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2019 IEEE SoutheastCon Hardware Competition: A Systems Engineering Approach

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2019 IEEE SOUTHEASTCON HARDWARE COMPETITION:
A SYSTEMS ENGINEERING APPROACH

A Capstone Project Presented in Partial Fulfillment
of the Requirements for the Degree Bachelor of Mechanical Engineering
with Honors College Graduate Distinction at
Western Kentucky University

By
Emily L. Sage
May 2019

*****

CE/T Committee:
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2019
I dedicate this thesis to my parents, David and Laura Sage, who support me through all of my endeavors.
ACKNOWLEDGEMENTS

This work was made possible by my faculty advisor, Dr. Mark Cambron, who guided our team through the project. I would also like to acknowledge Dr. Julie Ellis, who attended the competition with us. The WKU engineering department provided countless resources. Lastly, Professor Robert Choate built my understanding of Systems Engineering.
VITA

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PRESENTATIONS

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ABSTRACT

The Institute for Electrical and Electronics Engineers (IEEE) Huntsville section invites college students to participate in their annual SoutheastCon Conference. Western Kentucky University sends a team of engineering students to the hardware competition, an opportunity for students to design and build autonomous robots. The 2019 hardware competition called for students to develop a robot that could collect and sort debris by color.

This thesis outlines the project lifecycle of the WKU 2019 SoutheastCon robot with an emphasis on implemented systems engineering tools and techniques. Systems Engineering is an interdisciplinary approach to project management that focuses on treating the overall project system as a combination on subsystems. A Systems Engineering approach was applied to the 2019 SoutheastCon robot senior project in an effort to simplify and navigate the complexity of the competition challenge. This thesis will outline the competition description, rules, and guidelines to develop an understanding of the motivation for design decisions. It will outline the specifications, requirements, and design decisions directly influenced by the competition handbook. It will also discuss the prototype and final fabrication of the robot. The thesis will conclude with insight on competition performance, and how the level of adherence to Systems Engineering technique implementation may have impacted the team’s success.
SECTION 1

COMPETITION THEME

The Institute of Electrical and Electronics Engineers (IEEE) is a global, professional society of engineers who aim to promote technological advancement for the benefit of humanity. The Huntsville section of IEEE consists of over 1200 IEEE members located in Huntsville and Northern Alabama. Among other events, the IEEE Huntsville section hosts SoutheastCon—“the annual Region 3 Technical, Professional, and Student Conference,” an influential event encompassing both the Southeastern United States and Jamaica. I was a member of the WKU senior project team who attended the 2019 event as participants in the student hardware competition.

The 2019 IEEE SoutheastCon Hardware competition is based on the concept that it is the year 2069 and mankind has colonized the Moon and Mars. There is daily space travel between the Earth, the Moon, Mars, and space-based hotels (spacetels). The increased space travel has resulted in a hazardous amount of debris. To maintain safe navigation, mankind is seeking a device to clear the debris from space.

The space-based scenario will be modeled by a flat, 8ft. by 8 ft. carpet playing field. The field is divided into two zones by a circle called the orbital line. Zone 1, outside of the orbital line, includes the four, color-specific corner squares. The corner squares are where debris will be disposed. Zone 2, within the orbital line, encompasses a central column and is divided into four equal, color-specific quadrants. The playing field is modeled in the following Figure 1.
Debris on the field consists of 2” by 2” wooden cubes and 2.5” diameter plastic balls. There will be two cubes and one ball of each of four colors: red, blue, green, and yellow. These colors coordinate with the four color quadrants on the field. At the beginning of each round, the debris will be placed within Zone 2 at random. The goal of the game is to leave a randomly specified home base, collect all debris and dispose of it in the corresponding bases, return to the original home base, and raise a flag. Points are also awarded for orbiting the central post while within Zone 2. Points are deducted for collisions with Spacetels, represented by flashing lights located on the intersections of the quadrant lines with the orbital line. All of the tasks must be completed within a 3-minute time frame. The game is point-based, so success will be defined by obtaining as many points as possible.

