Multi-Disciplinary Senior Design Conference
Kate Gleason College of Engineering
Rochester Institute of Technology
Rochester, New York 14623

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LVE: LAND VEHICLE FOR EDUCATION

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ABSTRACT

The Mechanical Engineering department at RIT has been working on developing a robotic platform that will introduce engineering concepts to freshman, while building upon their preexisting knowledge from high school math and science courses. Over the past few years, various senior design teams have worked toward developing such a robotic platform, with the Land Vehicle for Education, or LVE, being the most recent attempt. What makes the LVE unique is its ability to be connected to the Modular Student Attachment (MSA), a customizable assembly that is responsible for completing some sort of task. The purpose of this project was to manage the system level design components of the chassis, controls, and MSA in order to ensure customer satisfaction. A detailed testing plan was developed and carried out in order to verify that all specifications were met and to further guarantee that all customer needs were fulfilled. This paper details the process in which the LVE was designed and manufactured while also presenting an overview of the risk assessment and test results.

NOMENCLATURE

LVE: Land Vehicle for Education
MSA: Modular Student Attachment
WOCCS: Wireless open-source/open-architecture command and control system
RP1: Robotic Platform 1kg
RP10: Robotic Platform 10kg
RP100: Robotic Platform 100kg
DAQ: Data Acquisition
LV-1: Land Vehicle 1
MSD: Multidisciplinary Senior Design
RF: Radio Frequency
PCB: Printed Circuit Board

BACKGROUND

In the fall of 2006, the Mechanical Engineering department at RIT began developing the RP1, RP10 and RP100 platforms, along with motor modules and a Vehicle DAQ System. In 2009, an attempt to improve upon the RP projects was undertaken. The resulting LV-1 was designed be manufactured in larger quantities at a lower cost while still improving upon the aesthetics and durability of the previous Robotic Platform projects. Both projects were intended to aid in the education of engineering students throughout various disciplines and education levels. The LVE, on the other hand, has only one goal: to introduce freshman Mechanical Engineering students to various introductory engineering concepts in a way that will excite them and spark a lasting interest in mechanical engineering. In order to achieve this goal, the concept for the MSA was developed. The MSA is a platform that is the focus of the educational aspect of the LVE. The students will gain valuable design, CAD and machining experience as they construct the components that make up the MSA.

OVERVIEW

Customer Needs

One of the first steps in the design process was to identify the needs of the customer, which were to be satisfied by this project. In order to fully understand the desired outcome, individual meetings were held with Dr. Hensel, the head of the Mechanical Engineering Department, and Dr. Debartalo, the faculty member responsible for designing the course in which the LVE would be used. Through these meetings, one main goal was identified: the LVE should provide a valuable educational experience to the incoming mechanical engineering freshman in the fall of 2013.

Through further discussions, a substantial list of customer needs was identified. The following list is a summary of the most important customer needs:

1. LVE must be able to move about freely through the use of wireless controls.
2. LVE must be cost effective enough to be produced in larger quantities.
3. LVE must be well constructed and able to withstand repeated use.
4. LVE must be reliable, requiring minimal repairs and debugging.
5. MSA must incorporate design aspects from preexisting courses (Engineering Design Graphics & Materials Processing).
6. MSA must be complex enough to support small groups of students working at once.
7. MSA must build off of preexisting knowledge and be easily learned by students.

System Architecture

In order to make the LVE design and construction more manageable, it was broken down into three separate components: the chassis, the controls, and the MSA. Each team was then given their own specific components to design.

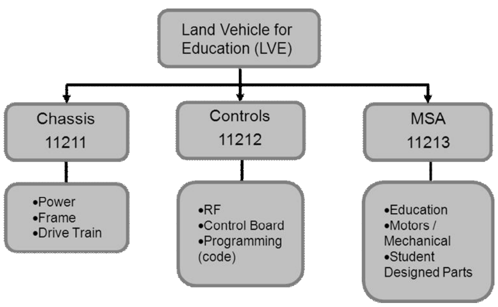


Figure 1: System Architecture

Chassis Team – The chassis team was responsible for the structure, upon which the entire LVE would be built. This includes the base plate and frame, as well as the drive motors and power supply for the entire LVE/MSA assembly. The chassis team was also responsible for providing attachment points for the MSA.

