# Rapid Battery Exchange

# (RBX)

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# Abstract:

Electric vehicles have begun to hit the main stream market, with sales raising form under 20,000 in 2001 to over 110,000 per year since 2014 [1]. With new models hitting the market every year, and more people becoming conscious about their fossil fuel usage, this trend will only continue until there are more electric vehicles than combustion vehicles on the road. A major drawback of electric vehicles is their limited range, and relatively long recharge times. Even with advancements in battery charging speed, such as the Tesla super charger, able to provide up to 90 miles of range in just 30 minutes, electric vehicles are still not practical for people who make regular, long distance trips [2]. These quick charging technologies not only take much longer than refueling a combustion vehicle, they providing less range, and they are also bad for the vehicles batteries. Regularly using them will greatly reduce the capacity and lifespan of the vehicles battery pack. The equivalent to refueling a combustion vehicle, is switching out the traction battery pack for a fully charged one. This gives the vehicle the full range of the battery pack, in the time it takes for the exchange to take place. This technology would help make electric vehicles more practical for people who do not want to wait around for their vehicle to charge, as well as help spread the cost of replacing depleted battery packs over the life of the vehicle.

# Overview:

This project will help alleviate the range anxiety felt by owners of electric vehicles, as well as help make electric vehicles more practical, by eliminating long charging stops currently needed to charge the vehicle once the battery is discharged. Currently, the only way to take an electric vehicle on long trips, is to plan charging stops along the way. This pre planning is needed to ensure the driver can make it to the next charging stop within the available range of the vehicle, sometimes requiring the driver to take different routes than desired, even adding more mileage to the already long trip. This system would allow the electric vehicle owner to drive up and exchange their discharged battery pack with a freshly charged one, in under a minute, making electric vehicles competitive with their fuel burning counterparts.

# Product Description:

This product is a Rapid Battery Exchange system (RBX), which is capable of replacing a discharged electric vehicle battery pack with a charged one, and begin charging the discharged pack. The system is fully automated, and the exchange will be completed within one minute of the driver pushing the transfer start button. This product will eliminate the range anxiety felt by electric vehicle drivers when on long trips, as well as eliminate long waits for the vehicle to charge. This product would also eliminate the need to use the quick-chargers in order to get back on the road quickly, which would in turn help to extend the life of the battery pack. The system will be self-contained, and enclosed for safety and weather resistance, as shown in Figure 1 below.

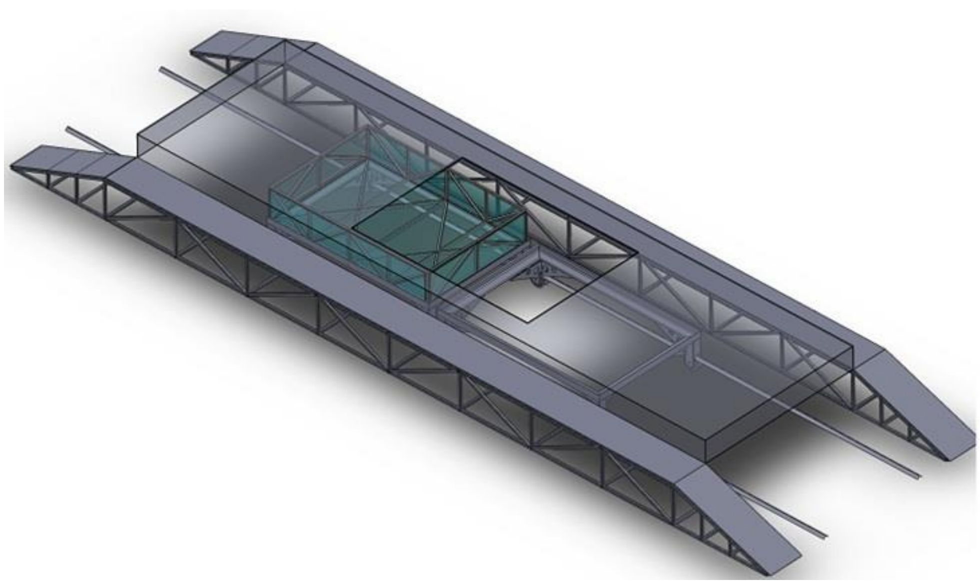


**FIGURE 1: RENDERING OF SYSTEM**

## Market Research:

The current solution to the problem of electric vehicle battery packs discharging on long trips is to stop and charge the vehicle. These charge sessions are either hours long, or quick and bad for the battery pack. Long stops interrupt long trips, and make electric vehicles impractical for people who make frequent trips that would require a charge stop. Even the fastest charge method available today takes 30 minutes to add 90 miles to the range of the vehicle, which is a much longer stop than a gas stop in a fuel vehicle [2]. This system would allow the electric vehicle driver to be back on the road within one minute, which is shorter than the average gas stop, and does not disrupt a trip. This short stop makes the electric vehicle directly competitive with gas vehicles with respect to range.

