Budget Proposal for Roadie

Sponsor

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

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Are We There Yet?

Revision History

Date	Reason for Change	Version
1 October 2014	Initial draft	0.1.0
2 October 2014	Motor section added	0.2.0
3 October 2014	Major parts and format	0.3.0
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1. Introduction

1.1 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.

1.2 Scope

This document is intended to provide a monetary budget as well as justifications for each item. Core components, with a price of $20[47**]** 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.

1.3 Team Information

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

2. Functional Decomposition of System

Roadie is broken down three main subsystems: (1) the communications and coordination subsystem, (2) the arm subsystem and (3) the movement subsystem. The division of these subsystems is illustrated in **Fig 1**.

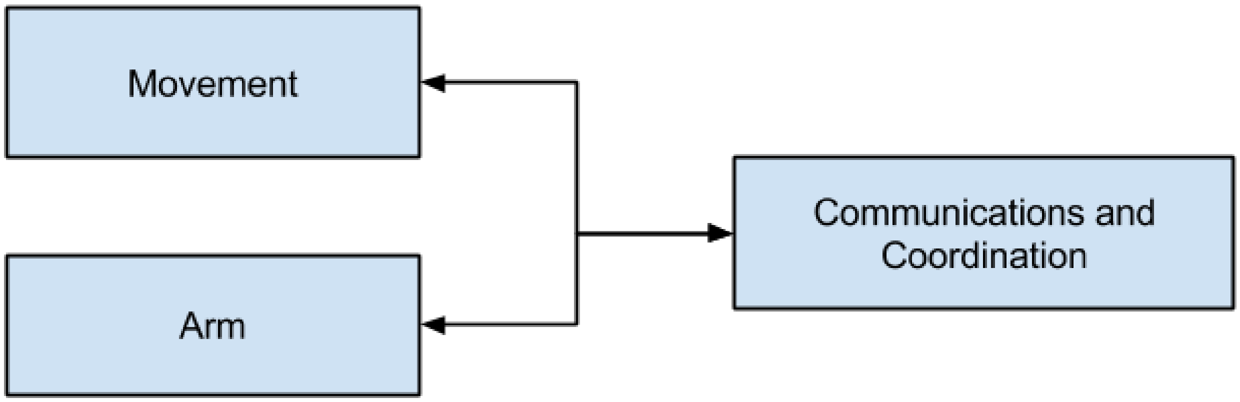

Fig 1: Division of Roadie into six subsystems.

The communication and coordination subsystem relays information to both the arm subsystem and the movement subsystem. These subsystems are further divided by functionality to create the high-level architecture as described in Section 2.1.

2.1 High-Level Architecture of System

The system architecture of Roadie is designed in a layered approach, depicted in **Fig. 2** below, in order to better divide the work being done and to aid in the conceptualization of the system design.

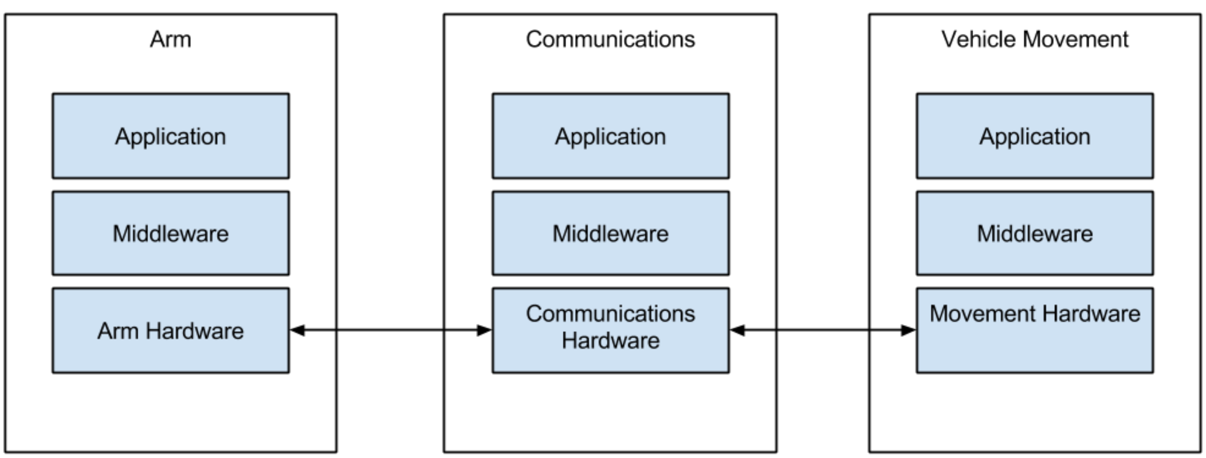

Fig. 2: High level description of the systems in Roadie.

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 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.

2.2 Decomposition of Communications and Coordination

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

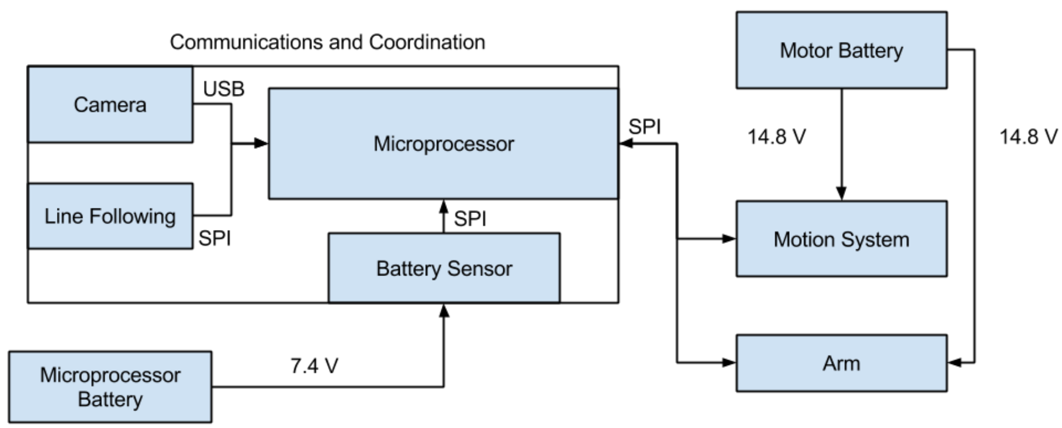

Fig 3: Decomposition of communications and coordination system for Roadie.

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.

All of the communications from the communication and coordination are a hard wire connection. That is to say that all of the communications occur over a physical medium. The camera communicates with the microprocessor over USB. The line following sensors, motion system and arm will all communicate with the microcontroller via serial peripheral interface (SPI). The microprocessor battery is connected to the battery sensor via a 7.4V DC line. The motor battery is connected to both the motion system and the arm system via a 14.8V DC line.

2.3 Decomposition of Arm System

Fig. 4 shows the decomposition of the arm system into its major components.

