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Throws Measurement: Final Report

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This report contains a description of the design problem, solution, and testing of the Throws groups capstone project for ENGR 4381. Following an explanation of the system constraints and objectives, the physical description of an indirect measurement system for field events is provided. By moving the measurement method outside of the throwing ring, it is projected that the primary objective of saving time can be achieved while satisfying all project constraints. Calculations necessary to determine and theoretically verify the procedure for the throws measurement are included. Data from testing is submitted in order to allow an understanding of how the system was evaluated on the project criteria. Based on the results from testing and calibration, the laser track measurement system has the potential of satisfying budgetary, political, and personnel constraints but is unable to its current form. While the system is under budget and can be operated by 2 users, the desired accuracy of the system of ±3mm has not been achieved on this iteration of the project.

Executive Summary

The current method for measuring throws events at track and field meets is time consuming, causing the throws events to run longer than the rest of the meet. The primary objectives of this project were to reduce the overall time needed to run the throwing events (30% overall reduction) and to reduce the number of personnel needed to run the events (3 people to 2). The primary constraints were that the new system had to be affordable by a Division 3 college or university, abide by the standards of the International Association of Athletics Federations (IAAF) on matters such as safety and accuracy, and have the capability of interfacing with the current database system, HyTek Meet Manager®.

The proposed measurement system utilizes an indirect method that decreases the measurement time compared to the current tape measurement method. By moving the measurement process outside of the throwing ring, athletes do not have to wait during measurement and can begin their warm up routine as soon as the previous competitor leaves the ring. Distance measurements are performed using a laser distance meter from Leica Geosystems (Leica D8). This product was chosen for its ability to transmit measurements via Bluetooth and its LCD display, which would aid in the accuracy and speed of measurement. A target placed over the measurement point in the field is used to measure the point of landing for the implement. The indirect measurement uses a Pythagorean conversion that uses the throw distance from the center of the ring as the hypotenuse and the measured implement's distance with a known distance away from the track, the radius, as the other two sides. To keep a constant distance and angle, the Leica is mounted on a sled that can move freely along a secured track. The measurement system database consists of an Excel spreadsheet that is used to collect

the data transmitted by the Leica DISTO™ Transfer software and convert it to distance measurements using the Pythagorean conversion mentioned previously.

Through Engineering Equation Solver analysis it was determined that the accuracy of the measurement system was most strongly influenced by the angular deviation of the sled track. The angular deviation in the second prototype track during testing fell within the requirement to gain the accuracy set forth by the IAAF except for a single point. This leaves high confidence that the track could be manufactured to the desired accuracy given additional resources. The time trials fell within requirements when aggregated, showing the required time reduction of 30%. The design did not meet all primary constraints with respect to final prototype accuracy and personnel, although the personnel requirement was changed by the client and accuracy had been met with earlier prototypes. It should be noted that the measurements need to be verified in a fully competitive environment.

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I. Introduction

The current system for measuring the four throwing events involves three track personnel and the use of a long tape measure. After an implement is thrown, the tape measure is placed with one end at the center of the throwing ring and the other where the implement landed. The throw distance is measured from the landing point to the inside lip of the ring as determined by a third person. While this process is effective, it is rather time consuming and uses three people for the duration of the event. The throwing events take up the most time during track and field meets; according to the head track and field coach, David Svoboda, the events typically start an hour before other events and end an hour afterward. This extra time increases the duration of the entire track meet.

Based on data collected from throw testing under simulated track and field conditions, the average time to measure each throw was approximated to be 33 seconds (Appendix B). With the addition of 25 seconds for the thrower to enter the ring, warm up, throw, and exit the ring, the total time per thrower can be estimated at 58 seconds. In this project, it is proposed that a design team develops an accurate measuring system which can speed up the process of the discus and hammer throws events while meeting all of the requirements set forth by the international regulatory body International Association of Athletic Federations (IAAF). The IAAF sets the rules and regulations for all internationally recognized track and field meets, including all official NCAA events.

The primary constraint for this design project is that the measurement system must meet all of the requirements set forth by the IAAF. Most notably this requires all throws measurements to be accurate to 1 cm. The project must also adhere to a total budget of $1200. The final design is required to reduce the duration of field events to 70% of the original event time or about 41 seconds per throw. The measurement system must also reduce the current number of staff members required to run the field events from three to two individuals. The system must also be able to interface with the track and field database program used by Trinity University, HyTek Meet Manager®. While not required for project success, a display board can be created as well to display the results of each throw to spectators, competitors, and coaches in the competition. If created, the display board must utilize at least four characters of at least 6 inches in height.

II. Design Description

A. Design Objectives and Constraints

The primary objective of the project was to reduce the amount of time to measure each throw in a throwing competition at a track and field meet. Each thrower gets a certain amount of time to do their preparatory routine and then make the throw. This preparatory time cannot be reduced as it is a required allotment of time by the IAAF. IAAF constraint is safety which requires that the design not pose a threat that the implement would ricochet and hit the competitor as well as maintain dimensions.

Another objective to the design was to reduce the personnel required for each measurement. With the current system three people are needed for each measurement. With the new design it is desired that number be reduced to two. Also, the measurement data obtained should be directly inputted into a computer system. This would allow faster determination of who made the final round and who won the event overall. The final objective listed in the project charter was a way to display the results to the athletes, coaches, and fans. However, after consulting with the head track coach and client, David Svoboda, he has other means to display and did not wish to include a display board in this project.

Table 1: Design Constraints Table

Constraints:	Details:
Budget	Must cost less than $1200 for Development and $2000 for Reproduction
Political	Conform to all IAAF standards
Personnel	Reduce personnel from three to two people
Time	Reduce overall time for event by 30%
Interface with computer	Input collected data to computer automatically
Display Board	Display results for athletes, coaches, and spectators

The objectives that were met have a few constraints that need to be achieved as well. One constraint is the budget. The developmental costs needed to be less the $1200. Also, the final prototype must cost less than $2000 to reproduce as given by the client based on his knowledge of the budget constraints of division three track teams.

The system must conform to all of the IAAF regulations, yet this constraint provides uncertainty in the project. IAAF requires all measurement systems to be within a centimeter in order to be used in an official meet. However, the current method of measurement, a tape measure, has accuracy greater than a centimeter. Therefore, for this project the desired accuracy of the device was to be as or more accurate than a tape measure.

