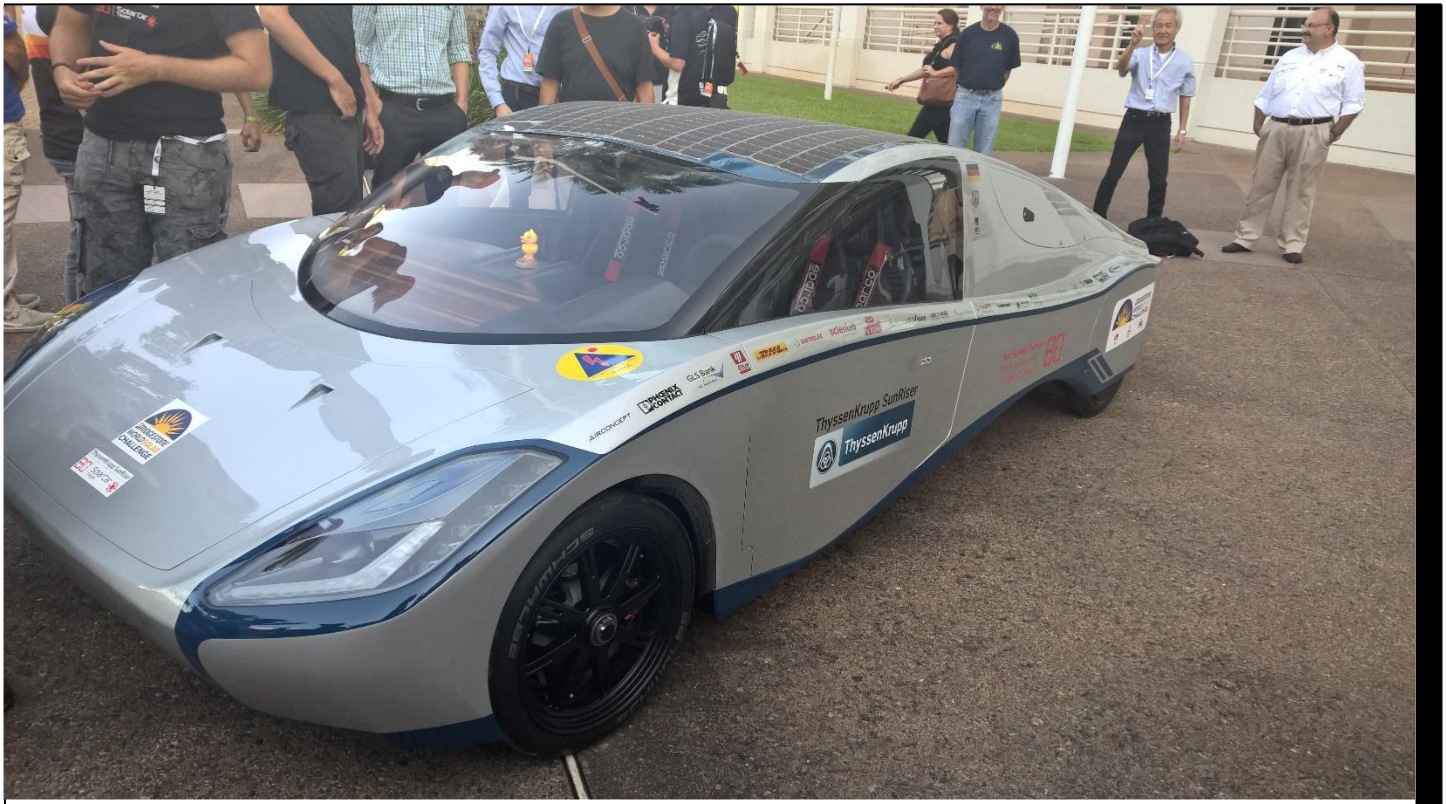

WHERE TO TAKE BREAKS IN AN ELECTRIC VEHICLE?

ENGN 2226 –SYSTEMS ENGINEERING ANALYSIS

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1.0 ABSTRACT

The Bridgestone World Solar Car Challenge is a solar car race that requires the highest level of energy efficiency for overall success. It has been identified that stopping on the peak of a gradient as opposed to a trough results in 10.34% in energy savings due to the harnessing of potential energy. In turn this results greater time at optimal speed (3.34% increase) which improves overall performance. In order to implement this conceptual model, systems analysis perspectives have been used to determine how the strategy concept will be practically adopted by Sol-Invictus. It has been recommended that multiple sources of altitude data along with local verification by the scout car are implemented to handle errors identified in altitude data. Risk assessment and driver safety have also been taken in consideration with their influence on model identification of optimal stopping points. The integration of these considerations with computational modelling has been suggested through a control process diagram. The modular design of the control diagram has allowed for ease of adoption be Sol-Invictus for integration with future work. The recommendation's listed in this report will enable the Sol-Invictus team to continue to build a robust model for finding the optimal stopping locations for driver change over.

2.0 CONTENTS

3.0 TABLE OF FIGURES

4.0 TABLE OF TABLES

5.0 INTRODUCTION

5.1 What is the Bridgestone World Solar Challenge?

The Bridgestone World Solar Challenge (BWSC) is an international challenge where teams from across the globe aim to cross 3000km of the harsh Australian outback in a highly efficient electric vehicle (EV).

5.2 Motivation for Analysis

The challenge is mainly focusses on energy management. Teams develop complex race strategies to optimise efficiency. To optimise the use of power that the electric vehicles capture, the motors and the electrical systems operate at above 95% efficiency, even in the most arduous of conditions.

While the motors used in the competition have among the highest efficiencies of all electric motors (The CSIRO/Marand electric motor operates at 98.4% peak efficiency) and aerodynamics that have been extensively modelled and tested (Brown, 2010), these technical areas provide marginal gain. In addition, they are costly, occupy significant amounts of time and the trade-off benefits are limited. Another avenue to provide efficiency gains is in the race strategy, and this is an active research area providing large time gains against competitors.

