**APPENDIX A: ONE-WAY ANOVA**

**(Fisher’s F – ratio)**

The Analysis of Variance (ANOVA) is the ratio of the model to its error or residual. In other words, it is the ratio of the variance explained by the hypothesis to the variance not explained by the hypothesis. The variance explained by the hypothesis is called the systematic variance; whereas the variance not explained by the hypothesis is called the unsystematic variance. This ANOVA ratio is called ANOVA F-statistic, or Fisher’s F-ratio.

In short,

Where *MSM* is the Mean Squares for the Model, and *MSR* is the Mean Squares for the Residual.

If F-ratio is less than 1, then *MSM* is less than *MSR*. This means there is more unsystematic variance than systematic variance. An F-ratio less than 1 indicates a non-significant effect. On the other hand, an F-ratio greater than 1 represents a significant effect.

From,

Where *SSM* is the Sum of Squares of the Model and *SSR* is the Sum of Squares of the Residual. On the other hand, *dfM* is the Degrees of Freedom of the Model ( =k-1), and *dfR* is the Degrees of Freedom of the Residual ( = n-k); where k = number of groups, and n = number of object in the group.

The Sum of Squares of the Model (*SSM*) refers to the error (difference) between the grand mean of the study value (i.e. the Cost Growth and the Change Order Cost Factor, separately) and the model.

The Sum of Squares of the Residual (*SSR*) refers to the error (difference) between the observed data and the model.

**APPENDIX B: ROBUST ANOVA**

**(Bootstrapping M-estimator)**

A robust ANOVA refers to a methodology where its result is valid though ANOVA assumptions are violated.

The robust ANOVA practiced in this study is the bootstrapping M-estimator. Both the bootstrap and the M-estimator are robust methodologies. The bootstrap methodology, initiated by B. Efron in 1979, can be used alone or in conjunction with another methodology, such as the trimmed means and the M-estimator (Wright, London, & Field, 2011).

According to Schumacker and Tomek (2013), bootstrap is a resampling technique from which the sampling distribution of a statistic is estimated by taking repeated values (with replacement) from the data set; so in effect, treating the data as a population from which smaller samples are taken. The statistic of mean is calculated for each sample, from which the sampling distribution of the statistic is estimated. The standard error of the statistic is estimated as the standard deviation of the sampling distribution created from the bootstrap samples. From this, confidence intervals and significance tests can be computed.

On the other hand, the trimmed mean methodology is based on the distribution of scores after some percentage (e.g. 10%) of outliers has been removed from each extreme of the distribution. In similar manner, M-estimator is a robust measure of location. It is a type of trimming, similar to trimmed mean, but the commonly used location is the median. Moreover, unlike the trimmed mean, M-estimator allows asymmetric trimming, trimming more or less on one tail comparing to another tail (Wu, 2002). The amount of trimming used to remove outliers – including the possibility of no trimming - is determined empirically (Field, Miles, & Field, 2012). For this reason, Wilcox (2005) recommends using the M-estimator over the trimmed means.

Wilcox (2005) explains the bootstrap method and M-measures of location as follows:

:

Where represents some measure of location (e.g. median) associated with the j*th* group

The test statistic is:

Where, and

Wilcox (2005) further stated that to determine the critical value, shift (center) the empirical distributions of each group so that the estimated measure of location is zero in all group, and the bootstrapped samples are drawn from the centered data to generate an estimate of the sampling distribution, yielding H\*. Repeat this B times, resulting in , and put these B values in order yielding Then an estimate of an appropriate critical value is , where . is rejected if .

**APPENDIX C: PLANNED CONTRAST**

**(METHODOLOGY)**

There are two ways to indicate where the differences lie among group means when the ANOVA test is significant - post-hoc tests and planned comparisons (so called Planned Contrasts). Post-hoc tests only focus on pairs of groups; whereas Planned Contrasts allow us to focus on more complex configurations. It assists us in specifying the prediction and testing it. Thus, this study used planned contrasts for this reason.

