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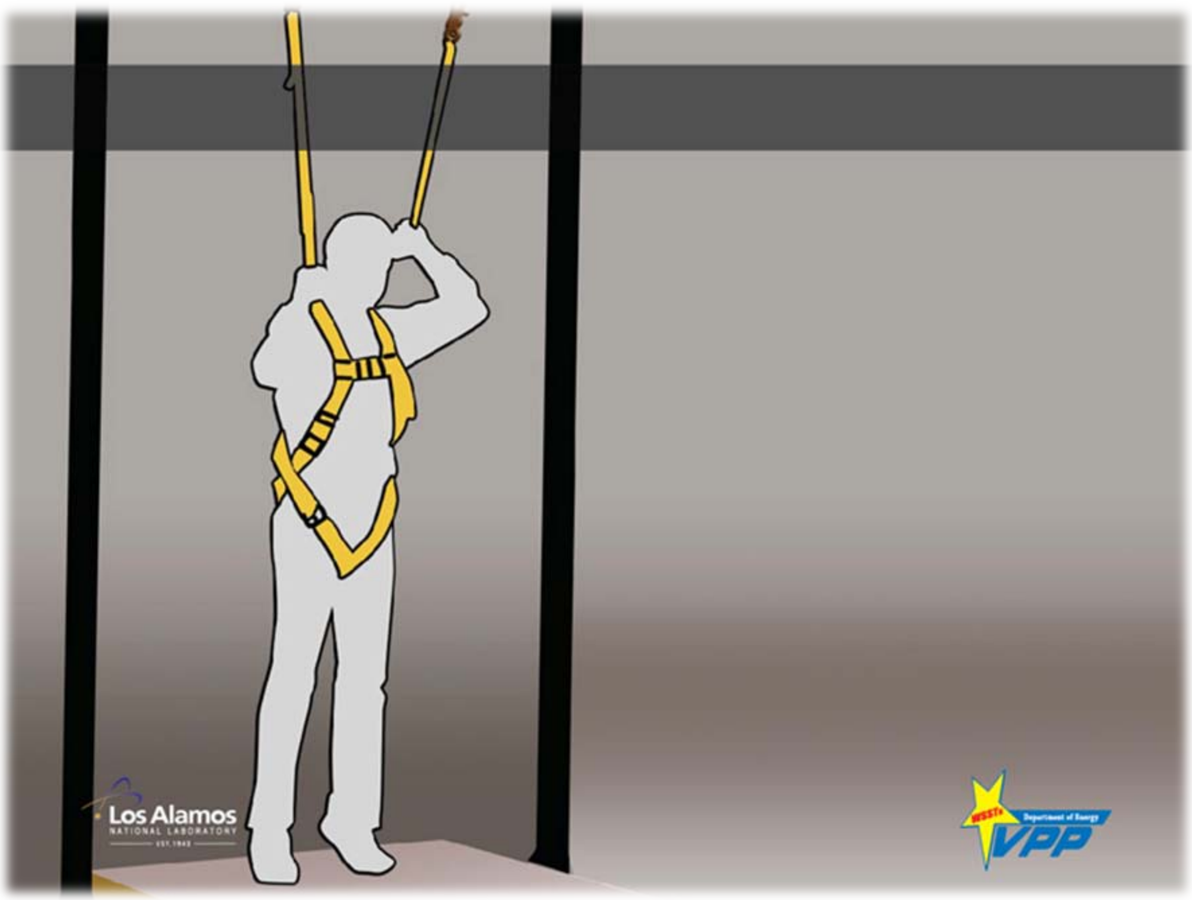
Statistical Impact of Slip Simulator Training at Los Alamos National Laboratory



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Front Cover – Logo for Slip Simulator at Los Alamos National Laboratory, sponsored by the Voluntary Protection Program.

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I. INTRODUCTION

In 2011 the LANL Voluntary Protection Program (VPP) Office procured a slip simulator to address slip injuries and began using the simulator to teach the workforce how to walk safely on slippery surfaces. Over 2500 LANL workers were trained in the first year of use, either as observers or participants. A preliminary analysis was conducted on effectiveness of the simulator by looking at the number of falls throughout the laboratory before and after beginning the slip simulator class. A more detailed statistical analysis is presented in this report using a more recent and larger data set.

