RECYCLE NATION

An Environmental Improvement Program
For Incentive Based Recycling

The Trash Masters
United States of America

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1 Abstract

The limited resources of our planet and overflowing landfills broadcast the usefulness of recycling. With over 139 million people in the United States having access to a curbside recycling program [1], recycling isn't just for hippies anymore. However, an undetermined cause for lack of motivation to utilize these programs still exists. Of those households with access to curbside recycling programs, only half of these take advantage of those programs [2]. On top of that, the households that do participate only recycle a third of approved recyclable materials [2]. The Recycle Nation project has two primary goals: to improve consumer recycling by providing monetary rewards in the form of a reduced bill for increased mass of recycled materials, as well as improving the efficiency of sorting mechanisms for recyclable materials by providing a mobile vehicular method of preliminary sorting.

There are two main varieties of curbside recycling programs:

- Single Stream: consumers place all recyclable items into a single recycling container for pickup. [2]
- Pay as You Throw: also referred to as unit pricing or by the acronym PAYT, consumers place garbage into individual fixed volume collection receptacles and are charged for each unit of garbage that they wish to have disposed of. This is coupled with unlimited recycling pickup [2] [3]. Consumers recognize the more they recycle, the less they have to pay to throw away as garbage.

Recycle Nation proposes an alteration and combination of these methods, focusing on positive benefits rather than negative punishment which we believe will result in an even higher participation rate in curb-side recycling programs. Specifically, using the single stream method and modifying the PAYT system to a "Get Paid as You Throw" system rewarding consumers for recycling.

2 System Overview

The general process for the Recycle Nation system is as follows:

A. Consumer places all recyclables into the Single Stream container.
B. Recycling pickup places all recyclables into truck.
C. Truck preliminarily sorts the recyclables.
D. System weighs separated categories of items, uses formula to establish rough estimate of value, and provides refund on consumer's next billing statement.

The Recycle Nation system is divided into four distinct components:

- Receptacle Identification (ID Module): uniquely tag individual recycling receptacles using Radio Frequency Identification (RFID) technology.
- Preliminary Sort of Recyclables (Sort Module): mobile sorting of material into different containers. Recycle Nation sorts into ferrous material and non-ferrous material.
- Recyclable Weight Sensing (Weight Module): weigh sorted material.
- Communication and Software (Comm. Module): storage of mobile data and wireless communication to transfer data to central server for use on public web site.

2.1 Innovation

The benefits of Recycle Nation can be seen from three different perspectives:

- The Consumer, which needs motivation and incentive to recycle. PAYT systems rely on a negative punishment for throwing away more trash. While this does result in increased recycling output in some cases, in other cases may result in an increase in illegal dumping to avoid having large waste fees. By providing a positive reinforcement method of rewarding the consumer for recycling, we believe that this will result in larger recycling output.
- The Recycling Collection Agency, which will increase the amount of recycling volume, improving efficiency of the program, resulting in a direct savings from materials otherwise subject to landfill fees. This

also results in direct payback in the form of commercial worth from reusing existing raw materials instead of the costly process of extracting new raw material.

- Municipalities, especially the ones that run their own recycling and garbage collection programs, will also benefit from the increased recycling. An efficient and working recycling program reflects positively on a community, which may attract new residents.

2.2 Hardware and Software Goals

The hardware will have to be able to uniquely identify a receptacle by reading a mounted RFID tag placed strategically on the waste bin. Then weight sensors reading the amount in the separated containers will then use the ID from the receptacle and place an entry in the database logging the differential weight amount per consumer per receptacle.

The software required will accept incoming readings from the weight sensors as well as the RFID reader and will log these entries into a useable form in a database on the mobile unit for later upload to the central server.

2.3 Performance Requirements

The system will be required to operate in a suburban municipal setting, meaning that the mobile unit should be able to store on the magnitude of hundreds of entries for weight/RFID logs. The central server should be able to store hundreds of thousands of data entries for individual customers across different recycling collection companies.

2.4 Design Methodology

Recycle Nation progressed using the Spiral Lifecycle Model, iterating over each of the four different modules available. Reduction of risk using iterations of module prototyping maximized individual module progress with focus on the combination of project modules coming together later.