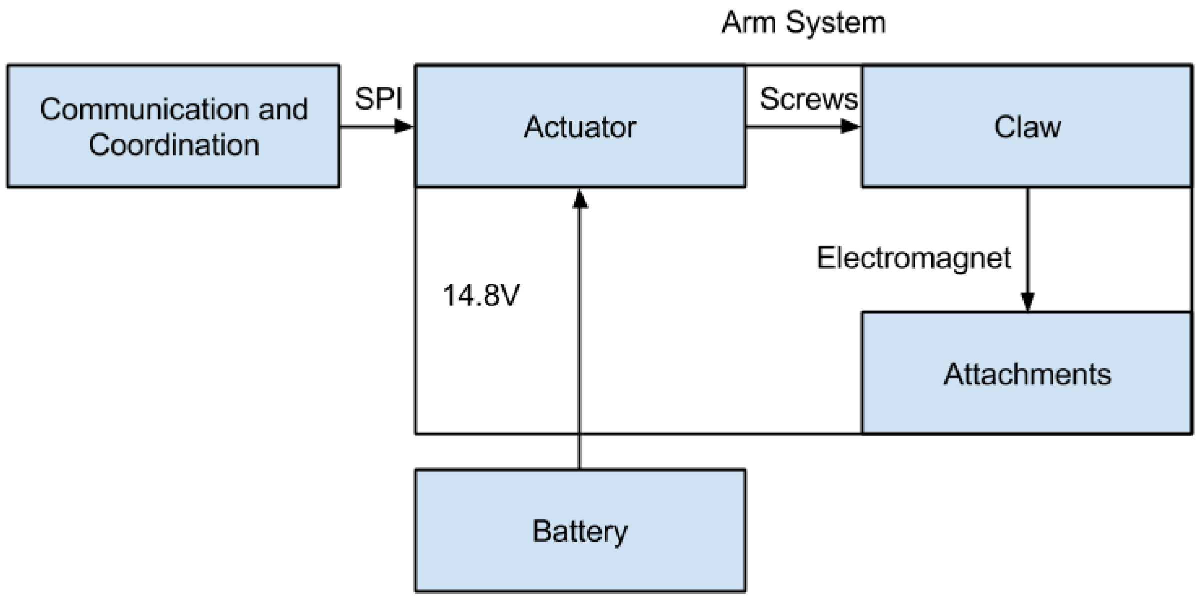

Fig. 4: Decomposition of arm subsystem for Roadie.

Information comes in from the communication and coordination system via SPI to the actuator. The actuator is powered via the 14.8V line off of the battery. The claw is physically attached to the actuator by way of a screw or some other mechanical means. The attachments to complete challenges are attached to the claw via an electromagnet.

2.4 Decomposition of Movement System

Fig. 5 shows the decomposition of Roadie's movement subsystem into major components.

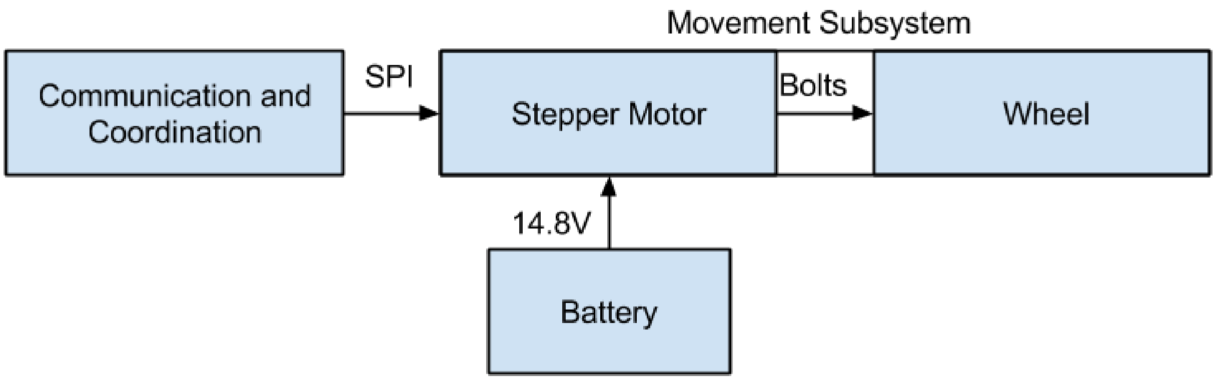

Fig. 5: Decomposition of movement subsystem Roadie.

Information from the communication and coordination system occurs to the stepper motors over SPI. The stepper motor is powered via the 14.8V line off of the battery. The wheel is physically attached to the stepper motor via bolts and nuts.

3. 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.

3.1 Microcontroller

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

3.1.1 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 43**: Line following equipment under consideration for Roadie.

Item ID	Item Name	Vendor	Description
UDOO Quad	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. [14]
B00K7EEX2U	BeagleBone Black Rev C	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 1 GB on-board flash storage, 3D graphics, and digital in and out pins. [17]
B006H0DWZW	Arduino MEGA 2560 R3	Amazon	The Arduino MEGA 2560 R3 is a small microcontroller with 54 digital in/out pins and 14 analog ins, 4 UARTs, a 16 MHz crystal oscillator, and a USB connection. Also, the Arduino MEGA has 14 MHz clock speed with 8 KB of RAM, and 256 KB memory. [15]
B009SQQF9C	Raspberry Pi Model B	Amazon	The Raspberry Pi B comes with a 700 MHz processor with 512 MB of RAM. Along with an Ethernet, HDMI, two USB, RCA video, audio out jack, and SD card socket. [16]

Table 1: Microcontrollers under consideration for Roadie.

3.1.2 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, ports, Wi-Fi, and Flash Storage.

Factor	Processing Power	RAM	Cost	Community	Power Consumption	Ports	Wi-Fi	Flash Storage	Total
Weight	0.2	0.2	0.1	0.15	0.05	0.15	0.05	0.1	
UDOO Quad	5	5	1	4	3	5	5	5	4.35
B00K7EEX2U	3	5	4	2	4	3	1	1	3.3
B006H0DWZW	1	1	5	5	2	2	1	1	2.2
B009SQQF9C	1	4	4	4	4	4	1	5	3.35

Table 2: 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 3.**The total score for each item in the decision matrix (**Table 2**) is calculated by summing the values for each row in the weighted value matrix

Factor	Processing Power	Ram	Cost	Community	Power Consumption	Ports	Wi-Fi	Flash Storage
UDOO Quad	1.0	1.0	0.1	0.6	0.15	0.75	0.25	0.5
B00K7EEX2U	0.6	1.0	0.4	0.3	0.2	0.45	0.05	0.5
B006H0DWZW	0.2	0.2	0.5	0.75	0.1	0.3	0.05	0.1
B009SQQF9C	0.2	0.8	0.4	0.6	0.2	0.6	0.05	0.5

Table 3: 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 4.** The information for the UDOO Quad was taken from [14]. The information for the B00K7EEX2U was taken from [17]. The information for the B006H0DWZW was taken from [15]. The information for the B009SQQF9C was taken from [16].