II. DATA

The overall laboratory population value used in both the preliminary report and in this report is 11,000.[1] A history of slips, trips, and falls incident reports in the form of Excel spreadsheets were obtained from Occupational Medicine. These cover the period from January 2011 to June 2012. The VPP office provided data from slip simulator class rosters that show class date, Z numbers, and which attendees are observers or participants. Note that all attendees who participate in the class by being strapped in the harness and walking on the slippery surface are counted in the database as *both* participants and observers. Class attendees who chose not to walk on the surface are counted as observers only. The information from both sources was manipulated and condensed in different forms to provide data for statistical analysis.

A key step in the data process is to cross reference the population of individuals with an accident report (slip, trip, or fall) against class attendance. This is a labor-intensive step that relies on Z numbers and class dates. Also, the falls data includes all slips, trips, or falls regardless of the cause or type of surface. The slips simulator focuses on techniques for walking safely on slippery surfaces.

One way to consider the data is by graphing three populations: 1) employees who have not taken the slips simulation class (No Class), 2) those who attended as observers only (Observers), and 3) those who attended the class as participants (Participants). Figure 1 illustrates the number of employees with falls or no falls within each of these populations at the laboratory. Note that the y axis is logarithmic to show all the data. It appears from the graph that the number of falls for participants (shown by the green histogram bars) is much lower than would be expected based on the typical laboratory population with no training shown in blue.

[1] "Impact of Slip Simulator Training at LANL," LANL unpublished working paper, Bethany Rich, July 10, 2012.

