**Budget Proposal for Roadie**

Sponsor

**Electrical, Computer, Software & Systems Engineering at Embry-Riddle Aeronautical University**

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**Are We There Yet?**

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|  |  |  |
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# **Introduction**

## **Purpose**

The purpose of this document is to provide the customers of Roadie with a preliminary budget as well as the selection process and justification for the items included in this budget. The justifications include analytical processes in the form of decision matrices and qualitative processes in the form of written justification. The quantitative and qualitative methods are backed by requirements traceability and risk analysis for the parts listed in this document.

## **Scope**

This document is intended to provide a monetary budget as well as justifications for each item. Core components, with a price of $20[**REF TO RUBRIC]** or higher are included in this document. The document contains the high-level design of Roadie as well as a description of the subsystems and functional description of Roadie. The sole purpose of the document is to provide the reader with an idea of the monetary costs involved in the creating of Roadie.

## **Team Information**

|  |  |
| --- | --- |
| Name | Role |
| Brian Powell | Team Leader |
| Michael Philotoff | Software Configuration Manager |
| Alex Senopoulos | Testing Leader |
| Brian Sterling | Development Leader |

# **Functional Decomposition of System**

Roadie is broken down into six main subsystems: (1) the Simon Carabiner subsystem, (2) the pocket Etch-A-Sketch subsystem, (3) the Rubik’s cube subsystem, (4) the playing card subsystem, (5) the line following subsystem and (6) the communications and coordination subsystem. The division of these subsystems is illustrated in **Fig 1**.



**Fig 1**: Division of Roadie into six subsystems.

The communication and coordination subsystem relays information to each of the challenge subsystems (line following, Simon carabiner, pocket Etch-A-Sketch, Rubik’s cube and playing card). As each of the challenge subsystems completes it task, it relays data back to the communications and coordination subsystem. These subsystems are further divided by functionality to create the high-level architecture as described in Section 2.1.

## **High-Level Architecture of System**

The system architecture of Roadie is designed in a layered approach, depicted in **Fig2** below, in order to better divide the work being done and to aid in the conceptualization of the system design.

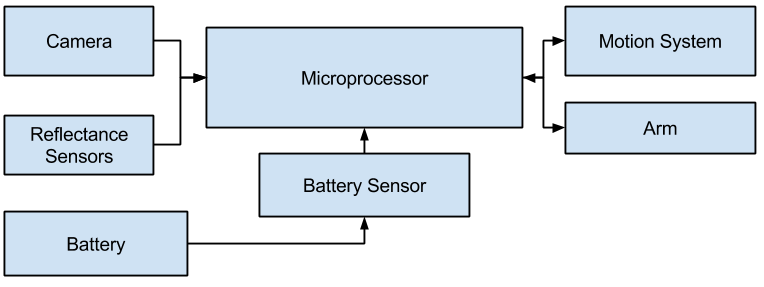


**Fig2**: High level description of the systems in Roadie.

The applications on the communications and coordination system in the form of feedback from the sensors (reflectance and camera) is translated by the middleware (software) to the physical communications means. From here, the arm subsystem and the movement subsystem are directed by the communications and coordination system in order to do complete the challenges. From there, middleware in the form of software is used to talk to the applications. In this instance, the application on the arm side represents the challenges (Simon Carabiner, pocket Etch-A-Sketch, Rubik’s cube, picking up a playing card), with the movement application being line following. As Roadie progresses along, it continues to send feedback from the movement system and the arm system to the communications and coordination system so that Roadie may understand what exactly is happening.

## **Decomposition of Communications and Coordination**

**Fig 3** below, better illustrates the communications that occur amongst the systems in Roadie.



**Fig 3**: Decomposition of communications and coordination system for Roadie.

As the figure shows, the camera, the reflectance sensors and the battery, (via the battery sensor), provide input to the communications and coordination system. From here, the communications system sends commands to both the arm and motion system so that they will be able to complete their individual tasks. As the arm and motion systems complete their tasks, they relay feedback back to the communications and coordination system for further guidance.

# **Budget Decision Matrices and Justifications**

This section contains the justification for the selection of the major components of Roadie. The driving force for the selection process are decision matrices. Decision matrices aid in the decision process by assigning a 1 through a 5, with 1 being least desirable, to characteristics applicable to each item. Each characteristic is given a weight, with higher weights being more important to each item. The total of the weight/score pair is calculated for each item. The item with the highest total score relative to its opponents is deemed the preferable option in its category.

## **Microcontroller**

The following tables and justifications are the basis for the decision making process of selecting a suitable microcontroller for Roadie.

### **Items under Consideration**

The following items have been considered for use as a camera on Roadie. Each item has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 1**

|  |  |  |
| --- | --- | --- |
| Item ID | Vendor | Description |
| UDOO Quad | UDOO | The UDOO Quad is a quad core 1 GHz microcontroller with 1 GB of Random Access Memory (RAM). There are many different types of ports provided on the board, including digital in and out pins, USB, SATA, CSI Camera, HDMI, and analog audio and mic ports. Additionally, the board comes with a Wi-Fi Module, which is great for debugging. [] |
| B00K7EEX2U | Amazon | The BeagleBone Black Rev C is a high power microcontroller with a 1 GHz CPU clock speed with 1 GB of RAM. Additionally, the BeagleBone Black Rev C comes with 4 GB on-board flash storage, 3D graphics, and digital in and out pins. [] |
| B006H0DWZW | Amazon | “The Arduino Mega 2560 is a microcontroller board based on the ATmega2560 (datasheet). It has 54 digital input/output pins (of which 14 can be used as PWM outputs), 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button.” [] |
| B009SQQF9C | Amazon | “The Raspberry Pi is a credit-card sized computer that plugs into your TV and a keyboard. It's a capable little PC which can be used for many of the things that your desktop PC does, like spreadsheets, word-processing, and games, as well as plays high-definition video.”[] |

**Table 1**: Microcontrollers under consideration for Roadie.

### **Decision Matrix**

Since the microcontroller is the brain of Roadie, it represents one of the most critical aspects of the system. The decision matrix used to select a microcontroller for Roadie is depicted in **Table 1**. Factors considered in the decision process of the microcontroller include processing power, RAM, cost, the community support for the microcontroller, the power consumption of the microcontroller, memory, size, Wi-Fi, and availability.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Factor | Processing Power | Memory | Community | Power Consumption | Ports | Wi-Fi | Availability | Cost | Total |
| Weight | 0.2 | 0.2 | 0.15 | 0.05 | 0.15 | 0.05 | 0.1 | 0.1 |  |
| UDOO Quad | 5 | 5 | 4 | 3 | 5 | 5 | 3 | 1 | 4.15 |
| B00K7EEX2U | 4 | 5 | 2 | 4 | 4 | 1 | 3 | 3 | 3.75 |
| B006H0DWZW | 2 | 1 | 5 | 2 | 2 | 1 | 3 | 5 | 2.6 |
| B009SQQF9C | 3 | 3 | 4 | 4 | 3 | 1 | 3 | 4 | 3.4 |

**Table 2**: Decision matrix for microcontroller.

### **Justifications**

The following section represents the reasoning behind each category and how their weights were determined.

#### **Processing Power**

An integral component in Roadie’s ability to quickly decipher and react to events that happen during competition is the processing power of the microcontroller. Since some of the challenges have an underlying time constraint such as the Simon Carabiner, the microcontroller must have enough processing power to allow Roadie to react in time. **Table 3** represents the values for processing power such as the number of cores the microcontroller has, the clock speed of the microcontroller, and the RAM on the microcontroller.

|  |  |  |  |
| --- | --- | --- | --- |
| Factor | Clock Speed | Cores | RAM |
| UDOO Quad | 1 GHz | 4 | 1 GB |
| B00K7EEX2U | 1 GHz | 1 | 1 GB |
| B006H0DWZW | 258 MHz | 1 | 128 KB |
| B009SQQF9C | 700 MHz | 1 | 512 MB |

**Table 3**: Values for processing power for each microcontroller.

Processing Power was given a weight of 20% since the processing power of the microcontroller plays such a large role in Roadie’s challenge completion abilities.

#### **Memory**

Memory is the combination of RAM and any additional memory store that is available to the microcontroller. **Table 4** shows a breakdown of RAM, on board storage and any additional storage that may be available to each microcontroller.

|  |  |  |  |
| --- | --- | --- | --- |
| Factors | RAM | On board storage | Additional storage |
| UDOO Quad | 1 GB | 1 GB | Micro SD Card |
| B00K7EEX2U | 1 GB | 1 GB | Micro SD Card |
| B006H0DWZW | 128 KB | 258 KB | N/A |
| B009SQQF9C | 512 MB | 512 MB | N/A |

**Table 4**: Storage space and RAM available to each microcontroller.

Memory was given a weight of 20% because having a large amount of RAM will enable Roadie to run more robust code without causing a hindrance to the overall performance of the system. Furthermore, having a large amount of additional storage allows more flexibility in code structures.

#### **Community**

The community score was based on how much community support is available for each microcontroller. Factors for this decision included how much example code is available as well as how much documentation exists within the community for each microcontroller.

The community was given a weight of 15% as it relates to how many code examples exist as well as how much assistance can be found when problems occur with integrating the microcontroller with all of Roadie’s systems.

#### **Power Consumption**

The power consumption score for each item was obtained from each microcontrollers lowest recommend voltage. Therefore, the higher the voltage need to run the microcontroller the lower the score it received.

Power consumption was given a weight of 5% as it directly relates to how fast Roadie will deplete its power source. However, as the power supply is a piece that is easily reconfigurable, power consumption was not one of the more important considerations for the microcontroller.

#### **Ports**

The ports score for each microcontroller was obtained by determining how many input and output ports each microcontroller has. The types of ports included in this decision are general purpose input pins, general purpose output pins, pulse width modulation (PWM) pins, HDMI, USB, Camera, SATA, and Ethernet ports.

Ports was given a weight of 15% as it directly relates to what hardware components can be used on Roadie.

#### **Wi-Fi**

The Wi-Fi score for each item was obtained by awarding the microcontroller a five if the microcontroller has Wi-Fi, and a one if the microcontroller does not have Wi-Fi.

Wi-Fi was given a weight of 5% as Wi-Fi is not a requirement for Roadie, however it will be useful for debugging purposes.

#### **Availability**

Scores for availability were awarded based upon whether the motor selected is in stock and ready to ship or not. Items which are out of stock received a score of one due to the much longer wait for the product to be delivered. Conversely, if an item was in stock, it received a score of three. Items available for immediate prototyping received a score of five which corresponds to having the item on hand.

Availability was given a weight of 10% as it directly relates to the ability to prototype Roadie.

#### **Cost**

The scores for the cost of the microcontroller were obtained by giving the most expensive microcontroller a score of one and the least expensive microcontroller a score of five. If the price of a microcontroller was within $10 of an item it was awarded the same score as the item it was nearest.

Cost was given a weight of 10% as the cost of items are a very import factor in any budget, but not the most important consideration for this item.

#### **Summary**

### **Risk Analysis**

The risk analysis section includes information regarding risks related to the line following equipment and solutions to mitigate those risks. Take, for instance, the fact that the microcontroller plays an integral role on Roadie. Therefore, mitigating any and all risks relating to the microcontroller is of the utmost importance. Should the microcontroller become damaged in any way, this would represent an annoying, yet minor failure. It would require the disassembly of essentially the whole system in order to replace the microcontroller. Risks and the methods in which they will be mitigated can be seen in **Table 5** below.

