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TRIPOD TORSIONAL RIGIDITY DATA ANALYSIS

PERFORMED BY DR. CRAIG G. DOWNING

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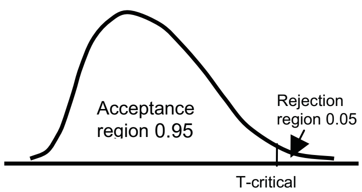
The following information presented in this report represents my personal, independent, analysis of the performance data for the Tri-Max Tripod and other similar tripods. More specifically, the analysis focuses on the technical requirements of ISO 12858-2: 1999(E) [Optics and optical instruments – Ancillary devices for geodetic instruments – Part 2: Tripods] – 6.6 Torsional Rigidity. The findings presented within this document are based upon the data collected for Tri-Max tripod and ten (10) similar tripod products.

Two sets of data were analyzed. The first data set assessed the performance of new, “out of box”, tripods while the second set of data assessed the performance of the tripods after field conditioning, both with respect to environmental and operational conditions. The data supplied represented a sample size of three of each different type of tripod. Since a sample size of three would be considered small for traditional statistical analysis, I employed the use of descriptive statistics and Student t-tests. It also should be noted that a sample size of three (3) of each different type of tripod is not the most desired sample size, but the t-test is designed for small sample sizes, $n < 30$. Where n is the number of samples.

Furthermore, the Student t-test was chosen because it has the capability to compare the means of two independent samples and determine if there is a statistically significant difference or if the difference in means is caused by chance. Calculated t-scores are compared against a t-critical value, which is determined by the alpha level, sample size, and the homogeneity of variances for the groups. Calculated t-scores that exceed the t-critical value for a given test indicate that the difference in means is not an issue of chance. The difference is statistically different and the null hypothesis is rejected, thereby indicating the averages for the two groups are statistically different and not by chance.



The two sample t-test is a hypothesis test for answering questions related to the means when data are randomly sampled from two distinct populations. The alpha level is selected to protect the researcher from rejecting a null hypothesis that is correct. This is more commonly known as a Type-I error. For example, in this study the null hypothesis is that there is no difference between Tri-Max’s average torsional rigidity value and the 10 other tripods. The alternate hypothesis is that Tri-Max’s average torsional rigidity value is significantly less than that of the other 10 tripods. The alpha level was set to 5% ($\alpha = 0.05$) which gives me a 95% confidence interval that the conclusions I draw are statistically sound and not an issue of chance.

The hypothesis and formulas used in the report are as follows. (Average torsional rigidity value for Tri-Max mT; Average torsional value for other similar tripods μ_O; Standard deviation of Tri-Max values sT; Standard deviation of the other tripods s_O)

$$H_o : \mu_T = \mu_O \qquad H_a : \mu_T \neq \mu_O \qquad t = \frac{\mu_O - \mu_T}{\sqrt{\frac{s_O^2}{n_O} + \frac{s_T^2}{n_T}}}$$

Figure 1. Null and Alternate Hypothesis; Student t-test Formula

Nomenclature used in the previous formulas (Fig. 1) will remain the same throughout the analysis, both for new and field conditioned testing.

The first step in my analysis determined the average torsional rigidity value for Tri-Max and the other tripods in their new, "out-of-box" condition. Listed below are the results of the descriptive statistic.

Table 1. Torsional Rigidity Test Result (New)

Product	Average Torsional Rigidity Value* (Arc-Seconds)	Result
Tri-Max	1.5	Pass
CST All Fiberglass	5.5	Fail
CST Bare Wood/FG	8.8	Fail
CST Robotics W/FG	3.3	Fail
CST Standard W/FG	11.7	Fail
Dutch Hill Aluminum Head	4.8	Fail
Dutch Hill Plastic Head	5.0	Fail
Leica GST 120	2.8	Pass
Nedo Quick Clamp	3.3	Fail
Sokkia Screw Clamp	5.8	Fail
Topcon Screw Clamp	13.5	Fail

* Values of 3 arc-seconds or less are considered passing. ISO 12858-2:1999(E) - 6.6 Torsional Rigidity.

From the values listed in Table 1 it is clear, on average, Tri-Max tripods possess greater torsional rigidity than the other tripods. Since the average value of Tri-Max was 1.5 arc-seconds and the average value of the other tripods was 6.45 arc-seconds, the data indicates Tri-Max tripod is a 330% more reliable unit when subjected to torsional loads. However, to further strengthen my position, I performed a comparative analysis of the means. To this end, I performed a series of one-tail Student t-tests with $\alpha = 0.05$.