B. Initial System Design

In the early stages of design, it was realized that no current products meet all of the criteria required for a quick and accurate throws measurement system. The speed criterion is the aspect that makes this system so unique; current methods of distance measurement focus on accuracy, trading speed of use for slow processes such as leveling, alignment, and calibration. To account for this, it was decided to look into electronic measurement systems as opposed to manual devices like the tape measure. In particular, research focused on the laser distance measurement systems used by surveyors. These typically have ranges of up to 100 meters or more, have accuracies on the order of millimeters, and can take a measurement in less than a second.

After comparing products of different manufacturers and price ranges, the Leica DISTO™ D8 distance measurement system (Leica D8) was selected for this design because of its digital display screen, accuracy, and Bluetooth technology (Fig 1-b). Based on early tests with other laser measurement devices, it was found that visual alignment of a laser with a target in broad daylight for the 100m range desired would be impossible. However, the four-time zoom perspective of the Leica D8's digital display screen allows for proper laser-target alignment without seeing the laser itself, ensuring that the laser and target can be properly aligned in all conditions. The Leica D8 also has a measurement accuracy of ±1.5 mm for its full 200m range, which is well within the desired accuracy requirement for this system. Finally, this laser measurement device can transmit measurement data wirelessly to a nearby computer, expediting the process of providing competition results. Unfortunately, the Leica D8 is more expensive than similar laser measurement systems because of its increased functionality; it cost about $800, which was two-thirds of our project budget. However, we determined that all of these functions would

Figure 1: a. Laser distance measurement in a normal setup. The Leica D8 is placed on a tripod held stationary and aimed at a stationary target. b. The 4x zoom camera included in the Leica D8 model.

be necessary for a successful overall design and our remaining budget would be sufficient for the rest of the project, so we purchased the Leica D8.

Normally, the Leica D8 is placed on a tripod and directed towards a target placed on another tripod (Fig 1-a). It was originally believed that a laser distance measurement system with this setup would be significantly faster than the conventional method of throws measurement because tape measures need to be rolled and unrolled and can twist and tangle. However, time tests proved otherwise, instead indicating that the Leica D8 with normal configuration would not save more than one second per throw (Appendix C). The problem is that the judges cannot determine the thrower's mark until they walk around the safety net and into the ring, regardless of which measurement device is used. Based on these findings, it was determined that the final system design must allow the actual throw measurement to take place without placing any part of the system inside the throwing ring in order to meet the overall speed objective (Fig. 2). This saves time by enabling throw measurement and thrower warm-up to take place simultaneously and removes the need for judges to walk in and out of the ring for each throw. Even with a 17 second break period to allow for the full measurement time, this will cut the average time per throw to about 42 seconds, a decrease of 28 percent. According to these throw duration measurements, an indirect measurement system utilizing this principal is adequate to meet the speed criterion (Appendix C).

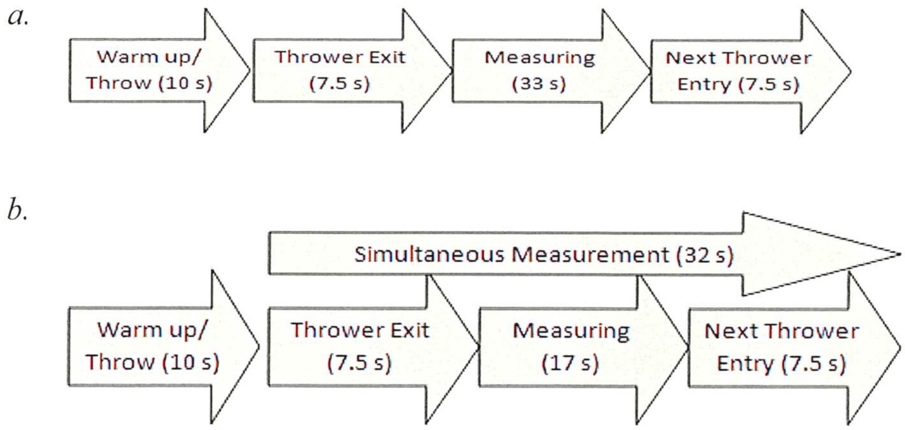


Figure 2:a. With the current method, the thrower's warm up, throw, exit, throw measurement, and the next thrower's entrance must all happen in succession, with an average total time of 58 seconds. b. A method of indirectly measuring each throw simultaneously.

C. Physical System Design

Many alternatives were considered for the physical setup of the laser measurement system, including an overhead measurement target, a rear curved target placed behind the throwing ring, and a laser track placed concentric to the throwing ring. All of these options utilized geometry, allowing for the indirect measurement of each throw by instead measuring other lengths and angles. Of these selections, the concentric laser track method was selected because of its accuracy and feasibility. It does not require the measurement of angles, which would be either slow and expensive or inaccurate, and it does not require the placement of any parts of the device inside the safety net, which could be a safety hazard.

Figure 3: The final design, placed on location next to the safety concentric with the throwing ring.

This throws measurement system utilizes a curved track placed around the safety net to indirectly measure throw lengths. This track composes an approximately 50 degree section of circle that is concentric with the throwing ring, allowing for measurement across the 34.92 degree legal throwing sector. The Leica D8 is placed on a rectangular Plexiglas sled that slides across the laser track so that it is always tangent to the track arc. Measurement of each throw requires the movement of a laser target placed in the field to the landing point of the throw and the alignment of the Leica D8 with this target.

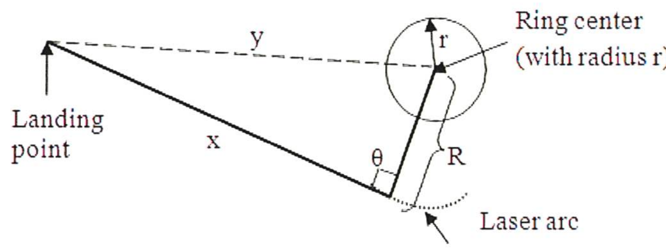


Figure 4: The laser track measurement system utilizes geometry to indirectly measure the length of each throw.