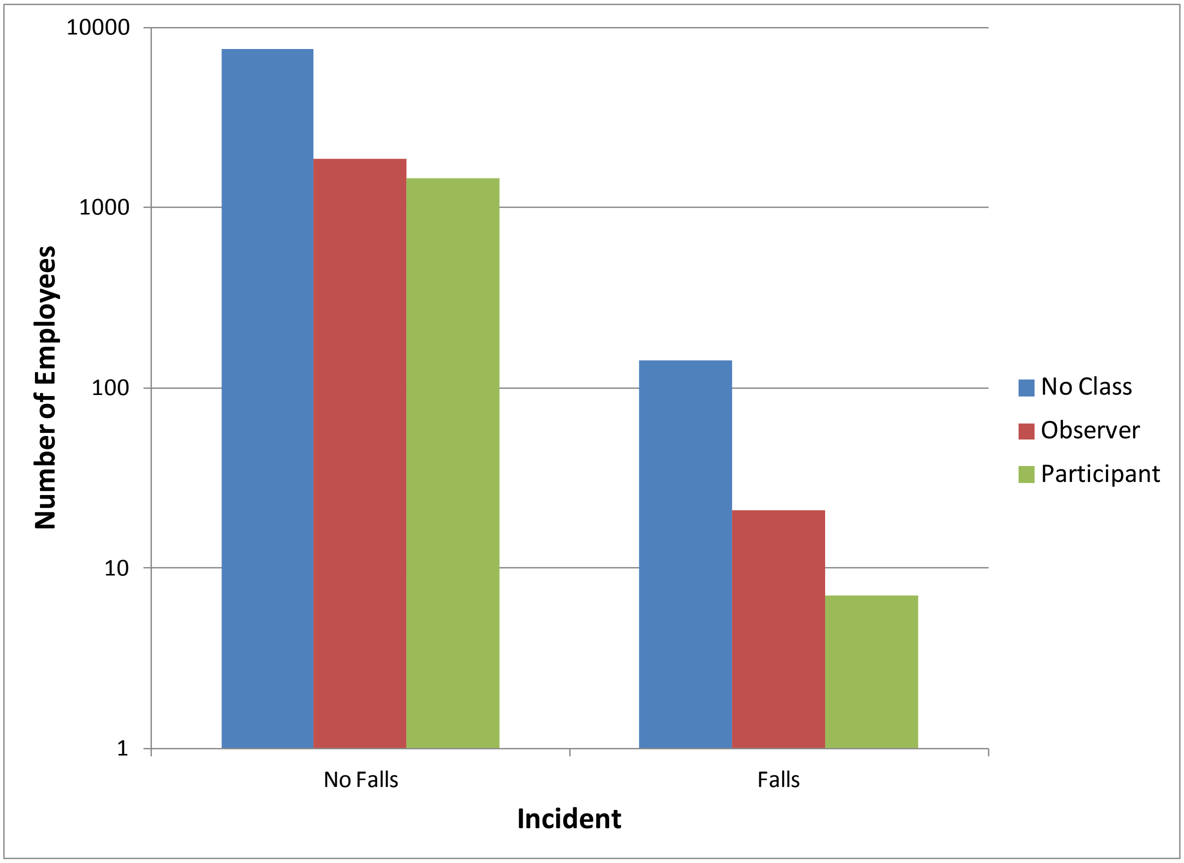

Figure 1. Population of individuals at the lab who have fallen or have not fallen.

III. STATISTICAL ANALYSIS

Although Figure 1 appears to indicate an improvement in the slip rate for class participants, a more rigorous analysis using statistical tools is needed. The key question is whether the slips simulator class provides a reduction in falls that is statistically significant. This question is answered in this section using three comparisons. The first measures the significance of fall rate differences between employees who took the class (participants and observers) versus those who did not. This represents the most general analysis of the efficacy of the slips simulator. The second is an examination of any differences between class observers versus those who did not take the class. This analysis tests whether observers are being trained sufficiently to make a significant improvement in the number of slips, trips, and falls over the general (untrained) lab population. The third comparison is between class participants versus observers. This tests whether attendees who actually participate in the simulator class have an identifiable improvement in slip rate over those who simply observe others attempting the device.

Three tables provide the needed data for these analyses. Table 1 shows falls reported for trained versus untrained employees. There have been only 28 slips, trips, or falls reported from the employees who have taken the class (3334), in contrast to 142 falls among the untrained population (7666).

TABLE 1
Falls for Trained and Untrained Employees

Population	Fall	No Fall	Total	Fall Ratio {1}
Slips Class	28	3306	3334	0.008
No Slips Class	142	7524	7666	0.018
Total	170	10,830	11,000	0.015

{1} Fall/Total.

Table 2 shows the number of falls reported by slips simulator class observers as compared to the general untrained lab population. The observers have 21 falls out of a population of 1885.

TABLE 2
Falls for Observers and Untrained

Population	Fall	No Fall	Total	Fall Ratio {1}
Observer	21	1864	1885	0.011
No Slips Class	142	7524	7666	0.018
Total	163	9388	9551	0.017

{1} Fall/Total.

Table 3 reports the number of slips, trips, or falls for class participants and observers. The raw data appear to show that participants get more out of the simulation class than observers, since participants make up only 7 of the 28 total falls for trained employees.

TABLE 3
Falls for Participants and Observers

Population	Fall	No Fall	Total	Fall Ratio {1}
Participant	7	1442	1449	0.005
Observer	21	1864	1885	0.011
Total	28	3306	3334	0.008

{1} Fall/Total.

Two statistical methods are used to identify the impact significance of the slips simulator: the chi-square test and proportions test. These are described below.

A. Chi-Square Test

In statistical terms, Table 1 is known as a contingency table. The information provided there can be viewed as a binomial distribution in terms of success or failure of falling. Each individual represents a sample observation or trial. The significance of the difference between the two proportions in the table can be assessed with Pearson's chi-square test as a goodness of fit comparison. The goodness of fit establishes whether the observed frequency is close to the theoretical or expected frequency. Pearson's test is described in the following equation.

$$\chi^2 = \sum_{i=1}^{n} \frac{\left(f_e - f_o\right)^2}{f_e} \tag{1}$$

where X^2 is Pearson's cumulative statistics test, f_e is the estimated (theoretical) frequency, f_o is the observed frequency, and n is the number of cells in the table. The chi-square statistic is used to calculate a p-value by comparing the value of X^2 to a chi-square distribution. The expected (theoretical) frequencies are calculated by the following equation.

$$f_{e_{i,j}} = \frac{\sum_{n_c=1}^{c} f_{o_{i,n_c}} \times \sum_{n_r=1}^{r} f_{o_{j,n_r}}}{N} \tag{2}$$

where c is the number of columns, r is the number of rows, and N is the total sample size.

