Telerobotics Experiment

Statement of the Research Problem:

We want to find the minimum frame rate required for humans to effectively explore an unfamiliar environment using low-latency surface telerobotics.

Background of the Problem:

Telerobotics is a useful tool for scientific exploration of our solar system because it combines the deployability of robotics with human ingenuity to create a cheaper method for scientific exploration in space that produces rapid meaningful results. The main benefactor from low-latency surface telerobotics will be future manned missions to Mars. This is the case because the large latency due to the distance between Earth and Mars makes low-latency surface telerobotics impossible to achieve when controlling from stations on Earth. Low-latency surface telerobotics can also be used on the lunar surface in the upcoming missions in cislunar space.

It is critical to investigate the limitations of this method on Earth before low-latency surface telerobotics can be applied in our solar system. Considering that the available bandwidth will vary depending on the line-of-sight from Orion to the teleoperated vehicle, we chose to investigate how variable bandwidth (in the form of frame rate) affects the ability to explore using telerobotics.

Experimental Design Layout: (Complete all necessary items)

Dependent Variable:	*Explorability*
Criteria Measures:	*Time to Discovery*
	Number of times stuck
Nature of the Underlying Distribution (C/O/N):	*TTD - Continuous*
	NTS - Ordinal
Nature of the Data as Measured (C/O/N):	*TTD - Continuous*
	NTS - Ordinal
Treatment Variable:	*Frame Rate*
Method (I or N):	*Incorporated (I)*
Classification (QL, QN):	*Quantitative (QN)*
Type (F, R):	*Fixed*
# Levels:	*4*
Nature of the Underlying Distribution (C/O/N):	*Continuous*
Nature of the Data as Measured (C/O/N):	*Nominal*
Blocked Variable (if any):	*Driver*
# Levels:	*3*
Limited Variables (if any):	*None*
Sample Size	*72*
Alpha	*0.05*
Beta	*0.10*

Research Question:

What is the minimum frame rate in which humans can successfully explore an unfamiliar environment with Telerobotics?

Time to Discovery

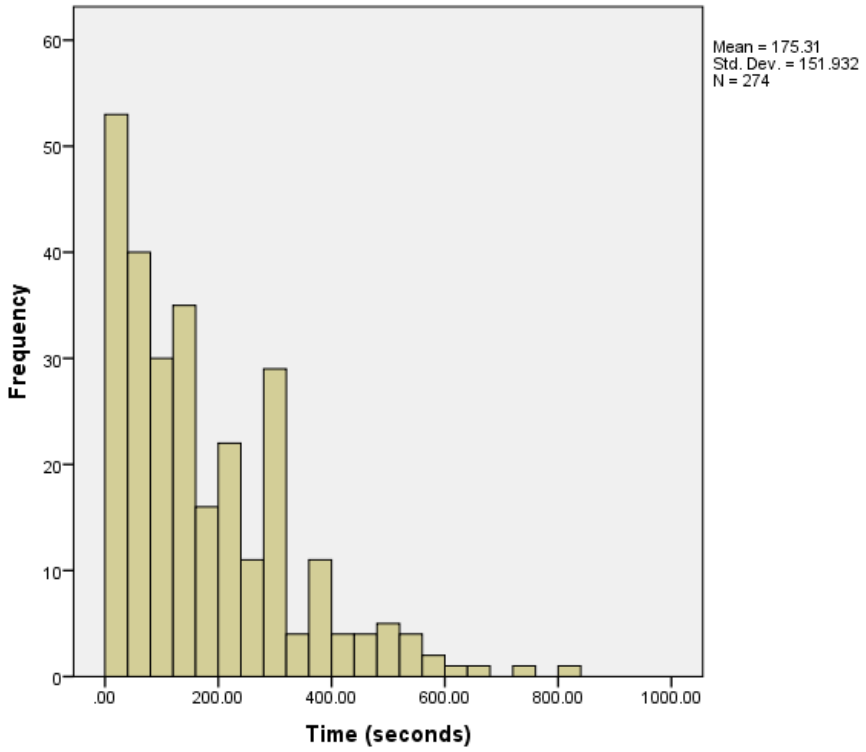
Descriptive Statistics:

Descriptive Statistics for data as a group:

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Time (seconds)	274	.00	819.00	175.3102	151.93203

Histogram of data as a group:



