# SUGAR CANE YIELD MONITORING SYSTEM

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science in Biological and Agricultural Engineering
In
The Department of Biological and Agricultural Engineering

By
Caryn Elizabeth Benjamin
B.S. B.E., Louisiana State University, 1998
December, 2002

## ACKNOWLEDGEMENTS

I would like to give my sincere thanks and gratitude to the following individuals:

Dr. Michael P. Mailander, for his support, help, guidance, and on-going commitment on this project.

Dr. Randy R. Price, the chairman of my graduate committee for his support and guidance on this project.

The members of my graduate committee, Dr. Kenneth Gravois and Dr. Steven Hall, for their help and suggestions in the development and testing of this project.

Dr. Kenneth Gravois and his team at St. Gabriel Sugar Cane Research Station, for their patience and tolerance with the field tests.

The people of the Biological and Agricultural Engineering Department; Tom Bride and Don Allen, who helped with the electronics and construction of the project and the office ladies, Angela Singleton, Rhonda Shepard, and Danielle Bayham for their support and help with the paper work.

CAMECO Industries, a John Deere Company, for allowing the use of their facilities and equipment and the engineers' time and efforts, especially Dominick Sciortino and John Scrivner.

Dr. Lynn LaMotte, for his support and guidance with the statistical analysis of the data.

I would like to give my special thanks to my parents without whom I would not be here.  Their never-ending support of my endeavors has allowed my to reach this height of achievement.

## TABLE OF CONTENTS

## LIST OF TABLES

## LIST OF FIGURES

## ABSTRACT

This project involved the design and testing of a sugar cane yield monitoring system during the 1999 and 2000-harvest seasons. The system was mounted on a CAMECO CH 2500 1997 sugar cane combine. The sugar cane yield monitoring system consisted of a scale, a data acquisition system, and a differential global positioning system (DGPS). The scale consisted of a weigh plate supported by load cell(s). The load cell(s) were supported by a protective box, which mounted to the frame of the harvester. The scale, which was mounted in the floor of the elevator, directly recorded instantaneous measurements of the sugar cane yield (weight). A dump wagon equipped with a weighing system (weigh wagon) was used for each test as the standard. Experiments were run with different levels of cane maturity, variety, row/section length, and flow rate. For each test, the scale readings were totaled and compared to the actual yield, which was measured by the weigh wagon. The yield sensor predicted the sugar cane yield with a slope of 0.900 and a R-squared of 0.966. The scale's average percent error was 11.05 percent. The results also showed that the different cane varieties had an effect on the scale readings, but the maturity of the cane, section length, and the flow rate did not have a significant effect on the scale readings.

## INTRODUCTION

Sugar cane is an economically important crop in many countries. It is especially important in south Louisiana, which produces about 43.8 percent of the United States sugar (Sugar and Sweetener Situation & Outlook, Sept. 2001). It is considered a high value and a high input crop (Cox et al., 1998). In farming sugar cane, previous management practices assumed that the soil in a field is homogenous. This is generally not true and within a field large variations can occur in the soil (Karlen et al., 1990). Precision farming allows the farmer to more effectively manage fields, which would optimize farm profit and minimize effects on the environment. Colvin et al. (1991) concluded that resources could be used more efficiently if precision farming practices were used. For these reasons, the adoption of precision farming practices to sugar cane production is desirable.

One important application of precision farming is yield mapping. Yield maps provide site-specific yields that can aid in managing fertilization and pesticide rates. Yield maps consist of two variables, the site-specific crop yield (lb), and the position (longitude, latitude) of that yield in the field. There is currently no commercially available yield monitor for measuring sugar cane billets harvested by a sugar cane combine harvester. Farmers that use mechanical means of harvesting, such as the CAMECO CH2500 harvester, will be able to measure their sugar cane crop yields with this system. The proposed system measures and stores data required to make yield maps. Another important aspect to using a yield monitor is that the farmer can reduce the problem of overloading the tractor-trailers with cane. In Louisiana there is a weight limit (100,000 lbs [45,360 kg] GVW) on tractor-trailers, and fines are given if the limit is exceeded. Also, sugar cane mills lock their scales to weigh up to 100,000 pounds (45,360 kg). Any overload is not paid out to the farmers.

## OBJECTIVES

The objectives of this study were to:

1. Design a scale that measures the yield of sugar cane as it is harvested by a sugar cane combine.
2. Install the scale on a sugar cane combine harvester and test the scale's accuracy scale by comparing its yield to a weigh wagon yield.
3. Also, tests the effects of sugar cane variety, maturity, flow-rate, and the harvested section/row length on the scale readings.

## LITERATURE REVIEW

Even though there is no commercially available sugar cane monitor, there have been studies and even some patents that focus on measuring the yield of sugar cane. According to the Cox et al. (1998), Australia's National Centre for Engineers in Agriculture has been working on a prototype sugar cane yield sensor for the Australian sugar cane combine harvester, the Austoft. This group has used direct and indirect techniques for measuring the cane yield on the harvester. The direct techniques involved mass and volume measurements. The indirect techniques involved measurements of power consumption. Results from field tests done with two indirect sensing techniques (data not given) showed a slope of 0.11 and an R-squared of 0.84 and the other with a slope of 0.05 and an R-squared of 0.84. After field tests, the final technique selected was the direct mass measurement technique. Supporting data was not given for the direct mass sensing technique. The details on how and where the sensor functions were not discussed in the paper due to an acquired provisional patent in Australia. The system was undergoing pre-market tests in 1998. The resulting patent was title, "Mass Flow Rate Sensor for Sugar Cane Harvesters", Australian Patent No. 744047 (Cox et al., 1999). The specific details of the sensor design were published by the Australian patent office on November 4, 1999. A U.S. patent for this sensor has not been acquired. The mass flow sensor consisted of a weigh platform support by a load cell(s) mounted in the upper section of the elevator of the harvester. Numerous variations of the weigh platform and load cell configuration were tested. Additionally, they used an accelerometer and an inclinometer for error correction means. Supporting test results were not given in the patent.

A similar yield sensor developed by Pagnano et al. (2001), in Brazil was discussed in the paper "Sugarcane Yield Measurement", which was presented at the 3rd European Conference on Precision Agriculture. The weight sensor consisted of a weighing frame, load cells, conveyor speed sensor, and a data acquisition apparatus. The weight sensor was mounted in the upper section of the harvester's elevator. Accelerometers were used to determine the frequencies produced by the harvester. A Butterworth low-pass filter was used to filter out certain frequencies. An instrumented trailer was used to check the accuracy of the developed system by measuring the harvested cane. Their data showed percent errors for measuring sugar cane yield ranging from 8.74 to -26.65 percent.

US Patent No. 6,272,819 (Wendte et al., 2001) described a sugar cane yield monitor that used an elevator pressure sensor, or a deflection plate to measure the quantity of the harvested sugar cane. They also used a low pass filter to smooth the peaks in the elevator pressure signal. To account for the effects of dynamic forces they pre-loaded the deflection plate load cell to always read positive even in the worst field conditions.

There are numerous sources for the application of precision agriculture to other crops such as grains. Yield monitors are most common on grain combines. For instance, Borgelt et al. (1992) described several grain flow rate sensors. These sensors included techniques such as gamma ray absorption, impact plate, capacitive, pivoted auger with a loadcell(s), and photo-detection. These sensors are only adaptive to grain flow requirements.

Other crop yield measurement techniques included the following: Both potato and sugarbeet mass-flow-rate have been measured by using load measuring idler wheels or supports under the crop conveyor on harvesters (Campbell et al. 1994; Schneider et al., 1996; Walter et al., 1996). Cotton yield has been measured by optical methods, where the blockage of light between a light emitting diode and a photodiode is measured in the delivery ducts of the picker as bolls of cotton are transported to the basket (Durrence et al., 1998). Thomas et al. (1997) and Perry et al. (1998) measured the peanut yield by weighing the basket on the peanut harvester. Auernhammer et al. (1995) measured the yield on a self-propelled forage harvester with a radiometric measurement device. Kromer et al. (1999) measured the crop yield on forage harvesters by using both volumetric- and mass-flow-rate measurement techniques. The volumetric-flow-rate variables considered were compression roller displacement, crop layer thickness, and crop-stream contour in the harvester's spout. Crop impact force in the spout was considered the mass-flow-rate variable. A dynamic weighing system using a load cell and paired with accelerometer was used to measure the citrus yield (Crews et al., 2001).

## DESIGN AND DEVELOPMENT

To develop a yield monitor for the sugar cane harvester, the harvesting process needed to be examined (see Figure 1). The sugar cane was cut at the ground by the harvester's base blades and topped by the topper as it enters the harvester. Once inside, the cane is cleaned and chopped into 8-12 inch (20-30 cm) pieces called billets. Seventy-five percent of the trash is blown out through the primary extractor fan as the billets are dumped onto the elevator (Sciortino, 1999). The billets are conveyed up the elevator by a chain driven slat system. Slats were approximately 24 inches (61 cm) apart and moved at a maximum speed of 88 in/s (223.52 cm/s), which can vary at the operator's control. Also, there was 0.125 inch (0.3175 cm) clearance between the slats and the floor. The elevator floor was about 31.5 inches (80 cm) wide. The elevator is divided into two sections. When the elevator was raised to its highest position during harvesting, the first section made a 50-degree angle with the horizontal and the second section made a 25-degree angle (see Figure 1). The first section floor was constructed of expanded metal to allow dirt to fall through. The second section floor was a solid 0.125 inch (0.3175 cm) thick steel plate. Before the billets are dumped into a wagon (see Figure E1) a secondary extractor fan removed about 10-15 percent of leftover trash (Sciortino, 1999). Burning the cane before it is harvested affects how much trash went into the wagon. If the cane was not burned, there was more trash harvested and weighed with the sugar cane billets. After an examination of the harvester, researching other crop yield monitors, and speaking with the manufacturer of the machine, the only practical place for a yield measurement device would be on the elevator.

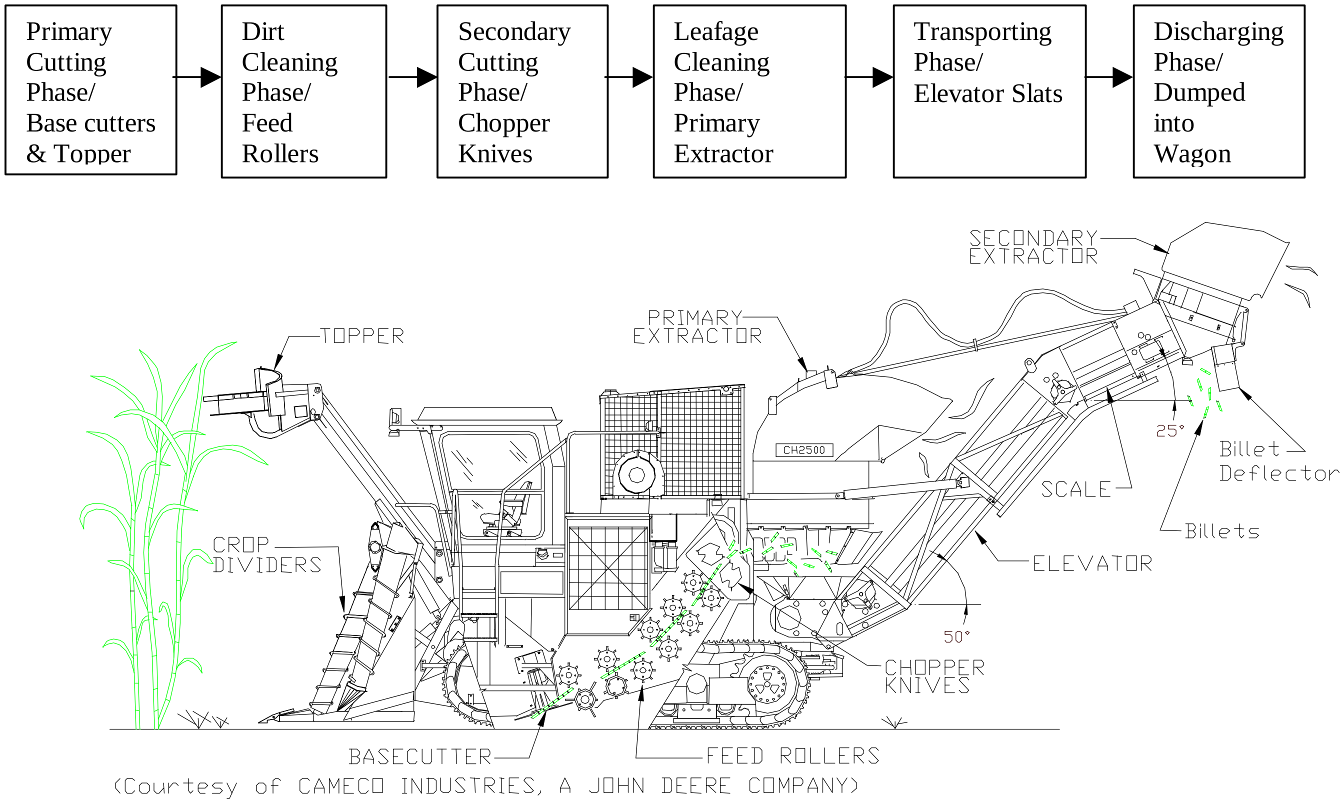



Figure 1. Sugar Cane Harvesting Process

Fundamental techniques considered for measuring the sugar cane yield were direct mass and volume measurements and indirect measurements. These measurement techniques that were considered, but ruled out, included volume measurement using an optical means, power consumption of the chopper knives that cut the cane into billets, force impact measurement on a deflector plate, and measuring the elevator hydraulic pressure of the elevator support cylinders. Each had disadvantages and advantages. The operating environment of a sugar cane combine harvester is harsh. The sugar cane combine harvester produces a significant amount of mechanical noise and vibration, which can interfere with sensors' ability to measure yield accurately. Dirt, mud and leaves accumulate as the cane is harvested. Furthermore, the sugar cane leaves are abrasive and the juice is sticky. For these reasons and others listed below direct weight measurement was used to determine the sugar cane yield. Direct weight measurement seemed to be a simple technique and feasible because trash weight (dirt and leaves) is small in comparison to the weight of the sugar cane.

Volume measurement was ruled out due to the fact that leaves have just as much surface area as sugar cane, if not more. Also, harvested sugar cane is not homogenous, and crop contamination by trash (Sciortino, 1999) can create additional problems with volume measurement. Power consumption measurement from the chopper knives would be impractical because of the correlation problems with the different varieties of cane having more leaves and having higher yields than other cane. The farmers would have to calibrate the device every time the cane variety changed or weather conditions changed. Force impact measurement (deflector plate) placed at the billet deflector (see Figure 1) was ruled out because not all of the cane hits the billet deflector as it is delivered into the wagon. Positioning the deflection plate to catch all of the cane would create the problem of getting all of the cane into the wagon. Another technique considered was tapping into the hydraulic pressure of the supporting cylinders of the elevator. This was also ruled out because the cylinders did not support the entire elevator; thus, the pressure would not represent the total load of the elevator and cane. Also, ground level variations in the field cause the elevator to bounce creating pressure fluctuations, which could give false yield readings.

Direct mass measurement or weighing the cane as it traveled along the elevator was decided to be the best way to measure the sugar cane yield. Noticing that the floor of the elevator was stationary, it seemed plausible to place a weighing device in the elevator floor. A scale was then developed and placed co-planar with the floor of the upper section of the harvester's elevator (see Figure 1). The elevator's upper section has the least inclination and would create less error than the lower section, which has a steeper slope. Also, the upper section would require less modification than the lower section.

**Scale Design**

The design of the scale consisted of a weigh plate supported by load cell(s), which would be supported by a protective box that mounted to the frame of the harvester. The 1999-scale design used only one load cell supporting the weigh plate (see Figure 2). Figure 2 shows the 1999-scale being mounted on the harvester's elevator.

Figure 2. 1999 Weigh Plate

After the 1999-field tests, this design proved to be unstable without extra support (Benjamin et al., 2000). The vibration and noise interference created both negative and positive signals that were beyond the maximum weight of the cane. The 2000-scale design used two load cells to support the weigh plate. The 2000-scale design also reduced the weigh plate's length in half (see Figure 3). Figure 3 shows the 2000-scale after a long day of harvesting. Half of the scale is caked with mud.

Figure 3. 2000 Weigh Plate

**Weigh Plate Design**

The weigh plate's dimensions played a critical role in the system's ability to measure the sugar cane billets accurately. The billets are moved up the elevator via slats, which were spaced 24 inches (61 cm) apart. To ensure that all of cane was measured, the platform was given the length of the distance between two slats and the width of the elevator floor (24 in x 30 in [61 cm x 76 cm]). See APPENDIX D for weigh plate drawings. The weigh plate's thickness was also critical because extreme deflections disrupt or prevent sugar cane flow and cause errors in the scale readings. The weigh plate's thickness (0.1875 in [0.5 cm]) was designed to have a maximum deflection of 0.125 inches (0.3175 cm), which was the elevator floor's thickness. Because the plate was rigidly supported at its center, it was assumed that the weigh plate could be represented as a cantilever beam having a uniform load (see Figure 4). Figure 4 also shows the equations that were used to calculate the deflection through an iterative process. Plate thickness (t) was selected until the maximum deflection was less than 0.125 inches (0.3175 cm).

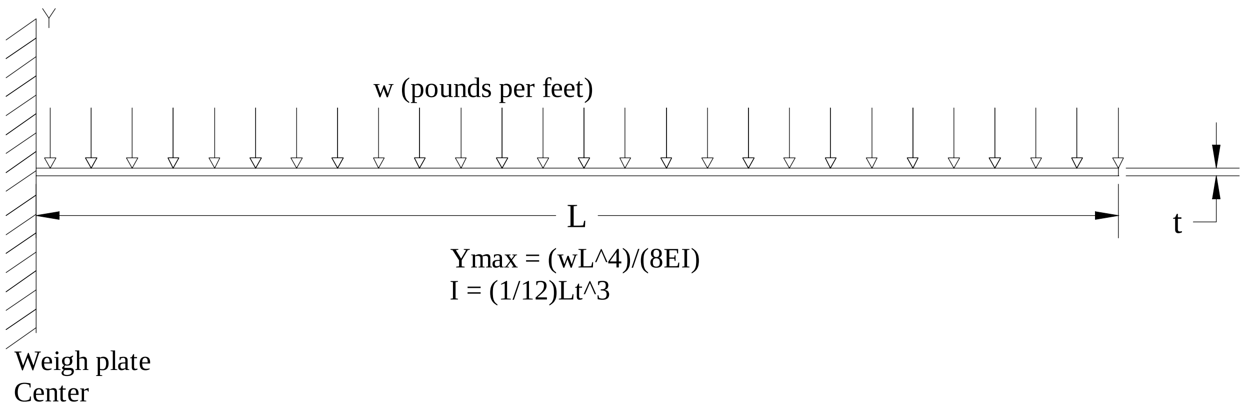



Figure 4. Cantilever Beam with a Uniform Load

Where:

Ymax = Maximum beam deflection in the Y direction

w = weight per length

L = length

E = Young's Modulus of Elasticity (30.0 Mpsi for steel)

I = Section moment of area about the x axis

t = thickness of the plate

The weigh plate's dimensions were changed after the 1999-field tests to reduce the amount of error created from the vibration of the weigh plate. To reduce the vibrations, the weigh plate's length was changed from 24 inches (61 cm) to 12 inches (30.5 cm). This meant that the sampling frequency would need to be doubled to make sure a whole slat of cane is measured. Also, two load cells were used to support the weigh plate to further reduce the vibrations.

### Load Cell Design and Selection

Since the slats that pushed the cane up the elevator traveled along both top and bottom of the elevator, the amount of room needed to place a scale in the floor was limited. Thus, the load cell was designed with a low profile design. The load cell's maximum capacity was based on the maximum sugar cane load and the weight of the weigh plate. Using the maximum density of sugar cane (22 lb/ft$^3$ [353 kg/m$^3$]) and the maximum volume of cane between two slats (3.33 ft$^3$ [0.0944 m$^3$]); the maximum weight of cane that filled up between two slats was approximately 73 pounds (33 kg). Since the load cell location was at an angle (25 degrees), the scale read less than the actual weight of the sugar cane billets (see Figures 1 & 5).

