

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

GOALS:

1. Learn the properties of the χ^2 Distribution.
2. Understand how the shape of the χ^2 Distribution changes as the df increases.
3. Be able to find p-values.
4. Recognize that χ^2 tests are right-tailed only.
5. Use the "Goodness of Fit" χ^2 test to compare samples to known or expected distributions.

Study Ch. 13.1, # 1-4 all

Study Ch. 13.2, # 9-15, 25, 27, 31

[# 11-17, ~27, 29, ~33]

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[link to geogebra demo](#)

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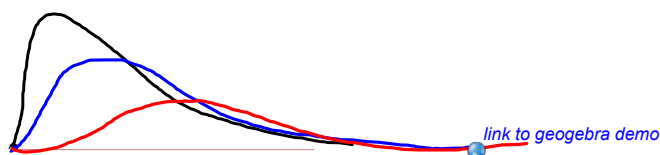
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[Homework2](#)

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

Chi-Squared distribution, χ^2

1. Not symmetrical: Right-skewed.
On left, starts at 0 on x-axis.
On right, approaches x-axis as asymptote.
2. Area under χ^2 Curve = 1
3. Different curves for different df
As df increases, $\chi^2 \rightarrow$ normal curve



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[Statistics Home Page](#)

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[Homework1](#)

[Homework2](#)

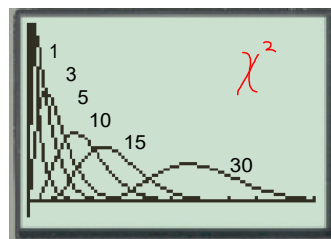
[link to geogebra demo](#)

χ^2

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

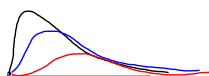
Graph Chi-Squared distribution, χ^2 , on Calculator[link to geogebra demo](#)

1. Enter into L1:
1, 3, 5, 10, 15, 30
2. WINDOW:
xmin: -0.02
xmax: 50
xscale: 5
ymin: -0.02
ymax: 0.25
3. $y = 2\text{nd DISTR } \chi^2\text{pdf}(x, L1)$
4. GRAPH



df from 1 to 30

Different curves for different df

As df increases, $\chi^2 \rightarrow$ normal curve

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[Statistics Home Page](#)[Class Notes](#) [Homework1](#) [Homework2](#) χ^2

