ENGG1000

Engineering Design and Innovation

2019 – Trimester 1

Project DELTA

Design Proposal for Team 15

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Asim, Rabie-Bin	z5265125	z5265125@student.unsw.edu.au
Colley, Thomas	z5257583	z5257583@student.unsw.edu.au
Cullen Feng, Maximilian	z5255095	z5255095@student.unsw.edu.au
Davie, Jacquelyn	z5258097	z5258097@student.unsw.edu.au
Matkowski, Andre	z5206752	z5206752@student.unsw.edu.au
Weekes, Madison	z5207741	z5207741@student.unsw.edu.au

Executive Summary

This proposal outlines the intended designs and procedures involved in the construction of a prototype DELTA vehicle for NASA. The vehicle must be unmanned, grounded, and capable of delivering a maximum number of spherical containers, represented by metal ball-bearings for the scale of this prototype. The prototype serves to demonstrate how a scaled version could operate in a hazardous Martian environment. It must therefore perform against a test track, within which are several environments to be overcome. Key features of this DELTA prototype are the use of four-wheel drive propagation, utilising a hook-zipline apparatus to descend vertical drops, pyramidal storage modules to carry payload, and the use of an Arduino board as a Bluetooth-ready microcontroller. Limitations are also specified in the form of vehicle dimensions, vehicle mass, budget, battery voltage, time to complete a given track, and engine/motor type. Additionally, required resources – chassis material, electrical components – are addressed. This document also includes the explored processes involved in each typical design phase, including problem formulation, concept generation, design evaluation, refining, and testing. The current design is expected to perform well against the testing apparatus as it has been refined to be more lightweight, electronically simpler, and easier to control remotely. This document also includes the explored processes involved in each typical design phase, including problem formulation, concept generation, design evaluation, refining, and testing. Furthermore, the proposal includes a high-level plan for future tasks in the form of a Gantt Chart. (Davis, n.d.)

Contents

Introduction

This project aims to fulfil the criteria set by NASA and expand upon the objective to create a full-functioning, well-rounded vehicle; aptly designed to accomplish the main objective of transporting payloads in a hazardous Martian environment. A prototype is to be created in a bid for the NASA contract, in regulation with certain specifications. The team's formulated problem statement (formulation meeting minutes in appendix) aims to summate the what the project is, who it is for, and why it is required:

"NASA has asked for the production of a prototype of an unmanned grounded DELTA vehicle capable of delivering a maximum load of spherical containers securely across hazardous terrain. This includes inclines, rough terrain and vertical drops, all under time, budget and spatial constraints."

Requisite knowledge is an important part in the design process, as it is important to compare what is already known to what needs to be explored. Thus, a section has been provided explaining the team's current knowledge in greater detail. The background of the DELTA project demonstrates dependence on the engineering design process (EDP), which consists of several linear phases. This is expanded upon in the conceptual design section, as well as how the EDP has positively impacted the project's progress.

The two major conceptual designs have been included in detail, as well as the reasoning behind using one over the other. Formulation of these designs has occurred through several iterations of conceptual generation, with profuse incorporation of decision matrices (i.e. Morph charts, function-means trees, binary objectives comparison, etc.). These concepts have been grouped into a "System Overview", containing broader-spectrum information about the designs.

Specifics have been explored in the "System Level Design" section, wherein sub-systems (i.e. single components) are detailed. A block diagram has been included to clearly display the mechanical and electronic connections between the Arduino microcontroller and the components it governs.

Finally, "Project Planning" outlines the way forward through the display of completed tasks and future tasks in a Gantt Chart. Supplementary risk analysis has been provided for key features/tasks, including deadlines and additional requirements. Expenses of building the vehicle cannot exceed the $200 budget, and so a budget table has been included, revealing the distribution of funds to each vehicle constituent.

