CNH
Round Baler Weighing System

MEEG 401 – Senior Design
University of Delaware

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Acknowledgments

We would like to thank CNH America for providing us with an outstanding project and allowing us the resources to see it through. More specifically, a very sincere thank you goes out to Doug Fitzkee and Kevin Smith at CNH for all of their hard work and time helping us along the path of this project. Additionally, we would like to thank Dr. James Glancey for his guidance over the course of this semester. He has been a constant source of incredibly insightful information that otherwise would have made this project impossible.

Lastly, we would like to thank the Mechanical Engineering department for providing their students with course of this nature, where all engineering principles come to fruition in a real life engineering design problem.

- Senior Design Team
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Problem Definition

As one of the leading manufacturers of agricultural tractors and combines in the world, CNH has asked our team to develop a round baler bale weighing system for their existing line of round balers. Presently, the round baler measures a growing bale based on diameter alone. Having the option to weigh the bale dynamically will give CNH a great advantage over competitors. Because different farm operations require bales of different sizes and weights, a method for measuring the bale in real-time would prove to be extremely helpful for operators. In this report we will detail our design process in full and provide a path forward for continuing towards a finalized product.

Figure 1. CNH Round Baler
Phase 1

Project Scope

The objective of this project is twofold. Our first goal is to develop a prototype kit that can be sold to customers and attached to an existing round baler model with limited modification, with the intent of giving real-time weighing capabilities to the baler. The second goal is to develop a method to accurately read and filter data with the intent of calculating the weight of the bale of hay in real time.

Some of our major limitations for completion of this project included the time we are given to create a prototype and test it. Since CNH needs at least two weeks to create the prototype from our drawings, we needed to work on concepts and finish them early in the semester in order to get them completed on time.

Our other major limitation was the modification of the current round baler. Since the load cell kit will connect to existing balers, we need to develop it in a way that connects to the baler easily and without many alterations to the baler itself.

Customer Wants

Our customers are Doug Fitzkee and Kevin Smith of CNH America, and after speaking with them and gaining more insight to what the project will require, we developed their top wants for the project. Using UDesign to rank and organize these wants, we produced the following table:

<table>
<thead>
<tr>
<th>Final Rank</th>
<th>Want</th>
<th>Rate of Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Easy to attach kit</td>
<td>25.0</td>
</tr>
<tr>
<td>2</td>
<td>Accurate Weight</td>
<td>20.0</td>
</tr>
<tr>
<td>3</td>
<td>Modification of Baler</td>
<td>20.0</td>
</tr>
<tr>
<td>4</td>
<td>Time to Fail</td>
<td>15.0</td>
</tr>
<tr>
<td>5</td>
<td>Cost</td>
<td>10.0</td>
</tr>
<tr>
<td>6</td>
<td>Simplicity</td>
<td>5.0</td>
</tr>
<tr>
<td>7</td>
<td>Size</td>
<td>5.0</td>
</tr>
</tbody>
</table>

*Easy to attach kit:*
The most important aspect of this project is the development of a kit that CNH can send out to its customers, allowing them to attach the tree load cells to their already existing bailers. This means
that we will strive for a mostly bolt on kit, eliminating as much necessary welding as possible. It is very important that little to no modification is made on the baler itself, allowing this kit to be successful.

**Accurate Weight:**
The baler weighing system needs to produce an accurate weight in real time and display this data to the tractor operator as the bale is moving.

**Modification of baler:**
The kit that we develop needs to keep the baler in the same state that we started with. We want to limit moving different parts around on the baler; this includes moving the wheels in any direction, or taking any parts off of the current baler.

**Time to Fail:**
The modified hitch and axle's of the baler need to be strong and last the life of the baler. A stress analysis for each concept will help us to determine the strength of our parts.

**Cost:**
For the weighing system to be appealing to the public and economic for CNH, the total cost of the product cannot be too great.

**Simplicity:**
The kit that we develop needs to be simple enough for a skilled dealer to easily install on their baler.

**Size:**
The kit that we create will need to be the correct size to fit in the existing balers.

### Key Metrics

After we created the ordered lists of wants for the project, we listed the important metrics that correlated to these wants.