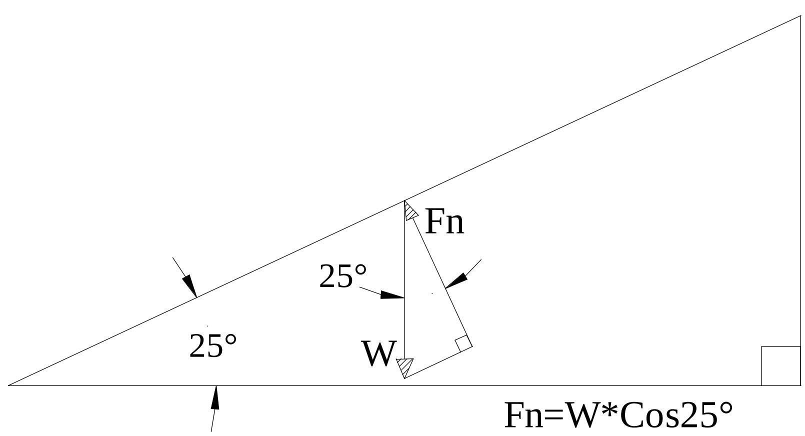



Figure 5. Harvesting Angle

Where:

Fn = normal force that the load cells exert

W = sugar cane weight due to gravity

The load cell(s) would have to withstand 66 pounds (30 kg) of cane plus the weight of the weigh plate (20.26 lb [9.2 kg]). The chosen capacity was 110 pounds (50 kg). Since the weigh plate would be 30 inches (76 cm) wide and 24 inches (61 cm) long, the load cell had to compensate for offset loading. Numerous load cells were evaluated, but only a few fitted the criteria. After speaking with the load cell manufacturers, a single-point low-profile load cell (Sensortronics, California) was selected. This particular one was made for a 36 in x 36 in (91 cm x 91 cm) plate and compensated for offset loading. See APPENDIX A for more load cell information.

**Protective Box Design**

As its name implies, the protective box was designed to protect the load cell from being damaged by the weather, billets, and trash such as leaves, and dirt; however, the main purpose of the box was to support and rigidly mount the load cell to the elevator. The tolerance between the elevator floor and the scale's weigh plate had to be as small as possible to prevent trash and dirt from becoming wedged and cause the scale to read incorrectly. The small tolerance (0.0625 in [0.15875 cm]) made it difficult to align the weigh plate with the elevator floor. The protective box was designed with bolts to eliminate this alignment problem. The bolts allowed the scale to move both horizontally and vertically (see Figure 6). Figure 6 shows the underside of the box where the two mounting bolts attach the box to the frame of the elevator. The other four bolts (in Figure 6) are used to help position the scale after it is mounted. After fine-tuning the position of the scale and making sure that no sides of the weigh plate touched the floor, a tack weld was added to make the mount rigid. See APPENDIX D for protective box drawing.

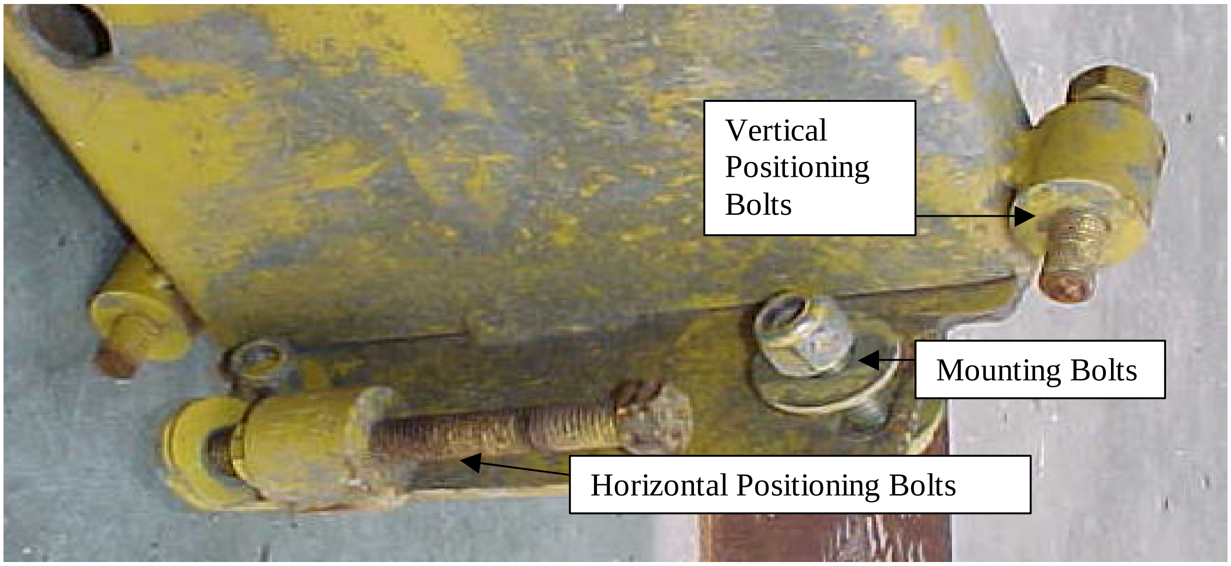



Figure 6. Bolt Positioning Design located underneath the protective box

# MATERIALS AND METHODS

## Testing Phase

### Laboratory Testing

A scale was setup in the research laboratory to run various tests. The laboratory scale was an exact replication of the scale that was mounted on the harvester. The load cells' linearity was tested in the laboratory by applying weight to the scale at increments of ten pounds (4.5 kg). The voltage was recorded and a regression was run on the data. The load cells' linearity was found to have a slope of 4.5 and an R-squared of 0.9998 (See Figure 7).

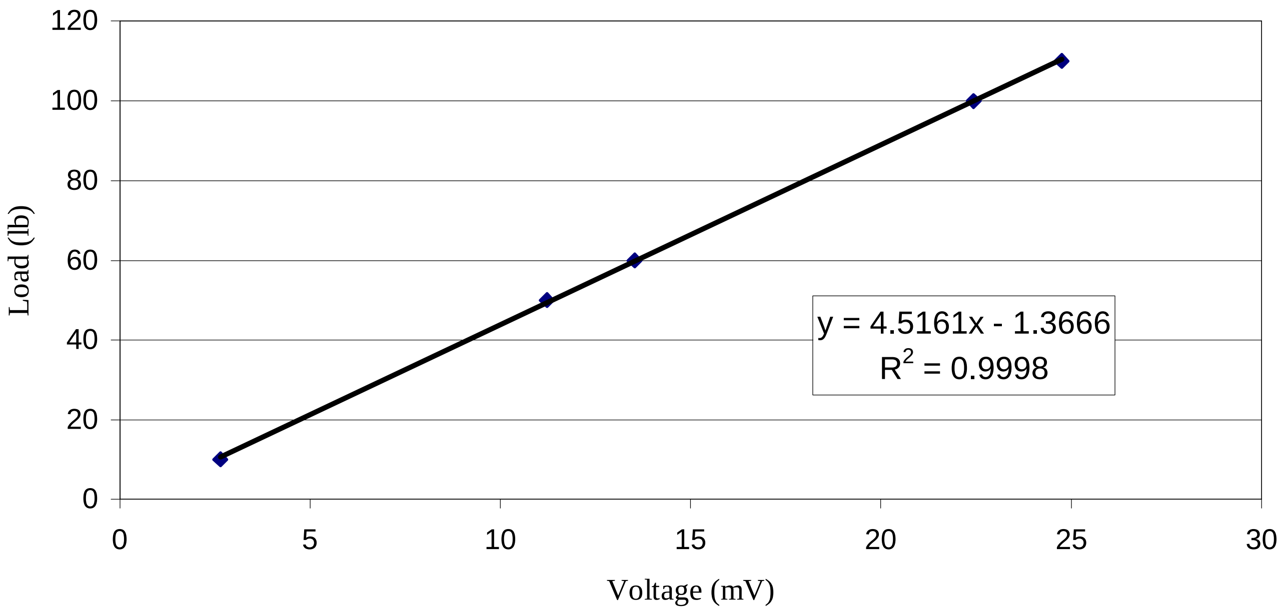



Figure 7. Load Cell Calibration

A laboratory test was done to determine the appropriate size and material of the weigh plate since 1999-field tests showed that vibration problems exist with using a large steel plate and only one support (Benjamin et al. 2000). For this reason, four plates (see Table 1) were tested to determine which one would have the smallest vibrational amplitude. Vibrations were induced in the weigh plates by setting an air pump (model # 2545B-01, Welch Vacuum Pumps) on top of the weigh plates (when mounted on the same load cell). The data was sampled at 10 hertz (see Figure 8). Figure 8 shows the results of the amplitude test done on four different plates. The results showed that the small steel plate was dampened the most with only a 0.37 mV amplitude. The small aluminum, big aluminum, and the large steel plate exhibited a 1.3 mV, 1.1 mV, and 1.0 mV amplitude respectively. For this reason, the small steel plate was assumed to have the best dampening qualities and was selected for the 2000-field tests.

**Table 1. Plate Vibration Test**

| **Plate #** | **Dimensions in (m)** | **Material** |
|---|---|---|
| Plate 1 | 12 x 30 x 0.1875 (30.5 x 76 x 0.476) | Aluminum (2014) |
| Plate 2 | 24 x 30 x 0.1875 (61 x 76 x 0.476) | Aluminum (2014) |
| Plate 3 | 12 x 30 x 0.1875 (30.5 x 76 x 0.476) | Steel (Exten 50) |
| Plate 4 | 24 x 30 x 0.1875 (61 x 76 x 0.476) | Steel (Exten 50) |

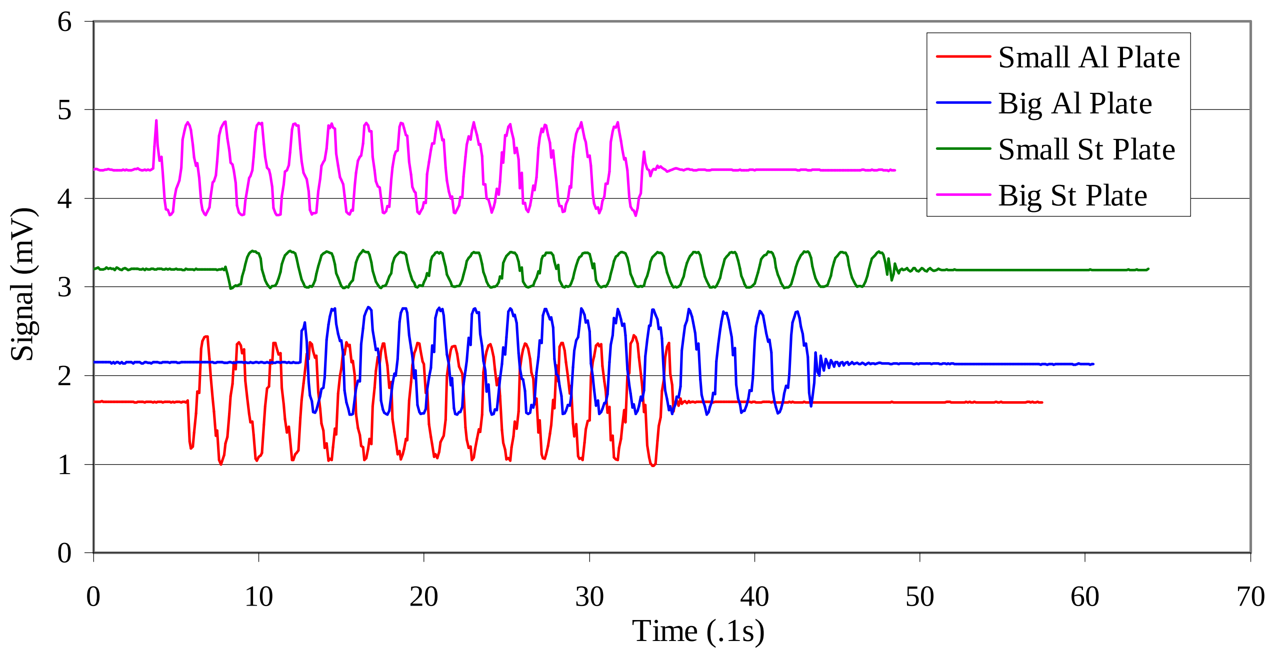



Figure 8. Laboratory Plate Size and Material Vibration Test

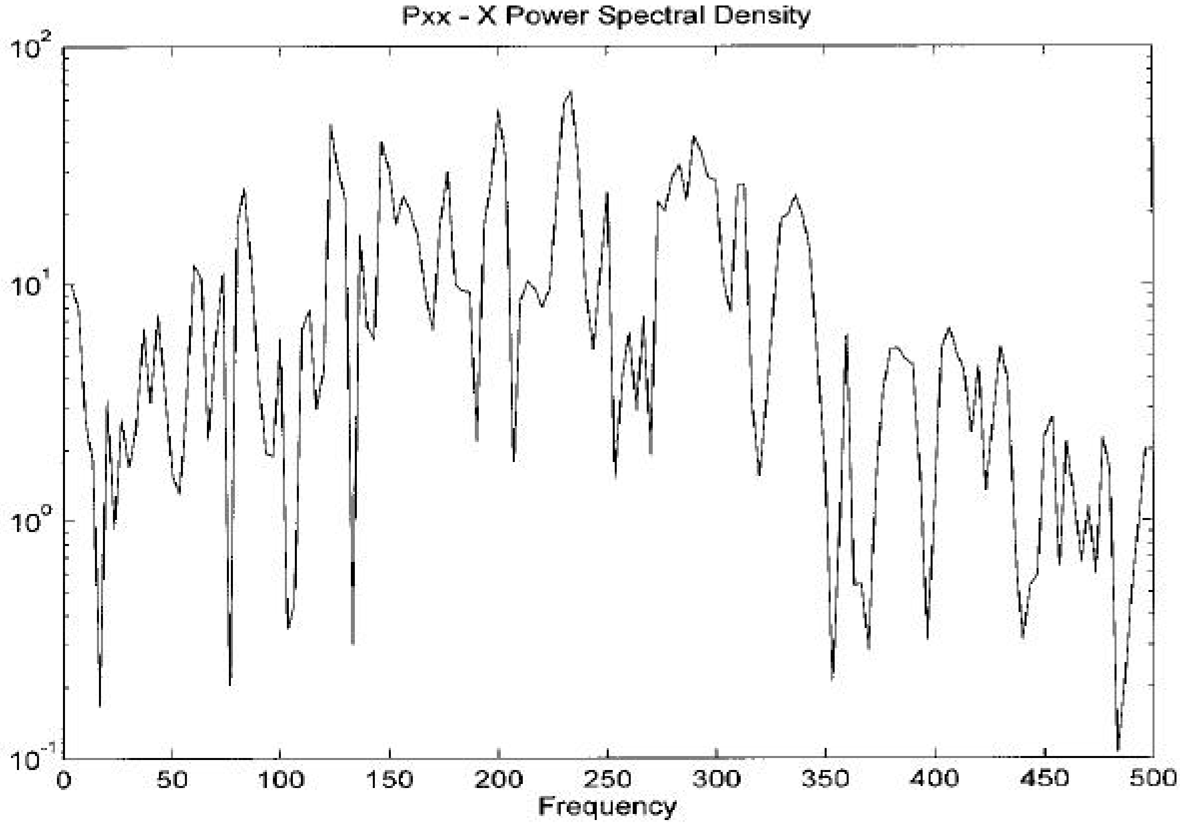



Figure 9. Power Spectral Density Plot

Also, a power spectral density test was done to determine the dominating frequencies. The test consisted of taking data at 10 hertz while the harvester went down a previously harvested row with everything running, but not cutting cane. These frequencies included 20, 75, 100, 130, 350, 370, 400, 440, and 480 hertz (see Figure 9).

## Field Testing

The scale was mounted to the harvester at CAMECO. The following procedure was used to calibrate the scale at the harvesting angle. First, several 10-lb weights and a person were loaded on the elevator. Once the elevator was at the highest position (harvesting angle), the weights were placed on the scale (10 pounds at a time) and a voltage was recorded. The GPS and data-logger were mounted in the harvester's cab for protection.  A small capacity weigh wagon (3-Ton Weigh Wagon, CAMECO) was used as a standard for testing the scale's accuracy.  The weigh wagon was instrumented with three load cells; two load cells on the axles at each wheel and one load cell on the tongue (Bischoff et al., 2001).

Field tests were conducted in the fall of 1999 and in the fall of 2000.  The 1999-field tests were considered preliminary because of the considerable loss of data due to the extreme vibrations of the harvester (Benjamin et al., 2000).  The 1999-field tests were performed at the Sugar Research Station in St. Gabriel, LA on one variety of sugar cane (LCP 85-454).  Twenty-four 50-foot (16 m) sections were marked off.  Three harvester speed levels were tested to produce different flow rates.  The levels were approximately 1.8 mi/h (2.9 km/h), 2.8 mi/h (4.5 km/h), and greater than 3.2 mi/h (5.1 km/h).  Each level was tested on eight sections.  The harvester would start before it entered the cane to achieve the appropriate speed and stopped at the end of the section.  At the end of each section the weight of the weigh wagon was recorded.  The GPS and data-logger ran continuously during the tests.  A slat of cane passes over the scale every 0.27 seconds, which was based on the elevator speed (88 in/s [223.52 cm/s]) and the weigh plate's length (24 in [61cm]).  So, to ensure that every load was measured only once, the scale's sample rate was set to 3.7 hertz.

The 2000-field tests were also performed at the St. Gabriel Research Station on two varieties of sugar cane (LCP 85-384 and CP 70-321).  Four tests were performed, numbered one through four.  Tests 1, 2, and 3 consisted of rows that were divided into four different lengths (see Figure 10 and Table 2).  Test 4 consisted of whole rows that were 375 feet (114 m) long.  Two harvester speed levels, slow (0 km/h – 2.8 mi/h [4.5 km/h]) and fast (2.9 mi/h [4.7 km/h]- 4.5 mi/h [7.2km/h]), were tested to produce different flow rates.  Test 1 was done on October 27, 2000, and the other three tests were done on December 5, 2000.  The cane harvested on December 5 was about 1.5 months older than the test 1 cane. The process of each sub-test (section) started with the harvester entering the cane to achieve the appropriate speed and stopped at the end of the section. At the end of each section the weight of the weigh wagon was recorded manually. See APPENDIX B for the field tests data. The GPS logged readings continuously during the tests. A slat of cane passed over the scale every 0.14 seconds (7.14 hertz), that was based on the elevator speed (88 in/s [223.52 cm/s]) and the weigh plate's length (12 in [30.5 cm]). This rate would ensure that every load was measured only once.

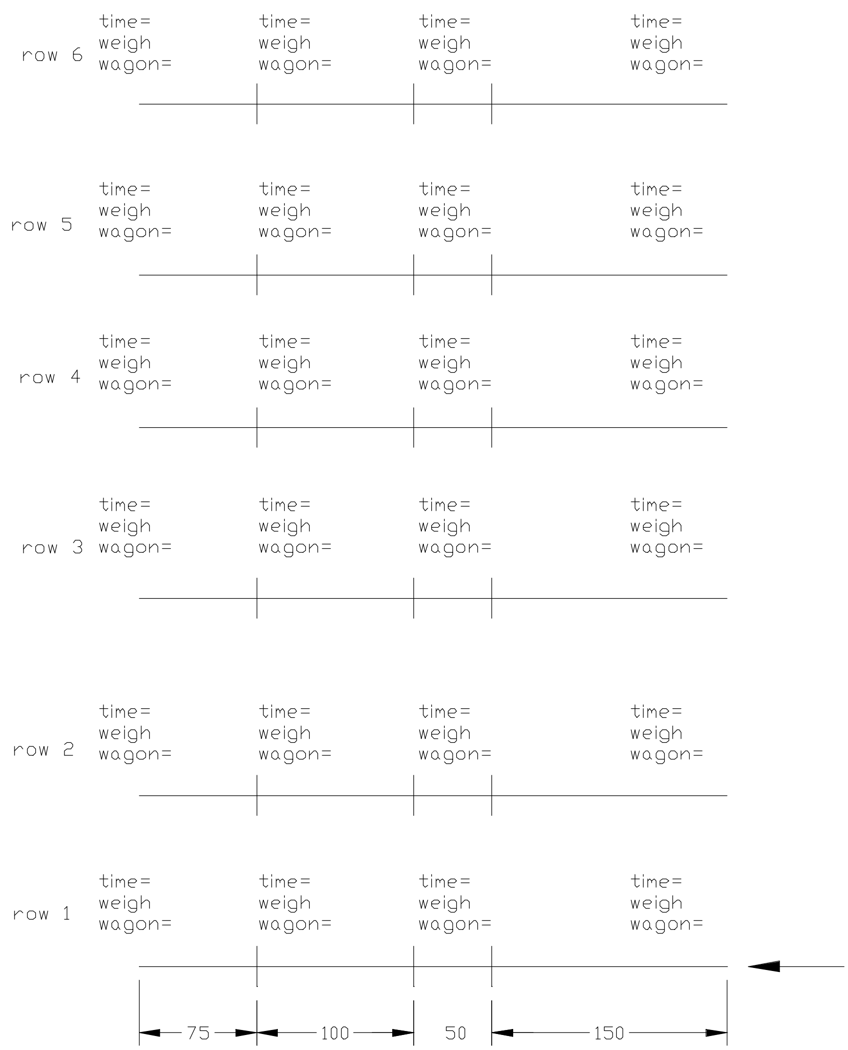



Figure 10. 2000-Field Tests Layout

| Table 2. Field Tests | | | | | | |
|---|---|---|---|---|---|---|
| **Tests** | **Rows** | **Sections** | **Variety** | **Maturity** | **Speed** | **Section lengths ft(m)** |
| 1 | 10 | 40 | LCP 85-384 | 10 months | Slow & fast | 50(15.2), 75(22.9), 100(30.5), 150(45.7) |
| 2 | 12 | 48 | LCP 85-384 | 12 months | Slow & fast | 50(15.2), 75(22.9), 100(30.5), 150(45.7) |
| 3 | 6 | 24 | CP 70-321 | 12 months | Slow & fast | 50(15.2), 75(22.9), 100(30.5), 150(45.7) |
| 4 | 6 | 6 | CP 70-321 | 12 months | Slow & fast | 375 (114.3) whole rows |

**Analysis Phase**

The following analysis was performed to determine the scale's accuracy and establish what factors affected the scale's ability to measure the yield.