Controls – The controls team was responsible for the providing an interface between the LVE and the user. This included programming for motor control as well as the incorporation of the WOCCS RF solution.

MSA – The primary goal of the MSA team was to provide an educational experience for freshman Mechanical Engineering students. The MSA incorporates an assembly that the students can model in CAD and fabricate in the machine shop.

DESIGN

Mission Profile

The next step in the design process was to define a typical day in the life of the LVE. The mission profile describes a typical cycle of the LVE in a quantifiable way. This information can then be used by the sub-system teams to drive the design of the chassis, controls and MSA. The mission profile not only describes the actions of the LVE, but also identifies the type of environment in which the LVE will operate.

During a typical class session, the LVE will travel across a carpeted classroom in the Kate Gleason College of Engineering. The MSA will lift and carry a foam block from one end of the room to the other, where it will place the block on a shelf. During the completion of this task, it is assumed that the LVE will make several turns in order to maneuver around obstacles in the classroom. It is also assumed that several movements will be required in order to line up to MSA with the foam block. This entire process will then be repeated two additional times, until a total of three blocks have been moved.

The following charts define the velocity of the LVE, turns, arm extensions and claw grasps throughout a typical LVE cycle in which three blocks are moved.

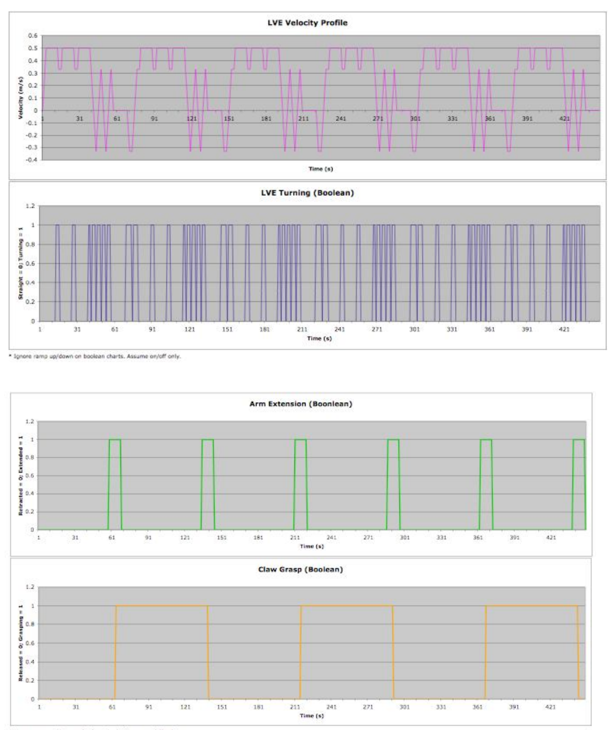


Figure 2: Mission Profile

Engineering Specifications

Once the Customer needs had been identified, it was necessary to translate them into quantifiable engineering specifications that could be tested in the future. The main purpose of the system level specifications was to ensure that the customer needs were satisfied. In order to accomplish this, the system engineering specifications included only aspects of the design that were directly visible to the customer. These specifications were divided into the following categories:

1. General – Mass production quantities and cost specifications.
2. Chassis – Weight, speed, size, durability, etc.
3. Power – Battery life and recharge time.
4. Safety – Temperature and shard edge standards

Interface Control

A critical aspect of the design was the interface control documents and the meetings related to the document. To manage the interfaces in the LVE they were divided into various categories and the systems they affected. The various interface types used to describe the system are power, mounting, communication, and volume. The two systems are then listed for example controls (to) and chassis (from). The labels of (to) and (from) help show which system has leverage in the relationship. While not all interfaces behave the same way, this general method allows for a quicker understanding when viewing the document of how the systems are interacting with each other. The value, tolerance, units, interface number, and a description exist for each of these interfaces further describing them in detail. A few of the interfaces also reference documents that are being handled by the various teams.

