Example 2 - Chemical Composition & Mechanical Properties (Steel)

The Problem: A steel casting facility is satisfied with the strength of its castings produced, but it is striving to improve their toughness. Sometimes a unanimous solution that is optimal across multiple responses does not exist. It becomes necessary to compromise by choosing one factor setting over another if one response is considered as more important than another. This example shows the power of p-matrix Data Visualizer 2013 software in assisting experts for choosing between conflicting parameter settings to achieve higher toughness, Charpy V-Notch (CVN) value at 70 degree F while maintaining the Ultimate Tensile Strength (UTS) and Yield Strength (YS) of steel casting.

The process experts identified 21 factors in the process which they felt may contribute to this problem. These are listed in the table below.

Process Parameters									
Operator	Shift	Furnace		Carbon Drop		Pouring Temperature		Argon stir, mts	
Chemistry									
Carbon	%C	Phosporus	%P	Chromium	Cr	Aluminium	%Al	Zirconium	%Zr
Manganese	%Mn	Silicon	%Si	Molybdenum	%Mo	Titanium	%Ti	CE	
Sulphur	%S	Nickel	%Ni	Copper	%Cu	Mn/S Ratio			

Data for above parameters and corresponding mechanical properties were collected for 35 heats. Each row in the Figure below presents a heat.

CVN at 70	UTS	YS	Operator	Shift	Furnac	Carbon Drop	CE	Pouring T	Argon s	%C	%Mn	%S	%P	%Si	%Ni	%Cr	%Mo	%Cu	%Al	%Ti
57	143700	131600	Bob	1	A	59	0.66	2845	10	0.225	0.99	0.006	0.0095	0.43	1.8	1.15	0.55	0.11	0.075	0.0007
56	148100	134700	Sam	2	A	64	0.68	2835	5	0.225	1.06	0.006	0.0165	0.55	1.71	1.28	0.57	0.12	0.083	0.0016
42	124800	106400	Dave	2	A	75	0.66	2855	10	0.225	0.95	0.008	0.0223	0.55	1.78	1.22	0.57	0.099	0.09	0.0011
55	131800	116600	Dave	1	A	35	0.64	2855	6	0.215	0.93	0.005	0.02	0.52	1.86	1.16	0.6	0.097	0.093	0.0013
59	151200	141300	Bob	1	A	62	0.71	2825	4	0.255	1.11	0.008	0.0128	0.41	1.82	1.2	0.58	0.103	0.082	0.0008

Aim: The objective of this study is to investigate if alterations to any of the above parameter ranges can result in high values of toughness while maintaining current levels of alloy strengths.

The Solution: p-matrix analysis is designed to discover how trends in factor settings influence multiple responses. Careful observation of optimal and avoid correlations and interactions will help experts choose the most appropriate setting to improve response(s) and avoid adverse effects. Its findings are proven by evidence in your in-process data. The analysis is not based on statistical assumptions and is free from any pre-conceived conclusions.

Penalty Function for Shrinkage: The foundry experts have indicated desired and undesired values of higher toughness and strength. p-matrix software applies 0 penalty value to desired response 100 penalty value to undesired response and linearly scales the remaining values from 1 to 99.

Response Name	Penalty function	Undesired values	Desired values
CVN at 70 ºF	Higher the better	Below 55	Above 60
UTS	Higher the better	Below 132400	Above 140000
YS	Higher the better	Below 120000	Above 130000

p-matrix Report: p-matrix discovered that low carbon is avoid for strength but optimal for toughness of casting. The interactions of carbon were studied to gain further insight. Low Carbon has strong optimal interactions with middle 50% of Argon stir and bottom 50% of %Mn. Low Carbon also has strong avoid interactions with top 50% of Mn/S ratio and bottom 50% of %S. High S for a lower Mn/S ratio supports high toughness and avoids bad interaction with the carbon. The ranges were compared against the trends reported in the literature.