The probability of each occurrence, denoted as **Prob.**, will give the likelihood on the scale of one to nine with one will be the lowest likelihood of occurrence. The severity of an occurrence, denoted as **Sev.,** will give the impact that the event will have on a scale of one to nine with one being lowest impact.

|  |  |  |  |
| --- | --- | --- | --- |
| Risk | Prob. | Serv. | Mitigation of Risk |
| CPU Overheating | 3 | 5 | If the CPU of the microcontroller was to overheat, this would pose a large problem to Roadie. This is especially true if this was to occur during competition. In order to mitigate this risk a supplemental heat dissipation system will be installed. This supplemental system, in conjunction with the heat sink already installed on the microcontroller will be robust enough to dissipate the heat generated by Roadie during operation. |
| Short Circuits | 2 | 9 | One of the concerns when working with electrical circuits are shorts. This problem becomes even more prevalent when working with high voltage systems in conjunction with components that do not react well to high voltage such as the microcontroller. To mitigate a short circuit running the microcontroller, a few design methods will be employed. One such method is using a non-conductive chassis. If the chassis does not conduct electricity, it will not allow the chassis to become charged, thus helping to lower the chances of short happening as a result of a wire touching the chassis. Another technique that will be employed is installing motor shields to prevent electrical feedback from the motors to the microcontroller. |
| Physical Damage | 4 | 6 | In order to mitigate physical damage to the microcontroller, a casing will be installed around the microcontroller to help adsorb any impact that may arise as a result of the microcontroller being hit dropped. |

**Table 5**: Risks that can be attributed to the microcontroller and their associated mitigations.

## **Power Source**

The section pertaining to the selection of the power source for the system will be divided into two parts: power source for the microcontroller and power source for the rest of the system.

### **Batteries for Microcontroller**

The following tables and justifications are the basis for the decision making process of selecting a suitable power supply for the microcontroller.

#### **Items under Consideration**

The following items have been considered for use as a power supply for the microcontroller on Roadie. Each product has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 6** below.

|  |  |  |  |
| --- | --- | --- | --- |
| Item ID | Item Name | Vendor | Description |
| B0027GEY3Y | Venom 800mAh 7.4 LiPo [b1mp] | Amazon | 7.4 volt LiPo battery with a 800 mAh capacity and a 16 A discharge rate. |
| B00DDTKYME | Dynamite 7.4V 180mAh LiPo [b2mp] | Amazon | 7.4 volt LiPo battery with a 180 mAh capacity and a 16 A discharge rate. |
| B0073VCS0O | Eflite Blade 800mAh 7.4V LiPo [b3mp] | Amazon | 7.4 volt LiPo battery with a 800 mAh capacity and a 16 A discharge rate. |

**Table 6:** Power sources under consideration for Roadie.

#### **Decision Matrix**

The decision matrix used to select a battery for Roadie’s microcontroller is depicted in **Table 7**. Factors considered in the decision process of the battery include the power output, cost, safety, and battery life of each battery. The highlighted row is the battery selected to power the microcontroller for Roadie.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Power | Battery Life | Safety | Cost | Total |
| Weight | 0.40 | 0.25 | 0.20 | 0.15 |  |
| B0027GEY3Y | 4 | 5 | 3 | 5 | 4.2 |
| B00DDTKYME | 1 | 2 | 3 | 3 | 1.95 |
| B0073VCS0O | 4 | 5 | 3 | 1 | 3.6 |

**Table 7**: Decision matrix for microcontroller.

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table #.**

**Justification table**

**CAPTION**

#### **Justifications**

The following section represents the reasoning behind each category and how their weights were determined.

##### **Power**

The scores for power of each battery was obtained by examining the voltage of the battery and how many milliamps per hour the battery provides. The battery must have sufficient voltage to power the microcontroller in addition to being below the maximum voltage the microcontroller can handle. Therefore the score of the voltage for each battery is proportional to how far the battery’s voltage is from the recommended voltage for the microcontroller. The milliamps per hour was used to determine if the batteries could provide enough amperage to the motors for them to run.

Power was given a weight of 40% as the power of the battery dictates how long Roadie can run without having to recharge the batteries.

##### **Battery Life**

The score for battery life of each battery was obtained by giving the battery with the lowest battery life a score of five, and the battery with the highest battery life a score of one. The other batteries were given a score proportional to how close their battery life was to the longest battery life. The estimated battery life for each battery is given by the **equation ()** at maximum load.

The battery life for each battery can be seen in **Table 8** below

|  |  |  |  |
| --- | --- | --- | --- |
| Factor | mAh | mA | Life (Hours) |
| B0027GEY3Y | 800 | 16000 | 0.035 |
| B00DDTKYME | 180 | 16000 | 0.00788 |
| B0073VCS0O | 800 | 16000 | 0.035 |

**Table 8**: Battery life for each battery under consideration for powering Roadie’s microcontroller.

Battery life was given a weight of 25% as the battery life is how long a battery will last on a single charge. This translates into how long Roadie will be able to operate.

##### **Safety**

The scores for safety of each battery was obtained by factoring in the inherent risks associated with each variant of battery as well as the impact each variant of battery will have on the environment. The risk for each battery rates to how the battery will react to mishaps. Examples of mishaps would be dropping, shorting out, or overheating the battery. The environmental impact of each battery is dependent upon the materials that the battery is composed of as most batteries contain some type of heavy metal that is harmful to both humans and the environment. [1mp]

Safety was given a weight of 20% as the safety of the team and the environment in which Roadie is worked on are both important aspects of the project.

##### **Cost**

The values for cost of the batteries were obtained by giving the most expensive battery a score of one, and the least expensive battery a score of five.

Cost was given a weight of 15% as the cost of items are a very items are a very important factor in any budget, but not the most important consideration for this item.

#### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in **Table 9** below, the requirement ID is followed by the requirement text and an explanation of how the B0027GEY3Y will fulfill said requirement.

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfillment |
| 4.2.1 | The system shall operate for a minimum of [TBD] minutes when the power source starts with a full charge. | By choosing batteries that provide more amperage than what is required to run the microcontroller and motors, it will be possible to ensure that Roadie will be able to operate for at least [TBD] minutes. |

**Table 9**: The requirements that the selection of B0027GEY3Y will fulfill.

### **Batteries for Motors**

The following tables and justifications are the basis for the decision making process of selecting a suitable power supply for the motors on Roadie.

#### **Items under Consideration.**

The following items have been considered for use as a power supply for the motors on Roadie. Each product has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 10**

|  |  |  |  |
| --- | --- | --- | --- |
| Item ID | Item Name | Vendor | Description |
| B0027G9F9M | Venom 5000 mAh 14.8V LiPo [b4mp] | Amazon | 14.8 volt LiPo battery with a 5000 mAh capacity and a 125 A discharge rate. |
| B003CUB4QO | Venom 5000 mAh 14.8V Hard Case LiPo [b5mp] | Amazon | 14.8 volt LiPo hard case battery with a 5000 mAh capacity and a 175 A discharge rate. |
| B003CUJ1WI | Venom 3800 mAh 18.5V Hard Case LiPo [b6mp] | Amazon | 18.5 bolt LiPo hard case battery with a 3800 mAh capacity and a 133 A discharge rate. |

**Table 10**: Power supplies under consideration for the motors for Roadie.

#### **Decision Matrix**

The decision matrix used to select a battery for the motors on Roadie is depicted in **Table 11**. Factors considered in the decision process of the battery include the power output, cost, safety, and battery life of each battery. The highlighted row is the battery selected to power the microcontroller for Roadie.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Power | Battery Life | Safety | Cost | Total |
| Weight | .40 | .25 | .20 | .15 |  |
| B0027G9F9M | 5 | 5 | 3 | 5 | 4.6 |
| B003CUB4QO | 1 | 3 | 3 | 1 | 1.9 |
| B003CUJ1WI | 3 | 3 | 3 | 3 | 3 |

**Table 11**: Decision matrix for the battery for the motors for Roadie.

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table #.**

**Justification table**

**CAPTION**

#### **Justifications**

The following section represents the reasoning behind each category and how their weights were determined.

##### **Power**

The scores for power of each battery was obtained by examining the voltage of the battery and how many milliamps per hour the battery provides. The battery must have sufficient voltage to power the motors in addition to being below the maximum voltage the motors can handle. Therefore the score of the voltage for each battery is proportional to how far the battery’s voltage is from the recommended voltage for the motors. The milliamps per hour was used to determine if the batteries could provide enough amperage to the motors for them to run.

Power was given a weight of 40% as the power of the battery dictates how long Roadie can run without having to recharge the batteries.

##### **Battery Life**

The score for battery life of each battery was obtained by giving the battery with the lowest battery life a score of five, and the battery with the highest battery life a score of one. The other batteries were given a score proportional to how close their battery life was to the longest battery life. The estimated battery life for each battery is given by the **equation ()** at maximum load.

The battery life for each battery under consideration for the motors can be seen in **Table 12**below

|  |  |  |  |
| --- | --- | --- | --- |
| Factor | mAh | mA | Life (hours) |
| B0027G9F9M | 5000 | 125000 | 0.028 |
| B003CUB4QO | 5000 | 175000 | 0.02 |
| B003CUJ1WI | 3800 | 133000 | 0.02 |

**Table 12**: Battery life for each of the batteries under consideration for powering Roadie's motors.

Battery life was given a weight of 25% as the battery life is how long a battery will last on a single charge. This translates into how long Roadie will be able to operate.

##### **Safety**

The scores for safety of each battery was obtained by factoring in the inherent risks associated with each variant of battery as well as the impact each variant of battery will have on the environment. The risk for each battery rates to how the battery will react to mishaps. Examples of mishaps would be dropping, shorting out, or overheating the battery. The environmental impact of each battery is dependent upon the materials that the battery is composed of as most batteries contain some type of heavy metal that is harmful to both humans and the environment. [1mp]

Safety was given a weight of 20% as the safety of the team and the environment in which Roadie is worked on are both important aspects of the project.

##### **Cost**

The values for cost of the batteries were obtained by giving the most expensive battery a score of one, and the least expensive battery a score of five.

Cost was given a weight of 15% as the cost of items are a very items are a very important factor in any budget, but not the most important consideration for this item.

##### **Summary**

#### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in **Table 13** below, the requirement ID is followed by the requirement text and an explanation of how the B0027G9F9M will fulfill said requirement.

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfillment |
| 4.2.1 | The system shall operate for a minimum of [TBD] minutes when the power source starts with a full charge. | By choosing batteries that provide more amperage than what is required to run the microcontroller and motors, it will be possible to ensure that Roadie will be able to operate for at least [TBD] minutes. |

**Table 13**: The requirements that the selection of B0027G9F9M will fulfill.

### **Risk Analysis**

The risk analysis section includes information regarding risks related to the line following equipment and solutions to mitigate those risks. Take, for instance,

The probability of each occurrence, denoted as **Prob.**, will give the likelihood on the scale of one to nine with one will be the lowest likelihood of occurrence. The severity of an occurrence, denoted as **Sev.,** will give the impact that the event will have on a scale of one to nine with one being lowest impact.

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

Batteries

Lithium Polymer batteries (LiPo) are extremely energy dense for a chemical battery. However since LiPo batteries are energy dense it also means they are unstable under abuse. When a LiPo battery is damage in anyway the battery has a chance to ignite and catch on fire, this is known as thermal runaway. This could come from the battery being physically damage or if the battery is shorted out. But the chances of LiPo to have a thermal runaway is every small. [4mp]

Environment Impacts

All batteries contain some sort of heavy metal or toxic and hazardous chemicals. Each battery should be disposed of properly to reduce the environmental impact of batteries. LiPo batteries are one of the few battery types that environment friendly meaning as long as the proper procedure is used to discharge the battery it can throw away in the normal trash. [4mp]

## **Camera**

The following tables and justifications are the basis for the decision making process of selecting a suitable camera for Roadie.

