ENGG1100 Concept Report

Figure (Fire and Rescue, n.d)

Unmanned Firefighting Truck Subsystem Report

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# Executive summary

It comes as no surprise that the risks involving fire fighting are extreme, and so, any measures to reduce such risk are advanced. A particularly favoured method of reducing the risk of injury or death to firefighters is the notion of an unmanned fire fighting truck. Within such a fire truck, the power subsystem would incentivise the importance of ensuring that a power system were not only able to run all components of the truck, but also able to run it at its most optimal performance. The system design would have to meet criteria of safety, lifespan, performance, cost, environmental impacts and weight, whilst also ensuring that enough power reached its primary components, namely, water pumps, servos, wheel motors/controllers, Arduinos and in the case of this investigation, Bluetooth receivers.

Three total battery solutions were compared, namely, Energizer NiHM Rechargeable AA batteries, Duracell Ultra Power AA alkaline (manganese dioxide) batteries and Energizers Eveready Super Heavy Duty AA Carbon Zinc Battery. When investigated against the criteria, it was concluded that Duracell Ultra AA batteries were far superior to its competitors and was therefore concluded as the final design.

Although this one battery setup is applicable using voltage regulators to ensure that each component is given their specific operating voltage, a possible improvement to the investigation would be to compare the single battery setup with one of multiple battery sources specific to each component.

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# 1.0 Introduction

## 1.1 Context

Although vehicles in the firefighting industry have certainly made their strides over recent decades, the safety and efficiency of an unmanned fire truck would be relatively unrivalled.

As such, the ARFF are interested in the design of a functioning unmanned firefighting truck (UFT). It is the purpose of this investigation to examine and decide on options for the power systems of a miniature prototype UFT.

## 1.2 Project Scope

The concepts discussed within this report will analyse the power and control subsystem of a small-scale prototype fire engine, more specifically the types of batteries used to power the truck and its functions.

The following table (table 1) was constructed prior to the investigation to ensure that the component options could be evaluated off a criterion suitable for the machine.

|  |  |  |
| --- | --- | --- |
| **Objectives** | **Constraints** | **Assumptions** |
| The truck can move forwards and reverse with accuracy. | Dimensions of truck:  Length: 300mm  Width: 200mm  Height: 300mm | The upscaling of the truck will not be an issue. |
| The truck can extinguish the fire. | A maximum of 1L of water can be stored onboard the truck. | It is assumed that the test track is a controlled environment, for example, flat ground, minimal wind resistance, etc. |
| The truck can be operated from a single person without being physically handled. | Operator must be within the radius of the Bluetooth connector (from the controller to the trucks receiver). | Negligible arial interference will be experienced around the test track. |
| The trucks power consumption and battery combination are such that it can be active for over 10 minutes. | Ideally the weight of the battery should be small enough such that the truck’s should not exceed 2kg. | Batteries will be fully charged in advance of the trial. |
| The truck is capable of functioning around water, fire and high temperatures. | All systems, drive, power, control and fluid must be enclosed in the core truck. | The test track is inside resulting in weather conditions being insignificant. |

Table : Objectives, Constraints and Assumptions

## 1.3 System overview

The function tree in figure 3 depicts the primary requirements of all 4 of the subsystems within the UFT, however, this investigation is to focus solely on the power and control subsystem.

Figure : Power system components

Prior to the investigation, the team concluded that the truck would utilise the components found in figure 2, and therefore this task investigated batteries that will be used to power such components.

Figure : Subsystems of the UFT

# 2. Design criteria

A sample of design criteria for the subsystem was constructed as seen in table 2. The criteria were constructed in adherence with the constraints and objectives outlined in table 1 whilst also ensuring that the subsystem met the function requirements outlined in figure 2.

|  |  |
| --- | --- |
| Design criteria |  |
| Safety | The batteries should be safe for the tasks they are put under. |
| Lifespan | The batteries should have the ability to undergo the duration of the task without running out or overheating. |
| Performance | The chosen battery must be able to run the required components (discussed in table 3) at an efficient and constant rate. |
| Weight | Lightweight batteries must be utilised to optimise total weight. |
| Cost | Batteries that are inexpensive are preferred. |
| Environmental impact | The healthier the recyclability and disposability of the batteries, the more the design option is preferred. |