Response	Re	Low	Higl	Factor nar	Level	Optin	Stre	No.	Max.	Min. Valu	Max. V	Level with Values
UTS	HB	1E+05	1E+05	%C	Bottom 25%	Avoid	2.8	2	3	0.185	0.255	{>=0.185 & <=0.205}
UTS	HB	1E+05	1E+05	%C	Bottom 50%	Avoid	3.5	0		0.185	0.255	[>=0.185 & <=0.215]
CVN at 70	HB	55	60	%C	Bottom 50%	Optimal	2.3	2	3.1	0.185	0.255	[>=0.185 & <=0.215]
CVN at 70	HB	55	60	%C	Bottom 25%	Optimal	2.5	1	2.9	0.185	0.255	{>=0.185 & <=0.205}
UTS	HB	1E+05	1E+05	%C	Top 50%	Optimal	3.5	0		0.185	0.255	[>0.215 & <=0.255]

Summary | Penalty Matrix - Main Effects | Penalty Matrix - Interactions | Main Effects | Interact

F1: %C, Range:Bottom 50%,[>=0.185 & <=0.215]; Strength: 2.3
F2: Argon stir, mts, Range:Middle 50%{>5 & <8}; Strength: 2.1
Strength of Optimal Interaction: 3.1

Penalty	F1:F2	F1:~F2	~F1:F2	~F1:~F2
80-100	1	4	3	6
60-80	1	1	0	1
40-60	0	0	0	1
20-40	0	0	0	0
0-20	8	4	1	4

F1: %C, Range:Bottom 50%,[>=0.185 & <=0.215]; Strength: 2.3
F2: %Mn, Range:Bottom 50%[>=0.89 & <=0.98]; Strength: 1.5
Strength of Optimal Interaction: 3.1

Penalty	F1:F2	F1:~F2	~F1:F2	~F1:~F2
80-100	1	4	5	4
60-80	1	1	0	1
40-60	0	0	0	1
20-40	0	0	0	0
0-20	9	3	2	3

F1: %C, Range:Bottom 25%,{>=0.185 & <=0.205}; Strength: 2.8
F2: Mn/S Ratio, Range:Top 50%[>118.75 & <=186]; Strength: 1.6
Strength of Avoid Interaction: 3.0

Penalty	F1:F2	F1:~F2	~F1:F2	~F1:~F2
80-100	6	2	2	3
60-80	0	0	1	0
40-60	0	1	0	0
20-40	0	0	1	1
0-20	0	4	7	7

F1: %C, Range:Bottom 25%,{>=0.185 & <=0.205}; Strength: 2.8
F2: %S, Range:Bottom 50%[>=0.005 & <=0.008]; Strength: 1.6
Strength of Avoid Interaction: 3.0

Penalty	F1:F2	F1:~F2	~F1:F2	~F1:~F2
80-100	6	2	3	2
60-80	0	0	0	1
40-60	0	1	0	0
20-40	0	0	1	1
0-20	0	4	8	6

The main effects sheet shows complementary settings of the avoid factor ranges with an optimal main effect. Bottom 50% of Manganese to Sulphur ratio and Top 50% of Sulphur are optimal for the response. Even if their main effect strength is low, it is important to note the trend.

Response	Re	Low	Higl	Factor name	Level	Optin	Stre	No.	Max.	Min. Valu	Max. V	Level with Values
CVN at 70	HB	55	60	%Mn	Bottom 50%	Optimal	1.5	4	3.4	0.89	1.17	[>=0.89 & <=0.98]
UTS	HB	1E+05	1E+05	%S	Top 50%	Optimal	1.6	2	3.3	0.005	0.098	[>0.008 & <=0.098]
CVN at 70	HB	55	60	Argon stir, mts	Middle 50%	Optimal	2.1	3	3.4	4	17	{>5 & <8}
CVN at 70	HB	55	60	Argon stir, mts	Bottom 50%	Optimal	2.1	3	3.5	4	17	[>=4 & <=6]
UTS	HB	1E+05	1E+05	Mn/S Ratio	Bottom 50%	Optimal	1.6	1	3.4	9.7959184	186	[>=9.79591836734694 & <=118.75]

Summary | Penalty Matrix - Main Effects | Penalty Matrix - Interactions | Main Effects | Interact

Conclusion: Refer to the YouTube presentation on 7Epsilon Confirmation Trial Plan for multiple responses for further details on this case study. For more information, visit us at www.7Epsilon.org.