Figure 1 illustrates the hardware competition playing field. This model shows the division between zone 1 and zone 2 by the orbital line. The color-specific home bases are located in zone 1. The debris is scattered in zone 2.
The point system is outlined as follows:

- 5pts - Leave home base and enter Zone 1
- 5pts - Cross the orbital line into Zone 2
- 5pts - Each counter-clockwise orbit within Zone 2
- 10pts - Each Debris removed from Zone 2
- 10pts - Debris placed in home base
- 10pts - Matching the color of the debris to the color of the corner square
- 10pts - Finish in home base
- 25pts - After removing debris, raise onboard flag while in home base
- Avoid Collisions with Spacetels (Each collision is -10pts)

Creating a device that could successfully perform in the IEEE competition was a multifaceted challenge. The device needed to accomplish multiple tasks, conform will multiple specifications, and integrate the concepts of multiple engineering disciplines. With a blind approach, the project was daunting. However, our team had a host of resources for simplifying the design and fabrication process. We implemented Systems Engineering concepts from the WKU ENGR 400 Principles of System Engineering course to manage the project. Systems Engineering is an interdisciplinary approach to the project lifecycle used to simplify complex systems. Systems Engineers view the overall system as a combination of subsystems, with focus on both those individual subsystems and the interfaces between them. The Systems Engineering techniques applied to the design process act as a map for the project execution. Though there are countless Systems Engineering tools, this thesis will explore the use and impact of 7 on the
project management of the 2019 SoutheastCon robot. These 7 consist of specifications, requirements, scope, concept of operations, a functional flow block diagram, a Pugh matrix and a Gantt chart. Developing and analyzing this Systems Engineering documentation on the 2019 SoutheastCon robot senior project will provide a realistic case study for understanding the Systems Engineering concepts and their impact on the project lifecycle.
SPECIFICATIONS

Specifications are tangible constraints either stated by a project stakeholder or derived from the product's environment or use. Specifications are non-negotiable aspects of the product. There is typically only one way to successfully adhere to a specification. ¹ For the 2019 SoutheastCon robot, we derived our specifications from constraints outlined in the competition rule book.

The specifications for the 2019 SoutheastCon robot are as follows:

- The robot must be a single, self-contained unit.
- The robot is limited to a maximum size of 9" by 9" by 11" in the starting square (including the bumper) and can expand a maximum of 3" in length and 3" in width while not in motion.
- Debris are 2" cubes and 2.5" balls.
- The robot must start with a manual button or a switch.
- The robot functions autonomously.
- A bumper is 1" high on a vertical surface must be present and covers at least 1.5" to 2.5" above playing field.
- The bumper must cover 80% of the outermost perimeter while robot is moving.
- The robot includes a flag with the school's logo. ³
Clearly stating our specifications before beginning the design process was significant in avoiding conceptual designs that would not qualify for the competition. Our specifications also became an important reference during prototyping and fabrication to ensure that we remained within the competition guidelines. The specifications regarding size constraint proved to be one of the biggest challenges for both conceptional design and fabrication. Fitting the frame of the robot into the size constraint of 9” x 9” 11” did not leave significant room for both internal components and debris storage. Thus, several component decisions were based on the need to meet this restraint. An immediate concern was the motors needed to drive the wheels. Motors are commonly designed with the shaft in parallel and concentric with the motor body. These types of motors would require great horizontal distance from the motor body within the collection cavity of the robot. They would, therefore, take away from vital debris storage space. To circumvent this issue, we selected right angle gear motors to drive the wheels. Right angle gear motors use an internal gear system to drive a shaft that is perpendicular to the motor body. This allowed us to mount the motors so that the motor body laid against the robot wall and took up vertical distance rather than horizontal distance. The selected right-angle gear motor is shown in Figure 2 below.

