Candidate 3 evidence

Outline

Project Proposal

Idea

- A system that is powered by renewable energy sources (solar, wind, wave & battery (in case there is not enough energy)) that needs to be on for 24 hours a day

Electronics/Control

- Can use Op-Amps to measure voltage of each energy source & switch between them
- Can use Op-Amps to set system at different outputs (e.g. a light can be set to different brightnesses)
- Can also use Op-Amps for pulse width modulation

Mechanisms/Structures

- Can use structures to decide what materials to use for the system to be operational 24/7
- Can use structures knowledge to make sure the system can withstand the environment it is in
- Can use structures knowledge to make sure the system can last a long time without needing proper maintenance

AIM

- To conduct research that has been done on the general topic and analyse it to decide on what type of system it is I will be basing my project on
- To then plan and design the electrical systems as well as power transmission for the system to work
- Finally, to put everything together and test it

TIME SCALE

Date (2024)	Aim For That Week
Wed 10th Jan	Complete Proposal & start outline
Mon 15th Jan	Start research & analysis
Thu 18th Jan	Finish outline & start Specification
Sun 4th Feb	Finish research & analysis
Tue 6th Feb	Finish Specification
Mon 5th Feb	Begin designing the individual components via Yenka
Sun 3rd Mar	Finish designing the individual components
Mon 4th Mar	Begin simulating the solution
Sun 10th Mar	Finish simulating the solution
Mon 11th Mar	Begin evaluation of project
Tue 26th Mar	Finish evaluation of project
Wed 27th Mar	Presentation

KEY EQUIPMENT/COMPONENTS NEEDED

- Yenka – for producing the circuits to make sure that the system works

MILESTONES

- Completing planning stage + research
- After testing individual components
- After testing project as a whole

Project Outline

Introduction

The continuous demand for uninterrupted electrical systems operating 24 hours a day has resulted in many challenges ingrained in the complex cooperation of technology, infrastructure, and human factors. As our world becomes increasingly dependent on continuous power supply, issues arise such as equipment deterioration and potential failures thus becoming an essential part of ensuring electrical systems are reliable and efficient. These problems highlight the delicate balance required to sustain constant operation, needing innovative solutions, constant maintenance, and advanced technologies to guarantee the continuous flow of electricity to the (type) system allowing it to be operational.

To start with there would need to be some sort of technology that monitors implemented into the system that detects potential issues before they escalate to ensure there is responsive interventions and minimal downtime. There would also need to be automated control systems to enable swift responses to issues, to optimise the system's performance. Renewable energy sources would need to be explored to adopt sustainable energy practices as it would contribute to reducing the strain on electrical systems which allows for long–term reliable performance.

Project Statement

To gain a proper understanding of my topic, I will carefully conduct research and start by doing a thorough review and analysis of existing research and studies within my topic's general scope. This examination of the current research and studies will aim to gain me a proper and full understanding of the energy efficiency of these types of systems to try and improve it, how it will be maintained allowing it to be used for a long time and how all the individual circuits will come together.

Following the analysis of the existing research and studies, the next phase of the project is to plan and design the electrical circuits. To complete this stage, I will need to use my existing knowledge of electronics as well as my newfound knowledge gained from my research. I will also need innovative solutions to problems that arise to create a blueprint for the envisioned system. The planning stage will see me consider several factors such as durability demands, efficiency standards, safety protocols and scalability. By evaluating these factors, I will have a clear understanding of the role that each individual circuit will have, how each individual circuit will look like by itself and how each individual circuit will come together to make one big system for it to function efficiently.

The concluding phase of the project involves integrating all the individual circuits together into a single big one. Once that is complete there will be testing undertaken to ensure that the envisioned electrical system operates without fault and meets all the objectives. This phase will require a lot of attention to detail to ensure that each individual circuit connects to the other ones in the right places. By the end of this phase, I should know that all the individual circuits have been connected properly, that the system operates and that it is reliable.

Methodology

For the research stage, I will start by understanding what I am researching and consider reliability, energy efficiency, safety and other key aspects involved in these electrical systems. I will then conduct the research and gather all the data I find on current research and studies that have been previously conducted, then I will evaluate the technology that is used and needed for this system to operate and if necessary, do further research about the individual pieces of tech. This phase has the advantage of me being able to conduct research whenever I can. I aim for this stage to begin on Monday 15th of January and will be finished by the 29th of January.

When my project reaches the planning stage, I will start by finalising my decision of what technologies/smaller sub-systems will be used for the project, then I will then try to gain an understanding of the environmental impact it will have due to it being constantly operational and if necessary, make changes to mitigate the size of the impact. I will then do some calculations and reach an understanding of what materials would be used to encase and protect the system from it's environment so it can operate properly. Finally, I will develop a conceptual design of the individual circuits making sure that I have met all the necessities that the system needs to be efficiently and reliably operational. I will have a disadvantage here as I will be using Yenka for parts of this stage and I will have limited access to it, but I have the advantage of being able to draw individual circuits meaning that when I am using Yenka I can quickly build them. This stage should begin on the 29th of January and aimed to be completed by the 19th of February.

Finally with the testing stage I will bring all the individual circuits/ components together to make one big system using Yenka, I will then proceed to test the system to make sure all the individual circuits do what they are supposed to do, that the full system is reliable, energy efficient and that the impact it has on the environment is somewhat lower than what there currently is. There is a disadvantage to this stage as I will only be able to use Yenka at specific times which will most probably cause this stage to be a bit slow and long. I am intending for this stage to begin by the 21st of February.

Basic Outline

I will need to clearly draw circuits and individual components with labels for when I am in the planning stage and designing the individual parts of the system. I will also need to know how to test the system in the ways I intend to test them to gather data to see if the project is a success or not (e.g., measuring voltage etc.).

Resource Requirements

- I will need to have access to a software called Yenka where I can construct and test the circuits I design
- I may also need some sort of software that allows me to test the materials I have chosen to protect the system so that I know it would be reliable
- I will need access to a classroom to be able to draw up & design the circuits that will be a part of the system
- Data will be gathered from testing to make sure the system can switch between power supplies efficiently
- I need to gather data from testing to make sure the system can operate through all times of the day
- Finally, I need to gather data from testing to make sure the system can be functional in it's environment
- I will need to find data on when these types of systems stop functioning properly or at what points of the day, they are least functional

Research, analysis and specification

Analysis and Specification

Specification 1

Functions

1.1 The vehicle must be able to extinguish fires or stop the spread of further fires
1.2 The vehicle must carry around with it a fire hose connected to a fire hydrant
1.3 The vehicle must use an effective nozzle and spray angle to target as much fire as possible
1.4 The vehicle must traverse obstacles in a burning building at the right speed
1.5 The vehicle must be small and compact, allowing it to travel through small spaces

Mechanisms

2.1 The vehicle must use a motor with a large enough torque to drive the vehicle
2.2 The vehicle use a suitable gear system to allow the drive axle to have the required torque
2.3 The vehicle must have mechanism which would allow it to steer
2.4 The steering mechanism must make use of a motor with the required torque to steer
2.5 The vehicle must have a mechanism for turning or aiming the fire hose
2.6 The turning mechanism for the fire hose must make use of a motor with the required torque

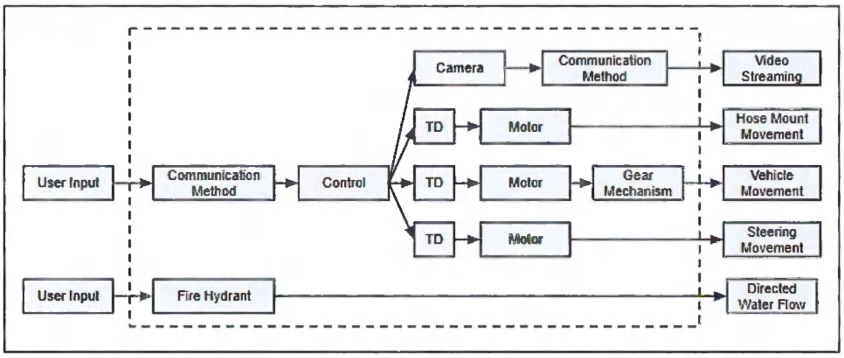
Structures

3.1 The vehicle must have a body structure to protect inner contents from fire
3.2 The body must be made out of a strong material which resists high temperatures
3.3 The vehicle must use wheels which would withstand high temperatures
3.4 The body of the vehicle must be supported by bearings connected to the axles
3.5 The axles must be thick enough to withstand the maximum stress
3.6 The vehicle must balance out all forces when shooting water and remain stationary

Electronics and Control

4.1 The vehicle must use an Arduino microcontroller for the control
4.2 The vehicle must make use of a way to remotely communicate with the device of the operator
4.3 The vehicle must have a camera module which would be visible from the operators device
4.4 The vehicle must be controlled by an app on the operators device
4.5 The motors should be powered by a battery which should last for a reasonable period of time
4.6 The vehicle should use an electronic module to efficiently control all the motors
4.7 The vehicle must have an electronic circuit or pcb for the final circuitry

Analysis



The user input would be controlling the movement of the vehicle. The movement commands would be sent from an operating app to the control using a remote communication method. The control in this case would be an Arduino microcontroller. The vehicle would then move according to the user's commands with a steering motor and a drive motor which would be connected to a gear mechanism to increase the torque. A camera would stream video to the operating application, the user would control the vehicle and the rotation of the hose mount to move the hose mount in the direction of the fire. Once aimed, the user would turn on the water flow from the fire hydrant until the water is extinguished.

