LiquiRubber.com: Finding the right temperature

Overview

LiquiRubber.com is a producer of liquid rubber used in the production of molded parts. The company have, of late, been receiving negative feedback from their customers regarding loss of manpower hours due to the need to adjust temperature settings in their mold process for each new shipped batch of liquid rubber material. Adjusting temperature settings cost them about 30 minutes a day which is over 2 shifts lost per month. The management at LiquiRubber.com has organized a multidisciplinary team consisting of Process Engineers, Chemists, Operators and Supervisors to identify a solution to this problem.

Define

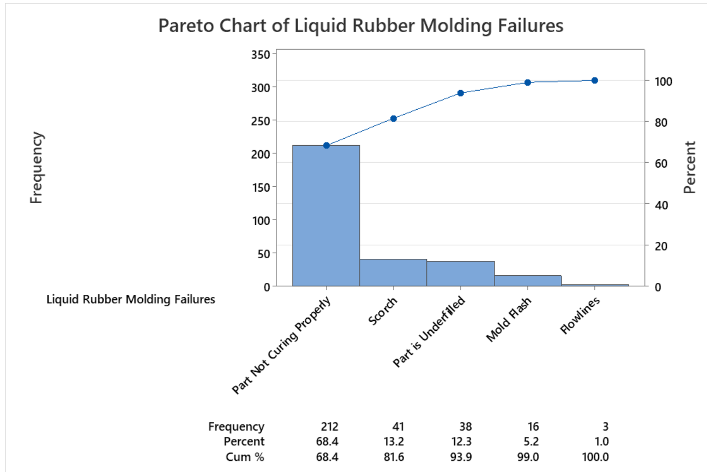
The objective of this six-sigma project is to study and analyse the processes involved in the production of liquid rubber, point out existing flaws and suggest appropriate improvements and control measures to maintain consistency of desired properties of the rubber produced so that the customers will be satisfied. This involves extensive study and analysis of historical sales data. The report also focusses on quantifying the benefits of implementing the improvements/suggestions in terms of DPM as well as in financial terms

Project Charter

Project Information		**Resources**	
Project #	1234	Project Leader	William B
Project Name	Liquirubber	Black Belt:	Steven A
Project Start Date	xx-xxx-2021	Champion:	John R
Project End Date	xx-xxx-2022	Process Owner	LiquiRubber.com
Team Members	Stuart, Allan, Son, Jake		
Problem Statement:			
The customers have been complaining about variation in curing temperatures of liquid rubber among different batches causing them loss of manpower hours. We need to study, analyze and make improvements in the production process to ensure the product has the desired curing properties as expected by the customers.			
Goal Statement:			
The objective of this project is to find process inputs causing curing temperature defects and make improvements to reduce curing defects.			
Project Scope: This project is based on data collected over a period of product samples collected from the company. The recommendations will be hence based on raw materials, suppliers that supplied materials to the company during this period.			

As part of the project, a multidisciplinary team consisting of Process Engineers, Chemists, Operators and Supervisors had collected a summary of failures from their customer's internal mold inspection process. The summary carried the following data regarding failures:

Liquid Rubber Molding Failures	Frequency
Part Not Curing Properly	212
Scorch	41
Part is Underfilled	38
Mold Flash	16
Flowlines	3



As can be seen from the pareto chart for the different failure reasons, improper curing of the product makes up 68.4% of all failures. This again, is the major complaint raised by the customers which causes them a considerable monetary loss. This project will hence be focused on this aspect of the product.

Measure

A schematic of the processes involved in the production of liquid rubber is shown below:

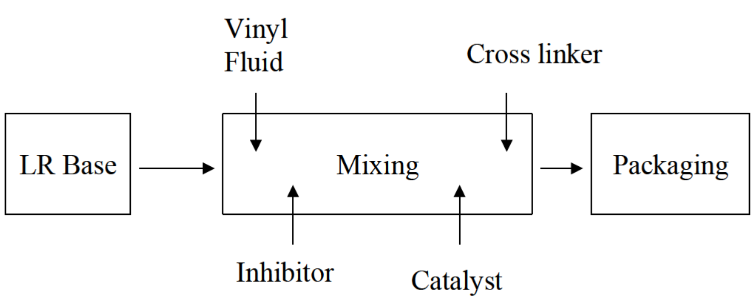
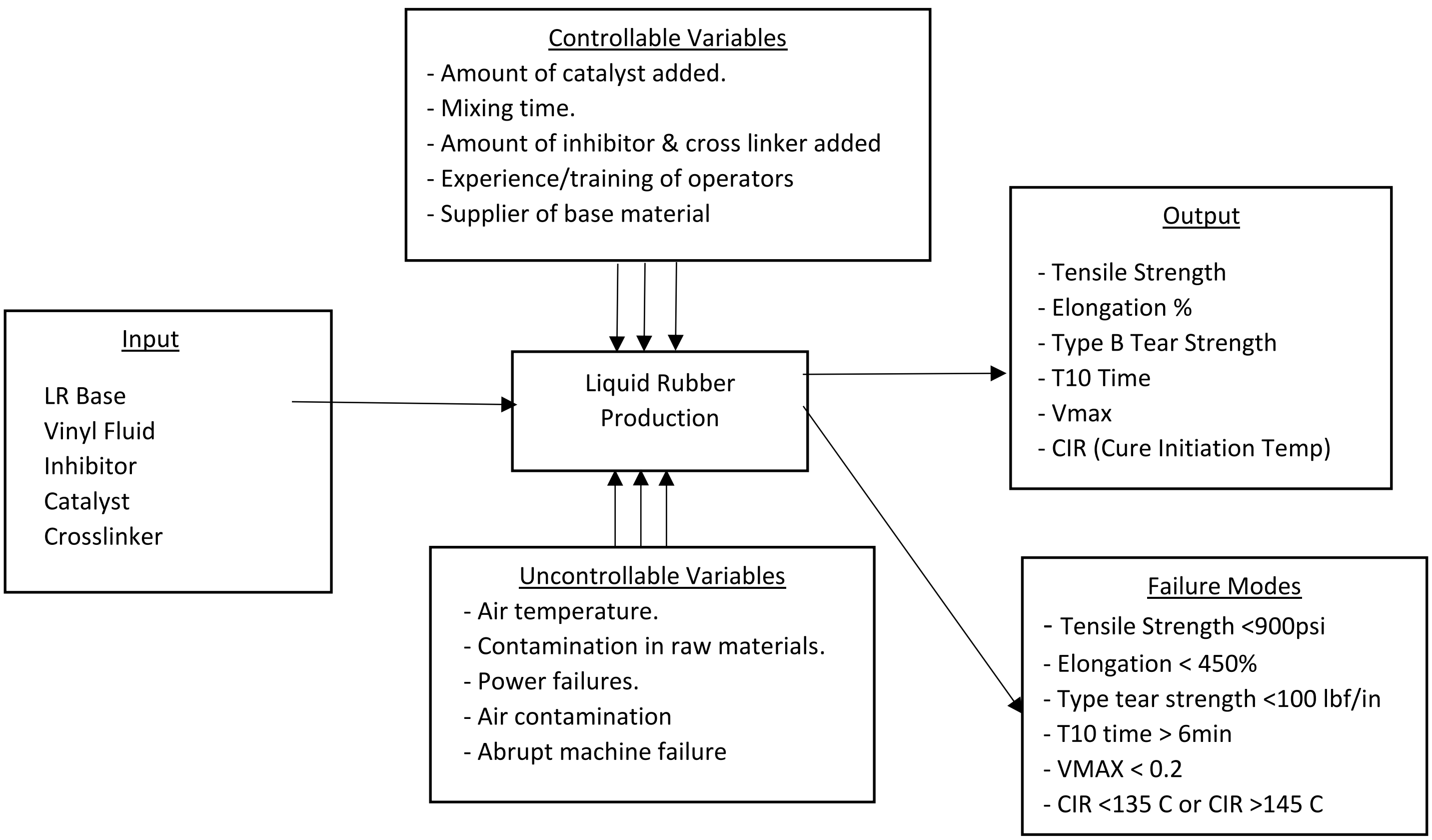


