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Team 514: Robot to Traverse Uneven Terrain

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Abstract

Dow Inc. is a company known for producing polyurethane, rubber, and acrylic acids. Producing these materials creates toxic gases that can cause explosions and chemical fires. To uphold safety standards, Dow sends employees to inspect and repair pipes used for production. This task has put workers at risk of toxic gas exposure. This exposure can lead to fainting or death. Team 514 aims to reduce the risk of harm to the worker as they perform inspections and repairs.

To help workers safely perform these tasks, Team 514 designed a robot named Luffy. This robot removes the need to send someone to find out if the environment is safe for workers to enter. The worker will have a controller that controls Luffy's tank tracks and a telescoping arm. The arm helps Luffy climb up or down a pipe by constantly pressing against the pipe wall. The robot body holds three gas sensors and two wide-angle cameras. These parts should allow the user to inspect cracks and gas levels inside a pipe without exposing the worker to a toxic environment.

The following constraints motivated the design of Luffy: it must fit within different pipe sizes, move using a remote control, and use gas sensors to detect gas leaks. These limited the list of solutions that satisfied the project objective. This gave the team more time to evaluate and verify the final design. Luffy successfully moved through pipes and climbed areas with 45- to 90-degree inclines. The cameras mounted on Luffy successfully livestreamed video to a computer screen with minor delay. Also, the gas sensors reported accurate air quality levels to the user through Wi-Fi. Team 514 created a successful design that can help identify basic inspection targets like gas leaks and pipe cracks.

Keywords: *inspections, telescoping arm, gas*

Acknowledgement

These remarks thank those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

- Paragraph 1 thank sponsor!
- Paragraph 2 thank advisors.
- Paragraph 3 thank those that provided you materials and resources.
- Paragraph 4 thank anyone else who helped you.

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Notation

A17	Steering Column Angle
A27	Pan Angle
A40	Back Angle
A42	Hip Angle
AAA	American Automobile Association
AARP	American Association of Retired Persons
AHP	Accelerator Heel Point
ANOVA	Analysis of Variance
AOTA	American Occupational Therapy Association
ASA	American Society on Aging
BA	Back Angle
BOF	Ball of Foot
BOFRP	Ball of Foot Reference Point
CAD	Computer Aided Design
CDC	Centers for Disease Control and Prevention
CU-ICAR	Clemson University - International Center for Automotive Research
DDI	Driver Death per Involvement Ratio
DIT	Driver Involvement per Vehicle Mile Traveled

Difference	Difference between the calculated and measured BOFRP to H-point
DRR	Death Rate Ratio
DRS	Driving Rehabilitation Specialist
EMM	Estimated Marginal Means
FARS	Fatality Analysis Reporting System
FMVSS	Federal Motor Vehicle Safety Standard
GES	General Estimates System
GHS	Greenville Health System
H13	Steering Wheel Thigh Clearance
H17	Wheel Center to Heel Pont
H30	H-point to accelerator heel point
HPD	H-point Design Tool
HPM	H-point Machine
HPM-II	H-point Machine II
HT	H-point Travel
HX	H-point to Accelerator Heel Point
HZ	H-point to Accelerator Heel Point
IIHS	Insurance Institute for Highway Safety
L6	BFRP to Steering Wheel Center

Chapter One: EML 4551C

1.1 Project Scope

Project Description

The objective of this project is to reduce the risk of injury when inspecting and navigating potentially hazardous environmentwith uneven terrain.

Key Goals

There are several key goals that form the foundation of success for this project. First, the user must have the ability to effectively control the design. Doing so will ensure that the operation of the device is intuitive and user-friendly. Additionally, the design must be able to withstand harsh environmental conditions that may affect the functionality of the design when placed in a hazardous scenario. Also, the design must include a dependable and real-time perception of the surrounding environment to help facilitate informed decision-making when outside the vicinity of the hazardous environment. Furthermore, one of the primary goals of this design is to navigate uneven terrain with ease, emphasizing the importance of having traversing capabilities. Finally, the design must also be durable to ensure a long service life and minimize maintenance requirements.

Markets

The design chosen for this project shall demonstrate a wide range of applications across primary and secondary markets. In primary markets, the solution will play a pivotal role in enhancing safety and operational efficiency at Dow Inc. properties, offering a safer alternative to sending external contractors or employees to identify welding cracks and gas leaks. Additionally, it addresses the needs of search-and-rescue and emergency services, aiding in disaster-stricken or wilderness environments and benefiting organizations such as the police, firefighters, and the defense/military by improving reconnaissance, surveillance, and gas detection capabilities. In secondary markets, the design may appeal to hobbyists interested in robotics, providing a platform for outdoor exploration and personal educational pursuits. Moreover, the design will serve as a valuable tool in educational institutions and research labs, enabling the study of locomotion, terrain analysis, and the development of technology.

Assumptions

The following assumptions have been made to set the scope of this project: the operator may have access to a 120 Volt type-A wall outlet that is commonly found in the United States if necessary, the user will be an industry safety inspector or should have knowledge of the safety codes and standards relating to the hazard being inspected, and the operator will have the information necessary to clear the hazard once identified. The operator will be responsible for the clean-up and repair required due to the presence of the hazard; the design shall not have this capability. Furthermore, due to the primary markets identified for this design, a hazard can be defined as a gas leak or crack in some material. Finally, it is assumed that the design will not be used during extreme weather conditions.

Stakeholders

Stakeholders are individuals who have interest, control, or investment in the project. The stakeholders for this project include the Senior Design professor Dr. Shayne McConomy, other faculty at the FAMU-FSU College of Engineering, and our sponsor from Dow Inc. Marcus Rideaux. Table 1 below provides a visual representation of who the stakeholders of this project are (left column) and how they may affect the outcome of this project (top row).

Table 1 – Stakeholders

	Investor	**Decision Maker**	**Advisor**	**Receiver**
Sponsor(s) Marcus Rideaux, Dow Inc.	**X**	**X**	**X**	**X**
Manager Dr. McConomy		**X**	**X**	
Experts Dr. McConomy, additional university faculty			**X**	
Operators Undergraduate students, Dow Inc. inspectors				**X**

General Readers Other educational institutions, primary markets, secondary markets				**X**

Note: Some stakeholders may impact the project in more than one way. For example, sponsors are investors, decision-makers, advisors, and receivers.

Dr. Shayne McConomy is an advisor for this project and Team 514 shall represent various other faculty members at the FAMU-FSU College of Engineering, therefore they must be interested in the success of this project. Marcus Rideaux and other experts at Dow Inc. are the sponsors for this project and will play a pivotal role in providing the essential resources and support needed for the success of this project. Dow Inc. specifically is interested in the success of this project because the application of this design can be included as a part of their organization.

1.2 Customer Needs

Investigating Needs

After establishing the scope of this project, the team communicated again with our sponsor and advisor, Marcus Rideaux and Dr. Shayne McConomy. Marcus Rideaux is a Project Execution Leader in Digitalization & Innovation for Dow Inc. with a background in Electrical Engineering and served as our source of information regarding the environmental conditions the product is expected to face. Dr. McConomy answered the questions regarding the product's robotic requirements and provided insight about resources the team may be able to use to successfully complete this project. The team was unable to meet in-person or virtually. Instead, we corresponded with both parties through email and based their responses on the discussion we had during our Sponsor Meet & Greet meeting. Our most important questions were related to the level of interaction expected between the operator and the device, as well as the type of environment the device should be able to traverse. The team chose to leave most questions open-ended to avoid steering the customer towards a specific response. The table below displays what questions were asked, what their responses were, and how the team interpreted these responses.

Table 2 – Customer Needs Questions, Responses, and Interpretations

Customer Needs Questions, Responses, and Interpretations			
	Question	**Customer Statement**	**Interpreted Need**
1	How soon should operators be made aware of the hazard?	"When the robot can see it – oh, yup. You got a leak."	The product will inform the operator of the hazard as soon as possible.
2	Are there any size constraints that we need to account for?	"It would be nice to have something that can climb up pipe walls to check for cracks. And these are large pipes – mind you."	The product can fit in a large pipe. The product is light enough to lift itself.

3	How long should the lifespan of the product be?	“About 6 years.”	The product can last for at least 6 years.
4	Can you define uneven terrain?	“Uneven terrain, uneven surfaces – it would be cool to have something with magnetic capabilities to climb pipes.”	The product is capable of traversing through rough, unlevel terrain.
5	How should the user interact with the product?	“We hire people to work a PlayStation/Xbox controller.”	The product is going to be operated by a controller provided to the user.
6	What type of interface should the product communicate with?	“We would love to be able to send something inside to help us see instead of sending someone in.”	The product uses visual feedback to alert the user that a hazard has been detected.
7	Other than the inspector, who else can control the product when in use?	“Third-party contractors and welders.”	The product is primarily used by trained experts but may be used by un-trained, technical individuals.
8	How long will the product be operated for each day?	“Welders will work for approximately 8-12 hours, but not daily.”	The product can be used for approximately 8- to 12-hour sessions.
9	What is the max distance that the product will the operated at?	“We have men at the end of a pipe watching a man at the bottom and the readings.”	The product will be operated within close range to the operator.
10	What temperature range should the product be able to withstand?	“There may be molten plastic coming out of a pipe.”	The product may be working in temperatures high enough to melt plastic.

11	What types of hazards may our system be sent to identify?	“It would be nice to have something to send in to check gas leaks or cracks in pipes”	The product is used to help detect gas leaks or deformities in pipes.

Explanation of Results

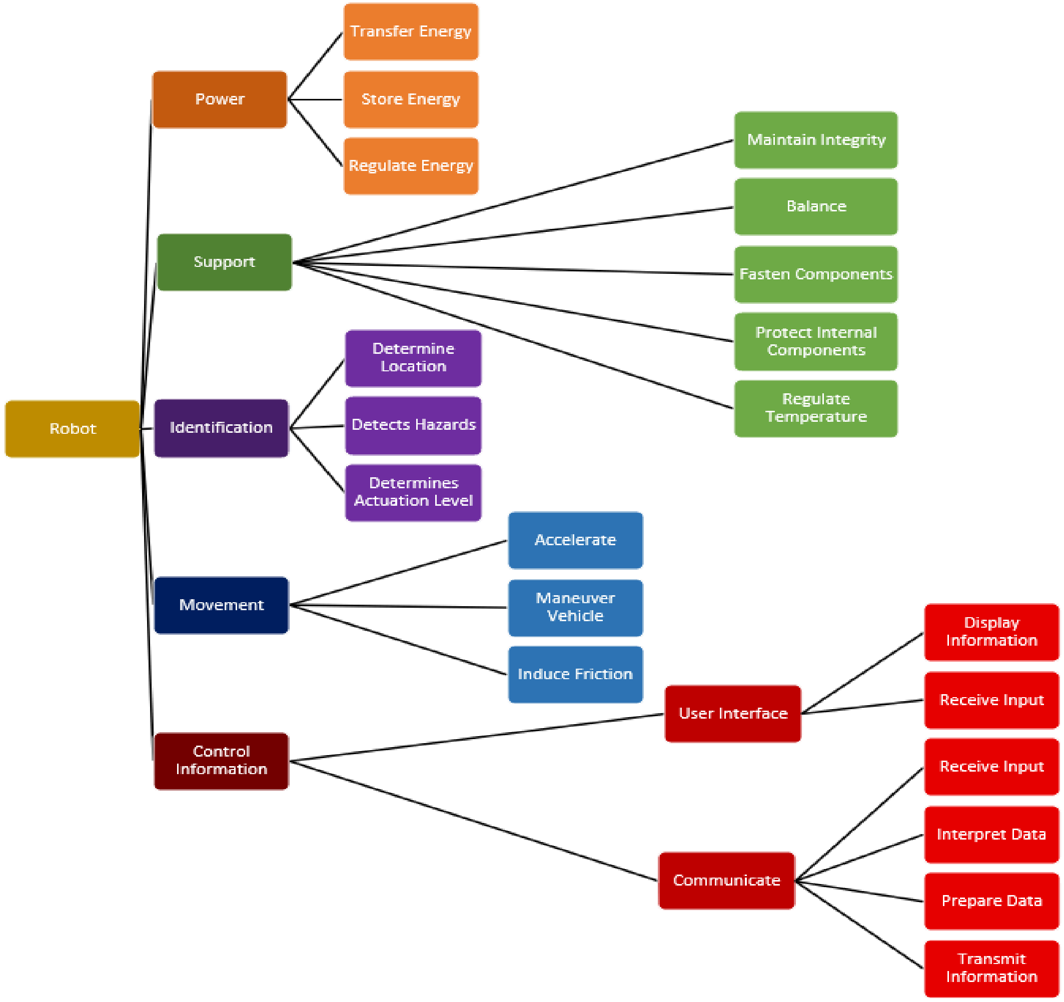
Team 514 identified that the needs of the project are to recognize the presence of a hazard, alert the operator of the hazard with some form of visual feedback, and allow the operator to control the product. These were identified as the most important needs because of our sponsor’s constant emphasis on these specifications when gathering more information regarding our project. The response to question 10 in Table 2 is determined to be more of a want rather than a need for this project, as the sponsor emphasized that this was an aspect of future work that will not be necessary to successfully complete this project.

1.3 Functional Decomposition

Introduction

The purpose of functional decomposition is to reduce a complex process into individual elements to analyze the whole. This was applied to a robotic system modified for pipe inspection. The system split into the five major functions shown in Figure 1: power, support, identification, movement, and control information.

Figure 1 – Functional Hierarchy Chart



Data Generation & Hierarchy Chart

The minor functions in each group were created based on the needs of the customer and the system; for example, most robotic systems require different sensors with varying power requirements, so the system must be able to regulate the power supplied to each of these sensors to avoid damaging the component.

Connection to Systems

For the system to properly complete the objective of this project, the subsystems must complete a series of functions. If all key functions are not met, the system will not be able to complete its task. The five main systems are power, support, identification, movement, and control information.

The power system must supply the required energy the system needs during its operation and manage how the power is delivered to each subsystem. Additional power storage may be required depending on the solutions generated. Once the system is powered, feedback must be received from the environment and the user through the control information system. The control information system is responsible for all communications between the user and the robot. The robot must be able to receive data from both the user and the environment, interpret and prepare that data, and then display it on the user interface.

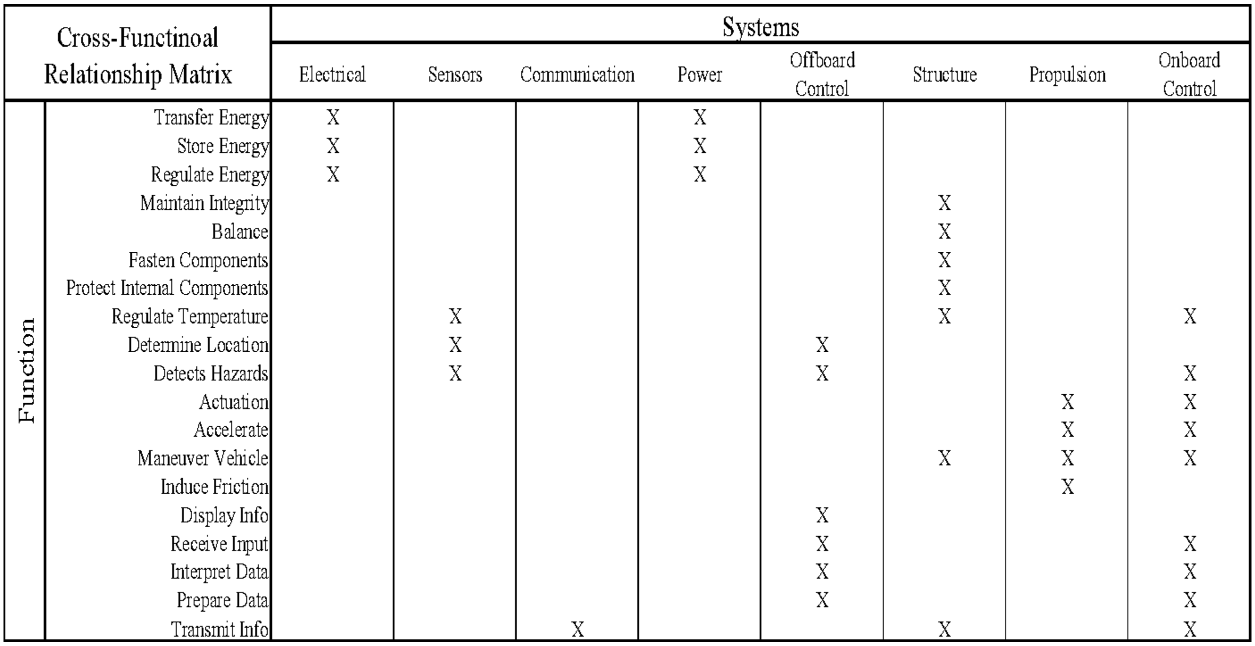
This communication must also undergo an identification process simultaneously to complete the goal of identifying a hazard and tracking the whereabouts of the robot. The identification system is how the system aids the user in identifying faults in piping and/or facilities and locating the device and its movements.