Since the driving hours (08:00 to 17:00) are dictated by the safety requirements in the Bridgestone BWSC regulations, there must be driver changes, limiting each driver to around 4 hours of racing each (Bridgestone, 2016). At each of these driver changes, the EV must slow down, stop, and then accelerate back up to cruising speed. As each of the motors are "constant run" (they draw the same amount of power regardless of speed), accelerating the vehicles takes valuable energy away from the battery. To minimise this energy loss, stopping the EV at the top of an incline, changing the driver, and then coasting down the hill provides an energy gain without drawing energy from the batteries. This "free" energy required for accelerating back up to speed provides an easily adapted race strategy that has the potential to provide a high leverage benefit to a BWSC team.

Descriptive statistics were generated in relation to the slopes the teams will have to traverse during the journey from Darwin to Adelaide, and a Gaussian distribution with a mean slope of -0.00581 m/km and a standard deviation of 5.59 m/km was produced (see Appendix A). This analysis demonstrates that there will be numerous instances of steep slopes, and that an optimisation of stopping locations will be relevant and useful.

5.3 Aim and Scope

Given the sufficient evidence from the model and statistical analysis, a research question was established to give structure and guidance to further investigation into the strategy (Duke University). After establishing a theme, topic and focus, the following was the research question developed:

'Where does the Sol Invictus team stop the electric vehicle to optimise energy efficiency based on altitude data?'

The research question also indicates that the following is not within the scope of the problem:

Overtaking Procedures	Current or predicted solar radiance
Wind speed	Speed Limits
Battery Levels	Location of Control Stops

TABLE 1: OUT OF SCOPE FACTORS

These aspects are still to be considered in the final race strategy though due to limitations in time and scope they have been excluded from the analysis.

6.0 THE MODEL

6.1 Development of Model

The following MatLab model has been created to demonstrate the potential energy savings of stopping at peaks within the course. Details of relating to idealisations pertaining to speed, acceleration, altitude and slope have all been derived from statistical analysis of available world solar car challenge data in order to illustrate the most realistic outcomes. This model will compare the energy cost savings between two scenarios which represent a varying gradient over time.

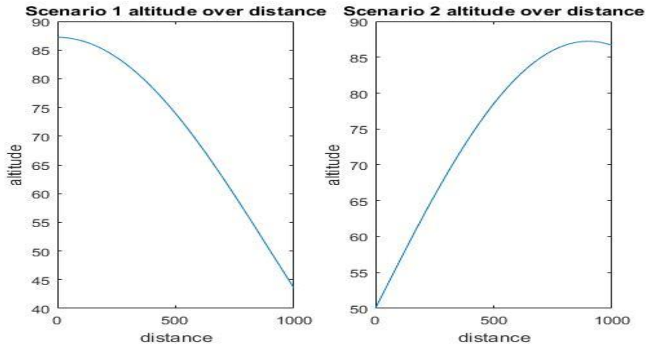


FIGURE 1: GRADIENTS OF SCENARIO'S FOR MODELS

The aim of this model is to prove that energy and speed savings in Scenario 1 (S1) are higher than those of Scenario 2 (S2).

6.2 Insights from the Model

This simulation show S1 is at an optimal speed for 3.82% longer than S2. If this same advantage was to be summed across a number of stops, it would add to high gains in distance travelled. Results from this model provide sufficient evidence that the concept of stopping on peaks was an advantageous strategy. Further details of this model can be found in Appendix D.

	Scenario 1 (S1)	**Scenario 2 (S2)**	**Difference**
Kinetic Energy	110.7MJ	100.1MJ	10.5%
Percentage at optimal speed (130 km/hr)	73.34%	70.7%	3.82%

TABLE 2:ADVANTAGES AND DIFFERENCES IN ENERGY AND OPTIMAL SPEED TIME

6.3 Limitations of the Model

Idealization's surrounding altitude, gradient and acceleration all were made in order to undertake the simulation. Small errors within the model that can be accounted to code structure and preferences for how MatLab handles data types. Factors considered out of the scope would also affect these results if they were considered.

Remaining sections of this report will analyse systems factors that must be considered in order to make the strategy model a viable option for Sol-Invictus.

7.0 Error Types

While using altitude data from previous challenge teams, sampling intervals for altitude affect the accuracy of any potential model being used. Sampling from the given altitude data was set in 1km intervals. Gradient variations between measuring points can potentially cause errors if data is directly fed into a control model (i.e. there may be a 600m flat followed by a sharp climb for 400m). Strategy must be put in place in order to manage these large sampling intervals.

7.1 CROSS CHECKING WITH TELEMETRIC DATA (NON- SAMPLING ERROR): Errors can be eliminated by cross-checking the telemetric data collected from other transponders – if a data point shows something out of the ordinary, it can be eliminated and the average gradient can be calculated for 2km instead of 1km.

7.2 VERIFICATION VIA SCOUT VEHICLE: Once a section of road was chosen (via given altitude data) a scout vehicle from the convoy will be sent out to verify peaks identified. Variance in the track that given data cannot account for will be reported back to the main convoy to determine the most suitable location for driver change over.

8.0 Safety Considerations

Safety and risk considerations must be considered and how they influence stopping strategy. Successful evaluation of risk and human safety is to identify the hazards present with the activity. Risk assessment must be conducted and influence the decision making particularly regarding the time between driver breaks and locations of driver stops.

There are five fatal factors outlined by the Queensland Government as being the primary causes of fatal crashes (Queensland Government, 2016). These are included below and the factors that are most relevant to the driving of an electric vehicle are bolded:

- **Distraction and Inattention**
- Drink and Drug Driving
- **Dangerous Driving**
- **Fatigue**
- **Failure to wear a seat belt.**

The next 3 steps are included in the Table located in Appendix B. These steps are:

1. Identification of the associated risk.
2. An assessment of the risk: This has been done by referring to a risk matrix seen in Appendix B.
3. Control of the risk – This has been done by referring to the Hierarchy of controls seen in Appendix B.

Risk analysis has identified a number of precautions to take when deciding on stop location. Driver safety and fatigue in particular will be managed as team members decide on the time frames of where to look for highest peaks.