Specification and analysis

Specification 2

Functions

1.1 The vehicle must be able to extinguish fires or stop the spread of further fires
1.2 The vehicle must carry around with it a fire hose connected to a fire hydrant
1.2.1 The vehicle should use a 45mm diameter hose, 23m long
1.2.2 The vehicle will use water from a fire hydrant with a pressure of 7 bar and an output of 35 L/s
1.3 The vehicle must use an effective nozzle and spray angle to target as much fire as possible
1.3.1 A fog nozzle inclined at 45° with an included spray angle of 100° should be used
1.4 The vehicle must traverse obstacles in a burning building
1.5 The vehicle must be small and compact, allowing it to travel through small spaces

Mechanisms

2.1 The vehicle must use a motor with a large enough torque to drive the vehicle
2.1.1 The vehicle must be driven by a motor with a torque of 16Nm
2.1.2 The motor used for the drive is the RS PRO Brushed Geared Type 454-0877 DC Motor
2.1.3 The vehicle must be able to move 87.3 kg
2.2 The vehicle use a suitable gear system to allow the drive axle to have the required torque
2.2.1 The velocity ratio of the gear system should be 80
2.2.2 The drive axle should rotate at a minimum speed of 38.2 rpm
2.3 The vehicle should have the required acceleration to travel at the right speed
2.3.1 The vehicle should have a speed of 0.3 ms^{-1} and an acceleration of 0.25 m/s^2
2.4 The vehicle must have mechanism which would allow it to steer
2.5 The steering mechanism must make use of a motor with the required torque to steer
2.5.1 A torque of 75 kg-cm is required for the steering mechanism
2.5.2 The INJORA, INJS075 High Torque Digital Servo should be used for steering
2.6 The vehicle must have a mechanism for turning or aiming the fire hose
2.7 The turning mechanism for the fire hose must make use of a motor with the required torque

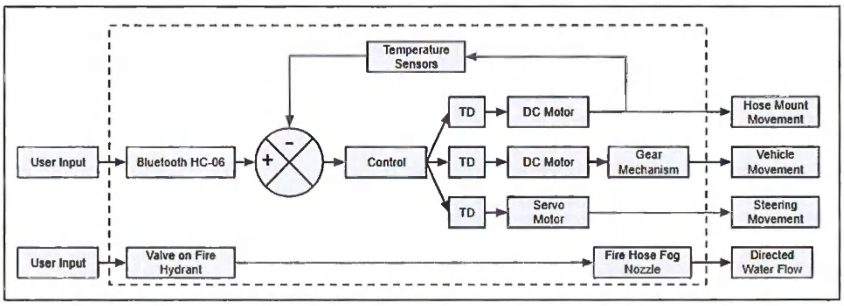
Structures

3.1 The vehicle must have a body structure to protect inner contents from fire
3.2 The body must be made out of a strong material which resists high temperatures
3.2.1 The body of the vehicle should be made out of mild steel
3.2.2 The vehicle must be able to withstand a temperature of 500°C
3.3 The vehicle must use wheels which would withstand high temperatures
3.3.1 The vehicle should use wheels made out of a nitinol mesh
3.3.3 The wheel should have a radius of 75cm
3.4 The body of the vehicle must be supported by bearings connected to the axles
3.5 The axles must be thick enough to withstand the maximum stress
3.6 The vehicle must balance out all forces when shooting water and remain stationary
3.6.1 The vehicle should counteract a force of 560N
3.6.2 The vehicle should have a minimum mass of 40.4kg to withstand the force from the nozzle

Electronics and Control

4.1 The vehicle must use an Arduino microcontroller for the control
4.2 The vehicle must make use of a way to remotely communicate with the device of the operator
4.2.1 The vehicle should be controlled using Bluetooth by an app on a device
4.2.2 The HC-06 bluetooth module should be used for the remote communication
~~4.3 The vehicle must have a camera module which would be visible from the operators device~~
4.3 Temperature sensors should be used to determine the direction of the fire
4.4 The vehicle must be controlled by an app on the operators device
4.5 The motors should be powered by a battery which should last for a reasonable period of time
4.6 The vehicle should use an electronic module to efficiently control all the motors
4.7 The vehicle must have an electronic circuit or pcb for the final circuitry
4.8 The vehicle must have a flashing warning light when moving

Analysis



The user input in this sub system diagram would be controlling the movement of the vehicle on the app. The user would also turn on the water flow by turning a valve on the fire hydrant when fires are present, and turn the water flow off when the fires have been extinguished.

The user would input commands to the operating system for the movement of the vehicle which would be received by the bluetooth module. The vehicle would then be driven by a DC motor which makes use of a gear mechanism which would allow the drive axle to have the required torque. The turning mechanism of the vehicle would make use of a servo motor.

The temperature sensor would feedback to the control through an error detector. The error detector would be either two state control or proportional control which could be achieved by programming a microcontroller or by using an analogue electronic circuit. The control will rotate using a DC motor until it reaches the direction of the largest fire. It would then signal for the water flow to be turned on until the fire is extinguished.

All the motors would be connected to an electronic circuit which would supply the required voltage and current to all motors from the battery.

Research Plan

What needs to be researched	*How it is going to be researched*
Research types of available fire hose nozzles and fire hoses and their suitability for this project	Look at the available and most commonly used fire hose and their dimensions on a government website, and google advantages of different nozzle types to determine the most suitable one
Research the flow rates and pressures of water from a different fire hoses in the UK and determine suitable values	Look at national guidance documents on fire hydrants, and look at official fire hydrant tests by the government
Research the spray coverage for the selected nozzle type	Look at articles on spray nozzles from qualified companies to determine the optimal spray angle
Research ways for the operators device to remotely communicate with the microcontroller on the vehicle	Google different communication methods like bluetooth, BLE, radio communication, and infrared communication and determine the most suitable
Research the average temperature that will be exerted to the vehicle in a building	Read different articles from different sources on the temperatures within fires and burning buildings
Research materials which would be suitable for the wheels which would withstand a high temperature	Investigate different tyre materials that have been used in various circumstances, investigate their properties and determine if they could withstand the high temperatures
Research the frictional force acting on the vehicle and research the coefficient of friction between the tyres and the floor	Look at articles and tables of values of coefficients of friction for different similar materials
Research different materials which could be used for the body of the vehicle	Online research to find tables of different materials and their properties to determine a suitable one
Research different motors and in which circumstances they would be effective to use	Look at websites and read articles which compare stepper motors, DC motors and servo motors to determine the most suitable type
Research and select motors to use	Visit motor industrial web stores, find motors which could be used by considering the torque, speed and velocity ratio
Research steering mechanisms	Read articles on how steering mechanisms work and determine a suitable motor which could be used
Research electronic remote communication modules	Read articles on the suitability of the modules and the function of the pins, visit online web stores to compare and find suitable modules
Research electronic modules for streaming video	Read articles on the suitability of the modules and the function of the pins, visit online web stores to compare and find suitable modules

Initial Research

Types of nozzles and hose

38mm diameter - Straight Stream Nozzle: this type of nozzle produces a constant single stream. This is really effective when high pressure water is required and has a larger reach but is not as effective for ventilating space or absorbing ambient heat, but is not as effective for ventilating space or absorbing ambient heat.

32mm diameter - Fog Nozzle: this nozzle sprays water with a fog pattern as a cone shaped stream of small water droplets. The fog nozzle provides wide area coverage and helps prevent the spread of fires, it is very effective in confined areas, and for absorbing ambient heat.

The most effective nozzle for the vehicle would be the 32mm diameter fog nozzle. The vehicle would be mostly used in confined areas in which firemen would not get into, it would also mean that less precision is required, making the fog nozzle more effective. This would mean that the vehicle would absorb ambient heat and stop the spread of fires in the confined areas before the firefighters finally get in with their straight stream fire hoses.

The vehicle would be used to quickly get into small spaces or rooms and will never travel deep into buildings, thus the distance from the vehicle to the firetruck / fire hydrant will never be big, a length of 20m for the hose will be enough. For this reason, a 45mm hose – at 23m in length standard hose reel will be used. It is the most commonly used hose for house fires, and it is suitable for all situations.

(1), (2), (3)

Flow rates

The water flow rate from fire hydrants in the UK ranges from 500 to 2100 Litres / minute (8 - 35 L/s). The water flow from fire engines' water tanks ranges from 1000 to 4000 Litres / minute (17 - 67 L/s).

Fire hydrants and water engines should always maintain a minimum pressure of 6 bar, however, depending on the situation and fire hose used, they should go up to a maximum of 12 bar. The typical water pressure used for a fog hose would be 100 psi (around 7 bar).

For this specific vehicle, the water would be supplied at 35 L/s because it is the maximum pressure output found in a normal fire hydrant, and a water pressure of 7 bar as it is the most suitable for the nozzle and situation.

(4), (5), (6), (7), (8)

Forces on the vehicle

A fire hose mounted to the vehicle would exert a very large amount of force on the vehicle while it sprays water forward. This force will depend on the water pressure, hose diameter, flow rate, and the configuration of the nozzle.

$$A = \frac{\pi d^2}{4}$$

$$A = \frac{\pi(0.032)^2}{4}$$

$$A = 0.000804247 \text{ m}^2$$

$$F = P \cdot A$$

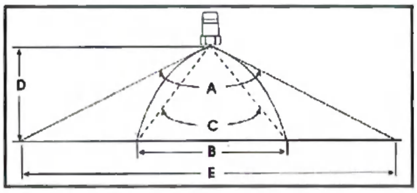
$$F = 700000 \cdot 0.000804247$$

$$F = 562.97340\ldots \text{N}$$

$$F = 560 \text{ N}$$

This means the fire hose will exert a minimum force of 560N on the vehicle. The vehicle must have a frictional force of the same magnitude or use something else to counteract this force to prevent the vehicle from accelerating backwards.

Spray coverage



Angle A: this is the included spray angle at which droplets of water immediately acted upon external forces, this angle determines the spray coverage right at the nozzle.
B: this is the actual spray coverage at a distance of D from the nozzle.
Angle C: this is the angle for the actual spray coverage at a distance of D from the nozzle.
E: this is the theoretical spray coverage of the nozzle at a distance of D from the nozzle.