### **Items under Consideration**

The following items have been considered for use as a camera on Roadie. Each item has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 14** below

|  |  |  |  |
| --- | --- | --- | --- |
| Item ID | Item Name | Vendor | Description |
| B00IUYUA80 | Pixy (CMUcam5) | Amazon | Pixy is an image sensor paired with a dedicated processor. Pixy is able to process images from the image sensor and send condensed image and location data to the microcontroller at a frame rate of 50Hz. [1] |
| B008GWPC1Q | Fosmon USB 6 LED Webcam | Amazon | 1.3 Megapixel webcam with six LEDs to illuminate objects. |
| B00K11RI6W | TeckNet C015 Webcam | Amazon | 5.0 Megapixel webcam with built in microphone. |

**Table 14**: Cameras under consideration for Roadie

### **Decision Matrix**

The decision matrix used to select a camera for Roadie is depicted in **Table 15**. Factors considered in the decision process of the camera include the resolution of the camera, if lights are installed on the camera, perceived ease of use, availability of the camera as well as the cost of the camera. The highlighted row is the camera selected for use on Roadie.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Factor | Resolution | Lighting | Ease of Use | Availability | Cost | Total |
| Weight | 0.3 | 0.2 | 0.3 | 0.1 | 0.2 |  |
| B00IUYUA80 | 2 | 1 | 5 | 3 | 1 | 2.8 |
| B008GWPC1Q | 2 | 5 | 2 | 3 | 5 | 3.5 |
| B00K11RI6W | 4 | 1 | 2 | 3 | 4 | 3.1 |

**Table 15**: Decision matrix for camera

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table 16**. The total score for each item in the decision matrix (**Table 15**) is calculated by summing the values for each row in the weighted value matrix.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Resolution | Lighting | Ease of Use | Availability | Cost |
| B00IUYUA80 | 0.6 | 0.2 | 1.5 | 0.1 | 0.2 |
| B008GWPC1Q | 0.6 | 1.0 | 0.6 | 0.1 | 1.0 |
| B00K11RI6W | 1.2 | 0.2 | 0.6 | 0.1 | 0.8 |

**Table 16**: Weighted value matrix. It is comprised of the score for each category multiplied by the weight for the category.

The weightings for the decision matrix were created by using the data in Table 17

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Resolution | Lighting | Ease of Use | Availability | Cost |
| B00IUYUA80 | 1.0 Megapixel | No | Plug and play | In stock | $69.00 |
| B008GWPC1Q | 1.3 Megapixel | No | In-depth configuration required | In stock | $8 |
| B00K11RI6W | 5.0 Megapixel | Yes | In-depth configuration required | In stock | $10 |

**Table 17**: Quantitative and qualitative values of the cameras under consideration that led to the decision matrix.

### **Justifications**

The following section represents the reasoning behind each category and how their weights were determined.

#### **Resolution**

The resolution for a camera is directly related to how clear and image will be. Since the camera will be the primary way in which Roadie will be able to identify challenges, having the best resolution possible is very important. Therefore, items with a resolution low relative to the average resolution in the group (2.3 Megapixels) were ranked low and items with a resolution high relative to the average resolution in the group were ranked high.

Resolution was given a weight of 20% because if the resolution of the camera is low, it will result in a fuzzy or grainy image which may compromise Roadie’s ability to correctly identify the challenge.

#### **Lighting**

In order for the object to be reliably identified, lighting conditions must remain relatively constant. One way to assure lighting remaining constant is to purchase a web cam with lights on it. It is for this reason that a camera without lights was scored at one, where as a camera with lights on it was scored at five.

Lighting was given a weight of 20% because the ambient light in the room is something to be considered when identifying objects. If the lighting changes, the ability of Roadie to identify the challenges might as well.

#### **Ease of Use**

Ease of use is how AWTY perceived the difficulty in implementing each camera. A device that is plug and play with little to no set up was ranked a five, whereas a camera that has a learning curve with a great degree of difficulty would be ranked as a one. From our selections, two of the cameras, B008GWPC1Q and B00K11RI6W received a score of two as they will be difficult to implement, but their implementation will be guided by examples found on the internet. B00IUYUA80 was ranked a five because it includes software to natively recognize up to seven objects as well as software to recognize rotation angle and distance of an object.

The weighting for ease of use is set to 30% because Roadie will be completely dependent upon some form of camera to be able to correctly identify any challenge it arrives at. If the camera is not behaving as expected due to a difficult or poorly understood implementation, the whole system will fail.

#### **Availability**

Scores for availability were awarded based upon whether the motor selected is in stock and ready to ship or not. Items which are out of stock received a score of one due to the much longer wait for the product to be delivered. Conversely, if an item was in stock, it received a score of three. Items available for immediate prototyping received a score of five which corresponds to having the item on hand.

Availability was given a weight of 10% as it directly relates to the ability to prototype Roadie.

#### **Cost**

The values for cost for the cameras were obtained by giving the most expensive camera a score of one, and the least expensive camera a score of five. As there was only one other camera to consider, and its price was $2 more than the cheapest camera, a score of 4 was awarded since the price was so close.

Cost was given a weight of 20% as the cost of items are a very important factor in any budget, but not the most important consideration for this item.

#### **Summary**

### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in Table 18,below, the requirement ID is followed by the requirement text and an explanation of how the B008GWPC1Q will fulfill said requirement.

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfillment |
| 3.1.7 | The system shall wait for red [RGB value TBD] LED in starting area to turn off before exiting the starting area. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the red LED in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the red LED. |
| 3.2.3 | The system shall identify the challenge zone and stop movement upon arrival. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify all challenge zones in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify all challenge zones. |
| 3.3.1 | The system shall correctly identify the challenge upon arrival. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the challenge it has arrived at in lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the challenge zone it has arrived at. |
| 3.3.1.1 | The system shall correctly identify the Simon Carabiner depicted in Figure5. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the Simon Carabiner in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the Simon Carabiner. |
| 3.3.1.2 | The system shall correctly identify the Rubik’s Cube depicted in Figure6 | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the Rubik’s cube in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the Rubik’s cube. |
| 3.3.1.3 | The system shall correctly identify the pocket Etch-A-Sketch depicted in Figure7. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the pocket Etch-A-Sketch in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the pocket Etch-A-Sketch. |
| 3.3.1.4 | The system shall correctly identify the playing cards depicted in Fig. [TBD]. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the playing cards in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the playing cards. |
| 3.3.3.3 | The system shall correctly sense color blue [exact RGB values TBD] when illuminated on the Simon Carabiner. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the blue LED on Simon in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the blue LED on Simon. |
| 3.3.3.4 | The system shall correctly sense color red [exact RGB values TBD] when illuminated on the Simon Carabiner. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the red LED on Simon in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the red LED on Simon. |
| 3.3.3.5 | The system shall correctly sense color yellow [exact RGB values TBD] when illuminated on the Simon Carabiner. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the yellow LED on Simon in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the yellow LED on Simon. |
| 3.3.3.6 | The system shall correctly sense color green [exact RGB values TBD] when illuminated on the Simon Carabiner. | With the selection of B008GWPC1Q, Roadie will be able to reliably identify the green LED on Simon in all lighting conditions. Additionally, B008GWPC1Q provides a fine enough resolution to correctly identify the green LED on Simon. |

**Table 18**: Requirements traceability for camera.

### **Risk Analysis**

The risk analysis section includes information regarding risks related to the camera and solutions to mitigate those risks. Take, for instance, if Roadie was to completely lose its camera system. Roadie would be unable to operate since the camera is the main way in which Roadie will identify challenges. In order to mitigate such an event, extensive testing will be performed. Other such examples of risk and their mitigations can be found in **Table 19**.

The probability of each occurrence, denoted as **Prob.**, will give the likelihood on the scale of one to nine with one will be the lowest likelihood of occurrence. The severity of an occurrence, denoted as **Sev.,** will give the impact that the event will have on a scale of one to nine with one being lowest impact.

|  |  |  |  |
| --- | --- | --- | --- |
| Risk | Prob. | Sev. | Mitigation of Risk |
| Complete loss of camera system | 2 | 9 | In the even that Roadie loses the camera system, its ability to complete the remaining challenges will be compromised. Since Roadie is completely dependent upon its camera to be able to identify the challenges, a loss of the camera would cause Roadie to fail that round of competition. In order to mitigate the occurrence of such an event, extensive stress testing will be done to ensure that the camera performs flawlessly. |
| Misidentification | 3 | 7 | If Roadie were to misidentify a challenges, this would cause the system to attempt to complete the wrong challenge. This could pose problems for the overall completion of the round as well as potentially cause damage to the system as it may attempt to perform tasks the attachments cannot handle. In order to mitigate such an event, extensive vision recognition testing will be performed in various lighting conditions. Additionally, the system will be tested for its recognition abilities with the batteries at various states of charge to ensure that all external factors have been accounted for. |

**Table 19**: Risks that can be attributed to the chassis and their associated mitigations.

## **Chassis**

The following tables and justifications are the basis for the decision making process of selecting a suitable chassis for Roadie.

### **Items under Consideration**

The following items have been considered for use as a chassis on Roadie. Each item has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 20**

|  |  |  |  |
| --- | --- | --- | --- |
| Item ID | Item Name | Vendor | Description |
| ROB-12866 | Magician Chassis | Sparkfun | Acrylic chassis with two gearmotors, two 65mm wheels and a rear caster. Pre-drilled mounting holes. An AA battery holder with barrel plug termination is included. |
| KIT660 | Build Your First Robot Chassis Kit | Budgetrobotics.com | Dual level chassis with wheel well cutouts for drive wheels. Includes mounts for two servos. |
| DG012 | DG012-Tank | Hobbyking | Square chassis made out of aluminum. It come with two 48:1 geared motors, an AA battery holder and pre-drilled mounting points. |
| Custom | Custom Chassis | N/A | Constructed to resemble a cargo container crane. Room for four drive motors. Attachment point for arm mounted high on chassis. |

**Table 20**: Chassis under consideration for Roadie

### **Decision Matrix**

The decision matrix used to select a chassis for Roadie is depicted in **Table 21**. Factors considered in the decision process of the chassis include the surface area of the chassis, the perceived adaptability of the chassis, availability of the chassis and the cost of the chassis. The highlighted row is the camera selected for use on Roadie.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Surface Area | Adaptability | Availability | Cost | Total |
| Weight | 0.3 | 0.4 | 0.1 | 0.2 |  |
| ROB-12866 | 2 | 1 | 3 | 5 | 2.3 |
| KIT660 | 5 | 2 | 3 | 4 | 3.4 |
| DG012 | 3 | 1 | 3 | 1 | 1.8 |
| Custom | 5 | 5 | 5 | 3 | 4.6 |

**Table 21**: Decision matrix for chassis

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table 22**. The total score for each item in the decision matrix (**Table 21**) is calculated by summing the values for each row in the weighted value matrix.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Factor | Surface Area | Adaptability | Availability | Cost |
| ROB-12866 | 0.6 | 0.4 | 0.3 | 1 |
| KIT660 | 1.5 | 0.8 | 0.3 | 0.8 |
| DG012 | 0.9 | 0.4 | 0.3 | 0.2 |
| Custom | 1.5 | 2 | 0.5 | 0.4 |

**Table 22**: Weighted value matrix. It is comprised of the score for each category multiplied by the weight for the category.

The weightings for the decision matrix were created by using the data in **Table 23**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Factor | Surface Area | Adaptability | Availability | Cost |
| ROB-12866 | 110 x 174 mm | Not very | In stock | $14.95 |
| KIT660 | 177.8 x 127 mm per deck (2 decks) | Moderately | In stock | $16.95 |
| DG012 | 157 x 149mm | Not very | In stock | $44.96 |
| Custom | Variable | Very | Available | $25.00 |

**Table 23** Quantitative and qualitative values of the chassis under consideration that led to the decision matrix.

### **Justifications**

The following section represents the reasoning behind each category and how their weights were determined.