9.0 Planning Perspectives

It will be important to develop a comprehensive plan as managing the time of the different cars each day is a complex task. The Gantt chart in Appendix F demonstrates that the turnaround for new stopping locations to be identified and checked for validity can be tight. The scout car does have other responsibilities as it may also be utilised as a supply vehicle. This role would include moving off the route and collecting supplies from nearby towns. These towns will be scarce and if the car is resupplying it may be impossible to check the validity of the proposed stopping locations. Teams also arrive at control stops ahead of their vehicles in order to prepare for the cars arrival and the scout car is might also be required to fulfil this role.

Adding a fourth vehicle could add some redundancy which would also increase the ability of the team to adjust to a mechanical failure in one of their support vehicles.

10.0 Control Systems: Integration of computational and qualitative assessment

The integration of error management in altitude data and safety and risk factors are taken into account in the control process diagram illustrated in Figure 2. Data, along with checks carried out by challenge personnel, feeds back into decision making points (coloured in grey) of the strategy.

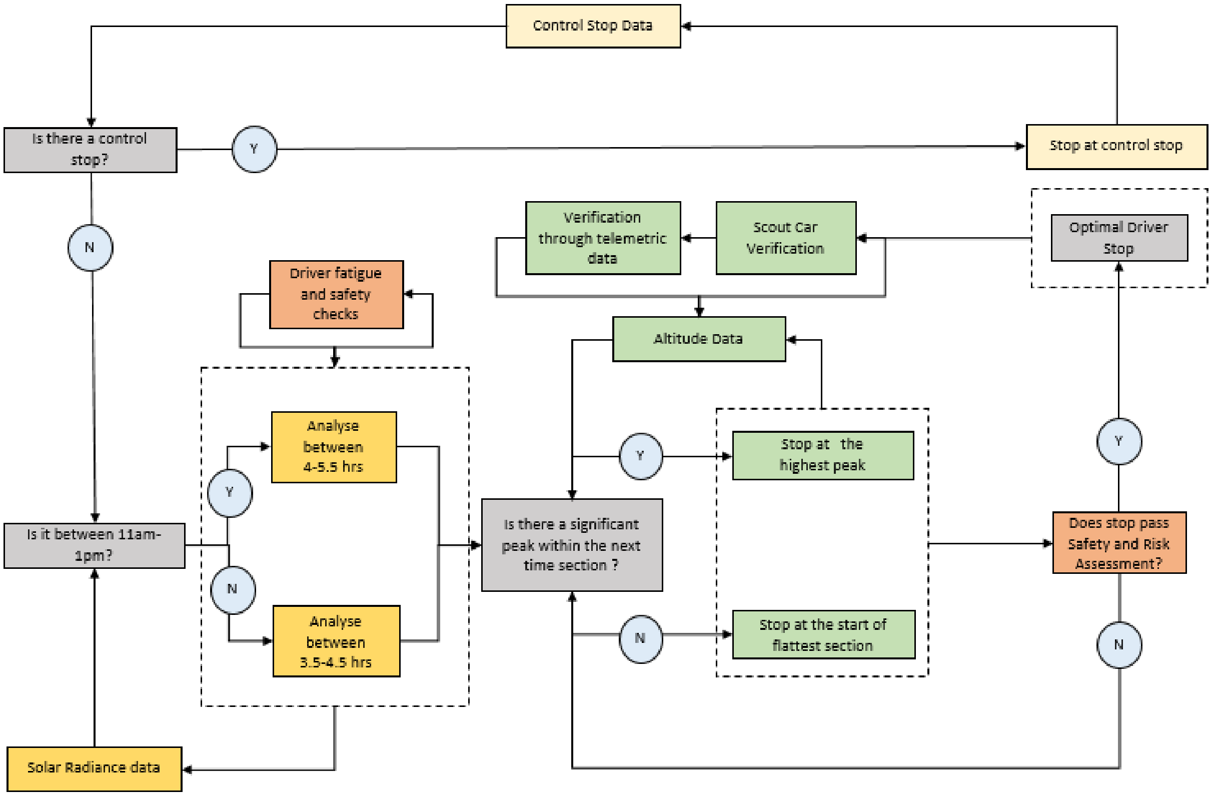


FIGURE 2: CONTROL PROCESS DIAGRAM FOR RACE STRATEGY

The aim of Figure 2 is to illustrate the integration of qualitative measures such as risk assessment into a dynamic computational model that will be used during the challenge. This diagram will provide Sol-Invictus with a frame work to continue building and implementing the strategy alongside other factors that have been considered out of the scope of this report.

10.0 RECOMMENDATIONS

The conceptual strategy of stopping at the highest peaks in the track for driver changeover has proved to be an advantageous strategy in harnessing the potential of the slope to increase time at optimal speed. For the concept to be actualized on the ground in the challenge, a number of practical measures must be implemented in order for full adoption. Analysis perspectives have been used in this report to explore these practical measures and to create recommendation's as to how they will be implemented and integrated within the Sol-Invictus team.

RECOMMENDATION 1: ERROR HANDLING AND VERIFICATION OF ALTITUDE DATA:

It is recommended that Sol-Invictus cross reference the given WSC altitude data with more refined data from other sources in order for more accurate prediction of stopping location. A potential issue identified with running a highest peak finder in a computational model has been the accessibility of accurate data. This is an issue for identifying both global peaks (i.e. 1km sampling size, altitude could be sampled in between two peaks) and local gradients (i.e. altitude data could be measured on a steep slope).

These issues can be rectified by identifying other more accurate sources of local data. Satellite and GPS data have been identified as a viable option in terms of accuracy, although further work will consider cost-benefit analysis.

RECOMMENDATION 2: USING THE SCOUT CAR TO VERIFY ALTITUDE DATA AND PERFORM RISK ASSESSMENT.

It is recommended that Sol-Invictus harness the use of a scout car to verify location gradient and perform risk assessment on the localized area chosen for a stopping point. In the scenario that the computational model has identified a local area for an optimal stop the scout car will be harnessed to scope and verify the optimal stopping point and perform risk assessment. Planning approaches and the Gantt chart (Appendix F) demonstrate the challenges associated with managing other scout car responsibilities.