Factor	Processing Power	RAM	Cost	Community	Power Consumption	Ports	Wi-Fi	Flash Storage
UDOO Quad	1 GHz/4 cores	1 GB	$135	Good	2.7 watts	Digital, Analog, SATA, USB, Ethernet, Analog Audio and Mic	Yes	SD Card
B00K7EEX2U	1 GHz/1 cores	1 GB	$55.67	Okay	2.34 watts	Digital, Analog, USB,	N/A	4 GB
B006H0DWZW	258 MHz/1 cores	128 KB	$37.46	Great	5.18 watts	Digital, Analog,	N/A	258 KB
B009SQQF9C	700 MHz/1 cores	512MB	$52.99	Good	1.48 watts	USB, Ethernet, HDMI, Audio, Micro USB	N/A	SD Card

Table 4: Quantitative and qualitative values of the microcontrollers under consideration that led to the decision matrix.

3.1.3 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 5** represents the values for processing power such as the number of cores the microcontroller has, and the clock speed of the microcontroller.

$$4\left(\frac{Clock\ Speed * Core}{Max\ Clock\ Speed * Max\ Cores}\right) + 1 = Score$$

Factor	Clock Speed	Score
UDOO Quad	$4\left(\frac{1\ GHz * 4}{1GHz * 4}\right) + 1 = 5$	5
B00K7EEX2U	$4\left(\frac{1\ GHz * 1}{1GHz * 4}\right) + 1 = 3$	3
B006H0DWZW	$4\left(\frac{258\ MHz * 1}{1GHz * 4}\right) + 1 = 1$	1
B009SQQF9C	$4\left(\frac{700\ MHz * 1}{1GHz * 4}\right) + 1 = 1$	1

Table 5: 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.

RAM

RAM helps reduce the time it takes for the processor to access the memory, so the more RAM that the less time the processor must access the flash memory. **Table 6** shows a breakdown of RAM, on board storage and any additional storage that may be available to each microcontroller.

$$5\left(\frac{Item\ under\ consideration}{Max\ RAM}\right) + 1 = Score$$

Factor	RAM	Score
UDOO Quad	$4\left(\frac{1\ GB}{1\ GB}\right) + 1 = 5$	5
B00K7EEX2U	$4\left(\frac{1\ GB}{1\ GB}\right) + 1 = 5$	5
B006H0DWZW	$4\left(\frac{128\ KB}{1\ GB}\right) + 1 = 1$	1
B009SQQF9C	$4\left(\frac{512\ MB}{1\ GB}\right) + 1 = 1$	1

Table 6: Storage space and RAM available to each microcontroller.

RAM 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.

Cost

The score for the cost was obtained by normalizing the costs, multiplying the normalized value by the maximum score and subtracting from five. One was added to the result in order to prevent the case of zero from occurring. For instance, if the cheapest cost was $1, and the chassis under consideration has a cost of $5, the following equation would be constructed:

$$5\left(\frac{\$1}{\$5}\right)$$

The **Table 7** depicting the resulting scores is pictured in with $37.46 (B006H0DWZW) serving as the lowest cost

Factor	Cost	Score
UDOO Quad	$5\left(\frac{\$37.46}{\$135.00}\right) = 5$	5
B00K7EEX2U	$5\left(\frac{\$37.46}{\$55.67}\right) = 4$	4
B006H0DWZW	$5\left(\frac{\$37.46}{\$37.46}\right) = 1$	1
B009SQQF9C	$5\left(\frac{\$37.46}{\$52.99}\right) = 4$	4

Table 7: Cost score for each microcontroller under consideration for Roadie.

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.

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 by calculating watts by using the recommend voltage or 7.4, whichever one was the lowest and using the average milliamps per hour (mAh) of the microcontroller. Using the equation as depicted below to find the wattage as shown in **Table 8**.

$$Watts = Voltage * Amperage$$

Factor	Voltage	Amperage	Watts
UDOO Quad	7.4V	365 mAh	2.7
B00K7EEX2U	5V	460 mAh	2.34
B006H0DWZW	7.4V	200 mAh	5.18
B009SQQF9C	7.4V	700 mAh	1.48

Table 8: Wattage for each microcontroller

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.

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.

Flash Storage

The flash storage score for each item was obtained by using a 16 GB SD card for the max flash storage if SD card port is available on the microcontroller. The equation below was used to calculate the score shown in **Table 9**.

$$\left(\frac{Item\ under\ consideration}{Max\ Storage}\right) * 5 = Score$$

Factor	Flash Storage	Score
UDOO Quad	$5\left(\frac{16\ Gb}{16\ GB}\right) = 5$	5
B00K7EEX2U	$5\left(\frac{4\ GB}{16\ GB}\right) = 1$	1
B006H0DWZW	$5\left(\frac{258\ KB}{16\ GB}\right) = 1$	1
B009SQQF9C	$5\left(\frac{16\ GB}{16\ GB}\right) = 5$	5

Table 9: Cost scores for microcontroller.

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

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.

Summary

The UDOO Quad Microcontroller was not the cheapest microcontroller, but the other catagories the UDOO Quad excels in. The other microcontrollers were cheaper, but they laked in RAM, processing power, or Flash Storage.

3.1.4 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 10** 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.	Sev.	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 10: Risks that can be attributed to the microcontroller and their associated mitigations.

3.2 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.

3.2.1 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.

3.2.1.1 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 11** below.

Item ID	Item Name	Vendor	Description
B0027GEY3Y	Venom 800mAh 7.4 LiPo [21]	Amazon	7.4 volt LiPo battery with a 800 mAh capacity and a 16 A discharge rate.
B00DDTKYME	Dynamite 7.4V 180mAh LiPo [22]	Amazon	7.4 volt LiPo battery with a 180 mAh capacity and a 16 A discharge rate.
B0073VCS0O	Eflite Blade 800mAh 7.4V LiPo [23]	Amazon	7.4 volt LiPo battery with a 800 mAh capacity and a 16 A discharge rate.

Table 11: Power sources under consideration for Roadie.

3.2.1.2 Decision Matrix

The decision matrix used to select a battery for Roadie's microcontroller is depicted in **Table 12**. 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	4.15
B00DDTKYME	1	2	3	4	2.1
B0073VCS0O	4	5	3	3	3.9

Table 12: 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 13.** The total score for each item in the decision matrix (**Table 12**) is calculated by summing the values for each row in the weighted value matrix

Factor	Power	Battery Life	Safety	Cost
B0027GEY3Y	1.6	1.25	0.6	0.75
B00DDTKYME	0.4	0.5	0.6	0.6
B0073VCS0O	1.6	1.25	0.6	0.45

Table 13: 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 14**.

Factor	Power	Battery Life	Safety	Cost
B0027GEY3Y	7.4V/800 mAh	0.035	LiPo	$13.99
B00DDTKYME	7.4V/180 mAh	0.00788	LiPo	$14.99
B0073VCS0O	7.4V/800 mAh	0.035	LiPo	$18.59

Table 14: Quantitative and qualitative values of the batteries under consideration that led to the decision matrix.

3.2.1.3 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 how much amperage the batteries can supply at max load capacity.