Table : Design criteria

|  |  |  |
| --- | --- | --- |
| Component | Operating Current | Operating Voltage |
| Zyw680 DC water pump (run at lowest voltage) | 1A | 12V |
| 2 x 9G micro servo motors | 2 x 500mA | 4.8V – 6V |
| 4 x Jaycar motorised wheels | 4 x 70mA | 3V |
| UNO R3 arduino | 40mA | 5V |
| L293D motor driver | 600mA | 4.5V |
| Bluetooth module (HC-06) | 8.5mA | 3.6-6V |
|  | Total Current | Highest Voltage |
|  | 3.05A | 12V |

Table : Component operating requirements

For the batteries to meet the performance standards suggested, the current and voltage requirements of the components were first evaluated in table 3. It was found that the battery must be able to provide 12V at 3.05A. However, as the system will only run for approximately 10 minutes, only one sixth of a 3.05Ah current would be required, this came out to be 0.508Ah. It was also determined that our design would incorporate voltage regulators such that each component was given their specific operating voltage from the total battery.

It was then established that table 4 was to be constructed in order to determine which design criteria were of up most importance to the task at hand. This was achieved by constructing a pairwise comparison decision matrix in which the weighting was determined by how many a particular criteria beat the others in importance.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Criteria | A: Safety | B: Lifespan | C: Performance | D: Weight | E: Cost | F: Environmental Impact | Sum | Weighting |
| A | - | A | A | A | A | A | 5 | 0.33 |
| B | - | - | C | B | B | B | 3 | 0.2 |
| C | - | - | - | C | C | F | 3 | 0.2 |
| D | - | - | - | - | E | D | 1 | 0.06 |
| E | - | - | - | - | - | E | 2 | 0.13 |
| F | - | - | - | - | - | - | 1 | 0.06 |

Table : Design criteria weighting

Table 4 clearly demonstrated that the main design criteria to be considered when choosing the power system was safety. This was then closely followed by performance and lifespan, leaving cost, environmental impacts and weight as the least important, however, not completely ignorable.

# 3.0 Design options

Whilst conducting the investigation on the three design options it was important to maintain the assumptions placed on the other subsystems such that the batteries met the 0.508Ah and 12V previously discussed. In order to fairly evaluate multiple types of batteries, it was decided that the comparison would consist of a nickel metal hydride battery, alkaline battery and carbon zinc battery connected in series to meet the required 12 volts, namely:

1. Energizer NiHM Rechargeable AA battery
2. Duracell Ultra Power AA alkaline (manganese dioxide) battery
3. Eveready Super Heavy Duty AA Carbon Zinc Battery

|  |  |
| --- | --- |
| Design option 1: Energizer NiHM Rechargeable AA batteries | |
| Safety | NiHM batteries have been reviewed as completely safe (sciencedirect, 2004). Concerns only arise when the batteries are ingested, mixed with other batteries or left in places of high heat (energizer, n.d). However, it is notable that recharging of the batteries is a greater risk to a person’s safety than purchasing new disposable batteries. |
| Lifespan | As the battery provides a total of 2.3Ah, if run at the 0.508Ah required, the battery should theoretically last for 4.53 hours (energizer, 2018). Although the practical lifespan will be significantly less than the theoretical, it is likely to still be sufficient for the UFT. |
| Performance | As seen in figure 4, a single AA NiMH battery can maintain a stable voltage of approximately 1.2. It is because of this stability throughout its entire lifespan that the battery can be considered relatively constant and efficient.  Figure : Voltage against %DOD (Energizer 2018) |
| Cost | As the batteries are rechargeable, they were expected to be more expensive than disposables. 12 (three packs of four) energizer NiHM batteries summed to $66 (Bunnings, 2023) |
| Environmental Impact | The batteries are efficiently rechargeable as seen in figure 5. This in-turn makes them environmentally friendly alternatives to the traditional single use, disposable batteries (energizer, 2018).  Figure : Voltage against Charge input (Energizer, 2018) |
| Weight | As each of the batteries only supplies 1.2V, 10 would be required in series in order to supply the 12V required. This would result in a total weight of 300g (thebatterysupplier, n.d). |