This setup allows throw distances across the entire sector to be measured indirectly using the Pythagorean Theorem (Fig. 4). Because the Leica D8 is tangent to the track arc at all times, it forms a right angle with an imaginary line drawn through the center of the throwing ring. These two lengths, l_{meas} and l_{rad}, then form the two sides of a right triangle that can be used to determine the throw length, l_{throw}, represented by the triangle's hypotenuse as shown in Eq. 1:

$$l_{throw} = \sqrt{l_{meas}^2 + l_{rad}^2} - ring\ radius \quad (1)$$

This design entails a trade-off between measurement accuracy and speed; while it is faster than conventional methods, the indirect measurement does introduce new measurement errors due to inaccuracies inherent in the overall system setup. Using Engineering Equation Solver (EES), it is found that the laser arc radius, Leica D8 device, and perpendicular angle between l_{meas} and l_{rad} have the most significant effect on the overall measurement accuracy (Appendix D). A description of how these accuracies are met can be found in the following *Methods* section.

a. Laser Track

The laser track component is composed of a 1 inch diameter hollow rod supported by a wooden structure (Fig. 5-a). Originally, a precision bent steel rod was selected as the ideal material for the track itself due to its ability to be fabricated into an arc accurate to 1/16 of an inch. However, this would have been a too expensive option for the given budget, so PVC was chosen instead. The PVC track is held in the correct arc using bolts drilled through the PVC into the wood structure. These bolts are placed through larger holes in the top of the PVC so that the bolt heads do not impede the sled from sliding across the track. Three 2" by 10" wood planks cut and connected into a 20'

Figure 5: a. The PVC laser track with wood support structure. b. bases are not permanently attached to the track to allow for dismantling and storage. c. bolts are placed through holes in the top of the PVC to allow the sled to slide without catching.

long, 6" wide arc support the PVC underneath to prevent it from sagging. This is important because the PVC track must be level in order to properly align the Leica D8 with the target. These wood planks are made of treated wood to help prevent weather-related warping and corrosion that could affect measurement accuracy. Five triangular wooden bases made of 2" by 4" planks provide support for the track along its length as well as stability. Four screws attach the wooden support for the track to each base, which can be removed when workers need to move or store the system (Fig. 5-b).

b. Laser Sled

The laser sled is an 18 inch Plexiglas structure that holds the Leica D8 and slides across the laser track (Fig 6). The Leica D8 fits into two Plexiglas slots on top of the sled: one faces forward, ensuring that the laser measurement is taken tangent to the laser track, and the other faces towards the center of the throwing ring and is used to calibrate and test the track radial accuracy. Plexiglas was selected because it is cheap, easily available, easy to work with, and resistant to deterioration due to weather. 1 inch long, 1.25 inch diameter PVC sections attach the sled to the track by clamping on to PVC track. The PVC on PVC interface that this creates allows the sled to slide easily across the track while still providing enough friction to stay in place when not being moved. The two PVC clamps also allow the sled to be easily placed on and removed from the track.

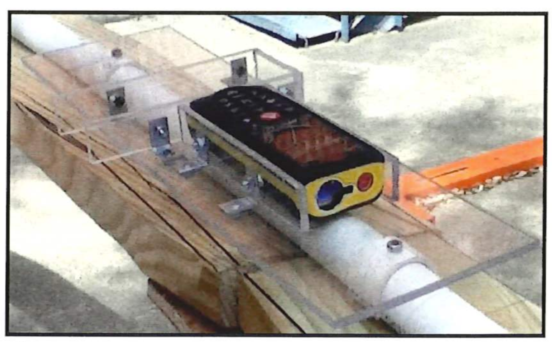


Figure 6: Plexiglas sled has slots to hold the Leica D8 during measurement and calibration. Cut PVC sections allow the sled to slide while still providing enough friction to keep the sled from tipping.

c. Target

The target includes a 10" by 10" Plexiglas target mounted on a Dynex DX-NW080 camera tripod (Fig. 7). The purpose of the tripod is to provide stability for the target while still being light enough to be carried across the throwing sector for the duration of the event. This particular model of tripod was selected because of its cheap cost at $24, light weight at 2 pounds, two bubble levels for calibration, and swivel head to allow for target rotation. A thin vertical rod placed underneath the target aligns the target over the point where the throwing implements land.

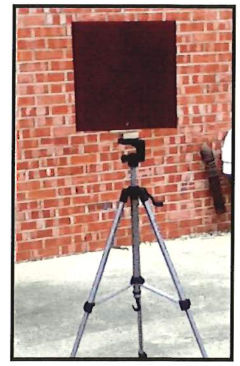


Figure 7: Laser Target

D. Software Design Description

The transfer system design will use the built in Bluetooth capabilities of the Leica to transmit the measurement data into a spreadsheet which can then be entered into the database software HyTek Meet Manager®. There will be two persons involved in the process: the Leica operator and the computer operator who will also be functioning as a line judge. Both the HyTek database and the excel data file will be stored on the Trinity server so that any authorized computer at the event can access both databases.

The operator of the Leica once a measurement is captured will press the transmit button which will then send the last measurement via Bluetooth. The DISTO™ Transfer Software reads the Bluetooth stack and uses a virtual keyboard interface to enter data. An optimal solution would be to modify the DISTO™ software to include a Pythagorean conversion in which it could interface directly with the HyTek GUI, but the DISTO™ software is not open source and cannot be modified. Microsoft Excel was chosen as an intermediary for this problem. HyTek Meet Manager® can export database tables as either delimited format or as an Access file which can