<table>
<thead>
<tr>
<th>Final Rank</th>
<th>Metric</th>
<th>Rate of Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Parts Changed on Current Baler</td>
<td>14%</td>
</tr>
<tr>
<td>2</td>
<td>Number of parts of kit</td>
<td>13%</td>
</tr>
<tr>
<td>2</td>
<td>Maintain Existing Position</td>
<td>13%</td>
</tr>
<tr>
<td>2</td>
<td>Manufacturing Cost</td>
<td>13%</td>
</tr>
<tr>
<td>3</td>
<td>number of steps in assembly</td>
<td>11%</td>
</tr>
<tr>
<td>4</td>
<td>dynamic weight accuracy</td>
<td>7%</td>
</tr>
<tr>
<td>4</td>
<td>Static weight accuracy</td>
<td>7%</td>
</tr>
</tbody>
</table>
4 | Weight of Kit | 7%
5 | Volume of Kit shipping box | 6%
5 | Miles to Failure | 6%
6 | Working Temperature | 4%

**Corresponding Target Values for Top Metrics**

*Parts changed on current baler:* Less than 1
   Changing any permanent features on the baler is not an option, this includes moving parts, drilling extra holes, or removing anything from the baler.

*Number of parts per kit:* Less than 15
   The amount of parts that the kit contains will directly affect how easy it is to assemble and attach to the baler.

*Maintain Existing Position:* Hitch – within 2 inches in any direction; Axle – Only Back, and less than 6 inches
   The hitch does have the freedom to move slightly in any direction without interfering with any permanent hardware. The Axle cannot move forward, up, or down any direction, although it does have the freedom to move back anywhere less than 6 inches.

*Manufacturing Cost:* Less than $1300
*Number of steps in assembly:* Less than 50
*Dynamic and Static Weight Accuracy:* 5%

**Benchmarking**

Talking about and brainstorming this project resulted in many different problems that need to be taken into consideration.

**Accurate Dynamic Weight**

As the baler is moving on unsteady ground, there will be a great amount of bouncing that will affect the weight reading that the load cell will produce. These inaccurate readings will greatly affect the accuracy of the system and need to be filtered using our generated algorithm.

**Dynamic Weight Benchmarking**

To filter the data and obtain a more accurate final weight, we will utilize both running averages as well as other types of filters. Our benchmarking shows that a bandpass filter will help to eliminate some of the noise frequencies generated by the running PTO and the vibrating wheels.
Angle of Land

Since the load cells that we are using only read a weight on one axis, any type of hill that the baler is moving on will move the weight off of this vertical axis. This will give a reading of a lower weight, thus lowering the accuracy of the system.

Angle of Land Benchmarking

To solve this problem, we looked into inclination sensors that will read the angle of the baler and give this information to the controller where it will be accounted for and allow the weight to be adjust accordingly. The product that we found was the CR9060 NH Combine Inclination Sensor P/N 87026294.

![Error vs. Angle Graph](image)

If we only consider error due to incline, our target value of 5% error will allow a maximum incline of approximately 20 degrees.

Competitors Benchmarking

Currently, Vermeer’s is the only other company in the world that offers a hay baler that can dynamically weigh a bale of hay as it is being created, the “Vermeer 605 Super M Cornstalk Special Baler.” Looking at their product we got a better understanding of how they attached the load cells to the axles and the price that their product is offered.
Filtering Benchmarking

We found two articles (both from www.elsevier.com) where teams worked on similar projects that we did. Their filtering techniques were taken into consideration and are show later.

CNH Grinder-Mixer

CNH currently has a grinder-mixer machine that utilizes three load cells to display the weight of the mixture. One load cell is placed at the hitch, and the other two load cells are placed at the axle at each one of the wheels.