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 below from [20] at maximum load.

$$\frac{mAh}{mA}0.7 = estimated\ life\ (hours)$$

The battery life for each battery can be seen in **Table 15** below

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

Table 15: 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. [18] [19]. Since the batteries of the same type of battery they all have the same safety and risk score.
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 score for the cost was obtained by normalizing the costs, multiplying the normalized value by the maximum score and subtracting from five. One was added to the result in order to prevent the case of zero from occurring. For instance, if the cheapest cost was $1, and the chassis under consideration has a cost of $5, the following equation would be constructed:

$$5\left(\frac{\$1}{\$5}\right)$$

Table 16 depicting the resulting scores is pictured in with $13.99 (B0027GEY3Y) serving as the lowest cost

Factor	Cost	Score
B0027GEY3Y	$5\left(\frac{\$13.99}{\$13.99}\right)$	5
B00DDTKYME	$5\left(\frac{\$13.99}{\$14.99}\right)$	4
B0073VCS0O	$5\left(\frac{\$13.99}{\$18.59}\right)$	3

Table 16: Cost score for each battery under consideration for powering Roadie's microcontroller.

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

The B0027GEY3Y battery was the cheapest and most powerful for its price. The other batteries cost for for no increase in performance or power since they either had less power or the same power as the battery that was choose.

3.2.1.4 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 17** 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 30 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 30 minutes.

Table 17: The requirements that the selection of B0027GEY3Y will fulfill.

3.2.1.5 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 battery plays a major role on Roadie. Therefore, mitigating any and all risks relating to the battery is of the utmost importance. Should the battery 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 battery. Risks and the methods in which they will be mitigated can be seen in
Table 18 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.	Sev.	Mitigation of Risk
Overheating	3	7	Batteries can overheat by being left on the charger for too long or by being used for a extend amount of time. To help mitigate this risk the batteries should be taken off of the charger once they are fully charge. Also, to help mitigate overheating from extend usage for a max of 30 minutes.
Shorting Out	2	9	Batteries that are shorted out have a chance to have a thermal runaway, which to ignite and catch on fire. [19] To help mitigate this risk proper techniques shall be used when wiring and soldering batteries.

Table 18: Risks that can be associate with batteries and the mitigation of risk.

3.2.2 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.

3.2.2.1 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 19.**

Item ID	Item Name	Vendor	Description
B0027G9F9M	Venom 5000 mAh 14.8V LiPo [24]	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 [25]	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 [26]	Amazon	18.5 bolt LiPo hard case battery with a 3800 mAh capacity and a 133 A discharge rate.

Table 19: Power supplies under consideration for the motors for Roadie.

3.2.2.2 Decision Matrix

The decision matrix used to select a battery for the motors on Roadie is depicted in **Table 20**. 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	4.3
B003CUB4QO	1	3	3	4	2.35
B003CUJ1WI	3	3	3	4	2.95

Table 20: 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 21.** The total score for each item in the decision matrix (**Table 20)** is calculated by summing the values for each row in the weighted value matrix.

Factor	Power	Battery Life	Safety	Cost
B0027G9F9M	2.0	1.25	0.6	0.75
B003CUB4QO	0.40	0.75	0.6	0.6
B003CUJ1WI	1.20	0.75	0.6	0.6

Table 21: 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 22.**

Factor	Power	Battery Life	Safety	Cost
B0027G9F9M	14.8V/5000 mAh	0.028	LiPo	$79.43
B003CUB4QO	14.8V/5000 mAh	0.02	LiPo	$99.99
B003CUJ1WI	18.5V/3800 mAh	0.02	LiPo	$99.99

Table 22: Quantitative and qualitative values of the batteries under consideration that led to the decision matrix.

3.2.2.3 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 then calculating the watts 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 how much amperage the batteries can supply at max load capacity. 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 below from [20] at maximum load.

$$\frac{mAh}{mA} 0.7 = estimated\ life\ (hours)$$

The battery life for each battery under consideration for the motors can be seen in **Table 23** below

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

Table 23: 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. [18][19] Since the batteries of the same type of battery they all have the same safety and risk score.

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 score for the cost was obtained by normalizing the costs, multiplying the normalized value by the maximum score and subtracting from five. One was added to the result in order to prevent the case of zero from occurring. For instance, if the cheapest cost was \$1, and the chassis under consideration has a cost of \$5, the following equation would be constructed:

$$5\left(\frac{\$1}{\$5}\right)$$

The **Table 24** depicting the resulting scores is pictured in with \$79.43 (B0027G9F9M) serving as the lowest cost

Factor	Cost	Score
B0027G9F9M	$5\left(\frac{\$79.43}{\$79.43}\right)$	5
B003CUB4QO	$5\left(\frac{\$79.43}{\$99.99}\right)$	4
B003CUJ1WI	$5\left(\frac{\$79.43}{\$99.99}\right)$	4

Table 24: Cost score for each battery under consideration for powering Roadie's motors.

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

The B0027G9F9M battery was the cheapest and most powerful for its price. The other batteries cost for no increase in performance or power since they either had less power or the same power as the battery that was chosen.

3.2.2.4 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 25** 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 30 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 30 minutes.

Table 25: The requirements that the selection of B0027G9F9M will fulfill.

3.2.2.5 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 battery plays a major role on Roadie. Therefore, mitigating any and all risks relating to the battery is of the utmost importance. Should the battery 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 battery. Risks and the methods in which they will be mitigated can be seen in **Table 26** 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.	Sev.	Mitigation of Risk
Overheating	3	7	Batteries can overheat by being left on the charger for too long or by being used for a extend amount of time. To help mitigate this risk the batteries should be taken off of the charger once they are fully charge. Also, to help mitigate overheating from extend usage for a max of 30 minutes.
Shorting Out	2	9	Batteries that are shorted out have a chance to have a thermal runaway, which to ignite and catch on fire. [19] To help mitigate this risk proper techniques shall be used when wiring and soldering batteries.

Table 26: Risks that can be associate with batteries and the mitigation of risk.

3.3 Camera

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

3.3.1 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 Error! Reference source not found. 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. [30]
B008GWPC1Q	Fosmon USB 6 LED Webcam	Amazon	1.3 Megapixel webcam with six LEDs to illuminate objects [31].
B00K11RI6W	TeckNet C015 Webcam	Amazon	5.0 Megapixel webcam with built in microphone [32].

Table 27: Cameras under consideration for Roadie

3.3.2 Decision Matrix

The decision matrix used to select a camera for Roadie is depicted in **Table 28**. 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	0.3	0.2	0.1	0.2	
B00IUYUA80	1	1	5	3	1	1.9
B008GWPC1Q	1	5	2	3	5	3.3
B00K11RI6W	5	1	2	3	4	3.1

Table 28: 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 29**. The total score for each item in the decision matrix (**Table 28**) is calculated by summing the values for each row in the weighted value matrix.