Another benefit of this project is reduction in unnecessary wear on the battery pack. Because the electric vehicle owners are constantly worried about having enough "juice" to make it through the day, they often take every opportunity they can to charge their batteries. This leads to many partial charge cycles on the battery pack, which expedites the wear process of the battery pack. If the drivers instead only exchanged the batteries when they were close to discharged, and then let the RBX fully charge the battery pack correctly, the pack will last longer.

## Customer Archetype:

People with an electric vehicle, that make frequent long trips would be interested in the product, for it to be practical to use, however, the auto manufactures would have to be in on the deal. The end customer would be an electric vehicle owner, who frequently drives close to the maximum range of their battery pack. They would also not have much time to wait around for the vehicle to charge, and be environmentally conscious enough to not want to drive a fuel vehicle. The customer would be able to pull into a station and exchange their discharged battery for a fully charged one. This would help the customer get around without having to worry about their battery dying, and reduce the amount of time needed tor the battery to be charged.

This product solves the problems of short range, and long charging time of electric vehicles. This will help eliminate the range anxiety felt be electric vehicle owners, in that when there battery runs low, they will be able to quickly "re-fuel" and extend their range. This helps make electric vehicles more practical for people who make frequent, or occasional, long trips.

This is a new market, as there are no products available that achieve the same goal. The closest thing to this is the Tesla super charger, which can charge from 10% to 80% in approximately 30 minutes. All Tesla model S vehicles are capable of using the super charger, this makes around 90,000 vehicles [2]. This is assuming that every model S owner will use the superchargers on long trips where they will need to charge along the way. This may not be true, as there are only a limited number of superchargers, mostly in the US and Europe. Depending on how accepted the RBX is by the auto manufactures, all of this market and more can be captured. The product can be designed in a way to be compatible with any model vehicle that is fit with the correct battery pack, size, and location. This amount of standardization may not be practical for all auto makers to implement, but if enough interest can be show, most would be willing to comply. The target market for this product is California at first, if this system can be shown to work in California, it can be adopted by the rest of the United States. California is an easy place to start because it is an eco-friendly state, with a large renewable energy and electric vehicle community.

## Market Description:

This product will be an automated system that will exchange the discharged battery pack from an electric vehicle with a fully charged one. The system is operated from inside the vehicle, and the exchange takes less than one minute to complete. The benefits can be seen in Table 1.

| Charge Time | Vehicle | | |
|---|---|---|---|
| Charger | Nissan Leaf | Prius Electric | Tesla model s |
| 110 | 21 hours | 3 hours | 63-81 hours |
| 220 | 4 hours | 1.5 hours | 10 - 12 hours |
| 440 | 0.5 hours | N/A | N/A |
| Supercharger | N/A | N/A | 30-75 minutes |
| RBX | 1 min | 1 min | 1 min |

**Table 1: Vehicle Charge times for various electric vehicles**

As seen in the table, the charge times of the various vehicles are at least 30 minutes, with these quick charges being hard on the battery pack, and are not recommended for daily charging. With the RBX, the exchange process takes less than one minute, and does not stress the battery pack, as it can be charged slowly while in the system. The system being fully automated means that the driver does not have to do anything other than press the start button, making the process much simpler and quicker than both charging the battery of a current electric vehicle, or re-fueling a fuel vehicle.

Limitations to the present solution of re-charging the discharged vehicle are that the driver must find a charging station, and wait hours for their vehicle to be charged enough to get them to their destination, or to the next charging station. These long waits interrupt an already long trip, making it impractical for users who make trips that will discharge the battery fully. There is also the problem of reducing the life of the battery pack when these quick, high current, chargers are used, or when the battery pack is partially charged and discharged. The new product would be able to replace the discharged battery in much less time, all without adding extra stress to the battery pack, as the idle battery packs can be charged at a safer rate.

Areas that are not being currently achieved by any of the similar products are the speed and simplicity of the exchange process. This system, being fully automated, means that the driver only presses a button in the vehicle, and one minute later, can drive off with a fully charged battery. Other leveraging points include being able to perform easier maintenance on the battery pack, as it is easily removed with the exchange apparatus.

Currently, there are no ways to extend the range of an electric vehicle in the same amount of time as it takes to get gas in a fuel vehicle. Being able to change the battery pack and continue driving will make electric vehicles much more practical for the average driver, and help the movement away from fossil fuels.

Entering the market will require a large amount of effort, because the design will need to be implemented into the design of the vehicles, as the battery pack needs to be easily removable by the exchange system. The entire project will need to be designed and a prototype needs to be show in order to get the attention of the automakers, and customers. In order to be a taken seriously, there would need to be a plan to implement the system in various vehicle models. Since the exchange system will need to interface directly with the vehicle, electric vehicle manufacturers would have to be involved in the design and implementation of the system. Key partners include the major automakers that make electric vehicles today. Each of these automakers would need to comply with the specifications required by the exchange system, so the RBX could replace the battery pack easily. They would gain the ability to control which users have access to the exchange systems, whether it be by subscription, or a pay per use system.