Figure 1 Process Schematic

The process starts when a liquid material base is added into a mixing tank. Next, a catalyst, vinyl fluid, inhibitor, and cross-linker are added. The cross-linker and inhibitor provide working time once the other parts have been mixed.

Variables

There are multiple factors that influence the properties/quality of the finished liquid rubber. Most important variables are identified and categorized into –(a) Input Variables, (b) Controllable Variables, (c) Uncontrollable Variables and (d) Output. These variables are shown in the P – Diagram.

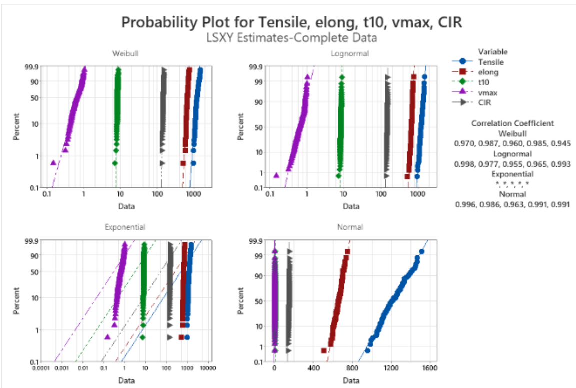


Data Collection

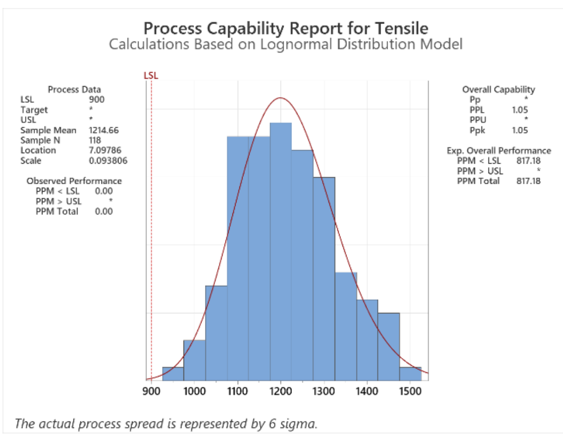
Historical data of 118 samples collected over a period of 4 hours is examined and the material variables and process settings are recorded.

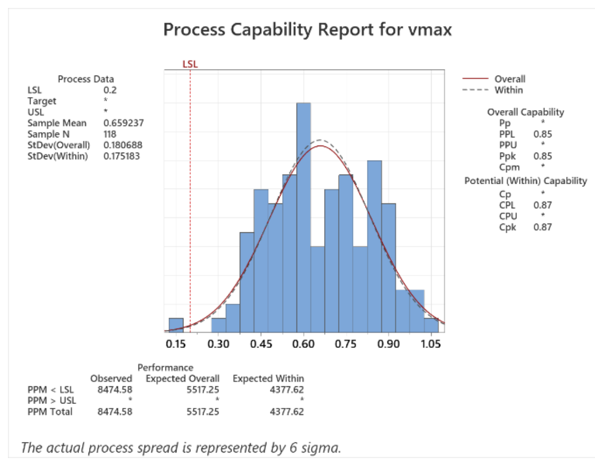
Process Capability Analysis

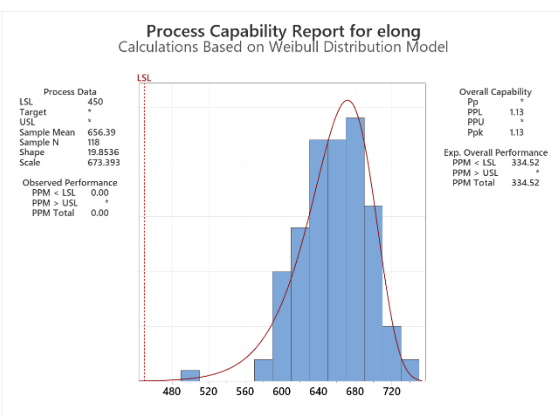
The performance of the liquid rubber w.r.t the target specifications for all the critical output parameters are measured which gives a clear picture about the capability of the existing process. As we have multiple output parameters to be checked, capability of each of these are checked individually based on the distribution that fit it the most.