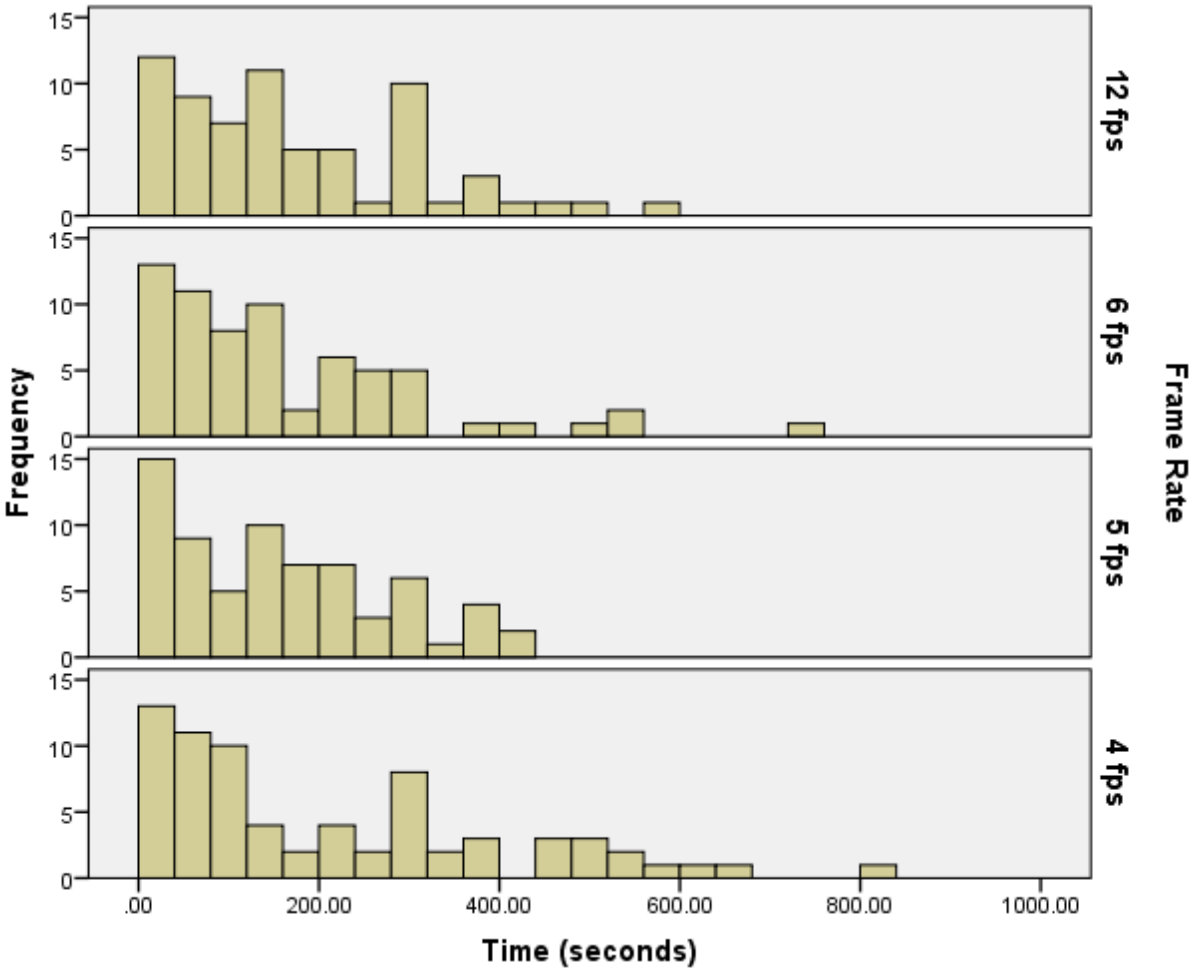
Descriptive Statistics for each level:

Report

Time (seconds)

Frame Rate	N	Mean	Std. Deviation	Minimum	Maximum
12 fps	68	172.7206	133.95130	1.00	585.00
6 fps	66	159.6667	149.02290	2.00	723.00
5 fps	69	154.7681	115.41232	7.00	410.00
4 fps	71	212.2958	193.00107	.00	819.00

Histograms for each level:



Inferential Statistics:

1) Test for Normality (Shape)

1) State the Null (H_0) and Research (H_1) Hypotheses

   $H_0 : \gamma_3 = 0$

   $H_1 : \gamma_3 \neq 0$ *Note: These Statistical Hypotheses are Tested for All Levels, Individually*