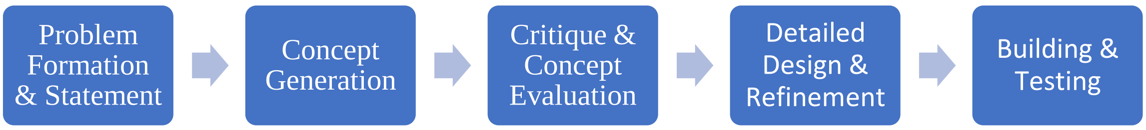
Requisite Knowledge

Total Required

To successfully complete this project, a great deal of information is required – specifically regarding the engineering design process, criteria/guidelines, and the functioning of both mechanical and digital components. The engineering design process will be needed to proceed through different phases smoothly and most importantly – efficiently (reducing waste of time, budget, resources). This process contains several sub-processes which also need to be progressed through with efficiency. The criteria and guidelines of the project references both the limitations of the track and constraints on the vehicle. These must be reviewed thoroughly to ensure the final design conforms to NASA's requirements. Finally, a solid understanding of both mechanical components (e.g. fasteners, materials, motors) and digital processes (e.g. programming the Arduino) is a necessity to be able to design and construct models with such constituents. Such information can be from previous personal experience or from technical lectures on specific topics.

Current

Presently, our design team has examined the aforementioned specifics in a reasonable amount of detail. The engineering design process has come from common lectures and EDP assessments (individual and group). Our research has led us to explore the EDP in five major stages:



The first three of these processes have been completed successfully as of the present. Criteria and guidelines have been studied in detail (as explored in the introduction). Mechanical components are familiar to some of the team who have personal experience with constructing vehicles of this nature. (Dym, (2013))

Still Required

The remaining two processes are in progress as we construct and refine our prototype. The build phase overlaps with the refining as it is a continuous cycle until the final prototype is constructed. Coding is also quite new to most of the team and will require additional time to learn online. The Arduino common lecture helped our understanding, but a hands-on approach is likely to enrich it further.

Conceptual Design

System Overview

Vehicle Propagation & Storage – The "Tread Container"

One of the original designs that the team came up with was the 'Tread-Container' design. This design allowed for secure transportation of the ball-bearings across the track, whilst also boasting an innovative and aesthetic appeal.

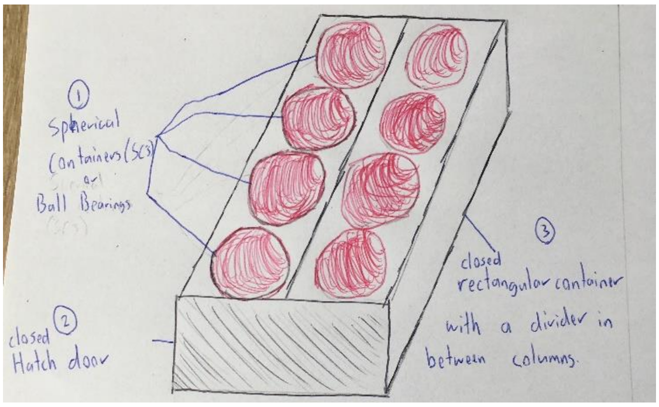


Fig 3.1 – Dual-Column Container

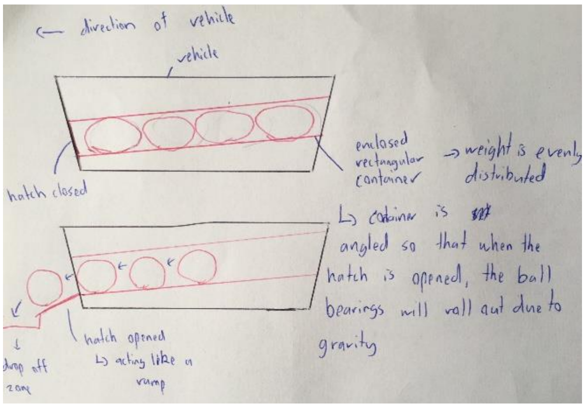


Fig 3.2 – Angled Container Side View

The aim of this design was to successfully and securely transport a maximum payload across the track and its many obstacles with great reliability. This design integrates a number of efficient subsystems, all used in conjunction, to meet the aims of the given problems. This includes:

- A secure two-column container that enables secure transportation of the payload
- Motors to power the tread-wheels on either side, providing necessary torque
- A servo-operated latch which acts as a ramp and barrier for securely delivering payload
- An Arduino Bluetooth module to allow for a connection with a Bluetooth remote (e.g. mobile phone), which in turn manoeuvres the vehicle (Thakur, 2017))
- Even distribution of payload across the design