The first step in evaluating significance in the data is to list the variables (Falls, No Falls, Class, and No Class) and determine the data type. In this case the data type is numerical rather than categorical. The chi-square test compares the counts between the independent groups using actual reported values, in this case between the populations Class and No Class. The null hypothesis states that there is no difference between the two populations and their rate of falling. The research or alternative hypothesis states that there exists a significant relationship between populations attending the class and the fall rate. The null hypothesis is rejected if the probability of the reported fall rate is statistically shown to occur less than five percent of the time, i.e., $\alpha = 0.05$. That is, if the slips class has no impact on fall rate, the actual rate will be expected to be close to the No Class rate. If the actual value is shown to be sufficiently rare (expected to occur less than five percent of the time), we will reject the null hypothesis and accept the alternative that the class improves the fall rate.

The expected frequencies of each cell are important in calculating the chi-square value. These are the number of falls we would expect to appear in the cells if the null hypothesis were true. To obtain the expected cell frequency for Table 1, using Equation (2), multiply the column total for that cell by the row total for that cell and divide by the total number of observations for the whole table. Table 4 contains the expected frequency values for the first comparison.

TABLE 4
Falls for Trained and Untrained Employees: Expected Frequency Values

Population	Fall	No Fall	Total
Slips Class	51.5	3282.5	3334
No Slips Class	118.5	7547.5	7666
Total	170	10,830	11,000

Equation (1) is calculated for chi-square using Tables 1 and 4 with a result of $X^2 = 15.65$. The degrees of freedom (*df*) are needed to look up the critical value for $\alpha = 0.05$ in the chi-square distribution.

$$df = (r-1) \times c \tag{3}$$

In Equation (3) *r* is the number of rows and *c* is the number of columns, so in our case $df = 1$. The critical value for chi-square with $df = 1$ and $\alpha = 0.05$ is $X^2 = 3.84$. The test value is so large as to satisfy the significance level of $\alpha = 0.0001$.

The results of this test indicate that there is a significant difference between the population of those who have taken the slip simulator class and those who have not. The computed value of chi-square at a level of alpha and degrees of freedom is a type of pass-fail measurement; it does not measure association, probability of error, nor provide absolute proof of a relationship. The computed value of chi-square either reaches the level of statistical significance or it does not.

The second comparison is for slip simulation class observers and the general untrained laboratory population. The null and alternative hypotheses are the same as for the above test: the null hypothesis states that there is no difference between the two populations and their rate of falling, and the alternative hypothesis states that there exists a significant difference between them.

The level of significance is kept the same as before, $\alpha = 0.05$. The raw data for this test are shown in Table 2 and the expected frequency values are in Table 5.

TABLE 5
Falls for Observers and Untrained: Expected Frequency Values

Population	Fall	No Fall	Total
Observer	32.2	1853	1885
No Slips Class	130.8	7535	7666
Total	163	9388	9551

The calculated chi-square value using Equation (1) is $X^2 = 4.92$, which is greater than the critical value of 3.84. From this test it can be said there exists a statistically significant difference between the number of falls of those attending a slips simulator class as an observer and the general untrained laboratory population at better than the five percent level. In this case, observers have a significantly lower frequency of falls than employees who did not attend the class.

The third chi-square test is between the population of those who attended the slip simulator class as observers only and those who attended as participants. The null hypothesis states there is no difference in the frequency of falls between the two groups. The alternative hypothesis states there is a difference in taking the class as an observer and participant. The level of significance is kept the same as before, $\alpha = 0.05$. The raw data for this test are shown in Table 3 and the expected frequency values are in Table 6.

TABLE 6
Falls for Observers and Participants:
Expected Frequency Values

Population	Fall	No Fall	Total
Participant	12.2	1437	1449
Observer	15.8	1869	1885
Total	28	3306	3334

The calculated chi-square value using Equation (1) is $X^2 = 3.92$, which is greater than the critical value of 3.84. From this test it can be said there exists a statistically significant difference between being an observer and participant in the slip simulator class at the five percent level. In this case, participants have a significantly lower frequency of falls than observers.