3 Implementation and Engineering Considerations

3.1 Design Objectives

The core of the project revolves around the incentive program, and its ability to convince consumers to start utilizing the curbside recycling programs. The incentive program consists of multiple sub-objectives:

3.1.1 Accuracy

The accuracy of the hardware and software must be high to ensure the program's success. The company needs to be able to rely on all collection data to be able to keep the consumer's trust in the program.

- RFID: The tags inside of the receptacles must be properly read to the mobile unit to ensure the accuracy of the consumer receiving their money back at the end of the month.
- Conveyor Belt: The belt must have a decent level of accuracy when separating the ferrous materials from the non-ferrous materials. This will ensure that the proper measurements can be read so the appropriate amount of money can be rewarded to the consumer.
- Weight Sensor: The weight sensors must be calibrated and measuring correctly and accurately to ensure the integrity of the incentive program.

3.1.2 Usability

Another key objective of the design is to make the program actually usable in the real world. For our program to be truly usable there needs to be a minimal amount of work required by the collection agency as well as keeping the program and benefits truly visible to the company's customers. The following guidelines were used to keep the design aligned with these goals:

- Weight sensor automation: The weight sensors are automatically monitored on the data is logged without needing assistance from a garbage collection employee.
- Wireless transfer: Have the mobile unit able to upload all the collection data to the central server and automatically uploaded to the web so that all of the data for each customer can be visible to them via the web.

3.1.3 Adaptability

The design was also created taking into account that curbside recycling is often already in place. Keeping the pre-existence of recycling programs in mind the design followed this set of guidelines:

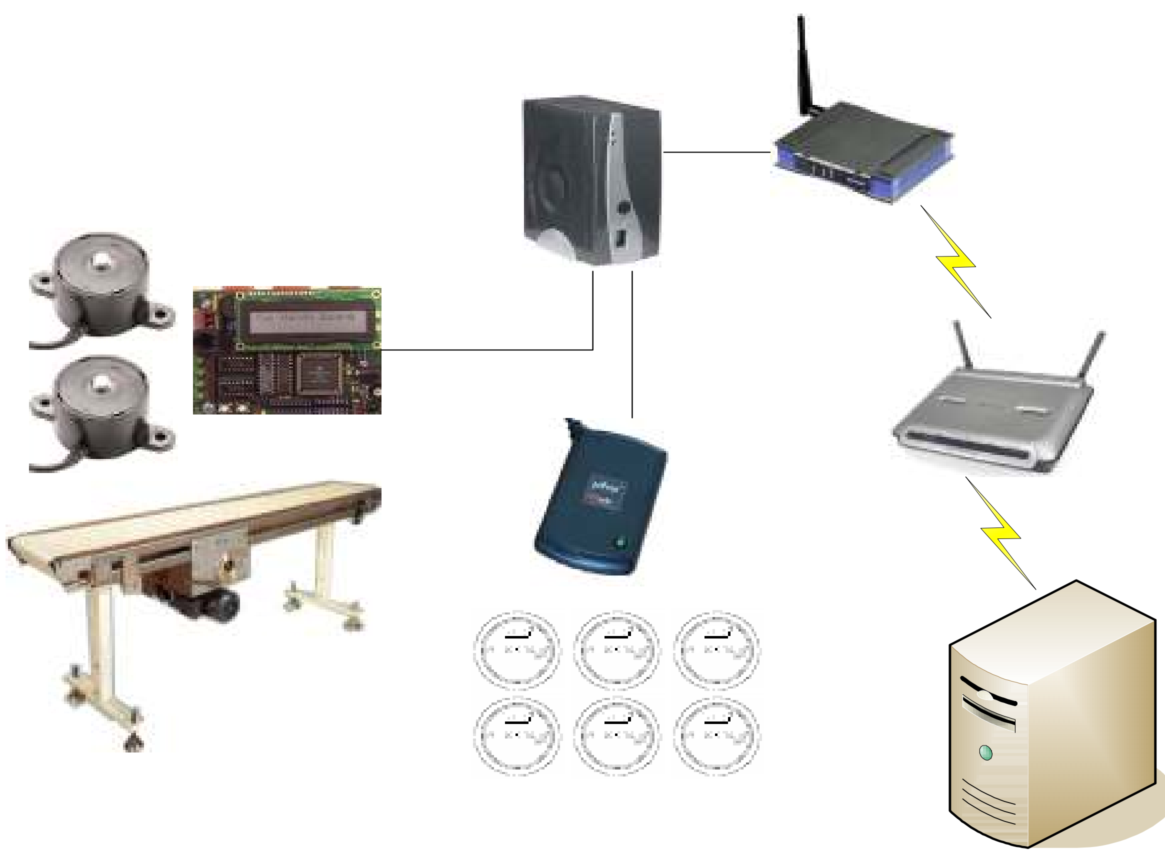
- RFID Tagged Receptacles: The ability to re-use the customer's receptacles that they already have by placing an RFID tag onto each one to correlate to the appropriate address.
- Web Interface: The customer web interface can easily be adapted to each companies needs upon implementation of the Recycle Nation program. If there is already a web server being hosted by the company, the customer interface becomes even cheaper.
- Collection Vehicles: Due to the conveyor belt being of smaller size, the adaptation of putting it inside of the garbage truck should not propose too many issues.

