Penalty Matrix Approach

Casting Process Optimization using the penalty matrix approach is the methodology of using existing knowledge to discover new knowledge by studying patterns in data. Most foundries record production or in-process data on mold/cast material properties, chemical compositions, process parameters, design changes done, operators and machines, ovens or furnaces etc. Current rejection levels in foundries are around 4-5%. The penalty matrix approach aims to reduce the rejection levels further down by 1-2%. Penalty matrices help you visualize process data on factors to choose optimal ranges of several process parameters for simultaneous adjustment to attain desired response.

The Method is demonstrated on a typical production data for a Ni based alloy with chemical factors and defect shrinkage values for 60 batches. Each row in the Figure below presents a batch.

Shrink Scrap (%)	Parts	Carbon	Aluminium	Boron	Cobalt	Chromium	Copper	Iron	Molybdenu	Niobium
0.12	SF01	0.101	3.23	0.009	7.857	15.2	<0.02 %	0.086	1.663	0.846
0	SF01	0.093	3.145	0.009	7.971	15.295	<0.02 %	0.086	1.644	0.798
0.15	SF01	0.107	3.249	0.009	7.781	15.248	<0.02 %	0.152	1.691	0.893

Data was collected for 15 chemical factors shown below:

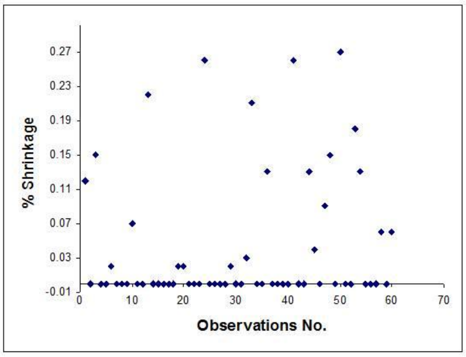
Carbon	C	Cobalt	Co	Iron	Fe	Tantalum	Ta	Tungsten	W	Al + Ti
Aluminium	Al	Chromium	Cr	Molybdenum	Mo	Titanium	Ti	Nitrogen	N	Ta/Ti
Boron	B	Copper	Cu	Niobium	Nb	Zirconium	Zr	Oxygen	O_2	

Objective: The objective of penalty matrix analysis for this example is to discover optimal factor settings and settings to avoid minimizing the occurrence of shrinkage in the casting.

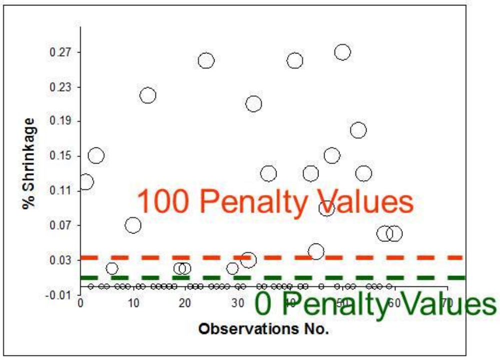
Penalty Function for %Shrinkage defect per batch: The variability of the process response is analysed using scatter diagrams. The response scatter diagram shows the scatter for %rejection due to shrinkage defect per batch. The first step in the data analysis stage is to identify regions of desired and undesired response variation. A zero penalty value is assigned to desired response i.e. 0 shrinkage values and a 100 penalty value is assigned to undesired response values e.g. when %shrinkage exceeds 3%. For intermediate values the penalty is scaled between zero and hundred. In the Figures shown on the next page, the smaller size bubbles represent 0 penalty for desired response and larger size bubbles as 100 penalty values for unacceptable response values.

Main Effects Bubble Diagram and Penalty Matrix: The novelty in this approach is that the response penalty values are transferred onto factor scatter diagrams. It checks if top, middle or bottom range of the factor explains the variability of penalty values in one or more responses. It’s clear that values in the top 50% region of Zirconium have shown correlation with desired variation or low percentage shrinkage rate as it has more number of bubbles with smaller diameter. The penalty matrix tabulates this information as number of points that occur in quartile factor regions (Q1-bottom 25%, Q1+Q2-bottom 50%, Q2+Q3–middle 50%, Q3+Q4-top 50%, Q4-top 25%) with corresponding response penalty in order to discover new knowledge after conducting a confirmation trial. This helps to innovate – a major driving force in the 7Epsilon approach.

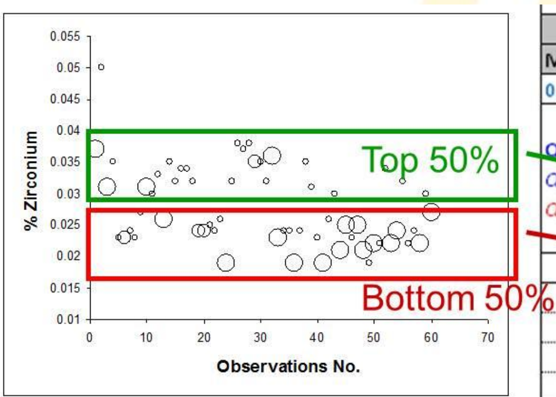
Interactions Bubble Diagram and Penalty Matrix: Interactions penalty matrices check whether any combination of factors settings is likely to explain the variability of penalty values in one or more responses. The interaction bubble diagram plots the Zirconium reading for a batch on the y-axis and Boron reading on the x axis and shows the corresponding penalty values as the diameter of the circle. Interactions become evident and visible in this format. The corresponding interactions penalty matrix is shown on the right. A factor setting with strong main effect strength is influential and can be included in your confirmation trial plan. However, the one with low strength is equally important if it has one or more strong interactions. Refer to 7Epsilon YouTube videos for further details. For more information visit us at www.7Epsilon.org.



Response Scatter Diagram



Response Bubble Diagram



Main Effects Bubble Diagram

	Q1	Q2	Q3	Q4
Minimum		Median		Maximum
0.019	0.023	0.026	0.032	0.05

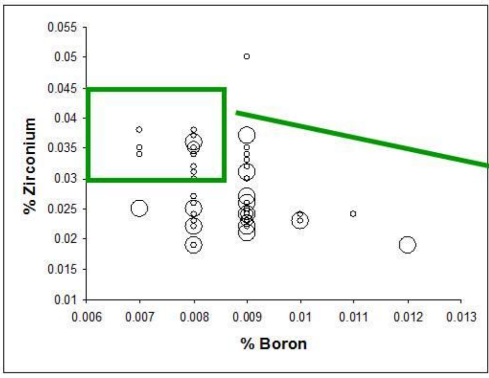
Q4: Optimal; Range: Top 25%, {>=0.032 & <=0.05}; Strength: 3.5; No. of Interactions: 0

Q3 & Q4: Optimal: Range: Top 50%, [>0.026 & <=0.05]; Strength: 2.8; No. of Interactions: 1

Q1 & Q2: Avoid; Range: Bottom 50%, [>=0.019 & <=0.026]; Strength: 2.8; No. of Interactior

Penalty	Q1	Q2	Q3	Q4
80-100	9	4	3	2
60-80	1	2		1
40-60				
20-40				
0-20	7	9	5	17

Penalty Matrix



Interactions Bubble Diagram

F1: Zirconium, Range:Top 50%,[>0.026 & <=0.05]; Strength: 2.8

F2: Boron, Range:Bottom 50%,[>=0.007 & <0.009]; Strength: 2.0

Strength of Optimal Interaction: 3.8

Penalty	F1:F2	F1:¬F2	¬F1:F2	¬F1:¬F2
80-100	1	4	5	8
60-80	1	0	0	3
40-60	0	0	0	0
20-40	0	0	0	0
0-20	15	7	5	11

Penalty Matrix