Key customers can be seen as the electric vehicle owner, or the auto maker, depending on how the system is used. If the auto maker uses the exchange system as a selling point for the vehicle, and bundles the right to use it with the sale of the vehicle, then they are the customer. If the system is left for the user to purchase separately, then they would be the customer. A lead customer will be Tesla Motors, as they have demonstrated a system similar to this one. The differences are that there system is complex, and will only work with their vehicles, it also takes much longer and costs much more to build. Since they have shown interest in this technology, they would be easiest to approach about implementing it in their vehicle line. When other automakers see the success, they will be easier to sell the idea to, and implementing a standard system that they can comply with would also be easier after the first company is on board.

Advantages to this solution, over charging the battery, are that it is much faster, and easier for the user. It is also much better for the battery pack in the vehicle, and thus will extend the life. Disadvantages include exchanging your battery pack with one that is more used, and has a lower range than the original, as well as the cost involved with integrating the system into current vehicle design. Table 2 bellow shows the marketing specifications that will help make the project interesting to potential customers.

| Item | Value |
|---|---|
| Weather Resistant | Can withstand outdoor conditions |
| Safe | Children and small animals should not be able to enter apparatus |
| Low-Maintenance | The user should not need to make regular adjustments |
| Easy to Operate | User should not have to do more than push a button to start exchange |
| Fast | Exchange should take one minute or less |
| Price | The system will have to be reasonably priced so it can be more quickly accepted |

TABLE 2: MARKET SPECIFICATIONS

# Block Diagrams:

**FIGURE 2: BLOCK DIAGRAM**

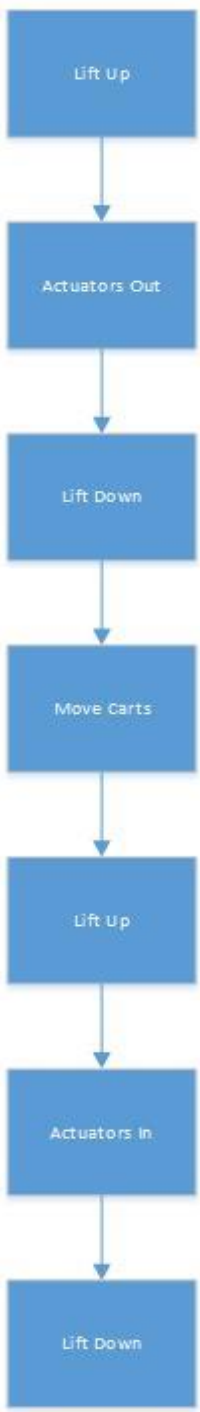
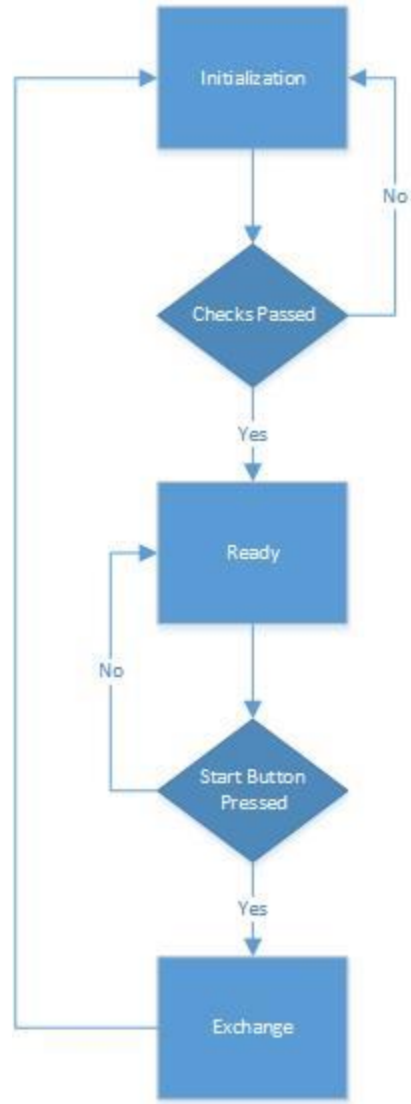



**FIGURE 3: LOGIC DIAGRAM**



# Engineering Specifications:

This system will utilize a hydraulic lift to take the weight off of retaining pins, holding the battery pack in the vehicle, when the lift is fully raised, the pins will be removed using actuators, when the pins are removed, the lift will lower the battery pack down into a cart. The cart will then be moved under a charging station so the batteries can be charged, a freshly charged battery will now be above the lift. The lift then raises the battery pack into the vehicle and the retaining pins are put in place. The lift is lowered and the exchange is complete. The states of a complete exchange can be seen in Figure 2.