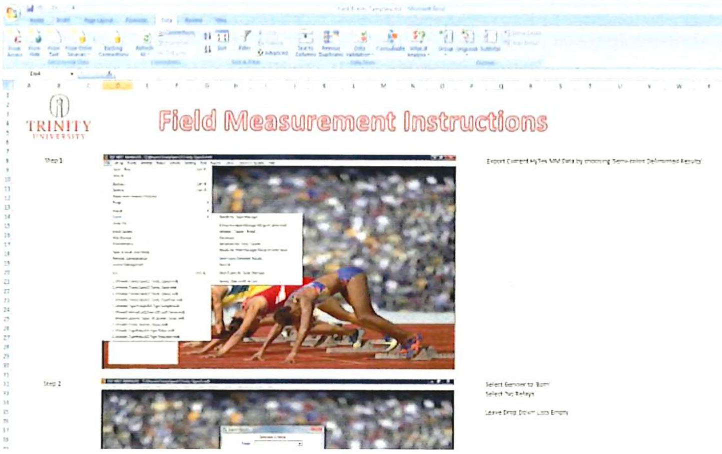
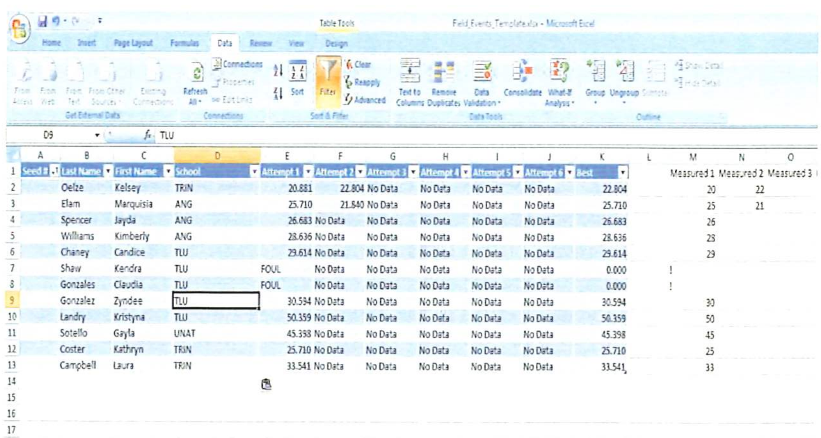


Figure 8: Excel Template Instructions Tab

be imported by Excel (or other available spreadsheet programs). The data can then be entered into the spreadsheet with automatic conversion of the throws data with little input by the computer operator. The data can then be copied into HyTek Meet Manager® once the throws event is completed.

The DISTO™ software can be configured to write the measurement data with or without unit information (default is in meters) and will write either a 'tab' or 'enter' key after the numerical entry (moving the cursor in the excel spreadsheet). The transfer software also displays the latest measurement along with the previous which allows a short-term store if there is an error in Excel data entry. If there is a loss of connection, the DISTO™ software will play a distinguishing sound alerting to computer operator of the problem. The Leica operator and computer operator will be in close proximity that communication between them should not be difficult.

Microsoft Excel can import the event information either from the text-based delineated format or from the access file. An excel template file will be used which will include step by step



Seed #	Last Name	First Name	School	Attempt 1	Attempt 2	Attempt 3	Attempt 4	Attempt 5	Attempt 6	Best		Measured 1	Measured 2	Measured 3
	Oelze	Kelsey	TRIN	20.881	22.804	No Data	No Data	No Data	No Data	22.804		20	22	
	Elam	Marquisia	ANG	25.710	21.840	No Data	No Data	No Data	No Data	25.710		25	21	
	Spencer	Jayda	ANG	26.683	No Data	No Data	No Data	No Data	No Data	26.683		26		
	Williams	Kimberly	ANG	28.636	No Data	No Data	No Data	No Data	No Data	28.636		28		
	Chaney	Candice	TLU	29.614	No Data	No Data	No Data	No Data	No Data	29.614		29		
	Shaw	Kendra	TLU	FOUL	No Data	No Data	No Data	No Data	No Data	0.000	!			
	Gonzales	Claudia	TLU	FOUL	No Data	No Data	No Data	No Data	No Data	0.000	!			
	Gonzalez	Zyndee	TLU	30.594	No Data	No Data	No Data	No Data	No Data	30.594		30		
	Landry	Kristyna	TLU	50.359	No Data	No Data	No Data	No Data	No Data	50.359		50		
	Sotello	Gayla	UNAT	45.398	No Data	No Data	No Data	No Data	No Data	45.398		45		
	Coster	Kathryn	TRIN	25.710	No Data	No Data	No Data	No Data	No Data	25.710		25		
	Campbell	Laura	TRIN	33.541	No Data	No Data	No Data	No Data	No Data	33.541		33		

Figure 9: Results Tab

instructions on the first page for importing data and navigating the Excel file (Screen Shot). Once data are imported the system should operate automatically until the end of a flight which will require moving the cursor to a new cell or until a foul need be manually entered which can be done by entering a "!" into the measurement cell (Screen Shots?). The spreadsheet will also include a summaries page of the results. Once the event is over the results can be copied over into HyTek by copying the numerical results section and pasting it into the field series datasheet in HyTek.

The using both programs will limit the possibility of losing data due to human error as the raw data will have a short term store in the DISTO™ software and the Excel file will save the pre-calculated data in case there is an error in the template and/or a dispute by a thrower. This should minimize human error in the data transfer for multiple reasons: typical users' familiarity with Excel, available visual representation of the process, and periodic engagement with tasks (Hollnagel & Woods, 2005).

III. Methods

Several testing methodologies are necessary to determine the effectiveness of the laser measurement system. Approaching these methods, there are two primary system constraints to be tested. The first principal evaluation addresses the project's accuracy constraint while the second tackles the timing issue of the throwing events. Determination of the accuracy requires several stages of assessment. By ascertaining the accuracy established by IAAF specifications, the theoretical track accuracy is ensured. Achievement of the maximum and minimum range of the system specified by the client of 25 meters to 75 meters, respectively, assures that all throws can be determined by the laser measurement system. Finally, the direct comparison of two accepted and established measurement systems, the universally accepted tape measure and the absolute measurement Leica DISTO™ D8, shows that the group's methods are comparable to acceptable standards. After the distance measurement capabilities reach the project objectives, the computer data basing potentials to tested.

Determination of the system accuracy occurred in three stages. The initial stage evaluated the accuracy of the track prototype. The PVC prototype track was transferred to Trinity University's football field to actuate proper testing conditions. First, the radius of the arc was defined from the center of the throwing arc at both outer positions of the PVC track sector and its midpoint, as shown to the right in Fig. 10. These distances were measured with the Leica DISTO™ D8. Once these values were within a tolerance of 3 cm, the arc calibration was initiated. This radius value was regarded as the absolute radius. The Plexiglass sled was then placed on the PCV track with the Leica inserted in the position normal to the track arc. As each data point was acquired, the Leica sled was moved 0.406 meters (16 inches). This number is based on the measured distance between the PVC connectors located on the underside of the sled. This occurred at 16 points and was limited to this value due to the length of the arc sector. In order to evaluate the radius of the arc, each data point was directly compared against the absolute radius procured at the beginning of the PPOC calibration. To determine the accuracy of the arc angle, each point was plotted relative to the previous with a maximum deviation of 1.8 mm between adjacent points.