$\chi^2_{0.10}$	$\chi^2_{0.05}$	$\chi^2_{0.025}$	$\chi^2_{0.01}$	$\chi^2_{0.005}$	df
2.706	3.841	5.024	6.635	7.879	1
4.605	5.991	7.378	9.210	10.597	2
6.251	7.815	9.348	11.345	12.838	3
7.779	9.488	11.143	13.277	14.860	4
9.236	11.070	12.833	15.086	16.750	5
10.645	12.592	14.449	16.812	18.548	6
12.017	14.067	16.013	18.475	20.278	7
13.362	15.507	17.535	20.090	21.955	8
14.684	16.919	19.023	21.666	23.589	9
15.987	18.307	20.483	23.209	25.188	10
17.275	19.675	21.920	24.725	26.757	11
18.562	21.026	23.337	26.217	28.306	12
19.833	22.362	24.736	27.688	29.829	13
21.064	23.685	26.217	29.141	31.319	14
22.262	25.000	27.688	30.578	32.695	15
23.435	26.296	29.141	32.000	34.152	16
24.568	27.587	30.578	33.409	35.583	17
25.669	28.771	32.000	34.805	37.000	18
26.742	29.937	33.409	36.191	38.582	19
27.779	31.073	34.805	37.566	40.015	20
28.791	32.191	36.191	38.932	41.401	21
29.765	33.291	37.566	40.289	42.796	22
30.813	34.379	38.932	41.638	44.181	23
31.833	35.454	40.289	42.980	45.559	24
32.842	36.516	41.638	44.314	46.928	25
33.842	37.566	42.980	45.642	48.290	26
34.833	38.582	44.314	46.963	49.645	27
35.813	39.578	45.642	48.278	50.994	28
36.779	40.551	46.963	49.588	52.336	29
37.733	41.501	48.278	50.892	53.672	30
38.684	42.437	49.588	52.196	55.000	31
39.633	43.459	50.892	53.496	56.329	32
40.579	44.460	52.196	54.796	57.658	33
41.513	45.449	53.496	56.092	58.988	34
42.435	46.426	54.796	57.378	60.309	35
43.346	47.391	56.092	58.658	61.651	36
44.246	48.334	57.378	59.924	62.996	37
45.135	49.256	58.658	61.158	64.324	38
46.013	50.156	59.924	62.378	65.645	39
46.881	51.034	61.158	63.578	66.959	40
47.739	51.899	62.378	64.766	68.256	41
48.587	52.743	63.578	65.946	69.546	42
49.425	53.566	64.766	67.111	70.829	43
50.253	54.368	65.946	68.266	72.106	44
51.071	55.149	67.111	69.406	73.367	45
51.879	55.909	68.266	70.534	74.622	46
52.677	56.649	69.406	71.651	75.874	47
53.465	57.369	70.534	72.758	77.153	48
54.243	58.069	71.651	73.851	78.421	49
55.011	58.749	72.758	74.934	79.679	50
55.769	59.409	73.851	76.006	80.929	51
56.517	60.049	74.934	77.066	82.161	52
57.255	60.669	76.006	78.116	83.379	53
57.983	61.269	77.066	79.156	84.584	54
58.701	61.849	78.116	80.186	85.776	55
59.409	62.409	79.156	81.206	86.956	56
60.107	62.949	80.186	82.216	88.124	57
60.795	63.469	81.206	83.216	89.279	58
61.473	63.969	82.216	84.206	90.421	59
62.141	64.449	83.216	85.186	91.549	60
62.799	64.909	84.206	86.156	92.664	61
63.447	65.349	85.186	87.116	93.766	62
64.085	65.769	86.156	88.066	94.856	63
64.713	66.169	87.116	89.006	95.934	64
65.331	66.549	88.066	90.034	97.001	65
65.939	66.909	89.006	91.054	98.056	66
66.537	67.249	90.034	92.064	99.101	67
67.125	67.569	91.054	93.064	100.134	68
67.703	67.869	92.064	94.054	101.156	69
68.271	68.149	93.064	95.034	102.166	70
68.829	68.409	94.054	96.006	103.164	71
69.377	68.649	95.034	96.966	104.151	72
69.915	68.869	96.006	97.916	105.126	73
70.443	69.069	96.966	98.856	106.091	74
70.961	69.249	97.916	99.786	107.036	75
71.469	69.409	98.856	100.706	107.971	76
71.967	69.549	99.786	101.616	108.896	77
72.455	69.669	100.706	102.516	109.811	78
72.933	69.769	101.616	103.406	110.716	79
73.401	69.849	102.516	104.286	111.611	80
73.859	69.909	103.406	105.156	112.496	81
74.307	69.959	104.286	106.016	113.371	82
74.745	69.999	105.156	106.866	114.236	83
75.173	70.029	106.016	107.706	115.091	84
75.591	70.049	106.866	108.536	115.936	85
76.000	70.059	107.706	109.356	116.771	86
76.399	70.059	108.536	110.166	117.596	87
76.789	70.049	109.356	110.966	118.411	88
77.169	70.029	110.166	111.756	119.216	89
77.539	70.000	110.966	112.536	120.011	90
77.899	69.960	111.756	113.306	120.796	91
78.249	69.910	112.536	114.066	121.571	92
78.589	69.850	113.306	114.816	122.336	93
78.919	69.780	114.066	115.556	123.091	94
79.239	69.700	114.816	116.286	123.836	95
79.549	69.610	115.556	117.006	124.571	96
79.849	69.510	116.286	117.716	125.296	97
80.139	69.400	117.006	118.416	126.011	98
80.419	69.280	117.716	119.106	126.716	99
80.689	69.150	118.416	119.786	127.411	100

Can use the tables to estimate the p-value:

If Given:

test $\chi^2 = 13.094$, df = 6 $0.025 < p < 0.05$

OR,

Can compute the p-value on the calculator:

$$p = 1 - \chi^2\text{cdf}(0, 13.094, 6)$$

$$= 0.0416$$

Using

$$p = 1 - \chi^2\text{cdf}(0, \text{test } \chi^2, \text{df})$$

* Right-tailed only *

p

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Goodness-of-Fit Test

Used to compare one distribution to another.

