How to Design and Analyze Experiments with Pass/Fail Responses Discovery Europe – March 2024

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JMP. STATISTICAL DISCOVERY

Design & Analysis of Pass/Fail Experiments Introduction

- Widget Experiment Example
- It's all about the model
- How to properly analyze experimental data
- How to right-size an experiment





Widget Experiment Example

- Does the widget have a defect? Current defect rate: 15%
- Goal: bring rate down to 5%
- Change of 3 5% or more is of practical importance
- Runs take about 10 minutes









	Hold Time	Pressure	Temp	Additive	Y1
1	30	1.25	45	20	
2	45	1	35	15	
3	37.5	1.5	45	15	
4	30	1	40	10	
5	37.5	1.25	40	15	
6	30	1	45	15	
7	37.5	1.25	40	15	
8	45	1	45	10	
9	45	1.5	45	20	
10	30	1.5	45	10	
11	45	1.5	35	10	
12	30	1.5	35	10	
13	37.5	1	45	20	
14	37.5	1.5	35	20	
15	37.5	1	35	10	
16	37.5	1.25	40	10	
17	45	1.5	40	15	
18	37.5	1.25	40	15	
19	37.5	1.25	40	15	
20	30	1.25	35	15	
21	45	1	40	20	
22	45	1.25	35	20	
23	30	1.5	40	20	
24	30	1	35	20	





Pick Role Variables		Personality:	Nominal Logistic	0)		
Y	optional	Target Level:	1 📀			,	• •
Weight	optional numeric	Recall	Keep dialog op	en			-
Freq	optional numeric	Remove					
Validation	optional numeric						
Switch	optional						Conv ►
Ву	optional						► F ► L
Construct Model Eff	leate						- F
Add Cross Nest	Hold Time & RS Temp & RS Temp*Temp Pressure & RS Additive & RS Hold Time*Hold Time Hold Time*Pressure						T F T
Macros V Degree 2 Attributes V Transform V	Pressure*Pressure Hold Time*Temp Pressure*Temp						

Nominal Logistic Fit for Y1

Effect Summary

Source	Logwo	rth			PValu
Hold Time(30,45	5) 4.2	202			0.0000
Temp(35,45)	2.4	06			0.0039
Temp*Temp	1.8	60			0.0138
Remove Add	Edit	FDR			
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terations					
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it Details ack Of Fit Parameter B	Estimat	es Estimate	Std Error	ChiSquare	Prob>ChiSq
Fit Details ack Of Fit Parameter B Ferm	Estimat	Estimate -1 3862944	Std Error 1.118034	ChiSquare 1.54	Prob>ChiSq 0.2150
Fit Details ack Of Fit Parameter B ferm ntercept Hold Time(30,4 5)	Estimat Unstable	es -1 3862944 -3 1.053912	Std Error 1.118034 2127.4196	ChiSquare 1.54 0.00	Prob>ChiSq 0.2150 0.9884
Tit Details ack Of Fit Parameter I form htercept fold Time(30,4 5) form(35,45)	Estimat Unstable Unstable	es Estimate -1 3862944 -3 1.053912 16 2459153	Std Error 1.118034 2127.4196 1451.2715	ChiSquare 1.54 0.00 0.00	Prob>ChiSq 0.2150 0.9884 0.9911
it Details ack Of Fit Parameter B erm Intercept Iold Time(30,4 i) emp(35,45) emp*Temp	Unstable Unstable Unstable	Estimate -1 3862944 -3 1.053912 16 2459153 -3 0.136765	Std Error 1.118034 2127.4196 1451.2715 2064.6278	ChiSquare 1.54 0.00 0.00 0.00	Prob>ChiSq 0.2150 0.9884 0.9911 0.9884