![Grinder-Mixer Hitch](image)

Figure 3. Grinder-Mixer Hitch

Project Timeline

After talking with CNH about the timeline that we will need to be working with to successfully create a prototype and have plenty of time to test and adjust it, we created the following rough schedule for the semester. Our final timeline can be seen in the table below.
Some important dates from throughout the course of the project include:

- September 3 – Trip to CNH to discuss project
- September 15 – Present load cell attachment concepts to CNH
- October 13 – Final solid drawings ready to send to CNH
- November 24 – Prototypes installed
- December 10 – Final baler testing
- December 15 – Final presentation to CNH
Phase 2

System Overview

The goal of our project is to determine if a load cell based weighing system is a feasible and marketable design. Using the three load cells provided by CNH, we need to develop a kit to modify the round baler so that it may dynamically weigh hay bales. After the kit is manufactured, we need to develop a method for accurately filtering and analyzing data.

As seen in the free body diagram, the weight of the baler and the hay will cause three reactions, one in the hitch, and two at each ends of the axle. The total weight of the baler will be the sum of these three reactions. Whenever the baler experiences an incline in any direction, the load cells produce
erroneous data. In order to account for this error, it is proposed that inclinometers positioned in orthogonal directions be installed that will measure the exact inclination, both pitch and role, of the baler at all times. With these angles known, corrections can be applied to the load cell readings.

**Concept Generation**

Our project requires us to create two separate kits for attaching the load cells to the baler. We need a single model for the hitch load cell attachment and a separate model for the axle load cell attachment. Keeping our constraints and metrics in mind, our team generated three concepts for the hitch and three concepts for the axle. After we created our valid concepts, we used the UDesign template to select the two best concepts. The UDesign template can be seen in Table 4. We later presented our results to CNH and our results are as follows:

**Hitch Concepts**

![Figure 6. Hitch Concept 1](image)

This concept keeps the exact location of the hitch intact. The green panels are shaped to prevent collision with the existing hitch assembly. Structural integrity was a concern for the area around the lower bolt-hole; however preliminary *SimulationXpress* analysis suggests that the plate will not bend under (see figure 7).
This concept moves the location of the hitch along the x-axis 3.04in (the previous location is represented by the semi-transparent cylinder). This concept eliminates much of the stress concentrations of concept 1; however moving the hitch forward may not be possible. Some combination of the two designs may be appropriate.

This concept was an attempt to keep the hitch in the same location in the x-direction as well as creating a strong bracket (shown in green). This resulted in dropping the load cell to a lower position. After more consideration, we saw that this concept would create problems with the accuracy of the weight due to the location of the load cell.
**Hitch Concept Selection**

To choose between these three concepts, we used the UDesign Concept Selection Template. Using the weighted metrics listed earlier, the template gave the following results

*Table 4. Hitch UDesign Concept Results*

<table>
<thead>
<tr>
<th>Concept</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark</td>
<td>220</td>
</tr>
<tr>
<td>Hitch 1</td>
<td>540</td>
</tr>
<tr>
<td>Hitch 2</td>
<td>320</td>
</tr>
<tr>
<td>Hitch 3</td>
<td>-100</td>
</tr>
</tbody>
</table>

Our first concept resulted with the highest score, so we presented this concept, along with concept two to CNH and learned that with the limited space that we are working with, moving the hitch forward is not an option. This made concept one the best overall model.

**Hitch Stress Analysis**

To test the structural integrity for the area around the lower bolt-hole, we did a *SimulationXpress* analysis and the tests showed that the concept holds a weight of 2200lbs with a factor of safety of 1.17. This confirmed that our concept is a feasible solution and will be the model that we will use for the load cell hitch attachment.

*Figure 9. Hitch Concept 1 Stress Analysis*
This concept would shift the axle back by 4.2in, but would remain the same distance from the ground. The pink and purple panels will be welded together, while the cyan C-shaped section will be used to keep the load cell from rotating. After more evaluation, we figured out that 4.2 inches is too far of a movement forward and the wheel would interfere with other parts of the baler. The stress analysis shows the concept holding a weight of 4500lbs with a factor of safety of greater than 1.
Figure 12. Axle Concept 1 Stress Analysis

Figure 13. Axle Concept 2 Assembled

This concept is a simple and completely bolt-on unit that attaches directly to the front of the already existing panels on the axle of the baler. Only one solid part would need to be manufactured, making the model easy to install and manufacture. Stress analysis shows this concept holding a weight of 4500lbs with a factor of safety of greater than 1.