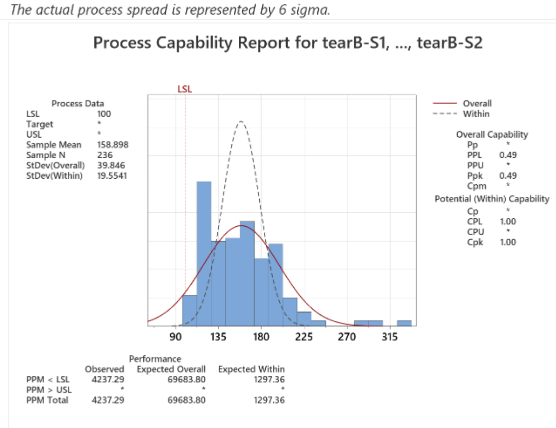


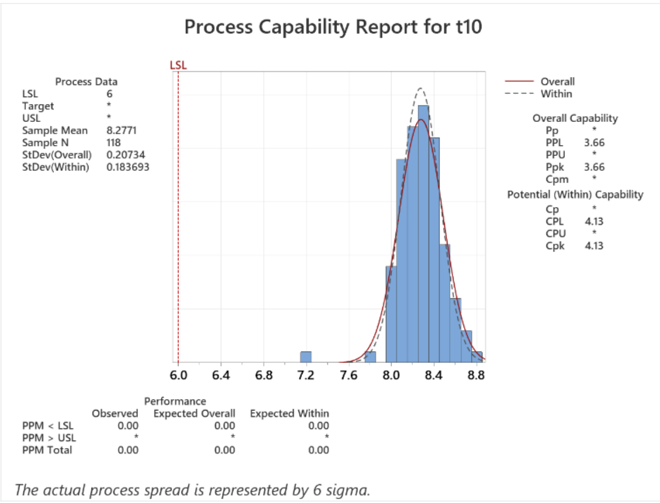
Output parameter	Distribution
Tensile strength	Lognormal
Elongation %	Weibull
T10	Normal
VMAX	Normal
Tear Strength	Normal
CIR	Lognormal

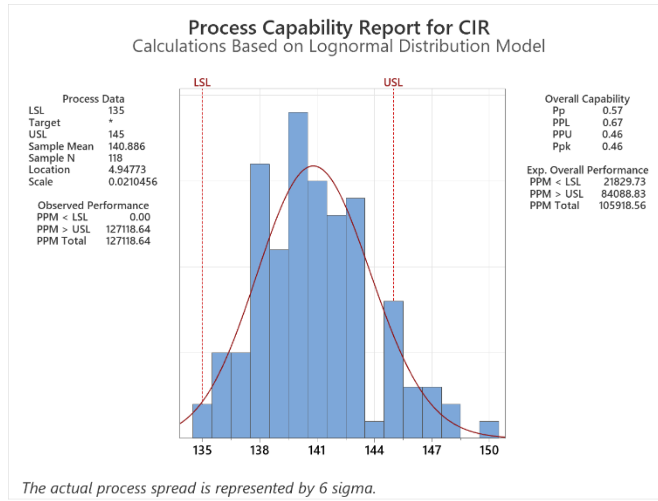










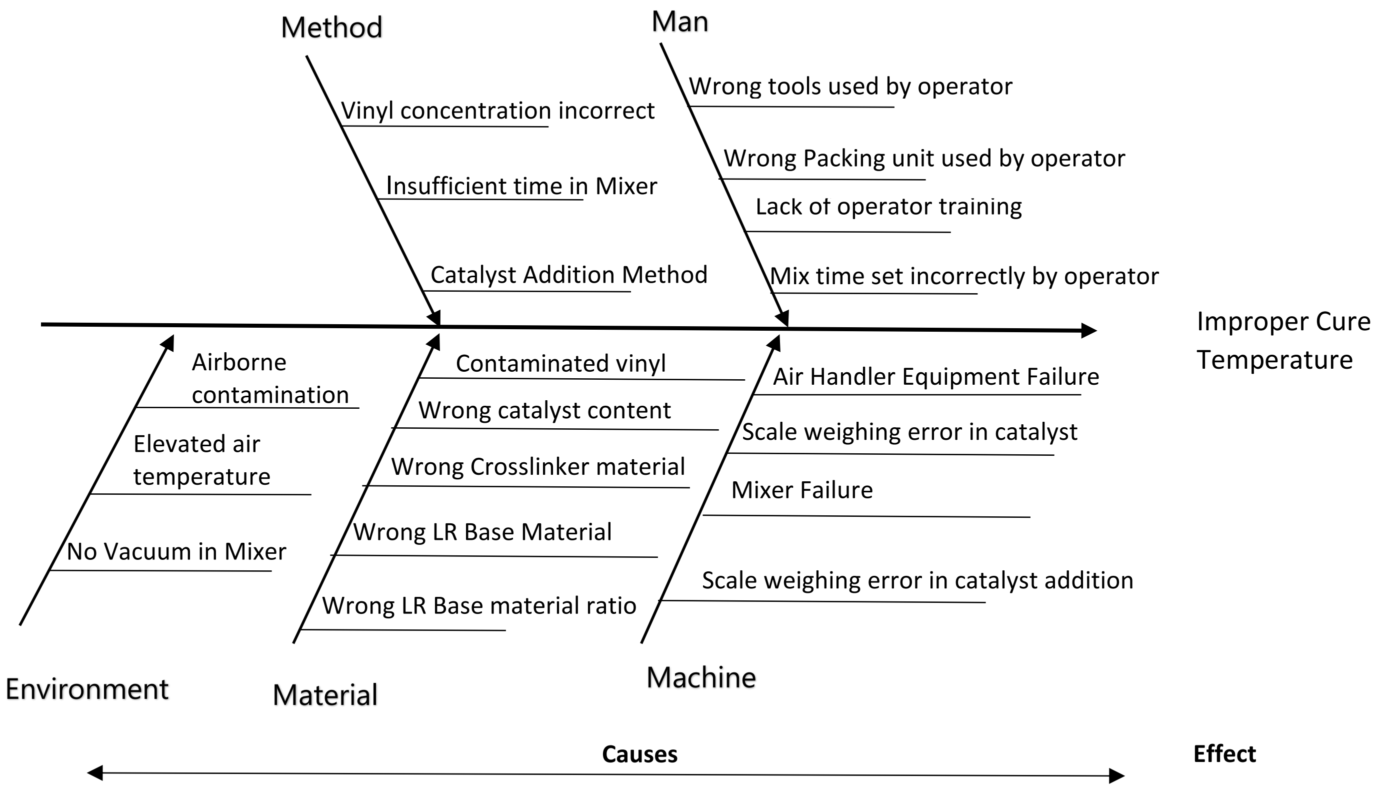


Output parameter wise defect level is given below:

Output parameter	**Tensile Strength**	**Elongation %**	**Tear Strength**	**T10**	**VMAX**	**CIR**
Mean	1215	656	159	8.2	.66	**141**
Observed DPM	0	0	4237	0	8474	**127118**
Expected DPM	817	334	69683	0	5517	**105918**

As can be seen from the table, the defect level of the product is very high in CIR (Cure Initiation Temp). We can observe that there are 0 observed defects in tensile strength, Elongation and T10 and <10000 observed defects in VMAX and Tear strength. DPM in CIR is **127118** which is high which makes **CIR** the most crucial and **dominant output**.