While the system attempts to deal with a complex issues in a simple manner, there have been issues regarding updates or changes that have not finding there way from or into the document. A good example of this is weight. Weight of the LVE was listed as 5 lbs on the system's team documentation, while it was 10 lbs on the Interface Control Document. It was unclear what the target was and this caused confusion over the target weight of the LVE.

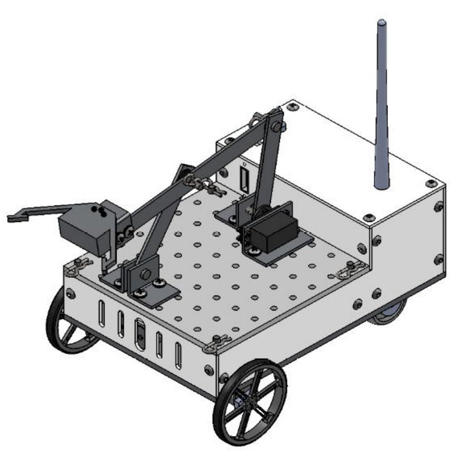


Figure 3: CAD Assembly

Mass Production Quantity Breakdown

One of the main requirements for this project is that that LVE be designed for mass production. In order to minimize the LVE mass production cost to the extent that would allow Dr. Hensel to purchase enough LVEs to support an entire quarter worth of students, the component breakdown is as follows:

- 10 LVEs (chassis and controls)
- 10 MSA control boards
- 30 MSA assemblies

This breakdown provides enough LVEs and controls to support one single class of students, while there are enough MSA assemblies to support an entire quarter's worth of students. Since the MSA was designed to be easily removed from the chassis, the LVEs can easily be used throughout multiple class sessions within the same quarter. The individual MSA assemblies will allow the students to keep their design intact from one class to another, reducing the breakdown and start-up time for each class session.

RISK ANALYSIS

QFD

The QFD is a house of quality, which shows the relationship between the customer need and the system specifications. The most important thing that came out of the document was that the required parts machinable by students satisfied a large portion of the customer's educational needs, accounting for 17.6% in comparison to all other specifications. Another area that received a relatively high weight was the budgetary aspect of the project, both for the prototype and mass production. Each had a relative weight of 5.8% by themselves. This clearly indicates the customer's desire for a cost efficient and highly educational LVE and MSA and that these are driving factors in the project.

A good example of this cost-efficiency emphasis is the motor and battery size. Both were reduced in order to meet cost targets, which sacrificed other areas of the LVE's performance. The amount of time the LVE can run was reduced along with the Speed of a fully loaded LVE. An aspect of functionality that was reduced was the charger type. The less expensive model has no indicator as to whether the LVE is charging or not. These sacrifices, while difficult, underscore how the certain customer requirements drove the design.

FMEA

The purpose of the Failure Modes and Effects Analysis (FMEA) is to identify any potential design and manufacturing flaws and develop mitigation strategies to deal with the potential failures. The FMEA served as a way to identifynot only potential problems within the design and construction, but also which failure modes would be the most detrimental to the system's ability to meet the needs of the customer. Based on the outcome of the analysis, greater attention was paid toward key aspects of the LVE.

During MSD I, which focused primarily on the design of the LVE, a functional FMEA was developed. This document focused solely on potential failures within the design itself. The following risks were identified as being the most critical:

- Improper voltage output to the controls – mitigated through IC meetings.
- WOCCS does not function as intended – mitigated through periodic updates from the WOCCS team and identifying alternative wireless devices.
- MSA tasks being too simple – mitigated by designing an MSA which incorporated the student design and manufacture of at least 5 components.