1 30 1.25 45 20 1 3 5 0.6 2 45 1 35 15 0 0 5 0 3 37.5 1.5 45 15 0 2 5 0.4 4 30 1 40 10 1 1 5 0.2 5 37.5 1.25 40 15 1 0 5 0 6 30 1 45 15 1 5 5 1 7 37.5 1.25 40 15 0 4 5 0.8 8 45 1 45 10 0 0 5 0 9 45 1.5 45 10 1 4 5 0.8 11 45 1.5 35 10 0 1 5 0.2 12 30 1.5 <t< th=""><th></th><th>Hold Time</th><th>Pressure</th><th>Temp</th><th>Additive</th><th>Y1</th><th>Y5</th><th>N</th><th>p Failure</th></t<>		Hold Time	Pressure	Temp	Additive	Y1	Y5	N	p Failure
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3 37.5 1.5 45 15 0 2 5 0.4 4 30 1 40 10 1 1 5 0.2 5 37.5 1.25 40 15 1 0 5 0 6 30 1 45 15 1 5 5 1 7 37.5 1.25 40 15 0 4 5 0.8 8 45 1 45 10 0 0 5 0 9 45 1.5 45 20 0 0 5 0 10 30 1.5 45 10 1 4 5 0.8 11 45 1.5 35 10 0 1 5 0.2 12 30 1.5 35 20 0 3 5 0 13 37.5 1 <	2	45	1	35	15	0	0	5	0
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5 37.5 1.25 40 15 1 0 5 0 6 30 1 45 15 1 5 5 1 7 37.5 1.25 40 15 0 4 5 0.8 8 45 1 45 10 0 0 5 0 9 45 1.5 45 20 0 0 5 0 9 45 1.5 45 20 0 1 4 5 0.8 11 45 1.5 35 10 0 1 5 0.2 12 30 1.5 35 10 0 3 5 0 13 37.5 1 45 20 0 3 5 0 13 37.5 1 35 20 0 2 5 0 14 37.5	4	30	1	40	10	1	1	5	0.2
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7 37.5 1.25 40 15 0 4 5 0.8 8 45 1 45 10 0 0 5 0 9 45 1.5 45 20 0 0 5 0 10 30 1.5 45 10 1 4 5 0.8 11 45 1.5 35 10 0 1 5 0.2 12 30 1.5 35 10 0 0 5 0 13 37.5 1 45 20 0 3 5 0 13 37.5 1.5 35 20 0 3 5 0 14 37.5 1.5 35 20 0 3 5 0 15 37.5 1.25 40 10 0 2 5 0 16 37.5 1.25 40 15 0 0 5 0 18 37.5 1.25<	6	30	1	45	15	1	5	5	1
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1637.51.254010005017451.5401500501837.51.25401500501937.51.254015005020301.25351500502145140200250.422451.2535200250.423301.540201250.42430135200150.2	15	37.5	1	35	10	0	2	5	0.4
17451.5401500501837.51.25401500501937.51.254015005020301.253515005021451402005022451.2535200250.423301.540201250.42430135200150.2	16	37.5	1.25	40	10	0	0	5	0
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1937.51.254015005020301.2535150050214514020005022451.2535200250.423301.540201250.42430135200150.2	18	37.5	1.25	40	15	0	0	5	0
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	24	30	1	35	20	0	1	5	0.2

p Failure	Personality: Emphasis:	Standard Least Squares Minimal Report	 O
optional numeric optional numeric	Help Recall Remove	Run Keep dialog open	
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•	Respo	nse p	Failure				
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	Remo	ve Add	Edit	FDR (**	denotes	effects with c	ntaining effects above them)
⊧	Lack (Of Fit					
v	Summ	ary of	Fit				
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¥	Analys	sis of \	Variance)		22	
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	Model	3	1.3187805	5 0.43	9593	9.3409	
	Error C. Total	20	0.9412195	5 0.04)	7061	Prob > F	
Ŧ	Param	neter E	stimate	S		0.0000	
	Term		Estimate	Std Error	t Rati	io Prob>	
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	Effect.						
▶.	Effect	lests					





Widget Experiment Example

	ne week res »	• • One	e week results	Data Filt	er Tabula	ate Grap	h Builder	Distributio	n Fit Y by X	Fit Model	>>
 Distrib Y1 	utions	One week Distriof Y1		Hold Time	Press ure	Temp	Additive	Y1			
			1	45	1.25	45	15	Fail			
			2	45	1.25	45	15	Fail			
			3	45	1.25	45	15	Fail			
		Columns (5/0)	4	45	1.25	45	15	Fail			
Pass		۹	5	45	1.25	45	15	Fail			
		Hold Time *	6	45	1.25	45	15	Fail			
		Pressure *	7	45	1.25	45	15	Fail			
		Additive *	8	45	1.25	45	15	Pass			
		📕 Y1 🛠	9	45	1.25	45	15	Fail			
			10	45	1.25	45	15	Fail			
			11	45	1.25	45	15	Fail			
Fail			12	45	1.25	45	15	Fail			
			13	45	1.25	45	15	Fail			
			14	45	1.25	45	15	Fail			
_		Rows	15	45	1.25	45	15	Fail			
-	•	All rows 1,000	16	45	1.25	45	15	Pass			
▼ Freq	uencies	Selected 0	17	45	1.25	45	15	Fail			
Level	Count Prob	Excluded 0	18	45	1.25	45	15	Fail			
Fail Pass	899 0.89900 101 0.10100	Labeled 0	19	45	1.25	45	15	Fail			
N Miss 2	sing 0 Levels										



It's all about the model

The typical model

$P[fail] = f(X) = \beta_0 + \beta_1 \text{Hold Time} + \beta_2 \text{Pressure} + \dots$

- Assumptions of typical model:
 - Linear relationship
 - Unbounded response range
 - Normal residuals
- Can we fix these issues with a transformation on the failure probability or by using a different distribution?