For successful delivery of the payload, the team decided on an angled rectangular container, with two columns separated by a wall (fig 3.1). This double-column container has a latch operated by a servo attached to it which once opened, acts as a ramp. Since this container is angled as seen in figure (fig 3.2), gravity causes the payload to roll down the ramp and unload successfully into the drop off zones. Treads were decided upon as they would provide constant contact with the ground, making the traversal of uneven surfaces more reliable. The vehicle would simply drop off the decent section, utilising the elasticity of the treads for regaining stability and reducing impact. Since the payload is evenly distributed (as well as the components), the vehicle would not tip upon landing.

Container Storage & Unload – "The Donkey Kong"

The Donkey Kong (TDK) design is a preferred solution for the DELTA project. This vehicle design integrates well planned subsystems to construct a secure, innovative, and aesthetic product.

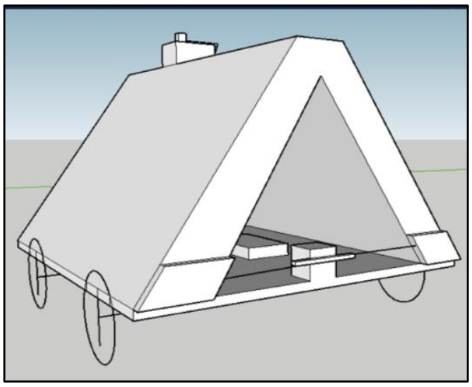


Fig 4.1 -- TDK Back w/ Servo & Hatches

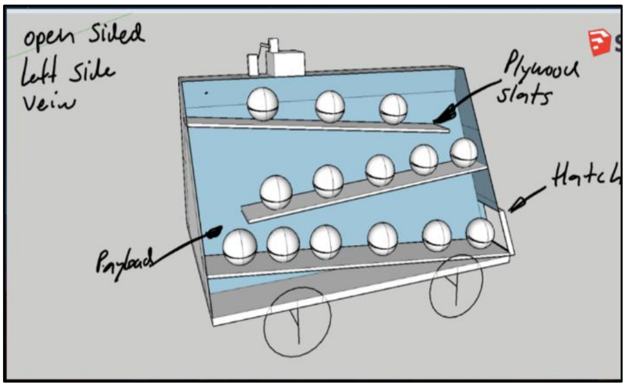


Fig 4.2 -- TDK Open Side w/ Shelves

TDK design aims to provide a solution to the problem of containing and delivering the payload safely. TDK provides:

- Secure transportation as balls are stacked against one another and two small openings
- Even weight distribution along vehicle
- Easy and safe release with no risk of ball-bearings clogging
- Up to 40 ball-bearings transportable (2 rows of 10 on each side)
- Flexibility to be attached to multiple bases

TDK features a servo-operated hatch (see fig.1). This allows for one servo to open both sides, by rotating one hatch downward and the other upward. TDK will have a clear outer wall, a yellow?? inside, and a black carbon fibre top and front/back, creating a unique and aesthetically appealing design. TDK has a flat top, upon which a hook will be mounted using an right-angle bracket and bent steel rod attached to a servo, to enable the vehicle to zipline down the 300mm drop (with minimal risk of payload spillage), which we have considered to be the greatest obstacle.

This design was decided upon as it provides solutions to all the key obstacles the track presents whilst also transporting the payload safely and providing a reliable method for unloading. The slanted shelves on which the balls will sit provides a secure compartment for the journey along the track (see fig.2), and the gravity-assisted release ensures that the ball-bearings will be deposited precisely. The design can also be attached to a wide variety of bases, allowing for flexibility in the vehicle's wheel layout and rendering modification of the base a lot easier.

