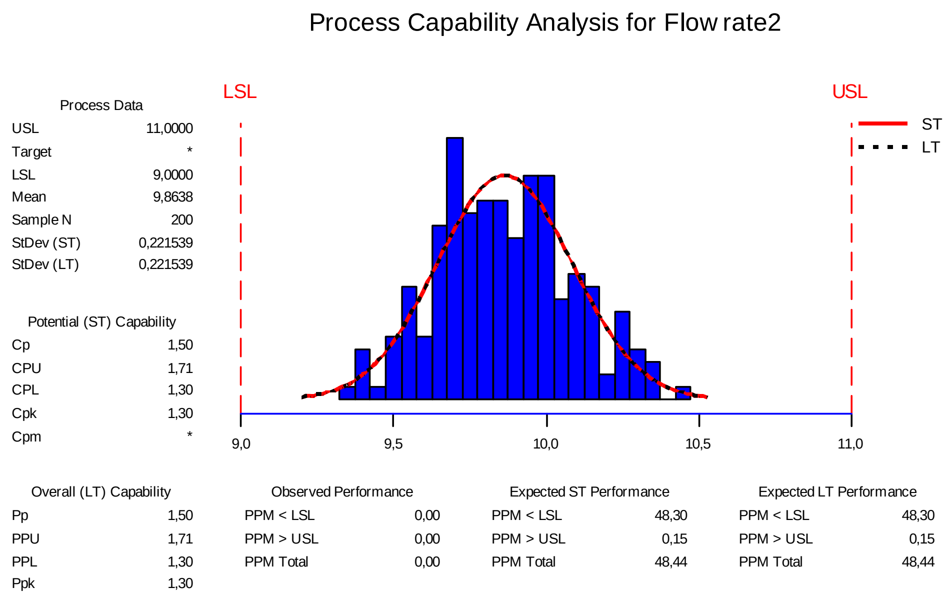
Observed Performance	
PPM < LSL	0,00
PPM > USL	0,00
PPM Total	0,00

Expected ST Performance	
PPM < LSL	48,30
PPM > USL	0,15
PPM Total	48,44

Expected LT Performance	
PPM < LSL	48,30
PPM > USL	0,15
PPM Total	48,44

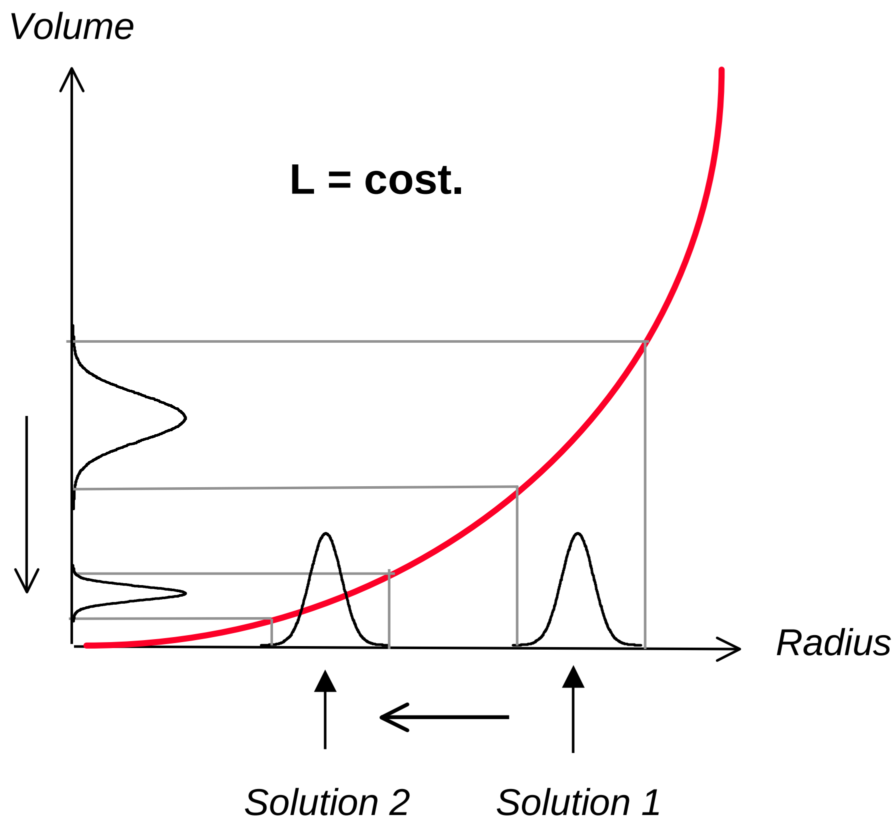


Comparison between solution 1 and solution 2.



We have achieved a ROBUST design NOT by changing the tolerances on the parameters, but by changing only their nominal values.
Robustness is obtained by designing a pump to be less sensitive to the variation of the inputs.
The inputs continue to vary, but less of this variation is transmitted to the output.