Factor	Resolution	Lighting	Ease of Use	Availability	Cost
B00IUYUA80	0.3	0.3	1.0	0.1	0.2
B008GWPC1Q	0.3	1.5	0.4	0.1	1.0
B00K11RI6W	1.5	0.3	0.4	0.1	0.8

Table 29: 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 30

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

3.3.3 Justifications

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

Resolution

The resolution for the camera is directly related to how clear an image will be. Since the camera will be the primary way in which Roadie will identify challenges, have a high resolution is very important. The score for the resolution was obtained by normalizing the resolution and multiplying the normalized value by the maximum score. For instance, if the maximum resolution was one megapixel, and the camera under consideration has a resolution of one megapixel, the following equation would be constructed:

$$5\left(\frac{1MP}{1MP}\right) = 5$$

The table depicting the resulting scores is pictured in **Table 31** with 5MP (B00K11RI6W) serving as the largest resolution.

Camera	Calculation	Score
B00IUYUA80	$5\left(\frac{1MP}{5MP}\right) = 1$	1
B008GWPC1Q	$5\left(\frac{1.3MP}{5MP}\right) = 1.3 \approx 1$	1
B00K11RI6W	$5\left(\frac{5MP}{5MP}\right) = 5$	5

Table 31: Resulting scores for resolution calculations.

Resolution was given a weight of 30% 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 30% 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 20% 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 score for the cost was obtained by normalizing the costs and multiplying the normalized value by the maximum score. For instance, if the cheapest cost was $1, and the chassis under consideration has a cost of $5, the following equation would be constructed:

$$5\left(\frac{\$1}{\$5}\right)$$

The table depicting the resulting scores is pictured in **Table 32** with $8 (B008GWPC1Q) serving as the lowest cost

Factor	Cost	Score
B00IUYUA80	$5\left(\frac{\$8}{\$69.00}\right) = 0.57 \approx 1$	1
B008GWPC1Q	$5\left(\frac{\$8}{\$8}\right) = 5$	5
B00K11RI6W	$5\left(\frac{\$8}{\$10}\right) = 1.6$	4

Table 32: Cost score for each camera under consideration for Roadie.

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

The main factors when selecting the camera were the resolution and lighting of the camera. By having a camera with a high resolution and lights, Roadie will be able to perform optimally in all lighting conditions. It is for these reasons that B008GWPC1Q was selected.

3.3.4 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 33, 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 Figure7.	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 Figure8	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 Figure9.	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 **Figure8**	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 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 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 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 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 33: Requirements traceability for camera.

3.3.5 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 34**.

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 34: Risks that can be attributed to the chassis and their associated mitigations.

3.4 Chassis

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

3.4.1 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 35**

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 [29].
KIT660	Build Your First Robot Chassis Kit	Budgetrobotics.com	Dual level chassis with wheel well cutouts for drive wheels. Includes mounts for two servos [28].
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 [27].
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 35: Chassis under consideration for Roadie

3.4.2 Decision Matrix

The decision matrix used to select a chassis for Roadie is depicted in **Table 36**. 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 36: 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 37**. The total score for each item in the decision matrix (**Table 36**) 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 37: 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 38**

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 38 Quantitative and qualitative values of the chassis under consideration that led to the decision matrix.

3.4.3 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 advantageous. The score for the surface area was obtained by normalizing the surface areas and multiplying the normalized value by the maximum score. For instance, if the maximum surface area was one square millimeter, and the chassis under consideration has a surface area of one square millimeter, the following equation would be constructed:

$$5\left(\frac{1mm^2}{1mm^2}\right) = 5$$

The table depicting the resulting scores is pictured in **Table 39** with 45,161.2mm^2(KIT660) serving as the largest surface area.

Item	Calculation	Score
ROB-12866	$5\left(\frac{19140mm^2}{45161.2mm^2}\right) = 2.11 \approx 2$	2
KIT660	$5\left(\frac{45161.2mm^2}{45161.2mm^2}\right) = 5$	5
DG012	$5\left(\frac{23393mm^2}{45161.2mm^2}\right) = 2.58 \approx 3$	3
Custom	$5\left(\frac{45161.2mm^2}{45161.2mm^2}\right) = 5$	5

Table 39: Resulting scores for the surface area calculations

The custom chassis used the same calculation as KIT660, the chassis with the largest surface area, because its surface area will be at least the same as KIT660.

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 the cost was obtained by normalizing the costs and multiplying the normalized value by the maximum score. For instance, if the cheapest cost was $1, and the chassis under consideration has a cost of $5, the following equation would be constructed:

$$5\left(\frac{\$1}{\$5}\right)$$

The table depicting the resulting scores is pictured in **Table 39** with $14.95 (ROB-12866) serving as the lowest cost

Factor	Cost	Score
ROB-12866	$5\left(\frac{\$14.95}{\$14.95}\right) = 5$	5
KIT660	$5\left(\frac{\$14.95}{\$16.95}\right) = 4.4 \approx 4$	4
DG012	$5\left(\frac{\$14.95}{\$44.96}\right) = 1.6$	1
Custom	$5\left(\frac{\$14.95}{\$25}\right) = 2.99 \approx 3$	3

Table 40: Cost score for each chassis under consideration for Roadie.

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

The main factors when selecting the chassis were the surface area and the adaptability as well as the availability and the cost of the chassis. By having a chassis with a large surface area that is very adaptable, Roadie will be able to perform optimally. It is for these reasons that the custom option was selected.

3.4.4 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 41**, below, the requirement ID is followed by the requirement text and an explanation of how the custom chassis will fulfill said requirement.

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.

Table 41: Requirements traceability for chassis.

3.4.5 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 42**.

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 42: Risks that can be attributed to the chassis and their associated mitigations.

3.5 Line Following

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

3.5.1 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 43** 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 43: Line following equipment under consideration for Roadie.

3.5.2 Decision Matrix

The decision matrix used to select line following equipment for Roadie is depicted in **Table 44**. 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	
ROB-09454	4	5	5	1	4.3
GL5516	2	4	5	5	3.7

Table 44: 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 45.** The total score for each item in the decision matrix (**Table 44**) 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 45: 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 46** 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 46: Quantitative and qualitative values of the line following sensors under consideration that led to the decision matrix.

3.5.3 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
The score for the cost was obtained by normalizing the costs and multiplying the normalized value by the maximum score. For instance, if the cheapest cost was \$1, and the line following hardware under consideration has a cost of \$5, the following equation would be constructed:

$$5\left(\frac{\$1}{\$5}\right)$$

The table depicting the resulting scores is pictured in **Table 47** with \$0.249 (ROB-12124) serving as the lowest cost.

Factor	Cost	Score
276-1447	$5\left(\frac{\$0.249}{\$2.95}\right) = 1$	1
276-3526	$5\left(\frac{\$0.249}{\$0.249}\right) = 5$	5

Table 47: Cost score for each piece of line following hardware under consideration for use on Roadie.

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

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.

3.5.4 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 48**, 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 48: Requirements traceability for line following sensors.

3.5.5 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 49**

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

3.6 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

3.6.1 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 [36].

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 50 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 50: A list of the different motors and their intended purpose in the system.