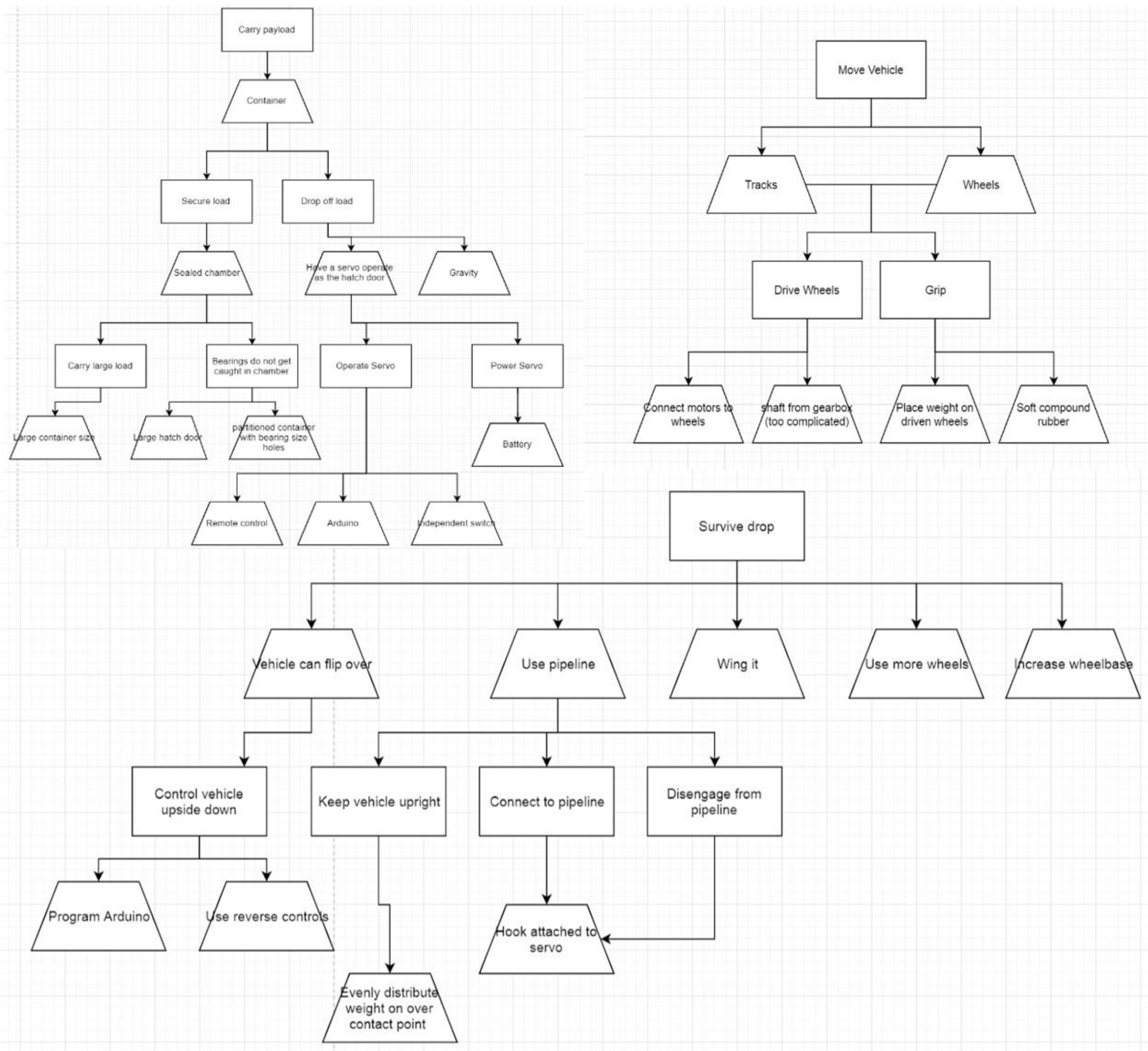
Decision Matrix

As our group formed different ideas of how our final design would look, our team eventually settled on a range of different design elements which could be implemented in our final design. To help convey our methodology in assessing and choosing our preferred designs, we utilised a range of design generation methods including but not limited to:

- Morphological Matrix
- Function-means Trees
- Binary Objective Comparison

Before our Morph matrix, 3 function-means trees were developed to address the 3 main dilemmas of the task – how the vehicle was going to be driven; how the vehicle was going to deliver a maximum payload; how the vehicle would survive the 300m drop outlined in the project specifications.