After hours of brainstorming based on measured data and input from the customers, potential root causes are identified and have been represented in the form of a fish bone diagram. The validity of the causes will be verified after deeper analysis of the data collected.


Method
Man
Vinyl concentration incorrect
Insufficient time in Mixer
Catalyst Addition Method
Wrong tools used by operator
Wrong Packing unit used by operator
Lack of operator training
Mix time set incorrectly by operator
Improper Cure Temperature
Airborne contamination
Elevated air temperature
No Vacuum in Mixer
Contaminated vinyl
Wrong catalyst content
Wrong Crosslinker material
Wrong LR Base Material
Wrong LR Base material ratio
Air Handler Equipment Failure
Scale weighing error in catalyst
Mixer Failure
Scale weighing error in catalyst addition
Environment
Material
Machine
Causes
Effect

Analyze

The data measured with the help of statistical tools is analyzed deeper to find inputs/factors that influence the most dominant output i.e, CIR.

The effect of process inputs on CIR is analyzed by using the correlation matrix among all the inputs is given below:

WORKSHEET 7

Correlation: CIR, Supplier, Inhibitor, crosslinker, catwt, mixtime, catdisp

Correlations

	CIR	Supplier	Inhibitor	crosslinker	catwt	mixtime
Supplier	-0.698					
Inhibitor	0.128	-0.089				
crosslinker	-0.018	0.017	-0.099			
catwt	0.919	-0.615	0.112	-0.059		
mixtime	0.100	-0.153	0.026	-0.092	0.089	
catdisp	0.896	-0.600	0.104	-0.054	0.973	0.067

Pairwise Pearson Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
Supplier	CIR	118	-0.698	(-0.780, -0.592)	0.000
Inhibitor	CIR	118	0.128	(-0.054, 0.302)	0.166
crosslinker	CIR	118	-0.018	(-0.198, 0.163)	0.847
catwt	CIR	118	0.919	(0.886, 0.943)	0.000
mixtime	CIR	118	0.100	(-0.083, 0.275)	0.283
catdisp	CIR	118	0.896	(0.854, 0.927)	0.000
Inhibitor	Supplier	118	-0.089	(-0.265, 0.094)	0.340
crosslinker	Supplier	118	0.017	(-0.164, 0.198)	0.852
catwt	Supplier	118	-0.615	(-0.716, -0.489)	0.000
mixtime	Supplier	118	-0.153	(-0.324, 0.029)	0.099
catdisp	Supplier	118	-0.600	(-0.705, -0.471)	0.000
crosslinker	Inhibitor	118	-0.099	(-0.275, 0.083)	0.286
catwt	Inhibitor	118	0.112	(-0.071, 0.287)	0.229
mixtime	Inhibitor	118	0.026	(-0.156, 0.205)	0.782
catdisp	Inhibitor	118	0.104	(-0.079, 0.279)	0.264
catwt	crosslinker	118	-0.059	(-0.237, 0.123)	0.526
mixtime	crosslinker	118	-0.092	(-0.268, 0.091)	0.324
catdisp	crosslinker	118	-0.054	(-0.233, 0.128)	0.560
mixtime	catwt	118	0.089	(-0.094, 0.265)	0.341
catdisp	catwt	118	0.973	(0.961, 0.981)	0.000
catdisp	mixtime	118	0.067	(-0.115, 0.245)	0.472

As seen from the table above, the 3 process inputs – **Supplier, catwt** (catalyst weight) and **catdis** (catalyst dispensed) have the highest correlation with CIR and hence has the maximum effect on the CIR of the liquid rubber. The p values of the pair wise correlation is given on the right. P values of catwt, catdisp and Supplier are less than alpha (for input vs CIR)

All other process inputs have low correlation with CIR, and p value greater than alpha which means that their effect on CIR is trivial (also, null hypothesis cannot be rejected).

The regression charts of the dominant inputs (Supplier, catwt and catdisp) plotted against CIR is shown below:

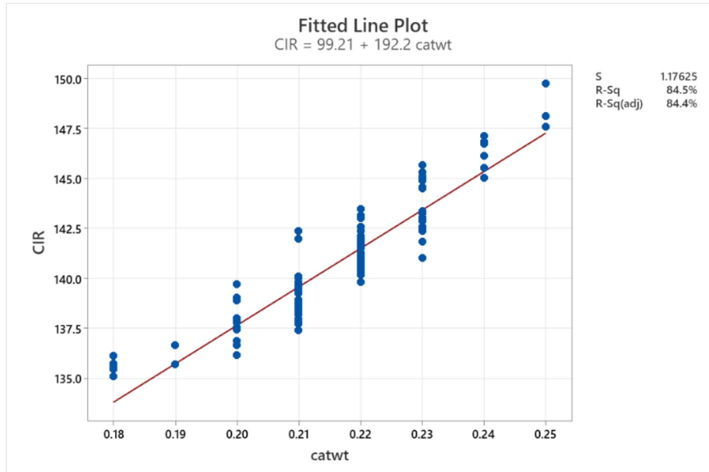
1. **CIR – catwt**.