Safety measures include an enclosure that ensures no children or animals can get into the apparatus, where they would be injured if it were to move. The exchange should not be allowed to begin unless the vehicle is detected in the correct position, and the secondary battery pack is in place. A high level logic diagram of the system can be seen in Figure 3. The initialization stage sets the system up for an exchange, then ensures all of the safety checks have been passes and the system is ready to begin. The system then waits for the driver to press the start button, once pressed, the exchange begins and lets the driver know when the exchange has completed with a light on the center console.

The system must be low maintenance, meaning that there should be minimal wearable parts, and those parts must be easily accessible when they need to be replaced. The system should also be easy to operate, the driver should only have to press the button, and wait for the exchange to complete. The speed of the system is a major selling point, because of this, a complete exchange should take no more than one minute. The price of the system should be reasonable, meaning that the price of the exchanges should offset the price of replacing a battery pack when needed, as well as the cost of electricity to charge the vehicle at home. These specifications can be seen in Table 3 on the next page.

| | |
|---|---|
| Weather Resistant | The system will be enclosed in a casing to protect against water. |
| Safe | The enclosure should be closed at all times when the system is not in operation, and there should be no opening large enough for a child or animal to enter |
| Low-Maintenance | Any wearable parts will be easily accessible and replaceable |
| Easy to Operate | All parts are automated, and start with the press of a button |
| Fast | The system will be able to remove the discharged battery, and replace it with a charged one, allowing the driver to pull away in less than one minute |
| Price | The system will be cost effective, with the price of an exchange being offset by the price of replacing a battery pack, as well as the cost of electricity to charge the battery pack at home. |

TABLE 3: ENGINEERING SPECIFICATIONS

# Design:

The design of the project can be broken down into two sections. The design of the new components in this iteration, and the design of the system as a whole.

## Iteration Design:

The design considerations for this iteration hinged on the major issues of previous iterations. The main areas keeping the system from working reliably and being safe were:

- Large openings exposing heavy moving parts
- Cart Drive system worn out
- Manual alignment of vehicle on ramp critical
- High friction between battery pack and lift reduced movability to self-align
- System did not look presentable

These areas were addressed individually, with many of the issues being addressed by the same element.

The large openings were a safety hazard, so they needed to be closed off, however, enclosing the entire system in a box would not have made it look nice. The decision was made to incorporate the aesthetic design of the system with the enclosure. Painted plywood would be used to cover the majority of the open spaces, with clear acrylic windows in areas where the inside could be showcased. The windows were placed over the charging stations to show the idle battery being charged. The acrylic accents were also to be placed along the sides of the ramp, and back lit with LED's to make the ramp more aesthetically pleasing.

The original cart drive system was a worm drive, driven by a large induction motor. Over time the nut on the worm drive was stripped out, and the carts would no longer move. The original design to replace this worm drive system was a cable driven winch system, with pulleys allowing the same cable to be attached to each end of the carts, and one winch to be run in opposite directions to move the carts back and forth. Once this system was implemented, unexpected issues made further design considerations necessary. The cable would get tangled on the spool, and was getting frayed where it was overlapping. The decision to move to a chain drive system came after this system failed. A garage door opener was modified in order to be able to push and pull the carts to their needed location. This opener is still not the ideal solution, as it has trouble pushing the carts to the front of the apparatus, further improvements include sizing this motor up to decrease the overall exchange time.

Alignment between the vehicle and ramp is critical, as the battery pack must fall into the cart, and the new battery must fit into the battery receptacle in the vehicle. To solve this problem, the existing guide plate design was adjusted in order to reduce the chance of the battery pack getting stuck during the exchange. The guide plates on the battery carts were made longer and steeper, to help funnel the battery pack into the cart more smoothly. The alignment plates in the battery receptacle were adjusted to help slide the battery pack to the center during an exchange. These alignment plates rely on the battery pack being able to slide on the lift to reposition, to help reduce the friction between the battery pack and the lift, sheets of PETG were attached to the top of the lift, and the bottom of the battery packs. This added height to the battery pack required the charging stations to be re-built in order to accommodate the higher battery pack, without reducing the clearance between the vehicle and the charging station when driving onto the ramp. Further work in this area includes adding alignment plates to the vehicle, so it can be aligned on the ramp more precisely each time.

## System Design:

This system has been worked on for many years, by many different groups, this iteration brought all of the previous work together in order to make a more reliable product that is a step closer to being usable. The RBX consists of two main components, the ramp and the battery receptacle in the vehicle. These systems need to be connected during an exchange to coordinate the release and locking of the battery pack.

The battery receptacle is a steel structure, mounted on the underside of the vehicle, where the original battery cage was housed. The system has two electronic actuators that control the removal and insertion of retaining pins that hold the battery pack in the system. The receptacle is controlled by a micro controller in the vehicle, which communicates with the ramp via wireless Xbee communication.