**Figure 2** shows the right-angle gear motor selected to drive the wheels. An internal gear system allows the shaft to operate perpendicular to the body of the motor. This allowed us to lay the motor against the frame of the device so that it utilized less internal storage space. ([Image from https://www.amazon.com/Yootop-120RPM-Torque-Turbine-Reduction/dp/B07G8TTVLQ])
REQUIREMENTS

System requirements define how the system will operate and in what environment it will operate. They are goals and guidelines for the final deliverable that provide a foundation for the planning and production of the desired product. Requirements are different than specifications because they can typically be met in a multitude of ways. The challenge in design is to use innovate concepts to meet requirements while still adhering to the specifications. The requirements are extremely important because they will be referred to throughout the entire design process, so they should include all necessary aspects of the device. A Systems Engineering technique for writing requirements is to write SMART requirements. SMART is an acronym for specific, measurable, achievable, relevant, and traceable. Specific calls for the requirement to include enough detail to prevent any uncertainty about its meaning. Measurable means that there must be a way to know when the requirement has been met. This ensures that requirements can later be verified through testing and analysis. Attainable assures the requirements can realistically be met. Relevant means that the requirement is clearly addressing a stakeholder need. Traceable means that the requirement can be linked back to the stakeholder need that it fulfills, the components that implement it, and the test that verifies it has been met. These SMART attributes ensure that the requirements are appropriately focused to drive a successful design. They also ensure that the project engineers are able to meet the requirements and prove that they are met. For the 2019 SoutheastCon robot, the requirements were derived from the game play rules and specifications outlined by the competition sponsors.
The requirements for the 2019 SoutheastCon robot are as follows:

- The robot shall be fully autonomous.
- The robot shall collect all 12 pieces of debris.
- The robot shall detect debris color.
- The robot shall dispose of debris into corresponding base.
- The robot shall not damage the playing field or cause interference with the function of other.

**SCOPE**

A scope outlines the boundaries of the project, thus clarifying the responsibilities of the project team. The scope includes needs, goals, objectives, assumptions, missions, operational concepts, constraints, and authority & responsibilities. Needs are the situational factors that motivate the project execution—they are ultimately the reason the project has begun. Goals are the project team’s desired results. Objectives are necessary project outputs. Assumptions are made about the project motivation and environment which may impact the project execution. Mission is the overall, general desired result of project completion. Operational Concepts offers a step by step analysis of the device’s function. This is similar a Concept of Operations (the next Systems Engineering tool) but requires less emphasis on user interface. Constraints are essentially the system specifications to which the team must adhere. Lastly, Authority & Responsibilities breaks down the tasks that both the whole team and individual team members are responsible for. This will avoid failure due to misunderstanding of work delegation.
The 2019 SoutheastCon robot scope is as follows:

- **Needs**—The playing field is littered with wooden cubes and plastic balls that represents space debris. The debris has become hazardous, so we need to create a device that can efficiently collect the debris and dispose of it in color coded bases. Based on the nature of the task, the device needs to focus heavily on navigating the field and color detection of the debris.

- **Goals**—Based on the competition concept, we are aiming to develop a device that autonomously navigates the playing field to collect debris while avoiding collisions with walls and spacetels. Additionally, we aim for the robot to detect the debris’ color and accurately dispose of it in the corresponding color base. The device should perform consistently and efficiently with minimal maintenance required between game rounds.

- **Objectives**—The device must perform autonomously after the flip of a switch. It should collect debris and detect and sort by color while avoiding collisions. At the end of the allotted 3 minutes, the device should return to its beginning home base and raise a flag.

- **Assumptions**—To be qualified for the competition, we must assume that all rules and specifications set forth by the 2019 IEEE SoutheastCon sponsors are unwavering. We should also assume that the device must perform all tasks and that our competitors’ robots will do the same.

- **Mission**—The mission is to design a robot that will be successfully competitive and meets all specifications and requirements set forth by the 2019 IEEE SoutheastCon.