Definitions:

*Spot yield*- the instantaneous weight measurement of cane taken by the scale.

*Scale yield*- is the summation of spot yields for a given section.

*Wagon yield*-is the weight of the cane measured by the weigh wagon for a given section.

The spot yields were smoothed with a twenty point moving average (see Figure 11) to reduce error. The spot yields were totaled for each section to get a total yield (scale yield) for each section. The weigh wagon yield for each section was considered the actual yield for that section of harvested sugar cane. The weigh wagon's accuracy was established through previous testing.

Figure 11 showed the result of using 20-point moving average to filter out the spikes in the scale's raw signal. Figure 11 is constructed from the scale's readings (load) versus time for a harvested row of cane.

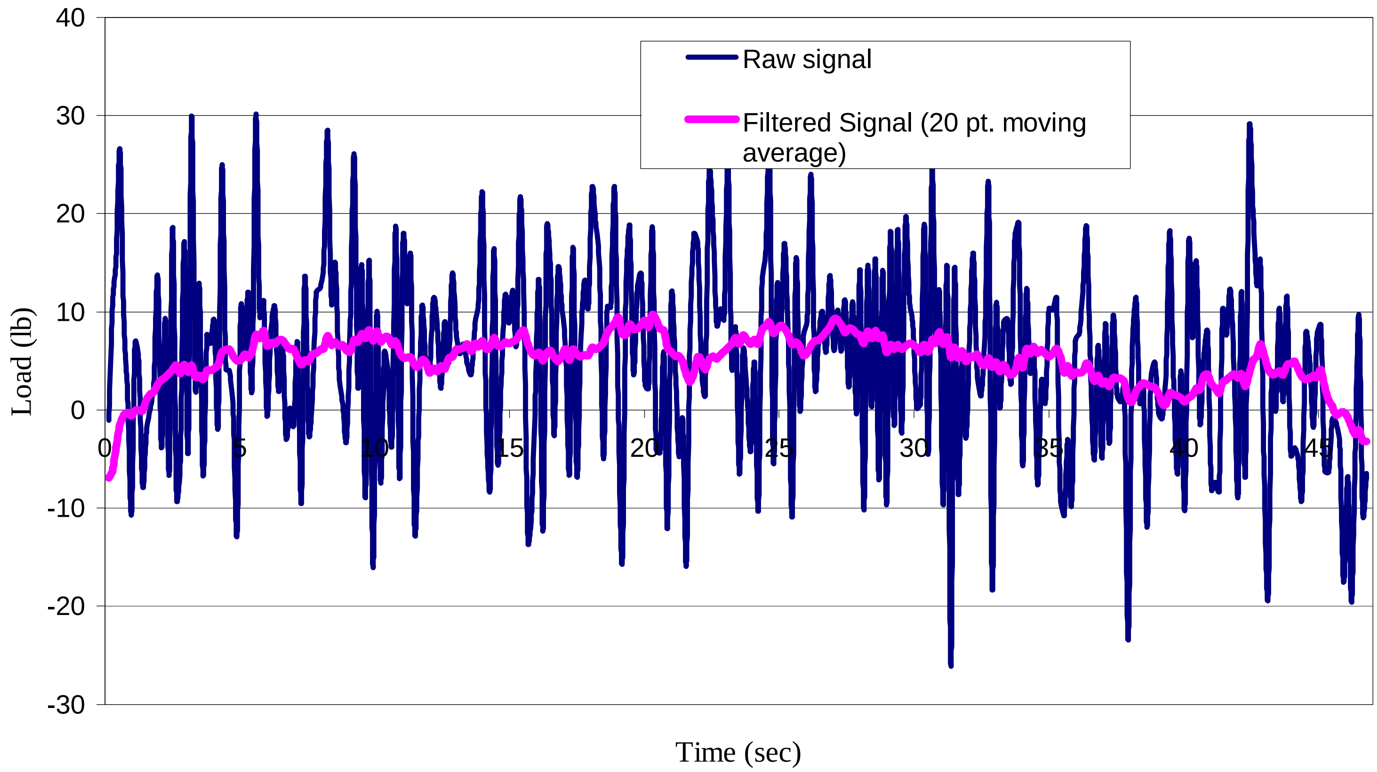



Figure 11. Raw and Filtered Signal for One Row

To determine correlation, statistical tests were conducted comparing the scale yield with the weigh wagon yield. In this analysis the weigh wagon was considered the standard or the independent variable. So, the weigh wagon yield was determined by the scale yield. To establish how well the scale predicted the weigh wagon yield, a regression was done (along with calculating residuals and 95 percentile prediction intervals). The regression was based on the following equation:

$$Wagon\ Yield = a_0 + Scale\ Yield * a_1$$

Where:

$a_0$ = intercept

$a_1$ = slope

Also, statistical tests were conducted comparing the scale yield and wagon yield for the different treatments. A general linear model was constructed to test the possible effects of variety (Var), maturity (Mat), flow-rate (Sp), and section length (Len) on the scale readings. The general linear model was based on the following equation:

$$\textit{Scale Yield} = b_0 + \textit{Wagon Yield}*b_1 + \text{Var}*b_2 + \text{Mat}*b_3 + \text{Sp}*b_4 + \text{Len}*b_5$$

Where:

$b_0$ = intercept

$b_1$ - $b_5$ = slopes

Var, Mat, Sp, & Len are variables equaling 1 or 0

Percent (%) error was calculated for each test using the following equation:

Percent Error = (Absolute Value (Scale Yield – Wagon Yield)) / Wagon Yield *100

## RESULTS AND DISCUSSION

The residuals (see Appendix C2 – Figure C1) were equally spaced about zero; thus there were no visible trends. The results of the scale yield compared to the weigh wagon yield are shown in Figure 12 and 13. Figure 12 indicated that the yield monitor predicted the wagon yield with a slope of 0.9 and an R-squared of 0.966. This figure is constructed from the regression and 95 percent prediction data of the weigh wagon yield versus the scale yield across all row/sections lengths (50 ft [15.2 m], 75 ft [22.9 m], 100 ft [30.5 m], and 150 ft [45.7 m]). Figure12 includes sections and whole rows.

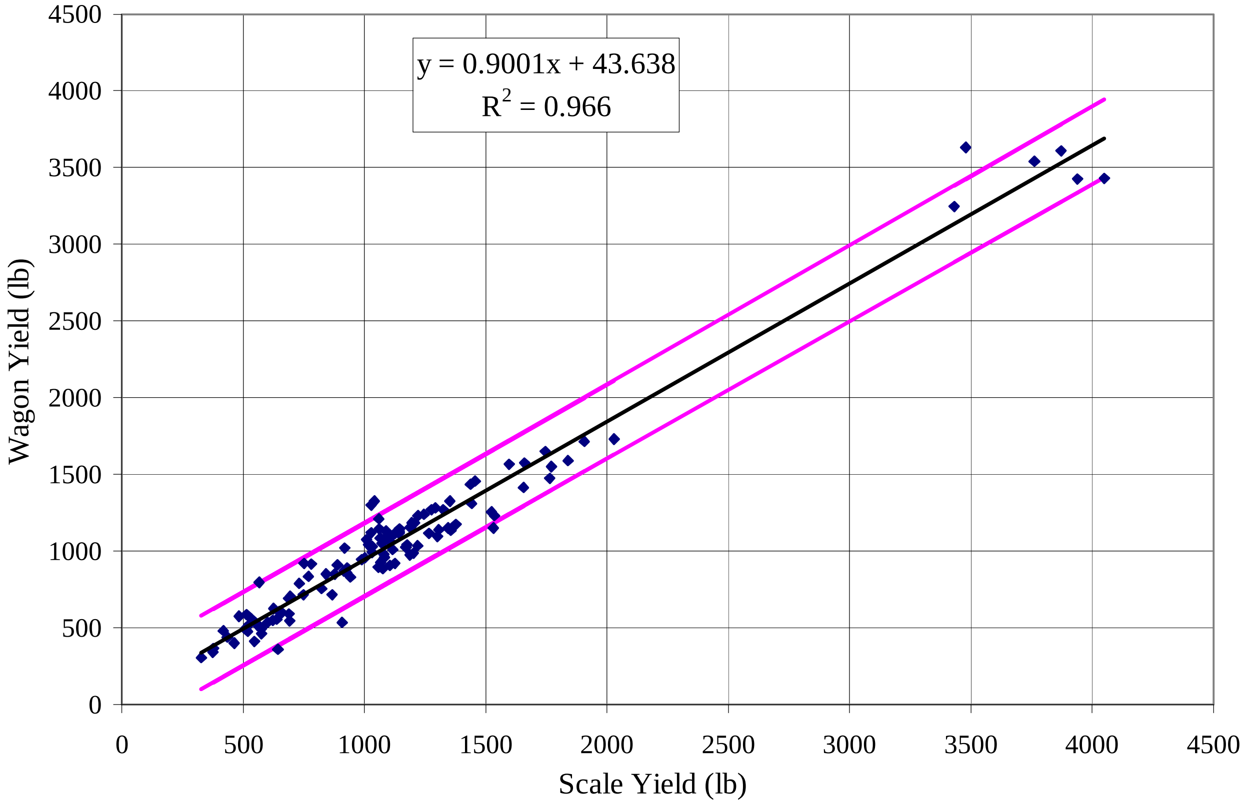



Figure 12. Wagon Yield vs. Scale Yield

Figure 13 is constructed from the regression and 95 percent prediction interval data of the wagon yield versus the scale yield on just the sections, not the whole rows (375 ft [114.3 m]). This figure indicated that the yield monitor predicted the wagon yield with a slope of 0.857 and an R-squared of 0.896. The purpose of plotting both was to show that the short sections were indicative of the spot yield accuracy, and the whole rows showed the expected accuracy for loading a wagon.

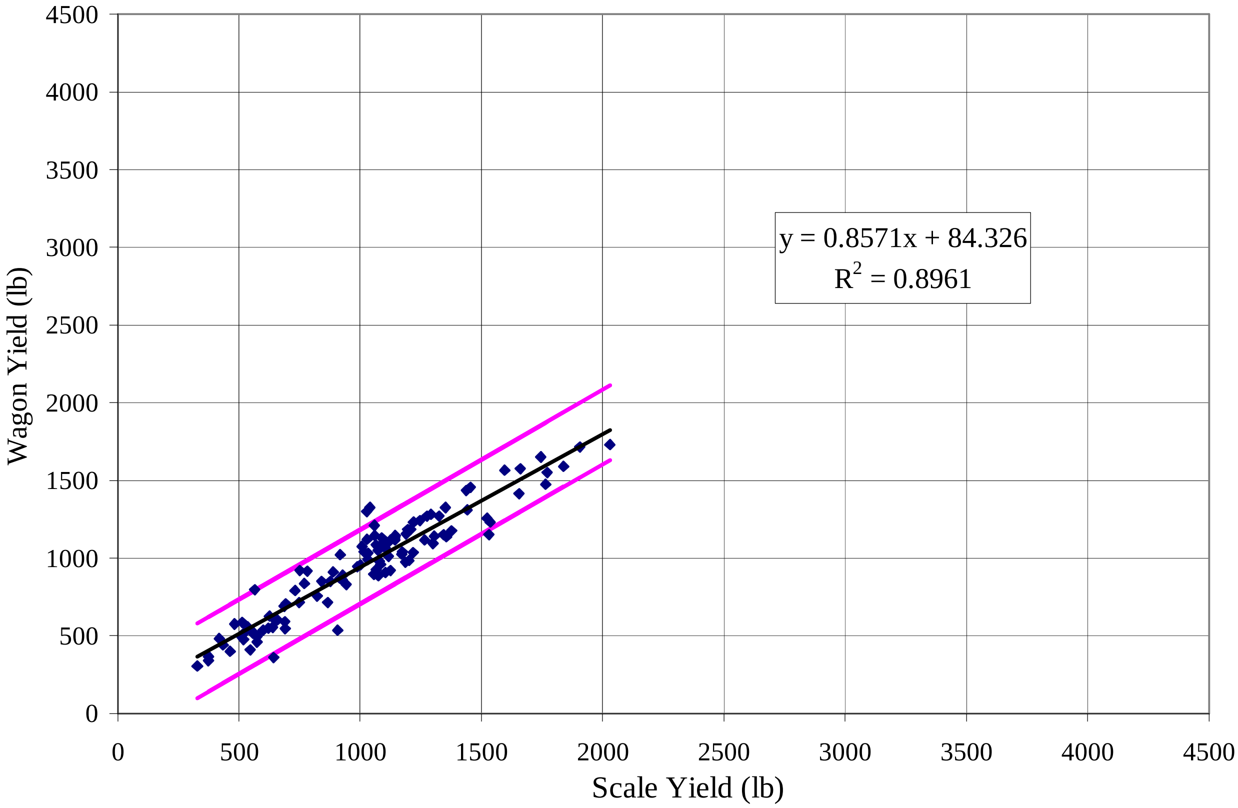



Figure 13. Wagon Yield vs. Scale Yield (no whole rows)

Table 3 shows the effect of the different parameters on the scale readings (See also APPENDIX C). Maturity, speed, and section lengths had very low F-values; thus each had the least effect on the scale readings. This indicates that the scale readings were not affected by the age of cane, the flow-rate of the cane through the harvester, or even the harvested row length. Wagon yield had the greatest effect, which was to be expected, since that is the value that the scale readings are being compared.  According to the Table 3, variety also had an effect.  Variety had an affect on the scale readings because one of the cane varieties (LCP 85-384) was higher yielding and had more trash content.  The total tonnage was greater for the tests that were done on the higher yielding variety.  Therefore, it is reasonable that the scale readings were affected by a change in the variety.

| **Table 3. General Linear Model Results** | | |
|---|---|---|
| **Parameters** | **F-Value** | **Probability** |
| Wagon | 187.81 | 0.0001 |
| Variety | 5.81 | 0.0176 |
| Maturity (age) | 1.08 | 0.3003 |
| Speed (flow-rate) | 0.29 | 0.5928 |
| Section Lengths | 0.73 | 0.5702 |

The percent error ranged from 0 to 33 percent (see Figure 14), and only 14 of the 118 tests were above 20 percent error.  The average error was 11.05 percent.  Thus on average, the yield monitor predicted the wagon yield with 89 percent accuracy.

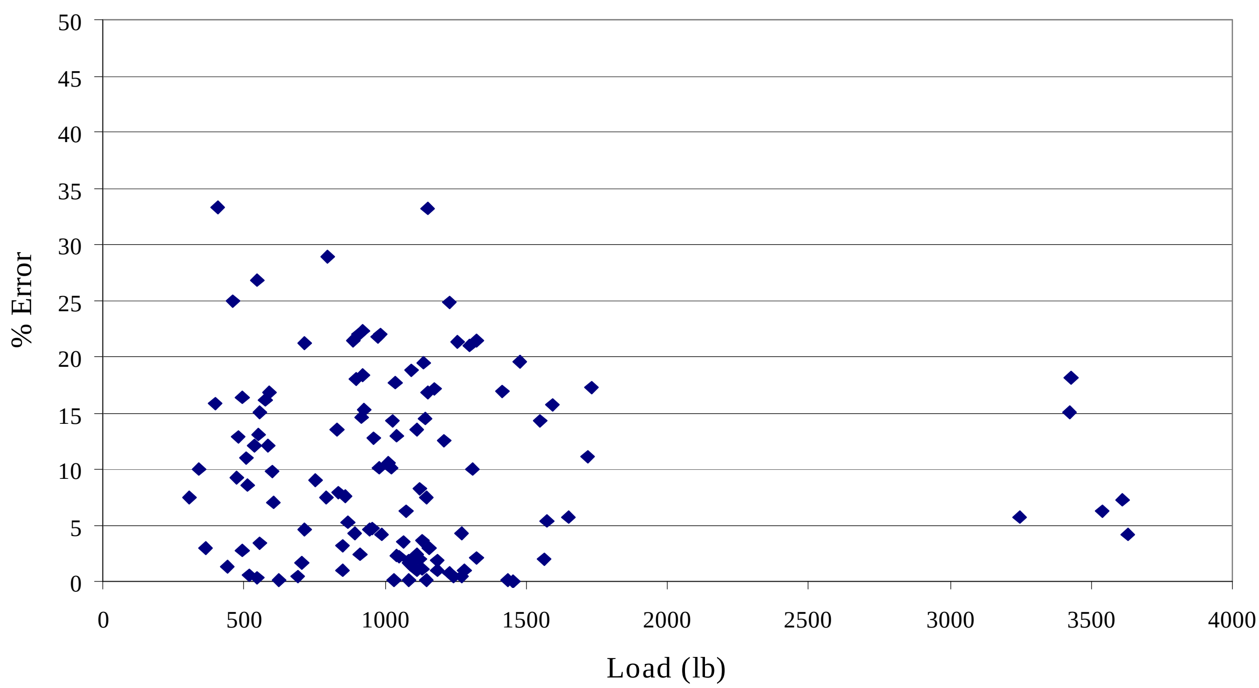



Figure 14. Persent Error vs. Load

One source of error is likely du to the large amount of vibrations induced by the ground and all the moving parts of the harvester. Another source of error is that the scale weighs more trash than the weigh wagon. The secondary extractor fan (see Figure 1) removes about 10 percent of trash as the cane goes into the wagon.

Figures 15 and 16 are the results of the Global Positioning System (GPS) for the 1999- and 2000-field tests. Both figures show the path of the harvester as it harvested the sugar cane during the field tests. The 1999-field tests had 400-foot (122 m) rows and the 2000-field tests had 375-foot (114.3 m) rows.