It's all about the model

Three options

$$Log\left(\frac{P[fail]}{P[pass]}\right) = Log\left(\frac{P[fail]}{1 - P[fail]}\right)$$

 $\Phi^{-1}[P[fail]] = Normal Quantile(P[fail])$

$$Log\{-Log(1 - P[fail])\}$$

- All three assume Binomial (i.e., not Normal) errors
- The first two are built into JMP platforms. The last one can be modeled using the Nonlinear platform.



Logit

Probit

Complementary Log-Log



Design & Analysis of Pass/Fail Experiments How to properly analyze experimental data – Overview

- Fit Model Nominal Logistic Regression (JMP)
- Fit Model Generalized Linear Model (JMP)
- Fit Model Generalized Regression (JMP Pro)
- Fit Y by X (one Y and one X only)/Nonlinear



How to properly analyze experimental data – Data Organization

• How should the data be organized? Example: 2 factor, four run experiment with five trials per unique treatment condition

	Time	Temperature	
1	30	37	
2	30	20	
3	45	20	
4	45	37	



F	Treatment Condition	Time	Temperature	Y
1	1	30	20	Green
2	1	30	20	Red
3	1	30	20	Green
4	2	30	37	Green
5	4	45	37	Green
6	1	30	20	Red
7	3	45	20	Red
8	3	45	20	Green
9	1	30	20	Red
10	2	30	37	Green
11	3	45	20	Green
12	2	30	37	Red
13	4	45	37	Green
14	3	45	20	Red
15	2	30	37	Green
16	2	30	37	Red
17	4	45	37	Red
18	3	45	20	Green
19	4	45	37	Green
20	4	45	37	Green

	Treatment Condition	Time	Temperature	Y	N	
1	1	30	20	Green	2	
2	2	30	37	Green	3	
3	3	45	20	Green	3	
4	4	45	37	Green	4	
5	1	30	20	Red	3	
6	2	30	37	Red	2	
7	3	45	20	Red	2	
8	4	45	37	Red	1	

	Treatment Condition	Time	Temperature	N Green	N Total	
1	1	30	20	2	5	
2	2	30	37	3	5	
3	3	45	20	3	5	
4	4	45	37	4	5	

Raw

Summarized Stacked

Summarized Split



Live demo here! Fitting models to pass/fail data



How to right-size an experiment

- Use the Custom Design platform to create the intended design.
- Before generating the final design table turn on Simulate Responses under the hotspot in the top outline.
- Create the JMP Data Table containing the design. A dialog box will appear letting you change the default coefficients and error distribution.
 - Change the coefficients to the desired magnitude. Details are on the next slide.
 - Change the error type to Binomial and set the sample size to the desired value.
 - Click Apply
- The equation to use for the simulation is saved as a formula in the Y Simulated column.

tended design. Simulate Responses under



How to right-size an experiment – Calculate Coefficients

- The coefficient values will depend on the underlying model, the value at the baseline probability and the probability value at which an observation is considered important. The absolute difference between these last two values corresponds to the effect size to use in the dialog
- Logit baseline

$$Log\left(\frac{P[target]}{1 - P[target]}\right) = Log\left(\frac{0.15}{1 - 0.15}\right) = -1.73$$

• If we are interested in detecting a change to at least a 10% failure rate

$$Log\left(\frac{0.1}{1-0.1}\right) = -2.2$$
 Making the coefficient Ab

 $ps[-1.73 - (-2.2)] \approx 0.5$



Continue live demo!

Sizing an experiment through simulation

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- Use the Fit Model platform for analysis. There are three options
 - Logistic Regression (+Stepwise Regression)
 - Generalized Linear Model
 - Generalized Regression (JMP Pro)
- Size the experiment properly by simulating experimental runs from the proposed design using JMP's built in bootstrap simulation feature (JMP Pro).



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Supplementary Slides

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How to properly analyze experimental data – Data Organization

- Raw data: One column containing the nominal response level. One row per observations.
- Summarized Stacked: One column of counts aggregated over response level and unique treatment conditions, one column giving response level
- Summarized Split: One column of counts aggregated over **one** response level and unique treatment conditions, one column giving total counts for the unique treatment condition.