#### **Surface Area**

The surface area of the chassis is how much surface will be available to mount components to Roadie. Since there will be many circuit boards, wires, and other sorts of devices, having an abundance of surface area will be to our advantage. Chassis with the highest surface area, KIT660, received a score of five. The custom chassis received a score of five because its surface area will be greater than or equal to that of KIT660. DG012 had a surface area approximately half of KIT660, therefore its score is half of KIT600’s score rounded up. ROB-12866’s surface area was close to that of DG012, earning it a two, one less point than DG012.

Surface area was given a weight of 30% because the more surface area Roadie has, the more space will be available for mounting of critical systems. Mounting systems to a chassis with little surface area will prove difficult as space would become a premium with larger items.

#### **Adaptability**

Adaptability of the chassis pertains to how well the chassis will be able to cope with our design changes. Currently, Roadie is still in the prototyping process. As such, we are not sure how well our system design will function. This means that the chassis of Roadie will need to be able to easily change as our design changes. Chassis that provide the ability to move components around without major modifications received a score of five and a chassis that would essentially require the building or purchase of another received a score of one. Both the ROB-12866 and the DG012 scored ones because they are designed to work with certain motors and wheels. Therefore, these chassis are not very adaptable. The KIT660 scored a two because while it does not come with any servos or motors, the wheel well cutouts limit the wheels that can be used. The custom chassis is very adaptable since it can be easily modified as the system design changes.

Adaptability was given a weight of 40% since the adaptability of the chassis directly correlates to the ability to rapid prototype. A chassis that is designed with particular wheels and motors in mind is not as adaptable to change as a chassis that is built independent of wheels and motors.

#### **Availability**

Scores for availability were awarded based upon whether the motor selected is in stock and ready to ship or not. Items which are out of stock received a score of one due to the much longer wait for the product to be delivered. Conversely, if an item was in stock, it received a score of three. Items available for immediate prototyping received a score of five which corresponds to having the item on hand.

Availability was given a weight of 10% as it directly relates to the ability to prototype Roadie.

#### **Cost**

The score for cost was obtained by ranking the lowest cost item, ROB-12866 as a 5 and the most expensive item, the DG012 as a one. Since the KIT660 was within $2 of the cost of ROB-12866, it received a score of 4. The custom option was budgeted at $25 as it is the average price of the other chassis in the group. This was awarded a 3 as it was about $8 more than the KIT660, and still significantly cheaper than the DG012. Since it was close to the lower priced chassis options, a score of 3 was awarded.

Cost was given a weight of 20% as the cost of items are a very important factor in any budget, but not the most important consideration for this item.

#### **Summary**

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfillment |
| 3.3.2 | The system shall align with the challenge before attempting to complete the challenge. | By implementing a custom design for the chassis, the time required to align with the challenge will decrease, thus shortening the overall time that Roadie is on the course. |
| 3.3.3.7 | The system shall not obstruct the Simon Carabiner during play. | By designing a custom chassis, it will be possible to ensure that Roadie will not obstruct the Simon Carabiner. |
| 3.3.4.1 | The system shall not obstruct the Rubik’s Cube during play. | By designing a custom chassis, it will be possible to ensure that Roadie will not obstruct the Rubik’s cube. |
| 3.3.5.2 | The system shall not obstruct the pocket Etch-A-Sketch during play. | By designing a custom chassis, it will be possible to ensure that Roadie will not obstruct the Etch-A-Sketch. |
| 4.1.1 | The system size shall be no greater than 1ft. x 1ft. x 1ft. within the starting area and the finishing area. | With a custom chassis design, it will be possible to ensure that Roadie fits into the mandated dimensions while still having enough surface area to mount all the required components. |
| 4.3.1 | The system shall have an easily accessible power switch. | With a custom design, Roadie will not be limited to where the power switch is mounted on an “off the shelf” chassis. |
| 4.3.3 | The system shall maintain contact with the competition area’s surface at all times. | Implementation of a custom chassis will ensure that Roadie will always maintain contact with the course. |

### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in **Table 24**,below, the requirement ID is followed by the requirement text and an explanation of how the custom chassis will fulfill said requirement.

**Table 24**: Requirements traceability for chassis.

### **Risk Analysis**

The risk analysis section includes information regarding risks related to the chassis equipment and solutions to mitigate those risks. Take, for instance, the fact that the chassis is the component that supports all of the other components of the systems. Therefore, it is imperative that Roadie is operated in a manner as to not cause harm or damage to the chassis. Should the chassis be completely damaged, this would represent a catastrophic failure as it would require many man hours to reassemble the chassis and resolve any issues rising from such an event. An example of an even that would be an inconvenience, yet Roadie would still be operable would be if one of the towers supporting the arms became misaligned. This would be a temporary hindrance to the system as it would last for one competition round. Further examples of risks and their mitigations can be found in **Table 25**.

The probability of each occurrence, denoted as **Prob.**, will give the likelihood on the scale of one to nine with one will be the lowest likelihood of occurrence. The severity of an occurrence, denoted as **Sev.,** will give the impact that the event will have on a scale of one to nine with one being lowest impact.

|  |  |  |  |
| --- | --- | --- | --- |
| Risk | Prob. | Sev. | Mitigation of Risk |
| Loss of Chassis | 1 | 9 | In the event that Roadie was to fail in such an extreme event that the chassis is not salvageable, this could potentially result in the project not being delivered on time. An example of such an occurrence would be in the power source was improperly handled, thus causing the chassis to ignite or melt in some spectacular fashion. Another such instance would be if the vehicle ran into some obstacle at ludicrous speed, causing the chassis to be rendered useless. In order to mitigate these events, safeguards will be implemented to ensure that Roadie always maintains a safe operating speed. Additionally, all power sources will be properly handled and maintained to ensure that the chassis does not catch fire. |
| Misaligned arm tower | 2 | 4 | In the event that one of the chassis towers supporting the arm were to become misaligned, this would cause a slight hindrance to Roadie. Roadie would still be able to attempt the challenges, however, the attempts may not be optimal. In order to mitigate this, the arms will be redundantly reinforced as well as designed with the ability to support a load at least 1.5 times that of the theoretical load the arm would have to support. |

**Table 25**: Risks that can be attributed to the chassis and their associated mitigations.

## **Line Following**

The following information composes the justifications that were made to make a decision on the line following equipment for Roadie.

### **Items under Consideration**

The following items have been considered for use as line following equipment on Roadie. Each item has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 26** below

|  |  |  |  |
| --- | --- | --- | --- |
| Item ID | Name | Vendor | Description |
| ROB-09454 | QRE1113 (Digital) | SparkFun | This product utilizes a capacitor in order to rapidly determine exposure of light by using the time of discharge. [12] |
| GL5516 | Optoresister GL5516 | Amazon | A photoresistor will slowly lose resistance when it is exposed to light. It is known to have trouble in lower light conditions. [13] |

**Table 26**: Line following equipment under consideration for Roadie.

### **Decision Matrix**

The decision matrix used to select line following equipment for Roadie is depicted in **Table 27**. Factors considered in the decision process of the line following equipment include community and peer support for the sensor, the perceived ease of implementation of the sensor, availability of the sensor and the cost of the sensor. The highlighted row is the sensor selected for use on Roadie.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Community | Ease | Availability | Cost | Total |
| Weight | 0.3 | 0.4 | 0.2 | 0.1 | 1 |
| ROB-09454 | 4 | 5 | 5 | 1 | 4.3 |
| GL5516 | 2 | 4 | 5 | 5 | 3.7 |

**Table 27**: Decision matrix for line following equipment.

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table 28.** The total score for each item in the decision matrix (**Table 27**) is calculated by summing the values for each row in the weighted value matrix.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Factor | Community | Ease | Availability | Cost |
| ROB-09454 | 1.2 | 2.0 | 1.0 | 0.1 |
| GL5516 | 0.6 | 1.6 | 1.0 | 0.5 |

**Table 28**: Weighted value matrix. It is comprised of the score for each category multiplied by the weight for the category.

The weightings for the decision matrix were created by using the data in **Table 29** below

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Factor | Cost per unit | Ease | Availability | Community |
| ROB-09454 | $2.95 | Compatible with Udoo | In stock | Online help easily found. Great support for Arduino IDE. |
| GL5516 | $0.249 | Compatible with Udoo | In stock | Various online tutorials can be found. |

**Table 29**: Quantitative and qualitative values of the line following sensors under consideration that led to the decision matrix.

### **Justifications**

The following sections represents the reasoning behind each category and how their weights were determined.

#### **Community**

The community is weighted fairly heavily since it is meant to regard how easy it is to find information and tutorials about the item. A large amount of information was found online about the QRE1113 model specifically.[12] Some information was found about generic photoresistors, but not nearly as much as the QRE1113.

This item was given a weight of 30% since help with integration into the microcontroller will be integral to the efficiency of line following implementation.

#### **Ease**

The ease category related to the ease of integration with the microprocessor. A rating of 5 would mean that integration would pose little to no risks or hardships for team AWTY, while a rating of 1 would mean that integration would pose many risks and hardships. There are many tutorials available online for the integration of the QRE1113 with Arduino IDE. Some are also available for generic photoresistors as well, including the GL5516.

This item was given a weight of 40% since integration of line following is critical for Roadie’s operation. The easier implementation is the quicker team AWTY can implement it into the system with little to no defects.

#### **Availability**

Scores for availability were awarded based upon whether the motor selected is in stock and ready to ship or not. Items which are out of stock received a score of one due to the much longer wait for the product to be delivered. Conversely, if an item was in stock, it received a score of three. Items available for immediate prototyping received a score of five which corresponds to having the item on hand.

Availability was given a weight of 10% as it directly relates to the ability to prototype Roadie.

#### **Cost**

Both options were very cheap, with the photoresistors being $4.98 per 20, and the QRE1113 being $2.95 each. [12][13] Within the decision matrix, the scale was based so that 1 was the most expensive on the scale and 5 was the least expensive. Even so, the price of both factors is fairly low.

Cost was given a weight of 10% since the cost is always a considering factor. However, especially since the overall cost of each factor is very low, it is not as important as other factors for line following.

#### **Summary**

The main concern in selecting an item for line following was ease of implementation and the community. With a large amount of information available for the QRE1113, it seems to be the best option for Roadie as it will be the most efficient sensor to use for implementation of the line following system.

### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in **Table 30**,below, the requirement ID is followed by the requirement text and an explanation of how the B008GWPC1Q will fulfill said requirement.

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfilment |
| 3.2.2 | The system shall progress forward along the blue guidance tape until reaching a challenge area or reaching the finish line. | The QRE1113 will allow Roadie to sense the tape, providing the ability to recognize the challenge areas as well as the finish line. |
| 3.2.3 | The system shall identify the challenge zone and stop movement upon arrival. | The QRE1113 will allow Roadie to sense challenge areas allowing the system to stop its movement. |
| 3.3.1 | The system shall correctly identify the challenge zone upon arrival. | The QRE1113 will be able to sense when the tape splits in order to identify challenge areas. |
| 4.3.2 | The system shall be completely autonomous after being powered on. | The QRE1113 gives Roadie the ability to navigate independent of human interaction. |

**Table 30**: Requirements traceability for line following sensors.

### **Risk Analysis**

The risk analysis section includes information regarding risks related to the line following equipment and solutions to mitigate those risks. Take, for instance, a damaged sensor. Should a sensor become damaged, this could hinder Roadie’s ability to correctly track the line. In order to help mitigate this risk, redundant sensors will be installed on Roadie. Additional risks and their associated mitigations can be seen in **Table 31**

The probability of each occurrence, denoted as **Prob.**, will give the likelihood on the scale of one to nine with one will be the lowest likelihood of occurrence. The severity of an occurrence, denoted as **Sev.,** will give the impact that the event will have on a scale of one to nine with one being lowest impact.

|  |  |  |  |
| --- | --- | --- | --- |
| Risk | Prob | Sev | Mitigation |
| Sensing distance changes | 1 | 8 | Ensure that proper measures are taken during construction of each prototype to keep the sensor in the same spot. As long as the sensor is secured tightly and properly to the system, there should be no surprises on competition day. The sensor's optimal distance is 3mm. [1] |
| Improper reading | 2 | 8 | Have redundancy of sensors. There will be five sensors attached to the system so that readings on each sensor can be compared to obtain the most accurate readings. |
| Damaged sensor | 1 | 4 | In the event that a sensor is damaged, one can be easily attached in its place. Having one or two backup sensors in case one fails will mitigate this risk. |

**Table 31**: Risks that can be attributed to the line following sensors and their associated mitigations.

## **Motors**

This section highlights the different motors utilized in the system and which task they are best suited for. From here, the motors groups are then evaluated through qualitative and quantitative analysis to determine the best motors to use for each section of the system. After this determination has been made, individual motors are compared within their subcategories to determine the best of each type of motor

### **Motor Types**

The different motors that will be utilized in the system are: stepper motors, direct current (DC) gearmotors, and linear actuators. The following sections will outline the strengths and weakness of each motor and evaluate their role in the system.