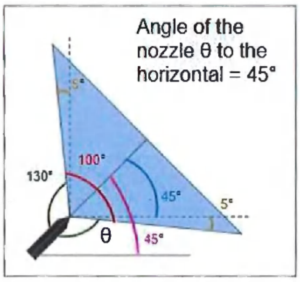
THEORETICAL SPRAY COVERAGE (E) IN MILLIMETERS

Included Spray Angle (A)	Distance From Nozzle Orifice (D) (mm)									
	50	75	100	150	200	300	400	600	800	1000
10°	9	13	17	26	35	52	70	105	140	175
20°	18	26	35	53	71	106	141	212	282	353
30°	27	40	54	80	107	161	214	322	429	536
40°	36	55	73	109	146	218	291	437	582	728
50°	47	70	93	140	187	280	373	560	746	933
60°	58	87	115	173	231	346	462	693	924	1155
70°	70	105	140	210	280	420	560	840	1120	1400
80°	84	126	168	252	336	503	671	1007	1343	1678
90°	100	150	200	300	400	600	800	1200	1600	2000
100°	119	179	238	358	477	715	953	1430	1907	2384
110°	143	214	286	428	571	857	1143	1714	2285	
120°	173	260	346	520	693	1039	1386	2078		
130°	214	322	429	643	858	1287	1716			
140°	275	412	549	824	1099	1648	2198			
150°	373	560	746	1120	1493	2239				
170°	1143	1715	2286							

As previously mentioned, I decided to go with a fog nozzle for the fire hose, as it covers a larger diameter spray coverage and would mean less accurate aiming of the nozzle would be required. A nozzle configured to produce a large enough coverage would eliminate the need for a turret to aim the nozzle up and down.

To have the maximum effect of fire absorption, the spray coverage should act at the largest possible spray diameter coverage over a relatively large distance away from the nozzle. The most suitable angle for this would be an included spray angle (A) of 100°, resulting in a spray coverage diameter of 2384mm at a distance of 1m from the nozzle.

The vehicle would be low to the ground so the nozzle should be mostly aimed upward as the fires are usually closer to the ceiling. However, if there is a fire on the floor straight in front of the vehicle, it should be able to light it out to continue. As the included spray angle is 100°, the angle of the nozzle to the horizontal should be 45° so that the vehicle would cover the fires right ahead of the vehicle. An angle of 45° would also maximise the actual spray coverage distance away from the nozzle because the horizontal and vertical components of the water would be equal.



(9)

Remote communication with vehicle

Different types of waves are used to control vehicles depending on the situation and requirements. Bluetooth, Bluetooth Low Energy (BLE), Infrared, and Bluetooth are the main types of transmission.

- Bluetooth Classic: Bluetooth waves are based on radio waves, they are designed for higher data transfer rates, meaning it consumes more power. It has a higher range than BLE of up to 100m.
- Bluetooth Low Energy: BLE waves are designed for less power consumption and are more efficient, however, they have a shorter range of about 10m, BLE waves are used in devices that use less power such as phones

- Infrared: Remote controls typically use infrared transmission; infrared transmission would not work as they are affected by heat, but they are cheaper and easier to use.
- Radio waves: can provide longer communication ranges than both bluetooth and infrared, they are not affected much by path obstructions, but they are more expensive and harder to implement.

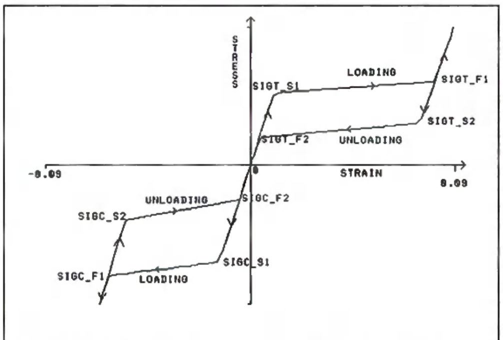
I have decided to go with Classic Bluetooth waves for transmission between the vehicle and the device because they have a long range, they are not affected by heat, they do not require direct line of sight and can penetrate most obstacles, and they are easier to implement and program with an Arduino microcontroller.

Temperatures and materials

The average temperature within a fire ranges from 1000°C (orange-red flames at the outside of the fire) to 1500°C (white flames at the centre of the fire).
However, considering that the vehicle would not directly drive into the flames, the average environmental temperature in a burning house, low to the ground, is about 500°C.

There are no rubber materials that would be able to withstand temperatures of 500°C so standard rubber tyres would not work. However, there exist airless steel mesh tyres which could withstand very large temperatures.

These super elastic airless tyres are made from a shape memory alloy consisting of a nickel titanium material - Nitinol.
This superelastic material would be able to withstand much greater deformation than normal steel, it would not wear over time, and it will never go flat. Nitinol has a density 6450 kg/m³ of melting point of 1240 - 1310 °C so it will withstand the required temperatures. Nitinol is elastic like rubber yet strong like titanium and allows deformations of up to 10% of its original shape, making it perfect for metal wheels.



UNIAXIAL STRESS-STRAIN BEHAVIOR FOR A SHAPE-MEMORY-ALLOY (NITINOL)
(EUL: MAXIMUM STRAIN FROM DETWINNING OF THE MULTIPLE-VARIANT MARTENSITE)

(10), (11), (12), (13)

Mechanical Research and Calculations

Forces on the vehicle

The frictional force is not affected by the contact surface area, this is because an increase in the surface area will result in a decrease in pressure and as F=P/A. This means that the frictional resistive force will only depend on the coefficient of friction between the floor surface and the nitinol wheels, and the normal contact force which in this case would be the Weight (Mg) of the vehicle and the vertical component of the force from the water.

Friction force

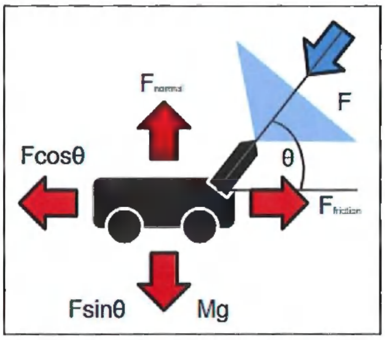
$$f = \mu N$$

f = friction force
μ = coefficient of friction
N = normal force

The coefficient of friction can vastly vary depending on the materials and the surface conditions. Most florings would be made out of concrete, tiles, wood, carpet, or vinyl. Carpets, wood and vinyl would most likely burn revealing the base structure which is commonly concrete. Some example of similar CoF scenarios are:

- Average CoF for dry Steel-Concrete is 0.57, but can range from 0.8 to 0.38
- CoF for pure titanium alloys range from 0.25 to 0.3, however, untreated surfaces-titanium can range from 0.8 to 0.9
- Average CoF for Nickel-Concrete can range from 0.5 to 0.8
- Average CoF of nitinol under dry friction is 0.6

To consider all possible scenarios, the lowest coefficient of friction should be taken into account so that the vehicle would remain stationary when firing out water even in low friction environments. However, the floor of a burning building (most likely made from concrete or other similar base materials) would be rough, and will be covered in rubble and debris. Thus it is unreasonable to think that the coefficient of friction will ever drop below a value of 0.5.



(14), (15), (16), (17)

$F = 560N$
$\theta = 45°$
$\mu = 0.5$

$F_{normal} = Mg + F\sin\theta$
$F_{friction} = \mu(Mg + F\sin\theta)$

At 0 acceleration:
$F\cos\theta = \mu(Mg + F\sin\theta)$

$560\cos45 = 0.5(Mg + 560\sin45)$
$Mg = 2*(560\cos45) - 560\sin45$
$Mg = 395.97979746$
$M = 395.97979746/9.8$
$M = 40.406101782$
$M = 40.4$ kg

Hence in these conditions, the mass of the vehicle should be at least 40.4 kg in for the frictional force acting on the vehicle to counteract the horizontal force from the water thus producing 0 acceleration.

Materials of body

The vehicle should withstand a constant temperature of 500°C, or up to a temperature of 1000°C (if the vehicle drives into fire). Thus, the body of the vehicle should be made out of metal to withstand the high temperatures. Some common metals which could be used are:

- Aluminium: MP, 660°C; Density, 2640-2710 kg/m³
- Mild Steel: MP, 1350-1530°C; Density, 7870 kg/m³
- Cast Iron: MP, 1204°C; Density, 6800 - 7800 kg/m³
- Stainless Steel: MP, 1375 – 1530°C; Density, 7480 - 7950 kg/m³

Properties:

- Aluminium: Good strength/weight ratio, not as strong as other metals, quite lightweight, ductile and malleable
- Mild steel: high tensile strength, ductile and malleable, tough and strong
- Cast iron: very difficult to shape, bend and forge, very strong
- Stainless steel: very similar to mild steel but more expensive, corrosion resistant, harder to cut and bend

Based on these properties, the most suitable material would be mild steel. Mild steel is strong so it would support the weight of the vehicle easily, it is quite a dense material so it would make up the required weight with little volume, it has a high enough melting point to withstand the temperatures, it is ductile and malleable so it will be easy to shape, and it is the least expensive of all steel types.

(18), (19)

Torque calculations for drive motor

The minimum torque required by the motors can be calculated by:
$F = m \cdot a$
$T = F \cdot r$
$T = m \cdot r \cdot a$

Subsequently, the torque depends on: The mass which the motor must move; The radius (the distance at which the torque from the motor is applied to the wheel to move the vehicle) which in this case is the radius of the wheels; And finally the required acceleration of the vehicle.

The mass of the vehicle itself was previously calculated to be 40.4kg. However, the vehicle must also carry the weight of the fire hose. The vehicle will use a 45mm diameter, 23m length standard hose. The weight of a spray nozzle is 1.5kg
From the product technical specification, the hose weights 380g per metre, which is 8.74kg. The volume of the water inside the hose would be:

$V = \pi r^2 h$
$V = \pi * 0.0225^2 * 23$
$V = 0.036579919...$

$m = \rho V$
$m = 1000 * V$
$m = 36.6kg$

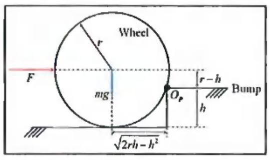
Thus the total weight of the fire hose with water would be 45.4kg, so the total weight which the motor must move is rounded up to 87.3 kg for extra precaution

The maximum speed of the vehicle does not need to be exceptionally high: The vehicle would only be used to traverse the small rooms or spaces of the building, the speed of the vehicle must not be high enough that it will tip over the vehicle as it goes to drive over an obstacle, the speed of the vehicle must be slow enough to easily traverse the floors and avoid obstructions, but the maximum speed should also be reasonable in order to overcome obstacles.