It is also recommended that the team engage in practice training runs where the model is being utilised.in order to practice the complex timings that are indicated in the Gantt chart located in Appendix F.

RECOMMENDATION 3: INTEGRATION INTO THE SOL-INVICTUS BROADER CHALLENGE STRATEGY MODEL.

It is recommended that Sol-Invictus take the model (Figure 2) to integrate into further challenge strategy. It has been identified to be of high importance to demonstrate how the conceptual strategy that has been demonstrated in the model (Section 6.0) and further explored in through error and risk analysis will be taken by the Sol-Invictus team for further work. The control process diagram (Figure 2) is the collation of the conceptual strategy and the how other factors will be considered for successful implementation.

Variables listed in Table 2 will need to be considered in future work and how qualitative checks by Sol-Invictus personnel (i.e. Risk assessment) illustrated in Figure 2, can be connected to decision processes with respect to other variables.

FURTHER WORK AND OPPORTUNITIES FOR IMPROVEMENT:

As the technical team of Sol-Invictus mature and development of more complicated control systems and race strategy are considered, it is expected that the factors listed in Table 3 will be modelled into computational models and integrated with the work shown in this report.

Overtaking Procedures	Current or predicted solar radiance
Wind speed	Speed Limits
Battery Levels	Location of Control Stops
Speeding up or slowly done to avoid unnecessary stops.	The length of time that each driver can drive for before fatigue becomes a risk (see Appendix F.)
Ways to triangulate Data	Planning of Car locations

TABLE 3: FURTHER WORK

The final goal of the model will be to account for all variable listed in Table 3 to inform the team's race strategists a number of optimal stop locations. It is then important for the team's race strategists to use this information combined with information from other sources like the scout, communication with the driver to refine the recommended stop locations. By the combination of computational modelling of quantitative variables alongside qualitative assessments of risk and planning, a stop location which helps conserve the electric vehicles energy will be found.

7.0 BIBLIOGRAPHY

AUSTRALIAN GOVERNMENT 2016. ELVIS - Elevation Information System. *In:* AUSTRALIA, G. (ed.). http://www.ga.gov.au/elvis/.

AUSTRALIAN NATIONAL UNIVERSITY. 2016. *Data Organisation Guidelines* [Online]. Available: https://services.anu.edu.au/research-support/tools-resources/data-organisation-guidelines [Accessed 10/09/2016 2016].

BRIDGESTONE 2016. 2017 Regulations. *In:* CHALLENGE, B. W. S. (ed.).

BROWN, J. 2010. High Efficiency Permanent Magnet Motor. Marand Precision Engineering.

BROWNE, C. 2016. ENGN 2226 Analysis Toolkit (Release Candidate). Wattle: The Australian National University.

DUKE UNIVERSITY. What Makes a Good Research Question? [Accessed 12/09/2016].

MENDOZA, A. 2016. WSC Design Challenge Info Pack. *In:* COURSE, E. (ed.). Wattle: Ed Muthiah.

NIKOLIC, N. 2015. *Risk Assessment* [Online]. Arriscar. [Accessed 14/09/2016 2016].

QUEENSLAND GOVERNMENT 2016. Fatal Five. *In:* QUEENSLAND POLICE (ed.).

6.0 APPENDICES

Appendix A: Descriptive Statistics

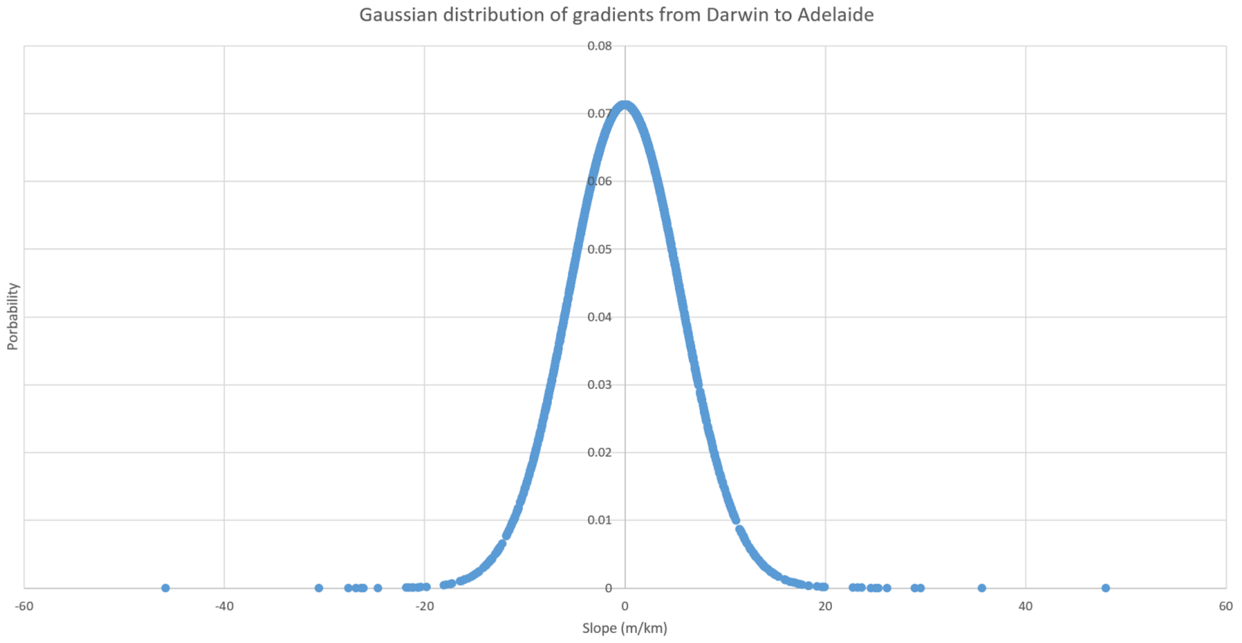
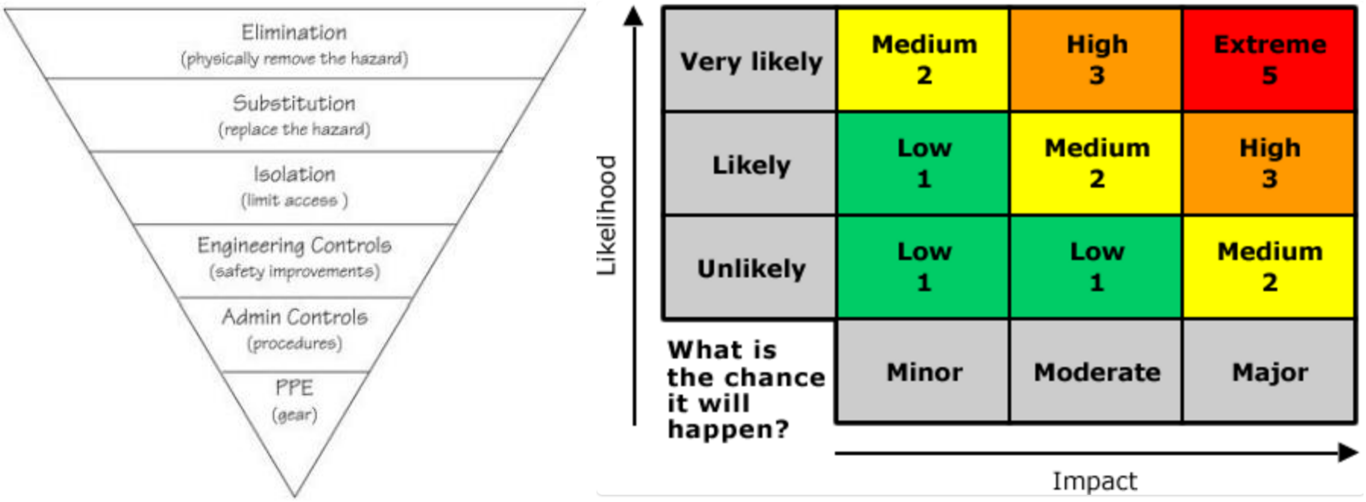