- **Operational Concepts**—The device will power on and complete the entire task with the manual flip of a switch. The device will collect debris and dispose of them in their correlating color-coded home base. The device will orbit the center post. Once collecting
all debris, the device will return to its original home base and raise a flag. The device must complete all tasks within a 3-minute time frame.

- **Constraints**—The device must fit within the size restraint of a 9” x 9” base with an 11” height. The device may extend an additional 3” outside of the size restraint only when not in motion. The device must include a bumper around at least 80% of the device frame. The bumper must be the outer most surface, be at least 1” wide, and sit 1.5” to 2.5” from the bottom of the device. The device must be fully autonomous, meaning it will perform all tasks with the manual flip of a switch. The device must be able to operate safely and without collisions on the specified playing field.

- **Authority & Responsibilities**—Conceptual design will be developed as a team. Mechanical components will be fabricated by the mechanical engineering students and electrical systems will be developed by the electrical engineering students. Mechanical and electrical integration will be performed as a group.

  Defining all of the scope factors for the robot before beginning the design process aided our team in avoiding misunderstandings or miscommunications about the expectations for the team and its members. The scope gave us unified goals and a clear path to reach those goals.
CONCEPT OF OPERATIONS (CONOPS)

A concept of operations (ConOps) was developed to specify the external interface interactions of the device. The ConOps acts as an instruction manual for device users. Since the IEEE robot was required to be fully autonomous, the user interaction with the device is minimal. Thus, the ConOps is fairly simple. However, it was still important to develop a ConOps before the competition to ensure that all team members are confident in how the device is intended to be handled and activated. This prevents confusion, mishaps, and wasted time during the competition. It also makes the device usable by non-team members if desired.

The ConOps for the 2019 SoutheastCon robot is as follows:

1. The device should be placed in the specified home base.

2. The user will flip the switch to the “on” position to activate the device.

3. Without further interaction from the user, the device will strategically navigate the course to collect debris, sort debris into the corelating home bases, orbit the playing field, return to the original home base, and raise a flag.

4. All motors within the device will shut off upon completion of the task or after an operation time of 3 minutes.

5. The user will flip the switch back to the “off” position. At this time the device can be removed from the playing field.
FUNCTIONAL FLOW BLOCK DIAGRAM

Based on the foundations of a Systems Engineering approach, our design process began by decomposing the overall system into a set of subsystems. The core subsystems included collection, sorting, storage, release, and navigation. The priority hierarchy of the subsystems evolved throughout the design and fabrication process. Ultimately, collection and navigation became the top two priorities. The priority hierarchy was based heavily on the point system of the competition and the specification restraints set out in the rules. Our personal knowledge and skill set also influenced the priorities; we focused on systems that were more achievable with our current abilities.

A beneficial Systems Engineering tool for decomposing the functional subsystems of a system is a Functional Flow Block Diagram (FFBD). An FFBD is a multitier flow chart that outlines the step-by-step function of the product from start to finish. The function is decomposed into more detailed sub-functions as the levels go down. Developing a FFBD was especially important for our team because it addressed the challenge of integrating independently developed mechanical and electrical systems. The FFBD reminded team members of the order of operations of the mechanical and electrical components and, consequently, when those components when interact.
The FFBD for the 2019 SoutheastCon robot is shown in the following *Figure 3*.

*Figure 3* is the Functional Flow Block Diagram (FFBD) for the 2019 SoutheastCon robot. The order of function is read from left to right as indicated by the arrow at the bottom of the chart. The levels provide more detail about the function as they descend.