Function-means Trees



The 1st concern had two main solutions/means (wheels or tracks) which both led to the same functions required of them. Grip could be achieved with softer rubber tires and maintain a weight bias on the driven wheels, while wheels could be driven straight off the motor shaft. When addressing how we were to carry our payload, different forms of containers were proposed to transport the ball bearings. Further issues such as how we would prevent the cargo from getting jammed could be addressed by having the container partitioned and allowing the cargo to roll down the container when a hatch door is opened. This hatch could be controlled by a servo arm hooked to our Arduino and connected to an external power source to give higher current to our servos.

Finally, the drop could be handled by a number of means, for instance, having a vehicle which could flip upside down in worst case, but would still operate but with inverse controls (invertible vehicle). Our team thought that connecting to the installed zipline could produce the best results, and as such, a servo can control a hook which latches onto this zipline and maintains vehicles composure upon descent. From these tree's and other methods, the following morph matrix was generated:

Means / Functions	1	2	3	4
Hold bearings	Closed cylindrical or rectangular chamber	Open tray	Partitioned gallery	------
Drop off bearings	Hatch operated by servo	------	------	------
Move vehicle	Tracks	Wheels (2wd)	Wheels (4wd)	------
Survive drop	Suspended wheels	Hook	Invertible Vehicle	Longer wheelbase
Communicate with vehicle	Remote control and receiver	Cable to Arduino	Bluetooth to Arduino	Automated Arduino
Power Vehicle	NiMh	LiPo	Alkaline	------
Resist strong forces	Thickly built chassis	Suspension	Flexible materials	------
Grip multiple surfaces	Increase weight	Soft compound rubber	Reduce motor rpm	------

Purple = Design 1

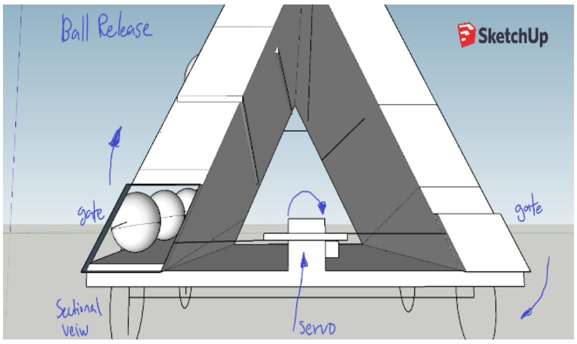
Red = Design 2

Each colour represents a different complete design that was formulated in the initial concept generation phase, with the function and means for each.

Additionally, other decision matrices such as binary comparison charts were supplementarily with the two main decision-making processes (function-means trees and Morph Chart). These can be viewed in the appendix, along with more design diagrams.

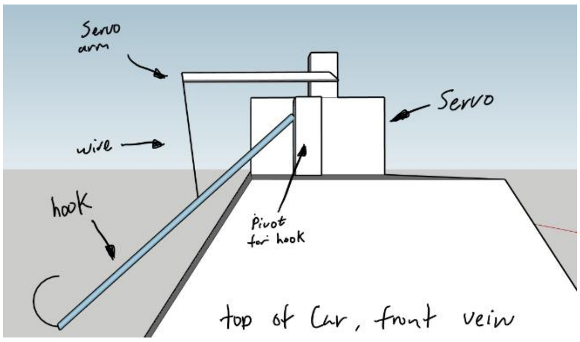
System Level Design

Sub-systems



Ball Release: The ball release system will use a servo connected to the Arduino. When activated, the servo will turn – raising one gate up and lowering the other down (leaving the balls free to roll out). This system is both light and simple, increasing efficiency and modifiability.

Hook: The hook will allow our car to negotiate the drop without reducing chassis integrity or payload security. The hook is operated by a servo motor mounted on top of the car and will rotate on its own pivot point. The hook will be lowered to drive under the bar then raised to sit above the rail.