Once the design was complete, it was necessary to identify the risks associated with the actual construction of the LVE. This was done through the use of the design FMEA, which identified the following failure modes as most critical:

- Board interference – mitigated through the proper grounding of the metal enclosure.
- Metal enclosure is not properly grounded – mitigated through the implementation of separate return wires.
- Trace on the PCB is scratched – mitigated through careful handling of the board.

CTQ

The Critical to Quality shows how the top levels customer needs translate all the way down to specific engineering specifications. This document goes one step further than the QFD in terms of relating the various aspects of the LVE. While not creating anything new it acts as a guideline for the entirety of the project and helps to flush out where various specifications are coming from and how the design was driven. A good example is how the customer need to provide educational value to freshmen translated into having parts of the MSA that need to be designed and machined by freshmen and the requirements for these pieces.

BILL OF MATERIALS AND BUDGET

Prototype Budget

The critical aspect of this project was the budget. With only $500 for the prototype and $5000 for mass production it became the limiting factor in the design. The budget was developed with each team creating a bill of materials and then the System's team reviewing the documentation and purchasing the components through the RIT Mechanical Engineering Department. The greatest challenge in ordering the parts for the prototype was how certain aspects of the LVE design changed and parts were ordered from different suppliers then listed in the documentation. With pressure for getting the parts ordered and the construction on the LVE going parts were ordered without finalized documentation.

A good portion of the costs, over %10, came from just shipping and handling. This put even more pressure to reduce the cost of the components to $400. This also made reordering a very tenuous possibility, since any repeat shipping costs would add considerably to the total cost of the prototype. The controls team did not have much variability in terms of components so it was the Chassis and the MSA that drove down costs. The most expensive parts were the control boards, battery, motors, and gripper.

There were two issues that drove up the prototype budget to over cost. The first was one of the motors was defective and another needed to be shipped immediately. The second issue was that the bottom aluminum plate was too small and needed to be reordered. With these two issues the cost went from $473 to $511. Despite these issues the constraint of the $500 budget was addressed and to lower the cost even further would require an entire redesign.

Figure 4: Prototype Materials Breakdown:

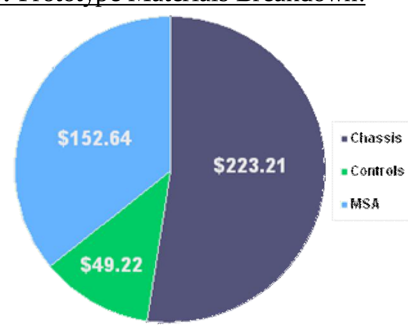
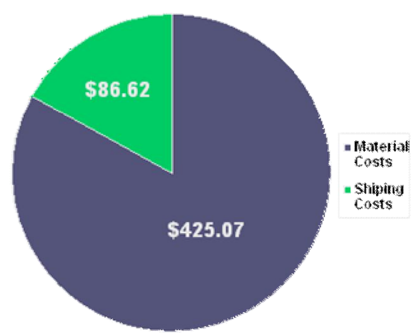


Figure 5: Prototype Shipping Breakdown:

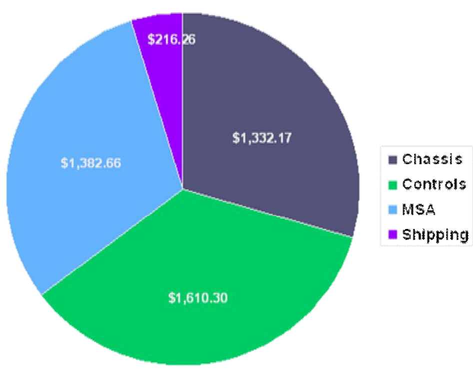


Mass Production Budget

The mass production aspect of the LVE was more challenging. Since the cost of a number of the parts shift constantly and the number needed compared to the number in a package it became very difficult to create a stable Mass Production budget. Since the mass production budget was based off of the prototype budget meeting the $5000 goal while having 30 units was a huge challenge. This is why it was suggested that the LVE and MSA costs could be reduced by ordering only 10 LVEs and 30 MSAs. This would still meet the educational requirement while also reducing the cost. Since the LVE was constructed by the time the Mass Production budget was fully considered it made it difficult to reduce costs by changing functionality or design.