Requires:

1. simple random sample,
2. adequate sample size.

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[Statistics Home Page](#)

[Class Notes](#)

[Homework1](#)

[Homework2](#)

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

In 1990 the distribution of cars, by type, was: 32.8 % small, 44.8% medium size, 9.4% large, and 13.0% larger (eg. SUV). For a recent simple random sample of 500 cars, car type is listed below. Has the distribution of car type changed?

	Obs
S	133
M	249
L	47
Lx	71
Total	500

Given Probability:

.328

.448

.094

.130

Need to compare observed values with **the expected distribution**, based on assumptions (prior data, general knowledge, etc.)

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[Statistics Home Page](#)

[Class Notes](#)

[Homework1](#)

[Homework2](#)

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

Chi-Square Goodness-of-Fit *only Right-tailed***Step 1A:** Calculate the expected frequencies $E = np$ where n = sample size, p = rel freq or probability; compare to assumptions

- Assumptions:
1. All expected frequencies ≥ 1
 2. At most 20% of the expected frequencies are less than 5
 3. SRS

Step 1B: H_0 : The variable has the specified distribution. H_a : The variable does not have the specified distribution.**Step 2:** Decide α **Step 3:** Compute the test statistic, using a table of values:

$$\chi^2_r = \sum \left[\frac{(O - E)^2}{E} \right]$$

O	E	(O-E)	(O-E) ²	(O-E) ² /E

Step 4: Find $df = k - 1$ where k = number of categories**Step 5:** Find CV(s) on Table VII.**Step 5:** p-value from calculator

$$p = 1 - \chi^2 \text{cdf} (0, \chi^2_r, df)$$

Step 6: Decide: reject H_0 or not?

Reject if test statistic is in rejection region (tail).

Step 6: Decide: reject H_0 or not?Reject if $p < \alpha$ **Step 7:** Verbal interpretation

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[Statistics Home Page](#)[Class Notes](#)[Homework1](#)[Homework2](#)

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

In 1990 the distribution of cars, by type, was: 32.8 % small, 44.8% medium size, 9.4% large, and 13.0% larger (eg. SUV). For a recent simple random sample of 500 cars, car type is listed below. At the 5% s.l., has the distribution of car type changed?

	Obs
S	133
M	249
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Lx	71
Total	500

Given Probability:

.328

.448

.094

.130

 H_0 : distribution is same as 1990 H_a : distribution is different from 1990

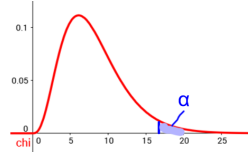
Need to compare observed values with the expected distribution, based on assumptions (prior data, general knowledge, etc.)

Calculator: χ^2 GOF Test

1. Enter observed data into L1
2. Enter expected probabilities into L2
3. Find Σx , the sum of observed values
4. In the header for L3, compute np :
 $L2 \times (\Sigma x)$ (expected values)
5. STAT/TESTS/ χ^2 GOF-Test
Observed: L1
Expected: L3
df: #categories - 1
CALCULATE

Calculator: χ^2 w/o GOF Test

1. Enter observed data into L1
2. Enter expected probabilities into L2
3. Find Σx , the sum of observed values
4. In the header for L3, compute np :
 $L2 \times (\Sigma x)$ (expected values)
5. In header for L4, compute indiv χ^2 :
 $(O - E)^2 / E$, or
 $(L1 - L3)^2 / L3$ using column headings
6. STAT/CALC/1-Variable Stats/ L4
Find Σx
7. This is the test statistic, χ^2 . Use critical value or find p from table.
 $p = 1 - \chi^2 \text{cdf} (0, \chi^2_r, df)$



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[Statistics Home Page](#)[Class Notes](#)[Homework1](#)[Homework2](#)

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

In 1990 the distribution of cars, by type, was: 32.8 % small, 44.8% medium size, 9.4% large, and 13.0% larger (eg. SUV). For a recent simple random sample of 500 cars, car type is listed below. At the 5% s.l., has the distribution of car type changed?