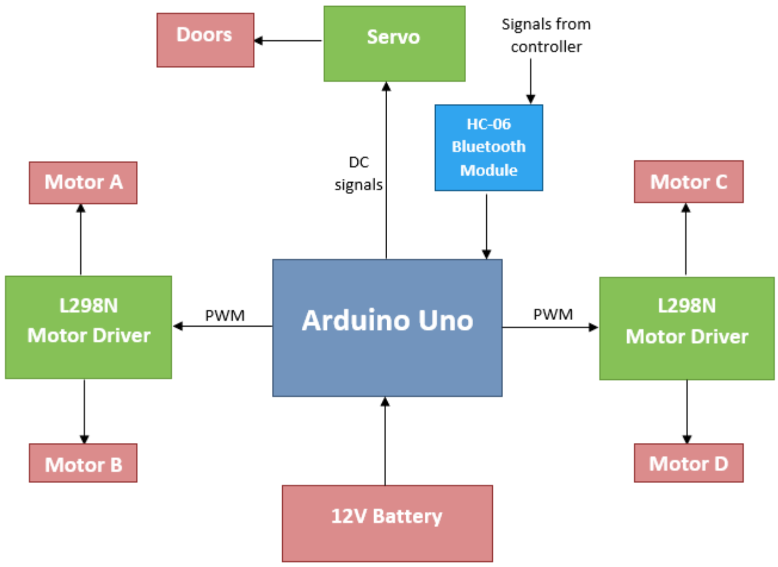
The vehicle will be slowly driven off the drop, lowering the hook into position around the rail. The rear wheels will eventually fall off the drop and the vehicle will slide down to the bottom. The hook is subsequently rotated off the rail and the vehicle is free to move at the bottom.

Chassis: The chassis will be constructed using a thin open-topped box. The Arduino and breadboard will be housed inside. The motors will be mounted onto the bottom of the box using wooden mounts, providing the vehicle with an acceptable ground clearance. Wires will be passed through the bottom of the box to the motor drive housed with the Arduino. The "Donkey Kong" transport/unload method will be attached to the top of the base. The chassis material will consist mainly of carbon-fibre to provide the best strength-to-weight ratio and will be reinforced by wooden strips for extra rigidity.

Block Diagram

Mechanical &

Electronic Connections



Project Planning

Gantt Chart

A Gantt chart was used to visualise the tasks to be completed and the corresponding time frame. In Fig 8.1, the tasks completed are blue and tasks that need to be completed are in red. (Berkley, n.d.)