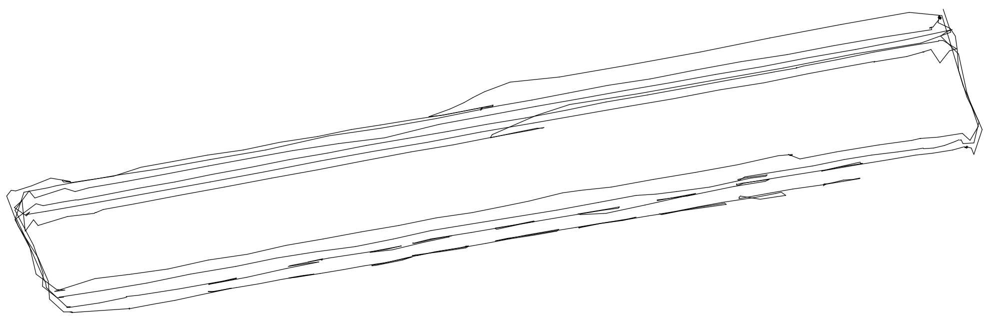


Figure 15. 1999 GPS Field Track

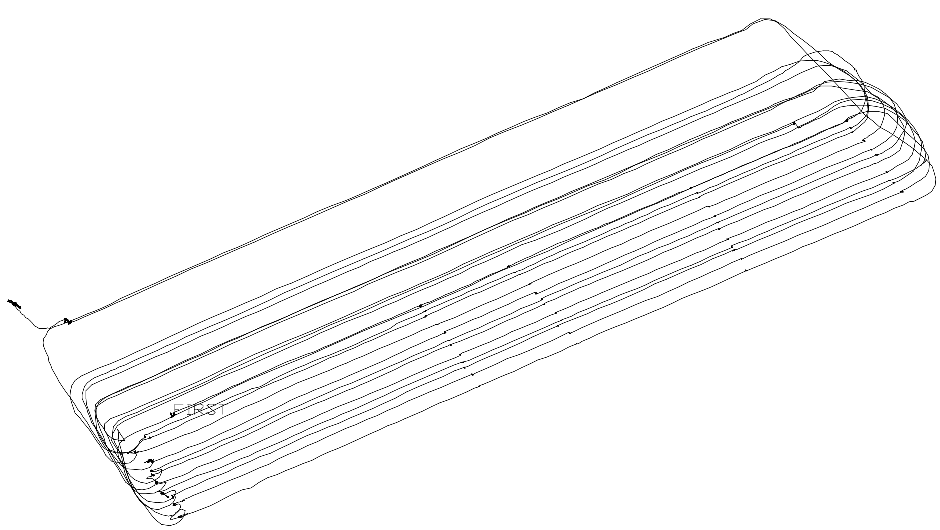



Figure 16. 2000 GPS Field Track

## CONCLUSIONS AND RECOMMENDATIONS

The goal of the project was to design a system that would accurately measure the yield of sugar cane as it's harvested by a sugar cane combine. Even though US Sugar (a large sugar producing company that owns their own sugar cane fields) and sugar cane farmers would accept errors ranging from zero to twenty percent, the system is not ready for production/market. This system needs to be improved for it to be deemed reliable. The error needs to be consistent so that it can be filtered out. The system's error was not consistent and ranged from zero to 33 percent, but averaged 11.05 percent. However, the scale yield correlated well with the weigh wagon yield, which indicates a good potential with further improvements for measuring sugar cane yield accurately. The recommended improvements include the following:

- Use the original weigh plate size of 24 in x 30 in [61 cm x 76.2 cm] and support it with four load cells at each corner to reduce plate vibrations.
- Use a magnetic device to determine when the slats pass the scale. This device will signal the data-logger to record the instantaneous weight of each slat of cane.
- Use a data-logging system that samples 3 times faster than the sampling frequency (3.7 hertz) and then average the readings for each slat of cane. This will reduce signal error.
- Run preliminary vibration tests using an accelerometer on the harvester to establish dominating frequencies and the forces that act on the weigh plate. Use pre-filter techniques such as a digital filter to eliminate those dominating frequencies.
- Use an inclinometer to compensate for the scale being at an angle, which will cut out the extensive field calibration described in the material and methods section.

With these improvements and more field tests, this device should prove to be a reliable and accurate yield monitoring system. Since yield maps may be used for the determination of crop management zones, the management of inputs, and the evaluation of results of these strategies, it is important that the accuracy of the yield maps be considered (Birrell et al., 1995). In order for site-specific management to succeed, it is important to have a reliable continuous yield monitor (Perez-Munoz et al. and Colvin et al., 1996).

## REFERENCES


Auernhammer, H., M. Demmel, and P.J.M. Pirro. 1995. Yield Measurement On Self Propelled Forage Harvester. ASAE Paper No. 951757. ASAE, St. Joseph, MI.

Benjamin, C.E., R.R. Price and M. P. Mailander, 2001. Sugar Cane Yield Monitoring System. ASAE Paper No. 011189. ASAE, St. Joseph MI.

Benjamin, C.E., and M. P. Mailander, 2000. Sugar Cane Yield Monitoring System. Paper No. 001125. ASAE, St. Joseph MI.

Birrell, S.J. and S.C. Borgelt. 1995. Crop Yield Mapping: Comparison Of Yield Monitors And Mapping Techniques. Site-Specific Management for Agriculture Systems. Pp. 15-31. ASA-CSSA-SSSA. Madison, WI

Bischoff, K.P., K.A. Gravois, H.P.Schexnayder, and G.L. Hawkins. 2001. The Effect of Harvest Method and Plot Size on Sugarcane Yield. The American Society of Sugar Cane Technology Journal, vol. 21, pp.3.

Borgelt, S.C. and K.A. Sudduth. 1992. Grain Flow Monitoring For In-Field Mapping. ASAE Paper No.921022. ASAE, St. Joseph, MI

Campbell, R.H., S.L. Rawlins and S. Han. 1994. Monitoring Methods For Potato Harvesting. ASAE Paper No. 941584. ASAE, St. Joseph, MI.

Colvin, T.S., K.L. Karlen, and N. Tischer. 1991. Yield Variability Within Fields In Central Iowa. Automated Agriculture for the 21st Century, Proceedings of the 1991 Symposium, pp. 366-372. ASAE, St. Joseph, MI.

Cox, G. J., H.D. Harris, and D.R. Cox. 1998. Application of Precision Agriculture to Sugar Cane. Proceedings of the Fourth International Conference on Precision Agriculture. ASA-CSSA-SSSA, St. Paul, MN.

Cox, G. J., H.D. Harris, D.R. Cox, D.M. Bakker, R.A. Pax, and S.R. Zillman. November 4, 1999. Mass Flow Rate For Sugar Cane Harvesters. Australian Patent No. 744047.

Crews, D.H., J.D. Whitney, M. Salyani, and J.K. Schueller. 2001. Dynamic Weighing to Improve Citrus Yield Mapping. ASAE Paper No. 01-1184. ASAE, St. Joseph, MI.

Durrence, J.S., C.D. Perry, G. Vellidis, D.L. Thomasa, and C.K. Kvien. 1998. Evaluation Of Commercially-Available Cotton Yield Monitors In Georgia Field Conditions.. ASAE Paper 98-3106. ASAE, St. Joseph, MI.

Karlen, D.L., E.J. Sadler, and W.J. Busscher. 1990. Crop Yield Variation Associated With Coastal Plain Soil Map Units. Soil Science Society American Journal, vol. 54, pp. 859-865.

Kromer, K.H., O. Schmittmann, and A.M. Osman. 1999. Crop Yield Monitoring on Forage Harvesters. ASAE Paper No. 991051. St. Josepth, MI.

Pagnano, N.B., and P.S. G.Magalhaes. 2001. Sugarcane Yield Measurement. Faculdade de Engenharia Agricola – Unicamp – Campinas – SP, Brasil 13083-970. 3rd European Conference on Precision Agriculture Proceedings, pp. 839-844. Montpellier, France.

Perez-Munoz, F., and T.S. Colvin. 1996. Continuous Grain Yield Monitoring. ASAE Paper No. 94-1053. St. Joseph, MI.

Perry, C.D., J.S. Durrence, G. Vellidis, D.L. Thomas, R.W. Hill, C.S. Kvien. 1998. Field Experiences With A Prototype Peanut Yield Monitor. ASAE Paper No. 983095. ASAE, St. Joseph, MI.

Sciortino, Dominick Jr., personal communication with the sugar cane combine production engineer, CAMECO, A John Deere Company, 1999-2000.

Schneider, S.M., S.L. Rawlins, S. Han, R.G. Evans, and R.H. Campbell. 1996. Precision Agriculture For Potatoes In The Pacific Northwest. Proceedings of the Third International Conference on Precision Agriculture. ASA-CSSA-SSSA, Madison, WI.

Thomas, D.L., C.D. Perry, G. Vellidis, J.S. Durrence, L.J. Kutz, C.K. Kvien, B. Boydell, and T.K. Hamrita. 1997. Development And Implementation Of A Load Cell Yield Monitor For Peanut. ASAE Paper No. 971059. ASAE, St. Joseph, MI.

Walter, J.D., V.L. Hofman, and L.F. Backer. 1996. Site-Specific Sugarbeet Yield Monitoring. Proceedings of the Third International Conference on Precision Agricultural. ASA-CSSA-SSSA, Madison, WI.

Wendte, K.W., A. Skotnikov, and K.K. Thomas. August 14, 2001. Sugar Cane Yield Monitor. United States Patent No. 6272819.

# APPENDIX A: LOAD CELL, DATA ACQUISITION SYSTEM, AND GLOBAL POSITIONING SYSTEM INFORMATION

## LOAD CELL

Sensortronics
677 Arrow Grand Circle
Covina, California 91722 USA
1-800-722-0820

Model 61250 - The model number has changed since the project began in 1999. It is now Model 60060.

Load Cell Performance Specifications:

Rated Capacities (lbs): 100, 250, 500, 750, 1K, 2K

Full Scale Output (FSO): 2.0 mV/V ±10%

Accuracy Class: Standard NTEP III NTEP IIIL OIML R60

Max. No. Verification Intervals -- 5,000 10,000 3,000

Multiple Multiple

Combined Error % FSO < 0.03 -- -- --

Non-Linearity % FSO < 0.03 -- -- --

Hysteresis % FSO < 0.02 -- -- --

Creep Error % FSO < 0.03 in 20 minutes -- -- --

Temperature Effect on:

• Zero % FSO/oF < 0.0015 -- -- --

• Output % of Load/oF < 0.0008 -- -- --

Non-Repeatability % FSO < .01

Zero Balance % FSO < 1.0

Insulation Resistance > 1000 Mohms at 50VDC

Compensated Temperature Range 14o to 104oF / -10o to 40oC

Operating Temperature Range 0o to 150oF / -18o to 65oC

Storage Temperature Range -60o to 185oF / -50o to 85oC

Input Resistance 400 Ohms Nominal

Output Resistance 349-355 Ohms

Recommended Excitation Voltage 10 Volts DC

Maximum Excitation Voltage 15 Volts DC

Sideload Rejection Ratio 500:1

Safe Sideload 100% of Rated Capacity

Safe Overload 150% of Rated Capacity

Ultimate Overload 300% of Rated Capacity

Material Aluminum

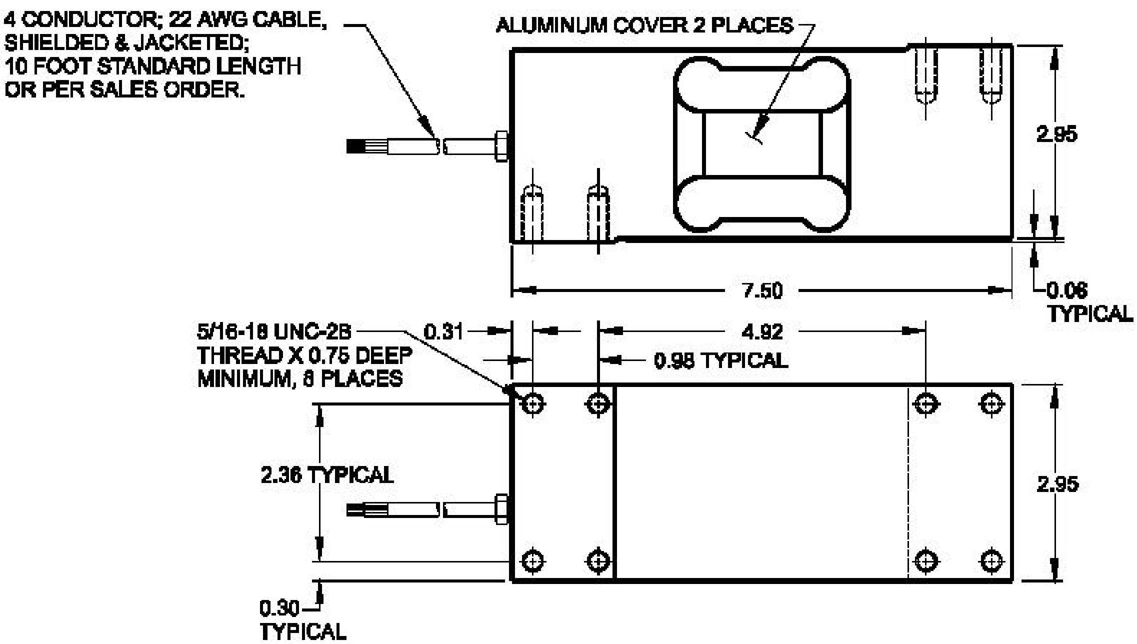
Moment Compensation: 250 - 1,000 lbs. 2,000 lbs.

•Moment Sensitivity (lbs - inch) < 0.005% of applied load < 0.005% of applied load

•Maximum Moment (lbs - inch) 10 x Capacity 10,000

•Platform Size (inch) 30 x 30 30 x 30

(1) Note: 250 to 2K Capacities Only




WIRING

| FUNCTION | COLOR |
|---|---|
| + Excitation | Red |
| − Excitation | Black |
| + Output | Green |
| − Output | White |

| CAPACITY | Deflection | Weight |
|---|---|---|
| 100 - 250 | 0.010 | 6.0 |
| 500 - 2K | 0.006 | 6.0 |

*Dimensions are in inches. Capacities are in pounds. Deflection is ±10%. Specifications are subject to change. Certified drawings are available.*

## Data Acquisition System

Campbell Scientific, Inc.
815 W. 1800 N.
Logan, Utah 84321-1784 USA
435-753-2342

Model: CR 23X Micrologger

Data-Logger Program using PC208W software (Campbell Scientific, Inc.):

```
;{CR23X}
;
*Table 1 Program
  01: .14       Execution Interval (seconds)

1:  Volt (Diff) (P2)
 1: 2        Reps
 2: 13       200 mV, Fast Range
 3: 1        DIFF Channel
 4: 1        Loc [ lc1       ]
 5: 1        Mult
 6: 0        Offset

2:  Z=X+Y (P33)
 1: 1        X Loc [ lc1       ]
 2: 2        Y Loc [ lc2       ]
 3: 3        Z Loc [ sum       ]

3:  Do (P86)
 1: 10       Set Output Flag High (Flag 0)

4:  Real Time (P77)
 1: 21       Hour/Minute,Seconds (midnight = 2400)

5:  Sample (P70)
 1: 1        Reps
 2: 3        Loc [ sum       ]

End Program
```

## Differential Global Positioning System (DGPS)

Trimble Navigation Limited
Surveying and Mapping Division
645 North Mary Avenue
P.O. BOX 3642
Sunnyvale, CA 94086 USA
1-800-827-8000

Model: Trimble TDC1

# APPENDIX B: FIELD TEST DATA

| Table B1. Legend |
|---|
| **Speed** |
| 1=1.8 mph |
| 2=2.8 mph |
| 3=3.2 mph |

| Table B1. 1999-Field Test Data | | | | | |
|---|---|---|---|---|---|
| **Section** | **Test** | **Scale (lbs)** | **Wagon (lbs)** | **Speed** | **Missing Values** |
| 1 | 1 | 1024 | 735 | 1 | 10 |
| 2 | 1 | 1005 | 785 | 1 | 16 |
| 3 | 1 | 978 | 705 | 1 | 11 |
| 4 | 1 | 915 | 720 | 1 | 8 |
| 5 | 1 | 1071 | 765 | 1 | 12 |
| 6 | 1 | 851 | 710 | 1 | 7 |
| 7 | 1 | 921 | 765 | 1 | 3 |
| 8 | 1 | 846 | 750 | 1 | 9 |
| 9 | 2 | 889 | 745 | 2 | 22 |
| 10 | 2 | 957 | 820 | 2 | 30 |
| 11 | 2 | 837 | 880 | 2 | 34 |
| 12 | 2 | 886 | 770 | 2 | 19 |
| 13 | 2 | 939 | 765 | 2 | 13 |
| 14 | 2 | 842 | 760 | 2 | 20 |
| 15 | 2 | 837 | 850 | 2 | 34 |
| 16 | 2 | 878 | 865 | 2 | 32 |
| 17 | 3 | 769 | 680 | 3 | 23 |
| 18 | 3 | 581 | 640 | 3 | 21 |
| 19 | 3 | 808 | 710 | 3 | 19 |
| 20 | 3 | 871 | 755 | 3 | 28 |
| 21 | 3 | 825 | 700 | 3 | 21 |
| 22 | 3 | 729 | 710 | 3 | 11 |
| 23 | 3 | 762 | 715 | 3 | 22 |
| 24 | 3 | 0 | 0 | 3 | lost data |

| Table B2. Legend | | |
|---|---|---|
| **Variety** | **Maturity** | **Speed** |
| 1=85-384 | 0=Younger | 0=slow |
| 2=70-321 | 1=Older | 1=Fast |

**Table B2. 2000-Field Test Data**

| Section | Test | Row | Scale | WW | Variety | Maturity | Speed | Sec Length |
|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | 1455 | 1455 | 1 | 0 | 0 | 150 |
| 2 | 1 | 1 | 543 | 545 | 1 | 0 | 1 | 50 |
| 3 | 1 | 1 | 1356 | 1135 | 1 | 0 | 1 | 100 |
| 4 | 1 | 1 | 928 | 890 | 1 | 0 | 0 | 75 |
| 5 | 1 | 2 | 1536 | 1230 | 1 | 0 | 1 | 150 |
| 6 | 1 | 2 | 622 | 550 | 1 | 0 | 1 | 50 |
| 7 | 1 | 2 | 1031 | 990 | 1 | 0 | 1 | 100 |
| 8 | 1 | 2 | 687 | 690 | 1 | 0 | 1 | 75 |
| 9 | 1 | 3 | 1839 | 1590 | 1 | 0 | 1 | 150 |
| 10 | 1 | 3 | 536 | 555 | 1 | 0 | 1 | 50 |
| 11 | 1 | 3 | 1325 | 1270 | 1 | 0 | 1 | 100 |
| 12 | 1 | 3 | 1066 | 925 | 1 | 0 | 1 | 75 |
| 13 | 1 | 4 | 1660 | 1575 | 1 | 0 | 1 | 150 |
| 14 | 1 | 4 | 566 | 510 | 1 | 0 | 1 | 50 |
| 15 | 1 | 4 | 1065 | 1085 | 1 | 0 | 1 | 100 |
| 16 | 1 | 4 | 925 | 860 | 1 | 0 | 1 | 75 |
| 17 | 1 | 5 | 1596 | 1565 | 1 | 0 | 1 | 150 |
| 18 | 1 | 5 | 691 | 545 | 1 | 0 | 1 | 50 |
| 19 | 1 | 5 | 1107 | 1090 | 1 | 0 | 1 | 100 |
| 20 | 1 | 5 | 1125 | 920 | 1 | 0 | 0 | 75 |
| 21 | 1 | 6 | 2029 | 1730 | 1 | 0 | 1 | 150 |
| 22 | 1 | 6 | 514 | 585 | 1 | 0 | 1 | 50 |
| 23 | 1 | 6 | 1089 | 1130 | 1 | 0 | 1 | 100 |
| 24 | 1 | 6 | 942 | 830 | 1 | 0 | 0 | 75 |
| 25 | 1 | 7 | 1745 | 1650 | 1 | 0 | 1 | 150 |
| 26 | 1 | 7 | 689 | 590 | 1 | 0 | 0 | 50 |
| 27 | 1 | 7 | 1207 | 1185 | 1 | 0 | 1 | 100 |
| 28 | 1 | 7 | 781 | 915 | 1 | 0 | 1 | 75 |
| 29 | 1 | 8 | 1771 | 1550 | 1 | 0 | 1 | 150 |
| 30 | 1 | 8 | 626 | 625 | 1 | 0 | 1 | 50 |
| 31 | 1 | 8 | 1126 | 1115 | 1 | 0 | 1 | 100 |
| 32 | 1 | 8 | 877 | 850 | 1 | 0 | 1 | 75 |
| 33 | 1 | 9 | 1437 | 1435 | 1 | 0 | 1 | 150 |
| 34 | 1 | 9 | 523 | 520 | 1 | 0 | 1 | 50 |
| 35 | 1 | 9 | 1079 | 980 | 1 | 0 | 1 | 100 |
| 36 | 1 | 9 | 693 | 705 | 1 | 0 | 1 | 75 |
| 37 | 1 | 10 | 1906 | 1715 | 1 | 0 | 1 | 150 |