From this information, a reasonable slow enough speed at which this vehicle should traverse is 0.3 ms^{-1}. There is no need for the acceleration to be high, the vehicle should reach this speed of 0.3 ms^{-1} in a time of 1.2 seconds.
$a = v/t$, $a = 0.3/1.2$, $a = 0.25\ m/s^2$

(20)

The vehicle should be able to drive over rubble, debris, wood remains, and bricks. The height of obstacles a vehicle can drive over will depend on the ground clearance, suspension and radius of the wheels. With good suspension and a ground clearance of greater than or equal to the radius, the maximum height a vehicle can drive over would be equal to the radius.



The vehicle must at least be able to drive over bricks. Standard bricks in the UK have a height of 65mm but there must be a 10mm allowance for mortar joints between bricks, and considering all other types of bricks, a height of 75mm should be taken into account. This means that the wheel radius must be 75mm (150mm diameter). Thus from the gathered information, the required torque of the motor can be calculated:

(21)

$$T = m \cdot r \cdot a$$
$$T = 87.3 * 0.075 * 0.25$$
$$T = 1.636875 \text{ kg-m}$$
$$T = 1.636875 * 9.8$$
$$T = 16.041375 \text{ Nm}$$
$$T = 16 \text{ Nm}$$

Types of motors

Stepper motors / DC motor for vehicle movement:

- The use of a stepper motor will allow for more control, they also have a holding torque so the vehicle would be less prone to moving while still and shooting water. However, stepper motors require a driver which converts pulse signals from the controller into motor motion to achieve precise positioning
- A DC motor would have less control and accuracy, however they can achieve much higher speeds, they would also be more energy efficient, they have continuous movement, and they would be cheaper.

I have decided to use a DC motor for this application because high precision and accuracy is not required, the DC motors can also have higher speeds and they would be cheaper to use.

(22)

Picking a suitable drive motor

The maximum required speed of the vehicle is 0.3 ms^{-1}, and the radius of the wheels is 75mm. From this the minimum required speed of the motor is 38.2 rpm to maintain the required acceleration of 0.25 m/s^2.

$$\omega = v/r$$
$$\omega = 0.3 / 0.075$$
$$\omega = 4 \text{ rad s}^{-1}$$
$$\frac{4}{(2\pi/60)}$$
$$= 38.197...$$
$$= 38.2 \text{ rpm}$$

These are the options for two motors which could potentially be used:

The Doga Brushed Geared Type 316.9731.30.00 DC Motor, has the following specifications:

- Supply Voltage - 24V
- Output Speed - 65 rpm
- Torque - 10 Nm

The RS PRO Brushed Geared Type 454-0877 DC Geared Motor, has the following specifications:

- Supply Voltage - 12V
- Output Speed - 3090 rpm
- Torque - 20 Ncm

(23)

VR calculations for motors

First motor:

VR = T_1 / T_2
VR = 16 / 10
VR = 1.6

VR = Input / Output
VR = 65 / 38.2
VR = 1.7

VR = Input Speed / Output Speed
1.6 = 65 / Output Speed
Output Speed = 40.625 = 40.6 rpm

As 40.6 > 38.2, this motor would be suitable and would provide the required torque and speed if a gear system would be used with a velocity ratio of between 1.6 and 1.7.

Second motor:

VR = T_1 / T_2
VR = 16 / 0.2
VR = 80

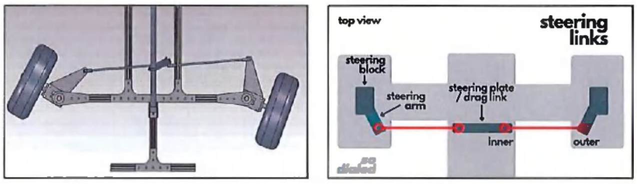
VR = Input / Output
VR = 3090 / 38.2
VR = 80.9

VR = Input Speed / Output Speed
80 = 3090 / Output Speed
Output Speed = 38.625 = 38.6 rpm

As 38.6 > 38.2, this motor would also be suitable and would provide the required torque and speed if a gear system would be used with a velocity ratio of between 80 and 80.9.

I have decided to use the second motor (RS PRO Brushed Geared Type 454-0877 DC Motor) for the drive motor. This motor is much cheaper than the first motor, it is smaller so it would take up less space, and it requires less supply voltage so a smaller battery could be used making the vehicle more compact.

Steering system



(24)

The steering plate / drag link for the steering mechanism can be controlled by either a dc motor with a rack and pinion, or a servo motor.

- Servo Motor: A servo motor will spin a precise angle limited to 180°, they would be easier to program.
- DC Motor: They can realign with the centre by simply using springs, they can run for longer amounts of time and are good for high speed applications, however, they are more suited where continuous rotation is required and don't have precise angular movement.

Although a DC motor can be realigned easily, by using a rack and pinion to stop the rotation of the motor it will be more prone to damaging and the gears will wear quicker. As a precise rotation is required, using a servo motor would be the more suitable choice.
Only the front part and wheels of the vehicle will be moved by the servo motor to turn the vehicle. It can be estimated that the front of the vehicle will be lighter than the back, however, the weight distribution of the vehicle must still be reasonably balanced to ensure that the vehicle will not flip when spraying water.

If the mass of the vehicle (without including the mass of the fire hose) is 40.4 kg, it can be estimated that the front wheels and steering links will weigh about 10 kg. The torque required for the steering will depend on:

- Friction and Resistance: the resistance caused by the mechanical components, bearings, and the resistance of the tires against the ground.
- Wheel Size and Surface: Larger wheels or rougher surfaces might require more torque to overcome the resistance.

So as $T = Fr$, $T_{steering} = F_{resistance} * R_{wheel}$, where $F = \mu N$.

The coefficient of friction was previously determined to be between 0.5 and 0.8. However, this does not take into account the efficiency, friction, and resistance of the system. To account for this, and for the turning mechanism to be quick, I am using a coefficient of friction of 1 which will increase the required torque. The torque could further be increased by reducing the distance from the steering link to the axle of rotation.

$$F_{resistance} = \mu N$$
$$F_{resistance} = 9.8 * 10$$
$$F_{resistance} = 98N$$

$$T_{steering} = F_{resistance} * r$$
$$T_{steering} = 98 * 0.075 = 7.35\ Nm$$
$$T_{steering} = 75\ kg\text{-}cm$$

For this reason, I will use the INJORA, INJS075 High Torque Digital Servo. The specifications for this servo motor are:
Supply Voltage - 8.4 V
Torque(8.4V) - 75 kg.cm
Rotation angle - 180°
Weight - 200g
Operating speed - 0.15" / 60°
rpm = 60/(Time for 360 degrees) = 66.67rpm

(25)

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Production and maintenance of a detailed project plan

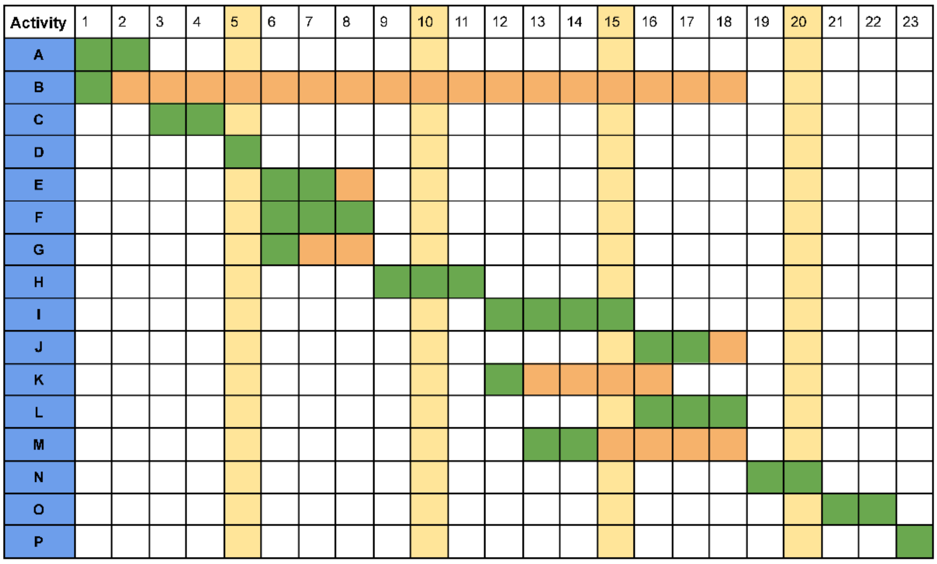
Project Plan

List of Actions

Activity	Activity Follows	Duration (hours)
A - Outline	Start	2
B - Project Plan	Start	1
C - Analysis	A	2
D - Research Strategy	C	1
E - Horn Bridge Research	D	2
F - Structure Design Research	D	3
G - PWM Research	D	1
H - Specification	E,F,G	3
I - Bridge Structure Calculations	H	4
J - Folding Mechanism Calculations	I	2
K - Control System Calculations	H	1
L - Simulate Bridge Structure	I	3
M - Simulate Control System	K	2
N - Evaluation	B,J,L,M	2
O - Finalise Project	N	2
P - Submit Project	P	1

Critical Path

The critical path is ACDFHINOP which means that any delay to these tasks would cause a delay to the entire project. The tasks that aren't on the critical path are B, E, G, J, K and M as they all have float time which means that any delays less than or equal to the float time will not cause a delay to the entire project.