FIGURE 3: A GUASSIAN DISTRIBUTION OF THE GRADIENTS THAT ALL SOLAR VEHICLES WILL ENCOUNTER

Altitude and distance data were together used to calculate the slope for each kilometre of the 3000 km journey from Darwin to Adelaide. Subsequently, the mean and standard deviation could then be calculated which would then provide an indication of the terrain undulation. If the terrain does not produce many steep slopes, then optimising stopping locations is likely to produce negligible improvements. However, with a calculated standard deviation of 5.59 m/km, there will be a considerable number of instances of steep slopes. A race strategy that optimises stopping locations will therefore have a number of opportunities to be implemented during the challenge.

Appendix B: Safety and Risk Perspectives



What is the chance it will happen?	Minor	Moderate	Major
Very likely	Medium 2	High 3	Extreme 5
Likely	Low 1	Medium 2	High 3
Unlikely	Low 1	Low 1	Medium 2

FIGURE 4: HIERACHY OF RISK (BROWNE, 2016) AND RISK MATRIX (NIKOLIC, 2015)

Hazard	Associated Risk	Risk Assessment	Control of Risk
Driver Fatigue	Crash	High (Likely, Major)	**Elimination:** It is unlikely that it will be possible to eliminate all or even most of driver fatigue. But some could be eliminated via shorter periods of driving before stopping. **Substitution:** N/A **Isolation:** N/A **Engineering Controls:** Centralised driving position can reduce the severity of a crash by moving the driver further from possible points of impact. **Administrative Controls:** Stopping more often and also increasing the time spent training are both ways to mitigate this risk. Establishing communication via radio to the driver is another way to manage this risk. **Personal Protective Equipment:** Helmets to protect the driver and cool suits to keep the driver from overheating.
Inexperience	Crash	Medium (Unlikely, Major)	**Elimination:** N/A

			Substitution: N/A **Isolation:** N/A **Engineering Controls:** Designing the car so that it is easier to drive by paying special attention to elements such as torque steering. **Administrative Controls:** It is necessary already to ensure that drivers get 12 hours of experience before the race. If possible more experience and ensuring that the controlled environment experiences are similar. **Personal Protective Equipment:** Helmets to protect the driver in the case of a crash.
Distractions	Crash	Medium (Unlikely, Major)	**Elimination:** It is possible to eliminate many distractions for example. Communications to other teams can be handled by a team member in a support vehicle. The driver will however need to have a communication channel with at least one person in the support convoy. **Substitution:** N/A **Isolation:** N/A **Engineering Controls:** Manufacturing the car so that hands free radio communication with the convoy is easy. **Administrative Controls:** Ensuring drivers surrender devices such as mobile phones and other devices that could act as a distraction. **Personal Protective Equipment:** Helmets to protect the driver in the case of a crash.
Dangerous Driving	Crash, time penalties	Medium (Unlikely, Major)	**Elimination:** This can be partially eliminated through a team culture of “Safety first”. Administrative controls are a way that this culture can be created. **Substitution:** N/A **Isolation:** N/A **Engineering Controls:** The car will have an optimum speed and it might be more efficient to have the car cruise control at that speed which will prevent one form of dangerous driving in the form of speeding.

			Administrative Controls: Drivers who act dangerously will lose their position. Could help establish the culture that can eliminate dangerous driving. **Personal Protective Equipment:** Helmet in the case of a crash.
Failure to wear a seat belt	Crash Severity	Medium (Unlikely, Major)	**Elimination:** This can be partially eliminated through a team culture of “Safety first” (always wear a seat belt). Administrative controls are a way that this culture can be created. **Substitution:** N/A **Isolation:** N/A **Engineering Controls:** The car will have to have a comfortable and easy to use seat belt installed. Sensor to determine if seat belt is secure. **Administrative Controls:** Drivers who do not wear a seat belt will lose their position. **Personal Protective Equipment:** Helmet in the case of a crash.

TABLE 4: RISK CONTROLS

Appendix C: Data Organisation

It is important to organise your data in order to increase the reliability, readability and overall usefulness of the data sets that you have either created or utilised. It is also important, as it is often necessary, to order data that is currently unstructured to achieve the goals outlined above.