WORKSHEET 7

Regression Analysis: CIR versus catwt

The regression equation is

CIR = 99.21 + 192.2 catwt

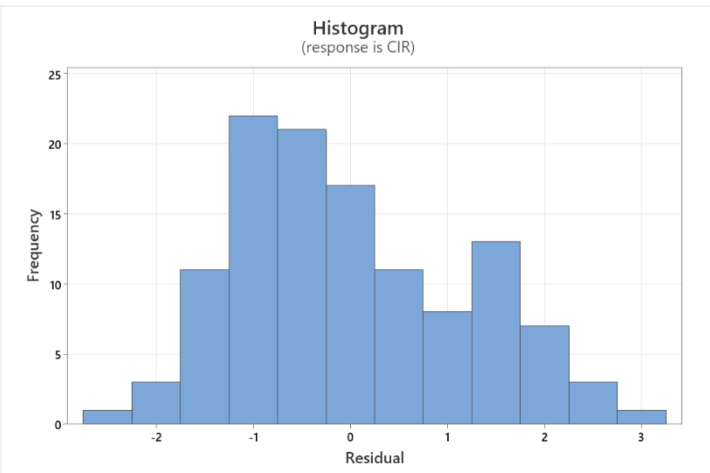


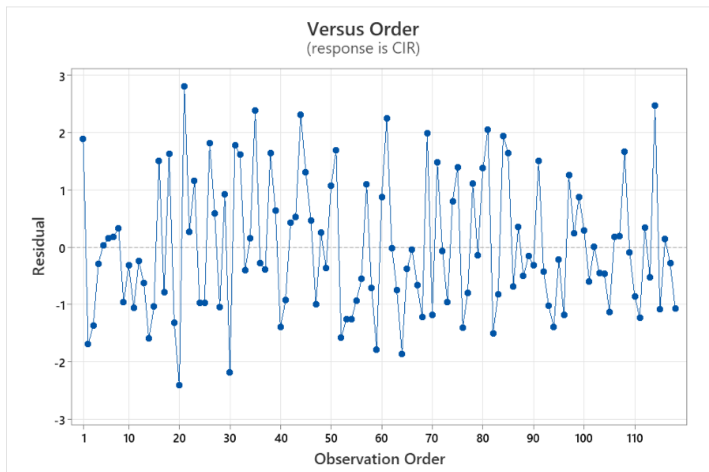
Model Summary

S	R-sq	R-sq(adj)
1.17625	84.53%	84.39%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	876.83	876.826	633.74	0.000
Error	116	160.49	1.384		
Total	117	1037.32			





2. **CIR – catdis**.

WORKSHEET 7

Regression Analysis: CIR versus catdisp

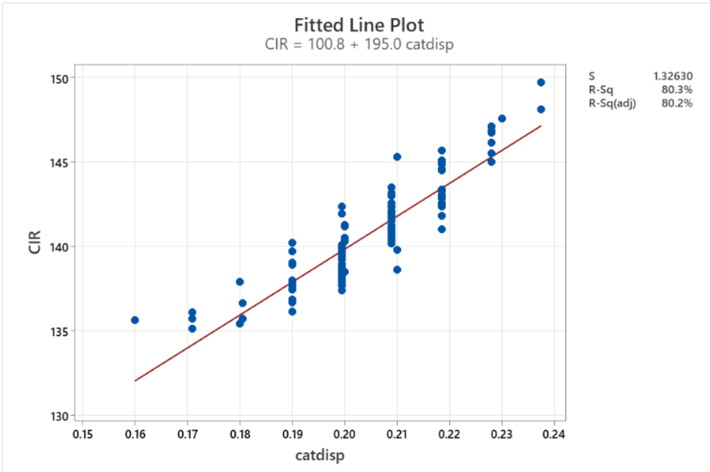
The regression equation is CIR = 100.8 + 195.0 catdisp

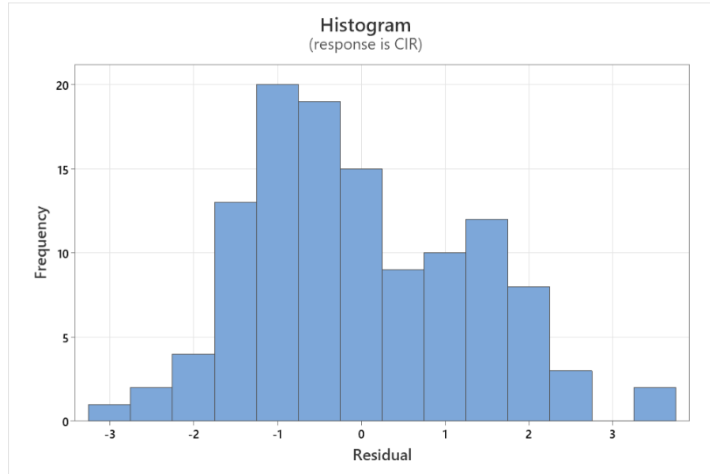
Model Summary

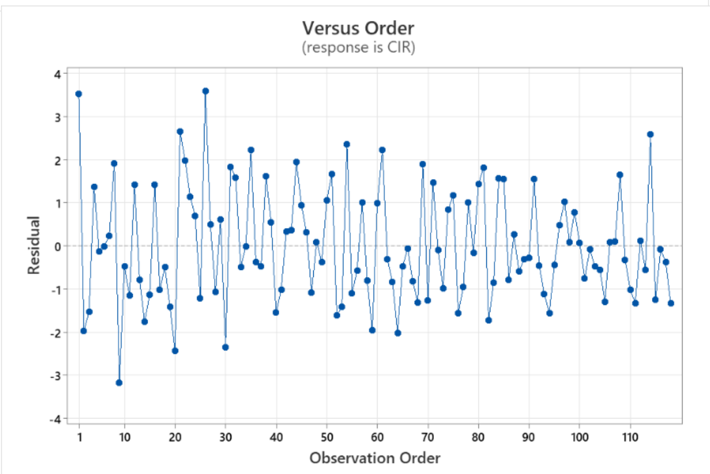
S	R-sq	R-sq(adj)
1.32630	80.33%	80.16%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	833.27	833.268	473.70	0.000
Error	116	204.05	1.759		
Total	117	1037.32			







3. **CIR – Supplier**.

WORKSHEET 7

Regression Analysis: CIR versus Supplier

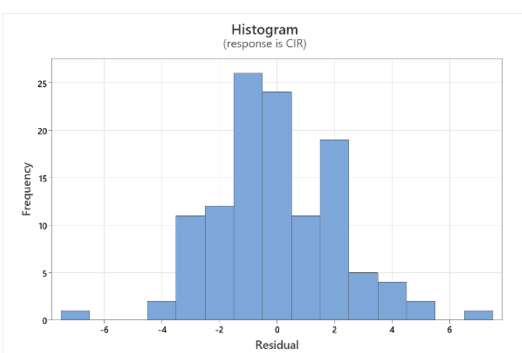
The regression equation is CIR = 143.0 - 4.138 Supplier