|  |  |
| --- | --- |
| Design option 2: Duracell Ultra Power AA alkaline (manganese dioxide) batteries | |
| Safety | Duracell Ultra batteries are considered non-hazardous unless leakages occur due to high temperatures or being electrically, physically or mechanically abused (Gillette Australia, 2003). |
| Lifespan | As shown in figure 6, when run at the required current of approximately 0.5A, a single Ultra Power Duracell AA can provide a constant current for around 3 hours. However, during comparison it must be recognised that other batteries lifespans may be built of theoretical values.  Figure : Voltage against service hours (Energizer, n.d) |
| Performance | When analysing figure 7, it can be seen that even when run at a high rate, the voltage provided is consistently between 1.6V and 1V even when it approaches its end of life.  Figure : Performance against %DOD (Energizer, n.d) |
| Cost | As the battery runs at 1.5V on average, 8 batteries would be required to sum to the total 12V required. The most cost-efficient method was a 10-pack costing $22.50 (Coles, n.d) |
| Environmental Impact | Although proper methods for recycling the batteries are advertised by retailers and Duracell, the batteries are non-rechargeable, single use batteries making them potentially harmful to the environment (Duracell, 2018). |
| Weight | A single Duracell Ultra AA battery weight 24g and as 8 are necessary, the total weight will be 192 grams (Duracell, 2018). |

|  |  |
| --- | --- |
| Design option 3: Eveready Super Heavy Duty AA Carbon Zinc Battery | |
| Safety | Similarly, the battery is only hazardous during a leakage usually caused by high temperatures, abuse or ingestion (Energizer, 2012). |
| Lifespan | The Eveready AA battery is theoretically capable of producing 1.1Ah of current. When run at the UFT’s required 0.508amps, the battery would theoretically last 2.17 hours. However, trials from Energizer in figure 8 found that when the battery was applied at a current of 0.508A (508mA), the battery only lasted approximately 45 minutes (Energizer, n.d).  Figure : Current against service hours (Energizer, n.d) |
| Performance | Studies found that the battery showed a similar steady decline in the voltage of the battery as it served time. This same decrease was seen over all trails, and it was therefore assumed that for our UFT’s components it would have the same trend making its performance questionable.  Figure : Voltage against service hours (Energizer, n.d) |
| Cost | As the batteries each supply 1.5 volts, only 8 would be needed in series to produce the total 12 volts. Two packets of four of the AA batteries costed $8.64 (Supplyhog, n.d). |
| Environmental impact | Similar to the Duracell AA, proper methods for recycling the batteries are advertised by retailers and Eveready, however, the batteries are non-rechargeable, single use batteries making them potentially harmful to the environment |
| Weight | The average weight of a single AA Eveready super heavy-duty battery was 15g and therefore the total weight required was 120 grams (Eveready, n.d). |

# 4.0 Evaluate and Validate

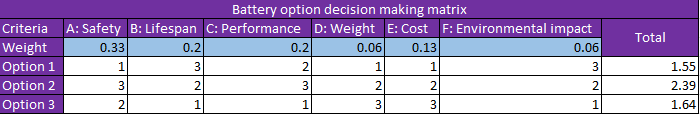
The three design options were compared using table 3’s criteria. Table 4 below demonstrates the rankings of the three potential options using a number system, 3 being the best, 1 being the worst. These rankings were then computed utilising the weighting system from table 3.

Table : Decision making matrix

As is clear from table 4, design option 2 (Duracell Ultra Power AA alkaline (manganese dioxide) batteries) was found to be the superior option by a considerable margin. To ensure that this conclusion was valid, a sensitivity analysis was conducted in which each criterion was changed by ±10% to examine whether any criteria had an unjustifiable effect on the results. As is evident from Appendix 1, in all trails of ±10% criteria weighting option 2 was always the highest rated.

# 5.0 Conclusion

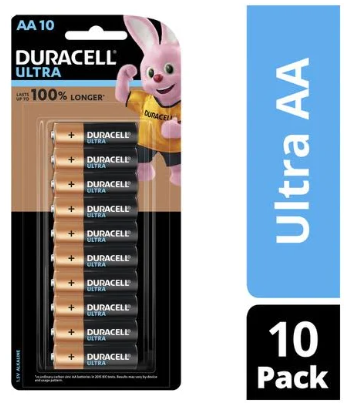
This concept report aimed at investigating the design of a battery system for a miniature prototype unmanned firefighting truck. Upscaled models of the UFT would prove to be not only more efficient, but also extremely beneficial to the safety of firefighters due to a lowered risk of injury and loss of life. The battery was to meet criteria in order to be a viable power solution to the truck’s components. These criteria were (in order of importance), safety, lifespan, performance, cost, environmental impact and weight. The subsequent battery chosen was the system of 8 Duracell Ultra Power AA alkaline (manganese dioxide) place in series. Although the report was thorough, a possible improvement would be to investigate using multiple batteries specific for each component rather than one source displaced through voltage regulators.

Figure : Duracell Ultra 10 pack (Coles, n.d)

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# 7.0 Appendices

## Appendix 1: Sensitivity matrix

A screenshot of a computer

Description automatically generated with low confidence