The ramp is where most of the exchange takes place, it is responsible for removing the battery pack from the vehicle, moving the battery pack to the charger, and replacing the battery pack in the vehicle. This is all controlled by a single micro controller that communicates with wireless Xbee to the vehicle system. The battery pack is removed from the vehicle using a 1500lb hydraulic lift, powered by an induction motor in the structure of the ramp, when the battery pack has been lifted off of the retaining pins, the actuators can remove them, allowing the lift to bring the battery pack down into the carts. The garage door opener can then move the discharged battery to the charging station, and the fresh battery under the vehicle. The lift then lifts the battery into place, the actuators replace the retaining pins, and the lift lowers back inside the ramp. At this point the driver can drive away with a fully charged battery pack.

## Construction and Integration:

After the design was completed, the construction of this project began. As this is a large project, and is also a club project, many people were involved in the construction and implementation of the system. This iteration included constructing the new guide plates, garage door opener, and covers, as well as integrating the existing electronics with the new automation code being written concurrently. The first task was completing the guide plates, and attaching the PETG to the battery packs and lift. Help was received from the BRAE 128 class in fabricating and installing the guide plates and PETG onto the battery carts and packs. They were supported by the batteries being removed so they could safely work on the system. The PETG was glued to the top of the lift using contact cement. The BRAE team also assisted in installing the garage door opener, and fabricating the mounting brackets to attach it to the ramp and carts.

While the BRAE team was working on the guide plates, integration between the existing electronics and the new automation code was being performed. The programming team was being supported by being given the signals needed to control the mechanical parts of the exchange, such as move the carts forward and back, or raising the lift. An interface between the microcontroller and the garage door opener was built to translate the 5V 20ma max output of the microcontroller, into the signals needed by the garage door opener to operate (See Figure 4 for control circuit). The garage door opener requires two of its pins to be shorted momentaraly as a signal to move the door to the other position, a relay to control the motor power was also included for emergency shutoff.