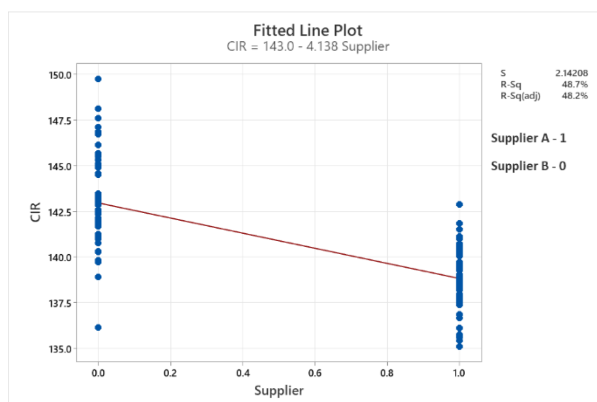
Model Summary

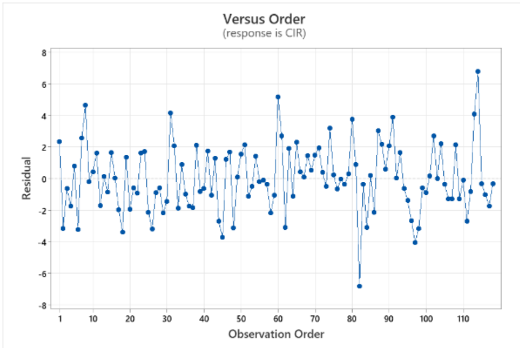
S	R-sq	R-sq(adj)
2.14208	48.69%	48.25%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	505.06	505.055	110.07	0.000
Error	116	532.26	4.588		
Total	117	1037.32			



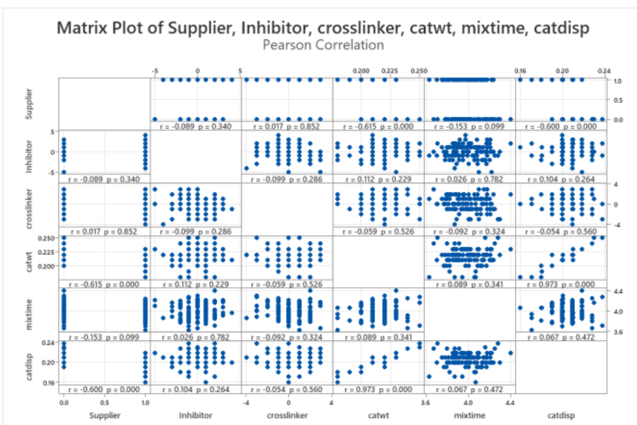




Also, we can see from the input correlation matrix below that the there is a strong correlation between the 2 dominating inputs – **catwt and catdisp**. Also we can see a considerable correlation between catwt-Supplier and catdisp Supplier.

WORKSHEET 7

Correlation: Supplier, Inhibitor, crosslinker, catwt, mixtime, catdisp



Correlations

	Supplier	Inhibitor	crosslinker	catwt	mixtime
Inhibitor	-0.089				
crosslinker	0.017	-0.099			
catwt	-0.615	0.112	-0.059		
mixtime	-0.153	0.026	-0.092	0.089	
catdisp	-0.600	0.104	-0.054	0.973	0.067

Pairwise Pearson Correlations

Sample 1	Sample 2	N	Correlation	95% CI for ρ	P-Value
Inhibitor	Supplier	118	-0.089	(-0.265, 0.094)	0.340
crosslinker	Supplier	118	0.017	(-0.164, 0.198)	0.852
catwt	Supplier	118	-0.615	(-0.716, -0.489)	0.000
mixtime	Supplier	118	-0.153	(-0.324, 0.029)	0.099
catdisp	Supplier	118	-0.600	(-0.705, -0.471)	0.000
crosslinker	Inhibitor	118	-0.099	(-0.275, 0.083)	0.286
catwt	Inhibitor	118	0.112	(-0.071, 0.287)	0.229
mixtime	Inhibitor	118	0.026	(-0.156, 0.205)	0.782
catdisp	Inhibitor	118	0.104	(-0.079, 0.279)	0.264
catwt	crosslinker	118	-0.059	(-0.237, 0.123)	0.526
mixtime	crosslinker	118	-0.092	(-0.268, 0.091)	0.324
catdisp	crosslinker	118	-0.054	(-0.233, 0.128)	0.560
mixtime	catwt	118	0.089	(-0.094, 0.265)	0.341
catdisp	catwt	118	0.973	(0.961, 0.981)	0.000
catdisp	mixtime	118	0.067	(-0.115, 0.245)	0.472

Since there is a strong correlation between process inputs, i.e **multicollinearity**, we use step wise regression method to get the dominant inputs influencing the dominant output – CIR.

Results of the backward elimination step wise regression is given below:

WORKSHEET 7

Regression Analysis: CIR versus Supplier, Inhibitor, crosslinker, catwt, mixtime, catdisp

Backward Elimination of Terms

Candidate terms: Supplier, Inhibitor, crosslinker, catwt, mixtime, catdisp

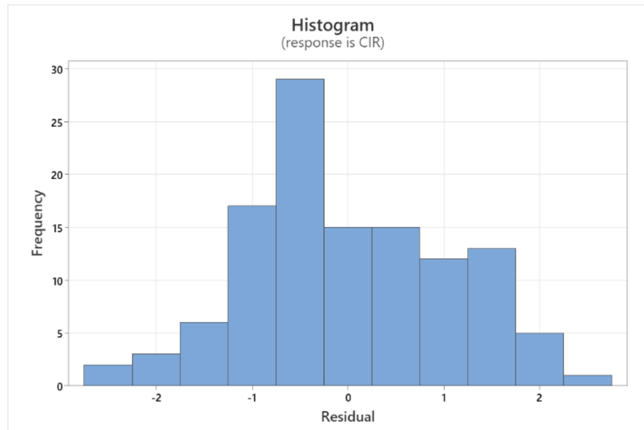
	-----Step 1---		-----Step 2---		-----Step 3---		-----Step 4---	
	Coef	**P**	**Coef**	**P**	**Coef**	**P**	**Coef**	**P**
Constant	105.65		105.71		105.73		105.64	
Supplier	-1.247	0.000	-1.248	0.000	-1.249	0.000	-1.254	0.000
Inhibitor	0.0434	0.459	0.0434	0.457	0.0432	0.458		
crosslinker	0.0703	0.308	0.0702	0.305	0.0703	0.302	0.0656	0.333
catwt	158.9	0.000	158.9	0.000	164.94	0.000	165.38	0.000
mixtime	0.015	0.982						
catdisp	6.5	0.837	6.4	0.838				
S		1.08072		1.07589		1.07132		1.06922
R-sq		87.50%		87.50%		87.50%		87.44%
R-sq(adj)		86.83%		86.94%		87.05%		87.11%
Mallows' Cp		7.00		5.00		3.04		1.59
AICc		363.29		360.99		358.78		357.13
BIC		384.14		379.37		374.64		370.45