Activity
1
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22
23
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P

Resources Required

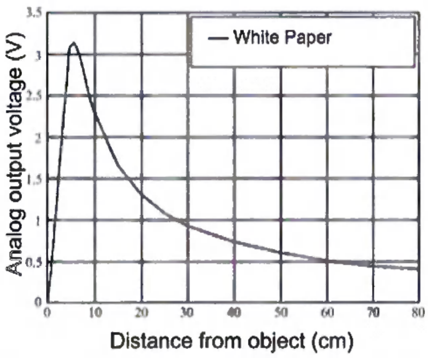
- Google Docs will be required throughout the project to write the full report
- A Pen and Paper will be required to write down all calculations during the mathematical modelling stage of the project
- A Calculator will be required to perform calculations during the mathematical modelling stage of the project
- Google Sheets will be required to create shear force and bending moment diagrams during the mathematical modelling stage of the project
- Autodesk Inventor will be required to simulate bridge structure during the simulation stage of the project
- Yenka will be required to simulate the control system during the simulation stage of the project

Mathematical modelling and analysis

Mathematical Modelling

Finding the output from Distance sensors

From my test coding and experiments, I have found that the SHARP 2Y0A21 distance sensors that I am using in my project only detect motion until a maximum distance of 24 cm, with a leeway of +/- 3 cm depending on the condition of the device. By linking a voltmeter to the circuit, I have created a graph showing the output voltage linked to the distance detected by the SHARP sensor.



Portion of the code written to find digital outputs of the distance sensors:

```
if (sensor_value > threshold) digitalWrite(portpin, HIGH);
else digitalWrite(portpin, LOW);
```

Investigating the 555 Timer for 'On' Switch

555 Timer for Spec 2.6

Through creating the 555 timer, I have to calculate the value of the resistors that would be used. Since I would like the light to turn on for 0.75 seconds and be off for 0.5 seconds I was able to use the Space and Mark equations, T=0.7R2xC and T=0.7(R1+R2)xC independently. These were all calculated using the assumption that I will be using a comparator with the value of 1 micro Farad. This will also be parallel with the arduino power, making the input voltage 4.8V.

T_{off}

$T = 0.7R_2 \times C$

$0.5 = 0.7R_2 \times 1\times10^{-6}$

$500000 = 0.7R_2$

$R_2 = 714285\,\Omega$

$= 700k\,\Omega$

T_{on}

$T = 0.7(R_1 + R_2)C$

$0.75 = 0.7(R_1 + 700\times10^3)\times1\times10^{-6}$

$750000 = 0.7(R_1 + 700\times10^3)$

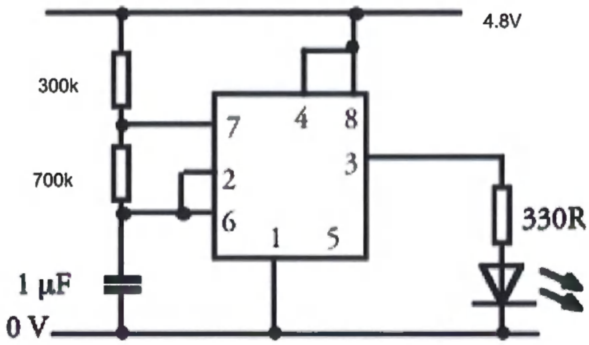
$1000000 = R_1 + 700\times10^3$

$R_1 = 300000\,\Omega$

$R_1 = 300k\,\Omega$

18

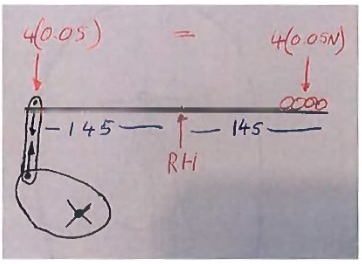
As seen above, the first resistor will equal 300kΩ and the second resistor will be 700kΩ, this makes the 555 timer diagram look like:

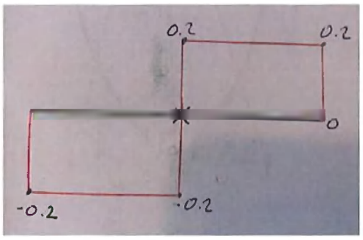


Forces on the Platform and Size of Gears used

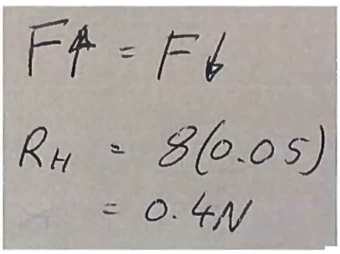
To find the forces and reactions of the gear system and marbles I started by drawing a diagram so I could visually see the impact that the forces will have on the platform. I have incorporated the standard weight of a marble (approximately 5.2 x 10^-3 kg or 0.05N).

Reaction Forces on Platform Diagram





Shear Force Diagram



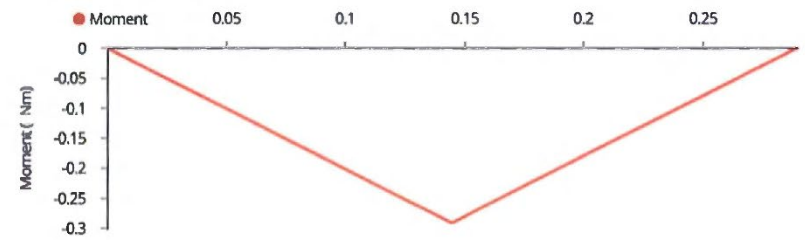
By using the laws of equilibrium, the hinge force of the crank and the force of the marbles of the platform must be equal. To calculate the reaction force at the hinge point in the centre of the platform I used the equation forces up = forces down and found it to have a force of 0.4N.

By calculating the second moment of acting on the platform, I was able to calculate the maximum deflection acting on the platform by using the calculation FL^3/3EI. Where E = Young's modulus.

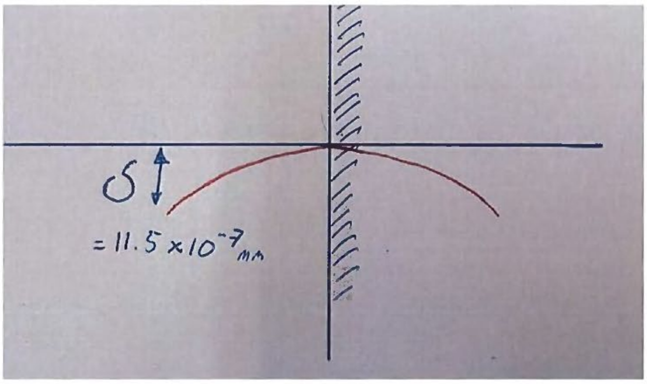
$$I = \frac{BD^3}{12} = \frac{70 \times 290^3}{12} = 142{,}269166.7\ \text{mm}^4 = 14.2 \times 10^7\ \text{mm}^4$$

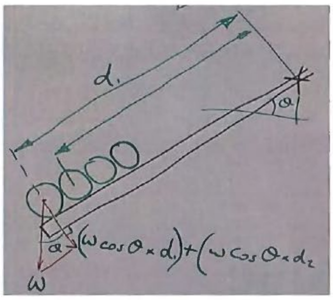
$$\text{Max. Deflection} = \frac{FL^3}{3EI} = \frac{4(0.05) \times 290^3}{3 \times 10 \times 10^3 \times 14.2 \times 10^7} = 0.000001145 = 11.5 \times 10^{-7}\ \text{mm}$$

Bending moment diagram



Maximum Deflection Diagram



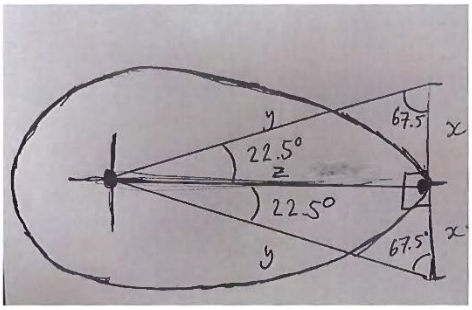


A diagram was then drawn of a different loading *(seen to the left)* on the right and calculating an equation to solve the forces of the marbles acting on the platform when at an angle. The result of this calculation was 47.65Nmm. This means that the axis in the centre of the platform will have to have a reaction force of

$$(w\cos\theta \times d_1) + (w\cos\theta \times d_2) + (w\cos\theta \times d_3) + (w\cos\theta \times d_4)$$
$$= 0.05\cos 22.5 \times 282 + 0.05\cos 22.5 \times 266 + 0.05\cos 22.5 \times 250 + 0.05\cos 22.5 \times 234$$
$$= 13 + 12.29 + 11.55 + 10.81$$
$$= 47.65\,N_{mm}$$

Size of Crank

To find the size of the crank in the cam and crank mechanism, I came up with this diagram:



x = vertical displacement of platform when raised +/-22.5°

Y = length of cam gear

Z = length of platform from centre = 145mm

To find y, I did some basic trigonometry to find x = 60mm. Then with the equation below I calculated the length of the maximum radius of the cam gear to be 55mm.

$$y = 60\cos 22.5$$
$$= 55.4\,mm$$

Reflective Commentary

Although some of the equations used were not Advanced Higher Engineering level of difficulty I feel that my mathematical modelling has demonstrated a high level of technical precision in the implementation of gear/structural analysis and design principles. The bending moment, maximum deflection, stresses, and structural integrity were all calculated in detail. This helped me locate all of the measurements and sizes I needed to simulate/build my design. Overall, the findings provided important information on the relationship between the forces operating on the platform and the design of the gear system. However, it is crucial to acknowledge the models' limitations, particularly their ability to accurately represent real-world complexity such as nonlinearities and external disturbances such as friction. Next time I would try to develop the gear system more to add complexity to the design.