#### **Stepper Motors**

Stepper motors take a digital signal and convert it into mechanical rotation. Stepper motors are unique from other motors because one revolution of the motor is broken down into many equal parts, otherwise known as steps. For instance, on a 200 step motor, the motor will run through 200, 1.8° steps, for one full rotation. This is useful because it allows the system to define the number of steps for the motor to rotate, allowing for very precise positioning of the motor. Stepper motors also allow for very precise stopping and reversing. This is because when the stepper motor is not rotating, it is still operating by holding the motor at the current step. Therefore, stopping is immediate. Stepper motors also allows for easy synchronization between motors. Since each motor’s speed is dependent on the frequency of the input pulse, setting two motors at the same frequency will allow them to work synchronously (1).

#### **Gearmotors**

Gearmotors are very simple motors which are generally used to drive gears, much as the name implies. Consider the transmission in an automobile. These transmissions are capable of producing variable power output by either driving large gears at low speed and high torque or small gears at high speed and low torque. For Roadie, a simple motor is required which will possess the ability turn at a low speed with high torque. Even though gearmotors may not be as complex as servomotors or stepper motors, they are certainly cost effective and efficient.

#### **Linear Actuators**

Linear actuators are unique relative to both the stepper motors and the gear motors due to the fact that linear actuators produce linear motion rather than rotational motion. Linear actuating motors, otherwise referred to as linear actuators, often provide feedback on position to allow for precise positioning. The one pitfall of the linear actuator is that it also requires a decoder. Due to this, linear actuators are usually very expensive compared to stepper motors and gearmotors. However, these are the only motor in consideration that creates linear motion rather than rotational motion.

#### **System Roles**

**Table 32** shows the purpose for each selected motor.

|  |  |
| --- | --- |
| Motor Type | Purpose |
| Stepper Motor | Driving Wheels |
| DC Gearmotor | Rotation of arm attachments |
| Linear actuator | Linear motion |

**Table 32**: A list of the different motors and their intended purpose in the system.

### **Stepper Motors**

Stepper motors will be used to drive the wheels on the robot due to the precision of their step properties and ability to synchronize. There will be 4 motors total, one for each wheel.

#### **Items under Consideration**

The following items have been considered for use aon Roadie. Each item has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 33**

|  |  |  |  |
| --- | --- | --- | --- |
| Item ID | Name | Vendor | Description |
| SY42STH38-0406B | Soyo - Unipolar Stepper Motor | Robotshop.com | A double shafted, 200 step motor. ± 5% Precioson. Maximum torque 36 oz.-in. Operates at 12V DC (2). <http://www.robotshop.com/en/rbsoy07-soyo-unipolar-stepper-motor.html> |
| SY42STH47- | Soyo - 1684MB RepRap Stepper Motor | Robotshop.com | 200 step high torque motor. Holding Torque 4.4 Kg-cm. ± 5% precision (2). <http://www.robotshop.com/en/soyo-reprap-stepper-motor.html> |
| ROB-10846 | Wantai 42BYGHM809 | Sparkfun.com, Wantmotor.com | 400 step medium torque motor. 48 N-cm holding torque. Rated for 3V. ± 5% precision (5). <https://www.sparkfun.com/products/10846> |
| ROB-10847 | Wantai 57BYGH420 | Sparkfun.com, Wantmotor.com | 200 step medium torque unipolar stepper motor. Holding trque of 90 N-cm. 1/4 in diameter shaft (5). <https://www.sparkfun.com/products/10847> |

**Table 33**: Stepper motors under consideration for Roadie.

#### **Decision Matrix**

The decision matrix for determining which stepper motors to use for the Roadie is depicted in **Table 34**. Factors considered in the decision process of the stepper motors include the price, availability, power output, overall size and precision of each motor. The highlighted row is the stepper motor selected for use on Roadie.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Factor | Power | Size | Precision | Availability | Cost | Total |
| Weight | 0.25 | 0.25 | 0.3 | 0.1 | 0.1 |  |
| SY42STH38-0406B | 2 | 4 | 3 | 1 | 4 | 2.9 |
| SY42STH47 | 5 | 1 | 3 | 3 | 3 | 3.0 |
| ROB-10846 | 3 | 2 | 4 | 3 | 4 | 3.15 |
| ROB-10847 | 4 | 1 | 3 | 1 | 3 | 2.55 |

**Table 34**: Decision matrix for stepper motors

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table 35.**The total score for each item in the decision matrix (**Table 34**) is calculated by summing the values for each row in the weighted value matrix.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Power | Size | Precision | Availability | Cost |
| SY42STH38-0406B | 0.5 | 1.0 | 0.9 | 0.1 | 0.4 |
| SY42STH47 | 1.25 | 0.25 | 0.9 | 0.3 | 0.3 |
| ROB-10846 | 0.75 | 0.5 | 1.2 | 0.3 | 0.4 |
| ROB-10847 | 1.0 | 0.25 | 0.9 | 0.1 | 0.3 |

**Table 35**: Weighted value matrix. It is comprised of the score for each category multiplied by the weight for the category.

The weightings for the decision matrix were created by using the data in **Table 36**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Model | Power | Size | Precision | Availability | Price |
| SY42STH38-0406B | Lowest Torque | Very compact | 200 step | Out of Stock | $15.34 |
| SY42STH47 | Highest Torque | Very Large, potentially too big for the robot | 200 step | In Stock | $25.91 |
| ROB-10846 | 3rd highest Torque | Large, however should not be too large | 400 step | In Stock | $16.95 |
| ROB-10847 | 2nd Highest torque | Very Large, potentially too big for the robot | 200 step | Out of Stock | $23.95 |

**Table 36**: Quantitative and qualitative vales for the stepper motors under consideration that led to the decision matrix.

#### **Justification**

This section defines how the weighting values were selected for the decision matrix as well as the reasoning behind each category.

##### **Power**

For this decision matrix the power score for each motor was awarded based upon the maximum torque output for each motor compared to each other. The selected motor is in the middle of all motors considered in the power rating. As there are no requirements pertaining to speed in the current version of the System Requirements Specification for Roadie, revision 1.0.0, the torque output of the motor must be higher than the torque required to turn the wheels which will be used in the system. The torque output ROB-10846 is 48 N.cm which is more than enough to drive the largest wheels considered for the system. Even leaving a buffer there is no need to have excessive amount of torque output from the motor we can save money by purchasing a motor with the required power and not an excessive amount.

Power received a weight of 25% because if the motor is not strong enough, it will not be able to turn the wheels. If the wheels don’t move Roadie will be stationary, thus unable to compete. It is for this reason that power has received such a high weight.

##### **Size**

Since Roadie must fit within a one foot by one foot by one foot cube, size is very important factor to consider when choosing the drive motors. The wider the drive motor, the wider Roadie must be in order to securely mount the motors to its chassis. Since two motors will be working in tandem to simulate an axel, the length of the motor is considered to be twice is the amount of space they will occupy. For instance, if a motor was two inches in length, the length factored into consideration would be four inches. Additionally, if each motor is six inches long, there will be no room for wheels or other components as Roadie cannot be wider than one foot.

As the size of the motors directly translates into how wide Roadie’s overall width will be, size was awarded a weight of 25%.

##### **Precision**

Scores for the stepper motors was awarded based upon the number of steps in each motor. Every stepper motor has a set number of steps per full rotation. ROB-10846 has 400 steps per revolution, whereas the other motors under consideration have only 200 steps per revolution. This means the precision of ROB-10846 in full step mode 0.9°per step, opposed to the other motors which offer 1.8° per step. This is crucial because if the motor were to slip steps, the consequences for such an event would be higher on a motor with a smaller step count. Points for precision were awarded based on the information in **Table 37**

|  |  |
| --- | --- |
| Number of Steps | Corresponding Score |
| 0-99 | 1 |
| 100-199 | 2 |
| 200-399 | 3 |
| 400-599 | 4 |
| 600+ | 5 |

**Table 37**: Table used to justify cost scores awarded to each stepper motor.

For these reasons the precision category had the highest weighting factor at 30%, the highest weight in the decision matrix.

##### **Availability**

Scores for availability were awarded based upon whether the motor selected is in stock and ready to ship or not. Items which are out of stock received a score of one due to the much longer wait for the product to be delivered. Conversely, if an item was in stock, it received a score of three. Since there are no elements available for immediate prototyping, no items received a score of five which corresponds to having the item on hand.

Availability was given a weight of 10% as it directly relates to the ability to prototype Roadie.

##### **Cost**

Since there will be at least four stepper motors for Roadie, it is important to consider that the total for the stepper motors will be four times the cost of the selected stepper motor. Each motor was given a score of one to five with one being a very expensive motor, based upon which price range it fell in. **Table 38** shows how points were awarded for the decision matrix.

|  |  |
| --- | --- |
| Price Range | Corresponding Score |
| $0-$10 | 5 |
| $10.01-$20 | 4 |
| $20.01-$30 | 3 |
| $30.01-$40 | 2 |
| >$40 | 1 |

**Table 38**: Table used to justify cost scores awarded to each stepper motor.

Cost was given a weight of 10% as the cost of items are a very important factor in any budget, but not the most important consideration for this item.

##### **Summary**

ROB-10846 is the cheapest motor available which satisfies our power and precision characteristics. Other motors that cost more money are overkill for our purpose and often are too large to work with our system which is why a smaller more inexpensive motor is ideal for our system.

#### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in **Table 39**,below, the requirement ID is followed by the requirement text and an explanation of how the stepper motor will fulfill said requirement.

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfillment |
| 3.1.1 | The system shall move in the two-dimensional playing field | The stepper motors will rotate the wheels of the robot giving it mobility across the playing field |

**Table 39**: Requirements traceability for stepper motors.

### **Gearmotors**

Gearmotors were selected to rotate the arm due to their simplicity in operation and their relatively small size. The following section contains the decision making process for selecting the appropriate gearmotor.