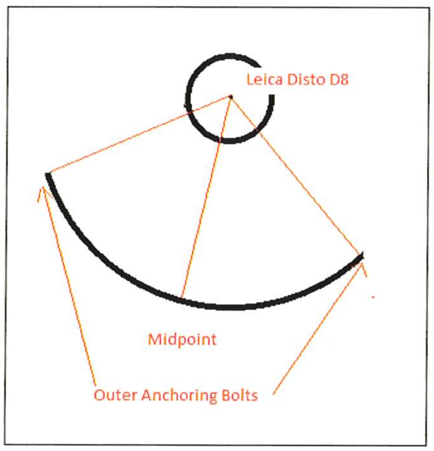


Figure 10: Measurement Position for Initial Calibration

The second stage of arc calibrations required more precise procedures. These procedures were defined on a new system tolerance based on deviations from the ideal 1 centimeter system accuracy. Empirical observations led the group to discover that the accuracy of the tape measure was in the range of 5-9 centimeters due to the method of measurement and Trinity's football field. The results of this analysis are displayed in Appendix D.

Once again, the calibrations occurred outside to simulate conditions present in a competitive environment. The DISTO™ D8 was placed on top of a tripod equipped with bubble levels on both the legs and rotating top, as shown to the right in Fig. 11. These levels will ensure that the tripod is properly leveled with the laser track. Based on the curvature of the track, this tripod was set at a point equidistant from the beginning, midpoint, and final point of the PVC arc. When these three positions were verified by the Leica DISTO™ D8, the next step of the calibration was performed. This distance was regarded as the absolute radius. The center of the Plexiglass target was placed on the particleboard base and aligned flush against the PVC track.

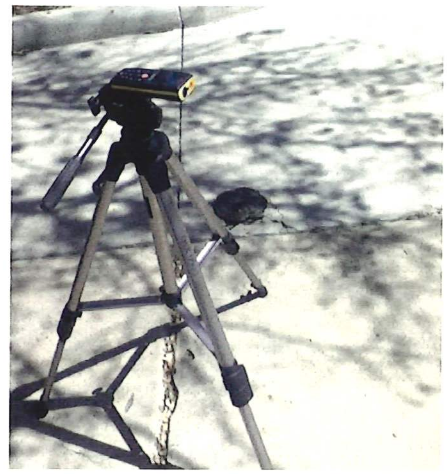


Figure 11: Leica on Tripod

20 data points were taken with the target placed flush along the PVC track corresponding with the position of each securing bolt. This is shown below in Fig. 12. In order to correct for human error during the second round of calibration, the Plexiglass target was secured to the tripod mount to maintain proper grounding. In addition to this, the mount provides a consistent verticality for target. It was imperative to ensure that the target is oriented perpendicular to the Leica DISTO™ D8; a deviation of

Figure 12: Target flush with PVC track

Figure 13: Operator handling target during calibration

1° from the desired placement could introduce a maximum error of 2.667 mm. This error is also dependent on the location of the DISTO™ D8's laser sight. The target was further stabilized by placement of the operator's hand at the top of the square to reduce the effects of wind drag. Due to environmental conditions present within the experimental setup, the target was sprayed with a maroon coating to maintain visibility in direct sunlight and compensate for the material's diffusivity. For each position, 5 measurements were taken to account for the scatter and inherent ±1.5 mm uncertainty of the DISTO™ D8 [8]. Of these, minimum and maximum values were attained with the average of these readings taken down as the measurement for that particular point. Similar to the previous test, the radial uncertainty was determined by directly comparing each measurement to the absolute radial measurement. Once again, evaluation of the arc radius required that all points adhere to a maximum 3 cm deviation from the absolute radial measurement. Based on new values procured from an error analysis, every position 0.406 m apart must be within 3mm relative to the adjacent point. After the calibration procedure, the results influenced the reposition of the anchoring bolts. If the calibration necessitated alterations to the track greater than 5 mm, a new hole was drilled along the PVC track approximate 1 centimeter from the original hole. Otherwise, the hole was bored out up to 5 mm and the track naturally conformed to the desired position on the track.

Once the track was calibrated to the necessary tolerance level, the final design of the track was brought down to Trinity University's football field. Similar to the first stage testing, the radius was calibrated from the midpoint and the two exterior anchoring bolts. After completion of the calibration procedures, the Leica laser measuring system was set against the standard tape measure. These two were compared against the Leica D8 positioned at the center of the throwing circle after the collection of the laser track measurement. The purpose of this phase of testing was to assess the full requirements necessary of the final design; points were randomly located in the throwing sector to encompass both the distance range, 25 m to 75 m, and angular range, 0° to 34.92°. An example schematic showing the locations of multiple test sites is shown below in Fig 14. The collected measurement data was then statistically compared to the data procured from the tape measure.

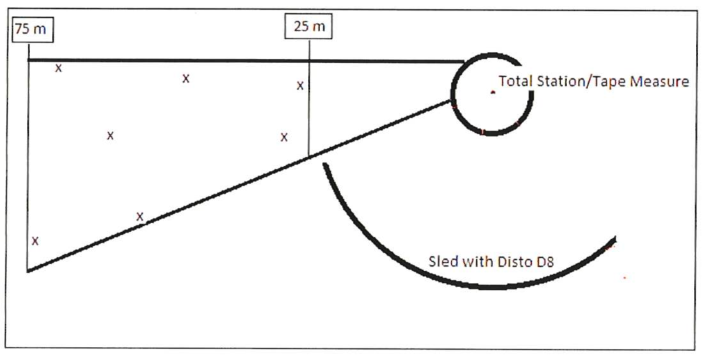


Figure 14: Sample locations for final testing

One of the primary objectives of the Throws design project was to lower the overall event time for throwing events, particularly hammer and discus. Although track administrative duties cannot be affected by the design and implementation of the measurement system, the measurement protocol could be augmented in a beneficial fashion. Currently, athletes must exit the ring before measurements can take place during field events. By moving the measurement method outside of the throwing ring, it was hypothesized that the desired time percentage of 30% can be achieved.

Despite the collection of simulated time data in previous research, it was necessary to acquire competition-based throw and measurement times to ensure validation of the time test. Based on data taken at a collegiate track meet, a standard was procured for the basis of time comparison. Following the completion of distance data acquisition during the final stage of arc calibration, time trials were performed to determine whether the system's time constraint was satisfied.