As well, an objective of this project is to ensure that the robot is durable and able to withstand harsh conditions. For the power, identification, and control systems to be successful, there must be a support system that is responsible for ensuring the robot remains functional, balanced, and temperate throughout while encountering loads, stresses, and hazards. This system shall also work in conjunction with the movement system which is responsible for moving the system based on user input. This system should be able to change directions and speed. This system is also responsible for inducing friction to allow the system to maintain a connection with the terrain it is traversing.

Smart Integration

Critical functions are crucial to the product because it can affect several subsystems when impacted. Also, major subsystems that encompass a large portion of minor functions can render a device useless if unavailable. Smart integration identifies these major components so that design engineers can consider these functions during concept generation. Using the cross functional relationship matrix in Table 3, critical functions and major subsystems are identified. The detect hazard's function is considered a crucial function. The robot will utilize the sensor, offboard controls, and onboard controls systems. The sensor will be used to read live data of the environment; this data will be sent to either the onboard control systems or offboard control system. Another example would be the regulate temperature function; the robot will use the sensor, structure, and onboarding systems.

Table 3 – Cross Functional Relationship Matrix



Cross-Functinoal Relationship Matrix		Systems							
		Electrical	Sensors	Communication	Power	Offboard Control	Structure	Propulsion	Onboard Control
Function	Transfer Energy	X			X				
	Store Energy	X			X				
	Regulate Energy	X			X				
	Maintain Integrity						X		
	Balance						X		
	Fasten Components						X		
	Protect Internal Components						X		
	Regulate Temperature		X				X		X
	Determine Location		X			X			
	Detects Hazards		X			X			X
	Actuation							X	X
	Accelerate							X	X
	Maneuver Vehicle						X	X	X
	Induce Friction							X	
	Display Info					X			
	Receive Input					X			X
	Interpret Data					X			X
	Prepare Data					X			X
	Transmit Info			X			X		X

Actions and Outcomes

The physical actions the robot will perform are traversing uneven terrain in response to the user's inputs and analyzing the environment, which allows the robot to create a perception profile of the environment and send information to the user so the user can identify hazards.

Function Resolution

The robot will have to perform the movement inputs it receives from the user. The robot will then have to interpret and send environmental data, such as its location and perception of the environment, back to the user. This will allow the user to identify any potential hazards that are present.

1.4 Target Summary

Targets

Targets are precise values intended to quantify the qualities of a design. Metrics are the instruments used to validate those targets. The functional decomposition hierarchy chart and cross reference table were used to identify the critical functions of this project. The project scope, customer needs, and team's assessment of a feasible goal were the basis for the targets and metrics determined for each function. Table 4 displays the critical functions of the project along with the targets that must be achieved. Table 5 provides an understanding of the metrics that are used to validate each target. Appendix C contains a complete catalog of all targets and metrics assigned to each function.

Table 4 – Critical Functions and Defined Targets

Function	Targets
Detects Hazards	< 2.1 [PPM per Minute]
	70 [%]
Maneuver Vehicle	0.5 [Meters]
	< 0 [m/s]
Transmit Information	< 40 [Milliseconds]
Regulate Temperature	131.8 [Degrees Celsius]

Critical Targets

Detects Hazards

Hazard detection is a fundamental function of this project. To decrease the risk of injury for the user while identifying gas leaks and cracks in metal piping, the product must be able to identify concentrations of gas that exceed 2.1 PPM every 1 minute which is 1000 PPM in 8 hours and have a 70% accuracy of detecting deformities in a metal pipe.

Maneuver Vehicle

Vehicle maneuvering ensures the vehicle is able to navigate in and through pipes, if needed. This has a target that maximum turn radius of the vehicle must be is set to 0.5 meters to be able turn within a pipe. Another critical target involves controlling the speed of the vehicle. To satisfy this target, the user must be able to increase the speed of the vehicle to a magnitude greater than 0 m/s.

Transmit Information

The transmission of information is how the user sends data from the vehicle. To ensure that the user is notified of the hazard as soon as possible, the target transmit time should be less than 40 milliseconds. This target is based on average transmitter relay times for similar devices. This time would allow for almost seamless control and accurate detection when the device is in use.

Regulate Temperature

Without effective temperature control, the product's operation would be rendered unfeasible given its operation by heat-sensitive electrical components. Consequently, the selected upper temperature limit for our product is set at 131.8°C, aligning with the melting point of high-density polyethylene (HDPE), the plastic material manufactured by our sponsor. This cohesive approach ensures that our product remains both efficient and reliable in its performance.

Metrics

Table 5 – Critical Functions and Defined Targets

Function	**Targets**
Detects Hazards	Rate of Detection
	Accuracy of Detection
Maneuver Vehicle	Turn Radius
	Speed
Transmit Information	Time Taken to Transmit Data
Regulate Temperature	Maintain Constant Temperature

Critical Metrics

Detects Hazards

The metric for detecting hazards is rate of detection and accuracy of detection. For detecting gaseous hazards, this defines how much of the gas being detected is acceptable in a room. This can be tested using a small pressure box with the gas streaming in. For detecting cracking hazards, a ratio of false negatives and positive over a total number overclassification is defined. This target can be measured by having a known number of blemishes on a wall and feeding it through a computer then summing the false negatives and false positives.

Maneuver Vehicle

For turning radius, the metric can be tested by forcing the vehicle to rotate in a circle or oval and measuring radius. Another way of testing is making the vehicle drive in a circular path and placing tape where the vehicle is 0 degrees and 90 degrees. Changing speed can be tested by starting the vehicle and measuring the time it takes to reach a certain distance in meters once the vehicle begins to move.

Transmit Information

The metric for the transmission of information between systems is time based. To validate this target and metric, two-time capture methods will be used, one within the CPU of the product to track overall time and when specific aspects of the code (i.e. sensor data, motor encoder pulses, etc.) update. The other will be a stopwatch used by the team, controlled with visual cues, such as when the controller is given an input and when robot moves, or when sensor is exposed to gas and when display notifies user. By taking two measures of time, a comparison between both can be conducted to assure validity of measurements, as well as a timing of components missed by the other measurement method can be collected. A successful product will perform tasks within 40 milliseconds of an input from either user or product.

Regulate Temperature

The metric for regulating temperature is maintaining a constant temperature. To validate the target and metric of this function, an array of temperature sensors will be placed around the temperature-sensitive components to ensure there will be no overheating. A successful target will keep the temperature of the components cool enough to not break while being in an extreme environment for an extended period.

Summary of Targets & Metrics

Appendix C: Target Catalog contains a comprehensive list of all the project's targets and metrics. The lowest-level functions from the functional decomposition hierarchy chart served as the foundation for these targets and metrics. Functions that were determined to be functionless were derived from interpreted customer needs. The success of this project depends on the creation of a product that satisfies all targets in the target catalog.

Targets and metrics are subject to change as the project progresses as real-world testing may render them impractical.

1.5 Concept Generation

Concept generation Is a vital step in the design process that contributes to the development of creative and effective ideas towards solving problems. The use of several concept selection tools enables the team to create a wide range of unique concepts, as well. By combining all our achievable targets and constraints, the team was able to use this methodology to develop a total of 100 potential concepts for our product. The complete list is shown in table 1 of appendix E.

Concept Generation Tools

The team utilized a diverse set of tools such as brainstorming, the crap shoot method, SCAMPER, and a morphological chart, to generate a total of 100 potential concepts. To begin concept generation, Team 514 gathered in the ME Help Center to encourage an environment of open communication where all ideas were welcomed without judgment. This approach enabled the team to think creatively and consider a wide array of ideas capable of fulfilling the key functions outlined in the project's functional decomposition.

Subsequently, each promising idea was meticulously refined by assigning each on to a specific function and implementing the crap shoot method to further develop these concepts. The comprehensive table corresponding to the results of the crap shoot method can be found in table 2 of appendix E.

As well, Team 514 created a morphological chart, delineating the significant functions derived from the functional decomposition. By structuring a table that encompassed various categories and their respective options, the team systematically amalgamated options from diverse categories, leading to the creation of distinct design configurations. The morphological chart used for this project is displayed in table 3 of appendix E.

Finally, each team member was also expected to employ the SCAMPER and Biomimicry methods to gain additional perspectives on other unique characteristics the team may consider when creating the final product. SCAMPER utilizes an existing idea expands upon it using one or more actions defined in the acronym meaning “Substitute, Combine, Adapt, Modify (Magnify, Minify), Put it to other use, Eliminate, Rearrange, and reverse.”. Biomimicry uses nature to inspire ideas that mimic the mannerisms or characteristics of plants and animals. Team 514 also used the Fantasy/Wishful Thinking method to gain a better understanding of the pitfalls of certain ideas or desires the customer may have from using competing products.

Concept Fidelity

To optimize the concept selection process, the team chose five medium fidelity concepts and four high fidelity concepts.

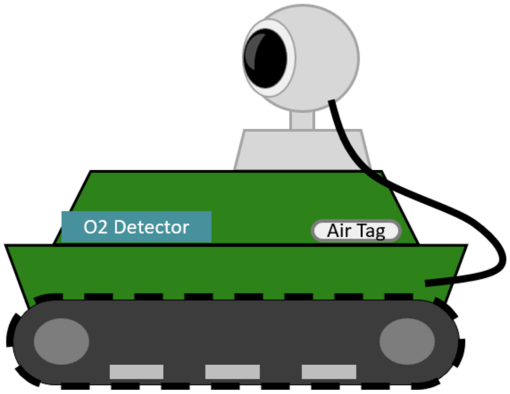
1.5.1.1 Medium Fidelity

Medium fidelity concepts include appealing traits that align with some important functions delineated in the functional decomposition, but not all. These concepts will be used to determine how effective different features of each design will be at satisfying the interpreted needs of the customer. A smaller sample of somewhat feasible designs will help identify which features are most important to achieve the objective of this project.

Concept 90 – Thomas

A tank vehicle with magnets on the tracks to climb surfaces, The core has liquid cooling to prevent overheating, equipped with a camera to provide visual feedback, an oxygen detector to detect gasses, and uses an air tag to justify location. Remote controlled via Bluetooth, and battery powered.

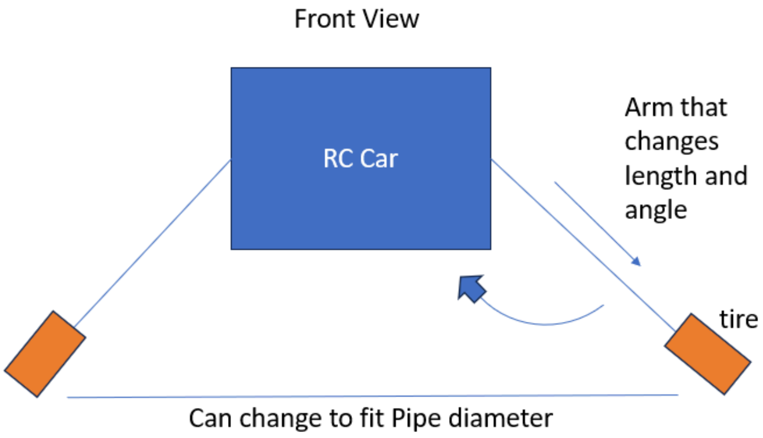
Figure 2 – Drawing of Thomas with Projected Placement of Outer Components



Concept 56 – Inspector Gadget

The remote-controlled (RC) system has an insulated body and is equipped with articulated arms capable of adjusting their angle and length relative to the body using motors. Each arm is fitted with driven wheels and tires, enabling the vehicle to maneuver effectively. The configuration allows the arm/wheel assembly to be positioned perpendicular to the body, with the capacity to extend the arms to match the diameter of the pipe for vertical movement. Directional changes are facilitated by the left wheel turning backward and the right wheel turning forward. Moreover, the system incorporates three interchangeable gas sensors and a front-facing, pivoting camera seamlessly integrated into the body to offer users a comprehensive visual understanding of the surrounding environment.

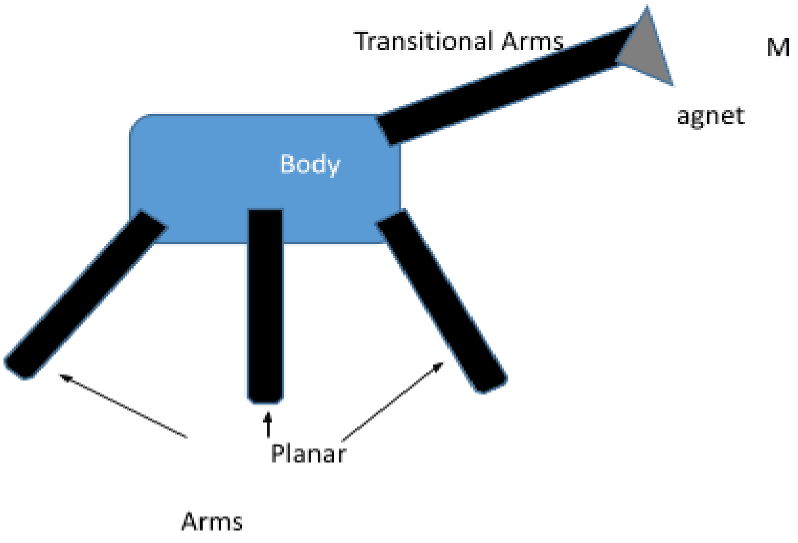
Figure 3 – Drawing of Inspector Gadget with Arrows to Illustrate Movement



Concept 63 – Charlotte

Charlotte is a spider-like robot with Spring Loaded Inverted Pendulum (SLIP) model walking arms and rotary transitional arms that maintain ground connection. 6 limbs would have restricted rotary motion underneath the body to be used for planar movement, and 2 would have less restricted rotary motion in front of the body to be used for sloped and perpendicular transitions. The transitional arms would be fitted with magnets to adhere the robot to the uneven terrain as the other limbs propel it forward with a walking gate. The body would be well insulated, fitted with all the necessary sensors and a camera inside it. The robot would be remotely controlled.

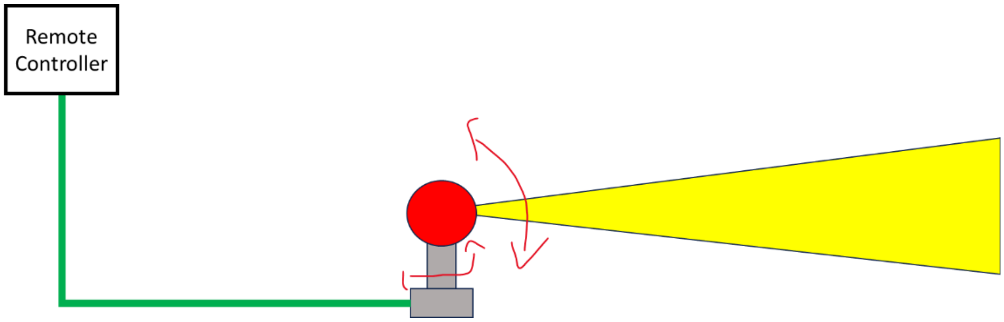
Figure 4 – Drawing of Charlotte Indicating Limb Location and Desired Material



Concept 83 – PIC-Man

Pipe Inspection Camera Module (PIC-M) is a remote-controlled car accessory that is resistant to high temperature fluids. Equipped with an ozone sensor to detect gas levels and flood lights to illuminate dark areas. It sends and receives data through a tether and is capable of tilting and panning the camera. The idea behind this concept is to reduce the whole system into one module that can be attached to remote control car to avoid feature creep. Its goal is to maximize the effectiveness of the inspection at the cost of its mobility.