   $H_0 : \gamma_4 = 0$

   $H_1 : \gamma_4 \neq 0$

2) State the Type I Error Level

   $\alpha = 0.05$

3) State the Associated Test Statistic

   Since n > 25, use the moment tests

   Skewness: Approximate t

   Kurtosis: g4

4) State the RSD of the Test Statistic When H_0 Is True

   The RSDs of the statistics vary based on sample size. Skewness: t ~ t (calculated) df if H_0 is true

   Kurtosis: Critical table using sample size to determine g4 critical value

5) State the Rejection Rule for H_0 as A Critical Value or p-Value

   Reject H_0 if p < 0.05 (α) for all statistics generated

6) Present the Value of the Test Statistic Calculated

Normality Tests

Frame_Rate	Skewness	p-value	Kurtosis	p-value
(All)	1.268	0.000*	1.552	<.02*
1	0.988	0.006*	0.838	>.10
2	1.545	0.000*	3.113	<.02*
3	0.540	0.103	-0.805	>.10
4	0.816	0.016*	-0.256	>.10

Frame rate legend: 1 = 12 fps, 2 = 6 fps, 3 = 5 fps, 4 = 4 fps

7) State Your Conclusion Related to the Statistical Hypotheses that is being tested in this Set:

a) Accept OR Reject H_0 : *Reject H_0*

b) p = *See within cell normality results in table above.*

c) We Have Sufficient Statistical Evidence to Infer that: *for the populations represented by the data sets: $\gamma_3 \neq 0.00$ $\gamma_4 \neq 0.00$*

2) Variance/Dispersion Analysis

1) State the Null (H_0) and Research (H_1) Hypotheses
   Frame rate legend: 1 = 12 fps, 2 = 6 fps, 3 = 5 fps, 4 = 4 fps

   H_0 : $\sigma_1^2 = \sigma_2^2 = \sigma_3^2 = \sigma_4^2$

   H_1 : *Not H_0*

2) State the Type I Error Level

   α = *0.05*

3) State the Associated Test Statistic

   $F = MS_B / MS_W$

4) State the RSD of the Test Statistic When H_0 Is True

   $F \sim F(J - 1, J(n - 1))$ *df* When H_0 is True or
   $F \sim F(3, 197)$ *df* When H_0 is True

5) State the Rejection Rule for H_0 as A Critical Value or p-Value
   Reject H_0 if $p < 0.05$ (α)

6) Present the Value of the Test Statistic Calculated

   Ran Levene's Test for Homogeneity of Variance on the ADM's (A using Fisher's ANOVA since normality was rejected.

Tests of Between-Subjects Effects

Dependent Variable: Time_ADM

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Frame Rate	247425.764	3	82475.255	9.834	.000
Driver (Blocked)	1689.797	2	844.898		
Error	1652170.503	197	8386.652		
Total	1901179.222	202			

7) State Your Conclusion Related to the Statistical Hypotheses that is being tested in this Set:

   a) Accept OR Reject H_0: *Reject H_0*

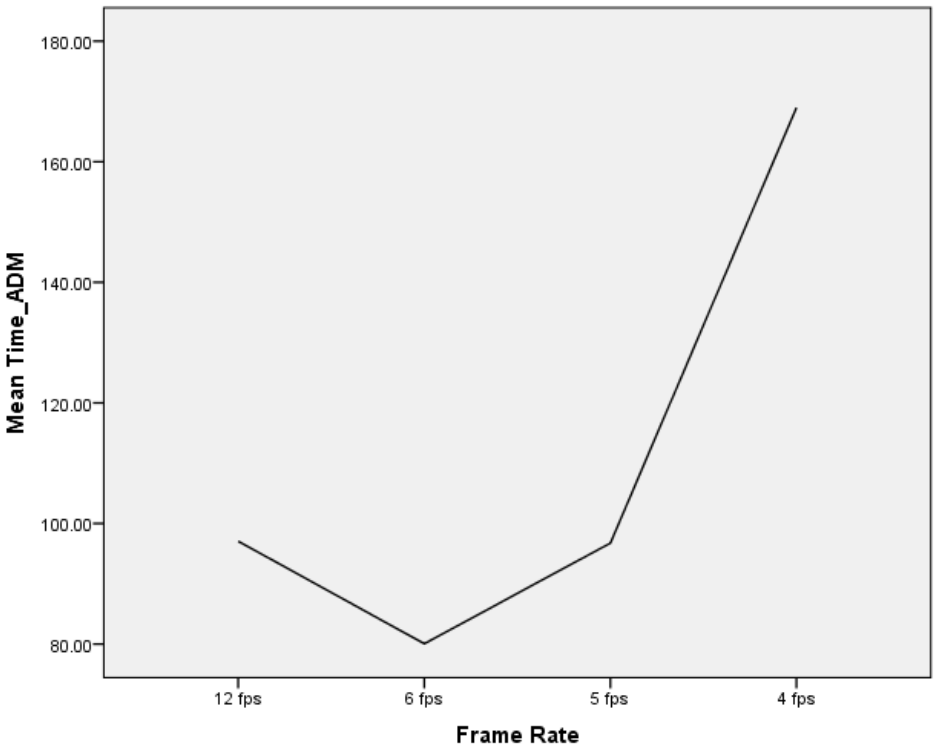
   b) $p = 0.000 < 0.05$

   c) We Have Sufficient Statistical Evidence to infer that: *all of the population variances are not equal*

Post-Hoc Analysis

d) Illustration

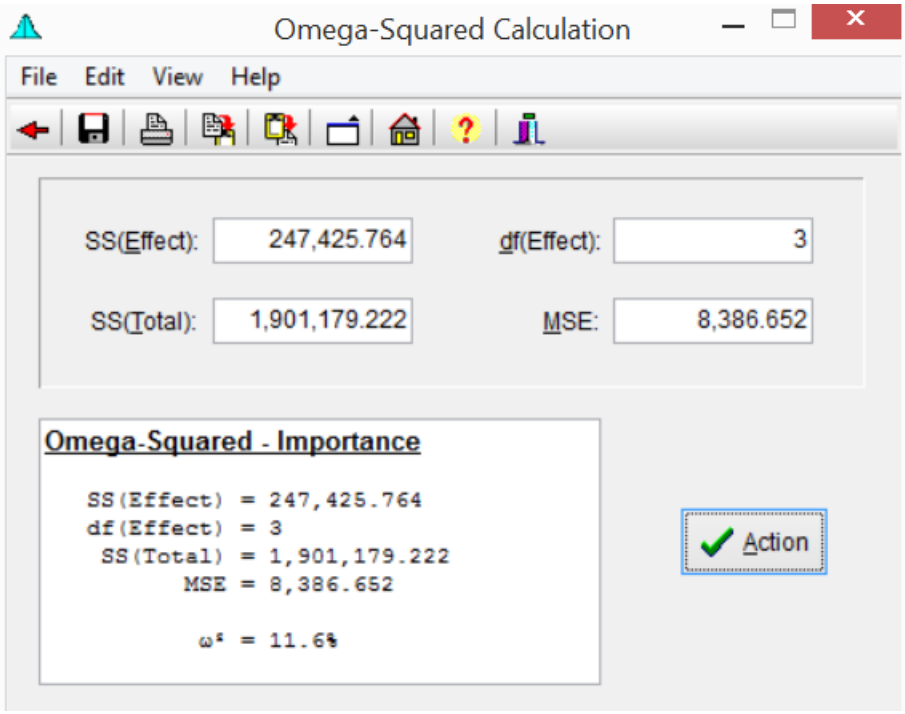
Means plot of ADM



Frame Rate	n	Mean ADM	Std Dev	Low	High
12 fps	50	97.060	79.561	0	373
6 fps	48	80.063	73.736	0	405
5 fps	51	96.745	63.592	0	265
4 fps	54	168.982	129.291	6.5	602.5

e) Importance Calculation

ω^2 = 11.6 %



f) Post-Hoc Analysis (if Appropriate)

Will do all pairwise comparisons. Performed Tukey's HSD Test for the ADM's.

Time_ADM

Tukey HSD[a,b]

Frame Rate	N	Subset for alpha = 0.05	
		1	2
6 fps	48	80.0625	
5 fps	51	96.7451	
12 fps	50	97.0600	
4 fps	54		168.9815

Variance Point Estimates

Frame Rate	N	Sample Variances		Point Estimate	Point Estimate #
		S1	S2		
6 fps (2)	48	13080.936		14757.15	**1**
5 fps (3)	51	13812.540			
12 fps (1)	50	17329.808			
4 fps (4)	54		42164.71	42164.71	**2**

Conclude: $\sigma_1^2 = \sigma_2^2 = \sigma_3^2 < \sigma_4^2$

3) Means Analysis (Location)