3.2 System Description

3.2.1 Description Overview

Our system is the combination of several parts. We have the mobile unit running software we have labeled our mobile control program. Attached to the mobile unit through a USB connection is our RFID reader. The RFID reader reads RFID tags, which will be placed on trash receptacles, as the receptacle is lifted into the truck. We also utilize a HandyBoard which is attached to the mobile unit through a RS-232 serial connection. The HandyBoard runs a weight sensor program which reads in analog inputs from two different load cells. One of our load cells measure the weight of our ferrous metal and the other load cell measures the weight of all other recyclables. All of these things are mounted to a conveyer belt system that moves our trash and separates it at the end of the belt.

The mobile unit is also connected to a wireless bridge which will send data to the central server when ready. The central server is a database and a web server which after receiving data from the mobile unit places our data in the database and makes it accessible from a web interface.



3.2.2 Conveyor Belt System

Our conveyer belt system is a small work of art. It turned out to work much better then we had imagined it would. Our conveyor belt is constructed from neoprene and is 10 inches wide and 82 inches long. It is mounted across four 3 inch diameter PVC pipes. This is then mounted in a wooden frame and a rubber belt is attached around the starting pipe. The belt is then also attached to a 1/15 horsepower motor. Originally the belt ran too fast and we had to slow it down using additional pulleys. The main component that makes our system able to separate the ferrous material is that the inside of our front PVC pipe is lined with magnets making it a magnetic head pulley. As ferrous material runs off the end of the conveyor belt instead of falling in the normal trajectory that all the non-ferrous material will take it wraps under the belt and falls off as the belt pulls away from the front pulley or gravity overpowers the magnetic field of the head pulley. Also attached to our conveyer belt system are two plastic bins that collect our recyclables. One receptacle is mounted under the conveyer belt to collect the ferrous material and the other receptacle is placed just past the conveyer belt to collect the non-ferrous material.

3.2.3 Mobile Unit

The mobile unit will ideally be replaced by an EBox, which is a very small form factor computer running a Windows CE operating system. As it stands currently, the mobile unit is a laptop computer. The mobile command listener program reads RFID tags which are placed on the trash receptacles. When tags are read it also takes weight measurements of the deposited recyclables which are then stored in MySQL on the mobile unit. When the trash route is over and all trash has been recorded the data from the mobile unit is loaded to the central server when the wireless bridge is within range. The wireless bridge is connected to the mobile unit through the RJ-45 Ethernet port. More detail will be given on the mobile control program in the algorithm section.

3.2.4 RFID Reader

Our RFID solution is a PCprox RFID reader made by RFIdeas. The reader is connected to the mobile unit through a RJ-45 Ethernet port. The reader is small with dimensions of 3 3/8 x 0.875 x 0.6 inches. The RFID reader also has an LED mounted on it which acknowledges when a tag is read. The read range of the RFID reader is within 1 to 3 inches. This allows us to make sure every tag is read. So the tags on the trash must be placed within this distance so the tags can be read. We believe this will be sufficient since we are assuming the garbage company can design the trash receptacles so that when they lift them into the truck the tags always come very close to the RFID reader. We could have used a higher range reader with higher range tags however we determined this was an unnecessary additional cost for our prototype. However this may be something to consider in a real-life solution.

Our weight sensor implementation utilizes an MSIsensors 100lb. load cell. We chose this weight sensor due to its low cost and low noise output. It is powered from a 5 volt source outputs a voltage range of 0.5 to 5 volts over 2 to 100 lbs. The weight sensor uses silicon piezoresistive strain gages to determine the weight. Although the load cell will not measure over 100lbs it can handle up to 250 lbs of force.