#### **Items under Consideration**

The following items have been considered for use as gearmotors on Roadie. Each item has a unique product ID as well as the vendor and a short description of the product as depicted in

|  |  |  |  |
| --- | --- | --- | --- |
| Model | Name | Distributor | Description |
| ROB-08911 | Micro Metal Gearmotor 30:1 Shenzen Kenmore KM-12FN20-30-06430 | Sparkfun.com | A small gearmotor with a 30:1 gear ratio. Roughly 1in by 1.5 in. Operates at a 430 rpm at 6 V (3).  <https://www.sparkfun.com/products/8911> |
| ROB-12285 | Micro Gearmotor – 90 RPM | Sparkfun.com | A small gear motor with a 298:1 gear ratio that operates at 45-90 rpms at 6V-12V respectively (3). <https://www.sparkfun.com/products/12285> |
| CYT-29 | Cytron 12V 12RPM 166oz-in Spur Gearmotor | Robotshop.com | A gear motor that operates at 12 rpm max with 1.1 N-m output torque (2). <http://www.robotshop.com/en/cytron-12v-12rpm-166oz-in-spur-gearmotor.html> |

**Table 40**: Gearmotors under consideration for Roadie.

#### **Decision Matrix**

The decision matrix used to select stepper motors for Roadie is depicted in **Table 41**. Factors considered in the decision process of the stepper motors include the size, power output, availability and cost of each motor

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Size | Power | Availability | Price | Total |
| Weight | 0.5 | 0.3 | 0.1 | 0.1 |  |
| ROB-08911 | 1 | 1 | 1 | 3 | 1.2 |
| ROB-12285 | 3 | 2 | 3 | 2 | 2.6 |
| CYT-29 | 2 | 3 | 3 | 1 | 2.3 |

**Table 41**: Decision matrix for gearmotors.

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table 42**. The total score for each item in the decision matrix (**Table 41**) is calculated by summing the values for each row in the weighted value matrix.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Factor | Size | Power | Availability | Price |
| ROB-08911 | 0.5 | 0.3 | 0.1 | 0.3 |
| ROB-12285 | 1.5 | 0.6 | 0.3 | 0.2 |
| CYT-29 | 1.0 | 0.9 | 0.3 | 0.1 |

**Table 42**: Weighed value matrix. It is compromised of the score for each category multiplied by the weight for the category.

The weightings for the decision matrix were created by using the data in **Table 43**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Model | Size | Power | Availability | Price |
| ROB-08911 | Smallest | Lowest Power | Out of Stock | $9.95 |
| ROB-12285 | Largest | Middle | In Stock | $12.95 |
| CYT-29 | Middle | Highest Power | In Stock | $15.48 |

**Table 43**: Quantitative and qualitative values of the gearmotors under consideration that led to the decision matrix.

#### **Justification**

This section defines how the weighting values were selected for the decision matrix and why each element is important in selecting the proper product.

##### **Size**

In order to determine the score each motor received for size, the criteria shown in **Table 44** was used.

|  |  |
| --- | --- |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |
|  |  |

**Table 44**: Table used to justify size scores awarded to each gear motor.

When selecting the gear motors for Roadie, size was determined to be the most important factor. This is because the motors will be used to rotate small components in the arm and claw of the robot, thereby making a smaller motor more desirable. For these reasons, the size factor was given a weight of 50%.

##### **Power**

For the selection of gear motors, power was not nearly as important as it was when selecting the stepper motors to drive the wheels of the robot. This is because these smaller gearmotors at most will have to either rotate a Rubik cube row or twist and etch-a-sketch knob which requires much less torque than powertrain of the robot. However it is still important that the motor outputs enough torque that is doesn’t burn itself out when attempting to rotate components of the challenges. This is why the power weighting factor was set a .3 which made is the second most important factor by 20%. All motors in the given selection possess the power required to complete the challenges, however selecting a small motor that has more than enough power is a much better option than selecting a motor that can barely complete the task at maximum output.

##### **Availability**

Scores for availability were awarded based upon whether the motor selected is in stock and ready to ship or not. Items which are out of stock received a score of one due to the much longer wait for the product to be delivered. Conversely, if an item was in stock, it received a score of three. Since there are no elements available for immediate prototyping, no items received a score of five which corresponds to having the item on hand.

Availability was given a weight of 10% as it directly relates to the ability to prototype Roadie.

##### **Cost**

Since Roadie will require multiple gear motors, the cost of the motors was important to determining what motor to select. Each motor was given a score of one to five with one being a very expensive motor, based upon which price range it fell in. **Table 45** shows how points were awarded for the decision matrix.

|  |  |
| --- | --- |
| Price Range | Corresponding Score |
| $0-$10 | 5 |
| $10.01-$20 | 4 |
| $20.01-$30 | 3 |
| $30.01-$40 | 2 |
| >$40 | 1 |

**Table 45**: Table used to justify cost scores awarded to each gearmotor.

Cost was given a weight of 10% as the cost of items are a very important factor in any budget, but not the most important consideration for this item.

##### **Summary**

### **Linear Actuators**

Linear actuators are motors that drive pistons forward and backward, opposed to other motors which rotate a drive shaft. Linear actuators are particularly useful for pushing things, making them useful for extending and retracting the arm of Roadie. This will allow Roadie to push buttons on challenges and better position the height of the arm.

#### **Items under Consideration**

(Table ?) is a table containing the three considered products, their distributor and a brief description, containing the URL for the item.

|  |  |  |
| --- | --- | --- |
| Model | Distributor | Description |
| Firgelli Technologies L12  Actuator 50mm 210:1  12V Limit Switch | Robotshop.com,  store.firgelli.com | The 50mm stoker length actuator in  the Firgelli line of miniature linear  Actuators. Capable of 5mm/s  movements speed, with no load,  and a peak force output of 45 N (5).  <http://www.robotshop.com/en/firge>li-technologies-l12-actuator-50mm  210-1-12v-limit-switch.html |
| Firgelli Technologies L12  Actuator 100mm 100:1  12V Limit Switch | Robotshop.com,  store.firgelli.com | This motor is in the same series as  the above motor but with a 100mm  stroke length. Capable of 8mm/s  no load speed, and a peak output  force of 23N (5).  <http://www.robotshop.com/en/firge>  li-technologies-l12-actuator  100mm-100-1-12v-limit  switch.html |
| Firgelli Technologies  L16 Linear Actuator,  140mm, 35:1, 12V w/  Limit Switches | Robotshop.com,  store.firgelli.com | This motor is a larger model of the  two previous linear actuators. With  140 mm stroke length and a higher  no load speed of 32mm/s (5).  <http://www.robotshop.com/en/line>  r-actuator-l16-140-35-12-s.html |

*Table ?:A List of the potential linear actuators, their distributor, and a brief description. The selected actuator is highlighted*

For these actuators, and as evident in the (Table ?), Firgelli motors has the most options when it comes to miniature linear actuators at a reasonable price, this is why all of our choices are from Firgelli Technologies. Each motor has a price of $70 USD.

#### **Justification**

For these linear actuators there is no decision matrix. Since every motor is the same motor with varying size, this is the only thing we have to choose our motor. Each motor costs exactly the same amount and they are all available and in stock form both Roboshop.com and directly from Firgelli Technologies. The specifications for force output and speed of the actuators is directly related to the stroke length of the motor which is why there is some variation in speed and force output of the motors. Ultimately the only deciding factor in selecting our linear actuator was size.

##### **Size**

Initially these three motors were considered for our project, however upon further consideration, it was determined that the 100mm and 140mm actuators would just be too large to fit the system. If a decision matrix were to be created the weighting factor for the size of the motor would have to be the main consideration and essentially remove the two larger motors form the selection process.

Our robot arm is intended to hover above the challenges and operate by moving up and down to complete the nectary tasks. The 100mm motors and 140mm would not allow us any room to raise the arm. This is because the resting length of the motor is the stroke length. This means that the 100mm stroke length motor, cannot retract more than 100mm but can extend out to 200mm. When we consider that this is nearly eight inches, and our robot cannot be taller than one foot, it drastically reduces the amount of space we have to work with and would physically not fit in the system. And if the 100mm motor is too large than the 140mm motor is also too large for the robot.

##### **Price and Availability**

All three linear actuators go for the exact same price at both distributors. This is another reason why we decided not to complete a decision matrix. Considering how expensive linear actuators are price was a very important factor in choosing our linear actuator, however, the Firgelli motors were the most cost effective motors and also happened to provide everything we need. Almost all of the more expensive motors were way to large and output too much power.

Since they are all the same cost that row of the decision matrix would be null and void anyway. This also goes hand in hand with availability because they are all sold by the same company and distributor and are all in stock they all have the same cost and availability.

##### **Power**

The L16 linear actuator is the only actuator that has a larger driving motor out of the three selected however as mentioned earlier its size eliminated it from use in the robot. The two other actuators, the 50mm and the 100 mm L12 actuator, both have the same driving motor, it is the piston length and weight that causes differences in the output speed and force. Since we selected the smallest motor the shaft length is the shortest translating into the highest output force. This also means that it has lower speed, but for this project speed is not as necessary as power. Fortunately, the smaller actuator which fits the robot design has the higher force output.

##### **Final Decision**

As already mentioned the only feasible linear actuator is the Firgelli 50mm L12 linear actuator, due to its compact size and relatively high pushing force. Due to a lack of vendors that sell affordable, miniature linear actuators, all of the considered motors were from the same family of Firgelli Technologies miniature linear actuators, removing the need for a decision matrix. In conclusion the only linear actuator we found that will satisfy all our needs is the Firgelli Technologies L12 Linear Actuator 50mm.

#### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in **Table 46**,below, the requirement ID is followed by the requirement text and an explanation of how the linear actuator will fulfill said requirement.

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfillment |
| 3.3.3 | The system shall play the Simon carabineer | The linear actuator and the gearmotors in conjunction will create an arm with rotating and horizontal movement, allowing the robot to push all button on the Simon Carabineer |
| 3.3.4 | The system shall twist one row of a Rubik’s cube 180 degrees | The linear actuator will lower a claw onto the row of the Rubik’s cube and a gearmotor will then rotate the claw with the single row of the Rubik’s cube |
| 3.3.5 | The system shall draw “IEEE” on a Pocket Etch-A-Sketch | The linear actuator will lower claw like devices onto the knobs of the etch-a-sketch allowing the robot to turn the knobs and draw on the etch-a-sketch |
| 3.3.6 | The system shall collect a single playing card | The Linear actuator will give the arm the ability to press down on the top card of the deck where an adhesive will grab the card and, then the actuator will move the arm back up so the card can be carried |

**Table 46**: Requirements traceability for linear actuators.

### **Risk Analysis**

The risk analysis section includes information regarding risks related to the motors on Roadie and solutions to mitigate those risks. With any part on a moving system, there is a possibility that the components may fail either catastrophically or otherwise. For instance, a component becoming stuck in a state that would cause Roadie to behave erratically would be considered a catastrophic failure. **Table 47** defines several of such instances.

The probability of each occurrence, denoted as **Prob.**, will give the likelihood on the scale of one to nine with one will be the lowest likelihood of occurrence. The severity of an occurrence, denoted as **Sev.,** will give the impact that the event will have on a scale of one to nine with one being lowest impact.

|  |  |  |  |
| --- | --- | --- | --- |
| Risk | Probability | Severity | Mitigation of Risk |
| Overheating | 5 | 6 | If a motor is run too long or it drawing too much current, the physical temperature of the motor will increase and could potentially cause the motor to fail or create a fire hazard. In order to reduce the probability of the motors overheating and potentially creating a fire hazard, it is important to ensure that the motor is wired correctly into the system. This prevents motors form drawing excessive amounts of current and causing the motor to overheat. Since stepper motors constantly draw current it is unavoidable that they will heat up, however, by ensuring they are only on when in use we can mitigate the probability of catastrophic overheating |
| "Burning out" a motor | 3 | 7 | If the motor is forced to drive a load that is too large or the motor is physically blocked from rotating, the internals of the motor will fail and it will no longer function properly. This is commonly referred to as “burning out” a motor. In order to reduce this risk we will calculate all loads for the motors prior to assembly and ensure that each motor can handle the load that it will be driving. We will also test extensively to ensure that all components are free to move and there are no errors in programing that would force a motor through an invalid range of motion. |
| Becoming misaligned | 6 | 2 | While the robot is moving or during construction, it is very possible that a motor could become misaligned. This could create problems such as the wheels not being in alignment. If the wheels are not aligned there will be slipping and the precession of motion will be decreased. If the actuators or the gearmotors in the arm become misaligned, the robot may not be able to complete a challenge or will complete a challenge incorrectly. We can mitigate this risk by securely mounting all motors and ensuring that they do not interfere with one another |

**Table 47**: Risks that can be attributed to the motors and their associated mitigations

## **Movement System**

The following information composes the justifications that were made to make a decision on the method of movement, more specifically the wheels of the entire system.