Blagov, P. and Peart, J. (2011) explained that planned contrasts are defined using contrast weights. Groups that are predicted to be similar will be assigned the same contrast weight, and groups that are expected to be different will be assigned different contrast weights. The relative magnitude of the weights reflects the direction of the predicted difference, but the actual numbers do not matter.

Blagov, P. and Peart, J. (2011) provided examples as:

|  |  |  |  |
| --- | --- | --- | --- |
| A | B | C | D |
| -1 | 1 | 1 | -1 |

A and D will be similar to each other, but differ from B and C. B and C are similar to each other, and have higher study weight than A and D.

H0: [(1)\*Mean A] + [(-1)\*Mean B] + [(-1)\*Mean C] + [(1)\*Mean D] = 0

H1: [(-1)\*Mean A] + [(1)\*Mean B] + [(1)\*Mean C] + [(-1)\*Mean D] = 0

In the same manner:

|  |  |  |  |
| --- | --- | --- | --- |
| A | B | C | D |
| -2 | 1 | 1 | 0 |

In this case, A will have the lowest study value weight; D is next, and then B and C. A and D are different. B and C are similar, but different from A and D.

This study uses R-language, a computer language and environment for statistical computing, as a tool in solving planned contrasts. Treatment and Helmert contrasts are the two R-langage functions selected for this study. Contrasts in R-language determine how linear model coefficients of categorial variables are interpreted.

Dalgaard (2008) stated Treatment contrasts can be explained when the ﬁrst group is treated as a baseline and the other groups are assessed relative to that. This notion is called Treatment contrasts because if the ﬁrst group is “no treatment” then the coefﬁcients immediately give the treatment effects for each of the other groups. On the other hand, Helmert contrasts compare a level to the mean of subsequent levels.

For this study, for example, the Treatment contrast matrix (when DBB is the baseline) is:

|  |  |  |
| --- | --- | --- |
|  | 1 | 2 |
| **DBB** | **0** | **0** |
| DB | 1 | 0 |
| CMGC | 0 | 1 |

This matrix indicates the model has two coefficients, one for the DB and another for the CMGC. DBB is the baseline.

Using Ford (2013) as an examples, the PDS’ Treatment and Helmert contrasts matrix can be explained as follows:

Assume: MeanDBB = 6.0

MeanDB = 10.1

MeanCMGC = 12.9

And, assume, R-language yields estimated coefficients for the Treatment contrasts as:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Estimated coeff** | Std. Error | t value | Pr (> |t|) |
| **(Intercept)** | **6.0000** | 0.3935 | 15.249 | 8.63e-15 |
| **DB** | **4.1000** | 0.5564 | 7.368 | 6.32e-.8 |
| **CMGC** | **6.9000** | 0.5564 | 12.400 | 1.17e-12 |

Based on Treatment contrast definition, Intercept (6.000) is the mean of DBB baseline. DB coeff (4.1000) is the mean of DB compares with DBB baseline’s. That is 10.1 – 6.0, which is 4.1000. In the same manner, CMGC coeff (6.9000) is the mean of CMGC compares with DBB baseline’s. That is 12.9 - 6.0, which is 6.9000.

Cross check these coefficient values with the linear model: Y = c + aX1 + bX2 ; where c is the Intercept, a is the DB coeff, b is the CMGC coeff, X1 is the DB contrast weight, and X2 is the CMGC contrast weight.