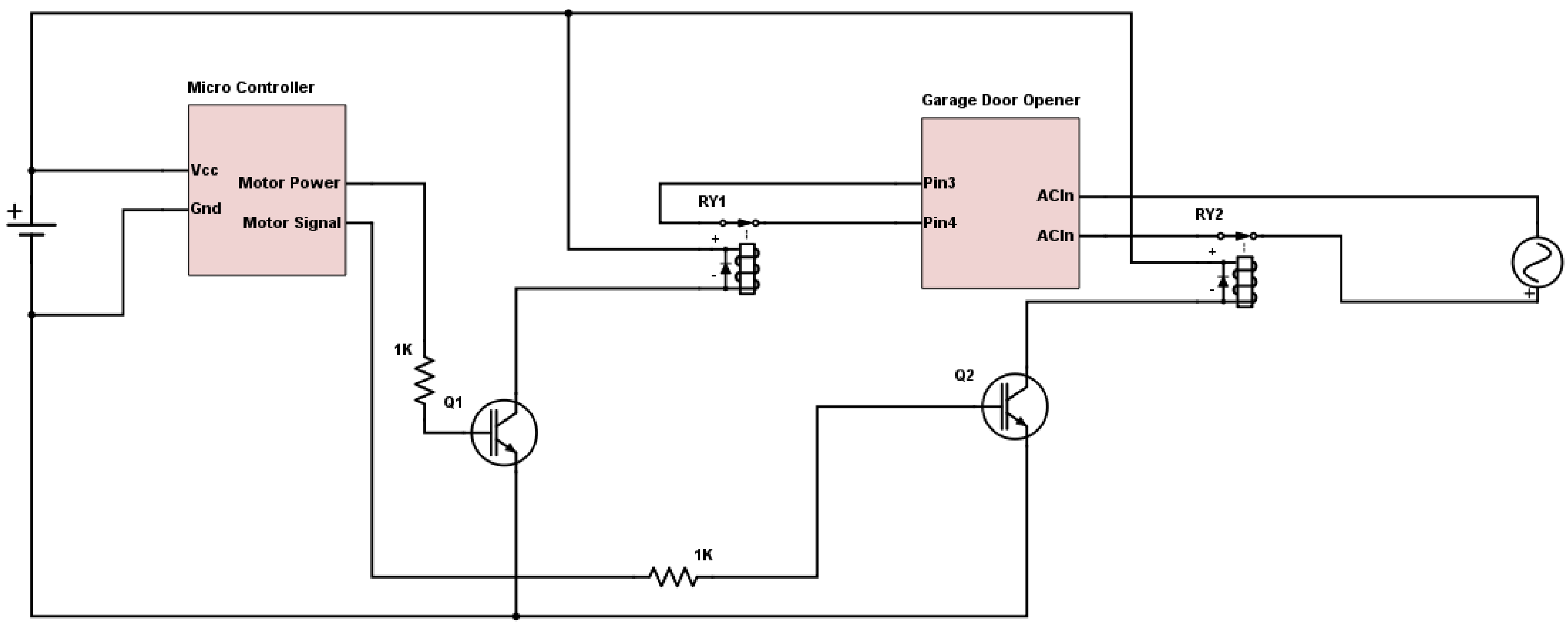



FIGURE 4: GARAGE DOOR OPENER CONTROL CIRCUIT

The large openings, and preventability of the system were solved at the same time. Plywood was cut to size, bordered with 2"x3" and made into a cover for the ramp. Holes were then cut into the plywood where the windows would go, and acrylic was attached. All moving parts were covered by the enclosure, except the space in the center where the battery pack enters and exits the ramp. The sides of the ramp were cover in translucent acrylic, and backlit with RGB LED's to help make the system look more complete. All exposed wood was painted to help improve ascetics and weatherproofing of the system.

# Testing

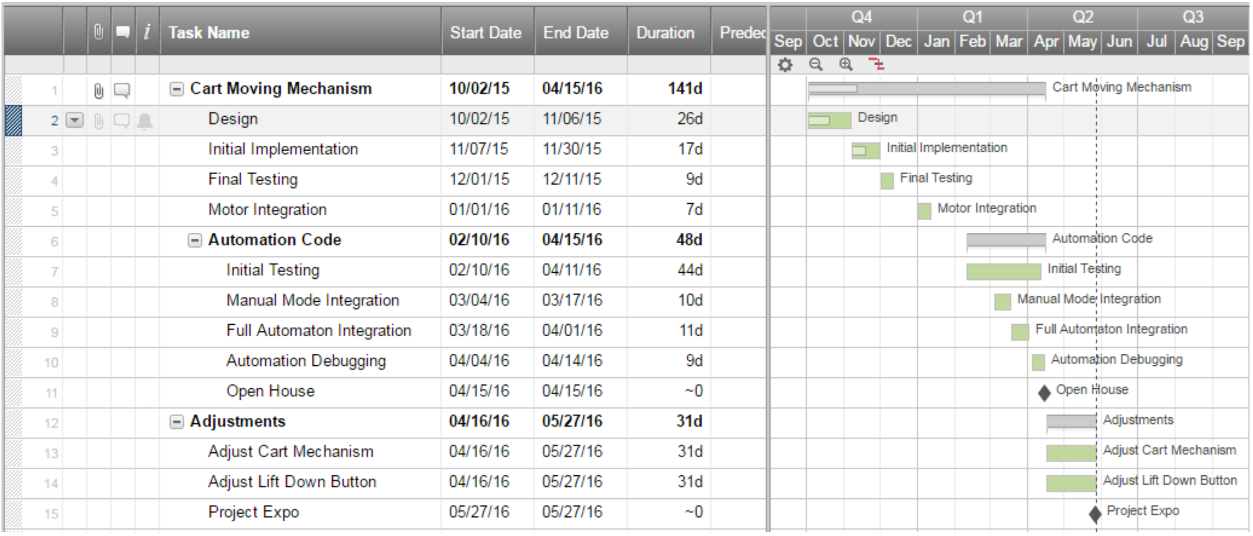
Testing of this iteration of the Rapid Battery Exchange system will be done incrementally, based on the engineering specifications. An in depth test method can be found in Table 4. These test methods were chosen to ensure the safety, practicality, and usability of the system.

| | |
|---|---|
| Weather Resistant | The system will be subject to a high pressure hose for 15 minutes, and no water should get inside the system. |
| Safe | No space large enough for a small child or animal(8” diameter) will be found on the enclosure |
| Low-Maintenance | Any part that will require replacement or adjustment must be accessible and replaced within 15 minutes |
| Easy to Operate | One button starts everything, no other input is needed |
| Fast | The system will be able to remove the discharged battery, and replace it with a charged one, allowing the driver to pull away in less than one minute |

TABLE 4: TEST METHOD

Testing of the system as a whole will also need to be completed, as changes were made to the overall design. The system can be tested incrementally, starting with using the manual controls to test each component individually, once the individual parts are known to work, automated exchanges can take place, with the emergency stop button in place to stop if an error occurs.

# Calendar:



| | Task Name | Start Date | End Date | Duration | Predec |
|---|---|---|---|---|---|
| 1 | **Cart Moving Mechanism** | **10/02/15** | **04/15/16** | **141d** | |
| 2 | Design | 10/02/15 | 11/06/15 | 26d | |
| 3 | Initial Implementation | 11/07/15 | 11/30/15 | 17d | |
| 4 | Final Testing | 12/01/15 | 12/11/15 | 9d | |
| 5 | Motor Integration | 01/01/16 | 01/11/16 | 7d | |
| 6 | **Automation Code** | **02/10/16** | **04/15/16** | **48d** | |
| 7 | Initial Testing | 02/10/16 | 04/11/16 | 44d | |
| 8 | Manual Mode Integration | 03/04/16 | 03/17/16 | 10d | |
| 9 | Full Automaton Integration | 03/18/16 | 04/01/16 | 11d | |
| 10 | Automation Debugging | 04/04/16 | 04/14/16 | 9d | |
| 11 | Open House | 04/15/16 | 04/15/16 | ~0 | |
| 12 | **Adjustments** | **04/16/16** | **05/27/16** | **31d** | |
| 13 | Adjust Cart Mechanism | 04/16/16 | 05/27/16 | 31d | |
| 14 | Adjust Lift Down Button | 04/16/16 | 05/27/16 | 31d | |
| 15 | Project Expo | 05/27/16 | 05/27/16 | ~0 | |