After running the series of t-tests, Tri-Max tripods exhibited a statistical significant difference in its mean when compared to the other tripods. The values of the other tripods were significantly larger than Tri-Max. Thereby, suggesting that when a torsional load is applied to the head unit of the other tripods they were less likely to return to their original position. Simply put, the Tri-Max tripod has less residual angular displacement than the other tripods. Table 2 shows the output of the analysis.

Table 2. t-scores Analysis (New)

Product	Average Torsional Rigidity Value* (Arc-Seconds)	Product	Average Torsional Rigidity Value* (Arc-Seconds)	*t*-critical	*t*-score
Tri-Max	1.5	CST All Fiberglass	5.5	2.35	7.59
Tri-Max	1.5	CST Bare Wood/FG	8.8	2.91	2.71†
Tri-Max	1.5	CST Robotics W/FG	3.3	2.35	5.50
Tri-Max	1.5	CST Standard W/FG	11.7	2.91	4.25
Tri-Max	1.5	Dutch Hill Aluminum Head	4.8	2.13	5.00
Tri-Max	1.5	Dutch Hill Plastic Head	5.0	2.13	8.57
Tri-Max	1.5	Leica GST 120	2.8	2.35	4.00
Tri-Max	1.5	Nedo Quick Clamp	3.3	2.13	5.50
Tri-Max	1.5	Sokkia Screw Clamp	5.8	2.13	4.67
Tri-Max	1.5	Topcon Screw Clamp	13.5	2.91	3.59

* Values of 3 arc-seconds or less are considered passing. ISO 12858-2:1999(E) - 6.6 Torsional Rigidity.
† Statistical significance was not achieved due to the large amount of variance in the test data. However, every individual test result failed. See appendix A.

As illustrated in Table 2, the statistical analysis shows Tri-max exhibited higher levels of resilience with its average test result of 1.5 arc-seconds. Since the calculated t-scores exceeded the t-critical, I was able to conclude that a statistically significant difference existed between the average torsional rigidity values of Tri-Max and the other tripods. More specifically, a new Tri-Max tripod exhibited a greater likelihood of returning to its original position than the other new tripods.

To further solidify my opinion of Tri-Max's product superiority related to the ISO 12858-2: 1999(E) – 6.6 Torsional Rigidity, a similar analysis was conducted on the same tripods after being exposed to field conditions. Samples were exposed to a series of simulated field conditions intended to approximate anticipated environmental conditions experienced by geomatic tripods in field use, transportation, and storage. These simulated field conditions included temperature and humidity extremes cycling, torsional loading and hinge cycling. The results of field conditioned samples may have greater weight than those of the new, "out-of-box" samples, as the field conditions may be more indicative of environmental conditions actually encountered by tripods in field use. Table 3 highlights the results of the torsional rigidity test after being field conditioned.

Table 3. Torsional Rigidity Test Result (Field Conditioned)

Product	Average Torsional Rigidity Value* (Arc-Seconds)	Result
Tri-Max	1.8	Pass
CST All Fiberglass	9.3	Fail
CST Bare Wood/FG	23.8	Fail
CST Robotics W/FG	27.8	Fail
CST Standard W/FG	16.0	Fail
Dutch Hill Aluminum Head	5.2	Fail
Dutch Hill Plastic Head	9.7	Fail
Leica GST 120	10.7	Fail
Nedo Quick Clamp	5.8	Fail
Sokkia Screw Clamp	23.7	Fail
Topcon Screw Clamp	10.7	Fail

* Values of 3 arc-seconds or less are considered passing. ISO 12858-2:1999(E) - 6.6 Torsional Rigidity.

Again, it is clear from the data in Table 3 that Tri-Max tripods are more resilient than the other ten (10) tripods when the torsional rigidity test is conducted after being field conditioned. After field conditioning Tri-Max, on average, was a 693% more reliable tripod than the other tripods. Tri-Max's average test value was 1.8 arc-seconds as compared to 14.27 arc-seconds for the other tripods. However, it was important to perform another series of t-tests to ensure the mean value of Tri-max tripod were statistically significant when compared to the other tripods after being field conditioned. The actual results of this analysis can be found in the following table.