Various ideas were developed to lower the cost to well under the $5000 goal. These changes included using a commercial version of WOCCS or redesigning it. The LVE was very heavy so reductions in weight would allow various other components to be reduced. Also the biggest change would be combining the control boards for the MSA and LVE. These changes would save over $1500 and make the final mass production cost $4541.39.

Figure 5: Mass Production Cost Breakdown:



SYSTEM TESTING

Test Plan

The system test plan is designed to verify that all of the engineering specifications have been met, therefore ensuring that all customer needs have also been met through the completion of this project. Each engineering specification must be tested, analyzed, observed or demonstrated in order to determine whether the final design passes or fails in meeting the engineering specification.

Each test plan details the strategy to be followed in performing the test. This includes a list of the equipment required, the steps to be followed in conducting the test and the pass/fail criteria for each engineering specification. The test plan is intended to contain enough detail that anyone, even someone with no prior knowledge of the LVE, can complete the testing procedures.

Test Results

Once the plan was developed, it was necessary to carry out each test. In order to do so, the required equipment was gathered and the LVE was tested. A total of nine engineering specifications required actual testing, while the rest were either demonstrated or analyzed.

The first test to be carried out was the drop test. Since there was a fear that the LVE would not be able to withstand a drop from the required three feet, an initial test was conducted from a height of only one foot. Upon the drop, the gears within one of the motors broke, causing the LVE to no longer be functional. Since the pass criteria required that it still function after the drop, the LVE failed this test and a replacement motor was purchased.

Figure 6: Broken Motor Gears

The second test conducted was intended to determine whether or not the educational requirements of the LVE were met. The best way to quantify this was through the use of a survey, which can be found attached to the detailed test plan (http://edge.rit.edu/content/P11211/public/Test%20Plan). The LVE was presented to ten mechanical engineering professors at RIT, and the student design and assembly process was explained. Once the faculty members were given time to ask questions, the survey was distributed and the results were collected. The overall approval of the professors was 80.4%, exceeding the required approval rating of 75% and providing the LVE with a passing grade.

The next test was designed to measure the weight of the entire LVE, which, for safety reasons, was not to exceed 15 lbs. With the use of a digital scale, the LVE and MSA combined were determined to be 9.9 lbs. Another measure to ensure safety was the maximum temperature restriction of 130 degrees Fahrenheit. Once the LVE was run through the mission profile three times to ensure maximum temperature, a thermocouple was used to take temperature readings at various locations. The maximum resulting temperature was found to be 89 degrees Fahrenheit, well within the acceptable range. The final safety precaution was the restriction of sharp edges. In order to minimize student injuries, the LVE was specified to have no edges which were capable of tearing through more than 3 sheets of tissue. Upon running three sheets of tissue over every exposed corner, edge and surface of the LVE and MSA, it was concluded that the LVE passed this test due to the fact that no more than two sheets were torn by any of the tested locations.

While safety was important in the design of the LVE, it was also necessary to produce a design that would be deemed impressive. In order to achieve this goal and increase functionality, a minimum speed of 0.5 mph was required. This was tested by placing two pieces of tape five yards apart and measuring the time it took the LVE to travel from one piece of tape to the other. The LVE was allowed a minimum distance of 2 yards prior to the first piece of tape to ensure that the maximum speed was reached prior to the start of the time recording. After three trials, the average speed of the LVE was calculated to be 0.86 mph, exceeding the minimum requirement.

A turning radius test was designed to ensure maximum mobility of the LVE. The turning radius was not to exceed one foot. In order to measure this, a marker was taped to the LVE and it was placed in the center of a 3 ft by 3 ft piece of paper. The LVE was then turned in a complete circle and the radius was measured. The LVE passed this test with a turning radius of only two inches.