| Table B2. 2000-Field Test Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Section | Test | Row | Scale | WW | Variety | Maturity | Speed | Sec Length |
| 38 | 1 | 10 | 659 | 600 | 1 | 0 | 0 | 50 |
| 39 | 1 | 10 | 1016 | 1040 | 1 | 0 | 1 | 100 |
| 40 | 1 | 10 | 823 | 755 | 1 | 0 | 0 | 75 |
| 41 | 2 | 1 | 1074.5 | 885 | 1 | 2 | 0 | 150 |
| 42 | 2 | 1 | 373.9 | 340 | 1 | 2 | 0 | 50 |
| 43 | 2 | 1 | 730.8 | 790 | 1 | 2 | 0 | 100 |
| 44 | 2 | 1 | 866.4 | 715 | 1 | 2 | 0 | 75 |
| 45 | 2 | 2 | 1144.2 | 1145 | 1 | 2 | 1 | 150 |
| 46 | 2 | 2 | 546.6 | 410 | 1 | 2 | 0 | 50 |
| 47 | 2 | 2 | 565.2 | 795 | 1 | 2 | 0 | 100 |
| 48 | 2 | 2 | 748 | 715 | 1 | 2 | 0 | 75 |
| 49 | 2 | 3 | 1040.6 | 1325 | 1 | 2 | 0 | 150 |
| 50 | 2 | 3 | 508.8 | 495 | 1 | 2 | 0 | 50 |
| 51 | 2 | 3 | 750.8 | 920 | 1 | 2 | 0 | 100 |
| 52 | 2 | 3 | 769 | 835 | 1 | 2 | 0 | 75 |
| 53 | 2 | 4 | 1292.6 | 1280 | 1 | 2 | 1 | 150 |
| 54 | 2 | 4 | 434.3 | 440 | 1 | 2 | 0 | 50 |
| 55 | 2 | 4 | 1343.7 | 1150 | 1 | 2 | 0 | 100 |
| 56 | 2 | 4 | 1082.7 | 960 | 1 | 2 | 0 | 75 |
| 57 | 2 | 5 | 1440.7 | 1310 | 1 | 2 | 1 | 150 |
| 58 | 2 | 5 | 418.2 | 480 | 1 | 2 | 0 | 50 |
| 59 | 2 | 5 | 1116.3 | 1010 | 1 | 2 | 0 | 100 |
| 60 | 2 | 5 | 916.1 | 870 | 1 | 2 | 0 | 75 |
| 61 | 2 | 6 | 1142.3 | 1120 | 1 | 2 | 1 | 150 |
| 62 | 2 | 6 | 647.4 | 605 | 1 | 2 | 0 | 50 |
| 63 | 2 | 6 | 1143 | 1130 | 1 | 2 | 0 | 100 |
| 64 | 2 | 6 | 1103 | 1085 | 1 | 2 | 0 | 75 |
| 65 | 2 | 7 | 1245.5 | 1240 | 1 | 2 | 1 | 150 |
| 66 | 2 | 7 | 638.3 | 555 | 1 | 2 | 0 | 50 |
| 67 | 2 | 7 | 1058.7 | 1210 | 1 | 2 | 0 | 100 |
| 68 | 2 | 7 | 888.02 | 910 | 1 | 2 | 0 | 75 |
| 69 | 2 | 8 | 1220.7 | 1230 | 1 | 2 | 1 | 150 |
| 70 | 2 | 8 | 599.8 | 535 | 1 | 2 | 0 | 50 |
| 71 | 2 | 8 | 1142.4 | 1115 | 1 | 2 | 0 | 100 |
| 72 | 2 | 8 | 1218.3 | 1035 | 1 | 2 | 0 | 75 |
| 73 | 2 | 9 | 1763.8 | 1475 | 1 | 2 | 1 | 150 |
| 74 | 2 | 9 | 481.9 | 575 | 1 | 2 | 0 | 50 |
| 75 | 2 | 9 | 1027.9 | 1120 | 1 | 2 | 0 | 100 |
| 76 | 2 | 9 | 1059.9 | 1145 | 1 | 2 | 0 | 75 |
| 77 | 2 | 10 | 1027.6 | 1300 | 1 | 2 | 1 | 150 |
| 78 | 2 | 10 | 559.3 | 515 | 1 | 2 | 0 | 50 |

| Table B2. 2000-Field Test Data | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Section** | **Test** | **Row** | **Scale** | **WW** | **Variety** | **Maturity** | **Speed** | **Sec Length** |
| 79 | 2 | 10 | 1031.6 | 1030 | 1 | 2 | 0 | 100 |
| 80 | 2 | 10 | 1007.2 | 1075 | 1 | 2 | 0 | 75 |
| 81 | 2 | 11 | 1655.2 | 1415 | 1 | 2 | 1 | 150 |
| 82 | 2 | 11 | 518.99 | 475 | 1 | 2 | 0 | 50 |
| 83 | 2 | 11 | 1523.2 | 1255 | 1 | 2 | 0 | 100 |
| 84 | 2 | 11 | 1265.3 | 1115 | 1 | 2 | 0 | 75 |
| 85 | 2 | 12 | 1274.9 | 1270 | 1 | 2 | 1 | 150 |
| 86 | 2 | 12 | 907.3 | 535 | 1 | 2 | 0 | 50 |
| 87 | 2 | 12 | 1189.1 | 1155 | 1 | 2 | 0 | 100 |
| 88 | 2 | 12 | 1376.3 | 1175 | 1 | 2 | 0 | 75 |
| 89 | 3 | 1 | 1300.9 | 1095 | 2 | 2 | 0 | 150 |
| 90 | 3 | 1 | 463.5 | 400 | 2 | 2 | 0 | 50 |
| 91 | 3 | 1 | 1000.6 | 955 | 2 | 2 | 0 | 100 |
| 92 | 3 | 1 | 1174.4 | 1040 | 2 | 2 | 0 | 75 |
| 93 | 3 | 2 | 1056 | 895 | 2 | 2 | 1 | 150 |
| 94 | 3 | 2 | 643 | 360 | 2 | 2 | 0 | 50 |
| 95 | 3 | 2 | 1531.1 | 1150 | 2 | 2 | 0 | 100 |
| 96 | 3 | 2 | 1201.3 | 985 | 2 | 2 | 0 | 75 |
| 97 | 3 | 3 | 1072.9 | 1050 | 2 | 2 | 1 | 150 |
| 98 | 3 | 3 | 327.85 | 305 | 2 | 2 | 0 | 50 |
| 99 | 3 | 3 | 917.4 | 1020 | 2 | 2 | 0 | 100 |
| 100 | 3 | 3 | 988.8 | 945 | 2 | 2 | 0 | 75 |
| 101 | 3 | 4 | 841.2 | 850 | 2 | 2 | 1 | 150 |
| 102 | 3 | 4 | 375.8 | 365 | 2 | 2 | 0 | 50 |
| 103 | 3 | 4 | 1186.9 | 975 | 2 | 2 | 1 | 100 |
| 104 | 3 | 4 | 1171 | 1025 | 2 | 2 | 0 | 75 |
| 105 | 3 | 5 | 1352 | 1325 | 2 | 2 | 1 | 150 |
| 106 | 3 | 5 | 574.5 | 460 | 2 | 2 | 0 | 50 |
| 107 | 3 | 5 | 1086 | 1085 | 2 | 2 | 1 | 100 |
| 108 | 3 | 5 | 1103 | 1065 | 2 | 2 | 0 | 75 |
| 109 | 3 | 6 | 1305.6 | 1140 | 2 | 2 | 1 | 150 |
| 110 | 3 | 6 | 576 | 495 | 2 | 2 | 0 | 50 |
| 111 | 3 | 6 | 1104.3 | 905 | 2 | 2 | 1 | 100 |
| 112 | 3 | 6 | 1196.1 | 1185 | 2 | 2 | 0 | 75 |
| 113 | 4 | 1 | 4050.6 | 3430 | 2 | 2 | 1 | 375 |
| 114 | 4 | 2 | 3939.4 | 3425 | 2 | 2 | 1 | 375 |
| 115 | 4 | 3 | 3478.5 | 3630 | 2 | 2 | 1 | 375 |
| 116 | 4 | 4 | 3761.6 | 3540 | 2 | 2 | 1 | 375 |
| 117 | 4 | 5 | 3871.6 | 3610 | 2 | 2 | 1 | 375 |
| 118 | 4 | 6 | 3431.6 | 3245 | 2 | 2 | 1 | 375 |

# APPENDIX C: SAS PROGRAMS AND OUTPUT

## Appendix C1: Regression Analysis

```
*Caryn E. Benjamin*
*2000-Field test Data Analysis*
*Regression Analysis of Scale versus Weigh Wagon*
```

***SAS Program***

```
dm"log;clear;output;clear";

data one;
        infile 'A:Scale-WW.dat';
        input scale wagon;
run;

proc reg data=one;
        model wagon=scale /clm cli;
        id scale;
        plot wagon*scale student.*scale;
run;

symbol interpol=rlcli95 ci=blue cv=red value=star height=1;

proc gplot data=one;
        plot wagon*scale / haxis=0 to 4500 by 500
                           vaxis=0 to 4500 by 500;
                                        hminor=100
                                        frame
                                        des='Scale vs. Weigh Wagon';
run;
quit;
```

***SAS Regression Output***

The SAS System        10:30 Monday, May 14, 2001

Model: MODEL1
Dependent Variable: WAGON

Analysis of Variance

| Source | DF | Sum of Squares | Mean Square | F Value | Prob>F |
|---|---|---|---|---|---|
| Model | **1** | **47347717.072** | **47347717.072** | **3290.769** | **0.0001** |
| Error | **116** | **1669012.8012** | **14388.04139** | | |
| C Total | **117** | **49016729.873** | | | |

| | | | |
|---|---|---|---|
| Root MSE | **119.95016** | R-square | **0.9660** |
| Dep Mean | **1082.24576** | Adj R-sq | **0.9657** |
| C.V. | **11.08345** | | |

Parameter Estimates

| Variable | DF | Parameter Estimate | Standard Error | T for H0: Parameter=0 | Prob > \|T\| |
|---|---|---|---|---|---|
| INTERCEP | **1** | **43.638498** | **21.20683463** | **2.058** | **0.0419** |
| SCALE | **1** | **0.900120** | **0.01569104** | **57.365** | **0.0001** |

| Obs | SCALE | Dep Var WAGON | Predict Value | Std Err Predict | Lower 95% Mean | Upper 95% Mean | Lower 95% Predict | Upper 95% Predict | Resid - ual |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 1455 | 1455.0 | 1353.3 | 12.011 | 1329.5 | 1377.1 | 1114.5 | 1592.1 | 101.7 |
| 2 | 543 | 545.0 | 532.4 | 14.622 | 503.4 | 561.4 | 293.1 | 771.7 | 12.5962 |
| 3 | 1356 | 1135.0 | 1264.2 | 11.489 | 1241.4 | 1287.0 | 1025.5 | 1502.9 | -129.2 |
| 4 | 928 | 890.0 | 879.0 | 11.597 | 856.0 | 901.9 | 640.3 | 1117.6 | 11.0499 |
| 5 | 1536 | 1230.0 | 1426.2 | 12.565 | 1401.3 | 1451.1 | 1187.3 | 1665.1 | -196.2 |
| 6 | 622 | 550.0 | 603.5 | 13.841 | 576.1 | 630.9 | 364.4 | 842.7 | -53.513 |
| 7 | 1031 | 990.0 | 971.7 | 11.209 | 949.5 | 993.9 | 733.1 | 1210.3 | 18.3375 |
| 8 | 687 | 690.0 | 662.0 | 13.251 | 635.8 | 688.3 | 423.0 | 901.0 | 27.9789 |
| 9 | 1839 | 1590.0 | 1699.0 | 15.411 | 1668.4 | 1729.5 | 1459.4 | 1938.5 | -109.0 |
| 10 | 536 | 555.0 | 526.1 | 14.694 | 497.0 | 555.2 | 286.8 | 765.5 | 28.8970 |
| 11 | 1325 | 1270.0 | 1236.3 | 11.364 | 1213.8 | 1258.8 | 997.7 | 1474.9 | 33.7022 |
| 12 | 1066 | 925.0 | 1003.2 | 11.128 | 981.1 | 1025.2 | 764.6 | 1241.8 | -78.167 |
| 13 | 1660 | 1575.0 | 1537.8 | 13.602 | 1510.9 | 1564.8 | 1298.7 | 1776.9 | 37.1619 |
| 14 | 566 | 510.0 | 553.1 | 14.388 | 524.6 | 581.6 | 313.8 | 792.4 | -43.106 |
| 15 | 1065 | 1085.0 | 1002.3 | 11.130 | 980.2 | 1024.3 | 763.7 | 1240.9 | 82. 7334 |
| 16 | 925 | 860.0 | 876.2 | 11.612 | 853.3 | 899.2 | 637.6 | 1114.9 | -16.25 |
| 17 | 1596 | 1565.0 | 1480.2 | 13.041 | 1454.4 | 1506.1 | 1241.3 | 1719.2 | 84.7696 |
| 18 | 691 | 545.0 | 665.6 | 13.217 | 639.4 | 691.8 | 426.6 | 904.6 | -120.6 |
| 19 | 1107 | 1090.0 | 1040.1 | 11.067 | 1018.2 | 1062.0 | 801.5 | 1278.7 | 49.9284 |
| 20 | 1125 | 920.0 | 1056.3 | 11.052 | 1034.4 | 1078.2 | 817.7 | 1294.9 | -136.3 |
| 21 | 2029 | 1730.0 | 1870.0 | 17.621 | 1835.1 | 1904.9 | 1629.9 | 2110.1 | -140.0 |
| 22 | 514 | 585.0 | 506.3 | 14.924 | 476.7 | 535.9 | 266.9 | 745.7 | 78.6997 |
| 23 | 1089 | 1130.0 | 1023.9 | 11.089 | 1001.9 | 1045.8 | 785.3 | 1262.5 | 106.1 |
| 24 | 942 | 830.0 | 891.6 | 11.532 | 868.7 | 914.4 | 652.9 | 1130.2 | -61.552 |
| 25 | 1745 | 1650.0 | 1614.3 | 14.421 | 1585.8 | 1642.9 | 1375.1 | 1853.6 | 35.6517 |
| 26 | 689 | 590.0 | 663.8 | 13.234 | 637.6 | 690.0 | 424.8 | 902.8 | -73.821 |
| 27 | 1207 | 1185.0 | 1130.1 | 11.074 | 1108.2 | 1152.0 | 891.5 | 1368.7 | 54.9164 |
| 28 | 781 | 915.0 | 746.6 | 12.496 | 721.9 | 771.4 | 507.8 | 985.5 | 168.4 |
| 29 | 1771 | 1550.0 | 1637.8 | 14.687 | 1608.7 | 1666.8 | 1398.4 | 1877.1 | -87.752 |
| 30 | 626 | 625.0 | 607.1 | 13.803 | 579.8 | 634.5 | 368.0 | 846.3 | 17.8862 |
| 31 | 1126 | 1115.0 | 1057.2 | 11.051 | 1035.3 | 1079.1 | 818.6 | 1295.8 | 57.8261 |
| 32 | 877 | 850.0 | 833.0 | 11.866 | 809.5 | 856.5 | 594.3 | 1071.8 | 16.9560 |
| 33 | 1437 | 1435.0 | 1337.1 | 11.903 | 1313.5 | 1360.7 | 1098.4 | 1575.9 | 97.8887 |
| 34 | 523 | 520.0 | 514.4 | 14.830 | 485.0 | 543.8 | 275.0 | 753.8 | 5.5986 |
| 35 | 1079 | 980.0 | 1014.9 | 11.105 | 992.9 | 1036.9 | 776.3 | 1253.5 | -34.868 |
| 36 | 693 | 705.0 | 667.4 | 13.199 | 641.3 | 693.6 | 428.4 | 906.4 | 37.5782 |
| 37 | 1906 | 1715.0 | 1759.3 | 16.162 | 1727.3 | 1791.3 | 1519.5 | 1999.0 | -44.268 |
| 38 | 659 | 600.0 | 636.8 | 13.499 | 610.1 | 663.6 | 397.7 | 875.9 | -36.818 |
| 39 | 1016 | 1040.0 | 958.2 | 11.252 | 935.9 | 980.4 | 719.5 | 1196.8 | 81.8393 |
| 40 | 823 | 755.0 | 784.4 | 12.202 | 760.3 | 808.6 | 545.6 | 1023.2 | -29.438 |
| 41 | 1074.5 | 885.0 | 1010.8 | 11.112 | 988.8 | 1032.8 | 772.2 | 1249.4 | -125.8 |
| 42 | 373.9 | 340.0 | 380.2 | 16.484 | 347.5 | 412.8 | 140.4 | 620.0 | -40.194 |
| 43 | 730.8 | 790.0 | 701.4 | 12.884 | 675.9 | 727.0 | 462.5 | 940.4 | 88.5536 |
| 44 | 866.4 | 715.0 | 823.5 | 11.928 | 799.9 | 847.1 | 584.8 | 1062.3 | -108.5 |

| Obs | SCALE | Dep Var WAGON | Predict Value | Std Err Predict | Lower 95% Mean | Upper 95% Mean | Lower 95% Predict | Upper 95% Predict | Residual |
|---|---|---|---|---|---|---|---|---|---|
| 45 | 1144.2 | 1145.0 | 1073.6 | 11.043 | 1051.7 | 1095.4 | 835.0 | 1312.1 | 71.4439 |
| 46 | 546.6 | 410.0 | 535.6 | 14.585 | 506.8 | 564.5 | 296.3 | 775.0 | -125.6 |
| 47 | 565.2 | 795.0 | 552.4 | 14.396 | 523.9 | 580.9 | 313.1 | 791.7 | 242.6 |
| 48 | 748 | 715.0 | 716.9 | 12.747 | 691.7 | 742.2 | 478.0 | 955.8 | -1.9284 |
| 49 | 1040.6 | 1325.0 | 980.3 | 11.184 | 958.2 | 1002.5 | 741.7 | 1218.9 | 344.7 |
| 50 | 508.8 | 495.0 | 501.6 | 14.979 | 472.0 | 531.3 | 262.2 | 741.0 | -6.6197 |
| 51 | 750.8 | 920.0 | 719.4 | 12.725 | 694.2 | 744.7 | 480.5 | 958.4 | 200.6 |
| 52 | 769 | 835.0 | 735.8 | 12.586 | 710.9 | 760.8 | 497.0 | 974.7 | 99.1690 |
| 53 | 1292.6 | 1280.0 | 1207.1 | 11.255 | 1184.8 | 1229.4 | 968.5 | 1445.8 | 72.8661 |
| 54 | 434.3 | 440.0 | 434.6 | 15.793 | 403.3 | 465.8 | 194.9 | 674.2 | 5.4393 |
| 55 | 1343.7 | 1150.0 | 1253.1 | 11.437 | 1230.5 | 1275.8 | 1014.5 | 1491.8 | -103.1 |
| 56 | 1082.7 | 960.0 | 1018.2 | 11.099 | 996.2 | 1040.2 | 779.6 | 1256.8 | -58.199 |
| 57 | 1440.7 | 1310.0 | 1340.4 | 11.924 | 1316.8 | 1364.1 | 1101.7 | 1579.2 | -30.442 |
| 58 | 418.2 | 480.0 | 420.1 | 15.974 | 388.4 | 451.7 | 180.4 | 659.7 | 59.9312 |
| 59 | 1116.3 | 1010.0 | 1048.4 | 11.058 | 1026.5 | 1070.3 | 809.9 | 1287.0 | -38.443 |
| 60 | 916.1 | 870.0 | 868.2 | 11.655 | 845.2 | 891.3 | 629.5 | 1106.9 | 1.7613 |
| 61 | 1142.3 | 1120.0 | 1071.8 | 11.044 | 1050.0 | 1093.7 | 833.3 | 1310.4 | 48.1541 |
| 62 | 647.4 | 605.0 | 626.4 | 13.605 | 599.4 | 653.3 | 387.3 | 865.5 | -21.376 |
| 63 | 1143 | 1130.0 | 1072.5 | 11.044 | 1050.6 | 1094.3 | 833.9 | 1311.1 | 57.5241 |
| 64 | 1103 | 1085.0 | 1036.5 | 11.071 | 1014.5 | 1058.4 | 797.9 | 1275.1 | 48.5289 |
| 65 | 1245.5 | 1240.0 | 1164.7 | 11.136 | 1142.7 | 1186.8 | 926.1 | 1403.3 | 75.2617 |
| 66 | 638.3 | 555.0 | 618.2 | 13.688 | 591.1 | 645.3 | 379.1 | 857.3 | -63.185 |
| 67 | 1058.7 | 1210.0 | 996.6 | 11.143 | 974.5 | 1018.7 | 758.0 | 1235.2 | 213.4 |
| 68 | 888.02 | 910.0 | 843.0 | 11.804 | 819.6 | 866.3 | 604.2 | 1081.7 | 67.0367 |
| 69 | 1220.7 | 1230.0 | 1142.4 | 11.092 | 1120.4 | 1164.4 | 903.8 | 1381.0 | 87.5847 |
| 70 | 599.8 | 535.0 | 583.5 | 14.054 | 555.7 | 611.4 | 344.3 | 822.7 | -48.531 |
| 71 | 1142.4 | 1115.0 | 1071.9 | 11.044 | 1050.1 | 1093.8 | 833.4 | 1310.5 | 43.0641 |
| 72 | 1218.3 | 1035.0 | 1140.3 | 11.089 | 1118.3 | 1162.2 | 901.7 | 1378.8 | -105.3 |
| 73 | 1763.8 | 1475.0 | 1631.3 | 14.613 | 1602.3 | 1660.2 | 1391.9 | 1870.6 | -156.3 |
| 74 | 481.9 | 575.0 | 477.4 | 15.268 | 447.2 | 507.6 | 237.9 | 716.9 | 97.5936 |
| 75 | 1027.9 | 1120.0 | 968.9 | 11.218 | 946.7 | 991.1 | 730.3 | 1207.5 | 151.1 |
| 76 | 1059.9 | 1145.0 | 997.7 | 11.140 | 975.6 | 1019.7 | 759.1 | 1236.3 | 147.3 |
| 77 | 1027.6 | 1300.0 | 968.6 | 11.219 | 946.4 | 990.8 | 730.0 | 1207.2 | 331.4 |
| 78 | 559.3 | 515.0 | 547.1 | 14.456 | 518.4 | 575.7 | 307.8 | 786.4 | -32.0758 |
| 79 | 1031.6 | 1030.0 | 972.2 | 11.208 | 950.0 | 994.4 | 733.6 | 1210.8 | 57.7974 |
| 80 | 1007.2 | 1075.0 | 950.2 | 11.280 | 927.9 | 972.6 | 711.6 | 1188.9 | 124.8 |
| 81 | 1655.2 | 1415.0 | 1533.5 | 13.558 | 1506.7 | 1560.4 | 1294.4 | 1772.6 | -118.5 |
| 82 | 518.99 | 475.0 | 510.8 | 14.872 | 481.3 | 540.2 | 271.4 | 750.2 | -35.7919 |
| 83 | 1523.2 | 1255.0 | 1414.7 | 12.471 | 1390.0 | 1439.4 | 1175.8 | 1653.6 | -159.7 |
| 84 | 1265.3 | 1115.0 | 1182.6 | 11.180 | 1160.4 | 1204.7 | 944.0 | 1421.2 | -67.5607 |
| 85 | 1274.9 | 1270.0 | 1191.2 | 11.204 | 1169.0 | 1213.4 | 952.6 | 1429.8 | 78.7982 |
| 86 | 907.3 | 535.0 | 860.3 | 11.700 | 837.1 | 883.5 | 621.6 | 1099.0 | -325.3 |
| 87 | 1189.1 | 1155.0 | 1114.0 | 11.056 | 1092.1 | 1135.9 | 875.4 | 1352.6 | 41.0285 |
| 88 | 1376.3 | 1175.0 | 1282.5 | 11.581 | 1259.5 | 1305.4 | 1043.8 | 1521.2 | -107.5 |
| 89 | 1300.9 | 1095.0 | 1214.6 | 11.281 | 1192.3 | 1236.9 | 976.0 | 1453.2 | -119.6 |
| 90 | 463.5 | 400.0 | 460.8 | 15.468 | 430.2 | 491.5 | 221.3 | 700.4 | -60.8442 |
| 91 | 1000.6 | 955.0 | 944.3 | 11.301 | 921.9 | 966.7 | 705.7 | 1182.9 | 10.7012 |
| 92 | 1174.4 | 1040.0 | 1100.7 | 11.047 | 1078.9 | 1122.6 | 862.2 | 1339.3 | -60.7397 |
| 93 | 1056 | 895.0 | 994.2 | 11.149 | 972.1 | 1016.2 | 755.6 | 1232.8 | -99.1655 |
| 94 | 643 | 360.0 | 622.4 | 13.645 | 595.4 | 649.4 | 383.3 | 861.5 | -262.4 |
| 95 | 1531.1 | 1150.0 | 1421.8 | 12.529 | 1397.0 | 1446.6 | 1182.9 | 1660.7 | -271.8 |
| 96 | 1201.3 | 985.0 | 1125.0 | 11.067 | 1103.0 | 1146.9 | 886.4 | 1363.5 | -140.0 |
| 97 | 1072.9 | 1050.0 | 1009.4 | 11.115 | 987.4 | 1031.4 | 770.8 | 1248.0 | 40.6225 |