For these time trials, several random locations of increasing distance were marked on the throwing sector. These locations included the minimum and maximum distances of 25 m and 75 m, respectively, and multiple points in between, similar to the previous distance test. If the average of these results was equal to or below the average of competition field time data, then the time constraint was considered satisfied. Satisfaction of this constraint rested on the assumption that by devising a system equally as fast as the tape measure, the placement of the system outside of the throwing ring reduced the overall time of these throwing events by 30%.

Following the testing of the physical manifestation of the measurement system, the group sought out to ascertain the data transmission and storage capabilities of the Leica DISTO™ D8 in conjunction with HyTek Meet Manager© databasing software. These capabilities were checked through three stages of evaluation. First, the laser measurement device communication capacity was tested by establishing a Bluetooth© connection between the Leica and the laptop. If this was successful, the next level of testing determined whether athlete data can be transferred from HyTek Meet Manager© to an Excel formatted file. The final stage of testing asserted if Leica data can be directly inserted into the Excel file from the previous test.

IV. Results

If a measurement is taken from contiguous points along the track, the group realized that the PVC could be manipulated to match the radius necessary for the arc to yield accurate distance measurements. In order to have a greater accuracy than the current method, the system needs to be accurate to 5 centimeters. This accuracy corresponds to a ± 3 mm deviation between two consecutive points located 16 inches apart on the arc, which would yield a maximum error of 4.9 centimeters for a 19.75 meter throw. These calculations are shown in Appendix D. The original design constraints call for 1 centimeter accuracy, which would require a deviation of no more than 1.3 mm between two consecutive points. The track also needed to have a displacement less than 2 cm between all points. Since the original plan was to measure accurately to 1 cm, this constraint was crucial to determining the overall accuracy of the new system.

Initial drilling of the holes did not provide this accuracy, so distance measurements were taken to the center of the circle from each point, then the holes were re-drilled in order to manipulate the placement of the PVC pipe, and new measurements were taken. This process continued until each point fell within the 2 mm constraint. After three run-throughs, all but one point fit the prescribed criteria (Appendix E). A summary of these data is displayed in Table 2.

Table 2: Radial accuracy data

Statistics for Radius of Curve				
	Mean	Stdev	Min	Max
Test 1	6.18445	0.00372	6.177	6.189
Test 2	6.19045	0.00193	6.188	6.194
Test 3	6.19475	0.00097	6.193	6.196

Statistics of Difference Between Bolts				
	Mean	Stdev	Min	Max
Test 1	3.263158	2.490919	0	8
Test 2	1.210526	1.134262	0	3
Test 3	0.736842	0.733493	0	3

Once the calibration was complete, time trials were performed. Random points were chosen within the sector in order to simulate a more diverse range of throws. A person with the target walked to the points while another person operated the Leica. The time measurement was taken from the instant the person with the target started walking to where the implement landed to when the person walked out of the sector after the Leica took the measurement. Table 3 shows the time taken for these measurements.

Table 3: Time trial data

Point	Time for Measurement [sec]
1	21
2	26
3	27
4	26
5	29
6	27
7	32
8	31
9	20
10	32

During the time testing, it was realized that a lot of the data received was subjective to the spotter and where the implement landed. The time data can be greatly increased or decreased depending on the proximity of the person with the target to where the implement lands. If this person is located on the left side of the sector and the throw happens to be on that side, the time required to get to the place of landing is much less than if the person has to cross the entire sector. Also, it should be noted that this time data was taken in a non-competitive atmosphere which can cause the data to be skewed. Due to the limited number of track meets, it was not possible to test the device at an actual competition. It is believed that these time measurements would be roughly the same as would be expected.

V. Conclusions and Recommendations

As included in the Project Charter the goals of the project were to implement a measurement system which will decrease the duration of field events by 30%, design the system such that no more than two people are necessary to measure each throw, and include a means to display the measurement results to athletes, coaches, and spectators within a 15 meter radius of the ring during competition. The constraints agreed upon initially were that the entire system must cost less than $2000 and that it must conform to all standards set for by the IAAF.

Due to the timing of the project being out of sync with track season, the group has been unable to obtain test data for the timing of the system at an actual track meet. Extensive simulation shows that the indirect system saves approximately 1/3 of the time the old tape measure system would use if the measurement was taken while the thrower is warming up in the ring. Further validation can be proven during future track meets, but regardless, the group has a clear indication that the system consistently recovers time from the throwing event.

The new system requires just two people to operate. The current system for measurement takes at least three personnel to run so by eliminating at least one person, the project is eliminating cost of employment while speeding up the measuring times. One person is required on the track/Leica system and another will be out on the field with the target. Once the implement lands, the two personnel will align the target and Leica to take the measurement and then report it back through Bluetooth to the computer program. However, it has recently been addressed that the personnel will be older individuals and so it might be necessary to have three to four people operating the system just for ease. Although it is not ideal for implementation, the system conforms to the objective of being fully operable with just two people.

The third objective, regarding the scoreboard, was not accomplished in the final design solution. The project was much more involved than originally expected and there was neither time nor budget to construct a scoreboard. Even though the group was not able to make a scoreboard, the client, Coach Svobeda, says that he will have an outside vendor make the scoreboard so that the track and field team will still have an improved scoreboard that is able to interface with the Bluetooth communication system to display results.

The project is still in the calibration stage for getting the system to conform to the standards of being accurate to ±3mm at all points along the track from the center of the ring. In the time given for the project, we were unable to get the track to the necessary accuracy to do distance exactness testing. In order to do this, it is crucial that the track be on a level surface and that the target is perfectly level while calibrating. Slight error in levelness causes extreme deviation in measurements taken at the same point. The culprit seems to be a significant amount of shear strain, deflection in the boards, bending of the metal braces on the target, and manufacturing of the general system. The conditions for testing are also a factor in the discrepancies in measurement shown during calibration. As the temperature and humidity change on a daily basis, so does the shape of the track. It would take hours to get the current prototype within the 3mm radius as is, without even factoring in that the track will change next time it is stored or moved. Because of this, it was decided to focus more on the fact that the system can improve measurement time even though the track itself may not be accurate at this point. The general scenario of taking a measurement can still be tested and the data shows a significant time improvement.