**FIGURE 5: SCHEDULE**

# Analysis of Senior Project

Student's Name: Daniel Rostom ______________________________

Advisor's Name: Art MacCarley ______________________________ Date: ________________

## 1. Summary of Functional Requirements

The Rapid Battery Exchange (RBX) system is capable of replacing the discharged battery in an electric vehicle, with a charged battery in under 60 seconds. The Vehicle and Ramp communicate with each other wirelessly in order to determine when to release and retain the battery. The RBX is a fully automated system that only relies on the driver for the start signal, all other processing is done by the onboard microcontroller. The system is also capable of charging the battery that was removed from the vehicle, with either of the vehicles original chargers (110V or 220VAC).

## 2. Primary Constraints

The main difficulty with the project was that it has been an Electric Vehicle Engineering Club project for many years. The system was partially completed, with many issues affecting reliability of the transfer. Also, since many iterations of the project had gone on, there were parts of the design that did not quite fit together.

The project was being worked on concurrently with a CPE student who was writing the automation code for the system. It was difficult to coordinate with them to plan when parts would be completed and ready for testing, and to aligning the schedules to meet major milestones. The coding not being completed with the mechanical aspects held the project up at times.

## 3. Economic

Human Capital:

The RBX eliminates time wasted while waiting for electric vehicles to charge, leaving more time to complete other tasks.

Financial Capital:

This system would help eliminate one of the largest criticisms of electric vehicles today, short range and long charge time. If this system is fully implemented across the country, there is no weight to this argument, and electric vehicles can take more market share away from combustion vehicles.

Manufactured or Real Capital:

The real capital of the RBX is in its value as a battery exchange station. The capability to rapidly exchange electric vehicle batteries, and get them back on the road within a minute saves people time, and in turn is worth money.

Natural Capital:

The natural capital of the RBX comes from the value to the earth of reducing the amount of fossil fuels used in transportation.

Costs for the project accrue during initial development, construction, and deployment, with benefits beginning to accrue once the project is in use. Additional costs will be accrued due to regular maintenance of the system, but these costs will be minimal due to design considerations requiring little maintenance.

To make the system usable in practice, construction materials to build the ramp into the ground would be needed, as well as running power to the system.

Cost of the system is difficult to estimate, as it has gone through many iterations, with many systems being reworked multiple times. Cost analysis for this iteration can be found in Tables 5 and 6 bellow.

| Item | Unit Price | Quantity | Total Price |
|---|---|---|---|
| Garage Door Opener | $150 | 1 | $150 |
| Plexi-Glass | $500 | 1 | $500 |
| Wood | $100 | 1 | $100 |
| Shutoff Relay | $3.00 | 1 | $3.00 |
| Actuation Relay | $1.00 | 1 | $1.00 |
| Total Cost | | | $754.00 |

TABLE 5: ESTIMATED ITERATION COST

| Item | Unit Price | Quantity | Total Price |
|---|---|---|---|
| Garage Door Opener | $200 | 1 | $200 |
| Plexi-Glass | $359.97 | 1 | $359.97 |
| Wood | $125 | 1 | $135 |
| Paint/Finishing | $50 | 1 | $50 |
| Shutoff Relay | $3.00 | 1 | $3.00 |
| Actuation Relay | $1.00 | 1 | $1.00 |
| Total Cost | | | 749.97 |

TABLE 6: ACTUAL ITERATION COST

Additional equipment required:

In addition to the components and materials required to finish the system, there were things needed to complete the work that are not included in the cost.

- Assorted Hand Tools
- Welder
- Drill Press
- Table Saw
- Band Saw

This equipment was available at facilities on campus to be used.

The RBX is currently a prototype, and is many years from making money. When the system is completed, it can be implemented and a fee can be charged for each exchange completed.

This iteration of the project was completed 5/27/2016, for a production version to be completed, there is one additional year of work needed. The RBX system should last many years without maintenance being required. When needed, the mechanical relays, actuators, and motors may need to be replaced. The cost of these components ranges from $1 - $200 depending on the component, with all wearable components in the system totaling around $600. The estimated development time of this iteration was 9 months, the complete project will require an additional year to be ready for use.

When this project ends, more improvements will be made to decrease total exchange time, increase reliability, and implement the project on campus.