DBB = 6.0000 + 4.1000 (0) + 6.9000 (0) = 6.0000

DB = 6.0000 + 4.1000 (1) + 6.9000 (0) = 10.1000

CMGC = 6.0000 + 4.1000 (0) + 6.9000 (1) = 12.9000

On the other hand, for this study, the Helmert contrast matrix is:

|  |  |  |
| --- | --- | --- |
|  | [,1] | [,2] |
| CMGC | -1 | -1 |
| DB | 1 | -1 |
| DBB | 0 | 2 |

And, assume, R-language yields estimated coefficients for the Helmert contrasts as:

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Estimated coeff** | Std. Error | t value | Pr (> |t|) |
| **(Intercept)** | **9.6667** | 0.2272 | 42.553 | < 2e-16 |
| **PDS1** | **2.0500** | 0.2782 | 7.368 | 6.32e-.8 |
| **PDS2** | **1.6167** | 0.1606 | 10.064 | 1.24e-10 |

For the Helmert contrasts, Intercept refers to the grand mean of the means of DBB, DB and CMGC. That is (6.0 + 10.1 + 12.9)/3, which is 9.6667. The PDS1 refers to the comparison between the mean of Innovative PDS category, which is (CMGC together with DB), and the traditional PDS (DBB).

The mean of CMGC and the mean of DB equal (6.0 + 10.1)/2, which is 8.05. Thus, the coeff of PDS 1 is 8.05 – 6.0, which is 2.05. The PDS2 refers to to the comparison between the grand mean (9.6667) and the mean of the Innovative PDS category (8.05). Thus 9.6667 - 8.0500, which is 1.6167.

Fitting these values in the model: Y = c + aX1 + bX2

DBB = 9.6667 + 2.0500 (-1) + 1.6167 (-1) = 6.0000

DB = 9.6667 + 2.0500 (1) + 1.6167 (-1) = 10.1000

CMGC = 9.6667 + 2.0500 (0) + 1.6167 (2) = 12.9000

**APPENDIX D: PLANNED CONTRAST**

**(ANALYSIS)**

**Figure 5: Cost Growth (Helmert Contrast) – can be explained as follows.**



*Figure 5: Cost Growth (Helmert Contrast)*

The hypotheses based on the information from contrasts matrix:

|  |  |  |
| --- | --- | --- |
|  | [,1] | [,2] |
| CMGC | -1 | -1 |
| DB | 1 | -1 |
| DBB | 0 | 2 |

H1: (Mean Cost Gwth)**DB**  > (Mean Cost Gwth)**CMGC**

**thus;** H0 of 1: (Mean Cost Gwth)**DB**  < (Mean Cost Gwth)**CMGC**

H2: (Mean Cost Gwth)**DBB**> (Mean Cost Gwth)**DB & CMGC**

**thus;** H0 of 2: (Mean Cost Gwth)**DBB**< (Mean Cost Gwth)**DB & CMGC**

Based on Field (2013) explanation, since the Estimated Coefficients (-0.2698 and -1.5175) and the t-value (-0.304 and -4.817) both show the negative sign which indicates the hypotheses assumed the opposite direction of the probability test results. Thus, the correct direction of the hypotheses should be:

H1: (Mean Cost Gwth)**DB**  < (Mean Cost Gwth)**CMGC**

**thus;** H0 of 1: (Mean Cost Gwth)**DB**  > (Mean Cost Gwth)**CMGC**

H2: (Mean Cost Gwth)**DBB**< (Mean Cost Gwth)**DB & CMGC**

**thus;** H0 of 2: (Mean Cost Gwth)**DBB**> (Mean Cost Gwth)**DB & CMGC**

The significant values of the one-tailed probability of the H1 is 0.761/2 = 0.3805, which is greater than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Cost Growth of DB is higher than that of CMGC.**

On the other hand, the significant values of the one-tailed probability of the H2 is 0/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Cost Growth of DBB (traditional PDS) is less than that of “DB & CMGC” (innovative PDS**). Note that, for this Helmert contrast analysis, “DB & CMGC” refers to a group/category called “innovative PDS” (Shakya, 2013; Walewski et al., 2001).