Table 4. t-scores Analysis (Field Conditioned)

Product	Average Torsional Rigidity Value* (Arc-Seconds)	Product	Average Torsional Rigidity Value* (Arc-Seconds)	*t*-critical	*t*-score
Tri-Max	1.8	CST All Fiberglass	9.3	2.91	3.29
Tri-Max	1.8	CST Bare Wood/FG	23.8	2.91	2.99
Tri-Max	1.8	CST Robotics W/FG	27.8	2.91	7.15
Tri-Max	1.8	CST Standard W/FG	16.0	2.91	4.60
Tri-Max	1.8	Dutch Hill Aluminum Head	5.2	2.13	6.03
Tri-Max	1.8	Dutch Hill Plastic Head	9.7	2.13	6.65
Tri-Max	1.8	Leica GST 120	10.7	2.13	3.14[?]
Tri-Max	1.8	Nedo Quick Clamp	5.8	2.13	5.00
Tri-Max	1.8	Sokkia Screw Clamp	23.7	2.91	3.55
Tri-Max	1.8	Topcon Screw Clamp	10.7	2.13	6.90

* Values of 3 arc-seconds or less are considered passing. ISO 12858-2:1999(E) - 6.6 Torsional Rigidity.
!! To achieve a homogeneous variance reading and valid analysis, a cut-off value of ten (10) was used in place of an extreme failure reading. See Appendix A for details.

From the information shown in Table 4, Tri-Max exhibited a clear statistical significant difference, when tested at $\alpha = 0.05$. Each of the tests shows the calculated t-test scores exceeded the t-critical value, thus indicating a significant difference between the mean scores of each group. More importantly, Tri-Max tripods on average can withstand a torsional load and return to its original position within a 3 arc-second limit.

Based upon the data received, it is my contention that Tri-Max tripods exhibit superior resilience when torsional loads are applied. Tri-Max's ability to consistently return to its original position within 3 arc-seconds, both as a new, "out of box", and field conditioned geodetic instrument is clearly seen in the data. However, this claim cannot be made for the other ten (10) tripods.

APPENDIX A

RAW DATA

Torsional Rigidity Test Data

Table A.1 New

Product	Observation 1	Observation 2	Observation 3	Average	Standard Deviation
Tri-Max	1.0	1.5	2.0	1.5	0.5
CST All Fiberglass	**	5.0	6.0	5.5	0.7
CST Bare Wood/FG	3.5	11.0	12.0	8.8	4.6
CST Robotics W/FG	3.5	3.0	3.5	3.3	0.3
CST Standard W/FG	4.0	26.0	5.0	11.7	12.4
Dutch Hill Aluminum Head	6.0	4.5	4.0	4.8	1.0
Dutch Hill Plastic Head	4.5	5.0	5.5	5.0	0.5
Leica GST 120	3.0	2.5	3.0	2.8	0.3
Nedo Quick Clamp	3.5	3.5	3.0	3.3	0.3
Sokkia Screw Clamp	4.5	5.5	7.5	5.8	1.5
Topcon Screw Clamp	4.5	2.5	33.5	13.5	17.3

** Unit not available for testing. A value of 5.5 was used in the analysis. It is the average value of the two tripods from which data was obtained.

Table A.1 Field Conditioned

Product	Observation 1	Observation 2	Observation 3	Average	Standard Deviation
Tri-Max	1.0	2.0	2.5	1.8	0.8
CST All Fiberglass	***	4.5	14.0	9.3	6.7
CST Bare Wood/FG	10.0	26.5	35.0	23.8	12.7
CST Robotics W/FG	35.0	23.5	25.0	27.8	6.3
CST Standard W/FG	6.5	33.0	8.5	16.0	14.8
Dutch Hill Aluminum Head	5.5	4.5	5.5	5.2	0.6
Dutch Hill Plastic Head	7.5	11.0	10.5	9.7	1.9
Leica GST 120	4.5	8.5	19.0 (10)	10.7	7.5
Nedo Quick Clamp	6.5	6.5	4.5	5.8	1.2
Sokkia Screw Clamp	11.5	31.0	28.5	23.7	10.6
Topcon Screw Clamp	10.0	13.0	9.0	10.7	2.1

*** Unit not available for testing. A value of 7.3was used in the analysis. It is the average value of the two tripods from which data was obtained. (10) is cut-off value used in the t-test analysis.