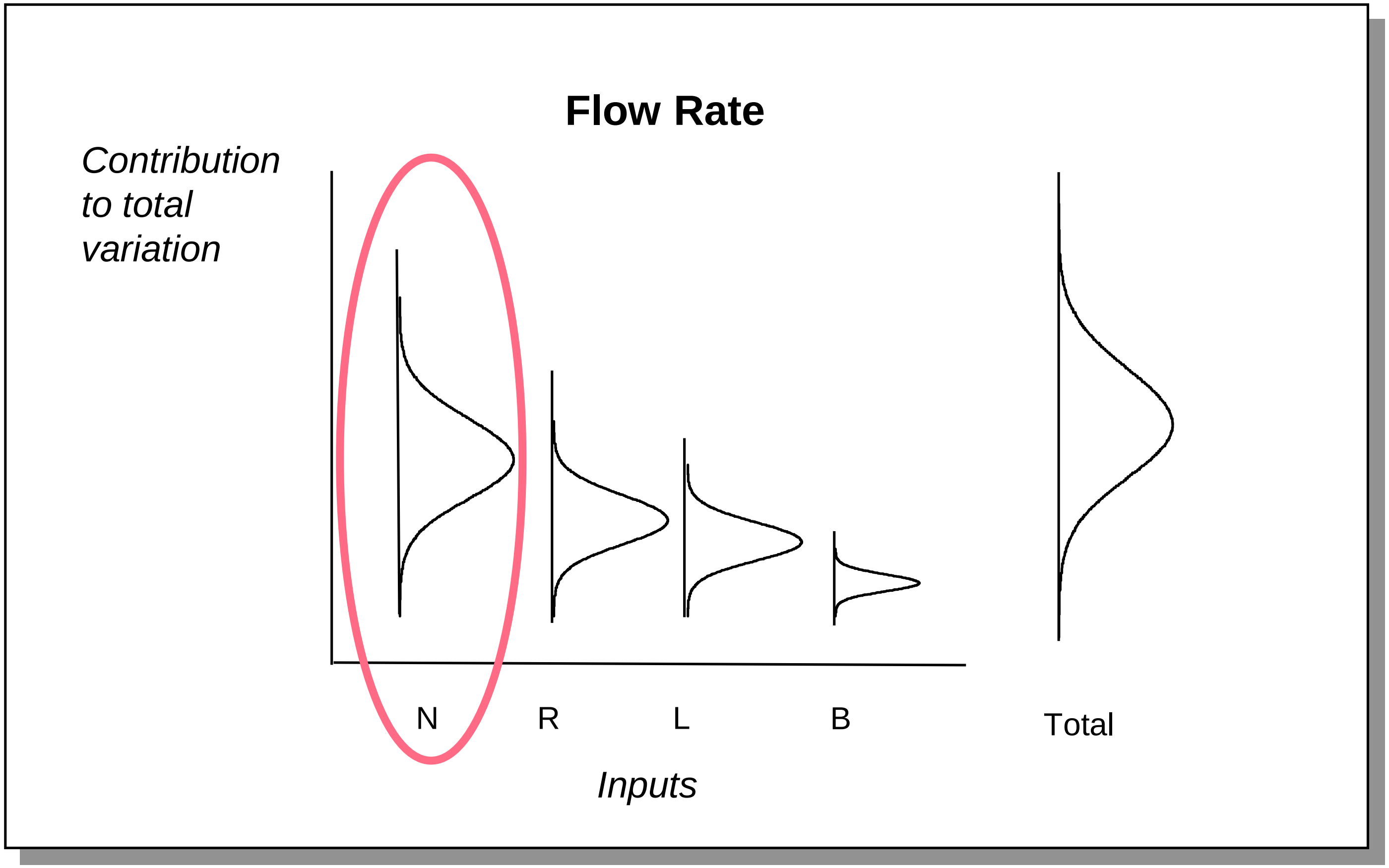
QUALITATIVE CONSIDERATIONS



Robustness achieved in solution 2 (compared to solution 1) is due to the non linear relationship between 'radius' and 'volume'.

The input (radius) continues to vary , but less variation is transmitted to the output (volume).

What if the desired performance has not been achieved?



The next step would be to tighten tolerances. This generally requires using more expensive components and processes.

The question is which tolerances and by how much?

Best Subsets Regression

Response is Flowrate

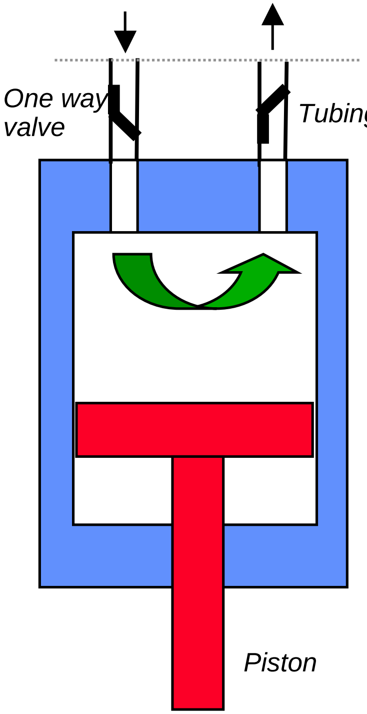
Vars	R-Sq	Adj. R-Sq	C-p	s	Radius	Length	Back-flo	N
1	78,7	78,6	6E+05	0,10767				X
1	28,7	28,4	2E+06	0,19703	X			
2	98,7	98,7	4E+04	0,026508	X			X
2	80,2	80,0	6E+05	0,10416		X		X
3	99,9	99,9	1297,5	0,0052753	X	X		X
3	98,8	98,8	4E+04	0,025855	X		X	X
4	100,0	100,0	5,0	0,0019136	X	X	X	X