3.2.5 HandyBoard

We used a 6811-based HandyBoard microcontroller system to convert the analog signal from the load cell into an 8bit digital signal. The microcontroller also runs a program written in Interactive C which is constantly measuring the signals from the load cell and sending these readings through the RS-232 serial port to the mobile unit. This program is discussed in more detail in the algorithm section.

We chose to utilize a HandyBoard since it had all the functions we would need in one package. We also utilized the HandyBoard LCD for debugging purposes. Our HandyBoard is powered off an attached lithium ion battery. The HandyBoard will read up to 7 different analog signals however we only utilize four. If this project were implemented in a commercial application a more inexpensive solution could be found for the microcontroller. However we chose the HandyBoard because we already had one in our possession therefore we didn't have to purchase or learn to use a different microcontroller and programmer.

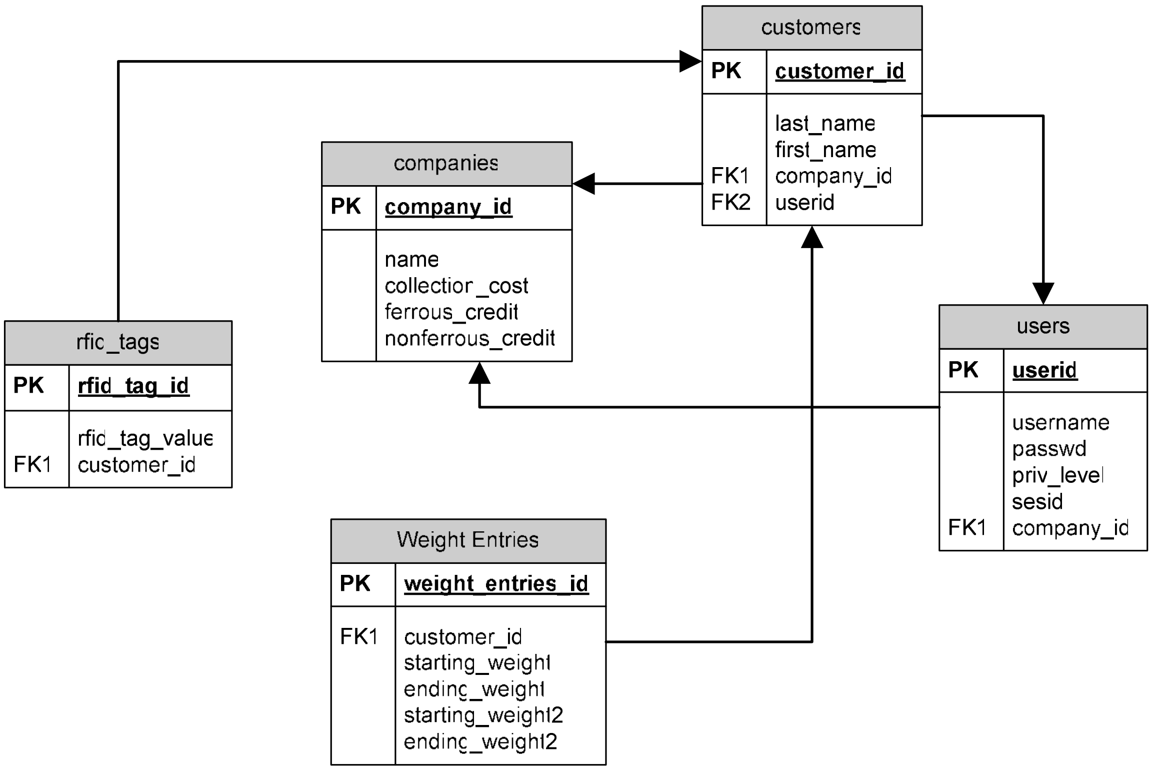
3.2.6 Wireless Bridge

We used a Linksys WET54G Wireless-G Ethernet bridge. Our wireless bridge uses the 802.11g standard but it is also backwards compatible with 802.11b. The wireless bridge operates in the 2.4 GHz frequency spectrum at a 54Mbps data rate. This data rate is more then enough for our needs however this was the lowest price wireless bridge we could find. The wireless bridge also could not be easier to use. It requires no drivers and acts just as a normal Ethernet connection. It connects to the mobile unit through a standard RJ-45 Ethernet cable.