B. Test of Proportions

Another statistical method is to examine the difference between the proportions of falls in the two groups. This test can measure the statistical significance of claims such as:

- *Undergraduate students who exercise an average of 30 minutes per day experience headaches at a rate that is 7% lower than inactive students.*
- *Fewer than 25% of LANL employees smoke.*

In this case we are claiming that employees who take a slips simulator class will have a lower fall rate than employees who do not attend the class.

The test statistic that is used to test a claim regarding a proportion is:[2]

[2] Triola, Mario F. Elementary Statistics. Ninth Edition, Pearson Education, Inc. Boston. 2004. p. 374.

$$z = \frac{\hat{p}-p}{\sqrt{\frac{pq}{n}}} \quad (4)$$

where n is the sample size of trials, $q = 1 - p$, $\hat{p}$ is the sample proportion, p is the population proportion (used in the null hypothesis).

The null hypothesis for this case is that there is no difference between the two proportions, i.e., slips simulator training has no effect. If this hypothesis were true, there would be no difference between the two proportions: $\hat{p} - p = 0$. The alternative hypothesis is that the class is efficacious in reducing the fall rate: $\hat{p} - p < 0$. In statistical nomenclature this is presented as:

$$H_o:\ \hat{p} = p$$
$$H_1:\ \hat{p} < p.$$

There are three assumptions for the proportions test. [3] First, the sample observations are a simple random sample, such that every possible sample of size n has an equal chance of being selected. In our case, out of the whole LANL population of employees, some people decided to take the slips simulator class. Because they self-selected to be part of the sample, is this truly a random process? Sample-selection bias may play a role here where employees who are more safety conscious are the ones who take the class. This could skew the results. Second, the conditions of a binomial distribution are met, such that there are a fixed number of trials, each of which is independent, there are two possible outcomes, and the probabilities remain constant across trials. Third, a binomial distribution of sample proportions can be approximated by a normal distribution with $\mu = np$ and $\sigma = \sqrt{npq}$ if $np \geq 5$ and $nq \geq 5$. The population can be approximated by a normal curve if these conditions are met.

The calculations for subjects who attended the class as participants or observers (values from Table 1) are:

n = sample size of number of trials = 3334
x = number of falls in the sample = 28
$\hat{p} = \frac{x}{n} = \frac{28}{3334} = 0.0084$ (sample proportion)
p = population proportion (assumed to be fall rate of all employees who did not attend class)
$p = \frac{142}{7666} = 0.0185$
$q = 1 - p$
$np = (3334)(0.0185) = 62$
$nq = (3334)(1 - 0.0185) = 3272$

Inserting the values into Equation (4) gives the test statistic value:

[3] Triola, p. 299.

$$z = \frac{0.0084 - 0.0185}{\sqrt{\frac{(0.0185)(1-0.0185)}{3334}}} = -4.33 \tag{5}$$

Checking this *z* value in a standard normal distribution table indicates that the cumulative area from the left of the curve to –4.33 makes up only 0.0001 of the distribution. As a comparison, the critical value for a one-tailed 95% significance test ($\alpha = 0.05$) is –1.64, and –2.33 for a 99% test ($\alpha = 0.01$). The test value indicates that if the null hypothesis were true, the observed sample value would be expected to occur less than one percent of the time. This is sufficiently unlikely that we should reject the null hypothesis and accept the alternative that slip simulator training has reduced falls among LANL employees. Another way to say this is, "The reduced proportion of falls in the trained employees as compared to the general (untrained) population is statistically significant at better than the one percent level."

The second comparison answers the question, "Do class observers have fewer falls than the general population?" The test data for this are as follows, taken from Table 2.

n = sample size of number of trials = 1885 (test subjects who attended the class as observers)
x = number of falls in the sample = 21
$\hat{p} = \frac{x}{n} = \frac{21}{1885} = 0.011$ (sample proportion)
p = population proportion (assumed to be fall rate of all employees who did not attend class)
$p = \frac{142}{7666} = 0.0185$
$q = 1 - p$

$$z = \frac{0.011 - 0.0185}{\sqrt{\frac{(0.0185)(1-0.0185)}{1885}}} = -2.37 \tag{6}$$

Since the test statistic in Equation (6) is smaller than the critical value of –2.33 for a $\alpha = 0.01$ test, we conclude that observers have significantly fewer falls than the general employee population at the one percent level.