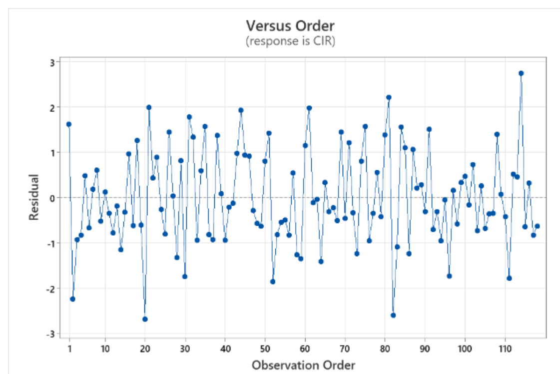
	-----Step 5----	
	Coef	**P**
Constant	105.76	
Supplier	-1.260	0.000
Inhibitor		
crosslinker		
catwt	164.86	0.000
mixtime		
catdisp		
S		1.06898
R-sq		87.33%
R-sq(adj)		87.11%
Mallows' Cp		0.51
AICc		355.93
BIC		366.66

α to remove = 0.15

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	105.76	1.99	53.13	0.000	
Supplier	-1.260	0.250	-5.04	0.000	1.61
catwt	164.86	8.80	18.73	0.000	1.61





Regression Equation

CIR = 105.76 - 1.260 Supplier + 164.86 catwt

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
1.06898	87.33%	87.11%	86.53%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	2	905.91	452.954	396.38	0.000
Supplier	1	29.08	29.082	25.45	0.000
catwt	1	400.85	400.853	350.79	0.000
Error	115	131.41	1.143		
Lack-of-Fit	114	129.18	1.133	0.51	0.837
Pure Error	1	2.23	2.234		
Total	117	1037.32			

Based on the stepwise regression done, we now know that the dominant inputs are **catwt** and **Supplier**. The result of the multilinear regression done with catwt and Supplier as the inputs are shown below. We have added cross predictor in the model ‘catwt * Supplier’ which increases the R sq value of the regression.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	926.18	308.726	316.67	0.000
catwt	1	281.69	281.686	288.93	0.000
Supplier	1	17.17	17.173	17.61	0.000
Supplier*catwt	1	20.27	20.271	20.79	0.000
Error	114	111.14	0.975		
Lack-of-Fit	8	15.94	1.993	2.22	0.032
Pure Error	106	95.20	0.898		
Total	117	1037.32			

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	96.54	2.73	35.32	0.000	
catwt	205.7	12.1	17.00	0.000	3.57
Supplier	14.96	3.56	4.20	0.000	384.49
Supplier*catwt	-74.5	16.3	-4.56	0.000	352.14

Regression Equation

CIR = 96.54 + 205.7 catwt + 14.96 Supplier - 74.5 Supplier*catwt

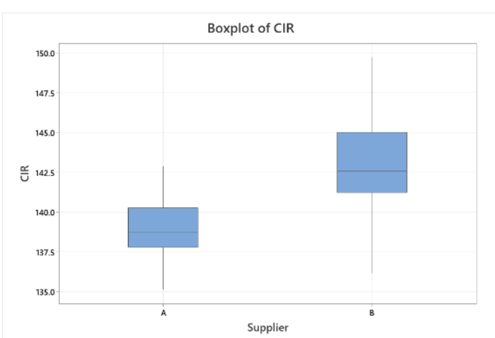
Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.987381	89.29%	89.00%	88.50%

<u>Supplier Effect:</u>

We have 2 suppliers A and B, where we denote A with 1 and B with 0. Carrying out ANOVA test, we get the following result:

Source	DF Num	DF Den	F-Value	P-Value
Supplier	1	103.003	110.07	**0.000**



Since the p value <alpha, there supplier effect which cannot be ignored.

We have already seen that Supplier is a significant process input determining CIR. The regression equation for CIR was calculated as:

CIR= 96.54 +205.7 catwt +14.96 Supplier – 74.5 Supplier * catwt

For Supplier A, Supplier value= 1 → CIR = 111.5 + 131.2 * catwt

For Supplier B, Supplier value= 0 → CIR = 96.54 + 205.7 * catwt

Regression Equation

CIR_A = 111.50 + 131.25 catwt_A

Regression Equation

CIR_B = 96.54 + 205.7 catwt_B

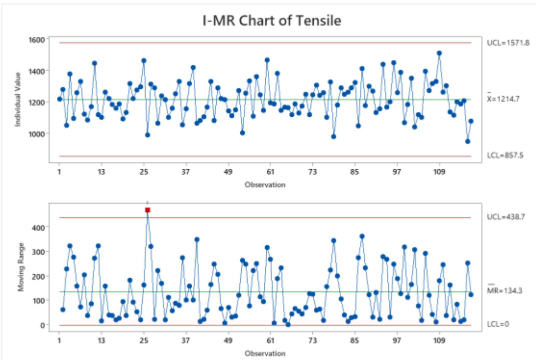
We can see that slope is more for supplier B which means that when base material from Supplier B is used, critical output **CIR** is more sensitive to changes in process input **catwt**.

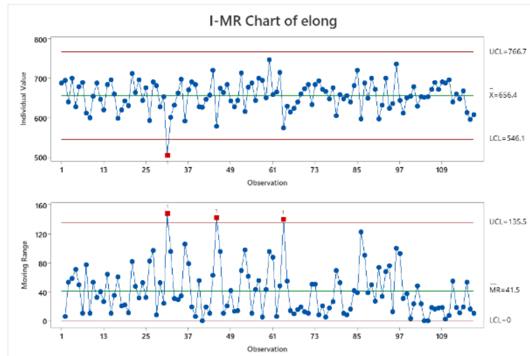
From the process capability analysis, it is evident that more than 90% of the CIR defect arises due to CIR crossing USL which is 145 C. Since the slope is highly positive for supplier B compared to supplier A, base material from supplier B makes the product more prone to CIR defect.