3.2.7 Central Server

Our central server for the sake of prototype is simply a PC running Microsoft Windows XP. It also runs MySQL for our database. For our internet hosting software we use Apache Server from the Apache Software Foundation. Ideally our database server and our web server would be separate but for our project it was much more cost efficient to include them on the same machine. This server runs our web interface and billing system.

3.2.8 Database Schema



3.3 Assumptions, Limitations and Tradeoffs

Since our project is simply a prototype for a larger system we had to make some assumptions as to how our project would operate in a commercial application.

A. Everything is done on a smaller scale. We only use small products since we are assuming if it works on a small scale we can always make it bigger. We estimate our conveyer system to be roughly 1/3 the width it would be in an actual garbage truck.
B. We are only implementing the conveyer area of the truck since we assume all other parts such as the waste receptacle lifting

mechanism are standard and already exist on nearly all garbage collection vehicles.

C. The RFID reader will always read tags from garbage receptacles with 100% accuracy since in a realistic environment we could control how the trash cans are lifted into the truck mechanically ensuring the tags always came near the RFID reader.

The following are the limitations we have determined through our research and design process.

A. Our system struggles to make its cost worthwhile without the government, city or otherwise subsidizing our recycling efforts. We can make the argument that this would be worthwhile for the argument since it often takes much more energy to make new materials then it does to recycle them.
B. Currently our system is limited by the fact that aluminum is not separated from the remaining trash after the ferrous separation. Although we do have an idea how this might be done using eddy currents [5] we chose not to implement this due to time constraints. However it is something we are considering implementing going forward.

We had a couple tradeoffs we had to make during our design process.

A. We wanted to use a PIC microcontroller for our load cell analog to digital conversion and RS-232 output however after much frustration with the PIC microcontroller and looming deadlines we utilized a HandyBoard that we already hand in our possession. Although the HandyBoard is more expensive to purchase it is much easier to program and perfect for what we need it for. Also with the included software we could program it using a regular PC and we didn't have to purchase a separate programmer.

B. We had explored other options of removing the ferrous materials from the stream of trash. We had considered placing a magnetized conveyer system above the stream of trash so that the ferrous metal would actually be lifted out of the stream of trash and placed in a bin on the side of the conveyer system. Although this might have been slightly more accurate it would be much more difficult to implement and could complicate the process causing jams and lots of false positives that would be pushed off the conveyer belt by the ferrous material.

3.4 Algorithms

3.4.1 Weight Sensor Polling Algorithm

The output from the HandyBoard to the RS-232 port is a series of readings which are continuously outputted in a certain order so the control program on the mobile unit can read these measurements at anytime. The program simply needs to listen to one cycle through this four step pattern and it has everything it needs to log a set of measurements for a customer into the database. Since the load cell outputs 0.5 to 5 volts the digital representation starts at 27 in decimal out of 255. The pattern for this output is as follows:

A. Sends the number 0 in ASCII representation to the mobile unit
B. Sends the weight measurement for the ferrous metal
C. Sends the number 1 in ASCII representation
D. Sends the weight measurement for the non-ferrous metal then start back at step A

We chose to implement the cycling pattern method over other methods because it allows us the most flexibility since the read times can be completely controlled by the mobile command program. Also it allows us to average weight measurements over a few cycles if we feel it’s necessary to get more accurate reading.

Another suggested method included having the mobile command center tell the HandyBoard when it needed a measurement. After the HandyBoard received this signal it would then respond with the measurements. This would allow us to save on power since we wouldn't be running constant iterations on the HandyBoard. However we decided not to go with this method since it involved unnecessary handshaking between the mobile unit and the Handyboard that could have caused unnecessary problems and difficulties if we made any changes to our program running on the mobile control listener program. Under the development time constraints the continuous pattern method seemed to be more flexible.

3.4.2 Variable Incentive Algorithm

For different population densities and geographical areas the cost of garbage removal and the value of different materials varies. So, municipalities and private businesses that wish to implement the design would benefit from being able to change these values. The code for the incentive program is easily adapted to different programs and requirements. As insurance to prevent a company from actually losing money from the incentive program, maximum and minimum refunds can be put into place. Obviously, the maximum needs to be set high enough to keep the consumer's interest in the incentive program.