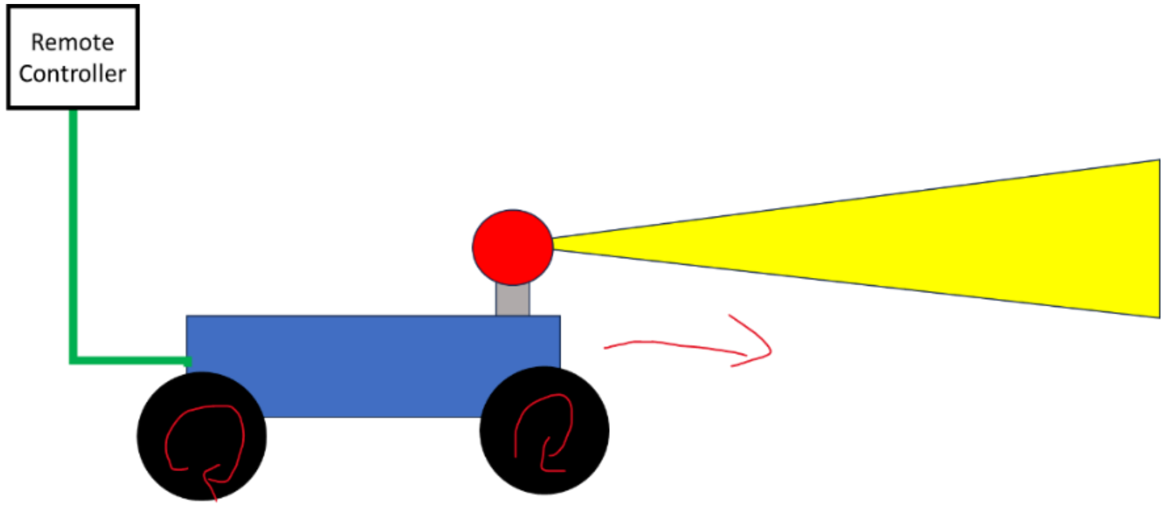
Figure 5 – Drawing of PIC-Man Component with Arrows to Illustrate Desired Movement



Concept 89– Charlie & Frank

RC pipe crawler resistant to high temperature fluids. Equipped with basic camera to get visual information pipe and basic environment sensors. Needs to be paired with remote controller. The front wheel set is on an axle and the back wheel set are each individually driven by motors. Controlled by remote control system designed by team.

Figure 6 – Drawing of Charlie & Frank Concept



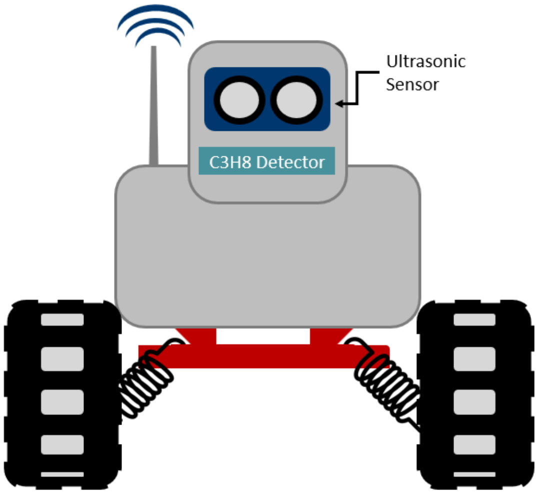
1.5.1.2 High Fidelity

High fidelity concepts include desirable features that satisfy the interpreted needs of the project the most. These four concepts will be used in the concept selection process to help determine which design best fits the customer's needs and represents the most functions that will achieve the goal of this project.

Concept 8 – Norman

A robot that stores energy using NiCd Battery, balance using a rigid suspension with springs, regulate temperature using no insulation in metal body with an internal fan, determine location using gyroscope and accelerometer, detects cracks using ultrasonic testing, maneuvers the vehicle using wheels, induces friction between the terrain and the vehicle using magnets, detects gas leaks using propane gas sensors, and transmits information using Bluetooth communication.

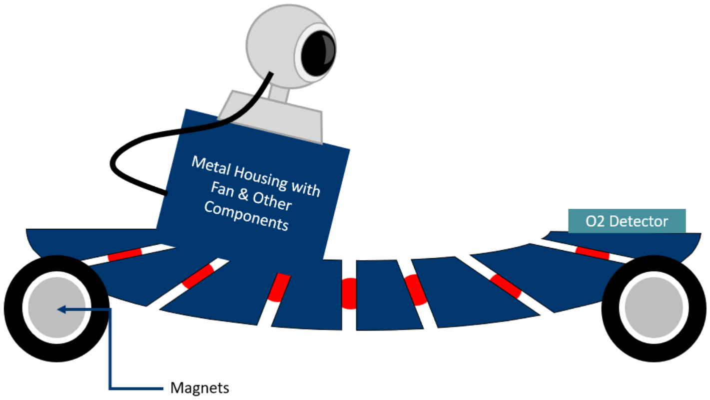
Figure 7 – Drawing of Norman with Location of External Components Denoted



Concept 35 – Steven

A robot that stores energy using Lithium-Ion battery, balance using a flexible body, regulates temperature using no insulation in metal body with an internal fan, determines location using GPS, detects cracks using visual inspection, maneuvers the vehicle using wheels, induces friction between the terrain and the vehicle using magnets, detects gas leaks using oxygen level sensors, transmits information using radio communication.

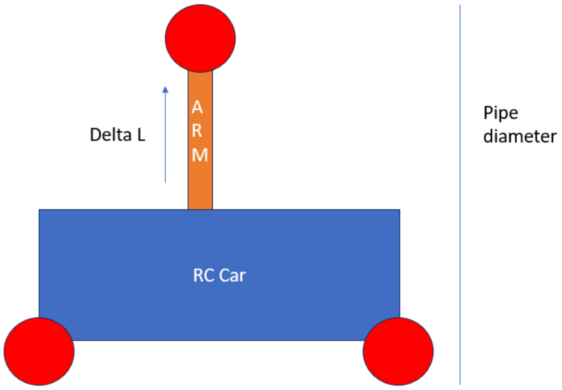
Figure 8 – Drawing of Steven Robot



Concept 54 – Luffy

The RC car is equipped with a heat shield and features a vertical arm positioned perpendicular to the wheel path. The tires are designed with sandpaper for enhanced friction. In instances where the vehicle enters a pipe and requires vertical movement, the top arm extends to match the diameter of the pipe. Utilizing the force generated by the extended arm and the sandpaper-equipped wheels, the RC car efficiently creates friction across all sets of tires, enabling it to ascend vertically within the pipe.

Figure 9 – Drawing of Luffy with Change in Length of Arm and Range of Pipe Diameter

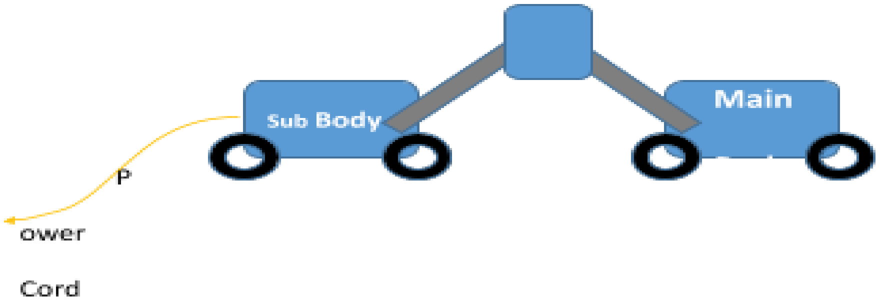


Concept 64 – Shelby

Create a small robot whose movement and shape are based on an inch worm. Robot is separated into 3 sections. The front and back sections will be RC vehicles, the middle section will be an actuated dual armed system connecting the front and back sections and able to lift as needed. Then the robot will be wheeled with magnetic connections.

The robot will be divided into a main body and a sub body, the main being the front section of the robot which will house the camera and main sensors, while the sub body will be the back section and house the backup sensors. Both bodies will have a heat shield. The robot shall be powered with a connected extension cord and controlled via a corded controller.

Figure 10 – Drawing of Anticipated Shape of Shelby Concept



1.6 Concept Selection

Engineers employed a comprehensive toolkit, including Binary Pairwise Comparison (BPwC), House of Quality (HoQ), Pugh Charts, and Analytical Hierarchy Processes (AHP), to methodically select the most promising concepts. These tools were instrumental in mitigating individual biases, as evidenced in the detailed selection process outlined in Appendix F.

House of Quality

Initiating the House of Quality phase, the teams focus centered on identifying the utmost priorities among customer needs. The team employed a binary pairwise comparison table to directly compare these needs, initially resulting in a priority sequence led by "Identify Hazards." Recognizing the critical nature of timely gas hazard detection, we iteratively revisited our approach. A significant learning opportunity arose as we identified and rectified an “and/or” statement misinterpretation in the customer needs that affected the logic in the BPwC. The "Identify Hazards" customer need was subdivided into "Identify Gas" and "Identify Deformity," addressing the nuanced relationship between detecting gases and deformities. The corrected binary pairwise table is available in Appendix F.

Table 3 – Customer Needs Used in BPwC

Customer Needs
Detection Time
Size
Life Span
Traversability
User Feedback
Control Method
Usability/ Versatility
Use time
Operable Distance
Temperature Constraints
Identify Gasses
Identify Deformities

Considering the weight factors derived from the BPwC, we meticulously assessed how each characteristic contributed to the customer requirements. Assigning scores (0, 1, 3, or 9) to these factors, the team created a House of Quality that translated the ideas into design characteristics. Notably, the most critical characteristic became "response time from environment," emphasizing the project's overarching goal of ensuring user safety by providing an accurate perception of the environment. Despite "weight" being deemed the least important engineering characteristic, a potential concern arose due to its direct correlation with most moving functions. The comprehensive House of Quality is detailed in Appendix F.

Pugh Chart

Continuing the design selection journey, the Pugh Charts played a pivotal role in evaluating and comparing potential design choices in a systematic manner. These charts provided a visual representation of the relative merits and drawbacks of each concept, guiding engineers toward the most viable solution. The team's initial iteration of Pugh charts utilized Super Droid Robotics TP-631-100 as the datum. Though not exact, this particular product was chosen due to its resemblance to our envisioned design and served as a baseline for comparison. The chart, depicted in the figure above, featured concepts with varying fidelity levels, allowing the team to objectively measure their performance against the established baseline.

Among the concepts, the "Shelby" concept emerged as the most promising during the initial Pugh chart iteration, boasting 11 positive assessments and only 1 negative assessment. This comparison highlighted the strengths of the "Shelby" concept, particularly in comparison to other alternatives.

As part of the teams' iterative process, they transitioned to the second iteration of the Pugh chart, using the "Inspector Gadget" concept as the new datum. This iterative approach allowed the team to refine their evaluations and obtain a more nuanced understanding of each concept's strengths and weaknesses.

During this second iteration, the "Thomas" concept emerged as the highest-scoring option, receiving 3 positive assessments and 2 negative assessments. This strategic shift in datum provided a fresh perspective on the relative merits of the concepts, ultimately guiding the team toward more informed decisions. Following the completion of the second iteration, the team identified the three most promising concepts: "Thomas," "Charlotte," and "Luffy." These concepts demonstrated consistent strengths and were deemed the top contenders for further consideration in the design process.

Analytical Hierarchy Process (AHP)

The AHP served as a critical tool to find potential biases in our concept judgments. The detailed chart in Appendix E provides a comprehensive overview of the criteria vs. criteria comparison, using a ranking order (1, 3, 5, 7, and 9) to quantify the relative importance of each criterion. Normalizing values and establishing criteria weights allowed the team to measure the impact of each criterion on the selected final design. Matrix operations and vector division generated Weighted Sum Vectors and Consistency Vectors, culminating in a consistency ratio 0.7 below the ideal value of 0.10, affirming the robustness of the decision-making process.

Final Selection

The same meticulous process was iteratively applied to compare our top three concepts. A lower consistency ratio, underscored as 0.2571 by Thomas, was indicative of a more robust decision-making framework. The Final Rating Matrix (FRM) was calculated to provide a numerical representation of each concept's perceived performance in each criterion. Transposing the FRM and multiplying it by the criterion weight matrix yielded final values, with larger values indicating a superior design. Following this thorough analysis and comparison methodology, the "Thomas" concept emerged as the best potential solution for the project, as detailed in Appendix F.

1.8 Spring Project Plan

Chapter Two: EML 4552C

2.1 Spring Plan

Project Plan.

Build Plan.

Appendices

Appendix A: Code of Conduct

Overview

This document will serve as a set of guidelines and expectations for Senior Design group T514. In this document, clear details about group expectations and the procedures lasting from Fall of 2023 through Spring of 2024 will be found. Each member of the group was involved in these decisions and signed the Statement of Understanding.

Mission Statement

To collaborate as a team to produce an original design that will successfully traverse pipelines, with respect to the needs and requirements defined by our customer. Team 514 intends to implement engineering design methods, principles, and experiences gained from our undergraduate careers in a professional manner. Each member is expected to operate ethically and respectfully to accurately represent the FAMU-FSU College of Engineering.

Outside Obligations

Team 514 shall meet twice weekly at a minimum. General team meetings will take place during the remaining lecture times every Tuesday and Thursday in Senior Design II. Additional team meetings shall be scheduled as needed based on the availability of the team specified in the when2meet titled ‘T514 Availability’ and the Microsoft Teams calendar. Team members shall notify the team of any changes to their schedule as soon as possible.

Communication

All methods of communication used by Team 514 shall maintain a professional tone, vernacular, and topics relevant to the project. Each team member shall agree to remain respectful and refrain from speaking in a non-derogatory, non-defamatory manner towards other members, teams, organizations, and advisors. Team members are expected to respond to any form of communication addressed below within **24 hours**. Each team member may only deliver a message between the hours of 8:00AM to 8:00PM every day, unless otherwise specified.

Microsoft Teams/Email

Microsoft Teams shall be the primary mode of communication for matters involving professional discussions, essential information, and project progress. This will be the primary method of file sharing and transfer of important documents. Team members are expected to check Microsoft Teams frequently to remain up to date with tasks assigned and meetings scheduled.

All communication with teaching assistants, project advisors, sponsors, and other College of Engineering personnel shall be conducted through school email accounts. Each team member is expected to CC the entire team on all project-related emails. Team members are encouraged but not required to be active through email communication or Microsoft Teams over the weekend and on holidays.

Text Messaging

A group chat shall exist for the purpose of sending reminders, scheduling emergency meetings, communicating absences, and for informal communication amongst all team members. All members are allowed to text the group chat at any time, as long as the communication respects the time of day or night and remains relevant to the success of the project. Team members are encouraged but not required to be active through text message over the weekend and on holidays.

In-Person/Virtual Meetings

Team meetings and locations will be scheduled **at least 1 week** in advance at an agreed upon time during the previous meeting. A meeting agenda shall be used to align all meetings to current team progress and will be adjusted to include the progress made or actionable tasks identified before the end of each meeting. Sponsor and advisor meetings will be set to their availabilities and needs.

Team Roles

The following team roles have been assigned for this project. As more information about the objective is given, additional roles may be assigned or re-evaluated through a unanimous agreement of the team.

Team member & Role	Description
Carson Clark Systems Engineer	The Systems Engineer is responsible for the seamless integration of each subsystem necessary for this project.
Roshard Jackson Design & Manufacturing Engineer	The Design & Manufacturing Engineer is responsible for the CAD and the build of the design.
Geraina Johnson III Modeling & Simulation Engineer	The Modeling & Simulation Engineer is responsible for the mechanical calculation of the robot's motion system.
Jacob Larkins Mechatronics Engineer	The Mechatronics Engineer is responsible for necessary electronic components and software.
Katherine Lopez Test & Verification Engineer	The Test & Verification Engineer is responsible for the approval and coordination of all test procedures.
David Ramos Quality Engineer	The Quality Engineer is responsible for the materials selection and the design analysis.