1) State the Null (H_0) and Research (H_1) Hypotheses
Frame rate legend: 1 = 12 fps, 2 = 6 fps, 3 = 5 fps, 4 = 4 fps

H_0 : $\mu_1 = \mu_2 = \mu_3 = \mu_4$

H_1 : Not H_0

2) State the Type I Error Level
$\alpha = 0.05$

3) State the Associated Test Statistic
$F = MS_B / MS_W$

4) State the RSD of the Test Statistic When H_0 Is True
$F \sim F(J - 1, J(n - 1))$ *df* When Ho is True or
$F \sim F(3, 197)$ *df* When Ho is True

5) State the Rejection Rule for H_0 as A Critical Value or p-Value
Reject H_0 if $p < 0.05$ (α)

6) Present the Value of the Test Statistic Calculated

Tests of Between-Subjects Effects

Dependent Variable: Time (seconds)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Frame_Rate	376155.953	3	125385.318	5.639	.001
Driver	8720.381	2	4360.191		
Error	4380600.584	197	22236.551		
Total	4765396.966	202			

7) State Your Conclusion Related to the Statistical Hypotheses that is being tested in this Set:

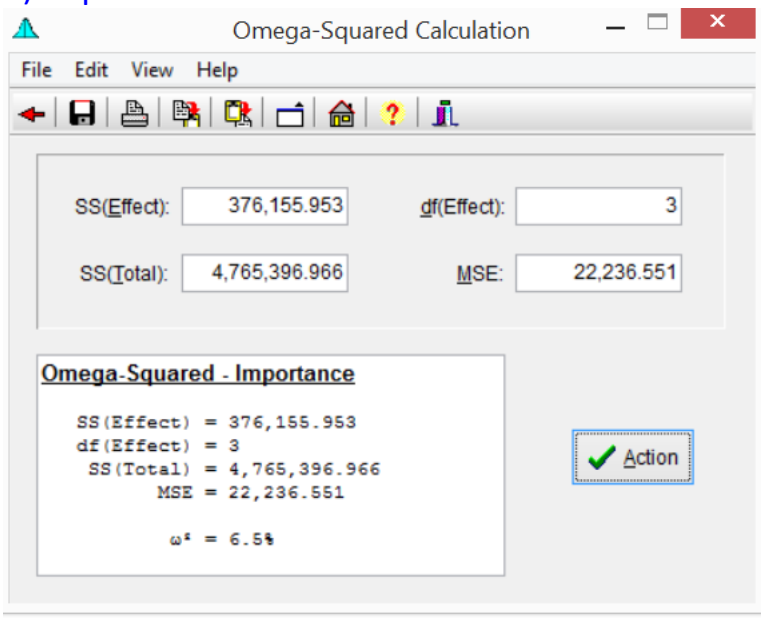
a) Accept OR Reject H_0: *Reject H_0*

b) p = *.000*

c) We Have Sufficient Statistical Evidence to infer that: *all of the population means represented by these four groups (levels) are not equal*