**PUGH MATRIX**

Since the collection system was determined to the be the top mechanical priority, we considered a number of designs. Each team member contributed a collection concept. The concepts were submitted as sketches and described at a design meeting. This resulted in four contenders for the collection system design. The design options were titled as such: Fork Lift, Paddle Wheel, Zamboni, and Scoop. To objectify the comparison of the four designs, we utilized a Systems Engineering tool called a Pugh Matrix. A Pugh Matrix is a tool used to aid decision making by quantifying and analyzing the strengths and weaknesses of each design based on a
selected base design, also called the datum. The design concepts are rated and compared based on a list of design criteria. The datum, which can be selected at random, is given a score of 0 for all criteria, and the rest of the designs are rated as equivalent to (S), greater than (+), or less than (-) the datum for each criterion. These ratings are summed and the design with the highest score is typically selected. One benefit of a Pugh matrix is that every design earns a score, so if the top scoring design fails, the team can move to the second highest score, etc.

For the 2019 SoutheastCon collection system Pugh Matrix, we selected the following design criteria: space, reliability, simplicity, cost, and speed. Space was defined as the physical surface area of the collection system. Due to extreme size constraints on the overall device, it was very important to us to limit the space delegated to each subsystem. Therefore, designs scored higher for space if they could be accomplished with less surface area. Reliability was defined as the likelihood of the collection system to operate without getting stuck. The system would face both force from encountered debris and possible friction and obstacles from the carpet and tape playing field. Designs scored higher if they showed ability to overcome these challenges and operate with consistency. Simplicity was defined by having the least moving parts. We saw benefit in selecting a simple design because it leaves less room for failure or error. Each moving part within the system has the risk for individual error which would affect the overall system performance. Minimizing the number of parts would therefore minimize the overall risk. Cost was estimated based on anticipated materials and fabrication processes. We sought to minimize cost since the project was on a budget allotted by the engineering department. Minimizing cost for each subsystem will allow for unexpected costs without exceeding the total budget. Therefore, designs scored higher if they had a lower cost estimate. The last criteria, speed, was defined by how quickly the system could collect debris. Speed of
collection was important because the competition was timed. Designs that were anticipated to collect debris more quickly were, thus, scored higher. Based on these 5 criteria, our zambonie design scored the highest. This design would consist of 2 spindles rotating inwards to collect debris. The Pugh Matrix for the collection system is shown in the following *Figure 4.*

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Space</th>
<th>Reliability (Likelyhood to get stuck)</th>
<th>Simplicity (Least moving components)</th>
<th>Cost</th>
<th>Speed</th>
<th>Sum 0</th>
<th>Sum +</th>
<th>Sum -</th>
<th>Total Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fork Lift</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-2</td>
</tr>
<tr>
<td>Paddle Wheel</td>
<td>-</td>
<td>+</td>
<td></td>
<td>0</td>
<td>+</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Zambonie</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Scoop</td>
<td>+</td>
<td>-</td>
<td></td>
<td>0</td>
<td>-</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-</td>
</tr>
</tbody>
</table>

*Figure 4* shows the Pugh Matrix developed for the selection of the collection system. The matrix compares a fork lift design, paddle wheel design, zambonie design, and scoop design based on space, reliability, simplicity, cost, and speed. The zambonie design was selected since it has the highest overall score.

A Pugh Matrix is useful when making a selection decision from a reasonable number of options. For the 2019 SoutheastCon robot, the Pugh Matrix was an important tool in making a decision without personal conflict. The matrix quantifies the comparison, leaving little room for argument about the final result. It also forced us to consider what criteria were important—a prioritization that remained relevant for the remainder of the project execution.
**GANTT CHART**

A Gantt chart is a horizontal bar chart used to illustrate the timeline of a project. The tool is named after its inventor, Henry Gantt. The chart is developed in the beginning of the project lifecycle, before any design or fabrication has begun. Completing the chart early allows it to act as a schedule for the project execution. The chart should be followed strictly and updated regularly to avoid failures due to lack of time.

The Gantt chart for the 2019 SoutheastCon robotics team is shown in *Figure 5*.