Dress Code

For Sponsor meetings, Virtual Design Reviews, and advising meetings, the team shall be dressed in business casual attire. Business casual for men refers to a button-down shirt, slacks, and dress shoes. For women, dresses, dress pants, blouses, and dress shoes are acceptable. On Senior Design Day, the team shall be dressed in formal business attire. All formal and business casual dress codes must include a blue suit, a white shirt, and brown accessories. General team meetings are considered informal events; therefore, a specific dress code is not applied. However, any events outside of those mentioned above that require a dress code shall be communicated to the team as needed.

Attendance Policy

All members are expected to attend all team meetings and class lectures. Team members are **required** to attend design reviews, advisor meetings, and sponsor meetings. The team must be notified about excused absences at least 24 hours before meetings and absentees are required to review the agenda and team minutes for that missed meeting on their own time and provide a summary at next meeting to ensure they are up to date on topics discussed. Unexcused absences, unless proven emergency, will be penalized at the discretion of the team members and advisors. The use of a vacation day on a team assignment must be agreed upon unanimously by the team 24 hours prior to the due date of that assignment. Should an individual miss 3 meetings, even with prior notice to the team, they must call for a team meeting to determine a better time that best fits their schedule. If the team member fails to correct their consistent absence, the team will be forced to act upon the Intervention Policy defined in this Code of Conduct.

Intervention Policy

The Intervention Policy must only be applied if a team member(s) has failed to operate within the clauses discussed in the Code of Conduct or in the best interest of the project, despite several attempts made by other members of the team to help the individual(s). Dr. McConomy and the Teaching Assistants for Senior Design must only be contacted when there is sufficient documentation of the team member’s failure to attend meetings, complete tasks, or communicate with the team. When the team contacts Dr. McConomy, a reminder of the individual’s commitment to the code of conduct is expected, as well as any other penalty Dr. McConomy may deem necessary to resolve the situation.

Amendments

This Code of Conduct may be revised at any time at the group's discretion. To amend the code of conduct a group meeting must be held with all members present to discuss and agree on desired amendments. Amendments will be accepted through a majority vote held by the team. All members must sign and date at the time of amendment.

Statement of Understanding

I am aware of all the guidelines that have been laid out to me throughout the code of conduct and will be shared on the Microsoft Teams page. It is my responsibility to understand and follow these procedures during the duration of this project. I hereby agree to these policies and the consequences decided on by the group for failure to reach these agreements.

Signatures:	Dates:
Carson Clark	01/12/2024*

Roshard Jackson 01/12/2024*

Geraina Johnson 01/12/2024*

Jacob Larkins 01/12/2024*

Katherine Lopez 01/12/2024*

David Ramos 01/12/2024*

* - Amended Date

Appendix B: Work Breakdown Structure

Milestone	Work Packet X	Tasks X.x	Assigned To	Status	Due Date
Code of Conduct	Generate Information	Develop Absence Policy	Geraina J.	100%	9/12/2023
		Pick Colors/Style for Dress Code	Geraina J.	100%	9/12/2023

		Address Outside Obligations	David R.	100%	9/12/2023
		Discuss Modes of Communication	Jacob L.	100%	9/12/2023
		Define Team Roles	David R.	100%	9/18/2023
	Complete Document	Create Document For Submission	Carson C.	100%	9/12/2023
		Write Mission Statement	David R.	100%	9/12/2023
		Fill Document With Generated Information	David R.	100%	9/18/2023
		Revise and Edit Document	Geraina J.	100%	9/18/2023
		Submit Assignment	Roshard J.	0%	9/19/2023
Customer Needs	Meet With Sponsor	Schedule Meeting With Sponsor	David R.	50%	9/14/2023
		Come Up With Questions	Geraina J.	0%	9/15/2023
		Attend Meeting	Roshard J.	0%	TBD
		Write Meeting Minutes	Jacob L.	0%	TBD
		Submit Meeting Minutes	Katherine L.	0%	10/5/2023
	Do Assignment	Create Document For Submission	David R.	0%	10/6/2023
		Reread Meeting Notes	Katherine L.	0%	10/7/2023
		Interpret Customer Needs	Geraina J.	0%	10/8/2023
		List Customer and Interpreted Needs	Carson C.	0%	10/9/2023
		Revise and Edit Document	Carson C.	0%	10/10/2023
		Submit Assignment	David R.	0%	10/11/2023
Project Scope	Generate Information	Read and Interpret Project Brief	Roshard J.	0%	9/20/2023
		Identify Stake Holders	Carson C.	0%	9/20/2023
		Identify Key Goals	Roshard J.	0%	9/20/2023
		Identify Market	Geraina J.	0%	9/20/2023
		Make Assumptions	Geraina J.	0%	9/20/2023

	Do Assignment	Create Document For Submission	Roshard J.	0%	9/20/2023
		Write Project Description	David R.	0%	9/21/2023
		Fill Document With Generated Information	Roshard J.	0%	9/27/2023
		Revise and Edit Document	Katherine L.	0%	9/28/2023
		Submit Assignment	Jacob L.	0%	9/29/2023
Submit VDR1	Submit Draft	Complete Assignment	Katherine L.	0%	10/13/2023
VDR1	Gather Required Content	Review Previously Submitted Deliverables	Roshard J.	0%	10/9/2023
		Review Feedback from TAs	Geraina J.	0%	10/14/2023
	Meet with Team	Send Teams Message	Geraina J.	0%	10/8/2023
		Agree on meeting date	Jacob L.	0%	10/8/2023
		Agree on meeting location	Carson C.	0%	10/8/2023
		Create Agenda for the Meeting	Jacob L.	0%	10/8/2023
		Read Through The Rubric Together	Roshard J.	0%	10/9/2023
		Discuss Key Points	David R.	0%	10/9/2023
		Discuss Presentation Structure	Katherine L.	0%	10/9/2023
	Slide Creation	Save file using naming convention	Geraina J.	0%	10/10/2023
		Create Title Slide	Carson C.	0%	10/10/2023
		Create Introduction Slide	Katherine L.	0%	10/10/2023
		Create Overview Slide	Roshard J.	0%	10/10/2023
		Create Data Presentation Slide	Roshard J.	0%	10/11/2023
		Create Key Findings Slide	David R.	0%	10/12/2023

		Create Conclusion Slide	Roshard J.	0%	10/13/2023
		Create Questions & Discussions Slides	Carson C.	0%	10/14/2023
		Add Visual Elements	David R.	0%	10/15/2023
	Practice Presentation	Proofread	Jacob L.	0%	10/14/2023
		Prepare notes if needed	Geraina J.	0%	10/15/2023
		Edit Presentation	Jacob L.	0%	10/14/2023
	Deliver Presentation	Submit Assignment	Roshard J.	0%	10/17/2023
		Attend Presentation Session	Katherine L.	0%	TBD
Functional Decomposition	Conduct Preliminary Research	Research features of market products	David R.	0%	9/25/2023
		Research features of academia platforms	David R.	0%	9/25/2023
		List specs/features found	David R.	0%	9/25/2023
		Transform features/specs into subsystems	Roshard J.	0%	9/25/2023
		Transform features/specs into functions	Jacob L.	0%	9/25/2023
	Make FD Diagram	Construct System/Subsystem Hierarchy	Geraina J.	0%	10/5/2023
		Incorporate Functions into Hierarchy	David R.	0%	10/5/2023
		Clean up diagram and save as separate file.	David R.	0%	10/5/2023
	Prepare Deliverable	Format the document.	Carson C.	0%	10/10/2023
		Write Main Body of Text	Roshard J.	0%	10/11/2023
		Incorporate FD into Report	Geraina J.	0%	10/11/2023

		Write Abstract	Geraina J.	0%	10/11/2023
		Append References	David R.	0%	10/11/2023
		Edit and Review the Deliverable	Jacob L.	0%	10/12/2023
		Submit Deliverable	Geraina J.	0%	10/13/2023
		Review Deliverable Feedback	Katherine L.	0%	TBD
		Adjust Document	Geraina J.	0%	TBD
Targets	Conduct Preliminary Research	Research Industry Standards	Carson C.	0%	10/15/2023
		Research Specs of Similar Products	Katherine L.	0%	10/15/2023
		Review Similar Academic Models	Roshard J.	0%	10/15/2023
		List References	Geraina J.	0%	10/16/2023
	List Functions to Metrics	Find metrics important to Primary F(x)s	Katherine L.	0%	10/20/2023
		Find metrics important to Auxiliary F(x)s	Roshard J.	0%	10/20/2023
		Rank metrics by importance for each F(x)s	Jacob L.	0%	10/20/2023
		Assign targets to the important metrics	Roshard J.	0%	10/20/2023
	Graphics	Create Targets/Metrics Table	David R.	0%	10/25/2023
		Format the Table	Jacob L.	0%	10/25/2023
		Apply Tolerance Control Functions	Katherine L.	0%	10/25/2023
		Save and Export Figure	David R.	0%	10/25/2023
	Prepare Deliverable	Format the Document.	Katherine L.	0%	10/20/2023

		Write Main Body of Text	David R.	0%	11/2/2023
		Create Figures/Table of Target/Metric Pairs	Carson C.	0%	11/2/2023
		Write the Abstract	Roshard J.	0%	11/2/2023
		Append References	Geraina J.	0%	11/2/2023
		Edit the document	Katherine L.	0%	11/2/2023
		Submit the document	Roshard J.	0%	11/3/2023
		Review Feedback	Katherine L.	0%	TBD
		Adjust Document	Carson C.	0%	TBD
Concept Generation	Brainstorming	Individual Brainstorm	Geraina J.	0%	11/3/2023
		Team Brainstorm via Methodical Tools	Carson C.	0%	11/4/2023
	Fidelity Concepts	Fidelity Concept Generation	David R.	0%	11/5/2023
		Fidelity Concept Ranking and Selection	David R.	0%	11/5/2023
	Discussion and Report	Discussion and Write Report	Geraina J.	0%	11/5/2023
		Submit Report	Jacob L.	0%	11/10/2023
Concept Selection	Selection Models	Develop Qualities	Geraina J.	0%	11/5/2023
		House of Quality	Roshard J.	0%	11/5/2023
		Pugh Charts	Carson C.	0%	11/5/2023
	Discussion and Report	AHP	Geraina J.	0%	11/6/2023
		Discussion and Final Selection	Carson C.	0%	11/6/2023
		Write Report and Submit Report	Roshard J.	0%	11/10/2023
Preliminary Prototype	Create Initial Design	Produce CAD Drawings of Selected Concept	Geraina J.	0%	11/13/2023
		Create Build Plans of Selected Concept	Katherine L.	0%	11/14/2023

	Build Initial Design	Gather Materials for Preliminary Build	Katherine L.	0%	11/15/2023
		Assemble Preliminary Prototype	Roshard J.	0%	11/15/2023
		Test Preliminary Prototype	Roshard J.	0%	11/16/2023
VDR2	Gather Required Content	Review Previously Submitted Deliverables	Katherine L.	0%	11/8/2023
		Review Feedback from Tas	Katherine L.	0%	11/8/2023
	Meet with Team	Send Teams Message	Geraina J.	0%	11/8/2023
		Agree on meeting date	David R.	0%	11/8/2023
		Agree on meeting location	Katherine L.	0%	11/8/2023
		Create Agenda for the Meeting	Jacob L.	0%	11/9/2023
		Read Through The Rubric Together	David R.	0%	11/9/2023
		Discuss Key Points	David R.	0%	11/9/2023
		Discuss Presentation Structure	Geraina J.	0%	11/9/2023
	Slide Creation	Save file using naming convention	Geraina J.	0%	11/9/2023
		Create Title Slide	Jacob L.	0%	11/9/2023
		Create Introduction Slide	Jacob L.	0%	11/9/2023
		Create Overview Slide	Carson C.	0%	11/9/2023
		Create Data Presentation Slide	Jacob L.	0%	11/10/2023
		Create Key Findings Slide	Geraina J.	0%	11/10/2023
		Create Conclusion Slide	Roshard J.	0%	11/10/2023
		Create Questions & Discussions Slides	Geraina J.	0%	11/9/2023
		Add Visual Elements	Roshard J.	0%	11/9/2023

	Practice Presentation	Proofread	Roshard J.	0%	11/11/2023
		Prepare notes if needed	David R.	0%	11/11/2023
		Edit Presentation	Roshard J.	0%	11/11/2023
	Deliver Presentation	Submit Assignment	Carson C.	0%	11/12/2023
		Attend Presentation Session	David R.	0%	TBD
Risk Assessment	Identify possible hazards	Look for Hazards Associated with Procedure	Roshard J.	0%	11/10/2023
		Who will be exposed	Jacob L.	0%	11/10/2023
		Define range of possible exposure	Geraina J.	0%	11/10/2023
	Research Hazards from Governing Bodies	Record and Document Possible Hazards	Katherine L.	0%	11/10/2023
	Determine Safety measures	How will they be exposed	Katherine L.	0%	11/10/2023
		follow governing body guidelines	Geraina J.	0%	11/14/2023
		decide control measures	Katherine L.	0%	11/14/2023
		provide protective gear	Carson C.	0%	11/18/2023
		create plan to avoid hazards	Jacob L.	0%	11/18/2023
	Determine Emergency response	Have an emergency contact	David R.	0%	11/24/2023
		Have plan in case of emergency	Jacob L.	0%	11/24/2023
Bill of Materials	Create Format	List All Materials	David R.	0%	11/15/2023
		Number Materials	Geraina J.	0%	11/18/2023