**Figure 6: Cost Growth (Treatment Contrast - DBB is the baseline category) – can be explained as follows.**



*Figure 6: Cost Growth (Treatment Contrast - DBB is the baseline category)*

The hypotheses based on the information from contrasts matrix:

|  |  |  |
| --- | --- | --- |
|  | 1 | 2 |
| CMGC | 1 | 0 |
| DB | 0 | 1 |
| **DBB** | **0** | **0** |

H1: (Mean Cost Gwth)**CMGC**  > (Mean Cost Gwth)**DBB**

**thus;** H0 of 1: (Mean Cost Gwth)**CMGC**  < (Mean Cost Gwth)**DBB**

H2: (Mean Cost Gwth)**DB**> (Mean Cost Gwth)**DBB**

**thus;** H0 of 2: (Mean Cost Gwth)**DB**< (Mean Cost Gwth)**DBB**

Based on Field (2013) explanation, the significant values of the one-tailed probability of the H1 is 0/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Cost Growth of CMGC is higher than that of DBB.**

On the other hand, the significant values of the one-tailed probability of the H2 is 0.00382/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Cost Growth of DB is higher than that of DBB.**

**Figure 7: Cost Growth (Treatment Contrast - DB is the baseline category) – can be explained as follows.**



*Figure 7: Cost Growth (Treatment Contrast - DB is the baseline category)*

The hypotheses based on the information from contrasts matrix:

|  |  |  |
| --- | --- | --- |
|  | 1 | 3 |
| CMGC | 1 | 0 |
| **DB** | **0** | **0** |
| DBB | 0 | 1 |

H1: (Mean Cost Gwth)**CMGC**  > (Mean Cost Gwth)**DB**

**thus;** H0 of 1: (Mean Cost Gwth)**CMGC**  < (Mean Cost Gwth)**DB**

H3: (Mean Cost Gwth)**DBB**> (Mean Cost Gwth)**DB**

**thus;** H0 of 3: (Mean Cost Gwth)**DBB**< (Mean Cost Gwth)**DB**

Based on Field (2013) explanation, since the Estimated Coefficients and the t-value of H3 show the negative sign which indicates the H3 hypothesis assumed the opposite direction of the probability test results. Thus, the correct direction of the hypotheses should be:

H1: (Mean Cost Gwth)**CMGC**  > (Mean Cost Gwth)**DB**

**thus;** H0 of 1: (Mean Cost Gwth)**CMGC**  < (Mean Cost Gwth)**DB**

H3: (Mean Cost Gwth)**DBB**< (Mean Cost Gwth)**DB**

**thus;** H0 of 3: (Mean Cost Gwth)**DBB**> (Mean Cost Gwth)**DB**

The significant values of the one-tailed probability of the H1 is 0.76121/2 = 0.3806, which is greater than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Cost Growth of CMGC is less than that of DB.**

On the other hand, the significant values of the one-tailed probability of the H3 is 0.00382/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Cost Growth of DBB is less than that of DB.**

**Figure 8: Cost Growth – (Treatment Contrast - CMGC is the baseline category) – can be explained as follows.**



*Figure 8: Cost Growth – (Treatment Contrast - CMGC is the baseline category)*

The hypotheses based on the information from contrasts matrix:

|  |  |  |
| --- | --- | --- |
|  | 2 | 3 |
| **CMGC** | **0** | **0** |
| DB | 1 | 0 |
| DBB | 0 | 1 |

H2: (Mean Cost Gwth)**DB**  > (Mean Cost Gwth)**CMGC**

**thus;** H0 of 2: (Mean Cost Gwth)**DB**  < (Mean Cost Gwth)**CMGC**

H3: (Mean Cost Gwth)**DBB** > (Mean Cost Gwth)**CMGC**

**thus;** H0 of 3: (Mean Cost Gwth)**DBB** < (Mean Cost Gwth)**CMGC**

Based on Field (2013) explanation, since the Estimated Coefficients (-0.5395 and -4.8222) and the t-value (-0.304 and -4.417) both show the negative sign which indicates the hypotheses assumed the opposite direction of the probability test results. Thus, the correct direction of the hypotheses should be:

H2: (Mean Cost Gwth)**DB**  < (Mean Cost Gwth)**CMGC**

**thus;** H0 of 2: (Mean Cost Gwth)**DB**  > (Mean Cost Gwth)**CMGC**

H3: (Mean Cost Gwth)**DBB** < (Mean Cost Gwth)**CMGC**

**thus;** H0 of 3: (Mean Cost Gwth)**DBB** > (Mean Cost Gwth)**CMGC**

The significant values of the one-tailed probability of the H2 is 0.761/2 = 0.3805, which is greater than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Cost Growth of DB is higher than that of CMGC**.