H_0 : distribution is same as 1990

H_a : distribution is different from 1990

	Obs	Exp	O-E	(O-E) ²	(O-E) ² / E
S	133	164	-31	961	5.860
M	249	224	25	625	2.790
L	47	47	0	0	0.000
Lx	71	65	6	36	0.554
Total	500	500			9.204

all $E \geq 1$
none ≤ 5
 \therefore assumptions met

Given Probability:

$$.328 \quad E = np = 500 \cdot .328 = 164$$

$$.448$$

$$.094$$

$$.130 \quad E = np = 500 \cdot .130 = 65$$

Step 1A: Calculate the expected frequencies $E = np$

where n = sample size, p = all freq or probability; compare to assumptions
Assumptions: 1. All expected frequencies ≥ 1
2. At most 20% of the expected frequencies are less than 5
3. SRS

Step 1B: H_0 : The variable has the specified distribution.
 H_a : The variable does not have the specified distribution.

Step 2: Decide α

Step 3: Compute the test statistic, using a table of values:

$$\chi_r^2 = \sum \frac{(O-E)^2}{E}$$

Step 4: Find $df = k - 1$ where k = number of categories

Step 5: Find CV(s) on Table VII.

Step 6: Decide: reject H_0 or not?
Reject if test statistic is in rejection region (tail).

Step 5: p-value from calculator
 $p = 1 - \chi^2cdf(0, \chi_r^2, df)$

Step 6: Decide: reject H_0 or not?
Reject if $p < \alpha$

Step 7: Verbal interpretation

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Statistics Home Page

Class Notes

Homework1

Homework2

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

In 1990 the distribution of cars, by type, was: 32.8 % small, 44.8% medium size, 9.4% large, and 13.0% larger (eg. SUV). For a recent simple random sample of 500 cars, car type is listed below. At the 5% s.l., has the distribution of car type changed?

H_0 : distribution is same as 1990

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	Obs	Exp	O-E	(O-E) ²	(O-E) ² / E
S	133	164	-31	961	5.860
M	249	224	25	625	2.790
L	47	47	0	0	0.000
Lx	71	65	6	36	0.554
Total	500	500			9.204

$$p = 0.0267 < 0.05 = \alpha \quad \therefore \text{Rej } H_0$$

Conclude that the distribution of car types (sizes) has changed.

Step 1A: Calculate the expected frequencies $E = np$
where n = sample size, p = all freq or probability; compare to assumptions
Assumptions: 1. All expected frequencies ≥ 1
2. At most 20% of the expected frequencies are less than 5
3. SRS

Step 1B: H_0 : The variable has the specified distribution.
 H_a : The variable does not have the specified distribution.

Step 2: Decide α

Step 3: Compute the test statistic, using a table of values:

$$\chi_r^2 = \sum \frac{(O-E)^2}{E}$$

Step 4: Find $df = k - 1$ where k = number of categories

Step 5: Find CV(s) on Table VII.