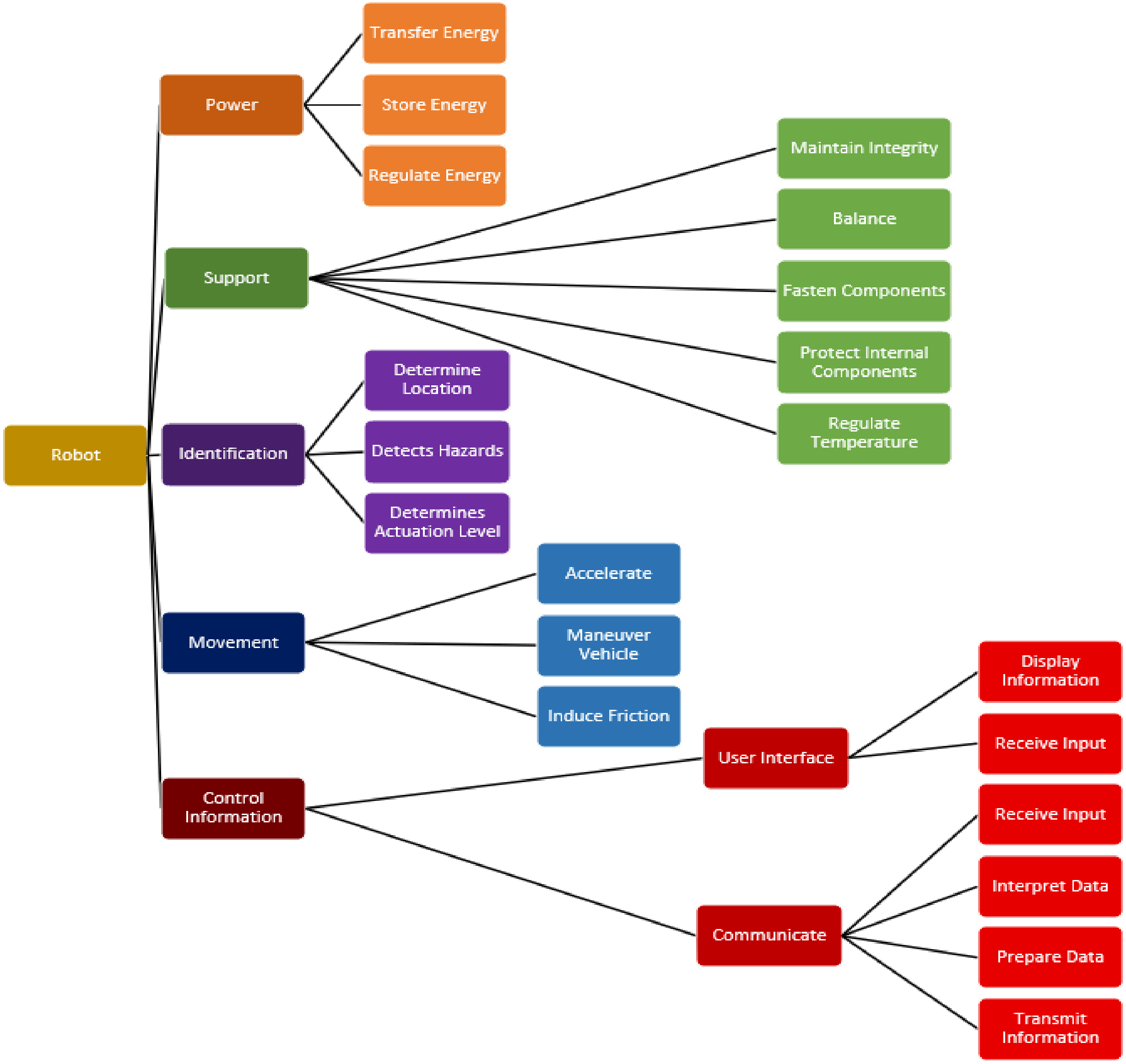
		Describe Materials	Katherine L.	0%	11/19/2023
		Measurement of Materials	Roshard J.	0%	11/19/2023
		Determine How Many of Each Material	Roshard J.	0%	11/19/2023
	Create Budget	Identify Total Project Budget	Katherine L.	0%	11/20/2023
		Determine Cost of Each Item	Carson C.	0%	11/21/2023
	Identify Vendors	Record Vendor	Carson C.	0%	11/25/2023
		List Vendor Part Information	Roshard J.	0%	11/25/2023
	Complete document	Review BoM	Katherine L.	0%	12/3/2023
		Submit BoM	David R.	0%	12/4/2023
VDR3 Prototype	Re-evaluate Chosen Design	Gather Preliminary Prototype Data	Carson C.	0%	11/25/2023
	Create Final Prototype	Get Prototype Materials	Jacob L.	0%	11/26/2023
		Put together prototype	Roshard J.	0%	11/27/2023
		List Issues with Prototype	Jacob L.	0%	11/28/2023
	Create Document	Save Document Using Naming Convention Section	Katherine L.	0%	11/27/2023
	Content Planning	Create Current State of Selected Design	Carson C.	0%	11/27/2023
		Create Work Forecast Section	Carson C.	0%	11/27/2023
		Create Problem Areas Section	Katherine L.	0%	11/27/2023
		Create Introduction Section	Carson C.	0%	11/27/2023

		Create Conclusion Section	Carson C.	0%	11/27/2023
	Write Document	Add More Sections if Needed	Geraina J.	0%	11/27/2023
		Proofread Document	Roshard J.	0%	12/3/2023
		Edit Back to Front	Roshard J.	0%	12/4/2023
	Complete Assignment	Submit Document	Roshard J.	0%	12/5/2023
Spring Project Plan	Engineering Design Day	Complete VDR4	Geraina J.	0%	12/5/2023
		Complete VDR5	Carson C.	0%	12/5/2023
		Complete VDR6	Roshard J.	0%	12/5/2023
		Collect Feedback from Advisors & TAs	David R.	0%	12/5/2023
		Practice Presentation	Carson C.	0%	12/5/2023
		Improve/Finalize Prototype	Katherine L.	0%	12/5/2023
	Finals	Study for Finals	Geraina J.	0%	12/5/2023
		Attend Finals	Jacob L.	0%	12/5/2023
		Add Finals to Calendar to Schedule Meetings	Katherine L.	0%	12/5/2023
	Graduation	Complete Graduation Checks	Carson C.	0%	12/5/2023
		Take Grad Photos	David R.	0%	12/5/2023
		Order Cap & Gown on Time	Roshard J.	0%	12/5/2023
Poster	Create Poster	Determine Layout & Color(s)	Roshard J.	0%	12/1/2023
		Choose Topics to Include	Carson C.	0%	12/1/2023
		Discuss Organization of Chosen Topics	David R.	0%	12/1/2023
		Pick Relevant & Clear pictures/graphs	Carson C.	0%	12/1/2023
		Define a Range of Acceptable Font Sizes	Carson C.	0%	12/1/2023

	Review Poster	Ensure Content Fits Poster Size	Jacob L.	0%	12/6/2023
		Check Grammar	Jacob L.	0%	12/6/2023
		Check Clarity of Objectives, Goals, & Outcomes	Roshard J.	0%	12/6/2023
		Store Poster in Poster Tube to Prevent Dmg	David R.	0%	12/6/2023
	Complete Poster	Submit Poster for Printing	Geraina J.	0%	12/6/2023
		Delegate Poster Sections to Presenters	Roshard J.	0%	12/8/2023
		Practice Presentation	Roshard J.	0%	12/8/2023

Appendix C: Functional Decomposition

Figure 1 – Functional Hierarchy Chart



Appendix D: Target Catalog

Functions	Target	Metric
Functionless (Weight)	7.5 [Kilograms]	Weight
Functionless (Size)	< 1 [Meter]	Length
	< 1 [Meter]	Width
	< 1 [Meter]	Height
Functionless (Lifespan)	6 [Years]	Time to Operate
Functionless (Traversability)	90 [Degrees]	Maximum Slope of Terrain
Functionless (Haptic Feedback)	Variable [Hertz]	Vibration
Functionless (Audio Feedback)	100 [Decibels]	Sound
Functionless (Duration of Use)	8 [Hours]	Time to Operate
Regulate Temperature	131.8 [Degrees Celsius]	Maintain Constant Temperature
Determines Location	> 90 [%]	Accuracy
Detects Hazards	< 2.1 [PPM per Minute]	Rate of Detection
	30 [%]	Accuracy of Detection
Determine Actuation Level	< 6 [Seconds]	Settling Time
	< 6 [Seconds]	Rise Time

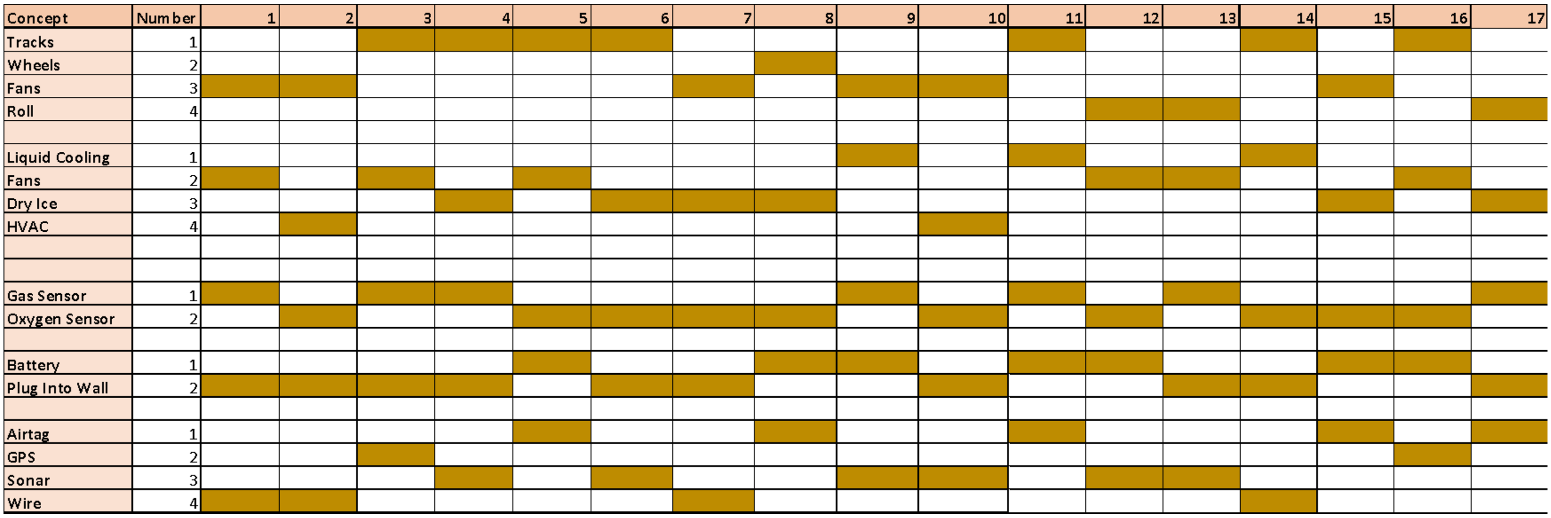
	< 1 [%]	Steady State Error
Accelerate	< 4 [Seconds]	Time Taken to Reach Max Velocity from Zero.
	< 1 [Meter]	Braking Distance
Maneuver Vehicle	0.5 [Meter]	Turn Radius
	< 0 [m/s]	Speed
Induce Friction	> 0.6	Coefficient of Friction
Display Information	>200 – 300 [nits]	Brightness of Display
	Information Appears	Visual
Receive User Input	50 [Milliseconds]	Time Taken to React to Command
Receive Environment Input	< 40 [Milliseconds]	Time Taken to Receive Input
Interpret Data	< 15 [Milliseconds]	Time Taken for Computations
Prepare Data	3 [Seconds]	Time Taken to Compile Data
Transmit Info	< 40 [Milliseconds]	Time Taken to Transmit Data
Store Energy	4800 – 6150 [mAh]	Energy Storage Capacity
Transfer Energy	4.8 – 6.1 [Amps]	Electrical Current
Regulate Energy	11.1 – 19.2 [Volts]	Electric Potential

Appendix E: Concept Generation

Table 1 – Morphological Chart

Function	Solution 1	Solution 2	Solution 3	Solution 4
Store Energy	NiCd Battery	Lithium-Ion Battery	NIMH Battery	
Balance	Gimble-like Suspension	Flexible Body	Rigid Suspension with Springs	
Regulate Temperature	Foam Insulation in Steel Body	Foam Insulation in Wooden Body	No Insulation in Metal Body with an Internal Fan	Liquid Coolant in Metal Body
Determine Location	GPS	Gyrosope & Accelerometer	Distance Traveled From User	
Detects Hazards (Cracks)	Visual Inspection	Ultrasonic Testing	Magnetic Particle Inspection	Sonar
Maneuver Vehicle	Legs	Wheels	Tracks	Wings/Propellers
Induce Friction	Magnets	Sand Paper	Suction Cups	Tape
Detects Hazards (Gas Leaks)	Propane Gas Sensors	Oxygen Level Sensors	Pressure Transducer	
Transmit Information	Bluetooth communication	Radio communication	Cable/Wired communication	Wi-Fi Communication

Table 2 – Resulting Chart from Crap Shoot Method



Concept	Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Tracks	1			■	■	■	■					■			■		■	
Wheels	2								■									
Fans	3	■	■					■		■	■					■		
Roll	4												■	■				■
Liquid Cooling	1									■		■			■			
Fans	2	■		■		■							■	■			■	
Dry Ice	3				■		■	■	■							■		■
HVAC	4		■								■							
Gas Sensor	1	■		■	■					■		■		■				■
Oxygen Sensor	2		■			■	■	■	■		■		■		■	■	■	
Battery	1					■			■	■		■	■			■	■	
Plug Into Wall	2	■	■	■	■		■	■			■			■	■			■
Airtag	1					■			■			■				■		■
GPS	2			■													■	
Sonar	3				■		■			■	■		■	■				
Wire	4	■	■					■							■			

Table 3 – Concept Generation List

Concept Idea	**Concept Description**
Morphological Chart	
1	A robot that stores energy using Lithium-Ion Battery, balance using a Flexible Body, regulate temperature using Liquid Coolant in Metal Body, determine location using GPS, detects cracks using Visual Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Propane Gas Sensors, and transmits information using Bluetooth Communication.
2	A robot that stores energy using Lithium-Ion Battery, balance using a Rigid Suspension with Springs, regulate temperature using No Insulation in Metal Body with an Internal Fan, determine location using Gyroscope & Accelerometer, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Oxygen Level Sensors, and transmits information using Radio Communication.

3	A robot that stores energy using Lithium-Ion Battery, balance using a Flexible Body, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Ultrasonic Testing, maneuvers the vehicle using Wings/Propellers, induces friction between the terrain and the vehicle using Suction Cups, detects gas leaks using Propane Gas Sensors, and transmits information using Cable/Wired Communication.
4	A robot that stores energy using Lithium-Ion Battery, balance using a Flexible Body, regulate temperature using Liquid Coolant in Metal Body, determine location using GPS, detects cracks using Visual Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Oxygen Level Sensors, and transmits information using Bluetooth Communication.
5	A robot that stores energy using Lithium-Ion Battery, balance using a Rigid Suspension with Springs, regulate temperature using No Insulation in Metal Body with an Internal Fan, determine location using Gyroscope & Accelerometer, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Suction Cups, detects gas leaks using Oxygen Level Sensors, and transmits information using Radio Communication.
6	A robot that stores energy using Lithium-Ion Battery, balance using a Flexible Body, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Ultrasonic Testing, maneuvers the vehicle using Wings/Propellers, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Propane Gas Sensors, and transmits information using Cable/Wired Communication.
7	A robot that stores energy using NiCd Battery, balance using a Gimble-like Suspension, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Oxygen Level Sensors, and transmits information using Radio Communication.
8	A robot that stores energy using NiCd Battery, balance using a Rigid Suspension with Springs, regulate temperature using No Insulation in Metal Body with an Internal Fan, determine location using Gyroscope & Accelerometer, detects cracks using Ultrasonic Testing, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Suction Cups, detects gas leaks using Propane Gas Sensors, and transmits information using Bluetooth Communication.

9	A robot that stores energy using NIMH Battery, balance using a Gimble-like Suspension, regulate temperature using Liquid Coolant in Metal Body, determine location using GPS, detects cracks using Visual Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Oxygen Level Sensors, and transmits information using Cable/Wired Communication.
10	A robot that stores energy using NIMH Battery, balance using a Rigid Suspension with Springs, regulate temperature using No Insulation in Metal Body with an Internal Fan, determine location using Gyroscope & Accelerometer, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Propane Gas Sensors, and transmits information using Radio Communication.
11	A robot that stores energy using NIMH Battery, balance using a Gimble-like Suspension, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Ultrasonic Testing, maneuvers the vehicle using Wings/Propellers, induces friction between the terrain and the vehicle using Suction Cups, detects gas leaks using Oxygen Level Sensors, and transmits information using Bluetooth Communication.
12	A robot that stores energy using NiCd Battery, balance using a Flexible Body, regulate temperature using Liquid Coolant in Metal Body, determine location using GPS, detects cracks using Visual Inspection, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Oxygen Level Sensors, and transmits information using Radio Communication.
13	A robot that stores energy using NiCd Battery, balance using a Rigid Suspension with Springs, regulate temperature using No Insulation in Metal Body with an Internal Fan, determine location using Gyroscope & Accelerometer, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Suction Cups, detects gas leaks using Propane Gas Sensors, and transmits information using Bluetooth Communication.
14	A robot that stores energy using NIMH Battery, balance using a Gimble-like Suspension, regulate temperature using Liquid Coolant in Metal Body, determine location using GPS, detects cracks using Visual Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Oxygen Level Sensors, and transmits information using Cable/Wired Communication.

15	A robot that stores energy using NIMH Battery, balance using a Rigid Suspension with Springs, regulate temperature using No Insulation in Metal Body with an Internal Fan, determine location using Gyroscope & Accelerometer, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Propane Gas Sensors, and transmits information using Radio Communication.
16	A robot that stores energy using NIMH Battery, balance using a Gimble-like Suspension, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Ultrasonic Testing, maneuvers the vehicle using Wings/Propellers, induces friction between the terrain and the vehicle using Suction Cups, detects gas leaks using Oxygen Level Sensors, and transmits information using Bluetooth Communication.
17	A robot that stores energy using Lithium-Ion Battery, balance using a Gimble-like Suspension, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Propane Gas Sensors, and transmits information using Radio Communication.
18	A robot that stores energy using NiCd Battery, balance using a Rigid Suspension with Springs, regulate temperature using No Insulation in Metal Body with an Internal Fan, determine location using Gyroscope & Accelerometer, detects cracks using Ultrasonic Testing, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Oxygen Level Sensors, and transmits information using Cable/Wired Communication.
19	A robot that stores energy using NIMH Battery, balance using a Rigid Suspension with Springs, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Visual Inspection, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Propane Gas Sensors, and transmits information using Bluetooth Communication.
20	A robot that stores energy using NiCd Battery, balance using a Gimble-like Suspension, regulate temperature using No Insulation in Metal Body with an Internal Fan, determine location using Gyroscope & Accelerometer, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Suction Cups, detects gas leaks using Oxygen Level Sensors, and transmits information using Radio Communication.