Figure 14. Axle Concept 2 Stress Analysis
Figure 15. Axle Concept 3

This concept uses a “sleeve” that the load cell would plug into. This entire assembly would then be bolted into the existing hole in the orange axle. The arrow indicates the far end of the load cell in the sleeve. Because of the positioning of the load cell, the new axle keeps exact angle as the existing axle. This is the simplest of the three concepts and would be very straight forward to create and install. This concept is also very similar to the way that the “Vermeer 605 Super M Cornstalk Special Baler” load cell attaches to the axle, as shown in our benchmarking.

Concept Selection

To choose between these three concepts, we used the UDesign Concept Selection Template. Using the weighted metrics listed earlier, the template gave the following results

<table>
<thead>
<tr>
<th>Concept</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark</td>
<td>220</td>
</tr>
<tr>
<td>Axle 1</td>
<td>-140</td>
</tr>
<tr>
<td>Axle 2</td>
<td>140</td>
</tr>
<tr>
<td>Axle 3</td>
<td>700</td>
</tr>
</tbody>
</table>

UDesign clearly indicates that concept three would be the better of the three concepts. Also, when presenting the concept ideas with CNH, the third axle concept was by far the consensus favorite. Not only is concept three simple to produce and install, it only moves the wheel in the outward position (parallel with the axle), otherwise the wheel is exactly in the same position, and the axle geometry does not need to be modified.
Stress Analysis

Upon selection of the best concept for the axle, a thorough stress analysis simulation was performed for validation. Using the SimulationXpress software, a dynamic load factor of two was applied to the area of the load cell where the wheel would typically be located. This load factor was determined to be 5500 lbs after a static weight was taken by CNH at their shop. This static weight provided the weights on each of the three points of contact, those being each wheel and the tongue, also known as the hitch. As the screenshots depict, the new and existing structure did not yield under the force applied, however it does show a yield in the load cell portion. This is simply due to the inability to test each pieces as part of a complete assembly. This analysis forces the assembly to be made as a single part and tested with uniform material properties. As per the load cell supplier, each load cell is rated as a weight that exceeds the total weight of the baler by an order of magnitude, and thus should not be of concern.

Figure 16. Axle Concept 2 Stress Analysis
With hitch concept 1 and axle concept 3 selected, the design specifics can now be finalized for manufacturing in phase three.
Phase 3

With concept selection completed, it then became necessary to outline the specific details necessary to build and test a proof-of-concept prototype. This section will clarify how the concepts were finalized, manufactured, and assembled.

Detailed Design

After CNH approved the two load cell attachment concepts, design specifics and dimensions needed to be clarified. Drawings were made of the six parts in the hitch assembly, and of the three parts in the axle assembly, and sent to CNH for review. The drawings underwent several revisions, and the final, master assembly drawings are shown below.

Hitch Drawing

Figure 18. Hitch Master Assembly Drawing
Axle Drawings

During this phase, we also began to assemble the control aspect of the project. The load cell wires needed to be cut and soldered into new plugs that would be compatible with the SoMat Conditioner provided by CNH. Control software was also acquired and time was spent establishing communication between all three types of components. Component specifics are listed below.

1. **Load Cell**
   - Output Rating: 1.0 mV/V = 9382 lbs
   - Accuracy = 99.75%
   - Max. Excitation Voltage = 20 V (AC or DC)
   - Input Resistance = 350 +20/-0 Ω
   - Output Resistance = 350 Ω

**Inclinometer**
2. **Conditioner**
   - Model: SoMat 2100
   - Eight inputs available (only five needed)
   - Allowable Input Voltage = 7.5–18 V
   - Use Analog for mV/V Calibration

3. **Cab Display**
   - Laptop (provided by the UD MEEG Dept.)
   - USB Powered

**Concept Installation**

Manufacturing of the individual parts and sub-assemblies was carried out by the machine shop at CNH. Upon their completion, approximately ten days after the submission of the design drawings, the group travelled to CNH for concept installation. The process was spread over two trips, and only minor issues were encountered. Revisions to the design drawings were made where appropriate for the production model. Holes were also drilled in the baler sides for the purpose of mounting the inclinometers.
Phase 4