Investigation of ServoMechanisms Outputs

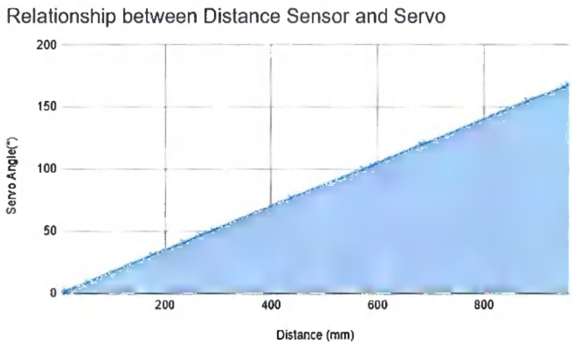
The process of creating mathematical models entailed converting the physical behaviour of servo systems into mathematical formulae. This requires determining critical factors such as voltage inputs, motor characteristics, and load dynamics. I formulated these equations using ideas from control theory and mechanical engineering, with the goal of correctly capturing the servo system's dynamic response.

Code Created for Finding Servo Outputs

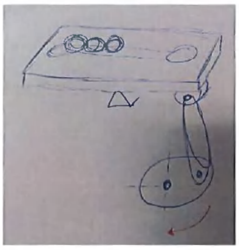
```
// C++ code
//

#include <Servo.h> // include servo library

Servo myServo; // create servo object
int servoPin = 9; // servo signal pin
int distancePin = A0; // distance sensor analog input pin
int distance; // variable distance value

void setup() {
  Serial.begin(9600);
  myServo.attach(servoPin);
}

void loop() {
  distance = analogRead(distancePin); // read distance sensor value
  int angle = map(distance, 0, 1023, 0, 180); // map distance value to servo angle range
(0-180)
  myServo.write(angle);
  Serial.print("Distance: ");
  Serial.print(distance);
  Serial.print(" | Servo Angle: ");
  Serial.println(angle);
  delay(500);
}
```

From the code used above, I have concluded my findings in the following graphs.

Distance (mm)	Servo Angle(°)
958	168
949	166
881	155
692	121
683	120
590	103
573	100
438	77
292	51
268	47
236	41
177	31
56	9
16	2
8	1



From this, we can see that there is a clear relationship between the Servo Angle and how far the object is from the Distance sensor. From using equations, I have created the equation, Servo Angle = (0.176)xDistance - 0.476. From my research, I have found that the torque of the standard servo-mechanism is 18.3kg/cm when input voltage is 6V. By using my code above in real life, I have found that it takes the servo 0.16 seconds to move 60°.



With the servo connected to the Cam gear and then attaching it to a rod, I can create rotary motion around the hinge at the centre. By altering the size of the cam gear, I will be able to make the platform move +/-22.5°. Then, by adding an indent down the centre line of the platform, this creates an easy space for the marbles to roll along either side without falling off.

Forces on gears of servo mechanism

Specifications

Modulation:	Analog
Torque:	**4.8V:** 44.00 oz-in (3.17 kg-cm) **6.0V:** 57.00 oz-in (4.10 kg-cm)
Speed:	**4.8V:** 0.23 sec/60° **6.0V:** 0.19 sec/60°
Weight:	1.31 oz (37.0 g)
Dimensions:	**Length:** 1.57 in (39.9 mm) **Width:** 0.79 in (20.1 mm) **Height:** 1.42 in (36.1 mm)
Motor Type:	(add)
Gear Type:	Plastic
Rotation/Support:	Bushing
Rotational Range:	60°
Pulse Cycle:	30 ms
Pulse Width:	500-3000 μs
Connector Type:	J

Brand:	Futaba
Product Number:	FUTM0031
Typical Price:	11.99 USD
Compare:	add+

...S3003 FUTABA SERVO...

Detailed Specifications

Control System:	+Pulse Width Control 1520usec Neutral	Current Drain (4.8V):	7.2mA/idle
Required Pulse:	3-5 Volt Peak to Peak Square Wave	Current Drain (6.0V):	8mA/idle
Operating Voltage:	4.8-6.0 Volts	Direction:	Counter Clockwise/Pulse Traveling 1520-1900usec
Operating Temperature Range:	-20 to +60 Degree C	Motor Type:	3 Pole Ferrite
Operating Speed (4.8V):	0.23sec/60 degrees at no load	Potentiometer Drive:	Indirect Drive
Operating Speed (6.0V):	0.19sec/60 degrees at no load	Bearing Type:	Plastic Bearing
Stall Torque (4.8V):	44 oz/in. (3.2kg.cm)	Gear Type:	All Nylon Gears
Stall Torque (6.0V):	56.8 oz/in. (4.1kg.cm)	Connector Wire Length:	12"
Operating Angle:	45 Deg. one side pulse traveling 400usec	Dimensions:	1.6" x 0.8" x 1.4" (41 x 20 x 36mm)
360 Modifiable:	Yes	Weight:	1.3oz. (37.2g)

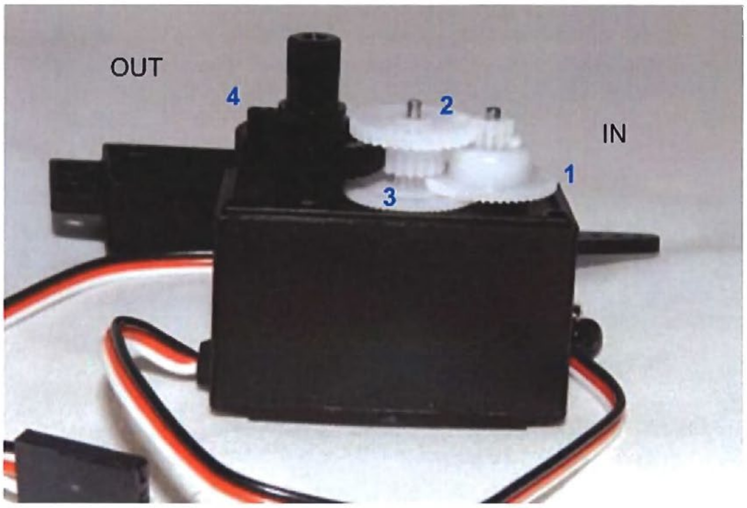
Input Speed

$\omega = 0.23$ sec/60°
$= 1.38$ sec/360
$= 1.38$ rev per sec ×60
$= 82.8$ revs per min

Using the servo motor's data sheet, I determined the angular speed (ω). The servo operates at 4.8 V and has an angular speed of 0.23/60°. To determine the rpm, multiply by 6 to get 1.38 revolutions per second. Then, multiply by 60 to get the input rpm. This equates to 82.8 revolution per minute.

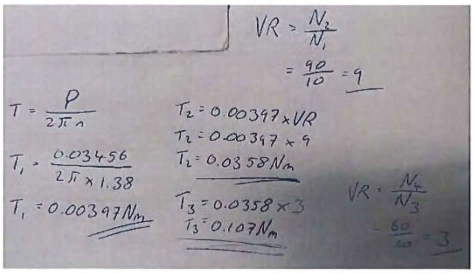
By applying the formula P=IV and consulting the servo's data sheet, I was able to determine that the current draw at 4.8V is 7.2mA. After that, I could figure out how much power the servo motor gears had to 0.034W.

$P = IV$
$= 7.2 \times 10^{-3} \times 4.8$
$= 0.03456W$



Gear Number	Number of teeth	Diameter (m)
1	10	0.06
2	90	0.36
3	20	0.12
4	60	0.24

Then use the equation T=P/2πn, where n represents rotations per second. Using the equation, I was able to determine the torque of each gear. To calculate the velocity of each gear, I utilised the velocity ratio of the number of teeth on each gear, VR = Driven/Driver.



$$T = \frac{P}{2\pi n}$$

$$T_1 = \frac{0.03456}{2\pi \times 1.38}$$

$$T_1 = 0.00397 Nm$$

$$VR = \frac{N_2}{N_1} = \frac{90}{10} = 9$$

$$T_2 = 0.00397 \times VR$$

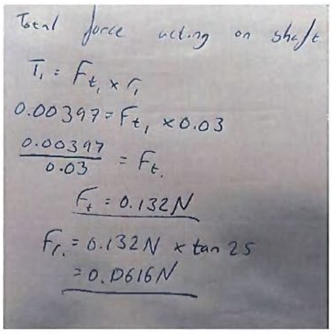
$$T_2 = 0.00397 \times 9$$

$$T_2 = 0.0358 Nm$$

$$VR = \frac{N_4}{N_3} = \frac{60}{20} = 3$$

$$T_3 = 0.0358 \times 3$$

$$T_3 = 0.107 Nm$$



Total force acting on shaft

$$T_1 = F_{t_1} \times r_1$$

$$0.00397 = F_{t_1} \times 0.03$$

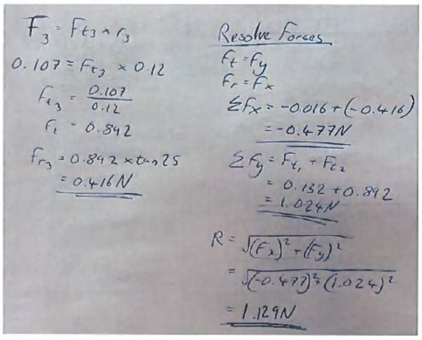
$$\frac{0.00397}{0.03} = F_t$$

$$F_t = 0.132N$$

$$F_{r_1} = 0.132N \times \tan 25$$

$$= 0.0616N$$

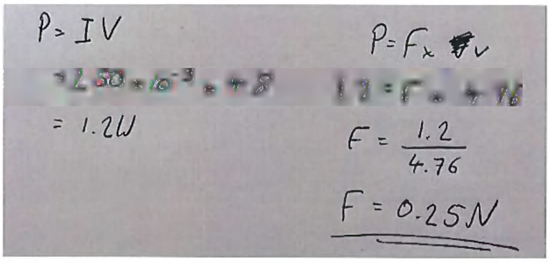
I calculated the resultant force on the axle to see if gears two and three were balanced. I started by using the formula T=Fr x r to determine the tangential force. where r is the gear's radius. I then used to compute the radial force. where the gear's pressure angle is represented by tan25. For the sake of this computation, I've assumed that the pressure angle is 25°.
The result of this calculation indicates that gears two and three are in balance.