Finally, it was necessary to test the battery life at full charge, as well as the recharge time for a fully depleted battery. The purpose of these tests was to verify the ability of the LVE to last for an entire class session and to be recharged in time to be used by a second class in the same day. The LVE was started with a full battery and run continuously for 90 minutes, the approximate amount of time it would be used in a classroom setting. At the end of 90 minutes, the voltage of the battery was measured to be 7.2 volts. This is above what is considered to be a fully drained battery of 7.0 volts, thus passing the test. The LVE was then run until the battery level dropped below 7.0 volts. Once the battery was fully depleted, it was plugged in to charge. Every ten minutes the battery was unplugged and allowed to rest for 60 seconds, the voltage was then measured. This was repeated until the voltage reached 8.0 volts, which indicates a full charged. This method resulted in a recharge time of 70 minutes, significantly less than the maximum allotted recharge time of four hours.

Test	Pass/Fail Criteria	Status	Actual Performance
Drop Height	Still function as intended when dropped from 3ft	Fail	Motor gears broke upon a 1 ft drop
Educational	At least 75% approval from faculty survey	Pass	Average faculty approval is 80.43%
System Weight	Weighs at most 15 lbs	Pass	LVE and MSA assembly weighs 9.9 lbs
LVE Speed	Maximum speed is greater than 0.5 mph	Pass	Average system speed after 3 trials was 0.86 mph
Turning Radius	Less than 12 inches	Pass	Turning radius is 2.3 in
Battery Life	At least 90 minutes	Pass	After 90 minutes of continuous operation, 7.2V remained
Recharge Time	Less than 4 hours	Pass	Battery was fully charged in 70 minutes
Surface Temperature	Never exceeds 130 deg F	Pass	The highest Temperature (89 deg F) was measured at the drive motors
Sharp Edges	No edges or corners tear through more than 3	Pass	No more than 2 sheets were torn by any corner or edge

Figure 7: Test Results

The next step in the testing process was to analyze the engineering specifications that could not be directly tested. First, the quantity of LVEs and MSAs that could be mass produced within the budget restrictions was analyzed through the use of a detailed bill of materials and quantity breakdown. Based on this analysis, it was determined that 10 LVEs and 30 MSAs could be produced. This fulfills course requirements as described in the mass production quantity breakdown. Furthermore, the mass production bill of materials was also used to determine whether or not the mass production would fall within the overall budget of $5,000. The LVE passed this test with an estimated mass production cost of $4,541.39, which includes an estimated shipping cost of 5%. The prototype cost was also analyzed and compared to the target of $500. Due to the last minute purchase of a replacement motor, the LVE prototype came in over budget at $511.69.

Also analyzed were the height and base area of the chassis. In order to minimize the space required for storage, the chassis was specified to be no taller than 8 inches with a base area no larger than 144 square inches. The chassis passed this test with a height and base area of 7 inches and 125 square inches respectively.

The final analysis was to determine the total time required to construct the LVE. The specification requires that the LVE be completely fabricated in less than 60 man hours in order to allow for the timely construction of the mass produced LVEs. Each team member was asked to estimate the total time that they spent constructing the LVE and this time was reduced by 15% to account for time spent troubleshooting. The time to construct the LVE was ultimately determined to be approximately 30 hours.

Test	Pass/Fail Criteria	Status	Actual Performance
Quantity of LVEs	At least 10 mass produced LVEs	Pass	Mass production budget accounts for 10 LVEs
Quantity of MSAs	At least 30 mass produced MSAs	Pass	Mass production budget accounts for 30 MSAs
Mass Production Cost	Less than $5,000 deployment cost	Pass	Final Mass production budget estimates a cost of $4,541.39
Prototype Cost	Less than $500	Fail	Final cost is $511.69 (over budget due to shipping costs for the replacement motor)
Chassis Height	Less than 8 inches	Pass	Chassis height measures 7 in
Chassis Base Area	Less than 144 square inches	Pass	Chassis base area measures 125 square inches
Time to Construct	Less than 60 man hours	Pass	The LVE took approximately 30 hours to construct.