System Calibration

Prior to the installation of the components (mentioned previously in phase three) on the baler, some initial component testing was carried out by the team. It was necessary to calibrate the load cells prior to permanently installing them to the baler. This was required because each load cell has a calibration number called a scale factor, which is different across each load cell, and is used by the software to interpret the load cell/inclinometer signals. This number can be deduced by applying a known force to the load cell, which will then result in the generation of a scale factor. To do this, known weights up to 250 lbs were hung from each load cell, ultimately providing the necessary scale factor. It is important to know that this would be nearly impossible once the load cells were installed on the baler. As part of the calibration process it is required to apply a zero load, then the known load, hence if the baler was being supported by the load cells, a zero load would be difficult to attain.

Following the initial calibration, preliminary system tests were performed to make sure all components were operating correctly. In order to simulate at least some of the vibrations that would be experienced during a real test on the baler, a University owned CNH spinning disc mower was obtained, and a load cell was affixed to an area near the wheel. The various system components, which included the laptop computer, SoMat conditioner, interconnects, and load cell, were setup as they would be during testing. The mower was set to the same PTO speed as the baler (540rpm) and a full scale system test was carried out. This process was used to become familiar with the software, as well as ensure that all systems were operating correctly. Each load cell was tested using this setup, and everything worked as expected.

As a benefit to this system test, we were able to obtain vibration data that could be used to begin preliminary algorithm development in order to reduce the noise in the readings. Since a similar PTO speed was used, there also existed similar frequencies of noise within the data. With all systems passing the mentioned tests, as well as preliminary data and finalized scale factors, installation and final testing could begin.

Testing

With installation complete a testing plan was put in place. It was vital to initially obtain data of the baler actively baling crop which would show in increasing mass over time; a necessary data set for our algorithm development. With this in mind, CNH allowed enough crop in their field for testing
of this nature to be performed. With two complete bales made, and corresponding data to match, other modes of testing followed.

While keeping a bale in the chamber of the baler, in order to maintain the maximum potential weight and inertia of the baler while in motion, further testing was performed in efforts to cover all potential forms of vibrations that could be exposed to the system. All with the PTO on, these tests included:

1. Sitting idle
2. Driving on Flat ground (test track pavement)
3. Bump Track (small bumps, alternating left, right)
4. Changed Roll (driving on incline)
5. Changed Pitch (driving on incline)

Each of the above mentioned tests had several constants to help eliminate variables. For example, each test had a PTO speed of 540 at idle, and aimed at bringing the tractor to the same velocity for each run. Also, each test used the same data acquisition technique, in that runs were initiated at the same point (idle) and ended after a predetermined time (approximately 90 seconds). Data acquisition was conducted at a sampling rate of 167Hz.

Data Analysis

Using the SoMat Infield software, the team was able to view and export the acquired data to a universal format. The data needed to be filtered or smoothed in order to get an accurate reading of the bale weight, due to the large amount of noise present in each of the five incoming signals. Some noise sources, such as bumps and variations in the crop, are unpredictable in the general case. However, some noise, such as the vibrations coming from the running tractor and engaged PTO, can be filtered with some level of success.

Several techniques for more accurate data interpreting were investigated, including frequency filtering using prebuilt Matlab filters, and simple running average calculators.
Filtering

Filtering using a butterworth filter, the team was able to smooth the curve significantly; however there is a significant amount of processing power needed to run such a filter, and a complete data set might be needed before any practical use can be made of it. After talking with CNH, it appears that a running average may be more practical in the long run.

For the purposes of data smoothing, the team established a running average program in Matlab, attached in the appendix. The smoothing algorithm is such that output frequency is traded away for the purposes of minimizing error. Using a value measured from the stationary run of testing, the data is averaged over a specific time interval (output frequency) and assigned an error. The graph above shows the trade-off between error and cab-controller output time, while the figure below gives a graphical example of the
Using this running average, the team has determined that the optimal output time while still remaining under 5% error is about 3.5 seconds.