Outputs from the ServoMechanism
Using the P=IV equation, I realised that this represents idle power. To determine the power at which the servo works. I was unable to determine this when doing testing in the workshop, but I did some research and discovered that the current draw is around 250mA. Using this quantity, I will assume that it is the proper value in my equation. This yields the figure for working power.

Using another equation proposed by Dr. Lee, a lecturer at Heriot Watt University. I calculated the constant speed and power of the servo while not idle. This produces a result of 0.252 N.

P=Fv
P is power (W) from servo.
F is force (N)
v is velocity (ms^-1)



Torque Calculations and Torque-Voltage Relationship

To calculate the torque output of the servo, I used the equation T=Fr.

$$T = F_r$$
$$= 16.18 \times 0.016$$
$$= 0.258\,Nm$$

4.8v = 0.31 Nm
6.0v = 0.40 Nm
0.31/4.8= 0.06458...
0.4/6= 0.0666...
1v≈0.06562...
Therefore, if the torque is equivalent to 0.258 Nm, the voltage needed is 3.96V. This implies that the Arduino Uno will be able to provide sufficient power for the servo.

Reflective Commentary

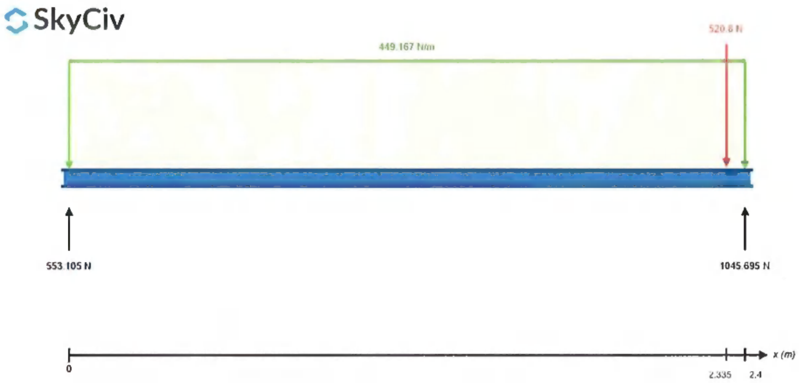
One of the most difficult issues I faced was coordinating theoretical models with actual behaviour. Servo systems frequently show nonlinearities, delays, and uncertainties that are difficult to express in mathematical models. Furthermore, acquiring correct values for the system components proved difficult since experimental validation was restricted. In future, I would like to expand the use of the Servo to further develop my understanding of it by doing more online research.

Constructing and/or simulating a solution

Simulation

Beam Simulation

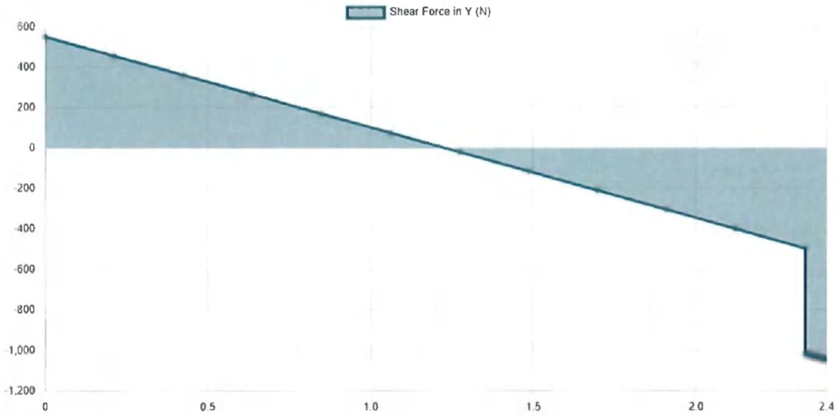
To simulate the top beam I have used SkiCiv to check if my calculations are correct and viable to use in this scenario. This will also show me how the bending moment of the beam is affected by the forces.



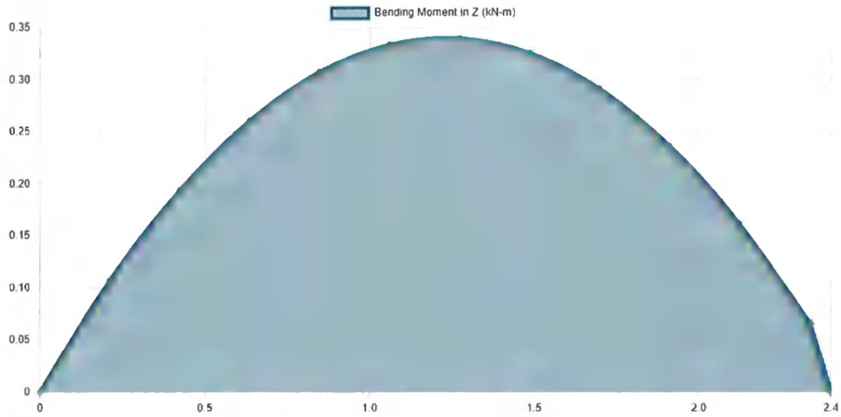
The simulation above shows the beam diagram that was originally created to assess the forces acting on the top of the wall. The calculation below shows that the values I had originally calculated were slightly different. This is because for the reaction at 2.4m (B) I rounded my answer to have 4 significant figures; this value would have impacted my calculation for the reaction at 0m (A) making it slightly smaller. However these values have notably small differences which are essentially negligible. This implies that my calculations were still very much applicable to the project as a whole. The beam subsystem would be integrated as the main structure of the wall. The diagram shows the supports needed on the top roller. The bending moments of the wall can also be simulated using the same software.

Support at	X	Y	Mx
0	0 N	553.105 N	0 kN-m
2.4	0 N	1045.695 N	0 kN-m

SkyCiv - www.skyciv.com

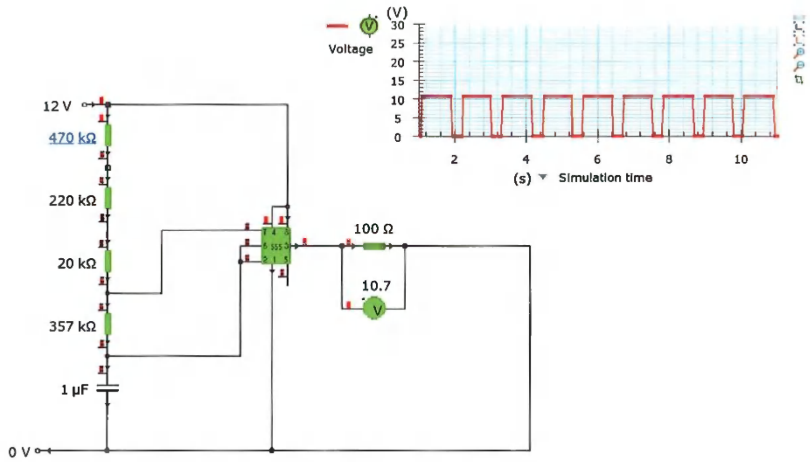


This shear force diagram was created using the software noted above. It follows the same shape as the graph I had originally calculated and plotted, although this plot starts and ends at 0N. As noted previously, my original modelling did not end at 0N due to the rounding errors present in the earlier calculations. These were negligible in magnitude as previously stated. Either way, the functionality of the simulation is still relevant and the modelling is absolutely applicable to the project as it still describes where the maximum bending moment will occur, this being where the line crosses the x-axis.

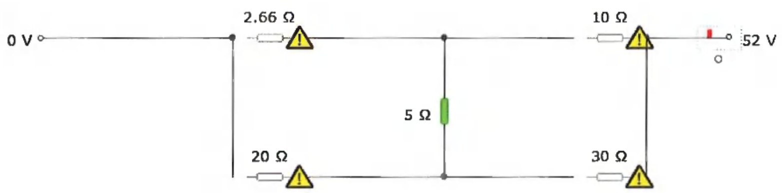


To conclude, the simulation is incredibly useful as it shows that my mathematical modelling, as shown above, is credible and relevant. This means that each subsystem can be implemented effectively into the treadmill allowing for it to be used with confidence that the structure will be strong enough to withstand the maximum forces that should be present on the wall. Moreover, as I have shown that there will be no deformation in the bar due to Young's modulus result calculated earlier, there is good reason to be confident that the beam is more than safe to be used in the climbing treadmill frame system.

Electronics



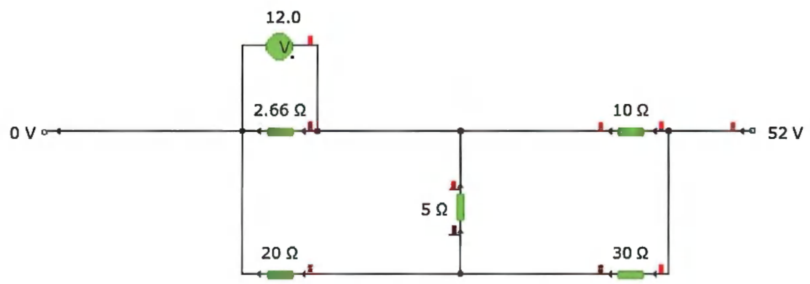
This simulated circuit above shows the 555 timer that was designed using the optimal resistor values calculated in mathematical modelling. When simulated, the output graph shows that within a 10 second timeframe there are 10 pulses of output voltage. This proves that the previous modelling calculations were correct and that using the specific resistor combinations allows for the correct frequency of flash. It also shows that the light flash will be on for longer than it is off, which was a requirement detailed in the specifications.



This is a simulation of the nodal analysis that was calculated previously. However the simulation software has calculated that all of the resistors will break (explode). The simulation supports the maths for my modelling of the resistors. However the simulation also shows that there is too much power in the system for the resistors to handle.

On further analysis and simulation, and to overcome this initial result, the maximum power allowed to each resistor was increased. This allowed for higher values of voltage to be used allowing the circuit to function correctly.

To show this system working correctly an alternative change that could be made would be by making the input voltage 1/10th of that used initially. This would show a relative and proportional output that will be the 1/10th of the actual output and would mean the original system could be powered at a relevant and credible level.