The motor speed (N) is responsible for 78,6% of the total variation of the output (flow rate)

Flow rate (l/min)

$$P = (3.141 \times R^2 \times L - B)\, N$$

R = Piston radius
L = Stroke length
B = Back flow
N = Motor speed (rpm)



DATA for DESIGN and MANUFACTURING PROCESSES

	Factors	Nominal value		Standard Dev.	
MAKE	Radius	0.4 dm	0.2 dm	0.001	From the actual manufacturing process
	Stroke length	0.4 dm	0.8 dm	0.002	
BUY	Back flow *(Inlet Valve)*	0.002 l	0.002 l	0.00005	0.00002
	N (rpm) *(Electrical motor)*	50	100	2	1
				Low cost	High cost
		Solution 1	*Solution 2*		

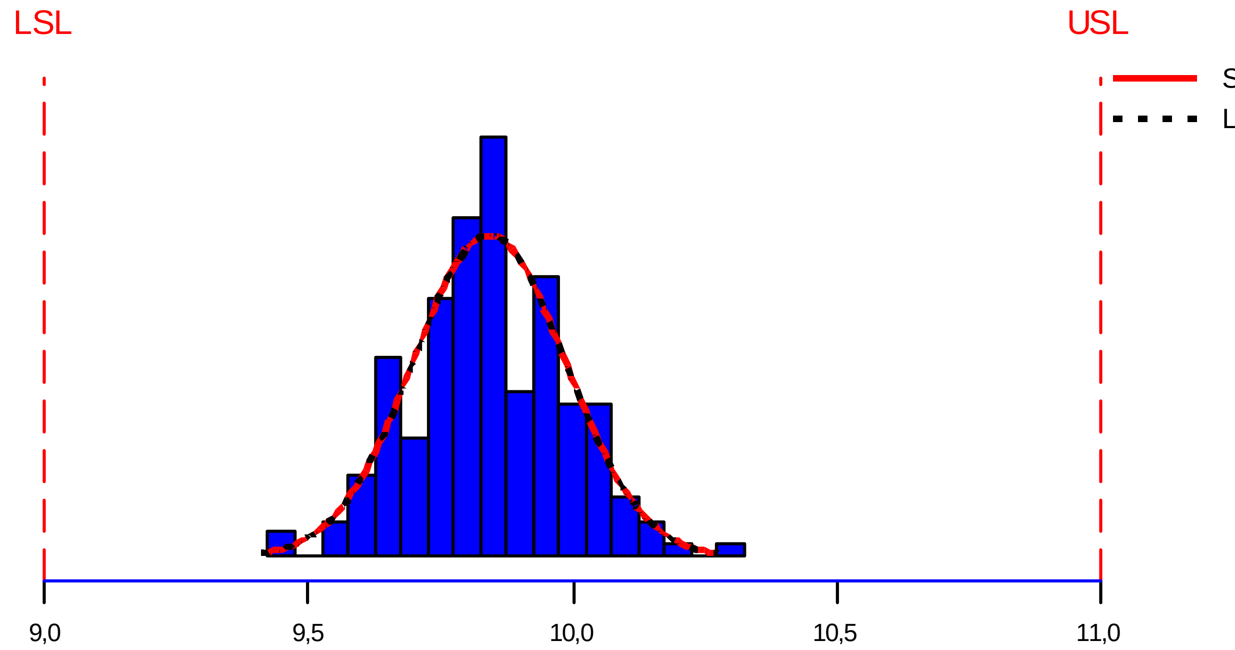
Data used for solution 3

Flow rate - Solution 3 *(Achieved by reducing the variation of motor speed)*

Process Capability Analysis for Flow rate3

Process Data	
USL	11,0000
Target	*
LSL	9,0000
Mean	9,8424
Sample N	200
StDev (ST)	0,144828
StDev (LT)	0,144828

Potential (ST) Capability	
Cp	2,30
CPU	2,66
CPL	1,94
Cpk	1,94
Cpm	*



Overall (LT) Capability	
Pp	2,30
PPU	2,66
PPL	1,94
Ppk	1,94

Observed Performance	
PPM < LSL	0,00
PPM > USL	0,00
PPM Total	0,00

Expected ST Performance	
PPM < LSL	0,00
PPM > USL	0,00
PPM Total	0,00

Expected LT Performance	
PPM < LSL	0,00
PPM > USL	0,00
PPM Total	0,00