**Possible Removal of Hitch**

After analyzing the collected data from our three runs, it appears that the hitch load cell is not contributing significantly to the measured weight of the bale. Here we will discuss whether or not a hitch system will be necessary in a production model, and whether correction factors based upon the incoming data from the inclinometers will be enough to compensate for the loss of this added input.
• **Measured weight from data start (@1):** 2525lbs
• **Average error calculated from data (red):** 0.1633%
• **Max error from running average with time interval = 1s (blue):** 9.2487%

Figure 24. Weight vs. Time without Hitch – Only axle data used in plots

• **Measured weight from data start (@2):** 2435lbs
• **Average error calculated from data (red):** 1.8325%
• **Max error from running average with time interval = 1s (blue):** 13.0517%
• **Error due to removing hitch:** 3.803%

With a correction factor using inclinometer data, baler geometry, and CG geometry we should be able to correct the added error resulting from removing the hitch.

As discussed previously, an additional correction factor will also be necessary to bring the measured/observed weights @1, 2 up to the actual weight of ~2700lbs. More testing will most likely be needed to narrow down this second correction factor.
Production Solution

The main purpose for prototyping is to determine if this type of weighing system is a feasible idea for production. Our data and error analysis showed acceptable prototype results, making a fine tuned production level design a marketable idea. With minor adjustments to the physical design, including the possible removal of the hitch pending further review, the concepts that we have presented are worthy of consideration for a production level analysis.

Figure 25. Production-level Concepts
Cost Analysis

Our cost analysis shows a standard cost of roughly $1080.00, which is well within the $1080.00. This cost includes the cost of raw material as well as plant labor to install. This price of $1080.00 will yield a retail price of $3,240 for the factory installed option.

Parts:

Table 7. Cost Analysis

<table>
<thead>
<tr>
<th></th>
<th>Raw Material ($/lb)</th>
<th>Weight (lb)</th>
<th>Assemblies (#)</th>
<th>Total Cost ($)</th>
<th>Cost ($)</th>
<th>Quantity (#)</th>
<th>Total ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Axle (Concept 1)</td>
<td>1.35</td>
<td>16.7</td>
<td>2</td>
<td>22.55</td>
<td>Load Cell</td>
<td>130</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Number of Raw Pieces</td>
<td>Time to Machine raw pieces</td>
<td>Time to assemble raw pieces including welds (#)</td>
<td>Cost ($)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------</td>
<td>----------------------</td>
<td>-----------------------------</td>
<td>-----------------------------------------------</td>
<td>-----------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hitch</td>
<td>7</td>
<td>4</td>
<td>1.5</td>
<td>165.00</td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Axle</td>
<td>4</td>
<td>4</td>
<td>2.5</td>
<td>135.00</td>
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<td></td>
<td></td>
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Table 8. Labor Cost Analysis

<table>
<thead>
<tr>
<th></th>
<th>Hitch</th>
<th>Total: 73.04</th>
</tr>
</thead>
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| Hitch          | 1.35                   |
|                | 15.2                   |
|                | 1                      |
|                | 20.52                  |
| Conditioner    | 300                    |
| Software       | 0                      |
|                | 1                      |
|                | 0                      |
|                | Total: 73.04           |
|                | Total: 751             |

| Hitch          | 1.35                   |
|                | 22.2                   |
|                | 2                      |
|                | 29.97                  |
| Inclinometer   | 31                     |
|                | 2                      |
|                | 61                     |

| Hitch          | 1.35                   |
|                | 15.2                   |
|                | 1                      |
|                | 20.52                  |
| Conditioner    | 300                    |
| Software       | 0                      |
|                | 1                      |
|                | 0                      |
|                | Total: 73.04           |
|                | Total: 751             |

Axle

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| Hitch          | 1.35                   |
|                | 15.2                   |
|                | 1                      |
|                | 20.52                  |
| Conditioner    | 300                    |
| Software       | 0                      |
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|                | Total: 73.04           |
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