Step 6: Decide: reject H_0 or not?
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Step 7: Verbal interpretation

Step 5: p-value from calculator
 $p = 1 - \chi^2cdf(0, \chi_r^2, df)$
Step 6: Decide: reject H_0 or not?
Reject if $p < \alpha$

Calculator: χ^2 w/o GOF Test

1. Enter observed data into L1
2. Enter expected probabilities into L2
3. Find Σx , the sum of observed values
4. In the header for L3, compute np :
 $L2 \times (\Sigma x)$ (expected values)
5. In header for L4, compute $\text{indiv } \chi^2$
 $(O - E)^2 / E$, or
 $(L1 - L3)^2 / L3$ using column headings
6. STAT/CALC/1-Variable Stats/ L4
Find Σx
7. This is the test statistic, χ_r^2
Use critical value or find p from table.
 $p = 1 - \chi^2cdf(0, \chi_r^2, df)$

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Statistics Home Page

Class Notes

Homework1

Homework2

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

Given

122

H_0 : distribution is same as 1990
 H_a : distribution is different from 1990

	Obs	Exp	O-E	(O-E) ²	(O-E) ² / E	Given Probability
S	133	164	-31	961	5.860	.328
M	249	224	25	625	2.790	.448
L	47	47	0	0	0.000	.094
Lx	71	65	6	36	0.554	.130
Total	500	500			9.204	

df = c - 1 = 4 - 1 = 3

$p = 0.0267$

$\alpha = 0.05$

$\chi^2_c = 7.879$

$CNTRB = \{5.860, 2.790, 0.000, 0.554\}$

Calculator: χ^2 GOF Test

1. Enter observed data into L1
2. Enter expected probabilities into L2
3. Find Σx , the sum of observed values
4. In the header for L3, compute np :
 $L2 \times (\Sigma x)$ (expected values)
5. STAT/TESTS/ χ^2 GOF-Test
 Observed: L1
 Expected: L3
 df: #categories - 1
 CALCULATE

Calculator: χ^2 w/o GOF Test

1. Enter observed data into L1
2. Enter expected probabilities into L2
3. Find Σx , the sum of observed values
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 $L2 \times (\Sigma x)$ (expected values)
5. In header for L4, compute indiv χ^2
 $(O - E)^2 / E$ or
 $(L1-L3)^2 / L3$ using column headings
6. STAT/CALC/1-Variable Stats/ L4
 Find Σx
7. This is the **test statistic**, χ^2
 Use critical value or find p from table.
 $p = 1 - \chi^2 cdf (0, \chi^2_T, df)$

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[Statistics Home Page](#) [Class Notes](#) [Homework1](#) [Homework2](#)

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

Calculator: χ^2 w/o GOF Test

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4. In the header for L3, compute np :
 $L2 \times (\Sigma x)$ (expected values)
5. In header for L4, compute indiv χ^2
 $(O - E)^2 / E$ or
 $(L1-L3)^2 / L3$ using column headings
6. STAT/CALC/1-Variable Stats/ L4
 Find Σx

This is the **test statistic**, χ^2

7. Use critical value or find p from table.

$$p = 1 - \chi^2 cdf (0, \chi^2_T, df)$$

CNTRB = {XXXX.XX XXXX ...} ARROW RIGHT
 each cell's contribution to test statistic

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[Statistics Home Page](#)

[Class Notes](#) [Homework1](#) [Homework2](#)

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

Geographical Distribution in US Population

At the 5% s.l., has the distribution changed?

H_0 : geographical distribution in US is as given

H_a : distribution is different from given

	Freq	Obs	Exp	(O-E) ² /E
NE	0.190	45		
MW	0.229	42		
S	0.356	92		
W	0.225	71		
		250	$\chi^2 =$	

all $E \geq 1$
none ≤ 5 ?

Use χ^2 GOF test, or $p = 1 - \chi^2\text{cdf}(0, \text{____}, \text{____})$
 $=$

$p = \underline{\hspace{2cm}}$? $0.05 = \alpha$
Reject H_0 or not?

Conclude: _____

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[Statistics Home Page](#)

Class Notes

es Homework

Homework2

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

Geographical Distribution in US Population

At the 5% s.l., has the distribution changed?