The design challenge data files included the data that was necessary to develop this initial model (Mendoza, 2016). The data that was useful as a starting point for our race strategy model was the altitude and the location (latitude and longitude). Other data like the speed limit and the location of control stops are vital to understand and predict but are not included in our simpler scoping model that has been produced for this project.

The ANU provides some guidelines when it comes to organising data that have not been followed already by the data set provided (Australian National University, 2016). Changes that were made to increase readability were:

Columns that represented data that were not used were removed in order to enhance the readability and reduce the unneeded complexity from the worksheet. More columns can be added when new factors are included in the model such as location of control stops.

Using a sheet in the excel workbook to put a brief description of the study and a data dictionary that will allow readers of our report to understand what the data represents and how it was used. This sheet also outlined how the MatLab analysis was conducted.

The data was screened in MatLab to provide a graphical representation for the data.

It has been discussed that the model presented in this report is relatively simplified compared to what would be needed to ensure a practical and robust race strategy. Building in further assumptions like reduced efficiency of solar cells due to dust, locations of control stops, solar radiation and speed limits would add to the complexity of the data that is needed and therefore it would be important to arrange this extra data in such a way that it could be linked easily to the existing data. This could be done in the same excel spreadsheet.

The other worry is that we are relying on a data set that has been supplied from an unknown source in an unknown year. Other sets of data can be included in a separate spreadsheet of the same workbook. Due to scope limitations this was not done but this could be done via a time intensive analysis of the Australian Government's Elevation Information System (ELVIS) (Australian Government, 2016).

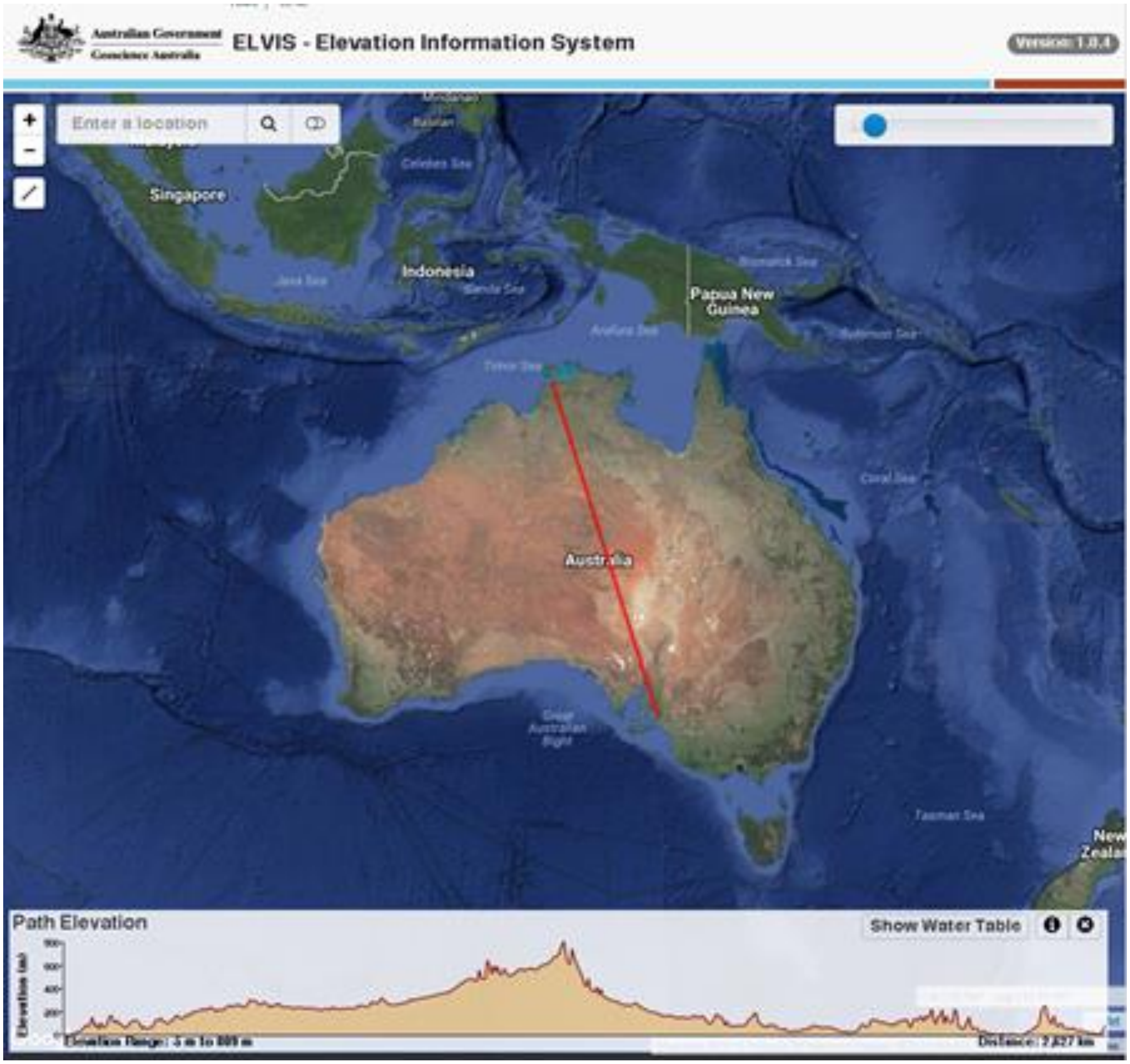


FIGURE 5: ELVIS DATA FOR THE CENTRE OF AUSTRALIA

Appendix D: Anthropometrics

Anthropometrics are an important consideration when designing any system as all humans are different and this can affect the suitability of the design. When talking about risk and safety driver fatigue was mentioned. The rate at which a driver becomes tired is going to be different for different drivers depending on their experience, training, heat resistance and many other factors. The BWSC regulations state that driver changeovers must happen once every 4 hours however the Queensland government recommends that a driver should stop every 2 hours and take a break.