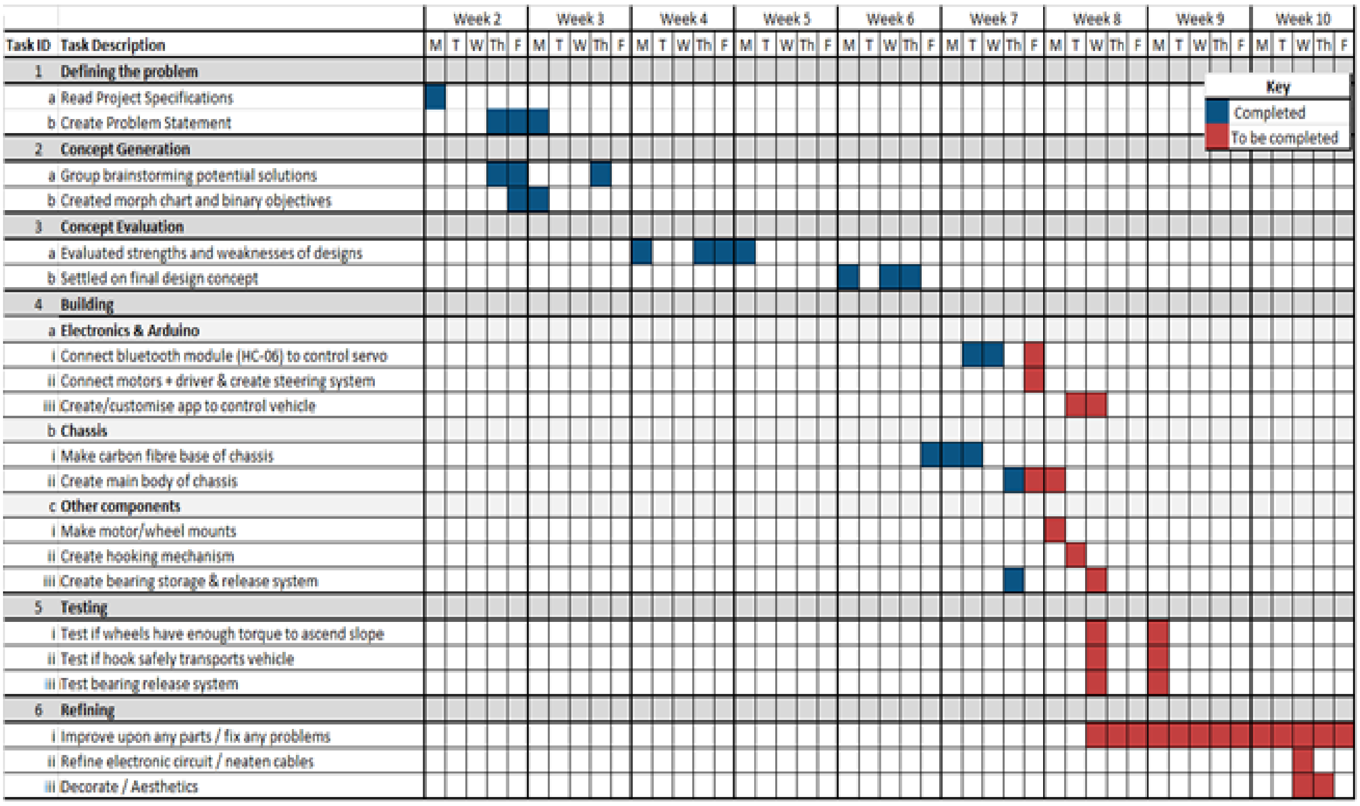


Fig 8.1 – Gantt Chart

Risk Analysis

Controlling the servo motors (4ai), controlling the wheels (4aii), building the motor mounts (4ci) and building the hook (4cii) may potentially take longer to complete than stated in the planned time frame. If this occurs, the deadline may be extended to the latest date of compliance testing (Thursday week 8). This is because all these tasks need to be completed in order to manipulate the basic mechanisms and functions of the vehicle. Tasks 4ai and 4cii are essential in the creation of a functional hook, which will allow our vehicle to safely descend the zipline. Task 4aii and 4ci are required for vehicle movement. All four of these tasks are assessed in compliance testing. The creation of the vehicle controls (4aiii) needs to be partially finished by week 8, as this is required to manoeuvre the vehicle and perform other necessary functions. All vehicle controls must be finalised before week 10, as the ultimate test run has time constraints and the vehicle needs to be with easy to control.

If setting up the controls of the bearing release system (4ciii) takes longer than expected, the deadline for completion may be extended to Thursday Week 8; ready for demonstration for the compliance testing. The deadline for completing the chassis (4bii) can be extended if required. The chassis is currently in a satisfactory state for compliance testing – as aesthetics are not being assessed. However, this should be completed before week 10 (final testing). By then, the other components must also be completed, and the vehicle fully assembled.

Table of Future Tasks

Task	Description	Date to be completed
4ai – Controlling servo motors	• Connect the servo for ball release to the circuit • Modify code for servo motors to move to the	Fri 05/04
4aii – Controlling wheel motors	• Connect motors to driver and Arduino • Create code for motors to turn at the required speed and direction at command	Fri 05/04
4bii – Building chassis	• Replace plastic with less flimsy plastic • Attach hook mount • Coat in carbon fibre and epoxy resin	Mon 08/04
4ci – Building motor mounts	• Calculate the optimum height for vehicle • Cut out wood and drill hole to size • Secure motors with epoxy or glue	Mon 08/04
4cii – Building hook	• Create a strong hinge system to attach hook to • Connect servo motor to lower and raise hook	Tues 09/04
4ciii – Building bearing release	• Create 'doors' that prevent the balls from rolling out • Connect servo to doors to open and close	Wed 10/04
4aiii – Vehicle controls	• Create a program / modify existing program and UI for control of the various components	Wed 10/04
6ii & iii - Aesthetics	• Neaten circuit wires • Decorate outside chassis	Thurs 25/04
5 - Testing	• Frequently test design	Fri 26/04
6i – Refining	• Frequently alter and fix design	Fri 26/04

Budget Table

Component	Quantity	Total Cost
Arduino Basics Kit (Arduino Uno, Breadboard, Small Plastic Servo, Wires)	1	$28
HC06 Bluetooth Module	1	$13
H-Bridge/Driver	2	$16
L298n Motor Driver	2	$6
LiPo Battery	1	$20
High-torque Servos	3	~$45
Wheels	4	$12
Carbon-Fibre Chassis Wrap	~	~$60