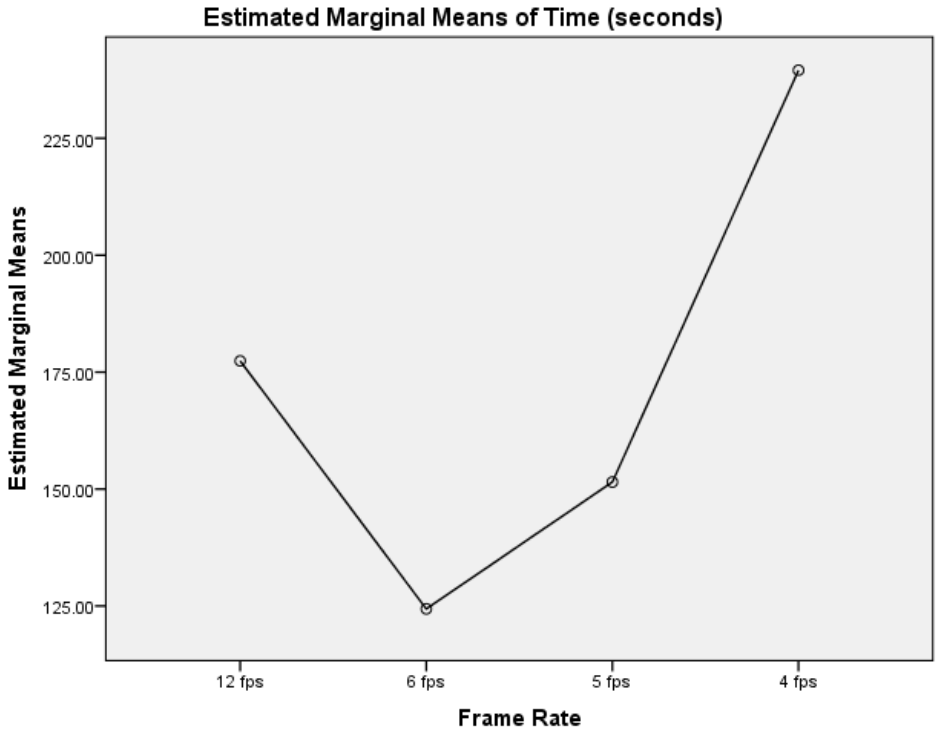
Post-Hoc Analysis

d) Importance $\omega^2 = 6.5\%$



e) Illustration

Means Plots



Frame Rate	n	Mean	Std Dev	Low	High
12 fps	50	177.2200	131.64273	1.00	585.00
6 fps	48	124.5208	114.37192	2.00	554.00
5 fps	51	151.3137	117.52676	7.00	410.00
4 fps	54	239.5370	205.34046	17.00	819.00

f) Post-Hoc Analysis (if Appropriate)

Chose to do all pairwise comparisons based on means plots. When there are unequal variances, use the Games-Howell test for the means.

Results of hypothesis tests:

Output Table
Alpha Per Contrast = .05

Contrast	Equal Varianc...	Degrees of Fr...	Equal Varianc...	Decision	UnEqual Varia...	S-W Degrees...	UnEqual Varia...	Decision
12 fps vs 6 fps	1.748891600...	197	0.301382878...	Accept	2.117961824...	95.07126735...	0.154844627...	Accept
12 fps vs 5 fps	0.872933338...	197	0.818854440...	Accept	1.042584896...	97.28397412...	0.724895846...	Accept
12 fps vs 4 fps	-2.12930579...	197	0.147446340...	Accept	-1.85593548...	91.08301106...	0.254391037...	Accept
6 fps vs 5 fps	-0.89345795...	197	0.808259905...	Accept	-1.14941918...	96.88769497...	0.659958903...	Accept
6 fps vs 4 fps	-3.88814734...	197	0.000811194...	Reject	-3.54383251...	84.80281080...	0.003553545...	Reject
5 fps vs 4 fps	-3.02996005...	197	0.014623159...	Reject	-2.72047783...	85.26890022...	0.038797915...	Reject

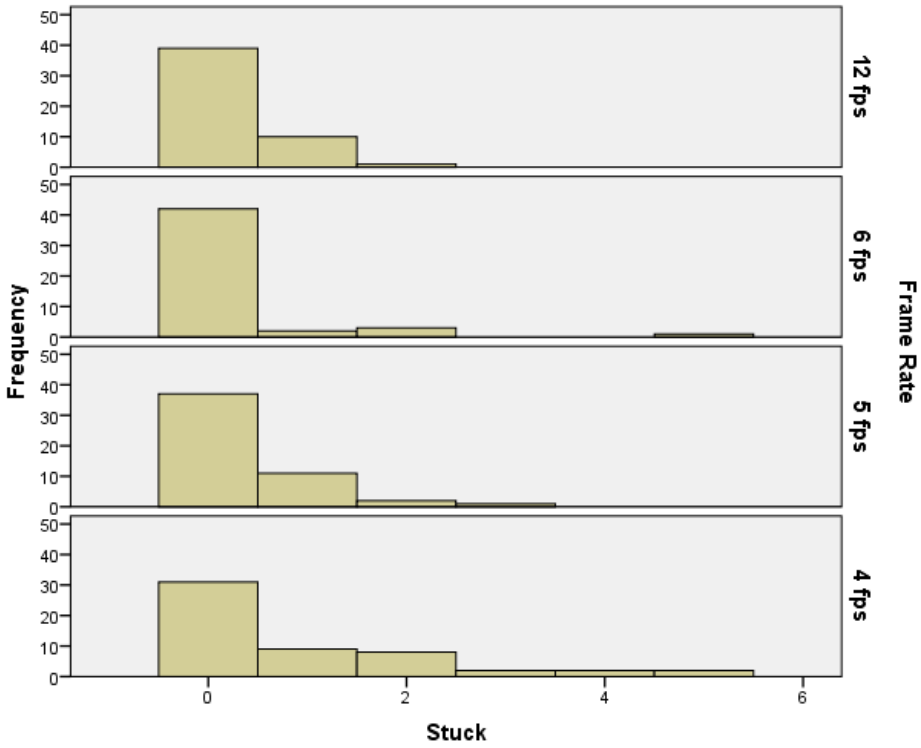
Point Estimates for the Means:

		Sample Means			
Frame Rate	N	S1	S2	Point Estimate	Point Estimate #
6 fps (2)	48	124.5208		138.323	1
5 fps (3)	51	151.3137			
12 fps (1)	50	177.2200	177.2200	177.220	2
4 fps (4)	54		239.5370	239.537	3

Conclude: $\mu_2 = \mu_3 < \mu_1 < \mu_4$

Stuck
(Count - # of times stuck per run)

Histogram: Number of times stuck by frame rate:



1) State the Null (H_0) and Research (H_1) Hypotheses
Frame rate legend: 1 = 12 fps, 2 = 6 fps, 3 = 5 fps, 4 = 4 fps

H_0 : $\mu_1 = \mu_2 = \mu_3 = \mu_4$

H_1 : Not H_0

2) State the Type I Error Level
$\alpha = 0.05$

3) State the Associated Test Statistic
$F = MS_B / MS_W$

4) State the RSD of the Test Statistic When H_0 Is True
$F \sim F(J - 1, J(n - 1))$ *df* When Ho is True or
$F \sim F(3, 197)$ *df* When Ho is True

5) State the Rejection Rule for H_0 as A Critical Value or p-Value
Reject H_0 if $p < 0.05$ (α)

6) Present the Value of the Test Statistic Calculated

Note: Converted data to mean ranks to run the ANOVA.

Tests of Between-Subjects Effects

Dependent Variable: Rank of Stuck

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Frame_Rate	54423.765	3	18141.255	5.250	.002
Driver	5789.968	2	2894.984		
Error	680692.430	197	3455.292		
Total	740437.525	202			

7) State Your Conclusion Related to the Statistical Hypotheses that is being tested in this Set:

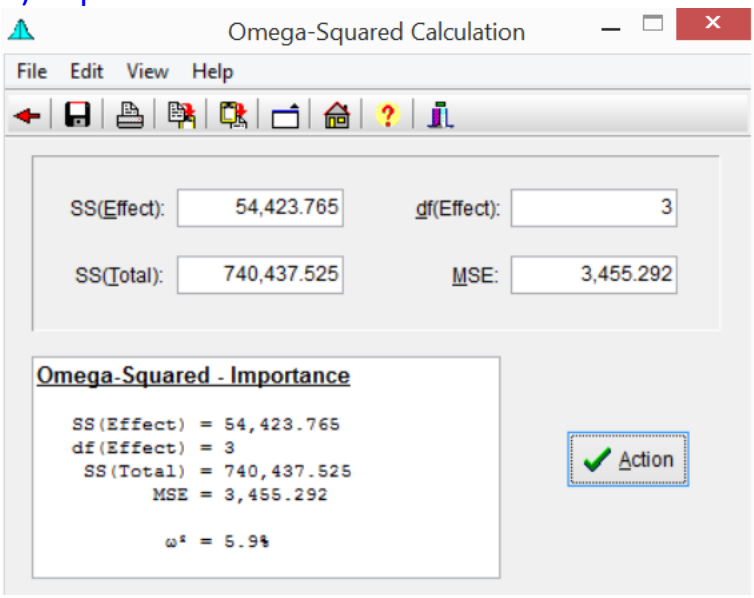
a) Accept OR Reject H_0: *Reject H_0*

b) p = *.002*

c) We Have Sufficient Statistical Evidence to infer that: *all of the population means represented by these four groups (levels) are not equal*