21	A robot that stores energy using NIMH Battery, balance using a Flexible Body, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Wings/Propellers, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Propane Gas Sensors, and transmits information using Cable/Wired Communication.
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24	A robot that stores energy using NIMH Battery, balance using a Rigid Suspension with Springs, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Propane Gas Sensors, and transmits information using Cable/Wired Communication.
25	A robot that stores energy using NiCd Battery, balance using a Gimble-like Suspension, regulate temperature using Liquid Coolant in Metal Body, determine location using Gyroscope & Accelerometer, detects cracks using Ultrasonic Testing, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Oxygen Level Sensors, and transmits information using Bluetooth Communication.
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27	A robot that stores energy using NIMH Battery, balance using a Gimble-like Suspension, regulate temperature using Foam Insulation in Steel Body, determine location using GPS, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Oxygen Level Sensors, and transmits information using Bluetooth Communication.
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37	A robot that stores energy using NiCd Battery, balance using a Rigid Suspension with Springs, regulates temperature using Liquid Coolant in Metal Body, determines location using Gyroscope & Accelerometer, detects cracks using Ultrasonic Testing, maneuvers the vehicle using Tracks, induces friction between the terrain and the vehicle using Magnets, detects gas leaks using Propane Gas Sensors, transmits information using Cable/Wired Communication.
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39	A robot that stores energy using NIMH Battery, balance using a Gimble-like Suspension, regulates temperature using Foam Insulation in Steel Body, determines location using GPS, detects cracks using Magnetic Particle Inspection, maneuvers the vehicle using Wheels, induces friction between the terrain and the vehicle using Sand Paper, detects gas leaks using Oxygen Level Sensors, transmits information using Bluetooth Communication.
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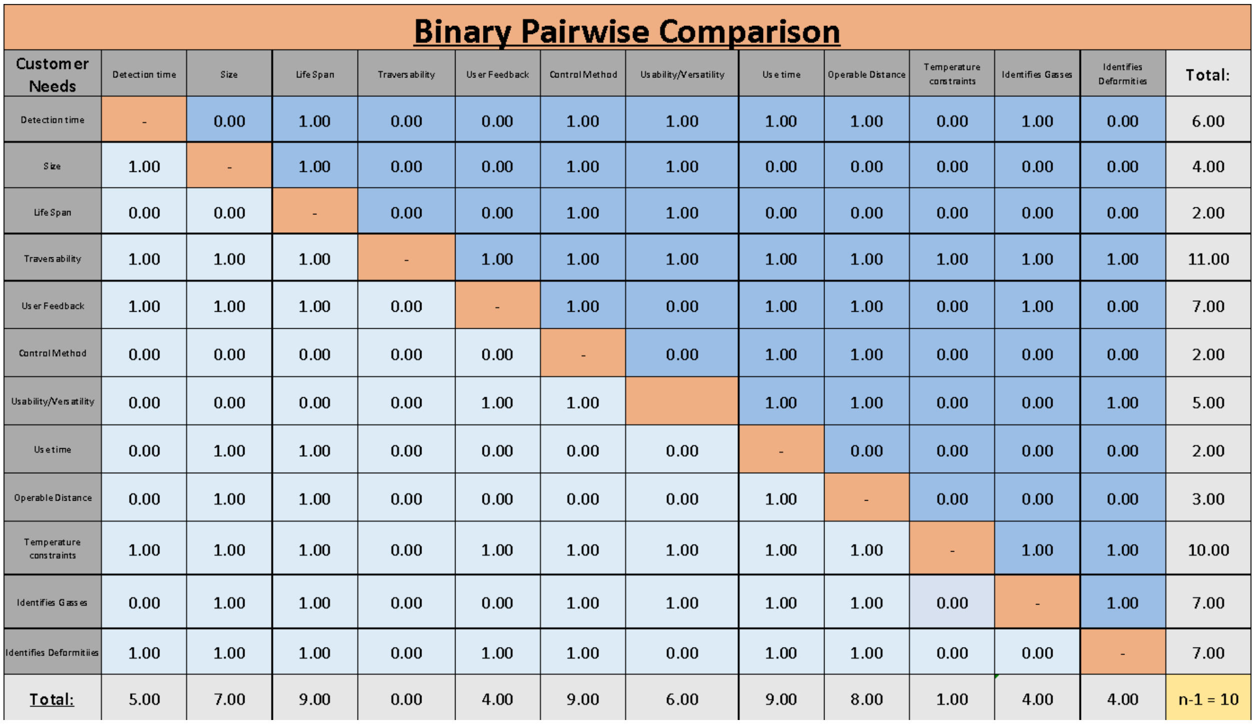
SCAMPER	
41	Drone fans on RC car
42	Helicopter fans on RC car
43	RC Tank with 2 magnetic tracks
44	RC Tank with 2 semi-magnetic tracks
45	RC Tank with 2 electromagnetic tracks
46	Drone with a circular bumper that has wheels to allow drone to fit perfectly in pipe
47	transforming wheels to catch on surfaces
48	RC Tank with 4 semi-magnetic tracks
49	RC Tank with 4 electromagnetic tracks
50	RC with 6 magnetic wheels in L formation
51	RC with 6 electromagnetic wheels in L formation
52	RC segway configuration with magnetic wheels
53	RC segway configuration with electromagnetic wheels
54	Heat shielded RC car with a vertical arm normal to the wheel path. The tires would use sandpaper to generate friction. When the vehicle enters a pipe, the top arm will extend out to the diameter of the pipe and will use the force generated by the arm to create friction for all sets of tires allowing the RC car to drive vertically.
55	A drone with an attached set of wheels on an outside ring that has an adjustable diameter. The drone can be flown in the pipe or can extend the wheels to the diameter of the pipe and uses the normal lift of the drone to drive within the pipe.

56	An RC with arms that can change angle and length via motors, on the end of the arms are tires and motors that spin to maneuver vehicle. Can use left backwards right forwards to change direction instead of using steering
57	Heat shielded RC car with a vertical arm normal to the wheel path. The vehcle would uses tracks made from sandpaper belts to generate friction. When the vehicle enters a pipe, the top arm will extend out to the diameter of the pipe and will use the force generated by the arm to create friction for all sets of tires allowing the RC car to drive vertically.
58	An RC car that can launch a magnet to tether to walls and spools the wire to move kind of like spiderman
59	An RC with arms that can change angle and length via springs, on the end of the arms are tires and motors that spin to maneuver vehicle. Can use left backwards right forwards to change direction instead of using steering
60	Use an R2D2 toy or Wall-E toy to traverse uneven terrain. To detect hazards, a GoPro and several sensors can be used to provide live feedback to the user.
Biomimicry	
61	6 insect-like legs on the robot that allows it to manuever.
62	A snake-like vehicle that uses magnets that rotate around the snake chassis to induce friction. The pros of this are that its innovative, if the vehicle is relatively light it keeps the center of gravity closer to the edge of the pipe for moving vertically. Cons are its probably pretty hard to make and magnets are tricky, our chassis probably cannot be metal which raises concern for heat conduction
63	Create a spider-like robot with 8 limbs. 6 limbs would be used for horizontal movement, and 2 would be used for vertical transitions.
64	Create a small robot that moves and is shaped like an inch worm.
65	A quadraped with full rotary front arms that resembles a monkey.
66	A robot with transparent insect wings for movement.
67	Use bacteria on outside to protect from heat like a pompeii worm.
68	A 4-legged spider with legs on 4 corners rather than around the body for easier, balanced movement.
69	A snake-like vehicle that uses magnets that rotate around the snake chassis to induce friction with a heat resistant body
70	A robot with a "vein like" water cooling system
71	A robot with a tail to help keep balance

72	A caterpillar-like robot that sticks and unsticks itself to move forward with a bunch of sensors around it.
73	Use a "nervous system"-like configuration of sensors on a robot body to detect deformation
74	Create a robot that is shaped like a hamster ball to move around the floor.
75	Add suction cups on end of legs to climb walls like lizard
76	Add frog-like legs to make it jump.
77	Produce a robot that crawls like a baby along the ground that can climb pipe walls.
78	Create legs similar to dog legs to traverse uneven terrain.
79	Use something similar to large owl-like eyes for camera to help see in low light.
80	Evaporating water from robot similar to sweating to help reduce overheating
Crap Shoot	
81	Articulated pipe crawler resistant to high temperature fluids. Equipped with basic camera to get visual information pipe and basic environment sensors. Needs to be paired with remote controller. Each wheel set is on an axle.
82	RC pipe crawler resistant to high temperature fluids. Equipped with basic camera to get visual information pipe and basic environment sensors. Needs to be paired with remote controller. Front wheel set is on an axle and the back wheel set are each individually driven by motors. Controlled by remote control system designed by team.
83	Pipe inspection camera module resistant to high temperature fluids. This module will be equipped with environment sensors easily installable onto an RC car. Needs to be paired with remote controller to control camera pitch and yaw.
84	A vehicle that expands to the shape of the pipe and moves forward by rolling. Conforms to the internal diameter of the pipe. Has a forward facing camera and a tether.
85	A submarine vehicle that swims through the molten plastic or fluid. Has a forward facing camera that pans and tilts.
86	A measuring apparatus that sits at the start of the pipe and sends in vibrations/waves. Apparatus reads integrity of the pipe based on the recieved signals.
87	A flow bob that records and scans the interior of the pipe while floating inside the fluid.
88	An autonomous fish robot that swims upstream of the pipe that records the information.

89	A pipe crawler robot that maintains internal temperature by having a heat external surface that bleeds out into environment. Uses a forward facing camera, battery power, and a bluetooth signal.
90	A tank vehicle that has liquid cooling to prevent overheating and is equipped with a gas sensor and an airtag to know location
91	A wheeled vehicle that uses fans to keep it cool and is equipped with an oxygen sensor and uses sonar
92	A wheeled vehicle that uses fans to keep it cool and is equipped with an gas sensor, uses sonar and is plugged into the wall with a long extension cord for power
93	Uses fan propulsion to move around while being plugged into the wall and uses dry ice to cool down
94	A tank vehicle that uses fans for cooling, and GPS to know precise location
95	A wheeled robot that uses dry ice to cool, is equipped with a gas senor, plugs into the wall, and has an airtag attached to know the location
96	Tank vehicle that is kept cool with liquid cooling, has an oxygen sensor and a spooled up wire that unravels as the robot moves farther away to know the location
Fantasy/Wishful Thinking	
97	It would be nice if our robot could shoot a grappling hook and swing
98	It would be nice if the pipe crawler from the FAU can be adapted and improved for this project.
99	It would be nice if the Stormer Pipe Crawler can be adapted and improved for this project.
100	It would be nice if a human-like robot existed to crawl into pipes.