3.6.2 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.

3.6.2.1 Items under Consideration

The following items have been considered for use 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 51**

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 [37].
SY42STH47-	Soyo - 1684MB RepRap Stepper Motor	Robotshop.com	200 step high torque motor. Holding Torque 4.4 Kg-cm. ± 5% precision [38].
ROB-10846	Wantai 42BYGHM809	Sparkfun.com, Wantmotor.com	400 step medium torque motor. 48 N-cm holding torque. Rated for 3V. ± 5% precision [39].
ROB-10847	Wantai 57BYGH420	Sparkfun.com, Wantmotor.com	200 step medium torque unipolar stepper motor. Holding torque of 90 N-cm. 1/4 in diameter shaft [40].

Table 51: Stepper motors under consideration for Roadie.

3.6.2.2 Decision Matrix

The decision matrix for determining which stepper motors to use for the Roadie is depicted in **Table 52**. 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	3	3	1	4	2.65
SY42STH47	3	1	3	3	3	2.50
ROB-10846	3	2	4	3	4	3.15
ROB-10847	5	1	3	1	3	2.80

Table 52: 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 53.**The total score for each item in the decision matrix (**Table 52**) 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	.75	0.25	0.9	0.3	0.3
ROB-10846	.75	0.5	1.2	0.3	0.4
ROB-10847	1.25	0.25	0.9	0.1	0.3

Table 53: 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 54**

Model	Power	Size	Precision	Availability	Price
SY42STH38-0406B	36 oz-in torque	42.3mm^3	200 step	Out of Stock	$15.34
SY42STH47	61.1 oz-in torque	42.3mm x 42.3mm x 48 mm	200 step	In Stock	$25.91
ROB-10846	68 oz-in torque	50mm^3	400 step	In Stock	$16.95
ROB-10847	128 oz-in torque	56mm x 56mm x 54mm	200 step	Out of Stock	$23.95

Table 54: Quantitative and qualitative vales for the stepper motors under consideration that led to the decision matrix.

3.6.2.3 Justification

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

Power

Since these motor will be driving the robot they need to have enough power rot turn the wheels under the weight of the entire system. Since we are using stepper motors, this power is measure in torque which is the amount of force.

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. Using a large estimate of a 40 kg complete robot design, we calculated that even the motor with the lowest output, 32 oz.-in of torque, has a high enough RMF to drive the robot. ***Table 55*** shows the criteria for awarding points for power.

Torque	Score
0-30 oz.-in	1
31-60 oz.-in	2
61-90 oz.-in	3
91-120 oz.-in	4
> 120 oz.-in	5

Table 55: Table which shows how points were awarded for power.

Power received a weight of 25% because if the motor does not output enough torque, 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 we selected the largest motor, it would be nearly 2.3 inches. Consequently this simulated axel would occupy no less than 4.6 inches of space which drastically reduces the amount of useable space. 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%. The length was the most important of the size factors and points were given based upon length of the motor. **Table 56** shows how points were given based on size.

Length	Score
>50 mm	1
46mm-50mm	2
41mm-45mm	3
31mm-40mm	4
<30	5

Table 56: Table which shows how the points were awarded for size of the stepper motors.

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 57**

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

Table 57: 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 58** 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 58: 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 also satisfies our power and precision requirements. There are many motor that also satisfy these requirements however they are more expensive and are larger in size. The ROB-10846 is the most well rounded motor, best suited for Roadie.

3.6.2.4 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 59**, 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 59: Requirements traceability for stepper motors.

3.6.3 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.

3.6.3.1 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 **Table 60**

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 [41].
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 [42].
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 [43].

Table 60: Gearmotors under consideration for Roadie.

3.6.3.2 Decision Matrix

The decision matrix used to select stepper motors for Roadie is depicted in **Table 61**. 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	2	1	1	3	1.7
ROB-12285	3	2	3	2	2.6
CYT-29	1	3	3	1	1.8

Table 61: 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 62**. The total score for each item in the decision matrix (**Table 61**) is calculated by summing the values for each row in the weighted value matrix.

Factor	Size	Power	Availability	Price
ROB-08911	1	0.3	0.1	0.3
ROB-12285	1.5	0.6	0.3	0.2
CYT-29	.5	0.9	0.3	0.1

Table 62: 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 63**

Model	Size	Power	Availability	Price
ROB-08911	10mm x 12mm x 34.2 mm	2.6 oz.-in	Out of Stock	$9.95
ROB-12285	26mm x 12mm x 10mm	70 oz.-in	In Stock	$12.95
CYT-29	27mm x 37mm x 37mm (Cubical space occupied by a cylinder for comparison)	166.53 oz.-in	In Stock	$15.48

Table 63: Quantitative and qualitative values of the gearmotors under consideration that led to the decision matrix.

3.6.3.3 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 64** was used.

Volume	Score
<4000 mm^3	3
4000 mm^3 – 8000 mm^3	2
>8000 mm^3	1

Table 64: Table used to justify size scores awarded to each gearmotor.

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. **Table 65** shows how each motor received its score for power

Torque	Score
0-50 oz.-in	1
51-100 oz.-in	2
>100 oz.-in	3

Table 65: Table used to justify power scored awarded to each gearmotor

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 three 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 66** 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 66: 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

Based upon our research of gearmotor is was determined that the best choice for Roadie is the ROB-12285 from SparkFun. This motor has the compact size and necessary power required to control the rotational motion of the robot arm.

3.6.4 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.

3.6.4.1 Items under Consideration

Table 67 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 [44].
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 [44].
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 [45].

Table 67: 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 67**, 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.

3.6.4.2 Decision Matrix

Table 68 shows the decision matrix for the linear actuators

Factor	0.5	0.25	0.15	0.1	Total
Model	Size	Power	Price	Availability	
L12 50mm Linear Actuator	3	2	1	2	2.35
L12 100mm Linear Actuator	2	2	1	2	1.85
L16 140mm Linear Actuator	1	3	1	2	1.6

Table 68: The decision matrix for the linear actuators

Table 69: shows the decision matrix with the weighted scoring values

Model	Size	Power	Price	Availability
L12 50mm Linear Actuator	1.5	0.5	0.15	0.2
L12 100mm Linear Actuator	1	0.5	0.15	0.2
L16 140mm Linear Actuator	0.5	0.75	0.15	0.2

Table 69: The weighted values for the decision matrix

Table 52 shows their qualitative or quantitative values used to determine score in the decision matrix.

Model	Size	Power	Price	Availability
L12 50mm Linear Actuator	50mm long 3.93 inches fully extended	45 N max force	$70.00	In Stock
L12 100mm Linear Actuator	100mm Long 7.87 inches fully extended	23 N max force	$70.00	In Stock
L16 140mm Linear Actuator	140 mm long 11.0236 inches fully extended.	75 N max force	$70.00	In Stock

Table 70: Qualitative and Quantitative decision matrix for the linear actuators

It is important to note that for this matrix price and availability are the same because all of these motors come from the same company and are of similar families. This makes the main points in the decision matrix size and power.