A recommendation for expanding the usefulness of the track beyond just its accuracy would be to add a 3 ft. long extension to the track so that we can reach the minimum and maximum throwing distances recorded in an official track meet. This extension would increase the arc range of the Leica and distances of 25-75m as specified by the client. For a competitor to be eligible they usually must meet the minimum throwing distance of 25m and the maximum distances recorded are well under 75m. Currently the design struggles to reach the minimum and maximum distances and this extension would ideally allow it to do so.

The client has also proposed that once the system is completed another system is made for the shot-put throwing sector. The shot-put event occurs at another throwing ring with different dimensions and ranges of throws. If another system was implemented there, then both systems could interface via Bluetooth to the software used to score and run the track meet.

As far as budget is concerned, the main expense was $800 for the Leica DISTO™ D8. Everything else after that was considerably more inexpensive. Even with multiple iterations of the design, we came in under budget with $120.62 remaining. If necessary, Coach Svoboda was willing to allow an extra $800 of track budget to make our total budget $2000. This extra financing from Svoboda was not necessary though and the entire project came in under the Engineering Budget alone at a grand total of $1079.38.

Overall, the design should not be considered complete, although it is definitely an improvement upon the current method. The system is under budget, meets the goal of improving measurement time by 30%, and interfaces via Bluetooth with the HyTek Meet Manager® software. However the distance accuracy has yet to be determined and will require another iteration to get the system accurate enough to even begin distance testing.

VI. Bibliography

Proper References

1. Buy, Best. BestBuy.com. 2010.

2. "Disto D5." *GeoSolutions*. 31 Mar 2011. HYPERLINK "http://www.geosolutions.com/DistoD5.htm" http://www.geosolutions.com/DistoD5.htm

3. Federations, International Association of Athletics. "iaaf.org Home of World Athletics." 2009. International Association of Athletics Federations. 15 November 2010 <http://www.iaaf.org/mm/Document/Competitions/TechnicalArea/05/47/81/20091027115916_httppostedfile_CompRules2010_web_26Oct09_17166.pdf>

4. Hollnagel, Erik; Woods, David D. Joint Cognitive Systems. Taylor & Francis, Boca Raton, FL, 2005.

5. Solutions, Distagage Leasure Measuring. Distagage.com. 2003. 10 Nov. 2010 <http://distagage.com/distod8.html>.

6. Svoboda, David. Background Information for Throws Measurement Device Zach Brush. 1 September 2010.

Equipment Specifications

Leica DISTO™ D8:

7. Product Page: http://www.leica-geosystems.com/en/Laser-Distancemeter-Leica-DISTO-D8_78069.htm}

8. User Manual and useful downloads: http://ptd.leica-geosystems.com/en/Support-Downloads_6598.htm

VII. Appendices

Appendix A: Bill of Materials

Item	Amount	Estimated Cost	Source	Description
Tripod	1	$24.00	Sony VCT-R640 -Amazon	Platform to support and stabilize the target.
Leica DISTO™ D8	1	$800.00	Leica-EasyDrive	Laser range finder used for primary measurement device
1/8" thick, 12"x12" Clear Plexiglas	1	$3.39	eStreetPlastics	Material for target: lightweight, resistive to shear stress
Rechargeable AA Batteries	4	$6.00	Energizer	Provide power for the Leica range finding device
Laser Pointer	2	$9.00	CanDoWillDo	Used to align the target and the Leica
Lumber: 2"x10", 2"x8", 2"x4"	3, 3, 6	$25.00, $15.00, $13.00	Home Depot	Material for the frame and legs of the track
Misc	-	$25.00	Home Depot	Bolts, Nuts, Screws, Truss Clips, Paint

Appendix B: Vendor List

Vendor:	**Contact Information:**
Home Depot	435 Sunset Rd West San Antonio, TX 78209 (210)824-9677
Lowes	1470 Austin Highway San Antonio, TX 78209 (210)828-6011
Easy Drive	906 Ruiz Street San Antonio, TX 78207 (210)227-5975
Best Buy	125 Northwest Loop 410 Ste 201 San Antonio, TX 78216 (210)377-1116

Appendix C: Throws Measurement Time Data

This appendix contains the time data used to determine how quick throws measurement with the Leica D8 would be in comparison to the normal tape measure system of measurement. In Table B.1, the data represents the measurement time required for the original tape measure system versus the Leica D8 when used in a normal configuration, the first picture under part B. initial system design), not including the time it takes for the thrower to warm-up, throw, and exit. Data was taken at 6 specific throw measurement locations across the throwing sector marked by flags. The exact same locations were measured in the same order every time for all five runs.

Table C.1: Throws measurement times using a Leica D8 versus a standard tape measure.

	Leica D8 time measurements		Tape Measure time measurements		
Location	**Run 1 [s]**	**Run 2 [s]**	**Run 1 [s]**	**Run 2 [s]**	**Run 3 [s]**
1	NT*	28.60	46.42	55.21	33.65
2	31.13	32.50	31.10	33.33	27.36
3	23.78	28.59	29.99	23.09	23.29
4	30.66	28.20	27.80	26.64	23.44
5	41.90	44.42	45.98	33.71	39.53
6	32.60	31.11	38.00	26.20	25.17
Average:	32.14 seconds		32.77 seconds		

*No time was taken for location 1, run 1; the Leica D8 turned off, causing an non-representative increase in time

Table B.2 includes the total thrower entry, throw, and exit times taken by throwers during a mock competition. Two males and two females' throw times were measured. Throw 1 by thrower 1 represents only the warm up and throw time; it does not include thrower entry and exit.

Table C.2: Amount of time required by throwers to complete a throw.

Thrower Time Data:			
Thrower	**Throw 1 [s]**	**Throw 2 [s]**	**Throw 3 [s]**
1	9.80*	23.6	21.8
2	22.9	29.7	29
3	24.8	24.6	22.2
4	22.6	23.6	25.3
Average Time: 24.6 seconds			

Appendix D: EES Analysis of Laser Arc Uncertainty

VIII. This appendix contains the formatted EES equations and code utilized to study the uncertainty propagation of the final design. In addition, the results of an uncertainty propagation table are included with the final uncertainties listed for laser measurement ranges from 20m to 100m, corresponding to actual throw lengths of up to 98.83m. Finally, a demonstration of the correlation between the angular uncertainty θ and the relative deviation in radius described in the Results section of the report.