![Gantt Chart Image]

*Figure 5* is the GANTT chart for the SoutheastCon 2019 robot. The left-hand column lists the individual tasks that need to be completed throughout the project lifecycle. The top row lists the weeks within the project timeframe. The cross-sectional squares are initially filled in according to when each task is planned to be completed. As tasks are actually completed, the squares are updated. Once the project is rolling, squares are also filled in with forecasted completion. As outlined by the key, planned competition is in pink, actual completion is in green, and forecasted completion is in orange.

The main deadline driving the team’s Gantt chart was the competition date of April 13, 2019. The inability of team members to perform work during winter break also had a major impact
on the timeline. This eliminated over a month of available time. The initial Gantt chart allowed reasonable time for design and preparations, and also ample time to test the device and perform necessary adjustments. Unfortunately, the Gantt chart was the tool that our team utilized the least. Our team did not adhere to the timeline. The final device was completed with only a few days to test before leaving for the competition, as opposed to the Gantt Charts promised 7 weeks of testing and modifying. A majority of testing was performed at the competition, which left little ability to perform major modifications. Stricter adherence to the Gantt chart would have greatly increased the team’s success at the competition.
PROTOTYPING

Since our team was composed of both mechanical and electrical engineers, we anticipated the greatest design and fabrication efficiency from focusing on the mechanical systems and electrical systems separately. We developed the two systems in parallel with constant communication to ensure smooth integration in the final steps of the project. Therefore, we created two initial prototypes: a mechanical prototype and an electrical prototype. Ultimately, the two prototypes were best represented by different mediums, and thus the segregation of the system prototypes proved necessary.

The mechanical components within the device were most constrained by size specifications. The mechanical prototype, therefore needed to provide spatial awareness. Since the focus of the mechanical prototype was to visualize physical size relations, we began with a virtual prototype. The design was created in Solidworks, a 3D modeling software. All components were drawn to size to ensure accurate size relationships. The model gave us reasonable size ranges for the wheels and collection spindles. The model also revealed that the storage space, after considering all mechanical and electrical internal components, would be even smaller than anticipated. We created models of the debris in Solidworks and placed them within the assembled design to determine the amount of debris that could be stored at one time.

At this point, it was clear that we would not be able to collect all debris at once. In fact, we determined that it was most realistic to collect only a few pieces at a time. Although this would create new challenges related to time constraints, it would eliminate the entire function of sorting. We could now focus more time and budget into the color detection, navigation, and collection systems instead. Rather than collecting debris at random, we would detect color externally and
navigate to indicated colors. This removed the burden of attempting to force so many functional subsystems into such small space.

The Solidworks model aided a smooth transition to fabrication by acting as a blueprint for the robot frame. An exploded view of the body offered a visualization of the individual pieces of wood needed to assemble the entire body. Since the device was modeled to scale, the exploded view model even specified dimensions for the individual pieces. We were, therefore, able to measure and cut our wood to the specifications of the Solidworks model, then assemble the pieces to fabricate a device that was safely within our size constraints. The collection system, however, still needed to be physically modeled to prove some degree of efficacy before beginning device fabrication. We selected foam spindles which would be a consideration for the final device and attached them to two drills. A team member held them at varied distances as we forced debris to approach them. This simple testing quickly proved that the foam spindles were capable of collecting the debris when supplied with sufficient torque. The specific foam spindles performed so well that they were selected as components for the final design.

The initial Solidworks model of the device and the derived exploded view are shown in 

*Figures 6* and *7*. 
Figure 6 is the initial Solidworks model of the robot body. The model is drawn to size to provide a blueprint for fabrication of the wooden frame. Drawing to size also allowed appropriate sizing of the wheels and collection system. Even as just virtual, this initial model revealed that meeting the size restriction was going to be a major challenge.

Figure 7 is the exploded view of the initial Solidworks model of the robot body. Since the model was drawn to size, the exploded view showed the shapes and sizes of the individual pieces that needed to be cut.
FABRICATION

The frame of the body was cut and fabricated based on the Solidworks exploded view dimensions. The frame of the robot is shown in Figure 8 below.