3.6.4.3 Justification

For these linear actuators there is a decision matrix however it was not very effective since every motor is the same motor with varying size parts. They are also 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 and we also considered power output even though it was minor.

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. **Table 71** shows the table which shows how we gave each actuator points for size.

Length in relation to 4in, fully expanded	Score
± 1in	3
± 4 in	2
> ± 4in	1

Table 71:How points for size with the linear actuators was assigned

For the linear actuators we decided that the ideal size would be 4 inches fully extended, this is why the matrix uses the actuators relative size to 4 inches. This worked to create a matrix however as already discussed, any of the larger motors would be too large for the system.

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. The decision matrix columns for price and availability were added anyway to show that extra though was needed when selecting a linear actuator and the decision matrix was very ineffective.

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. It is necessary that the motor can move forward and back ward with a load of roughly 10 N. So based upon this info we created **Table 72** to award points for power.

Pushing Force	Score
< 10 N	1
11 N – 50 N	2
> 50 N	3

Table 72: The table defining how each actuator received a score for power

Since it is only necessary for the motor to output a force of 10 N to hold the components and push buttons, any motor that output below 10 N received a 1 in the decision matrix, conversely any motor that could efficiently move more than 50 N, which would make the system much faster and more stable, received a 3. Any motor in between these ranges received a 2. In order to be fair they were all given scores in the decision matrix

Summary

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 effectiveness of the decision matrix. In conclusion the only linear actuator we found that will satisfy all our needs is the Firgelli Technologies L12 Linear Actuator 50mm.

3.6.4.4 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 73**, 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 from a bicycle brand bridge sized deck	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 73: Requirements traceability for linear actuators.

3.6.5 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 74** 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 74: Risks that can be attributed to the motors and their associated mitigations

3.7 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.

3.7.1 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 75**

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 75: Wheels under consideration for Roadie.

3.7.2 Decision Matrix

The decision matrix used to select the wheels for use on Roadie is shown in **Table 76.** 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	
276-1447	4	5	5	3	2	4.3
276-3526	4	4	5	3	3	4.15
ROB-12124	2	2	3	3	5	2.85

Table 76: 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 77**.The total score for each item in the decision matrix (**Table 76**) 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 77: 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 78**

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

3.7.3 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

The score for the cost was obtained by normalizing the costs and multiplying the normalized value by the maximum score. For instance, if the cheapest cost was $1, and the w under consideration has a cost of $5, the following equation would be constructed:

$$5\left(\frac{\$1}{\$5}\right)$$

The table depicting the resulting scores is pictured in **Table 79** with $27.96 (GL5516) serving as the lowest cost.

Factor	Cost	Score
276-1447	$5\left(\frac{\$27.96}{\$59.99}\right) = 2.33 \approx 2$	2
276-3526	$5\left(\frac{\$27.96}{\$39.99}\right) = 3.49 \approx 3$	3

Table 79: Cost score for each set of wheels under consideration for use on Roadie.

Cost was given a weight of 10% as the costs 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.

3.7.4 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 80**, 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 80: Requirements traceability for wheels.

3.7.5 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. **Table 81** shows the risks for the movement system and their associated mitigations.

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 81: Risks that can be attributed to the movement systems and their associated mitigations

3.8 Robotic Claw

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

3.8.1 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 82**

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."[33].
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 [34].
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 82: Claws under consideration for Roadie

3.8.2 Decision Matrix

The decision matrix used to select a claw for Roadie is depicted in **Table 83**. 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	5	2	3	3	3.7
Custom	5	5	5	5	1	4.7

Table 83: 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 84**. The total score for each item in the decision matrix (**Table 83**) 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	1.5	0.8	0.3	0.6
Custom	0.5	1.5	2.0	0.5	0.2

Table 84: 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 85**

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 85: 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 200g [35]. 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 [35]. Bearing this in mind, the ROB-11524 was scored a one because it may not work. The 276-2212 was scored a five because it opens wide enough to accommodate the Rubik's cube, the widest object Roadie will have to interact with. 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 score for the cost was obtained by normalizing the costs and multiplying the normalized value by the maximum score. For instance, if the cheapest cost was \$1, and the chassis under consideration has a cost of \$5, the following equation would be constructed:

$$5\left(\frac{\$1}{\$5}\right)$$

The table depicting the resulting scores is pictured in **Table 86** with \$11.95 (ROB-11524) serving as the lowest cost

Factor	Cost	Score
ROB-11524	$5\left(\frac{\$11.95}{\$11.95}\right) = 5$	5
276-2212	$5\left(\frac{\$11.95}{\$19.95}\right) = 2.99 \approx 3$	3
Custom	$5\left(\frac{\$11.95}{\$40}\right) = 1.49 \approx 1$	1

Table 86: Cost score for each claw under consideration for Roadie.

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

The main factors when selecting the claw were the claw opening, versatility and maximum holding weight in addition to the price and availability. The current system design is such that it is desirable to have a claw with multiple attachments. For these reasons, the custom claw came out with the highest rating on the decision matrix.

3.8.3 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 87**, 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 87: Requirements traceability for robotic claw

3.8.4 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 88** 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 88: Risks that can be attributed to the robotic arm and their associated mitigations.

4. Total System Budget

Item	Vendor	Backup Vendor	Price	Quantity	Shipping Cost	Replacement Cost	Total
Udoo Quad	Udoo Shop		$ 135.00	1	$ 11.00		$ 146.00
Mechanum Wheels (4)	VEXRobotics		$ 59.99	1	$ 11.72		$ 71.71
QRE1113 (Digital)	SparkFun		$ 2.95	5	$ -		$ 14.75
Venom 800mAh LiPo	Amazon		$ 13.99	1	$ -		$ 13.99
Fosmon USB 6 LED Webcam	Amazon		$ 7.99	1	$ -		$ 7.99
Custom Chassis	N/A		$ 25.00	1	$ -		$ 25.00
Custom Claw	N/A		$ 40.00	1	$ -		$ 40.00
Firgelli 50mm Miniature Linear Actuator	Robot Shop	Firgeli	$ 70.00	2	$ 9.00		$ 149.00
Micro Gearmotor ROB-12285	SparkFun		$ 12.95	3	$ -		$ 38.85
Wantai 42BYGHM80 Stepper Motor	SparkFun	Wantmotors	$ 16.95	4	$ -		$ 67.80
Venom 5000 mAh LiPo	Amazon		$ 79.43	1	$ -		$ 79.43
						Total:	$ 654.52

5. 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].	
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 **Figure9.**	
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 **Figure6**.	
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
Obstruct	SoutheastCon rules state that the system cannot obstruct any obstacle [1].	
Playing Card	The playing cards are bicycle brand bridge sized cards depicted in **Figure8**	
Random Access Memory	Memory available for CPU to use	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 **Figure8.**	
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 **Figure11.**	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 **Figure7.**	

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].	

6. 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

7. 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.

7.1 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.