	Treatment Condition	Time	Temperature	Y
1	1	30	20	Green
2	1	30	20	Red
3	1	30	20	Green
4	2	30	37	Green
5	4	45	37	Green
6	1	30	20	Red
7	3	45	20	Red
8	3	45	20	Green
9	1	30	20	Red
10	2	30	37	Green
11	3	45	20	Green
12	2	30	37	Red
13	4	45	37	Green
14	3	45	20	Red
15	2	30	37	Green
16	2	30	37	Red
17	4	45	37	Red
18	3	45	20	Green
19	4	45	37	Green
20	4	45	37	Green

Raw

riables		
	optional	
nt	optional numeric	
	optional numeric	



	Treatment Condition	Time	Temperature	Y	N	
1	1	30	20	Green	2	
2	2	30	37	Green	3	
3	3	45	20	Green	3	
4	4	45	37	Green	4	
5	1	30	20	Red	3	
6	2	30	37	Red	2	
7	3	45	20	Red	2	
8	4	45	37	Red	1	



Summarized Stacked

	Treatment Condition	Time	Temperature	N Green	N Total	
1	1	30	20	2	5	
2	2	30	37	3	5	
3	3	45	20	3	5	
4	4	45	37	4	5	



Pick



ole Variables	
Y	optional
Weight	optional numeric
Freq	▲ N

Role Variabl	es
Y	▲ Y ▲ N
Weight	optional numeric
Freq	optional numeric



	Treatment Condition	Time	Temperature	Y	N	
1	1	30	20	Green	2	
2	2	30	37	Green	3	
3	3	45	20	Green	3	
4	4	45	37	Green	4	
5	1	30	20	Red	3	
6	2	30	37	Red	2	
7	3	45	20	Red	2	
8	4	45	37	Red	1	



Summarized Stacked

	Treatment Condition	Time	Temperature	N Green	N Total	
1	1	30	20	2	5	
2	2	30	37	3	5	
3	3	45	20	3	5	
4	4	45	37	4	5	

Summarized Split

Pick



ole Variables	
Y	optional
Weight	optional numeric
Freq	▲ N

Role Variabl	es
Y	▲ Y ▲ N
Weight	optional numeric
Freq	optional numeric



Nominal Logistic Regression

- Fit Model (JMP)
- Data organized in raw or summarized stacked format
- Nominal response
- Personality: Nominal Logistic or Stepwise
- Target Level: associates the chosen level with the modeled probability . The other level is calculated as 1 minus the modeled probability.





Generalized Linear Model

- Fit Model (JMP)
- Data organized in any of the three formats
 - To use the Summarized Split format, both columns need to be **Continuous**. The first contains the counts for the target level, the other the total counts. The response needs to be Nominal for the other two formats.
- Distribution: Binomial
- Link Function: Logit or Probit





Generalized Regression

- **Fit Model** (JMP Pro)
- Any data organization. Similar set-up to Generalized Linear Model.
- **Target Level**: same as Logistic Regression
- Distribution: Binomial
- **Run** generates a report for a full logistic regression model. Reduced and alternative models are available under Model Launch.





Design & Analysis of Pass/Fail Experiments How to right-size an experiment – Determine the Effect Directions

- The direction of the coefficients (i.e., whether they're positive or negative) will affect the results to a lesser extent and can also be added.
- Main effects: will the response increase (+) or decrease (-) as the factor increases?
- Two factor interactions: is the relationship between factors synergistic (+) or antagonistic (-)
- Quadratic effects: do you expect the response curve to produce a maxima (+) or minima (-).

Effect	Main Effect	Quadratic
Hold Time	+	+
Pressure	+	+
Temperature	_	+
Additive	+	_

Effect	Direction
Hold Time x Pressure	+
Hold Time x Temperature	_
Hold Time x Additive	+
Pressure × Temperature	+
Pressure x Additive	+
Temperature x Additive	+



Design & Analysis of Pass/Fail Experiments How to right-size an experiment – Analyze Results/Run Simulation

- Using the Generalized Regression or Generalized Linear Model option, fit a model to the data. Logistic Regression can also be used, but only if the data is in raw format.
 - Data in Summarized Stacked format should be avoided because it requires complex changes be made to the simulation formula.
- Hover over a p-value column in a parameter estimates or effect tests table. Right click and select Simulate.
- In the resulting dialog, make sure Column to Switch Out and Column to Switch In are both selected to be the simulation column. Set Number of **Samples** to the desired value and click **OK**.
- Simulate will rerun the simulation column formula for each run and reanalyze the data using the method chosen above.



Design & Analysis of Pass/Fail Experiments How to right-size an experiment – Analyze Simulation Results

- The resulting report window contains Distribution and Power Analysis scripts. The later is a subset of the former.
 - **Power Analysis** provides an estimate of effect p-values along with a confidence interval at different alpha values. It also counts the number of rejected effects at four different alpha values (0.01, 0.05, 0.10, 0.20) and provides credible intervals for these value.
 - **Distribution** adds the distribution graphs, quantiles and summary statistics
- Creating a summary counting the number of correctly and incorrectly identified effects broken down by type (main effect, two-factor interaction and quadratic) could also be beneficial.