The changes analysed above are effective for the project as they show that the previous calculations were correct and that the resistor values are appropriate for the system. Alongside this the simulations show that the motor will have enough power to run effectively.

Again, as stated earlier, all of the values of resistance and capacitance throughout the electronic simulations have been chosen as they are standard units of each value. This means that they are not specialist pieces but instead are common items that are easily obtainable online (see resistors and capacitors in Appendix).

As an aside, this system could also be used to change the speed of the motor. Indeed, by changing the 10Ω resistors value the output voltage will change (implying that this could be a way to control or vary motor speed).

To conclude, all of the previous simulations have proven successful as they show that there is no need to adapt any of the circuits or original designs of the treadmill, and that the system design is able to be progressed and implemented.

Evaluation

Evaluation

Evaluation of Solution

Evaluating against the main specification points:

1.1 This specification point has been met in theory, i.e. the vehicle has been designed to hold a fire hose which is connected to a fire hydrant so it should be able to extinguish fires or stop the spread of further fires. However, due to the time limitations, I was not able to develop this vehicle or create a model of it so I couldn't know for sure how well this specification point is met.

1.2 This specification point has been met. The vehicle was designed around a fire hose which was to be connected to a fire hose and calculations were made with the dimensions of the fire hose and pressure from the fire hydrant.

1.3 This specification point has been met. The hose nozzle was carefully picked and calculations were carried out with the spray angle and water pressure.

1.4 This specification point was not met. Initially the vehicle was meant to have a camera module and the operator would be able to easily control the vehicle and traverse obstacles with live video feedback. However, after some research and speaking to experts from Heriot Watt University, I found that it would be too difficult to achieve this feedback using Bluetooth Classic so the decision was made to replace the camera module with temperature sensors which would be positioned around the hose mount.

1.5 This specification point was potentially met. The design of the vehicle was based around the sizes of the components and was made to be as small as possible. However, since the vehicle was not built and tested I cannot know for sure if it would be able to pass through small compartments.

2.1 This specification point was met. The motor was carefully picked after calculating the required torque that it must have and considering the space that the motor and other components that it requires would take up.

2.2 This specification point was met. The gear system was designed so that the chosen motor would rotate at the required torque and speed. The gear system was also designed so that it would take up as little space as possible.

2.3 This specification point was potentially met. The required speed and acceleration of the vehicle was carefully chosen and calculations were made so that the motors would allow the vehicle to travel at this speed, but as the vehicle was not tested, it is difficult to know how well this specification point was met.

2.4 This specification point was not met. Calculations were made to find the required torque for the steering mechanism, but the detailed steering mechanism itself was not created.

2.5 This specification point was met. The torque required for the steering was calculated and the servo motor that would control the steering mechanism of the vehicle was carefully picked from this.

2.6 This specification point was somewhat met. The rotation of the fire hose was thoroughly considered and programmed. However, the actual rotation of the fire hose was simply achieved by attaching the fire hose mount to a DC motor. A dedicated mechanism for the fire hose rotation was not created so it is unknown how well the motor would rotate the fire hose.

2.7 This specification point was met. The required torque for the rotation of the fire hose mount was calculated, and from this, a suitable motor was carefully selected.

3.1 This specification point was not met. For the design of the vehicle, a simple mild steel box was put around the vehicle in an attempt to protect the inner contents from a fire, but a detailed design for the bodyshell of the vehicle was not created. It is also difficult to say how well a mild steel box would protect the inner contents from fires if the vehicle was not tested.

3.2 This specification point was potentially met. Mild steel was chosen for the body of the vehicle as its melting point is beyond that found in the research for the average temperature in a burning building, but as this was not tested, it is difficult to say how well it would hold up.
3.3 This specification point was met. The material chosen for the wheels was Nitinol which has an extremely high melting point and it has interesting properties that would allow it to be used in a tyre mesh without significant wear damage.
3.4 This specification point was met. The forces acting on the drive axle were determined from the weight of the vehicle and the gears, from this the reaction forces in the bearings were diligently calculated.
3.5 This specification point was met. The minimum diameter of the axle was calculated so that the axle would withstand the maximum stress on the axle. This second moment of area was calculated from the maximum stress on the axle, vehicle design and maximum bending moment which was found from the bending moment diagram.
3.6 This specification point was met. The reaction force of the jetting water acting on the vehicle was found, from this the mass of the vehicle was found so that the frictional force between the wheels and ground would keep the vehicle in equilibrium. However, as this was not tested, it is unknown how accurate this is

4.1 This specification point was partially met. An Arduino microcontroller was used to program the Bluetooth communication and the rotation of the hose mount. However, Due to the time limitations, I was not able to program the movement control of the vehicle so that it could be operated from an app.
4.2 This specification point was met. A Bluetooth HC-06 module was programmed and tested for the communication between the vehicle and the app, but unfortunately there was no time to further develop the app.
4.3 This specification point was met. Three LM35DZ temperature sensors were positioned on the outside of the hose mount and the Arduino microcontroller was programmed to rotate in the direction of the greatest fire and send signals for the water flow to be turned on until all fires were extinguished.
4.4 This specification point was not met. Although the Bluetooth communication between a pre-installed app and the Arduino microcontroller was established, the app was initially meant to be designed for ease of operation and it was meant to have a channel for the live video streaming. Due to design changes and time limitations, the app was not developed.
4.5 This specification point was met. The capacity of the battery was picked after calculating the current that each motor should have and deciding a time limit for which the battery must be operable so the battery must provide a certain current for that period of time.
4.6 This specification point was met. The MDD10A motor controller was picked for controlling both batteries as it would allow the motors to spin in different directions by the control of a microcontroller, and they could be powered from the same source.
4.7 This specification point was met. A circuit diagram was created showing all of the electronic components. All the resistor values were also calculated so that the motors would have the required power and spin at the required torque.
4.8 This specification point was met. A 555 timer was created and the resistor values were calculated with the chosen capacitor value so that the LED would flash at the required mark time of 0.6s and space time of 0.4s.

Evaluation of the Process

The original gantt chart that was made at the very start of the project was very vague, the points were not very detailed, it was also very ambitious as little time was given to the mathematical modelling and I even hoped on creating a real model of the vehicle. At this stage, I had not yet fully appreciated the scale of the project, after some time of getting into the project, gantt chart 2 was made.

Gantt chart 2 followed a similar structure to gantt chart 1, but it gave a much clearer structure with detailed points for each stage of the process, and the deadline was also extended. However, I still hoped to complete a model of the project after completing all of the simulation and mathematical modelling.

However, I was unsuccessful in following this gantt chart after completing the research. The research took a lot longer than expected and it was clear that finishing the project on time and also completing a model of the vehicle would not be possible to complete on time. Gantt chart 3 was created after the research and it gave a clear guidance of how to complete the rest of the project on time with clear points for all the mathematical modelling and simulation stages.

Unfortunately, I have again been unsuccessful in following this structure. On gantt chart 3, I failed to allow float time for delays due to Christmas and prelims. Due to Christmas, preliminary exams over January, assignment work in other subjects, and procrastination, there was a major halt in the project completion. This delay meant that tasks on the critical path were not being worked on which could mean that the project might not be completed on time.

A lot of work was done after January to bring the project back on track to completion. Luckily, some of the tasks did not take as long as I initially thought they would. For example, the shear force and bending moment diagrams, and simulations of each major system took substantially less time to complete than the amount of time allocated to them in gantt chart 3 which can be seen from the record of progress. However, this did not allow me to get the project back to the timeline of the gantt chart, lots of time and work still had to be put in the last couple of weeks to get the project finished. This meant that the last weeks were extremely stressful and there was absolutely no float time.

If this project were to be repeated or if a similar project was carried out, I would like to spend more time outlining and looking into all the tasks that this project will include. This would allow me to designate a specific amount of time to each task instead of just estimating. This would also allow me to allocate more float time to the project and allow float time for when the project completion could be at a slower pace such as Christmas. Having a more detailed timeline and gantt chart at the start of the project would make it a lot easier to follow and it would allow me to complete the project in time with much time to spare.

Further Developments

If the project were to be continued, one of the main further developments would be the development vehicle or the construction of a model of the vehicle. This model would allow multiple specification points to be tested for which a simulation would not work. For example, a simple garden hose could be used instead of the fire hose, the model vehicle could then be scaled down so that the mass of the vehicle would produce a frictional force equivalent to the new force from the fire hose. The torque of the would also be scaled down so that the lighter vehicle would still move at the required speed and acceleration.

By creating this model, it would be possible to assess specification points that were either unmet or whose fulfilment level was unknown because they weren't tested previously, due to the absence of a suitable model for testing. With the model, it would be possible to test the following: How well the vehicle would extinguish fires (1.1); How well the vehicle could traverse through small spaces (1.5); How suitable the required speed and acceleration is to travel over obstacles (2.3); How well a mild steel body shell would protect the inner contents from fire (3.1). If these specification points would be met for the model, then they would be met for the actual vehicle meaning that the calculations carried out for the vehicle in this project would be correct.

Another major further development for this project would be to fully design all mechanical components of the vehicle as I did not have enough time to do so. These mechanical components would include: Designing a sophisticated steering system - calculating the length and position of the steering links, calculating the size and angle of the steering arms, positioning the steering components so the vehicle would steer at the right angle when a signal is received from the operator's device (2.4); Designing a sophisticated mechanism for the rotation of the hose mount - in this project the rotating hose mount was just placed on a DC motor for which the torque was calculated, but more work would have to be put in to create a mechanism that would ensure that the hose mount would not break, perhaps a gear system could also be used.

Lastly, a further development would be to program a proper app for the control of the vehicle instead of using a pre-installed app (4.4), And program the control of the vehicle (4.1). Due to the time limitations, I did not manage to design an app for the control of the vehicle, or program the actual control of the vehicle. If the model of the vehicle were to be made, these developments would first need to be done so that the model could properly be tested.