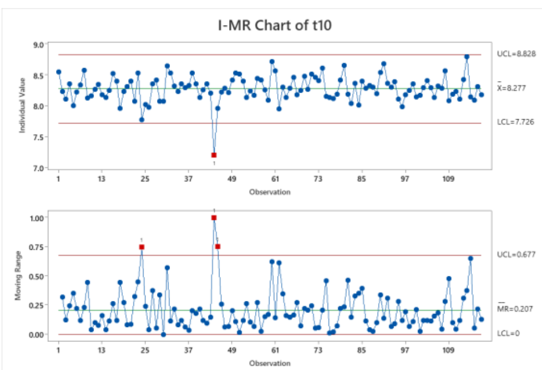
Stability:

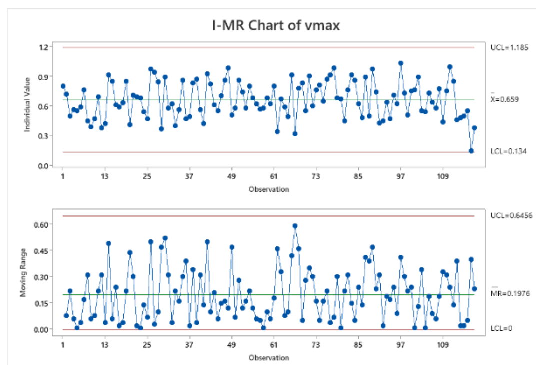
Stability analysis is done for various output parameters of the product and it is found that except vmax, all outputs are out of control or instable.

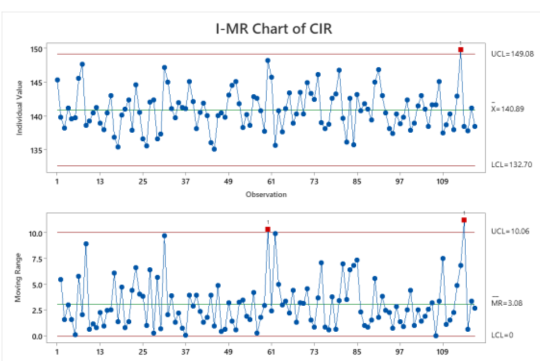
There are special causes affecting output parameters. Control measures should be taken to avoid deviation from standard operating procedure.

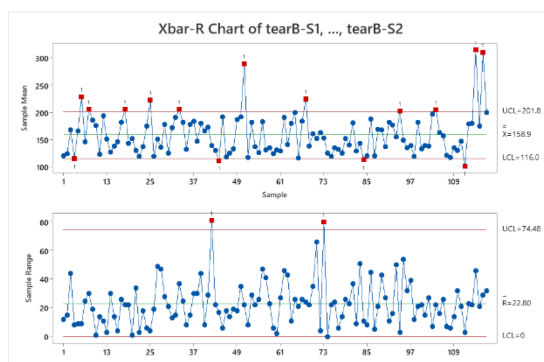










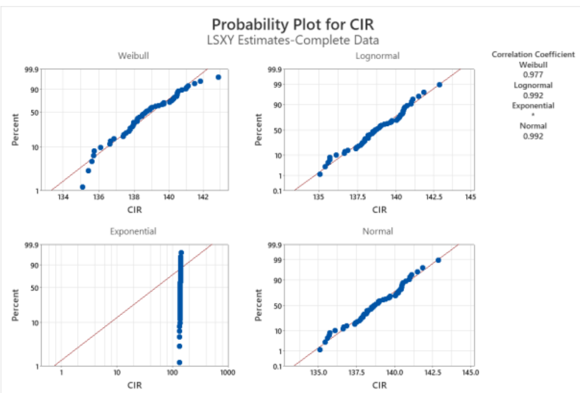


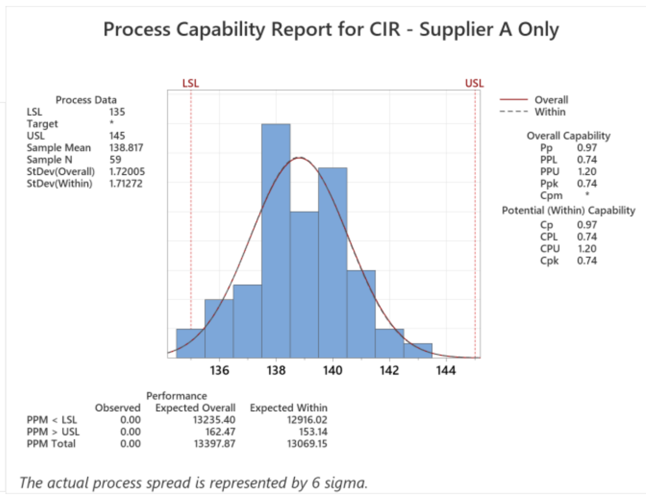
Improve/Control

Based on the regression analyses of the data, the following immediate amendments may be done to minimize CIR defect (which is the dominant defect of the product):

1. Base material from supplier B may be avoided.
2. Process input catwt is a the most significant parameter influencing CIR. Variation of catwt from 0.21% is to be strictly controlled or arrested to the maximum extent. Alternative methods to be used for catalyst addition in correct proportions.

DPM change if we don't use material from supplier B:- Analysis is done for only product data for which base material was supplied by Supplier A. CIR defect data is done for normal distribution.





We can see that observed CIR DPM for Supplier A is 0 and expected overall DPM is **13397**.

With Supplier A&B, expected overall DPM was **105918.** So if the company avoids Supplier B, the CIR DPM will reduce by **87.3%.** That is a major reduction in the product defects.

Financial implications of avoiding Supplier B:

Currently, due to improper curing of the product, it is estimated that customers loss an average of 30 mins a day. At $930/hour for 245 production days, it amounts to a total of 930*245*0.5= **$113925** annually. By avoiding Supplier B base material, the CIR DPM is 13397 against older DPM of 105918. Hence if supplier B is avoided, the loss due to curing temperature variation becomes 113925*(13397/105918) = **$14410.**

Customers will enjoy a financial benefit of 113925-14410 = **$99515** if Liquirubber.com avoids production from Supplier B base material.

A few control measures that may be implemented to keep CIR defects minimum are:

1. Since catwt is a crucial parameter affecting CIR, a better accurate method maybe implemented for catalyst addition. The current method of adding with a jar is highly error prone.
2. Workers/employees may be given additional training on chemical proportions and made to undergo periodic performance review.
3. Automation of chemical mixing may be introduced phase by phase to achieve maximum accuracy in correct chemical proportioning in production process.
4. Air temperature control system maybe employed to maintain optimum temperature level inside the production unit to avoid property variation of Liquirubber.
5. Regular proactive maintenance of machines by OEMs to avoid breakdowns.