Engineering Design VII-VIII

Uncertainty Analysis of the laser track method

Given

$R = 4$ [m] the radius the laser track

$r_{ring} = 1.25$ [m] radius of the ring

$\theta = 90$ [deg] angle between the ring center and the landing point

Varying the distance of the throw in a parametric table

Equation to calculate the horizontal distance of a throw: based on law of cosines

$$y = (x^2 + R^2 - 2 \cdot x \cdot R \cdot \cos(\theta))^{0.5} - r_{ring}$$

Uncertainty of the horizontal throw length based on x, R, and theta uncertainties

$$w_y = \text{UncertaintyOf}(y) \cdot \left| 100 \cdot \frac{cm}{m} \right|$$

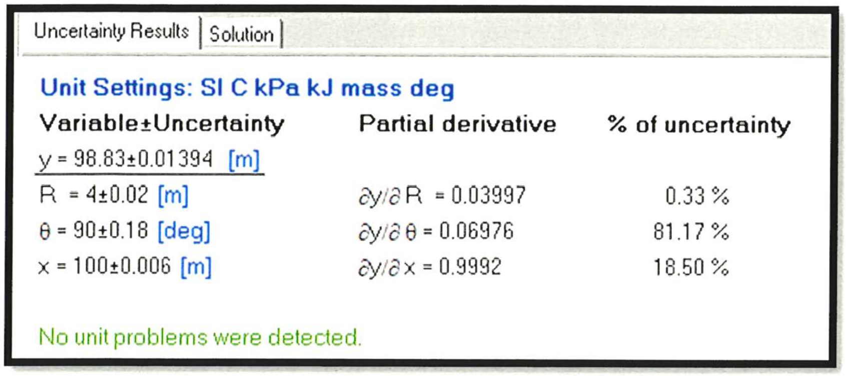
Uncompiled equations within $IF conditional statements

Figure D.1: EES code used to analyze uncertainty propagation of the laser arc method

Table 1

1..9	x [m]	y [m]	w_y [cm]
Run 1	20±0.006	19.15±0.01421	1.421
Run 2	30±0.006	29.02±0.01405	1.405
Run 3	40±0.006	38.95±0.014	1.4
Run 4	50±0.006	48.91±0.01397	1.397
Run 5	60±0.006	58.88±0.01396	1.396
Run 6	70±0.006	68.86±0.01395	1.395
Run 7	80±0.006	78.85±0.01394	1.394
Run 8	90±0.006	88.84±0.01394	1.394
Run 9	100±0.006	98.83±0.01394	1.394

Figure D.2: Uncertainty propagation table for the final design model. *x* represents the laser measurement length, *y* represents the throw length, and w_y is the propagated uncertainty in the throw length.



Uncertainty Results | Solution

Unit Settings: SI C kPa kJ mass deg

Variable±Uncertainty	Partial derivative	% of uncertainty
y = 98.83±0.01394 [m]		
R = 4±0.02 [m]	∂y/∂R = 0.03997	0.33 %
θ = 90±0.18 [deg]	∂y/∂θ = 0.06976	81.17 %
x = 100±0.006 [m]	∂y/∂x = 0.9992	18.50 %

No unit problems were detected.

Figure C.3: Percent uncertainty propagation based on each variable. As seen in the far right column, the deviation in θ, the perpendicular angle between R and x, has the most significant effect on the overall uncertainty.

Based on an analysis of the sources of error in the laser measurement system design, it has been determined that all of the uncertainty in the perpendicular angle $d\theta$ is due to relative inaccuracies in the laser track radius. Knowing this, the maximum angular deviation of .18° necessary to attain the desired theoretical accuracy of the overall system can be verified by determining the relative radial deviation of the laser track (Fig. C.4).

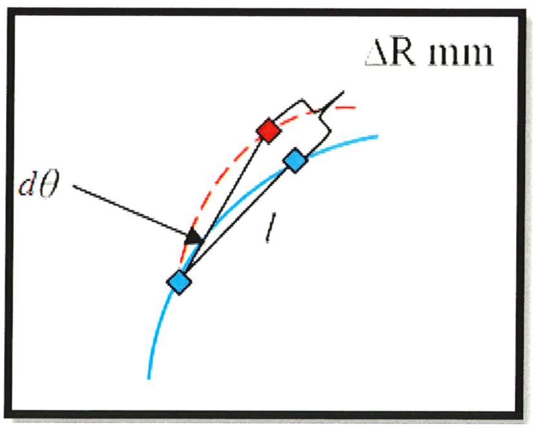


Figure C.4: Relationship between the perpendicular angle, $d\theta$, the length between discrete points, l, and the relative deviation in radius, ΔR.

As shown above, any discrepancy in the radius of a point along the laser track relative to another point causes deviation in the perpendicular angle $d\theta$. This deviation can be calculated using Eq. C.1, where $d\theta$ is .18° and l is the length of the laser sled. The resulting ΔR necessary to achieve the desired arc accuracy is 3 mm.

$$d\theta = \tan\left(\frac{\Delta R}{l}\right)^{-1} \tag{C.1}$$

Appendix E: Results of Calibration Testing

Bolt	Test #1		Test #2		Test #3	
	Radius [m]	ΔRadius [mm]	Radius [m]	ΔRadius [mm]	Radius [m]	ΔRadius [mm]
1	6.186	-	6.188	-	6.196	-
2	6.186	0	6.188	0	6.193	3
3	6.189	3	6.191	3	6.194	1
4	6.187	2	6.190	1	6.195	1
5	6.183	4	6.192	2	6.196	1
6	6.180	3	6.189	3	6.195	1
7	6.188	8	6.189	0	6.194	1
8	6.188	0	6.191	2	6.194	0
9	6.183	5	6.189	2	6.193	1
10	6.189	6	6.189	0	6.194	1
11	6.185	4	6.189	0	6.194	0
12	6.182	3	6.189	0	6.194	0
13	6.181	1	6.191	2	6.195	1
14	6.185	4	6.192	1	6.196	1
15	6.178	7	6.194	2	6.196	0
16	6.177	1	6.194	0	6.195	1
17	6.180	3	6.194	0	6.195	0
18	6.187	7	6.191	3	6.195	0
19	6.187	0	6.190	1	6.195	0
20	6.188	1	6.189	1	6.196	1