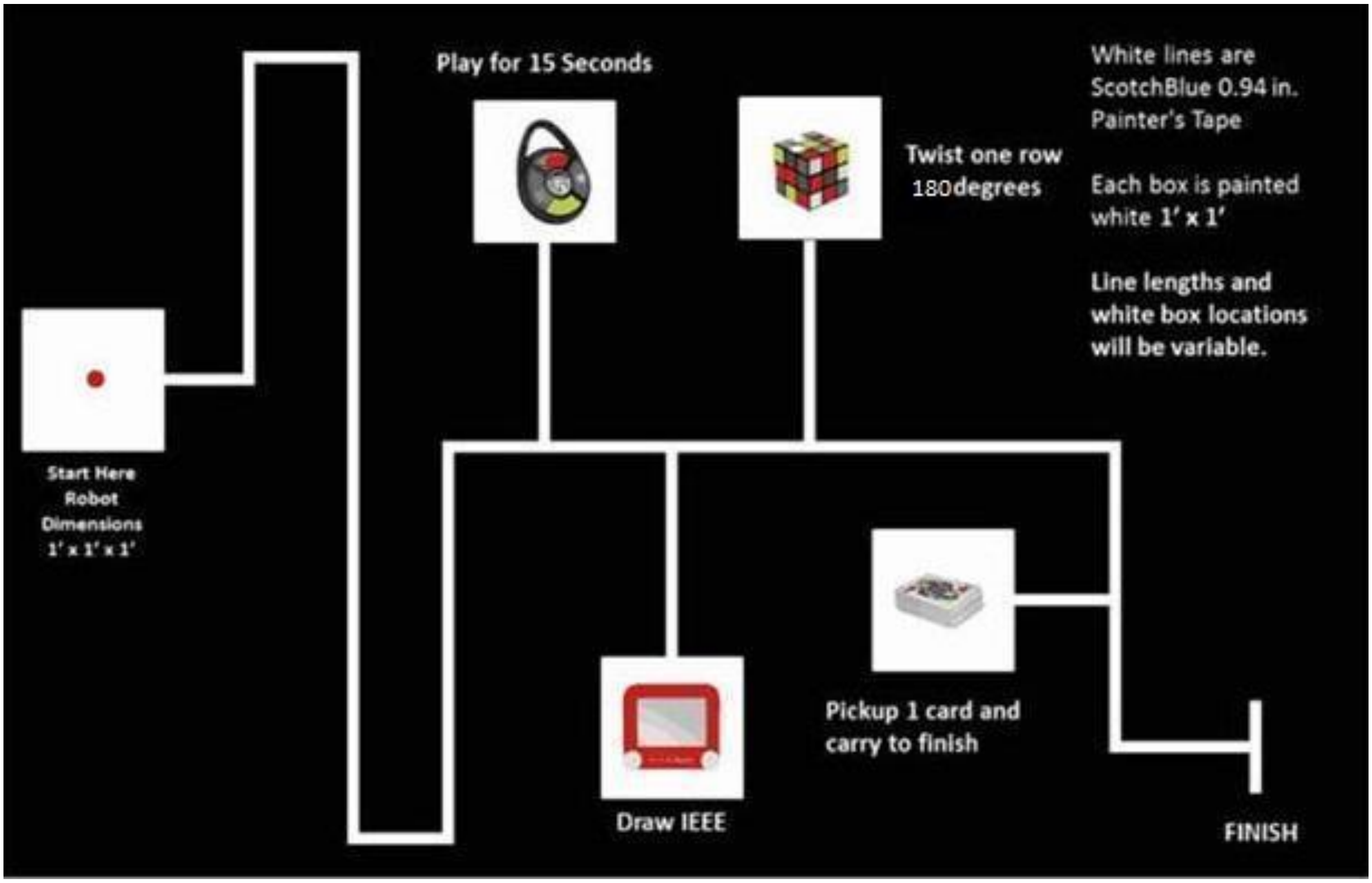

Figure6 Competition course for SoutheastCon[1].

7.2 Simon Carabiner

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

Figure7: The exact Simon Carabiner to be used during competition [5].

7.3 Rubik's Cube

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

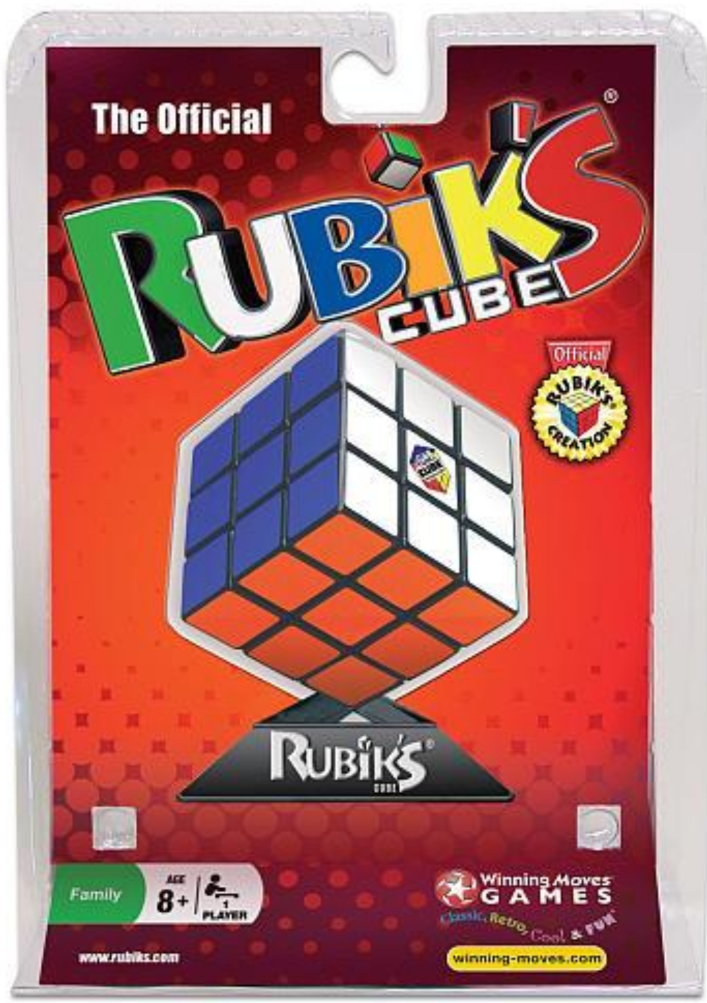

Figure8: The exact Rubik's Cube to be used during competition [6].

7.4 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.

Figure9: The exact pocket Etch-A-Sketch to be used during competition [7].

7.5 Playing Cards

The playing cards to be used are bicycle brand bridge sized cards.

Figure10: Bridge sized playing cards [46]

7.6 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.

Figure11: The exact painter's tape to be used on the course [8].

8. Appendix B

8.1 Updated Requirements

3.3.1.4 The system shall correctly identify the playing cards depicted in Figure10.
3.3.6 The system shall collect a single playing card from a bicycle brand bridge sized deck.
4.2.1 The system shall operate for a minimum of 30 minutes when the power source starts with a full charge.

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