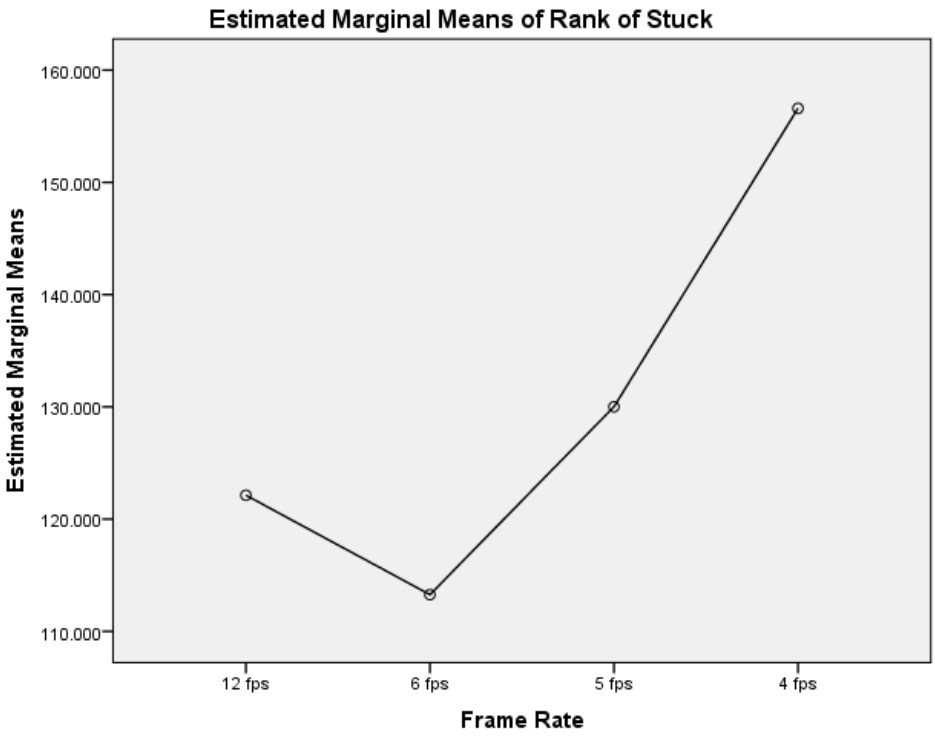
Post-Hoc Analysis

d) Importance *$\omega^2 = 5.9\%$*



e) Illustration

Means Plots



Frame Rate	n	Mean of Mean Ranks
12 fps	50	122.13
6 fps	48	113.54
5 fps	51	130.37
4 fps	54	156.59

f) Post-Hoc Analysis (if Appropriate)

Results of hypothesis tests:

Rank of Stuck

			Subset	
	Frame Rate	N	1	2
Tukey HSD[a,b,c]	6 fps	48	113.54167	
	12 fps	50	122.13000	
	5 fps	51	130.13725	130.13725
	4 fps	54		156.59259

Point Estimates for the Means:

		Sample Mean Rank			
Frame Rate	N	S1	S2	Point Estimate	Point Estimate #
6 fps (2)	48	113.54		117.923	1
12 fps (1)	50	122.13			
5 fps (3)	51	130.14	130.14	130.14	2
4 fps (4)	54		156.59	156.59	3

Conclude: $\mu_2 = \mu_1 < \mu_3 < \mu_4$

Summary, Results & Conclusions

Briefly describe what you found in your analysis above, and make a recommendation.

This experiment was designed to answer the research question, "*What is the minimum frame rate in which humans can successfully explore an unfamiliar environment with Telerobotics??*" Four frame rates were incorporated into the experiment, driver was included as a blocked variable, and time to discovery was evaluated using a stopwatch.

Results are summarized as follows:

- We can infer that each of the individual groups (levels) associated with frame rate are not distributed normally.
- We can infer that the variance of the frame rate levels are not equivalent. When the frame rate is set to 4 frames per second (fps), there is more variation with respect to time to discovery.
- We can infer that the means of each of the frame rate levels with respect to time to discovery are not equivalent. The mean level of the frame rate of 4 fps is significantly different from 6 fps and 5 fps. The mean level of 12 fps was not significantly different than 5 or 6 fps, and could also not be discerned from the mean level of 4 fps.
- We can infer that the mean level of each of the frame rate settings with respect to number of times stuck are not equivalent. The mean level of the frame rate of 4 fps is significantly different from 6 fps and 12 fps. The mean level of 5 fps was not significantly different than 12 or 6 fps, and could also not be discerned from the mean level of 4 fps.
- Overall, it appears that the settings of 6 and 5 fps yield better results with respect to time to discovery than the settings of 4 fps and 12 fps. Additionally, the setting of 4 fps yields worse performance with respect to number of times the rover was stuck during a run.

Frame Rate	**Point Estimates**		
	μ	σ^2	σ
1 – 12 fps	177.22	14757.15	121.48
2 – 6 fps	138.32	14757.15	121.48
3 – 5 fps	138.32	14757.15	121.48
4 – 4 fps	239.54	42164.71	205.34