Conclusion

After analysis of the two major design concepts, it was decided upon that the "Donkey Kong" model was the optimal solution for fulfilling the project requirements, while within the specified restrictions. In terms of weight, balsa wood and carbon fibre are to be used, minimising the weight of the chassis, while maintaining strength. This allows for heavier, higher-torque motors to be used to traverse across the bumpy terrain. The simple trapezoidal prism shape of the vehicle allows for efficient storage and release of the balls unlike design concept 1. A hooking mechanism is the most favourable option to descend the drop/zipline section, as opposed to the tread-container design, which would simply fall – risking the structural integrity of the vehicle and its ability to function.

Based on the project plan, it is feasible to complete the design well before the set deadline, enabling improvements to be made. The planned expenses are also within the $200 budget as listed in the budget table. Overall, this design is expected to satisfy requirements and be fully functional for the compliance testing stage. After which improvements can be made for final testing.

Acknowledgements

The authors of this proposal would like to gratefully acknowledge the contributions of: our mentor Will Tran – who advised us on several occasions and offered help in designing where required, the MakerSpace staff – who demonstrated construction procedures and machinery operation, and the lecturers – who we learnt the relevant information from in order to advance through the design process.

References

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Appendix

Problem Statement – Meeting Minutes

Venue: UNSW Library 407
Time: 4:00pm-5:00pm
Members Present:

- Maximilian Cullen Feng
- Rabie-Bin Asim
- Jacquelyn Davie
- Thomas Colley
- Andre Matkowski

Members Absent:

- Madison Weekes

Minutes:

i. Problem statements
    - Individual problem statement
        - Advised to complete in week 3 mentoring session (i.e. next Monday)
        - Should include (from common lecture):
            - Who?
            - What?
            - Why?
    - Group problem statement
        - Developed after individual problem statements
        - Combine best ideas and eliminate unnecessary information for a clear and concise statement

ii. Exploring design idea of a tank-like vehicle
    - Using treads increases traction
    - Treads require a lot of torque
    - Treads can easily maneuver over the ditch section
    - Treads are heavier
    - Rigid body of a tank-like vehicle can sustain impact from the drop better
    - Steering options
        - Differential
        - Skid-steer

I will volunteer to research different methods of steering in my own time.

iii. Arduino
    - Need to buy Arduino Board for team

    Jacquelyn has offered to buy the recommended control kit from the 'create' store on campus
    - Tom and Andre will research Arduino coding

iv. Parts needed and where to buy them
    - Create store will sell required electronics
    - Andre can provide a LiPo battery (and maybe motors too)
    - Plywood can be sourced from off-cuts at makerspaces (or bought relatively cheap)
    - Wheels/Tracks will need to be bought online or at a hobby store

Decision Matrices – Binary Objectives Comparison

	Durability	Ease of Use	Speed	Power Usage	All terrain	Modification	Aesthetics	Score	Priority
Durability	------	0	1	1	0	0	1	3	4
Ease of use	1	------	1	1	0	1	1	5	2
Speed	0	0	------	1	0	0	1	2	5
Power Usage	0	0	0	------	0	0	1	1	6
All terrain	1	1	1	1	------	1	1	6	1
Modification	1	0	1	1	0	------	1	4	3
Aesthetics	0	0	0	0	0	0	-------	0	7

Additional Design Diagrams

Tread-Container Side and Front

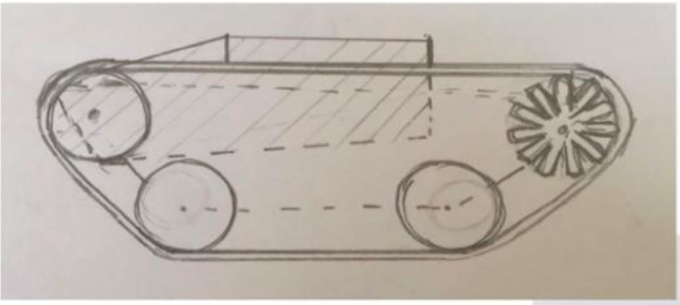

Figure 2.4(a)

Figure 2.4(b)