3.5 Verification Testing and Results

Testing of the conveyor belt must be done to ensure that the magnetic head pulley is operating with enough accuracy to create a reliable system for separation of ferrous material from non-ferrous. The following tests were conducted with varying size cans in two different configurations: standing vertical and horizontally on their side. For testing purposes the ideal speed for the conveyor was approximately 11 to 12 inches per second.

Can A	Clam Chowder	2.8 oz
Can B	Chicken of the Sea	0.8 oz
Can C	Generic Can	1.2 oz
Can D, E	Dog Food	1.6 oz

A hit for the test is classified as a ferrous can that successfully completes the loop around the magnetic head pulley and is pulled under into the ferrous container. A miss for the test is classified as a false positive, or a ferrous can that travels into the non-ferrous materials container. A ½ hit is a can that traveled around the magnetic head pulley a little ways, but not quite enough to make it into either container. These ½ hits can be easily fixed with minor tweaking of the container locations.

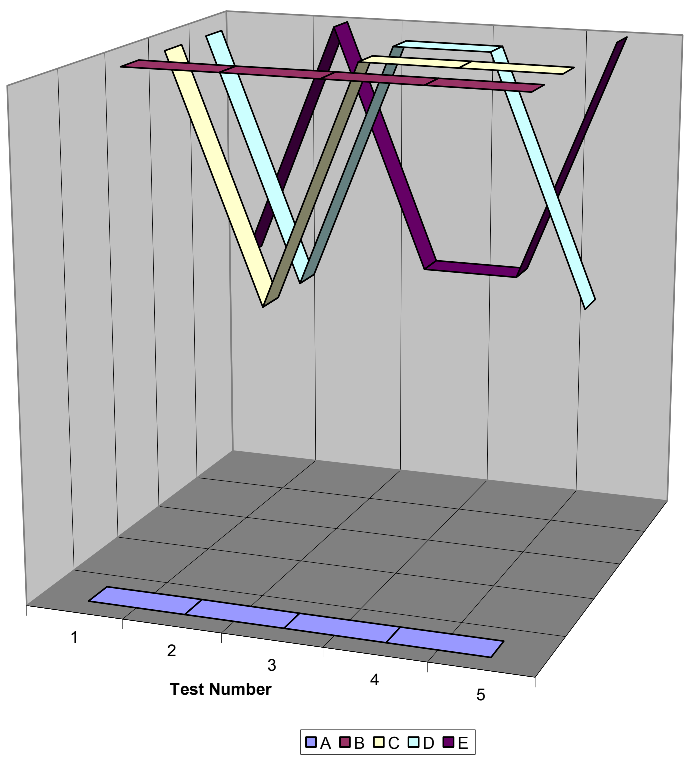
The results shown below indicate higher mass cans are more successful in a horizontal orientation, with two successful tests on the large 2.8 oz can. The lighter cans in a horizontal orientation were a little less reliable. These problems can be solved with slightly more powerful magnets or a better configuration of magnets on the outside of the PVC pulley rather than mounted from the inside as they are now.

Vertical Tests

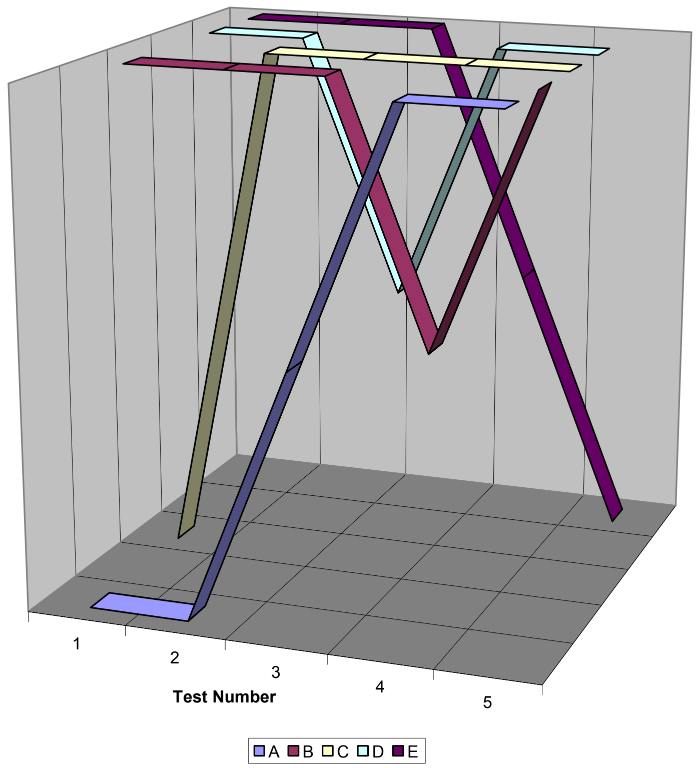
	Test 1	Test 2	Test 3	Test 4	Test 5
A	Miss	Miss	Miss	Miss	Miss
B	Hit	Hit	Hit	Hit	Hit
C	Hit	½ Hit	Hit	Hit	Hit
D	Hit	½ Hit	Hit	Hit	½ Hit
E	½ Hit	Hit	½ Hit	½ Hit	Hit