On the other hand, the significant values of the one-tailed probability of the H3 is 0/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Cost Growth of DBB is less than that of CMGC.**

**Figure 9: Change Order Cost Factor (Helmert Contrast) – can be explained as follows.**



*Figure 9: Change Order Cost Factor (Helmert Contrast)*

The hypotheses based on the information from contrasts matrix:

|  |  |  |
| --- | --- | --- |
|  | [,1] | [,2] |
| CMGC | -1 | -1 |
| DB | 1 | -1 |
| DBB | 0 | 2 |

H1: (Mean Cost Factor)**DB**  > (Mean Cost Factor)**CMGC**

**thus;** H0 of 1: (Mean Cost Factor)**DB**  < (Mean Cost Factor)**CMGC**

H2: (Mean Cost Factor)**DBB**> (Mean Cost Factor)**DB & CMGC**

**thus;** H0 of 2: (Mean Cost Factor)**DBB**< (Mean Cost Factor)**DB & CMGC**

Based on Field (2013) explanation, since the Estimated Coefficients (-0.003711 and -1.200084) and the t-value (-0.005 and -4.622) both show the negative sign which indicates the hypotheses assumed the opposite direction of the probability test results. Thus, the correct direction of the hypotheses should be:

H1: (Mean Cost Factor)**DB**  < (Mean Cost Factor)**CMGC**

**thus;** H0 of 1: (Mean Cost Factor)**DB**  > (Mean Cost Factor)**CMGC**

H2: (Mean Cost Factor)**DBB**< (Mean Cost Factor)**DB & CMGC**

**thus;** H0 of 2: (Mean Cost Factor)**DBB**> (Mean Cost Factor)**DB & CMGC**

The significant values of the one-tailed probability of the H1 is 0.996/2 = 0.498, which is greater than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Change Order Cost Factor of DB is higher than that of CMGC.**

On the other hand, the significant values of the one-tailed probability of the H2 is 0/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Change Order Cost Factor of DBB (traditional PDS) is less than that of “DB & CMGC” (innovative PDS).**

**Figure 10: Change Order Cost Factor (Treatment Contrast - DBB is the baseline category) – can be explained as follows.**



*Figure 10: Change Order Cost Factor (Treatment Contrast - DBB is the baseline category)*

The hypotheses based on the information from contrasts matrix:

|  |  |  |
| --- | --- | --- |
|  | 1 | 2 |
| CMGC | 1 | 0 |
| DB | 0 | 1 |
| **DBB** | **0** | **0** |

H1: (Mean Cost Factor)**CMGC**  > (Mean Cost Factor)**DBB**

**thus;** H0 of 1: (Mean Cost Factor)**CMGC**  < (Mean Cost Factor)**DBB**

H2: (Mean Cost Factor)**DB**> (Mean Cost Factor)**DBB**

**thus;** H0 of 2: (Mean Cost Factor)**DB**< (Mean Cost Factor)**DBB**

Based on Field (2013) explanation, the significant values of the one-tailed probability of the H1 is 0/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Change Order Cost Factor of CMGC is higher than that of DBB.**

On the other hand, the significant values of the one-tailed probability of the H2 is 0.00382/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Change Order Cost Factor of DB is higher than that of DBB.**

**Figure 11: Change Order Cost Factor (Treatment Contrast - DB is the baseline category) – can be explained as follows.**



*Figure 11: Change Order Cost Factor (Treatment Contrast - DB is the baseline category)*