H_0 : geographical distribution in US is as given

H_a : distribution is different from given

$$df = 4 - 1 = 3$$

all $E \geq 1$
none ≤ 5
assumptions met

	Freq	Obs	Exp	(O-E) ² /E
NE	0.190	45	47.5	0.132
MW	0.229	42	57.25	4.062
S	0.356	92	89.0	0.101
W	0.225	71	56.25	3.868
		250		$\chi^2 = 8.163$

Use χ^2 GOF test, or $p = 1 - \chi^2\text{cdf}(0, 8.163, 3)$
 $= 0.0427$

$p=0.0427 < 0.05 = \alpha$
Reject H_0

Conclude: population distribution in US has changed.

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[Statistics Home Page](#)

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Homework 1

Homework2

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

A traffic commissioner wanted to know if Road Rage occurred more often on some days of the week. She randomly selected 70 incidents of Road Rage and examined the days of the week on which they occurred.

F: At the 5% significance level, does the incidence of Road Rage occur more often on some days of the week than on other days?

Day	freq
Su	5
Mo	5
Tu	11
We	12
Th	12
Fr	18
Sa	7

How is this a GOF problem?

What is the null hypothesis?

What are the expected values?

H₀: Road Rage is not associated with the day of the week.
H_a: Road Rage is associated with the day of the week.

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[Statistics Home Page](#)

[Class Notes](#) [Homework1](#) [Homework2](#)

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Day	freq
Su	5
Mo	5
Tu	11
We	12
Th	12
Fr	18
Sa	7

How is this a GOF problem?

What is the null hypothesis?

No difference in days

What are the expected values?

Equal numbers $\therefore 70 \cdot (1/7)$

$$E = n \cdot p$$

H₀: Road Rage is not associated with the day of the week.

H_a: Road Rage is associated with the day of the week.

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[Statistics Home Page](#)

[Class Notes](#) [Homework1](#) [Homework2](#)

13.1, 13.2 Chi-Squared Dist, Goodness of Fit

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F: At the 5% significance level, does the incidence of Road Rage occur more often on some days of the week than on other days?

Day	Obs freq	Exp =np
Su	5	10.0
Mo	5	10.0
Tu	11	10.0
We	12	10.0
Th	12	10.0
Fr	18	10.0
Sa	7	10.0

n=70 all >1
none < 5

How is this a GOF problem?

What is the null hypothesis?

No difference in days

What are the expected values?

Equal numbers $\therefore 70 \cdot (1/7) = 10$

H₀: Road Rage is not associated with the day of the week.
H_a: Road Rage is associated with the day of the week.

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[Statistics Home Page](#)

[Class Notes](#) [Homework1](#) [Homework2](#)

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Day	Obs freq	Exp =np	(O-E) ² /E
Su	5	10.0	2.5
Mo	5	10.0	2.5
Tu	11	10.0	.1
We	12	10.0	.4
Th	12	10.0	.4
Fr	18	10.0	6.4
Sa	7	10.0	.9

n=70 all >1
none < 5 13.2

How is this a GOF problem?

What is the null hypothesis?

No difference in days

What are the expected values?

Equal numbers $\therefore (1/7) \cdot 69$

Find: test statistic

$$\chi^2_{\tau} = \sum \left[\frac{(O - E)^2}{E} \right]$$

$$= 13.2$$

H₀: Road Rage is not associated with the day of the week.
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[Statistics Home Page](#)

[Class Notes](#) [Homework1](#) [Homework2](#)

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How is this a GOF problem?
What is the null hypothesis?
No difference in days
What are the expected values?
Equal numbers $\therefore (1/7)*69$

Find: test statistic

$$\chi^2_{\tau} = \sum \left[\frac{(O-E)^2}{E} \right] = 13.2$$

Need p:

$$p = 1 - \chi^2 \text{cdf} (0, \text{test } \chi^2, \text{df})$$

Need df: $\text{df} = c - 1 = 7 - 1 = 6$

$$p = 1 - \chi^2 \text{cdf} (0, 13.2, 6) = 0.040$$

$$p = 0.040 < 0.05 = \alpha \text{ rej. } H_0$$

Conclude: Road Rage is different for different days of the week.

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[Statistics Home Page](#)

[Class Notes](#) [Homework1](#) [Homework2](#)

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