Horizontal Tests

	Test 1	Test 2	Test 3	Test 4	Test 5
A	Miss	Miss	½ Hit	Hit	Hit
B	Hit	Hit	Hit	½ Hit	Hit
C	Miss	Hit	Hit	Hit	Hit
D	Hit	Hit	½ Hit	Hit	Hit
E	Hit	Hit	Hit	½ Hit	Miss



Vertical Test for Correct Operation of Magnetic Head Pulley



Horizontal Test for Correct Operation of Magnetic Head Pulley

3.6 Development Tools

For the development of our project we used a variety of tools to construct software solutions to accomplish the goals of the Recycle Nation system. For development, we used Microsoft Visual Studio 2005, Microsoft Platform Builder 5.0, as well as developing in Interactive C on the HandyBoard.

3.7 Cost

The breakdown of cost for prototyping is summarized as follows:

Wood Supplies for Conveyor Frame	$37.41
Conveyor Belting and Lacing	$60.72
Miscellaneous Conveyor Supplies	$70
Magnets	$48.25
Load Cells (x2)	$110
RFID Readers	$189
20 RFID Tags	$59
Wireless Bridge for EBox	$79.99
Domain Name (recyclenation.org)	$9.95
Total	$664.32

The total of $664.32 is listed as an estimate due to the fact that some extra supplies were ascertained during the fabrication of the conveyor belt. Certain costs will definitely decrease with the purchase of items in bulk, the perfect example is the RFID tags. For our purposes we only needed a pack of 20, but bought in bulk their price decreases dramatically. Also, collection agencies have the option of using their own domain name for the front end web site solution or use recyclenation.org hosting solutions. We had to fabricate the belt in a fashion where it was free-standing and not mounted inside of a vehicle. Costs that will stay relatively stable throughout the implementation would include the RFID Reader, load cells, and magnets.

4 Summary

4.1 Conclusions

Recycling has many advantages for the environment. Everyone needs to do their part to help improve our environment, unfortunately when it comes to curbside recycling the numbers just aren't there. The design team hopes with programs such as Recycle Nation that these numbers can be turned around and that recycling in everyday homes can be increased.

4.2 Current Status

As the project stands right now, the four planned modules have been implemented with the following descriptions:

- ID Module: The RFID reader correctly reads and accurately reports tag identification numbers.
- Sort Module: The sorting module is fully functional; the conveyor belt operates physically and also performs the separation of ferrous materials from non-ferrous materials.
- Weight Module: The load cells that were purchased are being correctly run through a HandyBoard (used for analog to digital conversion) with weights being taken from two containers attached to the conveyor belt.
- Comm. Module: A website has been designed and is hosted at http://www.recyclenation.org this as well as the software to read the load cells through the HandyBoard and the software driver for the RFID reader have been completed.

4.3 Future Work

There is much work that could be done with the raw data collected from the recycling program, some of these include:

- Dynamic Web Upload: When the data is transferred to the central server, have the server dynamically upload everything to the web to make all the data immediately available to all customers.
- Data Mining: All of the raw data collected from the individual addresses, recycling trends could be tracked via neighborhoods, communities, cities, and if Recycle Nation programs are implemented in enough areas even entire states.
- Eddy Current Aluminum Separation [5]: eddy current separation is a method to separate aluminum material when ferrous material has already been extracted. A secondary conveyor would be placed after ferrous separation with a magnetic head pulley inside that would rotate very quickly, at approximately speeds of 5000 rpm. This would induce what is called an eddy current into aluminum material, levitating it over a separator into another container for weighing.

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