### **Items under Consideration**

The following items have been considered for use as wheels on Roadie. Each item has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 48**

|  |  |  |  |
| --- | --- | --- | --- |
| Item ID | Name | Vendor | Description |
| 276-1447 | Mecanum Wheels | VEX Robotics | Four inch Mecanum wheels sold as a pack of four. [9] |
| 276-3526 | Omni-Directional Wheels | VEX Robotics | 3.25 inch omni-directional wheels sold as a pack of four. [10] |
| ROB-12124 | Heavy Duty Wheels | SparkFun | Four inch standard heavy duty wheels sold individually. [11] |

**Table 48**: Wheels under consideration for Roadie.

### **Decision Matrix**

The decision matrix used to select the wheels for use on Roadie is shown in **Table 49.** Factors considered in the decision process of the wheels include their perceived ease of implementation. Their stability, their mobility, the availability of the wheel and the cost of the wheel set. The highlighted row is the sensor selected for use on Roadie.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Factor | Ease | Stability | Mobility | Availability | Cost | Total |
| Weight | 0.2 | 0.25 | 0.35 | 0.1 | 0.1 | 1.0 |
| 276-1447 | 4 | 5 | 5 | 3 | 2 | 4.3 |
| 276-3526 | 4 | 4 | 5 | 3 | 3 | 4.15 |
| ROB-12124 | 2 | 2 | 3 | 3 | 4 | 2.65 |

**Table 49**: Decision matrix for wheels.

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table 50**.The total score for each item in the decision matrix (**Table 49**) is calculated by summing the values for each row in the weighted value matrix.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Ease | Stability | Mobility | Availability | Cost |
| 276-1447 | 0.8 | 1.25 | 1.75 | 0.3 | 0.2 |
| 276-3526 | 0.8 | 1.0 | 1.75 | 0.3 | 0.3 |
| ROB-12124 | 0.4 | 0.5 | 1.05 | 0.3 | 0.4 |

**Table 50**: Weighted value matrix. It is comprised of the score for each category multiplied by the weight for the category

The weightings for the decision matrix were created by using the data in **Table 51**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Ease (bore size) | Stability (wheel weight) | Mobility | Availability | Cost per set |
| 276-1447 | 0.125 inch square bar | 0.41lb | Can strafe | In stock | $59.99 |
| 276-3526 | 0.125 inch square bar | 0.1885lb | Can strafe | In stock | $39.99 |
| ROB-12124 | 0.5 inch round bore | 0.0625lb | Cannot strafe | In stock | $27.96 |

**Table 51**: Quantitative and qualitative values of the line following sensors under consideration that led to the decision matrix.

### **Justifications**

The following section represents the reasoning behind each category and how their weights were determined.

#### **Ease**

The ease category related to the perceived ease of assembling and mounting the wheels to the motor shafts. It also pertains to how easily the wheels will adapt to a different system design. Since both the mecanum and omni-directional wheels can easily act as standard differential wheels if a design change is made, they both received a rating of 4. [9][10]

Ease was given a weight of 20% since it correlates with team AWTY’s ability to efficiently implement the wheels into the system.

#### **Stability**

The stability of each wheel relates to how effective each will be on a consistent basis along with the weight of each wheel. Stability also considers if the width of each wheel is sufficient for the system, which each factor satisfies. The mechanum wheels rated slightly above the others because of the ability to make finer adjustments when moving near an obstacle.

Stability was given a weight of 25% as it correlates to how stable the overall system will be with the wheel selection. Roadie will rely on the stability of the wheel especially when it comes to integration with the stepper motors to prevent slipping.

#### **Mobility**

The mobility relates not only to the effects the wheels have when in contact with the motor and the ground (i.e. the wheels cause the whole robot to rattle), but also to how many axis of movement they can use. The mecanum and omni-directional wheels rated above the heavy duty wheels because of their ability to strafe, meaning that they can easily move laterally.

Mobility received a weight of 35% be it describes how easily Roadie will be able to reposition itself as well as reach the challenges. The more mobile the system is, the easier it will be for it to reach the challenges in a timely manner. Therefore, mobility received the highest weight of all factors for the wheels.

#### **Availability**

Scores for availability were awarded based upon whether the motor selected is in stock and ready to ship or not. Items which are out of stock received a score of one due to the much longer wait for the product to be delivered. Conversely, if an item was in stock, it received a score of three. Since there are no elements available for immediate prototyping, no items received a score of five which corresponds to having the item on hand.

Availability was given a weight of 10% since wheels of each type are very easy to find. Other factors can be weighted more importantly because of this.

#### **Cost**

Each motor was given a score of one to five with one being a very expensive motor, based upon which price range it fell in. Table 52 shows how points were awarded for the decision matrix.

|  |  |
| --- | --- |
| Wheel Set Cost | Associated Score |
| $0-$19.99 | 5 |
| $20-$39.99 | 4 |
| $40-$59.99 | 3 |
| $60-$79.99 | 2 |
| $80+ | 1 |

**Table 52**: Table used to justify cost scores awarded to each wheel set

Cost was given a weight of 10% as the cost of items are a very important factor in any budget, but not the most important consideration for this item.

#### **Summary**

The main factors when selecting the wheels were to be the price and mobility options. The current system design is such that it is desirable to have wheels which possess the ability to easily strafe. For these reasons, the mecanum wheels came out with the highest rating on the decision matrix.

### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in **Table 53**,below, the requirement ID is followed by the requirement text and an explanation of how the custom claw will fulfill said requirement.

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfilment |
| 3.1.1 | The system shall move in the competition area shown in Fig. 7. | The wheels will directly allow Roadie to move about the competition area. |
| 3.3.2 | The system shall align with the challenge before attempting to complete the challenge. | The wheels will give Roadie the ability to strafe in order to aid in lining up with challenges. |
| 4.1.1 | The system shall align with the challenge before attempting to complete the challenge. | The wheels conform to all size restrictions. |

**Table 53**: Requirements traceability for wheels.

### **Risk Analysis**

This section will include information regarding risks related to the movement equipment and solutions to mitigate those risks. The probability of each occurrence, denoted as **Prob.**, will give the likelihood on the scale of 1 to 5. 1 will be the lowest likelihood while 5 will be the highest. The severity of an occurrence, denoted as **Sev.,** will give the amount of impact that an event will have, similarly as before with 1 being lowest impact and 5 being the highest.

|  |  |  |  |
| --- | --- | --- | --- |
| Risk | Prob | Sev | Mitigation |
| Loss of traction | 2 | 3 | Complete various tests to determine what rpm settings are at the most risks for loss of traction. Roadie will use a setting that is lower than these risk settings. |
| Damaged wheel | 1 | 3 | The likelihood of one of the wheels being damaged is very low. In the unlikely event that it does happen, all of the considered wheels are popular and always in stock. |

**Table x.** The major risks and mitigation for the system’s movement equipment.

## **Robotic Claw**

The following tables and justifications are the basis for the decision making process of selecting a suitable claw for Roadie.

### **Items under consideration**

The following items have been considered for use as a claw on Roadie. Each item has a unique product ID as well as the vendor and a short description of the product, as depicted in **Table 54**

|  |  |  |  |
| --- | --- | --- | --- |
| Item ID | Item Name | Vendor | Description |
| ROB-11524 | Robotic Claw – MKII | Sparkfun | Parallel opening claw which features brass sleeves in joints to make them more rigid. The claw opens to about 2 inches and “depending on the servo motor used, it can pick up some relatively heavy objects.”REF |
| 276-2212 | Claw Kit | Vex Robotics | Claw made of heavy duty plastic, it is dexterous enough to grab a feather and strong enough to hold a 12 oz. soda can.REF |
| Custom | Custom | N/A | A magnetic block attached to a rod that provides Roadie the ability to change attachments depending upon what challenge it arrives at. |

**Table 54**: Claws under consideration for Roadie

### **Decision Matrix**

The decision matrix used to select a claw for Roadie is depicted in **Table 55**. Factors considered in the decision process of the claw include the maximum holding weight, the claw opening, how versatile the claw is, the availability of the claw and the cost of the claw. The highlighted row is the claw selected for use on Roadie.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Factor | Maximum Holding Weight | Claw Opening | Versatility | Availability | Cost | Total |
| Weight | 0.1 | 0.3 | 0.4 | 0.1 | 0.2 |  |
| ROB-11524 | 5 | 1 | 2 | 3 | 5 | 3.3 |
| 276-2212 | 5 | 4 | 2 | 3 | 3 | 3.4 |
| Custom | 5 | 5 | 5 | 5 | 1 | 4.7 |

**Table 55**: Decision matrix for claw

The weighted matrix, or the matrix computed by multiplying the score in each category by its weight is show in **Table 56**. The total score for each item in the decision matrix (**Table 55**) is calculated by summing the values for each row in the weighted value matrix.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Maximum Holding Weight | Claw Opening | Versatility | Availability | Cost |
| ROB-11524 | 0.5 | 0.1 | 0.8 | 0.3 | 1.0 |
| 276-2212 | 0.5 | 1.2 | 0.8 | 0.3 | 0.6 |
| Custom | 0.5 | 1.5 | 2.0 | 0.5 | 0.2 |

**Table 56**: Weighted value matrix. It is comprised of the score for each category multiplied by the weight for the category.

The weightings for the decision matrix were created by using the data in **Table 57**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Factor | Maximum Holding Weight | Claw Opening | Versatility | Availability | Cost |
| ROB-11524 | Variable | Approx. 2 inches | Single purpose | In stock | $11.95 |
| 276-2212 | 12 oz soda can | 3.375 inches | Single purpose | In stock | $19.95 |
| Custom | Variable | Custom | Very versatile | Available | $40.00 |

**Table 57**: Quantitative and qualitative values of the claws under consideration that led to the decision matrix.

### **Justifications**

The following section represents the reasoning behind each category and how their weights were determined.

#### **Maximum holding weight**

The maximum holding weight of the claw is how much weight the claw can safely hold. For the ROB-11524, the manufacturer claims that the weight that the claw can hold depends solely on the servo or motor used to control the claw. For the 276-2212, the manufacturer claims that the heaviest the object that the arm can hold is a 12oz soda can, which weighs about 380g. A custom solution for Roadie would have a variable weight holding as it can be designed and modified to suit any issues that may appear. The Rubik’s cube used in competition has a weight of approximately 181.4g **REF**. Therefore, all of the arms will exceed the heaviest item Roadie may have to pick up, thus receiving a score of five across the board.

If the maximum holding weight is low, Roadie will not be able to pick up the items it needs to. It is for this reason that maximum holding weight was given a weight of 10% as the holding weight does have an effect on Roadie’s ability to complete the challenges.

#### **Claw opening**

In order for Roadie to be able to interact with the challenges, the claw must be able to open wide enough to support all the challenges. Since the ROB-11524 opens approximately 2 inches, this might not be wide enough given the Rubik’s cube to be used is approximately 2.2 inches wide **REF**. Bearing this in mind, the ROB-11524 was scored a one because it may not work. The 276-2212 was scored a four because it is not the widest opening claw in this comparison, though it does place a close second. For this reason, it has been given a score of four. The custom claw will be able to open and grip the items as AWTY deems fit. It is for this reason it was ranked the highest with a score of five.

Claw opening was given a weight of 30% because the claw must open wide enough to be able to interact with all of the challenges. If the claw is unable to do so, Roadie will not be able to perform its tasks.

#### **Versatility**

The versatility of the claw is how adaptable and readily changeable each claw is, as perceived by AWTY. In this particular instance, both ROB11524 and 276-2212 are simple claws that open and closed when attached to a servo motor. While this may work for all the challenges, AWTY feels that this is not adaptable enough, and may cause problems with the design as the system progresses. It is for this reason, that the “off the shelf” claws have been awarded a two. In their current state, they will require some modifications, however, they may suffice. It is also very likely that one “off the shelf” claw may not suffice. In this case, Roadie would require multiple claws to be able to complete challenges which is not desirable. The custom option received a score of five because AWTY is not locked into a single design or form factor. It is very customizable and modifiable as prototyping advances, making the custom route very attractive.