## 4. If Manufactured on a Commercial Basis

The number of devices sold per year would greatly depend on the acceptance and integration of the RBX system with the current transportation systems. If public transportation vehicles utilized the RBX, sales could be in the thousands per year until an infrastructure to support all vehicles in service was created. If personal vehicles were to adopt the system, the number could be hundreds of thousands per year until the infrastructure was in place.

If mass-produced, the RBX system could cost approximately $5,000 each, with an additional $1,500 in installation costs. The estimated purchase price of each unit, installed, should be approximately $10,000. Assuming there are 10,000 units sold per year, and a profit of $3,500 per unit, a profit of $350 Million per year.

Operation costs of the RBX are mainly in the cost of electricity. Assuming $0.18 per kWh is charged, and the vehicle has a 60kWh battery pack, with an 80% discharge depth used every day, the cost of electricity comes to $8.64 per day. Adding in $150 per year of maintenance, the yearly operations cost of the system would be $3303.6.

## 5. Environmental

Environmental impacts of manufacturing the RBX include those to gain the raw materials, including steel, wood, copper, silicon, and rubber. These are offset by the reduction in fossil fuel use for transportation, as the system would encourage the use of electric vehicles. The reduction in quick chargers would also increase average battery life of electric vehicle battery packs, reducing the amount of recycling needed to reclaim materials used in battery manufacturing.

The system uses steel, rubber, and copper directly, and indirectly uses Lithium, or any element used in electric vehicle battery production when the system is put in use. The project can help improve air quality due to reduced use of fossil fuels, especially if the system is put in place with renewable energy sources. The system will impact any species that is currently affected by reduced air quality, and changes in the earth due to the use of fossil fuels for transportation.

## 6. Manufacturability

A major issue with manufacturing this system is that it is currently in a prototype stage, using a vehicle that is no longer being used. In order for this system to be implemented with current electric vehicles, a change in the design would be needed to make the battery easily removable, and exchangeable between vehicles.

### 7. Sustainability

The largest issue with maintaining the system is its many moving parts. There are many parts that rely on proper alignment, and being obstruction free. Since the system would most likely be used outdoors, the enclosure would need to be sufficiently maintained in order to keep water and debris from entering the system. Another challenge is the complex automation of the system, everything must be working fully for the system to function, if any part fails, the system as a whole will stop functioning, which could cripple a transportation system, if many vehicles are relying on one exchange station.

The project encourages the use of sustainable resources by making electric vehicles more practical for people not wanting to wait for long charge times. If the system is paired with renewable energy sources, such as solar and wind, the transportation system can transition into a renewable system.

Upgrades to improve the design include increasing the size of motors and actuators in order to decrease the overall exchange time. Upgrading the system to work with an electric vehicle on the market today would help bring it closer to being used in a practical situation.

Issues with upgrading the design are getting an auto manufacture to comply with the requirements of the RBX system. The battery pack of the vehicle would have to be remotely disconnect-able from the chassis, as well as be removable from the bottom of the vehicle. This would require a complete redesign of the vehicle.

### 8. Ethical

Ethical implications relating to this system are that it improves the practicality of electric vehicles for transportation. This means reducing the reliance on fossil fuels, helping preserve the planet. This would mean a reduction in the number of jobs that rely on the creation of fossil fuels, this reduction of jobs is necessary in preserving the environment, and can be offset by increased jobs in electric vehicle manufacturing and battery technologies.

## 9. Health and Safety

Health and safety concerns with this project relate to the scale of the system. The system relies on large moving parts, requiring heavy machinery to lift and move in excess of 1000 pounds of batteries. The batteries are also high voltage packs that are dangerous if not handled properly, or if punctured and the acid is allowed to contact a person. These safety concerns are addressed by enclosing the system so nothing can enter the area where the batteries move around, and by using smart battery packs that disconnect the battery voltage from the exposed terminals until the battery is in the vehicle or charger.

## 10. Social and Political

Issues associated with design, manufacturing, and use of the RBX are the shift from fossil fuel burring vehicles, to electric vehicles. Oil companies do not want this shift to occur, and will fight any changes proposed.

Stakeholders include people wanting to have an electric vehicle, but not wanting to deal with limited range without long charging stops, as well as electric vehicle manufactures wanting to make their products more appealing to potential consumers. The project would impact these parties, as well as fuel and oil companies, as it would lead to a reduction in the amount of their product that is used for transportation.

The project will benefit those who want the longer range electric vehicles, and those who want to preserve the environment, but would harm those who rely of the oil industry for work.

Equal access to the system would require the system to be widely accepted, as it takes a group of users to be able to sustain one station. The system would not be owned by individuals, but more like a gas station, where many people would utilize the system, and could spread the cost between the group.

## 11. Development

I learned how to use many new tools, as well as many skills during the course of this project they include

- Welding
- Fabrication Skills
- In depth knowledge of how a garage door opener works
- I learned how to balance scheduling tasks around critical points in the project

# References

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