The hypotheses based on the information from contrasts matrix:

|  |  |  |
| --- | --- | --- |
|  | 1 | 3 |
| CMGC | 1 | 0 |
| **DB** | **0** | **0** |
| DBB | 0 | 1 |

H1: (Mean Cost Factor)**CMGC**  > (Mean Cost Factor)**DB**

**thus;** H0 of 1: (Mean Cost Factor)**CMGC**  < (Mean Cost Factor)**DB**

H3: (Mean Cost Factor)**DBB**> (Mean Cost Factor)**DB**

**thus;** H0 of 3: (Mean Cost Factor)**DBB**< (Mean Cost Factor)**DB**

Based on Field (2013) explanation, since the Estimated Coefficients and the t-value of H3 show the negative sign which indicates the H3 hypothesis assumed the opposite direction of the probability test results. Thus, the correct direction of the hypotheses should be:

H1: (Mean Cost Factor)**CMGC**  > (Mean Cost Factor)**DB**

**thus;** H0 of 1: (Mean Cost Factor)**CMGC**  < (Mean Cost Factor)**DB**

H3: (Mean Cost Factor)**DBB**< (Mean Cost Factor)**DB**

**thus;** H0 of 3: (Mean Cost Factor)**DBB**> (Mean Cost Factor)**DB**

The significant values of the one-tailed probability of the H1 is 0.99595/2 = 0.4980, which is greater than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Change Order Cost Factor of CMGC is less than that of DB.**

On the other hand, the significant values of the one-tailed probability of the H3 is 0.00321/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Change Order Cost Factor of DBB is less than that of DB.**

**Figure 12: Change Order Cost Factor (Treatment Contrast - CMGC is the baseline category) – can be explained as follows.**



*Figure 12: Change Order Cost Factor (Treatment Contrast - CMGC is the baseline category)*

The hypotheses based on the information from contrasts matrix:

|  |  |  |
| --- | --- | --- |
|  | 2 | 3 |
| **CMGC** | **0** | **0** |
| DB | 1 | 0 |
| DBB | 0 | 1 |

H2: (Mean Cost Factor)**DB**  > (Mean Cost Factor)**CMGC**

**thus;** H0 of 2: (Mean Cost Factor)**DB**  < (Mean Cost Factor)**CMGC**

H3: (Mean Cost Factor)**DBB**> (Mean Cost Factor)**CMGC**

**thus;** H0 of 3: (Mean Cost Factor)**DBB**< (Mean Cost Factor)**CMGC**

Based on Field (2013) explanation, since the Estimated Coefficients (-0.007421 and -3.603962) and the t-value (-0.005 and -4.006) both show the negative sign which indicates the hypotheses assumed the opposite direction of the probability test results. Thus, the correct direction of the hypotheses should be:

H2: (Mean Cost Factor)**DB**  < (Mean Cost Factor)**CMGC**

**thus;** H0 of 2: (Mean Cost Factor)**DB**  > (Mean Cost Factor)**CMGC**

H3: (Mean Cost Factor)**DBB**< (Mean Cost Factor)**CMGC**

**thus;** H0 of 3: (Mean Cost Factor)**DBB**> (Mean Cost Factor)**CMGC**

The significant values of the one-tailed probability of the H2 is 0.996/2 = 0.498, which is greater than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Change Order Cost Factor of DB is higher than that of CMGC.**

On the other hand, the significant values of the one-tailed probability of the H3 is 0/2 = 0, which is less than 0.05. Therefore, there is enough evidence to support the claim that **the average** **Change Order Cost Factor of DBB is less than that of CMGC.**

**ACRONYM**

ANOVA = Analysis of Variance

DB = Design-Build

DBB = Design-Bid-Build

CMGC = Construction Manager-General Contractor

dfM = Degrees of Freedom of the Model

dfR = Degrees of Freedom of the Residual

MSM = Mean Squares for the Model

MSR = Mean Squares for the Residual

PDS = Project Delivery System

SSM = Sum of Squares of the Model

SSR = Sum of Squares of the Residual