Figure 8: Analysis Results

The final step in the testing process was the demonstration of several engineering specifications. The first demonstration was the number of parts to be machined by the students. A minimum of 3 parts were required to be machined by the freshman in order to provide enough hands on activity for each student. In this demonstration, the MSA components were disassembled and the parts to be designed by the students were set aside and counted. It was determined that a maximum of 8 parts could potentially be designed and fabricated by the students. This quantity may be reduced by the instructor based upon the size of the group or the amount of time allotted for the MSA construction.

In order to minimize the complexity of the design, a maximum of five hand tools was specified in the assembly of the MSA. This was demonstrated by starting with the disassembled MSA and completely assembling it. The hand tools required to complete this construction were then counted. Only two hand tools were found to be necessary.

The LVE was to be designed with the environment in mind. For this reason, the material waste was to be restricted to no more than one lb. The waste from production was collected by each subsystem and the total waste was weighed. The LVE failed this test with 1.7 lbs of material requiring disposal.

The final demonstrations were intended to guarantee the timely assembly of the mass produced LVEs. For this reason, the lead time for parts was to be no more than two weeks, the number of machined parts per LVE was not to exceed 20 and there were to be no custom mechanical components. Due to the high lead time for the PCBs, the LVE did not meet the two week maximum requirement. The number of machined parts was, however, within the 20 part limit with a total of 17 parts, and the LVE contained no custom mechanical components.

Below is a summary of the demonstration results:

Test	Pass/Fail Criteria	Status	Actual Performance
Student Machined Parts	At least 3 student machined parts	Pass	There are 8 parts that can be made by the students
Hand Tools Required by Students	No more than 5 hand tools required	Pass	A maximum of 2 handtools were required
Material Waste	Less than 1 lb of material waste	Fail	1.7 lbs of material waste was produced
OTS Part Lead Time	Less than 2 weeks for parts to arrive	Fail	All parts arrived within 2 weeks except for the PBCs
Machined Parts per LVE	No more than 20 custom machined parts per LVE	Pass	The LVE contains 17 custom machined parts
Custom Order Components	No custom ordered mechanical parts	Pass	No mechanical components were custom ordered

Figure 9: Demonstration Results

CONCLUSIONS

The LVE was intended to educate freshman mechanical engineering students in a manner that allows for personal creativity and will spark an interest in the field. This was accomplished through the incorporation of a block moving competition that was intended to be fun as well as educational. The prototype is capable of lifting and moving blocks from one place to another through the use of wireless controls with a range that exceeds the length of a typical College of Engineering classroom.

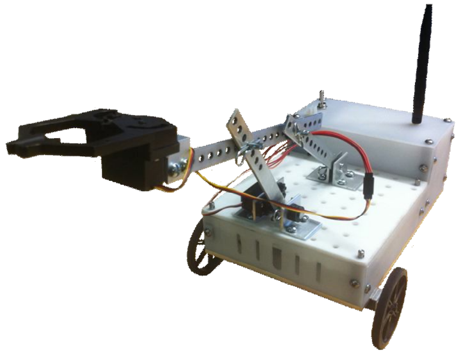


Figure 10: Completed LVE Prototype

Although the end result is a functioning LVE and MSA, not all engineering specifications were met. In retrospect, many of the engineering specifications developed had no specific relation to the needs of the customer and therefore could have probably been eliminated from the start. All of the engineering specifications that related directly to a customer need were met, with the exception of the drop test. A significant factor in the failure of the LVE to pass this test was the reduction in robustness caused by the limited budget. Through careful evaluation, it is likely that other changes in the LVE design would result in a more cost effective and durable robot. This failure could have been avoided if the budget was monitored more closely throughout the entire design stage, rather than trying to make hasty price cuts just before ordering parts.

Another way in which this could have been avoided is through more open communication between each team. Although the interface control meetings were useful, it was difficult to communicate between the different fields with only one member from each group present. In the future, meetings with all members of each group present would be of more help.

ACKNOWLEDGMENTS

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