APPENDIX B

RESEARCHER'S CREDENTIALS

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EDUCATION

BACHELOR OF SCIENCE, Applied Mathematics and Statistics, December 2005
Southeast Missouri State University, Cape Girardeau, MO

DOCTOR OF PHILOSOPHY, Workforce Education and Development, August 1999
Southern Illinois University Carbondale, Carbondale, IL
Dissertation Title: An Engineer's Application of Non-Technical Skills in Team-Based Environments

MASTER OF SCIENCE, Manufacturing Systems, August 1994
Southern Illinois University Carbondale, Carbondale, IL
Research Topic: Using Fuzzy Logic in Quality Function Deployment

BACHELOR OF SCIENCE, Mechanical Engineering Technology, December 1992
Southern Illinois University Carbondale, Carbondale, IL
Minor: Mathematics (Calculus and Statistics)

INSTRUCTIONAL & RESEARCH EXPERIENCE

Associate Professor, Industrial and Engineering Technology Department, August 1999 – Present
Southeast Missouri State University, Cape Girardeau, MO

- Develop curriculum and provide instruction to undergraduate Industrial and Engineering Technology students in the areas of Statistical Process Control, Total Quality Management, Industrial Management, Manufacturing Resource Analysis, Statics and Strength of Materials, Fluid Power, Engineering Economy
- Develop curriculum and supervise Graduate-level studies in Advanced Quality Concepts (Six-Sigma, Design of Experiments, ISO 9000:2002, ISO 14000:2004, and Lean Manufacturing) and Diversity Management
- Serve as Membership Consultant for the Society of Manufacturing Engineering
- Serve as member of the University's committee for Equity Issues
- Grant Reviewer for the National Science Foundation (NSF)
- TAC/ABET leader for the Manufacturing Engineering Technology program accreditation
- SAP R/3 coordinator for the Industrial and Engineering Technology Department

Visiting Instructor, Summer 2002 – Present
Southern Illinois University Carbondale: Engineering Outreach Program

- Develop Quality Control, Facilities Planning/Management, and Manufacturing Policy curriculum and provide weekend instruction to military and civilian personnel at Air Force Bases and Industrial facilities

INDUSTRIAL EXPERIENCE

Process Engineer/Operations Team Coordinator, August 1995 – May 1999

Spinnaker Electrical Tape Company (formerly Tesa Tape), Carbondale, IL

· Provided engineering support for design and startup of new production facility
· Served as ISO 9000 implementation team leader, auditor, and trainer for three facilities
· Supervised production, quality assurance, and maintenance staff
· Facilitated on-site safety and technical training sessions
· Designed cost-effective controls/mechanisms to maximize process capabilities
· Functioned as internal research and development coordinator for new product development

TECHNICAL/COMPUTER SKILLS

· Microsoft Office (Excel, Word, PowerPoint, Project 2003)
· MATLAB
· SPSS

CONSULTING ACTIVITIES

· Lockheed Martin/NASA: Material Science Evaluation (2004 – Present)
  o Perform material capability studies to develop general performance characteristics
· Parker Hannifin: Introduction to Design of Experiments Training (2002)
  o Provided SPC overview and Basic DOE training to Engineers and Management personnel
· Robert Gifford: AutoCAD Design Project (2001)
  o Provided quality control assessment of European designed electronic components
· Orpack-Stone: ISO 9002 Supplier Quality System Audit (1998)
  o Performed ISO 9002:1994 supplier audit for cardboard products
· Tesa Tape Research & Development Facility: ISO 9001 Quality System Audit (1998)
  o Performed ISO 9001:1994 research and product design audit for new products

PROFESSIONAL DEVELOPMENT (TRAINING) ACTIVITIES

· Introduction to Design of Experiments
· Design of Experiments II (Process Modeling and Optimization)
· SAP R/3 Logistics and Quality Management Modules (Enterprise Resource Planning)
· PC-DMIS CAD ++ (Brown & Sharpe Coordinate Measuring Machine software)

PROFESSIONAL MEMBERSHIPS

· American Society of Quality (ASQ) 2000 – Present
· Society of Manufacturing Engineers (SME) 1999 – Present
  o Certified Manufacturing Engineer
· American Society of Testing and Materials (ASTM) 2003 – Present