The weighting for versatility is set to 50% because Roadie will be completely dependent upon some form of claw to be able to implement each challenge. The claw chosen must be versatile enough to adapt to four very different, very distinct challenges. If the claw lacks this ability, not only will it compromise Roadie’s ability to complete the challenge, it also imposes more constraints on the design, as multiple claws may have to be employed to complete the challenges.

#### **Availability**

Scores for availability were awarded based upon whether the motor selected is in stock and ready to ship or not. Items which are out of stock received a score of one due to the much longer wait for the product to be delivered. Conversely, if an item was in stock, it received a score of three. Items available for immediate prototyping received a score of five which corresponds to having the item on hand.

Availability was given a weight of 10% as it directly relates to the ability to prototype Roadie.

#### **Cost**

The values for cost for the claws were obtained by giving the most expensive claw a score of one, and the least expensive claw a score of five. As there was only one other claw to consider, a score of 3 was awarded since it fit between most expensive and least expensive item. It should also be noted that the custom claw was allotted a budget of $40 since it will be doing the work of what may amount to four claws if the “off the shelf” route was chosen.

Cost was given a weight of 20% as the cost of items are a very important factor in any budget, but not the most important consideration for this item.

#### **Summary**

### **Requirements Traceability**

The following requirements traceability refers to the System Requirements Specification for Roadie, revision 1.0.0, published September 18, 2014. As shown in **Table 58**,below, the requirement ID is followed by the requirement text and an explanation of how the custom claw will fulfill said requirement.

|  |  |  |
| --- | --- | --- |
| ID | Requirement Text | Fulfillment |
| 3.3.3 | The system shall play the Simon Carabiner. | The custom claw will have a specific attachment dedicated to being able to play the Simon Carabiner. |
| 3.3.3.1 | The system shall play the Simon Carabiner for 15 seconds. | The custom claw will allow for Roadie to correctly interact and play Simon for the entire duration of 15 seconds. |
| 3.3.3.2 | The system shall initiate the Simon Carabiner by pressing the start button. | By having an attachment made specifically for Simon, Roadie will be able to precisely hit the start button on Simon to activate the game. |
| 3.3.4 | The system shall twist one row of a Rubik’s Cube 180 degrees. | The custom claw will have a specific attachment dedicated to being able to the Rubik’s cube, allowing Roadie to twist one row of a Rubik’s cube 180 degrees. |
| 3.3.5 | The system shall draw “IEEE” on the pocket Etch-A-Sketch. | The custom claw will have a specific attachment to twist the knobs on the Etch-A-Sketch, allowing Roadie to correctly draw “IEEE”. |
| 3.3.5.1 | The system shall use [Font and Size TBD] for drawing “IEEE”. | With the implementation of a custom claw, Roadie will have the ability to very finely manipulate the knobs on the Etch-A-sketch, thus allowing for a wide range of fonts and sizes. |
| 3.3.6 | The system shall collect a single playing card [Exact deck TBD]. | The custom claw will have a specific attachment for the retrieval of playing cards, allowing Roadie to pick up exactly one card. |
| 3.3.6.1 | The system shall carry playing card across finish line. | The custom claw will enable Roadie to maintain a grip on the single card, regardless of the time taken from Roadie picking up the card to Roadie crossing the finish line. |
| 3.3.6.2 | The system shall keep the card in a usable condition. | The custom arm will enable Roadie to keep the card in a usable condition. |

**Table 58**: Requirements traceability for robotic claw

### **Risk Analysis**

The risk analysis section includes information regarding risks related to the line following equipment and solutions to mitigate those risks. Take, for instance, if the arm of Roadie was to become stuck. Since Roadie’s arm represents the appendage in which Roadie will interact with all the challenges during competition, a failure of the arm would result in total failure of the competition. As such, precautions must be made to ensure that the arm operates in a safe and optimal manner. An example of a catastrophic of the arm would be if the means for attachment retrieval failed or was damaged during competition. A failure of this magnitude would render that round of competition as a definitive loss, very likely harming Roadie’s overall performance during competition. An example of a minor failure would be if the arm became misaligned. While this would affect Roadie’s performance, Roadie would still be able to complete the challenges, albeit not optimally, and receive some points for that particular round. **Table 59** depicts the risks associated with the arm system.

The probability of each occurrence, denoted as **Prob.**, will give the likelihood on the scale of one to nine with one will be the lowest likelihood of occurrence. The severity of an occurrence, denoted as **Sev.,** will give the impact that the event will have on a scale of one to nine with one being lowest impact.

|  |  |  |  |
| --- | --- | --- | --- |
| Risk | Prob. | Sev. | Mitigation of Risk |
| Attachment gets stuck on arm | 2 | 9 | If an attachment becomes stuck on the arm, this will cause Roadie to no longer be able to compete for that particular round. As the attachments will be held in place by an electromagnet, this is a very unlikely to occur. The reason being that once power is cut to the electromagnet, there will no longer be a magnetic field joining the attachment and arm. In order to mitigate this event extensive testing will be performed to ensure that this does not happen during competition. |
| Arm becomes misaligned relative to challenges | 3 | 3 | If the arm becomes misaligned during competition, this will hinder Roadie’s ability to complete each challenge. This would be attributed to Roadie thinking the arm is aligned in one place, when in fact it may be offset by a slight degree. In order to mitigate this, Roadie will have a form of track to make sure that the arm is always aligned in the proper spot. |
| Arm fails to extend or retract | 2 | 9 | If the arm fails to retract, Roadie would be unable to retrieve subsequent attachments for the arm. This would result in Roadie scoring less than optimally for the round. If Roadie is unable to extend the arm, Roadie would once again, be unable to retrieve the appropriate attachments. It is also possible that if the arm is extended in such a manner, Roadie will be unable to progress further, thus terminating the round. In order to mitigate this event, extensive testing will occur with various loads in order to ensure that the arm will always extend and retract, regardless of what may be attached. |
| Attachment falls off arm during competition | 1 | 9 | If the attachment were to fall off the arm during competition, this could pose several distinct problems for Roadie. The first of such problem would be subsequent round completion. If the part is damaged upon falling off, this would hinder Roadie’s ability to complete future course rounds. Additionally, if the part falls off in such a way that it impedes Roadie’s advancement during the round, Roadie would ultimately fail that round of competition. In order to mitigate these risks, all attachments to the arm will have some form of redundancy built in. This will help to assure that Roadie will reliably be able to maintain control of the arm attachments. |

**Table 59**: Risks that can be attributed to the robotic arm and their associated mitigations.

# **Glossary**

The glossary contains definitions of words and phrases used throughout this document.

|  |  |  |
| --- | --- | --- |
| Entry | Definition | Aliases |
| Align | The system will position itself so the appendages can properly reach the challenges. |  |
| Autonomous | Undertaken or carried on without outside control [2]. |  |
| Bad state | Any state that is not the line following state or the challenge state. |  |
| Challenge State | The state in which Roadie is completing one of the four challenges. |  |
| Challenge Zone | The 1ft. x 1ft. areas where each of the challenges will be played along the course. |  |
| Competition Area | The competition area is the plywood board where the competition is being held on. The system must maintain contact with the board at all times. |  |
| Course Round | A span of five minutes during which the system is expected to complete the 4 challenges [1]. |  |
| Pocket Etch-A-Sketch | The pocket Etch-A-Sketch is a popular children’s toy with two knobs to move the cursor up and down as well as left and right. For the competition, the specific version of the pocket Etch-A-Sketch being used is SKU:FD79DD3F from Toys R Us online [7], and can be seen in **Figure7.** |  |
| Finish Line | The finish line is the ending point of the competition. It is the point where the Scotch Blue Painter’s Tape comes to the final “T” shape on the course [1]. It is marked as FINISH in **Figure4**. |  |
| Good state | Either the line following state or the challenge state. |  |
| Institute of Electrical and Electronics Engineers | “IEEE is the world's largest professional association dedicated to advancing technological innovation and excellence for the benefit of humanity” [4]. That being said, IEEE is not only composed of electronic and electrical engineers as the name might suggest. Other types of members include computer scientists, software developers and even some doctors. | IEEE |
| Line Following State | The state in which Roadie is following the Scotch Blue Painter’s tape located on the competition area. |  |
| Obstruct | SoutheastCon rules state that the system cannot obstruct any obstacle [1]. |  |
| Playing Card | Information on the specific playing cards is still pending, thus, [TBD]. |  |
| Random Access Memory |  | RAM |
| Rubik’s Cube | The Rubik’s Cube is a puzzle game that achieved popularity in the 1980’s. For the competition, the specific version of the Rubik’s Cube being used is SKU:DAD09D9E from Toys R Us online [6], and can be seen in **Figure6.** |  |
| Scotch Blue Painter’s Tape | Scotch Blue is a brand of painter’s tape produced by the company 3M. For the competition, the specific model of painters tape being used is SKU: 958999 from Home Depot [8], and can be seen in **Figure8.** | Guidance Tape |
| Simon Carabiner | The Simon Carabiner is another version of the game, Simon, which is an electronic version of the children’s game “Simon Says”. For the competition, the specific version of Simon being used is SKU:226CE810 from Toys R Us online [5], and can be seen in **Figure5.** |  |
| SoutheastCon | SoutheastCon is the annual IEEE Region 3 Technical, Professional, and Student Conference. The conference includes technical sessions, tutorials, and exhibits. Additionally, various challenges and competitions are held for students to demonstrate their technical knowledge and understanding.“IEEE Region 3 encompasses the southeastern United States and includes the states of Alabama, Florida, Georgia, areas of Indiana, Kentucky, Mississippi, North Carolina, South Carolina, Tennessee, Virginia and the country of Jamaica” [3]. |  |
| Starting Area | A one foot by one foot area on the competition area marked by Scotch Blue Painter’s tape [1]. |  |
| Usable Condition | SoutheastCon rules state that the playing card must be left in a usable condition [1]. |  |

# **Acronyms and Abbreviations**

|  |  |
| --- | --- |
| Acronym | Meaning |
| AWTY | Are We There Yet |
| ECSSE | Electrical, Computer, Software & Systems Engineering |
| ERAU | Embry-Riddle Aeronautical University |
| IEEE | Institute of Electrical and Electronics Engineers |
| RAM | Random Access Memory |

# **Appendix A**

This appendix includes a diagram of the competition course as well as pictures of the individual challenges the system must complete. Also included is a picture of the tape that will designate the line the system must follow.

## **Competition Course**

The course, as shown in **Fig. 6** below, shows the rough outline of the track the system will follow, as well as what a challenge station would look like.

**Figure4** Competition course for SoutheastCon[1].

## **Simon Carabiner**

The Simon Carabiner, as seen in **Fig. 7** is the specific Simon game that the system will play.



**Figure5:** The exact Simon Carabiner to be used during competition [5].

## **Rubik’s Cube**

The Rubik’s Cube, as seen in **Fig. 8** is the specific Rubik’s Cube that the system will play.



**Figure6:** The exact Rubik's Cube to be used during competition [6].

## **Pocket Etch-A-Sketch**

The pocket Etch-A-Sketch as shown in **Fig. 9** is the specific pocket Etch-A-Sketch the system will play.



**Figure7:** The exact pocket Etch-A-Sketch to be used during competition [7].

## **Playing Cards**

[TBD] The playing cards will be updated with an appropriate picture once there is a specific set listed in the competition rules.

## **Scotch Blue Painter’s Tape**

The Scotch Blue Painter’s Tape as show in **Fig. 10** is the exact painter’s tape that will be used to designate the line the system must follow.



**Figure8:** The exact painter’s tape to be used on the course [8].

# **References**

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