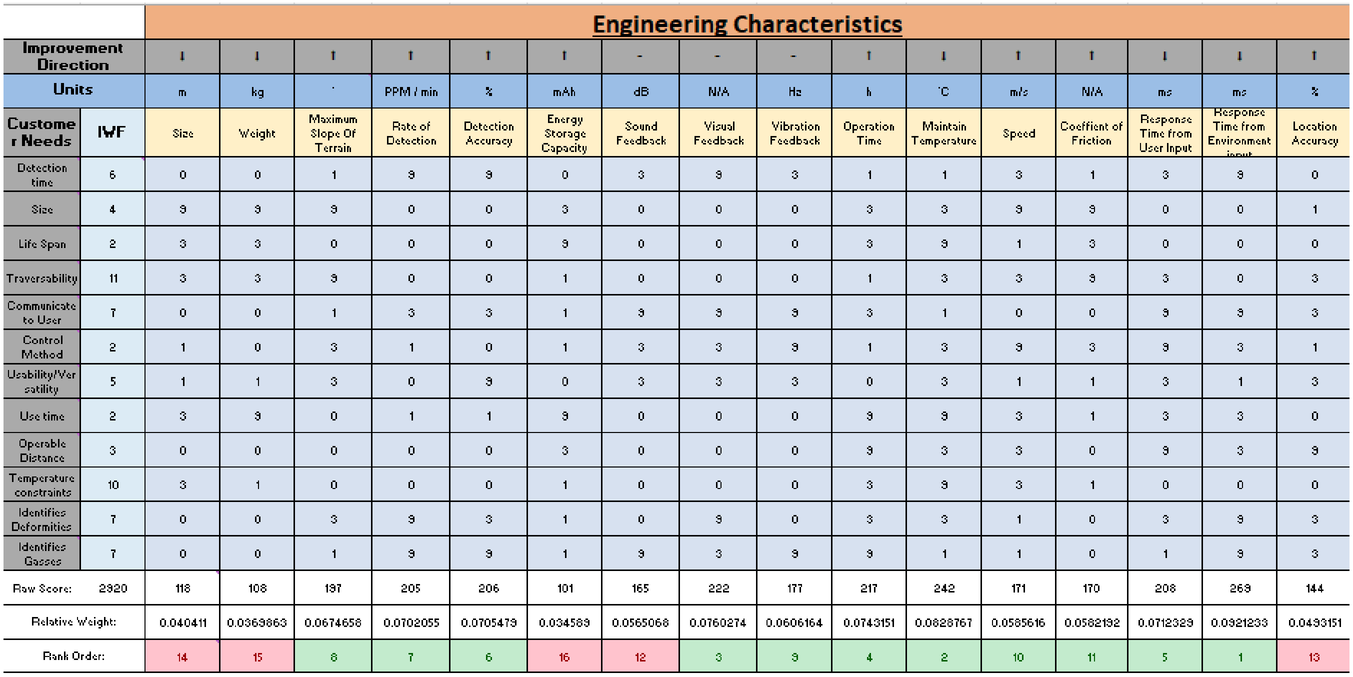
Appendix [F]: Concept Selection



Binary Pairwise Comparison

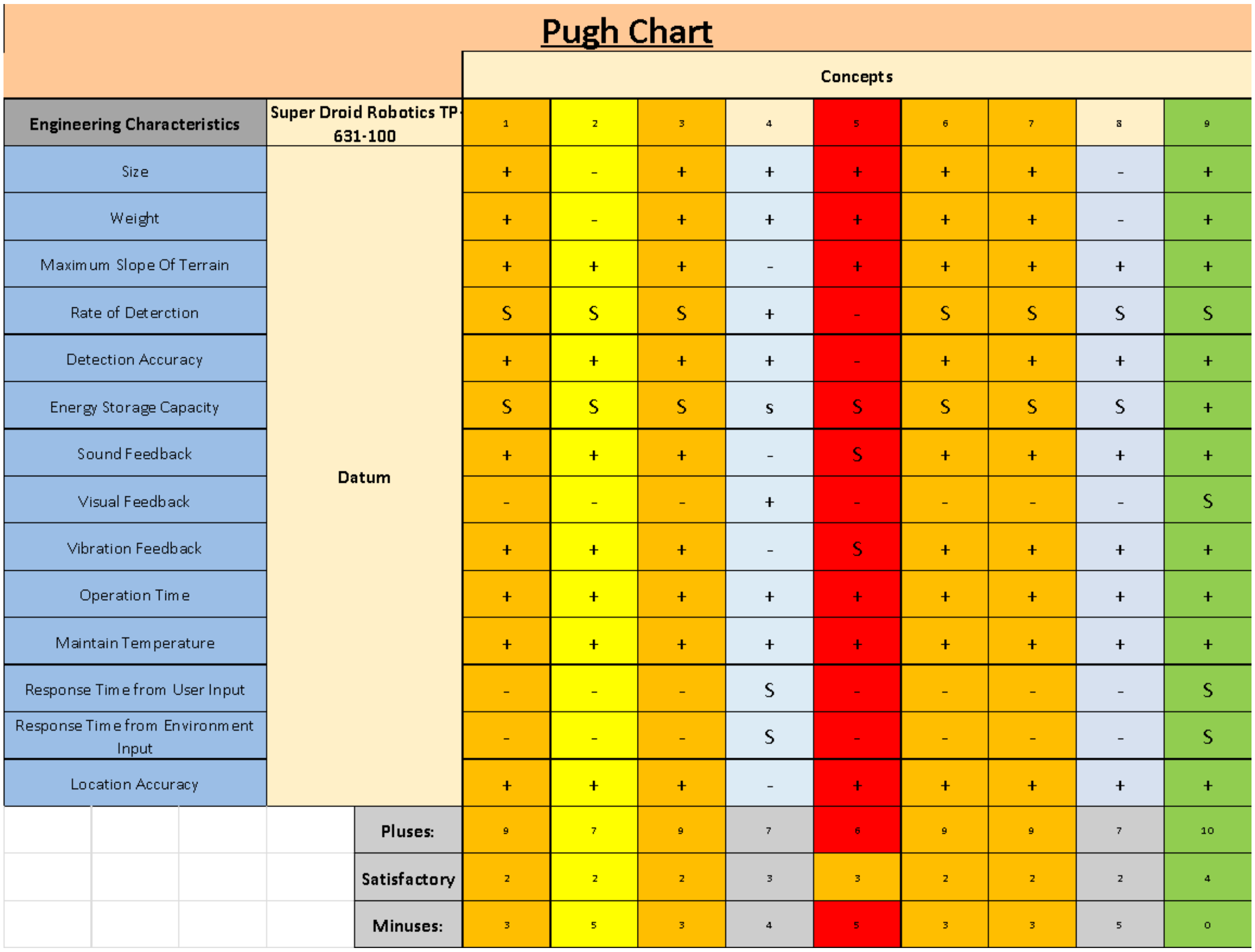
Customer Needs	Detection time	Size	Life Span	Traversability	User Feedback	Control Method	Usability/Versatility	Use time	Operable Distance	Temperature constraints	Identifies Gasses	Identifies Deformities	Total:
Detection time	-	0.00	1.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00	1.00	0.00	6.00
Size	1.00	-	1.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	4.00
Life Span	0.00	0.00	-	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	2.00
Traversability	1.00	1.00	1.00	-	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	11.00
User Feedback	1.00	1.00	1.00	0.00	-	1.00	0.00	1.00	1.00	0.00	1.00	0.00	7.00
Control Method	0.00	0.00	0.00	0.00	0.00	-	0.00	1.00	1.00	0.00	0.00	0.00	2.00
Usability/Versatility	0.00	0.00	0.00	0.00	1.00	1.00		1.00	1.00	0.00	0.00	1.00	5.00
Use time	0.00	1.00	1.00	0.00	0.00	0.00	0.00	-	0.00	0.00	0.00	0.00	2.00
Operable Distance	0.00	1.00	1.00	0.00	0.00	0.00	0.00	1.00	-	0.00	0.00	0.00	3.00
Temperature constraints	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	-	1.00	1.00	10.00
Identifies Gasses	0.00	1.00	1.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00	-	1.00	7.00
Identifies Deformitiies	1.00	1.00	1.00	0.00	1.00	1.00	0.00	1.00	1.00	0.00	0.00	-	7.00
Total:	5.00	7.00	9.00	0.00	4.00	9.00	6.00	9.00	8.00	1.00	4.00	4.00	n-1 = 10

Figure 1: Binary Pairwise Comparison



		Engineering Characteristics															
Improvement Direction		↓	↓	↑	↑	↑	↑	-	-	-	↑	↓	↑	↑	↓	↓	↑
Units		m	kg	°	PPM / min	%	mAh	dB	N/A	Hz	h	°C	m/s	N/A	ms	ms	%
Customer Needs	IWF	Size	Weight	Maximum Slope Of Terrain	Rate of Detection	Detection Accuracy	Energy Storage Capacity	Sound Feedback	Visual Feedback	Vibration Feedback	Operation Time	Maintain Temperature	Speed	Coeffient of Friction	Response Time from User Input	Response Time from Environment input	Location Accuracy
Detection time	6	0	0	1	9	9	0	3	9	3	1	1	3	1	3	9	0
Size	4	9	9	9	0	0	3	0	0	0	3	3	9	9	0	0	1
Life Span	2	3	3	0	0	0	9	0	0	0	3	9	1	3	0	0	0
Traversability	11	3	3	9	0	0	1	0	0	0	1	3	3	9	3	0	3
Communicate to User	7	0	0	1	3	3	1	9	9	9	3	1	0	0	9	9	3
Control Method	2	1	0	3	1	0	1	3	3	9	1	3	9	3	9	3	1
Usability/Versatility	5	1	1	3	0	9	0	3	3	3	0	3	1	1	3	1	3
Use time	2	3	9	0	1	1	9	0	0	0	9	9	3	1	3	3	0
Operable Distance	3	0	0	0	0	0	3	0	0	0	9	3	3	0	9	3	9
Temperature constraints	10	3	1	0	0	0	1	0	0	0	3	9	3	1	0	0	0
Identifies Deformities	7	0	0	3	9	3	1	0	9	0	3	3	1	0	3	9	3
Identifies Gasses	7	0	0	1	9	9	1	9	3	9	9	1	1	0	1	9	3
Raw Score:	2920	118	108	197	205	206	101	165	222	177	217	242	171	170	208	269	144
Relative Weight:		0.040411	0.0369863	0.0674658	0.0702055	0.0705479	0.034589	0.0565068	0.0760274	0.0606164	0.0743151	0.0828767	0.0585616	0.0582192	0.0712329	0.0921233	0.0493151
Rank Order:		14	15	8	7	6	16	12	3	9	4	2	10	11	5	1	13

Figure 2: House of Quality



Pugh Chart

		Concepts								
Engineering Characteristics	**Super Droid Robotics TP-631-100**	1	2	3	4	5	6	7	8	9
Size	**Datum**	+	-	+	+	+	+	+	-	+
Weight		+	-	+	+	+	+	+	-	+
Maximum Slope Of Terrain		+	+	+	-	+	+	+	+	+
Rate of Deterction		S	S	S	+	-	S	S	S	S
Detection Accuracy		+	+	+	+	-	+	+	+	+
Energy Storage Capacity		S	S	S	s	S	S	S	S	+
Sound Feedback		+	+	+	-	S	+	+	+	+
Visual Feedback		-	-	-	+	-	-	-	-	S
Vibration Feedback		+	+	+	-	S	+	+	+	+
Operation Time		+	+	+	+	+	+	+	+	+
Maintain Temperature		+	+	+	+	+	+	+	+	+
Response Time from User Input		-	-	-	S	-	-	-	-	S
Response Time from Environment Input		-	-	-	S	-	-	-	-	S
Location Accuracy		+	+	+	-	+	+	+	+	+
	Pluses:	9	7	9	7	6	9	9	7	10
	Satisfactory	2	2	2	3	3	2	2	2	4
	Minuses:	3	5	3	4	5	3	3	5	0

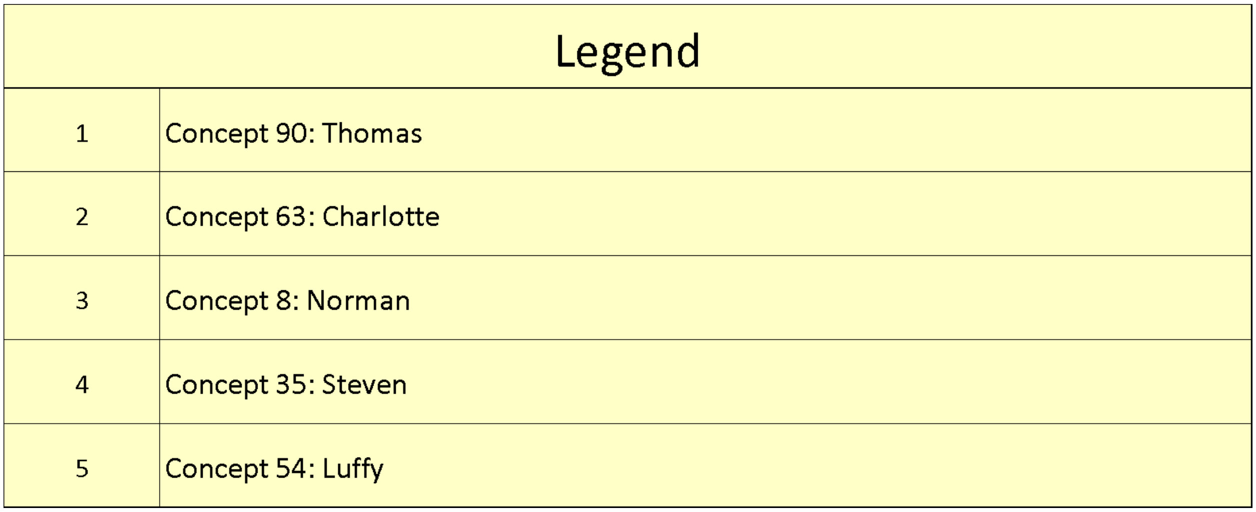
Figure 3: First Iteration of Pugh Chart

Legend	
1	Concept 90: Thomas
2	Concept 56: Inspector Gadget
3	Concept 63: Charlotte
4	Concept 83: PIC-Man
5	Concept 89: Charlie & Frank
6	Concept 8: Norman
7	Concept 35: Steven
8	Concept 64: Shelby
9	Concept 54: Luffy

Figure 4: Legend for First Pugh Chart

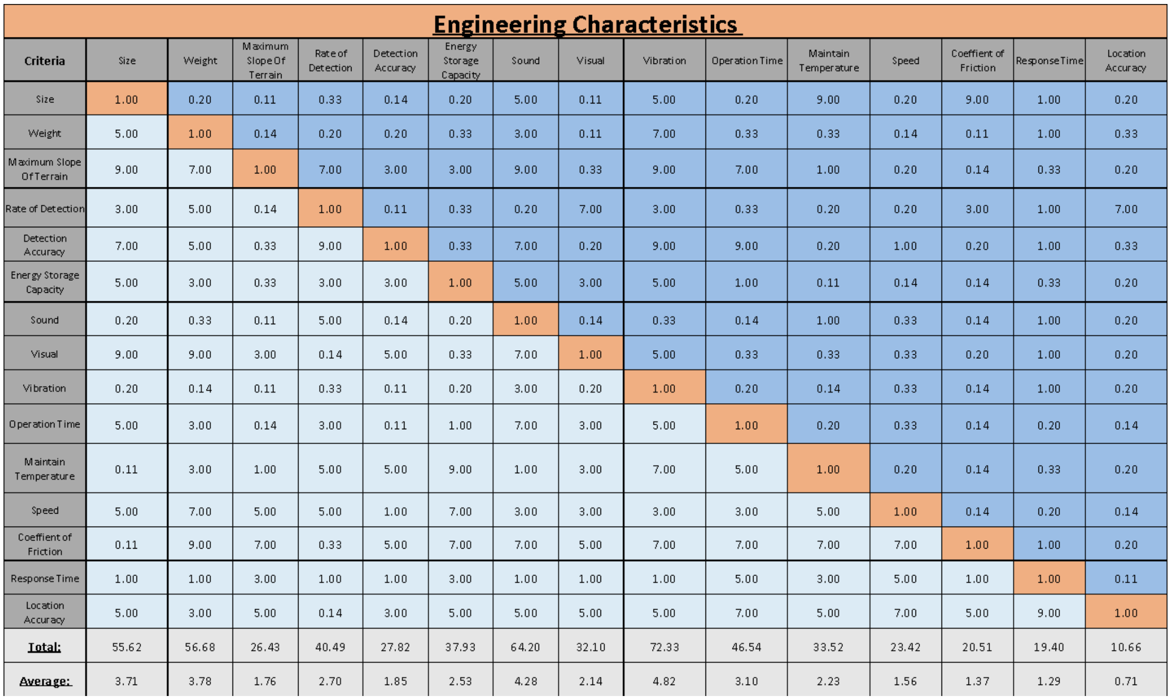
Pugh Chart						
		Concepts				
Engineering Characteristics	**Concept 54: Inspector Gadget**	1	2	3	4	5
Size	**Datum**	+	+	-	S	-
Weight		+	+	-	S	-
Maximum Slope Of Terrain		S	S	S	S	S
Rate of Deterction		S	S	S	S	S
Detection Accuracy		S	S	+	S	S
Energy Storage Capacity		S	-	S	S	+
Sound		S	S	S	S	S
Visual		S	S	S	S	S
Vibration		S	S	S	S	S
Operation Time		S	S	S	S	S
Maintain Temperature		-	+	-	-	S
Response Time from User Input		S	S	S	-	+
Response Time from Environment Input		S	S	S	S	S
Location Accuracy		S	S	S	+	+
	Pluses:	2	3	1	1	3
	Satisfactory	11	10	10	10	9
	Minuses:	1	1	3	2	2

Figure 5: Second Iteration of Pugh Chart



Legend	
1	Concept 90: Thomas
2	Concept 63: Charlotte
3	Concept 8: Norman
4	Concept 35: Steven
5	Concept 54: Luffy