| Obs | SCALE | Dep Var WAGON | Predict Value | Std Err Predict | Lower 95% Mean | Upper 95% Mean | Lower 95% Predict | Upper 95% Predict | Resid - ual |
|---|---|---|---|---|---|---|---|---|---|
| 98 | 327.85 | 305.0 | 338.7 | 17.027 | 305.0 | 372.5 | 98.7849 | 578.7 | -33.7429 |
| 99 | 917.4 | 1020.0 | 869.4 | 11.649 | 846.3 | 892.5 | 630.7 | 1108.1 | 150.6 |
| 100 | 988.8 | 945.0 | 933.7 | 11.342 | 911.2 | 956.1 | 695.0 | 1172.3 | 11.3226 |
| 101 | 841.2 | 850.0 | 800.8 | 12.083 | 776.9 | 824.8 | 562.0 | 1039.6 | 49.1803 |
| 102 | 375.8 | 365.0 | 381.9 | 16.461 | 349.3 | 414.5 | 142.1 | 621.7 | -16.9037 |
| 103 | 1186.9 | 975.0 | 1112.0 | 11.054 | 1090.1 | 1133.9 | 873.4 | 1350.6 | -137.0 |
| 104 | 1171 | 1025.0 | 1097.7 | 11.046 | 1075.8 | 1119.6 | 859.1 | 1336.3 | -72.6793 |
| 105 | 1352 | 1325.0 | 1260.6 | 11.472 | 1237.9 | 1283.3 | 1021.9 | 1499.3 | 64.3989 |
| 106 | 574.5 | 460.0 | 560.8 | 14.303 | 532.4 | 589.1 | 321.5 | 800.0 | -100.8 |
| 107 | 1086 | 1085.0 | 1021.2 | 11.094 | 999.2 | 1043.1 | 782.6 | 1259.8 | 63.8309 |
| 108 | 1103 | 1065.0 | 1036.5 | 11.071 | 1014.5 | 1058.4 | 797.9 | 1275.1 | 28.5289 |
| 109 | 1305.6 | 1140.0 | 1218.8 | 11.296 | 1196.5 | 1241.2 | 980.2 | 1457.5 | -78.8355 |
| 110 | 576 | 495.0 | 562.1 | 14.288 | 533.8 | 590.4 | 322.9 | 801.4 | -67.1078 |
| 111 | 1104.3 | 905.0 | 1037.6 | 11.070 | 1015.7 | 1059.6 | 799.1 | 1276.2 | -132.6 |
| 112 | 1196.1 | 1185.0 | 1120.3 | 11.062 | 1098.4 | 1142.2 | 881.7 | 1358.9 | 64.7277 |
| 113 | 4050.6 | 3430.0 | 3689.7 | 46.775 | 3597.0 | 3782.3 | 3434.7 | 3944.7 | -259.7 |
| 114 | 3939.4 | 3425.0 | 3589.6 | 45.081 | 3500.3 | 3678.9 | 3335.8 | 3843.4 | -164.6 |
| 115 | 3478.5 | 3630.0 | 3174.7 | 38.111 | 3099.2 | 3250.2 | 2925.4 | 3424.0 | 455.3 |
| 116 | 3761.6 | 3540.0 | 3429.5 | 42.382 | 3345.6 | 3513.5 | 3177.6 | 3681.5 | 110.5 |
| 117 | 3871.6 | 3610.0 | 3528.5 | 44.051 | 3441.3 | 3615.8 | 3275.5 | 3781.6 | 81.4559 |
| 118 | 3431.6 | 3245.0 | 3132.5 | 37.407 | 3058.4 | 3206.6 | 2883.6 | 3381.4 | 112.5 |

Sum of Residuals 0
Sum of Squared Residuals 1669012.8012
Predicted Resid SS (Press) 1791709.4967

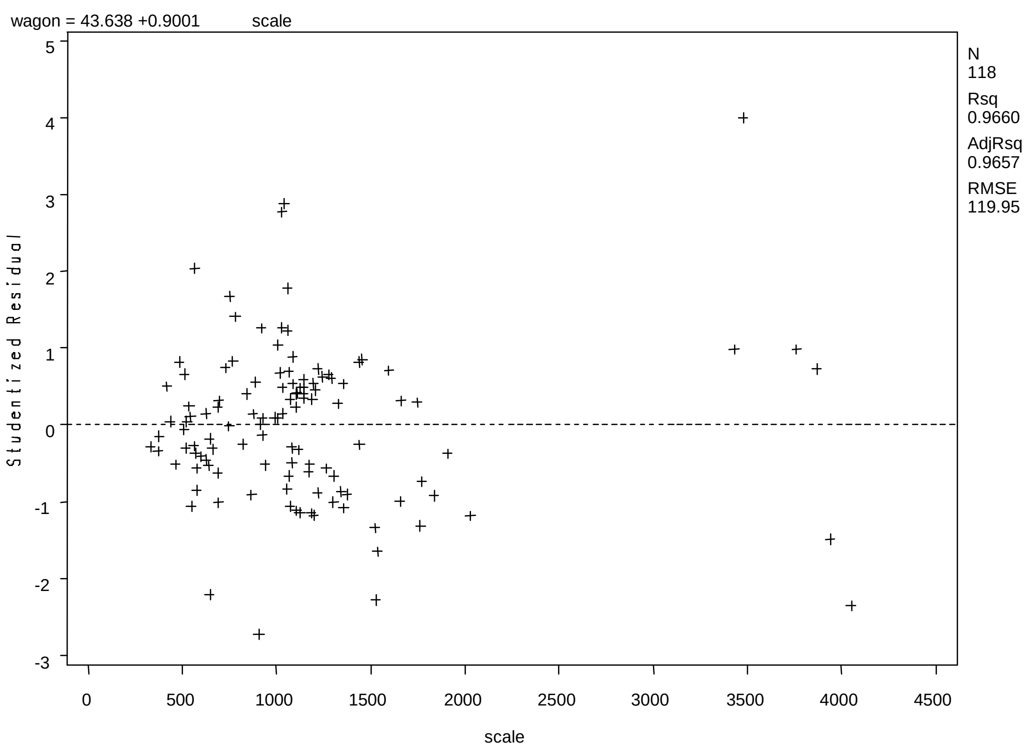



Figure C1. Studentized Residuals Plot

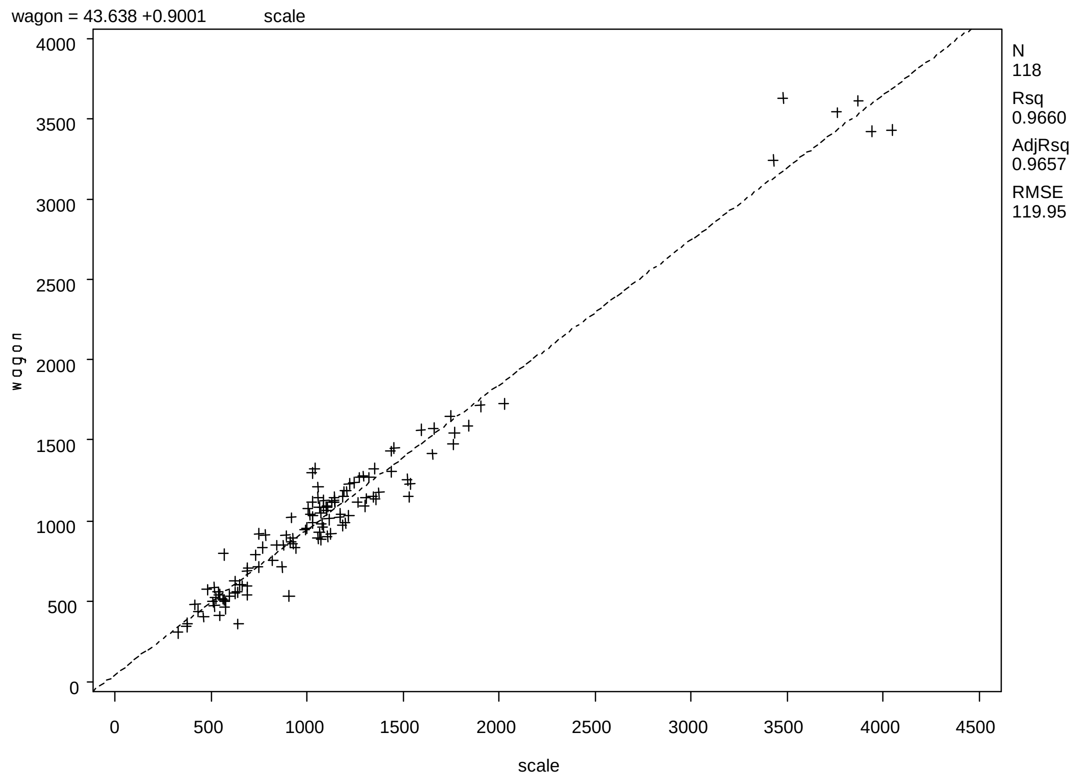



Figure C2. Wagon vs. Scale Regression Plot

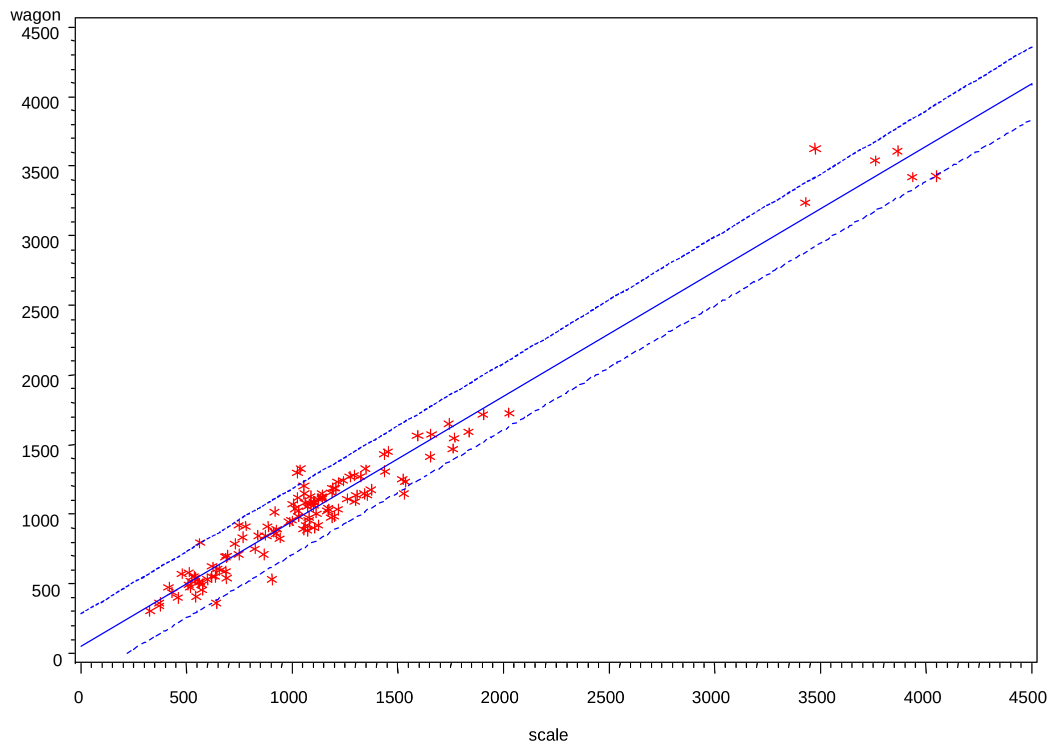



Figure C3. Wagon vs. Scale with 95 % Prediction Intervals

Appendix C2: General Linear Model – ANOVA Analysis

*Caryn E. Benjamin*
*2000-Field Test Data Analysis*
*General Linear Model for testing the effects of Variety, Age, Speed, and Section Length on the scale readings*

***SAS Program***

```
dm"log;clear;output;clear";

data one;
        infile 'A:RegData.dat';
        input scale wagon var mat sp len;
run;

proc glm data=one;
        class var mat sp len;
        model scale=wagon var mat sp len/clm cli solution;
        id wagon;
run;
quit;
```

***RegData.dat***

| Scale | WW | Variety | Age | Speed | Section Length |
|---|---|---|---|---|---|
| 1455 | 1455 | 1 | 0 | 0 | 150 |
| 543 | 545 | 1 | 0 | 1 | 50 |
| 1356 | 1135 | 1 | 0 | 1 | 100 |
| 928 | 890 | 1 | 0 | 0 | 75 |
| 1536 | 1230 | 1 | 0 | 1 | 150 |
| 622 | 550 | 1 | 0 | 1 | 50 |
| 1031 | 990 | 1 | 0 | 1 | 100 |
| 687 | 690 | 1 | 0 | 1 | 75 |
| 1839 | 1590 | 1 | 0 | 1 | 150 |
| 536 | 555 | 1 | 0 | 1 | 50 |
| 132 | 1270 | 1 | 0 | 1 | 100 |
| 1066 | 925 | 1 | 0 | 1 | 75 |
| 1660 | 1575 | 1 | 0 | 1 | 150 |
| 566 | 510 | 1 | 0 | 1 | 50 |
| 1065 | 1085 | 1 | 0 | 1 | 100 |
| 925 | 860 | 1 | 0 | 1 | 75 |
| 1596 | 1565 | 1 | 0 | 1 | 150 |
| 691 | 545 | 1 | 0 | 1 | 50 |
| 1107 | 1090 | 1 | 0 | 1 | 100 |
| 1125 | 920 | 1 | 0 | 0 | 75 |
| 2029 | 1730 | 1 | 0 | 1 | 150 |
| 514 | 585 | 1 | 0 | 1 | 50 |
| 1089 | 1130 | 1 | 0 | 1 | 100 |
| 942 | 830 | 1 | 0 | 0 | 75 |
| 1745 | 1650 | 1 | 0 | 1 | 150 |
| 689 | 590 | 1 | 0 | 0 | 50 |
| 1207 | 1185 | 1 | 0 | 1 | 100 |
| 781 | 915 | 1 | 0 | 1 | 75 |
| 1771 | 1550 | 1 | 0 | 1 | 150 |
| 626 | 625 | 1 | 0 | 1 | 50 |
| 1126 | 1115 | 1 | 0 | 1 | 100 |
| 877 | 850 | 1 | 0 | 1 | 75 |
| 1437 | 1435 | 1 | 0 | 1 | 150 |
| 523 | 520 | 1 | 0 | 1 | 50 |

| Scale | WW | Variety | Age | Speed | Section Length |
|---|---|---|---|---|---|
| 1079 | 980 | 1 | 0 | 1 | 100 |
| 693 | 705 | 1 | 0 | 1 | 75 |
| 1906 | 1715 | 1 | 0 | 1 | 150 |
| 659 | 600 | 1 | 0 | 0 | 50 |
| 1016 | 1040 | 1 | 0 | 1 | 100 |
| 823 | 755 | 1 | 0 | 0 | 75 |
| 1074.5 | 885 | 1 | 2 | 0 | 150 |
| 373.9 | 340 | 1 | 2 | 0 | 50 |
| 730.8 | 790 | 1 | 2 | 0 | 100 |
| 866.4 | 715 | 1 | 2 | 0 | 75 |
| 1144.2 | 1145 | 1 | 2 | 1 | 150 |
| 546.6 | 410 | 1 | 2 | 0 | 50 |
| 565.2 | 795 | 1 | 2 | 0 | 100 |
| 748 | 715 | 1 | 2 | 0 | 75 |
| 1040.6 | 1325 | 1 | 2 | 0 | 150 |
| 508.8 | 495 | 1 | 2 | 0 | 50 |
| 750.8 | 920 | 1 | 2 | 0 | 100 |
| 769 | 835 | 1 | 2 | 0 | 75 |
| 1292.6 | 1280 | 1 | 2 | 1 | 150 |
| 434.3 | 440 | 1 | 2 | 0 | 50 |
| 1343.7 | 1150 | 1 | 2 | 0 | 100 |
| 1082.7 | 960 | 1 | 2 | 0 | 75 |
| 1440.7 | 1310 | 1 | 2 | 1 | 150 |
| 418.2 | 480 | 1 | 2 | 0 | 50 |
| 1116.3 | 1010 | 1 | 2 | 0 | 100 |
| 916.1 | 870 | 1 | 2 | 0 | 75 |
| 1142.3 | 1120 | 1 | 2 | 1 | 150 |
| 647.4 | 605 | 1 | 2 | 0 | 50 |
| 1143 | 1130 | 1 | 2 | 0 | 100 |
| 1103 | 1085 | 1 | 2 | 0 | 75 |
| 1245.5 | 1240 | 1 | 2 | 1 | 150 |
| 638.3 | 555 | 1 | 2 | 0 | 50 |
| 1058.7 | 1210 | 1 | 2 | 0 | 100 |
| 888.02 | 910 | 1 | 2 | 0 | 75 |
| 1220.7 | 1230 | 1 | 2 | 1 | 150 |
| 599.8 | 535 | 1 | 2 | 0 | 50 |
| 1142.4 | 1115 | 1 | 2 | 0 | 100 |
| 1218.3 | 1035 | 1 | 2 | 0 | 75 |
| 1763.8 | 1475 | 1 | 2 | 1 | 150 |
| 481.9 | 575 | 1 | 2 | 0 | 50 |
| 1027.9 | 1120 | 1 | 2 | 0 | 100 |
| 1059.9 | 1145 | 1 | 2 | 0 | 75 |
| 1027.6 | 1300 | 1 | 2 | 1 | 150 |
| 559.3 | 515 | 1 | 2 | 0 | 50 |
| 1031.6 | 1030 | 1 | 2 | 0 | 100 |
| 1007.2 | 1075 | 1 | 2 | 0 | 75 |
| 1655.2 | 1415 | 1 | 2 | 1 | 150 |
| 518.99 | 475 | 1 | 2 | 0 | 50 |
| 1523.2 | 1255 | 1 | 2 | 0 | 100 |
| 1265.3 | 1115 | 1 | 2 | 0 | 75 |
| 1274.9 | 1270 | 1 | 2 | 1 | 150 |
| 907.3 | 535 | 1 | 2 | 0 | 50 |
| 1189.1 | 1155 | 1 | 2 | 0 | 100 |
| 1376.3 | 1175 | 1 | 2 | 0 | 75 |
| 1300.9 | 1095 | 2 | 2 | 0 | 150 |
| 463.5 | 400 | 2 | 2 | 0 | 50 |