Figure 8 is the frame of the robot’s body. This was the first stage of fabrication. At this point, the spindles, wheels, and electronic components had yet to be added. The device was fabricated with the anticipation of these additions, though. The top was attached with hinges so that once electronic components were placed inside the robot frame, they could be easily accessed for repairs of replacements.
The mechanical components were then added to the frame. This includes the spindles and their motors, wheels and their motors, and a castor added for balance. This updated version of the robot is shown in Figure 9 below.

*Figure 9* is robot body with all mechanical systems attached. At this stage, the robot was ready for integration of mechanical and electrical systems.
The final stage of fabrication was defined by integrating the mechanical and electrical systems. This consisted of mounting the electronic components within the robot. There were two key concerns to bear in mind during the integration: 1) the internal electronic components needed to be safe from collision with debris and 2) the Pixi camera, our color detection camera, needed to be mounted so that it had optimal visual input of the field. To mitigate the first concern, we simply mounted a piece of wood above the collection storage space and mounted the electronics on the wood. We attached the electronics with industrial grade Velcro so that they remained adaptable and replaceable. To optimize the view of the Pixi camera, we mounted it near the top of the robot, but at a downward angle.

The final addition to the robot was the bumper. The competition rulebook offered strict, but relatively unclear specifications regarding the bumper. Early in our design process, we ranked the bumper as low priority. We assumed it would be an easy addition at the end of the fabrication process. We did not even include a bumper in the initial Solidworks prototype. However, we quickly realized that we had not allowed enough room to add a bumper while remaining within the overall dimension specifications. As a result, we had to disassemble the entire frame and modify its size. In hindsight, the bumper should have been one of the main factors driving the design. This error on our behalf solidified the importance of proper planning before fabrication. The final robot is shown in Figure 10.
Figure 10 shows the final robot. The device was completed by adding a foam bumper, the starting switch, a flag attached to a servo, and the power supply. The power supply was strategically mounted at the back of the frame to prevent the robot from tipping forward when in motion.
SECTION 4

TESTING & CONCLUSIONS

Our lack of adherence to the Gantt chart greatly hindered our ability to comply with another significant system engineering tool: testing. We developed SMART, and specifically measurable, requirements so that we could validate our success with testing. Our initial Gantt chart had left 7 weeks for testing the robot and modifying it accordingly. This would have been sufficient time to determine design flaws and test several strategies. However, we did not allow ourselves this testing time because we spent longer than anticipated on design, thus beginning fabrication later than necessary. To prevent this timing issue, we should have performed design and fabrication in parallel.

As a direct result of our lost time, we did not perform as well as desired at the competition. During both qualification rounds, we scored a total of 10 points. Both times these points were the culmination of earning 5 points for leaving the home base and 5 points for entering zone 2. During the first round, our robot caught on the orbital line tape. Between rounds, we attempted to rectify this issue in two ways: 1) We removed a weight from within the robot frame and 2) We modified the code to turn off the spindles when driving over the tape so that more power was supplied to the wheels. These modifications improved the robot’s ability to cross the tape; however, it still caught long enough to interfere with the coded path. This caused the robot to collide with the center post in the second round. These two poor performances in the qualification rounds prevented us from scoring among the top 8 teams, and thus participating in the playoffs.
The purpose of this project was to successfully implement classroom knowledge, practice strong project management skills, and develop a competitive device to represent the Western Kentucky University engineering department at the 2019 IEEE SoutheastCon Hardware Competition. Though the team was short of reaching its personal goal of success at competition, we fulfilled the ultimate purpose of applying classroom knowledge and techniques to create a working device. The systems engineering tools that were effectively applied greatly benefited the project design and fabrication. Conversely, the tools that we failed to appropriately utilize caused our shortfalls. Both our successes and our failures solidified the positive impact of applying a Systems Engineering approach to a complex project.
REFERENCES