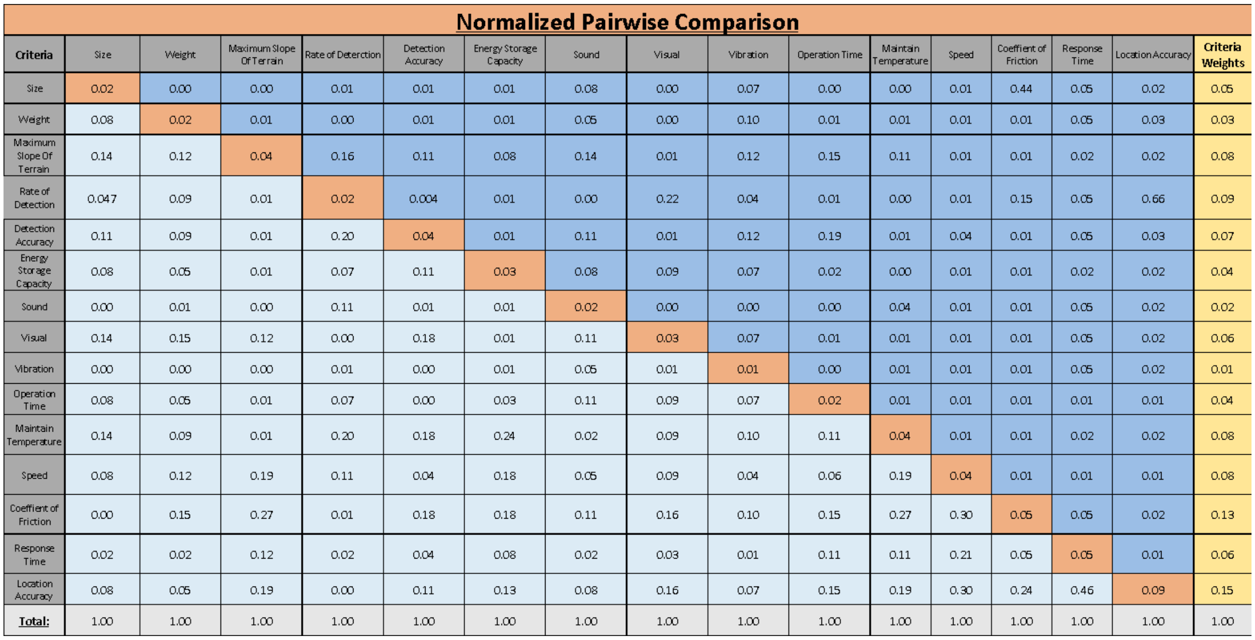
Figure 6: Legend for Second Pugh Chart



Engineering Characteristics

Criteria	Size	Weight	Maximum Slope Of Terrain	Rate of Detection	Detection Accuracy	Energy Storage Capacity	Sound	Visual	Vibration	Operation Time	Maintain Temperature	Speed	Coeffient of Friction	Response Time	Location Accuracy
Size	1.00	0.20	0.11	0.33	0.14	0.20	5.00	0.11	5.00	0.20	9.00	0.20	9.00	1.00	0.20
Weight	5.00	1.00	0.14	0.20	0.20	0.33	3.00	0.11	7.00	0.33	0.33	0.14	0.11	1.00	0.33
Maximum Slope Of Terrain	9.00	7.00	1.00	7.00	3.00	3.00	9.00	0.33	9.00	7.00	1.00	0.20	0.14	0.33	0.20
Rate of Detection	3.00	5.00	0.14	1.00	0.11	0.33	0.20	7.00	3.00	0.33	0.20	0.20	3.00	1.00	7.00
Detection Accuracy	7.00	5.00	0.33	9.00	1.00	0.33	7.00	0.20	9.00	9.00	0.20	1.00	0.20	1.00	0.33
Energy Storage Capacity	5.00	3.00	0.33	3.00	3.00	1.00	5.00	3.00	5.00	1.00	0.11	0.14	0.14	0.33	0.20
Sound	0.20	0.33	0.11	5.00	0.14	0.20	1.00	0.14	0.33	0.14	1.00	0.33	0.14	1.00	0.20
Visual	9.00	9.00	3.00	0.14	5.00	0.33	7.00	1.00	5.00	0.33	0.33	0.33	0.20	1.00	0.20
Vibration	0.20	0.14	0.11	0.33	0.11	0.20	3.00	0.20	1.00	0.20	0.14	0.33	0.14	1.00	0.20
Operation Time	5.00	3.00	0.14	3.00	0.11	1.00	7.00	3.00	5.00	1.00	0.20	0.33	0.14	0.20	0.14
Maintain Temperature	0.11	3.00	1.00	5.00	5.00	9.00	1.00	3.00	7.00	5.00	1.00	0.20	0.14	0.33	0.20
Speed	5.00	7.00	5.00	5.00	1.00	7.00	3.00	3.00	3.00	3.00	5.00	1.00	0.14	0.20	0.14
Coeffient of Friction	0.11	9.00	7.00	0.33	5.00	7.00	7.00	5.00	7.00	7.00	7.00	7.00	1.00	1.00	0.20
Response Time	1.00	1.00	3.00	1.00	1.00	3.00	1.00	1.00	1.00	5.00	3.00	5.00	1.00	1.00	0.11
Location Accuracy	5.00	3.00	5.00	0.14	3.00	5.00	5.00	5.00	5.00	7.00	5.00	7.00	5.00	9.00	1.00
Total:	55.62	56.68	26.43	40.49	27.82	37.93	64.20	32.10	72.33	46.54	33.52	23.42	20.51	19.40	10.66
Average:	3.71	3.78	1.76	2.70	1.85	2.53	4.28	2.14	4.82	3.10	2.23	1.56	1.37	1.29	0.71

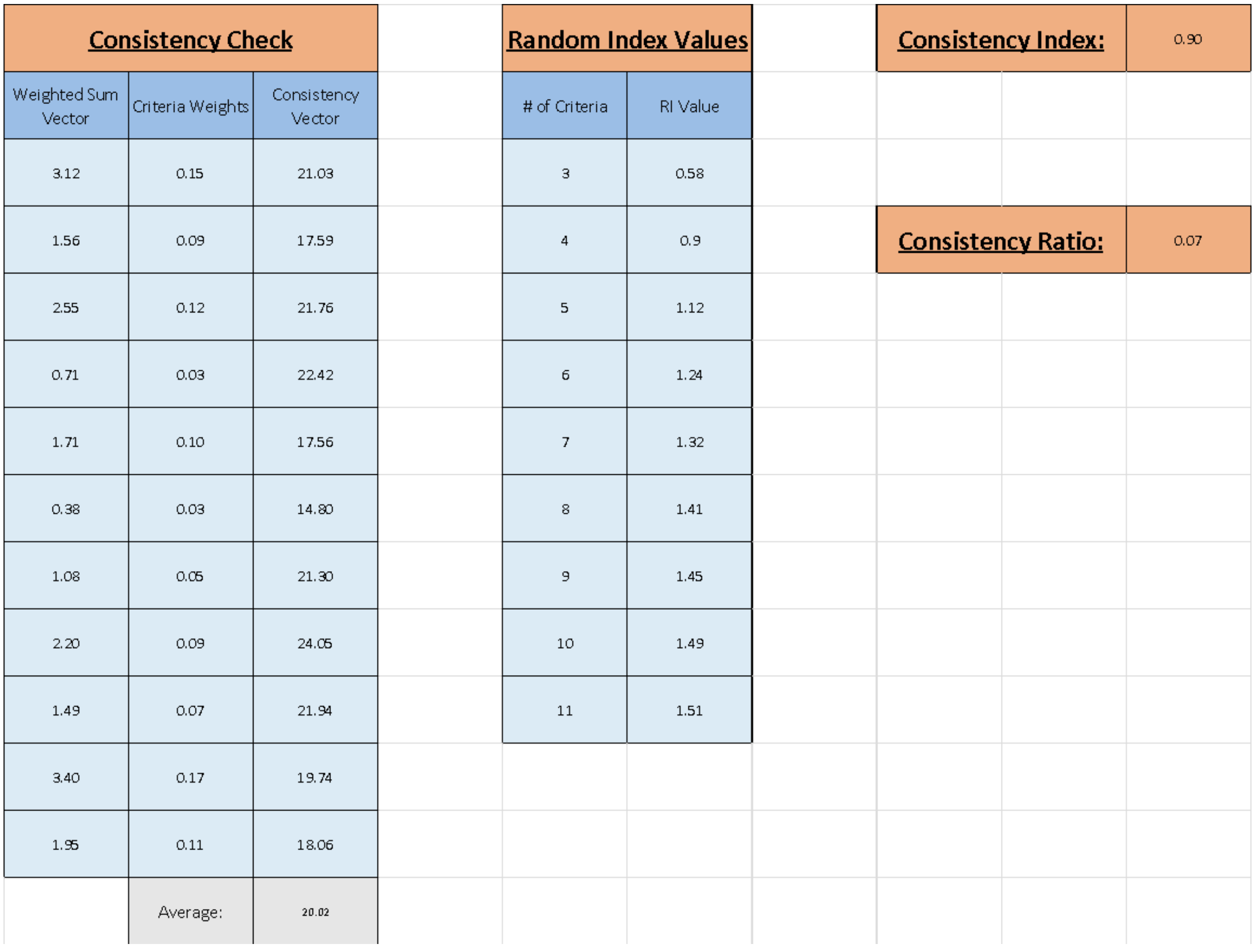
Figure 7: Second Pairwise Comparison



Normalized Pairwise Comparison

Criteria	Size	Weight	Maximum Slope Of Terrain	Rate of Deterction	Detection Accuracy	Energy Storage Capacity	Sound	Visual	Vibration	Operation Time	Maintain Temperature	Speed	Coeffient of Friction	Response Time	Location Accuracy	Criteria Weights
Size	0.02	0.00	0.00	0.01	0.01	0.01	0.08	0.00	0.07	0.00	0.00	0.01	0.44	0.05	0.02	0.05
Weight	0.08	0.02	0.01	0.00	0.01	0.01	0.05	0.00	0.10	0.01	0.01	0.01	0.01	0.05	0.03	0.03
Maximum Slope Of Terrain	0.14	0.12	0.04	0.16	0.11	0.08	0.14	0.01	0.12	0.15	0.11	0.01	0.01	0.02	0.02	0.08
Rate of Detection	0.047	0.09	0.01	0.02	0.004	0.01	0.00	0.22	0.04	0.01	0.00	0.01	0.15	0.05	0.66	0.09
Detection Accuracy	0.11	0.09	0.01	0.20	0.04	0.01	0.11	0.01	0.12	0.19	0.01	0.04	0.01	0.05	0.03	0.07
Energy Storage Capacity	0.08	0.05	0.01	0.07	0.11	0.03	0.08	0.09	0.07	0.02	0.00	0.01	0.01	0.02	0.02	0.04
Sound	0.00	0.01	0.00	0.11	0.01	0.01	0.02	0.00	0.00	0.00	0.04	0.01	0.01	0.05	0.02	0.02
Visual	0.14	0.15	0.12	0.00	0.18	0.01	0.11	0.03	0.07	0.01	0.01	0.01	0.01	0.05	0.02	0.06
Vibration	0.00	0.00	0.00	0.01	0.00	0.01	0.05	0.01	0.01	0.00	0.01	0.01	0.01	0.05	0.02	0.01
Operation Time	0.08	0.05	0.01	0.07	0.00	0.03	0.11	0.09	0.07	0.02	0.01	0.01	0.01	0.01	0.01	0.04
Maintain Temperature	0.14	0.09	0.01	0.20	0.18	0.24	0.02	0.09	0.10	0.11	0.04	0.01	0.01	0.02	0.02	0.08
Speed	0.08	0.12	0.19	0.11	0.04	0.18	0.05	0.09	0.04	0.06	0.19	0.04	0.01	0.01	0.01	0.08
Coeffient of Friction	0.00	0.15	0.27	0.01	0.18	0.18	0.11	0.16	0.10	0.15	0.27	0.30	0.05	0.05	0.02	0.13
Response Time	0.02	0.02	0.12	0.02	0.04	0.08	0.02	0.03	0.01	0.11	0.11	0.21	0.05	0.05	0.01	0.06
Location Accuracy	0.08	0.05	0.19	0.00	0.11	0.13	0.08	0.16	0.07	0.15	0.19	0.30	0.24	0.46	0.09	0.15
Total:	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Figure 8: Normalized Pairwise Comparison



Consistency Check		
Weighted Sum Vector	Criteria Weights	Consistency Vector
3.12	0.15	21.03
1.56	0.09	17.59
2.55	0.12	21.76
0.71	0.03	22.42
1.71	0.10	17.56
0.38	0.03	14.80
1.08	0.05	21.30
2.20	0.09	24.05
1.49	0.07	21.94
3.40	0.17	19.74
1.95	0.11	18.06
	Average:	20.02

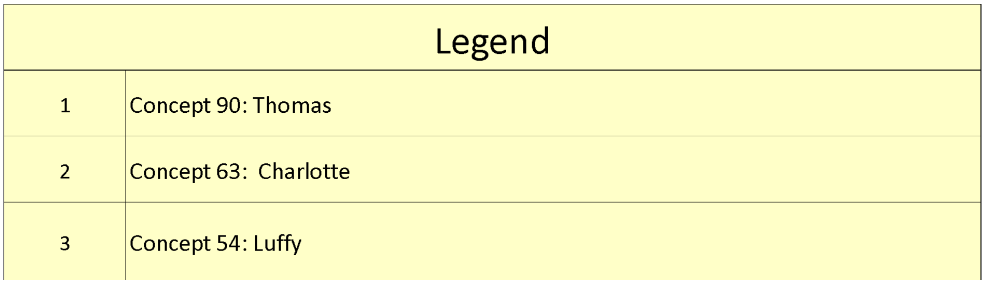
Random Index Values	
# of Criteria	RI Value
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51

Consistency Index:	0.90
Consistency Ratio:	0.07

Figure 9: Consistency Check

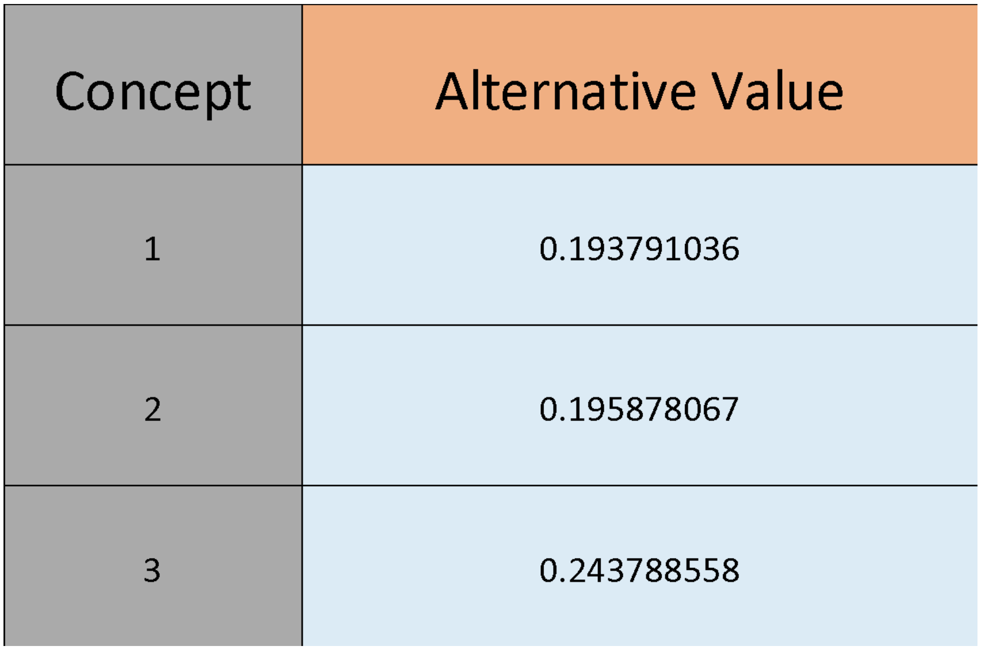
Selection Criteria	Concept 1	Concept 2	Concept 3
Maintain Temperature	0.09	0.53	0.43
Visual	0.14	0.29	0.60
Maxiumum Slope of Terrain	0.70	0.12	0.20
Rate of Detection	0.14	0.29	0.60
Detection Accuracy	0.14	0.29	0.60
Operation Time	0.14	0.29	0.60
Vibration	0.14	0.29	0.60
Speed	0.32	0.63	0.05
Response Time to User Input	0.32	0.63	0.05
Coefficient of Friction	0.32	0.63	0.05
Response Time from Environment Input	0.53	0.09	0.43

Figure 10: Final Rating Matrix



Legend	
1	Concept 90: Thomas
2	Concept 63: Charlotte
3	Concept 54: Luffy

Figure 11: Legend for Final Rating Matrix



Concept	Alternative Value
1	0.193791036
2	0.195878067
3	0.243788558

Figure 12: Alternative Value

Appendix [Z]: APA Headings (delete)

Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading

Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading

Heading 3 is indented, boldface lowercase paragraph heading ending with a period.

Heading 4 is indented, boldface, italicized, lowercase paragraph heading ending with a period.

Heading 5 is indented, italicized, lowercase paragraph heading ending with a period.

See publication manual of the American Psychological Association page 62

Appendix B Figures and Tables (delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 1 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.

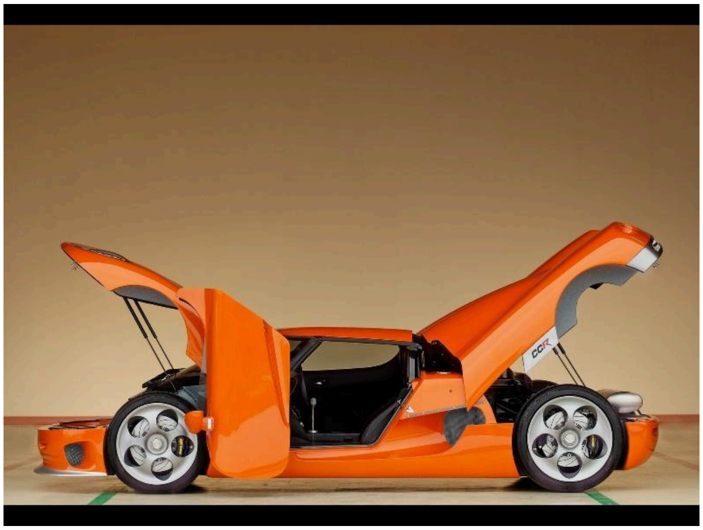


Figure 13. Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table 2

The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase

Level of heading	Format
1	**Centered, Boldface, Uppercase and Lowercase Heading**
2	**Flush Left, Boldface, Uppercase and Lowercase**
3	***Indented, boldface lowercase paragraph heading ending with a period***
4	***Indented, boldface, italicized, lowercase paragraph heading ending with a period.***
5	*Indented, italicized, lowercase paragraph heading ending with a period.*

References

There are no sources in the current document.