| Scale | WW | Variety | Age | Speed | Section Length |
|---|---|---|---|---|---|
| 1000.6 | 955 | 2 | 2 | 0 | 100 |
| 1174.4 | 1040 | 2 | 2 | 0 | 75 |
| 1056 | 895 | 2 | 2 | 1 | 150 |
| 643 | 360 | 2 | 2 | 0 | 50 |
| 1531.1 | 1150 | 2 | 2 | 0 | 100 |
| 1201.3 | 985 | 2 | 2 | 0 | 75 |
| 1072.9 | 1050 | 2 | 2 | 1 | 150 |
| 327.85 | 305 | 2 | 2 | 0 | 50 |
| 917.4 | 1020 | 2 | 2 | 0 | 100 |
| 988.8 | 945 | 2 | 2 | 0 | 75 |
| 841.2 | 850 | 2 | 2 | 1 | 150 |
| 375.8 | 365 | 2 | 2 | 0 | 50 |
| 1186.9 | 975 | 2 | 2 | 1 | 100 |
| 1171 | 1025 | 2 | 2 | 0 | 75 |
| 1352 | 1325 | 2 | 2 | 1 | 150 |
| 574.5 | 460 | 2 | 2 | 0 | 50 |
| 1086 | 1085 | 2 | 2 | 1 | 100 |
| 1103 | 1065 | 2 | 2 | 0 | 75 |
| 1305.6 | 1140 | 2 | 2 | 1 | 150 |
| 576 | 495 | 2 | 2 | 0 | 50 |
| 1104.3 | 905 | 2 | 2 | 1 | 100 |
| 1196.1 | 1185 | 2 | 2 | 0 | 75 |
| 4050.6 | 3430 | 2 | 2 | 1 | 375 |
| 3939.4 | 3425 | 2 | 2 | 1 | 375 |
| 3478.5 | 3630 | 2 | 2 | 1 | 375 |
| 3761.6 | 3540 | 2 | 2 | 1 | 375 |
| 3871.6 | 3610 | 2 | 2 | 1 | 375 |
| 3431.6 | 3245 | 2 | 2 | 1 | 375 |

***SAS General Linear Model Output** *

The SAS System **15**:**11** Wednesday, April **4**, **2001**

General Linear Models Procedure

Class Level Information

| Class | Levels | Values |
|---|---|---|
| VAR | **2** | **1 2** |
| MAT | **2** | **0 2** |
| SP | **2** | **0 1** |
| LEN | **5** | **50 75 100 150 375** |

Number of observations in **data** set = **118**

General Linear Models Procedure

Dependent Variable: SCALE

| Source | DF | Sum of Squares | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| Model | **8** | **56605454.06242230** | **7075681.75780279** | **420.78** | **0.0001** |
| Error | **109** | **1832899.99178441** | **16815.59625490** | | |
| Corrected Total | **117** | **58438354.05420670** | | | |

| R-Square | C.V. | Root MSE | SCALE Mean |
|---|---|---|---|
| **0.968635** | **11.23842** | **129.67496387** | **1153.85389831** |

| Source | DF | Type I SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| WAGON | **1** | **56448536.26647850** | **56448536.26647850** | **3356.92** | **0.0001** |
| VAR | **1** | **80571.39162756** | **80571.39162756** | **4.79** | **0.0307** |
| MAT | **1** | **19714.14466759** | **19714.14466759** | **1.17** | **0.2813** |
| SP | **1** | **7211.04989682** | **7211.04989682** | **0.43** | **0.5139** |
| LEN | **4** | **49421.20975185** | **12355.30243796** | **0.73** | **0.5702** |

| Source | DF | Type III SS | Mean Square | F Value | Pr > F |
|---|---|---|---|---|---|
| WAGON | **1** | **3158123.71026145** | **3158123.71026145** | **187.81** | **0.0001** |
| VAR | **1** | **97626.83495529** | **97626.83495529** | **5.81** | **0.0176** |
| MAT | **1** | **18210.09746852** | **18210.09746852** | **1.08** | **0.3003** |
| SP | **1** | **4836.36923346** | **4836.36923346** | **0.29** | **0.5928** |
| LEN | **4** | **49421.20975185** | **12355.30243796** | **0.73** | **0.5702** |

| Parameter | | Estimate | | T for H0: Parameter=**0** | Pr > \|T\| | Std Error of Estimate |
|---|---|---|---|---|---|---|
| INTERCEPT | | **-131.0829313** | B | **-0.45** | **0.6505** | **288.5044945** |
| WAGON | | **1.1168485** | | **13.70** | **0.0001** | **0.0814959** |
| VAR | **1** | **-79.7053464** | B | **-2.41** | **0.0176** | **33.0795036** |
| | **2** | **0.0000000** | B | **.** | **.** | **.** |
| MAT | **0** | **38.6457907** | B | **1.04** | **0.3003** | **37.1366050** |
| | **2** | **0.0000000** | B | **.** | **.** | **.** |
| SP | **0** | **20.2165283** | B | **0.54** | **0.5928** | **37.6966701** |
| | **1** | **0.0000000** | B | **.** | **.** | **.** |
| LEN | **50** | **164.1113239** | B | **0.62** | **0.5340** | **263.0631260** |
| | **75** | **117.5239056** | B | **0.51** | **0.6098** | **229.6363368** |
| | **100** | **82.6148483** | B | **0.38** | **0.7045** | **217.2869496** |
| | **150** | **108.2653961** | B | **0.56** | **0.5792** | **194.6320170** |
| | **375** | **0.0000000** | B | **.** | **.** | **.** |

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations. Estimates followed by the letter 'B' are biased, and are not unique estimators of the parameters.

| Obser- vation | Observed Value | Predicted Value | Residual | Lower 95% CL for Mean | Upper 95% CL for Mean |
|---|---|---|---|---|---|
| 1 | 1455 | 1581.35406825 | -126.35406825 | 1473.38477875 | 689.32335776 |
| 2 | 543 | 600.65129318 | -57.65129318 | 536.82765535 | 664.47493101 |
| 3 | 1356 | 1178.09545825 | 177.90454175 | 1118.21064597 | 1237.98027054 |
| 4 | 928 | 959.59315064 | -31.59315064 | 883.33020322 | 1035.85609806 |
| 5 | 1536 | 1309.84661765 | 226.15338235 | 1243.81708568 | 1375.87614962 |
| 6 | 622 | 606.23553590 | 15.76446410 | 542.38600029 | 670.08507151 |
| 7 | 1031 | 1016.15241945 | 14.84758055 | 953.25528409 | 1079.04955481 |
| 8 | 687 | 716.00691362 | -29.00691362 | 636.13123365 | 795.88259359 |
| 9 | 1839 | 1711.91209330 | 127.08790670 | 1642.92980318 | 1780.89438341 |
| 10 | 536 | 611.81977861 | -75.81977861 | 547.93414548 | 675.70541175 |
| 11 | 1325 | 1328.87001162 | -3.87001162 | 1263.84678366 | 1393.89323958 |
| 12 | 1066 | 978.46632133 | 87.53367867 | 912.01553400 | 1044.91710866 |
| 13 | 1660 | 1695.15936514 | -35.15936514 | 1627.28497542 | 1763.03375487 |
| 14 | 566 | 561.56159416 | 4.43840584 | 497.63322175 | 625.48996657 |
| 15 | 1065 | 1122.25303108 | -57.25303108 | 1062.33806255 | 1182.16799961 |
| 16 | 925 | 905.87116601 | 19.12883399 | 837.52814703 | 974.21418499 |
| 17 | 1596 | 1683.99087971 | -87.99087971 | 1616.81668257 | 1751.16507685 |
| 18 | 691 | 600.65129318 | 90.34870682 | 536.82765535 | 664.47493101 |
| 19 | 1107 | 1127.83727380 | -20.83727380 | 1067.97432984 | 1187.70021775 |
| 20 | 1125 | 993.09860694 | 131.90139306 | 918.15487233 | 1068.04234156 |
| 21 | 2029 | 1868.27088938 | 160.72911062 | 1786.17429689 | 1950.36748187 |
| 22 | 514 | 645.32523492 | -131.32523492 | 581.01012336 | 709.64034648 |
| 23 | 1089 | 1172.51121553 | -83.51121553 | 1112.67241634 | 1232.35001473 |
| 24 | 942 | 892.58223803 | 49.41776197 | 812.85854203 | 972.30593403 |
| 25 | 1745 | 1778.92300590 | -33.92300590 | 1704.87941669 | 1852.96659512 |
| 26 | 689 | 671.12600596 | 17.87399404 | 595.14166801 | 747.11034391 |
| 27 | 1207 | 1233.93788543 | -26.93788543 | 1173.00328747 | 1294.87248339 |
| 28 | 781 | 967.29783590 | -186.29783590 | 900.66002295 | 1033.93564885 |
| 29 | 1771 | 1667.23815156 | 103.76184844 | 1601.05419374 | 1733.42210937 |
| 30 | 626 | 689.99917666 | -63.99917666 | 624.55533347 | 755.44301984 |
| 31 | 1126 | 1155.75848738 | -29.75848738 | 1095.99242541 | 1215.52454935 |
| 32 | 877 | 894.70268057 | -17.70268057 | 825.93077138 | 963.47458977 |
| 33 | 1437 | 1538.80056906 | -101.80056906 | 1477.49869054 | 1600.10244758 |
| 34 | 523 | 572.73007959 | -49.73007959 | 508.88267113 | 636.57748805 |
| 35 | 1079 | 1004.98393401 | 74.01606599 | 941.56472732 | 1068.40314071 |
| 36 | 693 | 732.75964177 | -39.75964177 | 654.2189467 | 811.30033679 |
| 37 | 1906 | 1851.51816123 | 54.48183877 | 1771.02809176 | 1932.00823070 |
| 38 | 659 | 682.29449140 | -23.29449140 | 606.32578711 | 758.26319569 |
| 39 | 1016 | 1071.99484662 | -55.99484662 | 1011.12952605 | 1132.86016720 |
| 40 | 823 | 808.81859727 | 14.18140273 | 723.40892877 | 894.22826577 |
| 41 | 1074.5 | 906.10460777 | 168.39539223 | 802.68137341 | 1009.52784214 |
| 42 | 373.9 | 353.26807939 | 20.63192061 | 292.05805390 | 414.47810488 |
| 43 | 730.8 | 774.35344838 | -43.55344838 | 700.79890176 | 847.90799500 |
| 44 | 866.4 | 725.49886483 | 140.90113517 | 660.02346128 | 790.97426838 |
| 45 | 144.2 | 1176.26870075 | -32.06870075 | 1109.53959193 | 1242.99780957 |
| 46 | 546.6 | 431.44747743 | 115.15252257 | 373.79472757 | 489.10022730 |
| 47 | 565.2 | 779.93769110 | -214.73769110 | 706.87215926 | 853.00322293 |
| 48 | 748 | 725.49886483 | 22.50113517 | 660.02346128 | 790.97426838 |

| Obser-vation | Observed Value | Predicted Value | Residual | Lower 95% CL for Mean | Upper 95% CL for Mean |
|---|---|---|---|---|---|
| 49 | 1040.6 | 1397.51796690 | -356.91796690 | 1325.45658378 | 1469.57935002 |
| 50 | 508.8 | 526.37960363 | -17.57960363 | 470.21792315 | 582.54128411 |
| 51 | 750.8 | 919.54375903 | -168.74375903 | 856.53550006 | 982.55201800 |
| 52 | 769 | 859.52069005 | -90.52069005 | 801.58689350 | 917.45448659 |
| 53 | 1292.6 | 1327.04325412 | -34.44325412 | 1263.97677485 | 1390.10973338 |
| 54 | 434.3 | 464.95293374 | -30.65293374 | 408.19999519 | 521.70587229 |
| 55 | 1343.7 | 1176.41892403 | 167.28107597 | 1116.56789270 | 1236.26995535 |
| 56 | 1082.7 | 999.12675798 | 83.57324202 | 942.68359311 | 1055.56992285 |
| 57 | 1440.7 | 1360.54871042 | 80.15128958 | 1297.29619577 | 1423.80122507 |
| 58 | 418.2 | 509.62687548 | -91.42687548 | 453.44246108 | 565.81128987 |
| 59 | 1116.3 | 1020.06012794 | 96.23987206 | 960.98789370 | 1079.13236218 |
| 60 | 916.1 | 898.61038907 | 17.48961093 | 841.80893883 | 955.41183931 |
| 61 | 1142.3 | 1148.34748716 | -6.04748716 | 1080.19202156 | 1216.50295277 |
| 62 | 647.4 | 649.23294341 | -1.83294341 | 590.12174039 | 708.34414643 |
| 63 | 1143 | 1154.08195316 | -11.08195316 | 1094.86793216 | 1213.29597415 |
| 64 | 1103 | 1138.73282591 | -35.73282591 | 1076.84072684 | 1200.62492498 |
| 65 | 1245.5 | 1282.36931238 | -36.86931238 | 1218.97295469 | 1345.76567007 |
| 66 | 638.3 | 593.39051624 | 44.90948376 | 536.28254338 | 650.49848909 |
| 67 | 1058.7 | 1243.42983664 | -184.72983664 | 1180.70095760 | 1306.15871567 |
| 68 | 888.02 | 943.28433081 | -55.26433081 | 887.10432519 | 999.46433642 |
| 69 | 1220.7 | 1271.20082694 | -50.50082694 | 1207.61960150 | 1334.78205238 |
| 70 | 599.8 | 571.05354537 | 28.74645463 | 514.44329651 | 627.66379422 |
| 71 | 1142.4 | 1137.32922501 | 5.07077499 | 1078.48100509 | 1196.17744492 |
| 72 | 1218.3 | 1082.89039874 | 135.40960126 | 1023.94231902 | 1141.83847845 |
| 73 | 1763.8 | 1544.82872009 | 218.97127991 | 1474.33363345 | 1615.32380674 |
| 74 | 481.9 | 615.72748711 | -133.82748711 | 557.94520259 | 673.50977162 |
| 75 | 1027.9 | 1142.91346772 | -115.01346772 | 1083.95412343 | 1201.87281202 |
| 76 | 1059.9 | 1205.74373852 | -145.84373852 | 1139.18752755 | 1272.29994949 |
| 77 | 1027.6 | 1349.38022499 | -321.78022499 | 1286.23096170 | 1412.52948828 |
| 78 | 559.3 | 548.71657450 | 10.58342550 | 492.42277787 | 605.01037113 |
| 79 | 1031.6 | 1042.39709881 | -10.79709881 | 983.74434767 | 1101.04984995 |
| 80 | 1007.2 | 1127.56434048 | -120.36434048 | 1066.33489506 | 1188.79378590 |
| 81 | 1655.2 | 1477.81780749 | 177.38219251 | 1411.08739670 | 1544.54821827 |
| 82 | 518.99 | 504.04263276 | 14.94736724 | 447.82743267 | 560.25783285 |
| 83 | 1523.2 | 1293.68802109 | 229.51197891 | 1227.94032453 | 1359.43571765 |
| 84 | 1265.3 | 1172.23828222 | 93.06171778 | 1108.15474239 | 1236.32182205 |
| 85 | 1274.9 | 1315.87476868 | -40.97476868 | 1252.78765973 | 1378.96187763 |
| 86 | 907.3 | 571.05354537 | 336.24645463 | 514.44329651 | 627.66379422 |
| 87 | 1189.1 | 1182.00316675 | 7.09683325 | 1121.96677322 | 1242.03956027 |
| 88 | 1376.3 | 1239.24919483 | 137.05080517 | 1169.96918796 | 1308.52920169 |
| 89 | 1300.9 | 1220.34814827 | 80.55185173 | 1128.42987709 | 1312.26641945 |
| 90 | 463.5 | 499.98433837 | -36.48433837 | 431.44120692 | 568.52746981 |
| 91 | 1000.6 | 1038.33880442 | -37.73880442 | 965.93141795 | 1110.74619088 |
| 92 | 1174.4 | 1168.17998782 | 6.22001218 | 1095.02626017 | 1241.33371547 |
| 93 | 1056 | 976.76191125 | 79.23808875 | 888.93395107 | 1064.58987143 |
| 94 | 643 | 455.31039663 | 187.68960337 | 385.95217768 | 524.66861557 |
| 95 | 1531.1 | 1256.12427039 | 274.97572961 | 1180.81778159 | 1331.43075920 |
| 96 | 1201.3 | 1106.75331793 | 94.54668207 | 1036.51704853 | 1176.98958733 |
| 97 | 1072.9 | 1149.87343549 | -76.97343549 | 1074.46030232 | 1225.28656865 |
| 98 | 327.85 | 393.88372674 | -66.03372674 | 322.45941610 | 465.30803737 |
| 99 | 917.4 | 1110.93395974 | -193.53395974 | 1039.06519232 | 1182.80272716 |
| 100 | 988.8 | 1062.07937619 | -73.27937619 | 993.31870240 | 1130.84004999 |
| 101 | 841.2 | 926.50372679 | -85.30372679 | 834.10823896 | 1018.89921463 |
| 102 | 375.8 | 460.89463934 | -85.09463934 | 391.67075130 | 530.11852738 |

| Obser-vation | Observed Value | Predicted Value | Residual | Lower 95% CL for Mean | Upper 95% CL for Mean |
|---|---|---|---|---|---|
| 103 | 1186.9 | 1040.45924696 | 146.44075304 | 957.32270984 | 1123.59578408 |
| 104 | 1171 | 1151.42725967 | 19.57274033 | 1079.16576907 | 1223.68875028 |
| 105 | 1352 | 1457.00678494 | -105.00678494 | 1385.05806283 | 1528.95550705 |
| 106 | 574.5 | 566.99525097 | 7.50474903 | 498.54019268 | 635.45030927 |
| 107 | 1086 | 1163.31258674 | -77.31258674 | 1077.31480181 | 1249.31037168 |
| 108 | 1103 | 1196.10120141 | -93.10120141 | 1121.30949922 | 1270.89290360 |
| 109 | 1305.6 | 1250.38980440 | 55.21019560 | 1179.07590993 | 1321.70369887 |
| 110 | 576 | 606.08494999 | -30.08494999 | 537.05014737 | 675.11975262 |
| 111 | 1104.3 | 962.27984892 | 142.02015108 | 879.01850150 | 1045.54119633 |
| 112 | 1196.1 | 1330.12302663 | -134.02302663 | 1245.20575494 | 1415.04029832 |
| 113 | 4050.6 | 3699.70757283 | 350.89242717 | 3594.47268878 | 3804.94245687 |
| 114 | 3939.4 | 3694.12333011 | 245.27666989 | 3588.82338816 | 3799.42327206 |
| 115 | 3478.5 | 3923.07728152 | -444.57728152 | 3815.39176898 | 4030.76279406 |
| 116 | 3761.6 | 3822.56091261 | -60.96091261 | 3717.18976284 | 3927.93206237 |
| 117 | 3871.6 | 3900.74031065 | -29.14031065 | 3793.73531661 | 4007.74530469 |
| 118 | 3431.6 | 3493.09059228 | -61.49059228 | 3381.51126391 | 3604.66992066 |

| | |
|---|---|
| Sum of Residuals | 0.00000000 |
| Sum of Squared Residuals | 1832899.99178435 |
| Sum of Squared Residuals - Error SS | -0.00000006 |
| Press Statistic | 2250716.91086564 |
| First Order Autocorrelation | 0.03250469 |
| Durbin-Watson D | 1.92421729 |