If drivers were not able to last the full 4 hours, then the algorithm would be useless and would be analysing a section of the road that the team would not reach for the changeover. Over time, training will allow the team to get a more accurate time range where they will be stopping. This could be somewhere between 2 hours and 3 hours as an example.

Therefore, the recommendation is that continued development focus on outputting more than one stopping location for a time that can be set by the team. The team can then make the decision based on their knowledge which of these suggestions is the best for the situation and not always follow the recommendations the program delivers.

Appendix E: Sankey Diagram

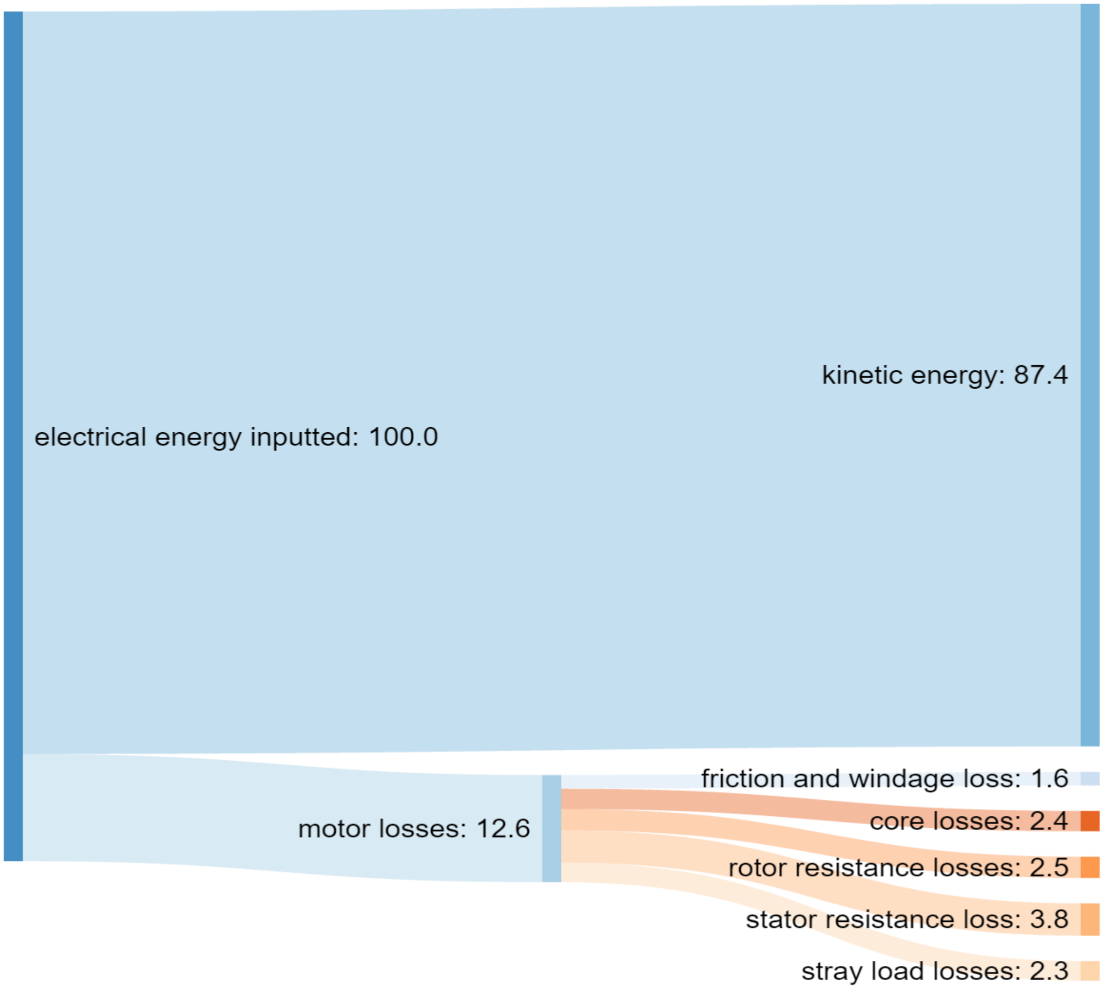


FIGURE 6: A TYPICAL ELECTRIC MOTOR WITH AN EFFICIENCY OF 87.4%.

While electric motors are effective ways of converting electrical energy to mechanical energy, operating in the 80% to 98% range of efficiencies (Australian Mining, 2006), a significant percentage of losses remain and over the course of great distances represent a suitable opportunity for optimisation. A mapping of energy flows for a typical electric motor was performed and the results can be seen in the form of a Sankey diagram (Figure 6) from which we can conclude that a reduction in the considerable motor losses could produce a substantial improvement in the overall performance for the Sol Invictus team.

Appendix F: Project Planning Perspectives

Day Planner

Period Highlight: #

▨ Plan

Day = 8am to 5pm or 9 hours/periods

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERIODS 1	2	3	4	5	6	7	8	9	10	11
Breakfast	1	1			▨										
Solar Car Driver 1	2	3				▨	▨	▨							
Packing Up Camp	2	1				▨									
Locate Viable Stop Points via Model	2	2				▨	▨								
Scout Car Checks Stop Point (Altitude and Safety)	4	1						▨							
Solar Car Driver 2	5	3							▨	▨	▨				
Locate Viable Stop Points via Model	5	2							▨	▨					
Scout Car Checks Stop Point (Altitude and Safety)	7	1									▨				
Solar Car Driver 3	8	2										▨	▨		
Locate Viable Stop Points via Model	8	1										▨			
Scout Car Checks Final Camp Site Viability.	9	1											▨		