The third and final useful comparison is whether there is an appreciable difference between the fall rates of observers and participants. The data are as follows (from Table 3).

n = sample size of number of trials = 1449 (test subjects who attended the class as participants)
x = number of falls in the sample = 7
$\hat{p} = \frac{x}{n} = \frac{7}{1449} = 0.0048$ (sample proportion)
p = population proportion (assumed to be fall rate of employees who attend class as observers)
$p = \frac{21}{1885} = 0.011$
$q = 1 - p$

$$z = \frac{0.0048 - 0.011}{\sqrt{\frac{(0.011)(1-0.011)}{1449}}} = -2.29 \tag{7}$$

This test value is slightly higher than the α = 0.01 significance critical value (–2.33), but much lower than the α = 0.05 value (–1.64). Therefore, we conclude that participants have a significantly lower rate of falls than observers at about the one percent significance level.

IV. CONCLUSIONS AND RECOMMENDATIONS

The results of chi-square and proportions tests show a strong statistically significant reduction in fall rates associated with attendees of the slips simulator class (see Table 7). The strongest significance is in comparing employees who took the class with those who did not. There is sufficient evidence for this comparison (at the 99.99% level) to warrant rejection of the claim that the fall rate is the same for the two groups. Overall, Table 7 shows that all three fall rate comparisons are statistically different:

- Combined class participant and observers fall rate < untrained employees fall rate;
- Class observers fall rate < untrained employees fall rate; and
- Participants fall rate < observers fall rate.

TABLE 7
Summary of Test Values and Statistical Significance

Fall Rate Comparison	Chi-Square Test Value (significance level)	Proportions Test Value (significance level)
Slips Class vs. No Slips Class	15.65 ($\alpha < 0.0001$)	–4.33 ($\alpha < 0.0001$)
Observers vs. No Slips Class	4.92 ($\alpha < 0.05$)	–2.37 ($\alpha = 0.01$)
Participants vs. Observers	3.92 ($\alpha = \sim 0.05$)	–2.29 ($\alpha = \sim 0.01$)

Note that the overall number of falls analyzed here is for all types and causes, rather than specific to only slippery surfaces. The statistical results indicate that slip simulator training increases awareness to help reduce all types of slips, trips, and falls, regardless of cause.

There are two recommendations for improving this analysis. First, additional variables should be considered in the analysis. For example, factors such as the weather on the date of each fall could be more significant than whether or not the employee took the slips simulator class. Including weather, employee work location, and other factors would entail improving the data set and re-assessing the test statistics. Also, the seasonal timing of when an employee took the slips class could be a key indicator of later falls. For example, fewer falls than average for those who took the class in April 2012 may indicate a lack of ice rather than their improved walking techniques. More months of data plus a more comprehensive analysis will be needed to address this.

The second recommendation considers the potential sample selection bias present in the current data set. Voluntary class participation may be skewing the results as safer employees self-select to attend the class. Using a sample population in the analysis where all employees in a group or division were required to attend the class would negate this effect. For example, LANL's guard force (SOC) took the training as a requirement, and their falls data could be used for this analysis. If their classes were all in the same time period, this may resolve the first recommendation also.

A caveat for the analysis is warranted. Taking the class may modify reporting behaviors and thereby skew the results. Consider an employee who has no slips simulator training. If this person falls there is a good incentive to report the fall and invest in training to prevent further issues. On the other hand, someone who has taken the class may be more reticent to report a fall because of a fear of being blamed for carelessness: "I walked too fast and fell even though the laboratory trained me specifically not to." The presence of this possible reporting bias between the two groups would skew the results.

Finally, while the Slip Simulator training is currently focused primarily on learning how to navigate slippery surfaces, analysis of the data shows improvements of slip/trip/fall injuries beyond just this focus area. Expanding the training to include scenarios of walking on other high risk slip/trip/fall surfaces may yield even more improvements in those areas such as gravel surfaces, inclines, or declines.