# APPENDIX D:  SCALE DRAWINGS

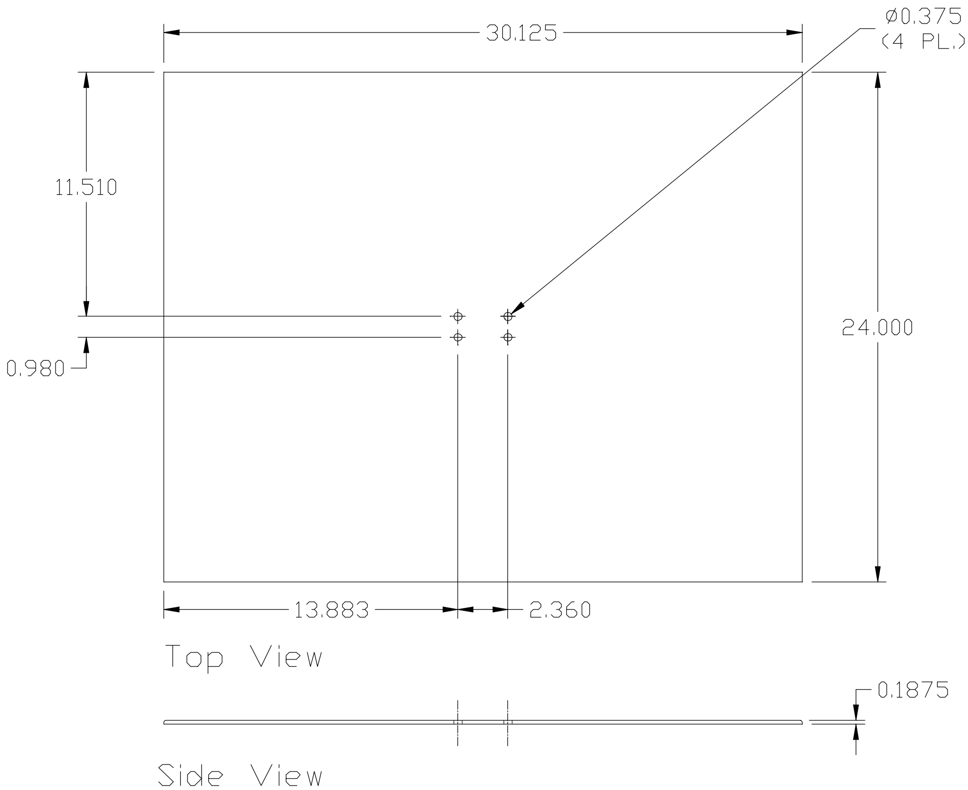



Figure D1. 1999-Weigh Plate Schematic

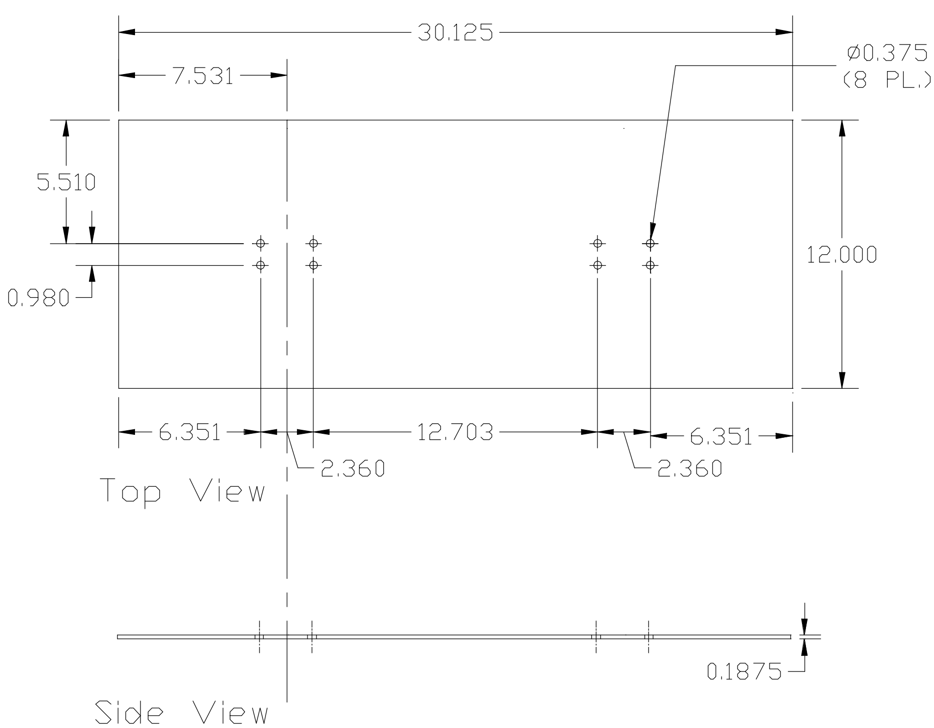



Figure D2. 2000-Weigh Plate Schematic

Note: all dimensions are in inches.

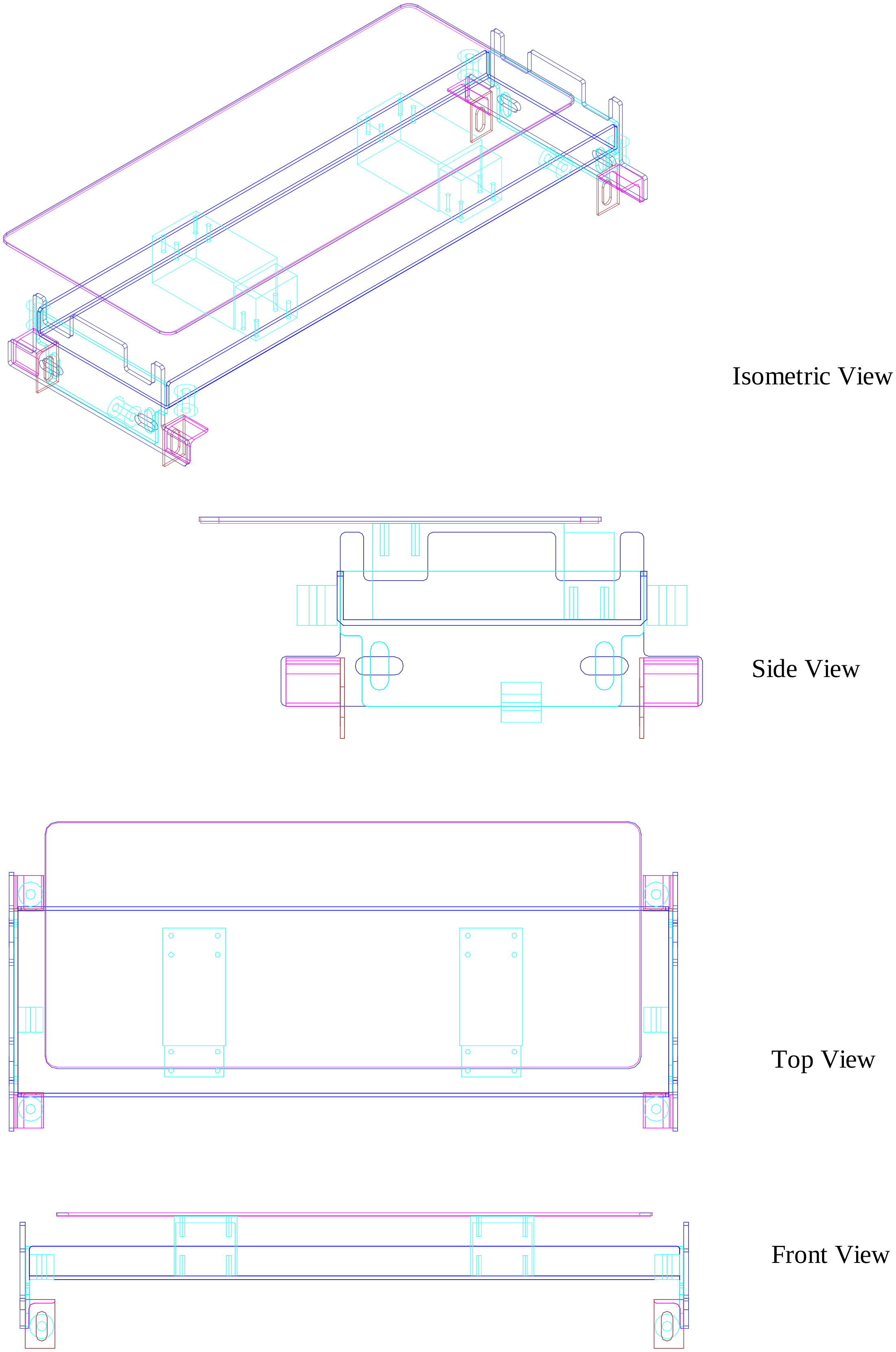



Figure D3. Scale Schematic

# APPENDIX E: PROJECT PHOTOGRAPHS

Figure E1. Sugar Cane Harvesting

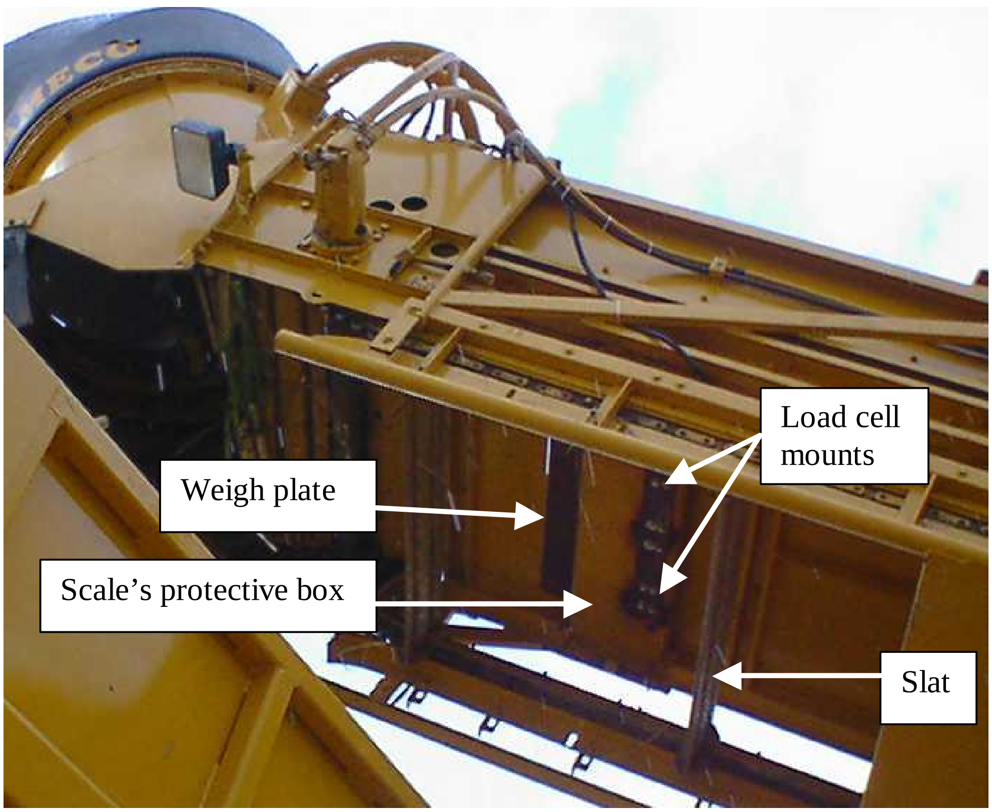



Figure E2. Underside of 2000-Scale

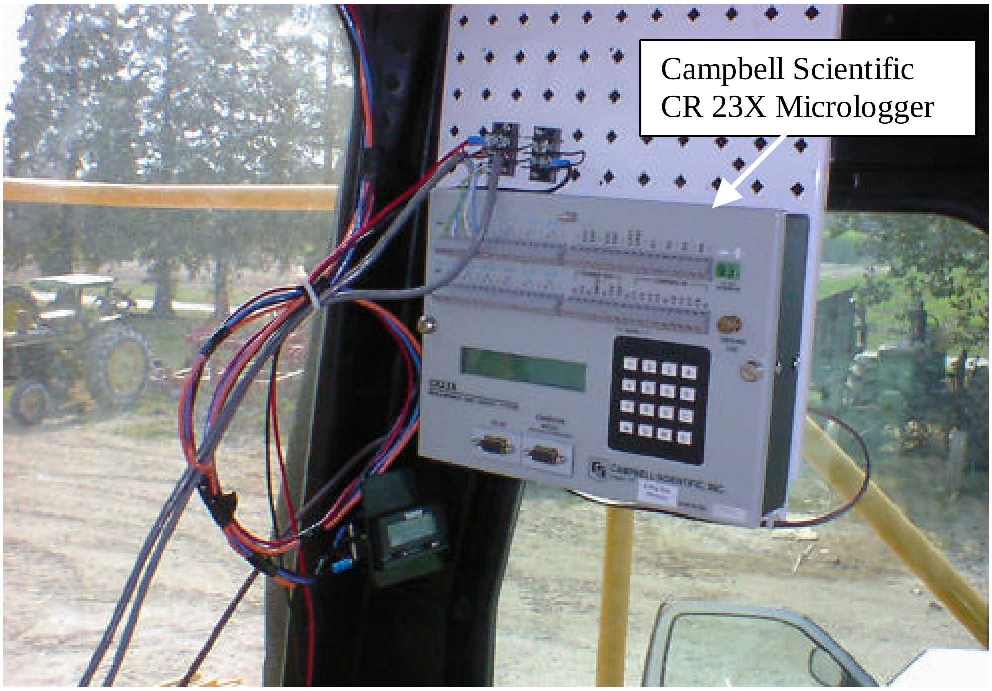



Figure E3. Data-logger inside the Harvester's Cab

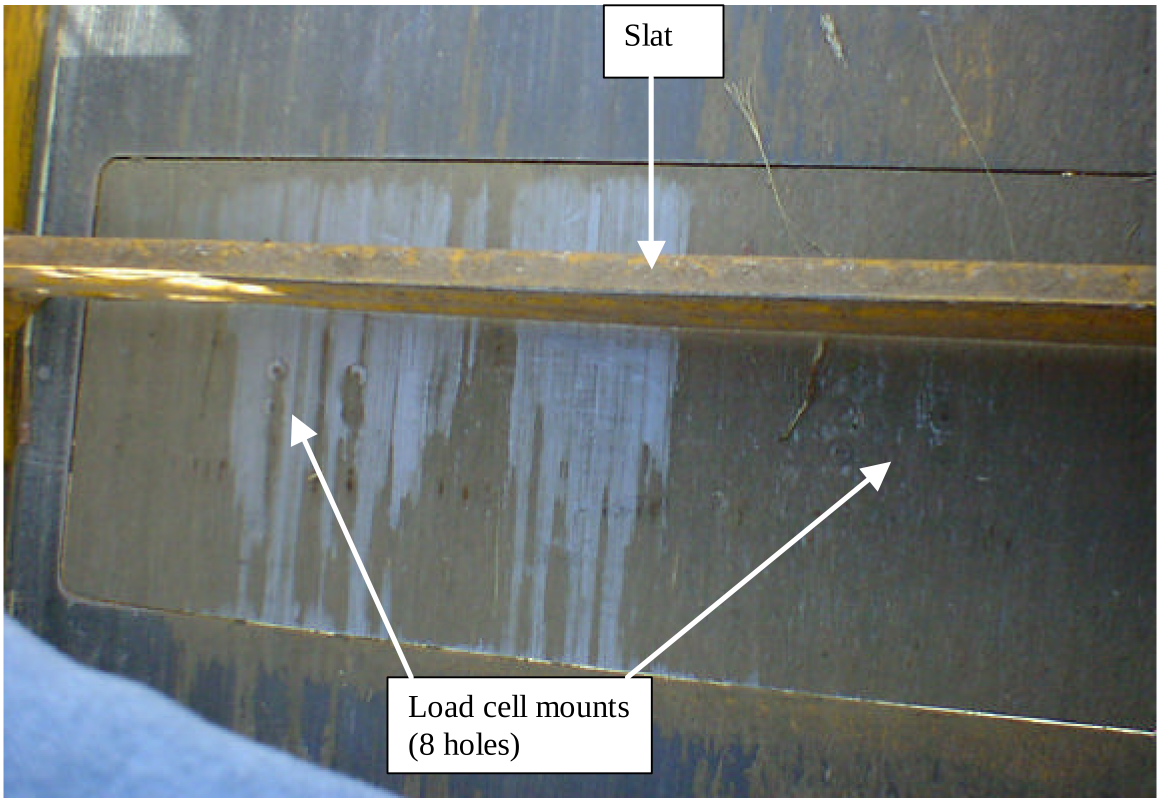



Figure E4. 2000-Scale in the Elevator's Floor

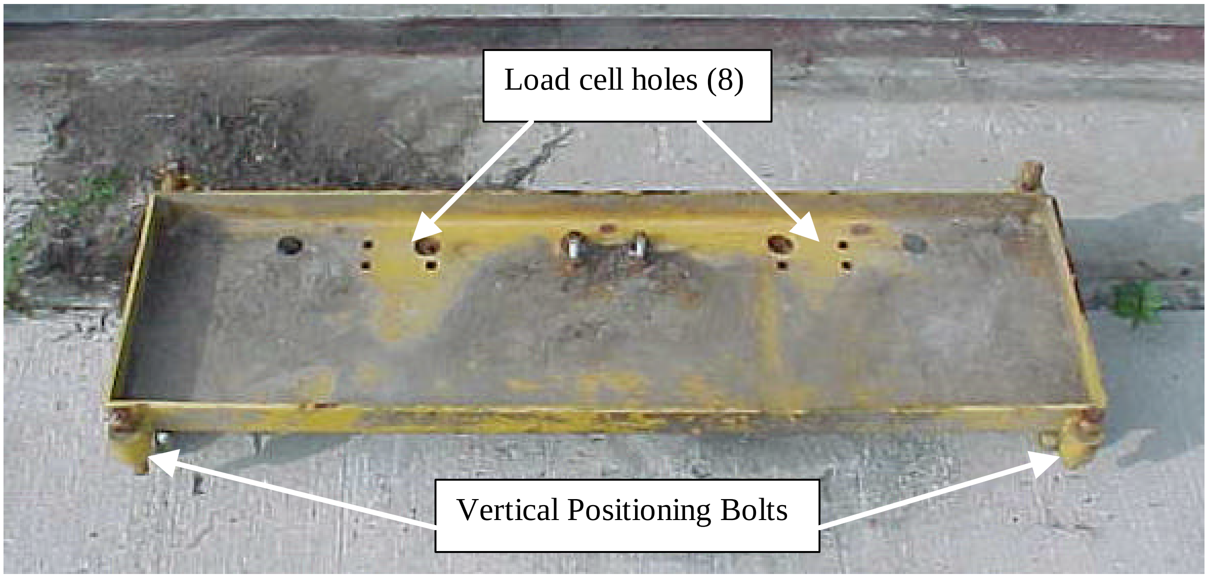


Figure E5. Load Cell Protective Box

## VITA

Caryn Elizabeth Benjamin was born in Baton Rouge, Louisiana, in 1975. She graduated from Edward Douglas White Catholic High School in Thibodaux in 1994. She attended Louisiana State University (LSU) in Baton Rouge, Louisiana, where she received a Bachelor of Science degree in biological engineering in 1998. During her undergraduate career she worked for the Department of Biological & Agriculture Engineering (BAE) as a Teaching Assistant for the Introductory Biological Engineering class, BAE 1250 – AutoCAD. After receiving her bachelor degree she accepted a graduate assistantship with the Department of BAE. Eight months later, she accepted a full time position as a Teaching Associate with the Department of BAE. During her employment with LSU she continued to do research and take classes to fulfill the BAE's master's degree program. Caryn completed her class work and took a job with Engineering Services of Center for Environmental Sciences-Office of Public Health. Caryn received her Master of Science Biological and Agriculture Engineering degree in 2002.