FIGURE 7: GANTT CHART FOR A TYPICAL RACE DAY

Appendix G: Model Code

```
clc
clear
close all
%% getting the average altitude differential
max_allowable_speed = 130*1000/3600; %m/s
Data = xlsread('total_wsc_travel_data.csv');
 alt = Data(:,5);
 speed = Data(:,6);
 ave_speed = sum(speed)/length(speed);
 median_speed = median(speed)*1000/3600;
 if median_speed >= max_allowable_speed
     speed = max_allowable_speed;
 else
     speed = median_speed;
 end
ave_dist = [];
pks = findpeaks(alt);
for i = 2:length(pks)
    if  (pks(i) - pks(i-1))< 20
        continue
    else
        average_dist = pks(i) - pks(i-1);
    ave_dist = [ave_dist, average_dist];
    end
end
average_height_differentail = sum(ave_dist)/length(ave_dist);

%% Proof of concept
m = 200;
g = 9.81;
%Creation of Gradient sine wave
distance = 0:1:1000;
%time for the acceleration
time = 0:0.1:1000;
%Horzintal Vechicle acceleration
horiz_accel = 3; %m/s^2 :  needs a number.

%Gradient for scenario 1
altitude1 = average_height_differentail.*sind(0.1*distance + 90)+ 50;
gradient_1 = diff(altitude1)./diff(distance);
theta1 = atand(gradient_1);
%Gradient for scenario 2
altitude2 = average_height_differentail.*sind(0.1*distance - 90)+ 50;
gradient_2 = diff(altitude2)./diff(distance);
theta2 = atand(gradient_2);

%% plotting the Gradient %%
figure(1)
subplot(1,2,1)
plot(distance,altitude1)
title('Scenario 1 altitude over distance')
subplot(1,2,2)
plot(distance,altitude2)
title('Scenario 2 altitude over distance')

%% Calculate the energy expendature from scenario 1 and 2
```

```
% need to calculate the transient period where acceleration differs.

%% Scenario 1
a_X1 =horiz_accel+ g.*sin(theta1);
Vi1 = 0;
Vf1 = 0;
Vf1_array = [];
break_count1 = 0;
for p = 1:length(distance(2:end))
    % Velocity equation
    Vf1 = sqrt(Vi1^2 +2.*a_X1(p).*distance(p));
    Vi1 = Vf1;
    if Vf1 > speed && gradient_1(p) < 0
        % Stop acceleration
        break_count1 = break_count1 +1;
        Vi1 = speed;
        Vf1 = Vi1;
    end
    if Vi1 > speed
        Vi1 = speed;
    end
    Vf1_array = [Vf1_array, Vf1];

end
KE_1 = 0.5.*(Vf1_array.^2).*m;

%% Scenario 2 %%
a_X2 =horiz_accel+ g.*sin(theta2);
Vi2 = 0;
Vf2 = 0;
Vf2_array = [];
break_count2 = 0;

for n = 1:length(distance(2:end))
    % Velocity equation
    Vf2 = sqrt(Vi2^2 +2*a_X2(n)*distance(n));
    Vi2 = Vf2;
    if Vf2 > speed && gradient_2(n) < 0
        % Stop acceleration
        break_count2 = break_count2 + 1;
        Vi2 = speed;
        Vf2 = Vi2;
    end
    if Vi2 > speed
        Vi2 = speed;
    end
    Vf2_array = [Vf2_array,Vf2];
end
KE_2 = 0.5.*(Vf2_array.^2).*m;
%residuals
residuals = KE_1 - KE_2;

%% plotting the figures
figure(2)
subplot(3,1,1)
plot(distance(2:end),KE_1)
title('KE 1')
subplot(3,1,2)
plot(distance(2:end),KE_2)
```

```
title('KE 2')
subplot(3,1,3)
plot(distance(2:end),residuals)
title('Residuals')
figure(3)
subplot(4,1,1)
plot(distance(2:end),a_X1)
title('a 1')
subplot(4,1,2)
plot(distance(2:end),a_X2)
title('a 2')
subplot(4,1,3)
plot(distance(2:end),theta1)
title('theta 1')
subplot(4,1,4)
plot(distance(2:end),theta2)
title('theta 2')


figure(4)
subplot(2,1,1)
plot(distance(2:end),Vf1_array)
subplot(2,1,2)
plot(distance(2:end),Vf2_array)
```

MatLab Model: Reasoning for variables:

Top Speed: The most occurring speed limit of through the WSC course is 130km/hr, therefore, this speed will be selected for the model.

Acceleration: A constant horizontal acceleration for the solar car must be defined to calculate the energy. Given the expected mass of the car and the power draw from the electric motors, the expected acceleration on a flat gradient will be 3 $m\,s^{-2}$ (refer to code in the appendix).

Altitude: The average altitude will be used to define the amplitude of the scenario course. This was found using the "*findpeaks*" function in MatLab which identifies all local maxima in a data set. Once this was done, the height difference was then calculated between each local maxima and extrapolated throughout the data set. The average of this was found and used for the amplitude.

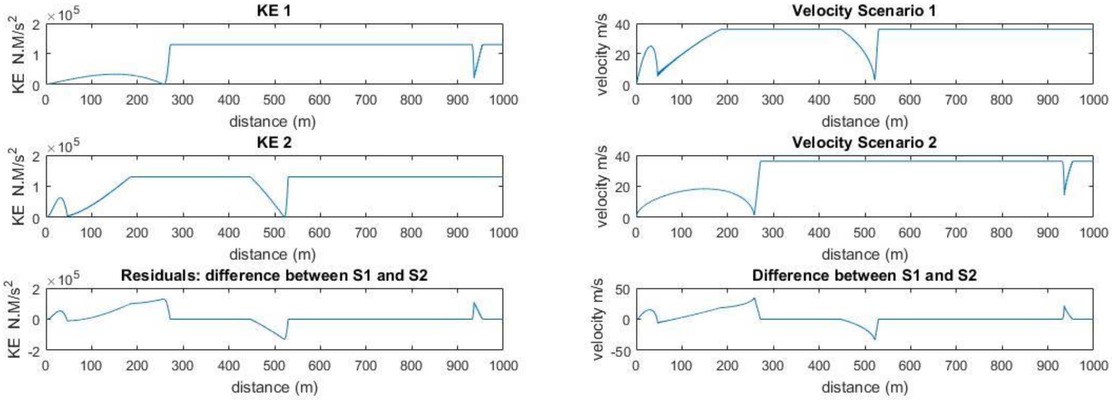


FIGURE 8: VELOCITY AND KINECTIC ENERGY DIFFERENCES