DESIGN REPORT

Analysis and report on a small pulley-driven car

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Introduction

Aim:
To design and manufacture a small pulley-driven car to traverse a 5 m inclined track in the quickest and most efficient manner.

Objectives:
-To achieve the shortest possible race time
-To use as few components as possible for a low cost of production
-To make the vehicle as light as possible
-To make a simple but efficient design for a quick manufacture time

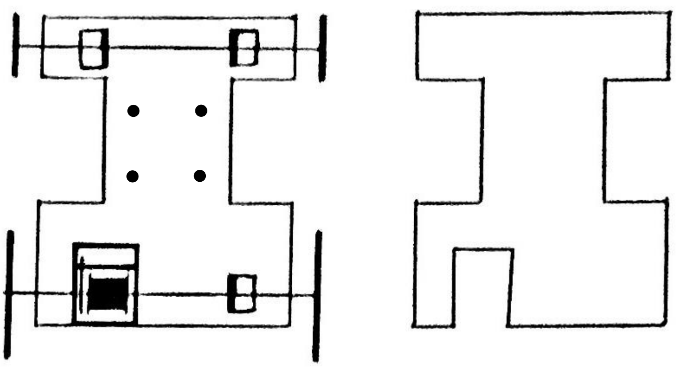
The main design consideration when creating a vehicle is the selection of components, the car has to make it all the way up the track in the fastest time which means using the most suitable components, this means calculating the results with several different set ups to find the best combination. One of the most important aspects to consider is the manufacturing process, any mistakes in the original design can lead to the final product not even being able to be fully manufactured. Things like the placement of drill holes, so that each component can be properly attached to the chassis and whether a cut is too small or tricky to make with the tools provided, must all be taken into account. Time management is crucial in a design, both in time taken to create the overall design, and the time to manufacture. The design deadlines must be met and a vehicle that is too complex would have an overly long production time. Finally, the overall quality of the design, the appropriate use of washers on bolts in contact with the plywood, any unnecessarily sharp points in the chassis design, etc. all need to be considered for a high-quality product.

The most considerable constraint on this design is the set components, each component is pre-fabricated and therefore has a set size with limited options. While this eases the overall design process it means there is a limit to what speed the car can reach.

Looking at the performance indicator, it's clear that the race time is the main focus. With a multiplier of 4 it has a rather large impact on the overall performance, much greater than the other factors. However, while trying to maximize speed for the best possible race time is the goal, there is a 60 second penalty for a car that is unable to make it up the track fully, therefore caution must be taken so that even if speed can be increased, the distance the car can travel must still be at least 5 m.

Design 1

Figure 1



View from Underneath Chassis

The initial design was a four-wheel car with two smaller wheels at the front (ø80 mm W3) and 2 larger wheels at the back (ø110 mm W5). The chassis was of rectangular shape with space cut away from each side to remove as much weight as possible, as shown in figure 1. The gearbox was placed on the rear axle and used a medium sized pulley (ø31.1 mm PPD2) for power with the gear ratio set to 1:1. Four guide rods were placed between the front and rear axle to make sure the car travelled in a straight line. All components were placed on the underside of the plywood.

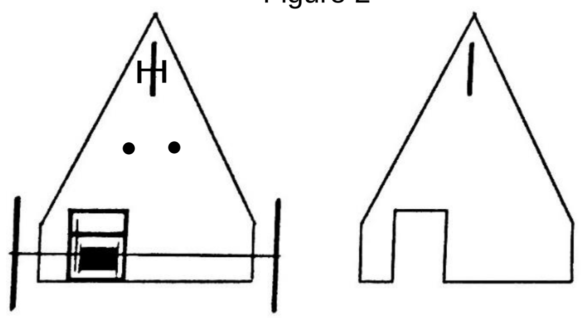
The thought behind this design was to give a basic idea of how the car worked and how each component affected the overall performance of the vehicle. A four-wheel format was chosen as this is usually what first comes to mind when thinking of a car, with the larger wheels at the back helping give more distance travelled per revolution. After running the calculations to see what effect each component would have, the decision was made for the first design to be one that focused on simply making it up the track. Not with the fastest speed, but instead a lot of leeway given to guarantee the successful finish of the car, even with a slow race time. Overall, this design was very slow but would leave no worries about the 60 second penalty for not finishing the track.

Pros:
- Safe option, this design will definitely make the full length of the track, therefore leaving no worries of a penalty.
- Easy to manufacture, due to the simplicity of the chassis with no curves or rounded corners there will be few cuts to make therefore a low production time.

Cons:
- Slow, due to the 1:1 gear ratio and medium pulley, this car doesn’t have much driving torque or acceleration leading to a low maximum speed and therefore slow race time.
- Heavy, a four wheel vehicle with two long axles meant this design had a high weight.
- Expensive, similar to the point above, a four wheel car with two long axles and 4 guide rods means more expensive components leading to a higher overall price.
- Structural integrity, if the cut sections on each side of the chassis leave too little material in the centre, it could lead to deformation or even breakage when the weight is released during the race.
- While the cuts to the plywood are simple, if too much force is applied with the hand saw then it could break at some of the more fragile areas of the chassis.

<u>Design 2</u>

Figure 2



View from Above   Chassis

The second design had three-wheels with 2 larger wheels at the back (ø80 mm W4) and one smaller wheel at the front (ø60 mm W2).The chassis had a triangular shape with a vertical cut just below the tip for the front wheel, as shown in figure 2. The gear ratio was upped to 2:1 with a large pulley (ø39.5 mm PPD3) for power. All components were placed on top of the plywood, except for two guide rods on the underside.

The goal of this design was the exact opposite of our initial design, it maximizes speed to traverse the full track in the shortest time possible. The four-wheel layout was changed to a three-wheel layout and the number of guide rods reduced to two in order to cut any unneeded weight. The gear ratio was upped to 2:1 in order to increase the rpm (revolutions per minute) of the wheels, while the sizes of both the wheels and the drive pulley were changed in order to increase the driving torque, for a smoother acceleration. Finally, the components were flipped onto the topside of the plywood to slightly lower the centre of mass. To summarise, this design was as fast as possible, but the calculations didn’t leave much leeway for any possible unforeseen energy losses during the race.

Pros:
- Fast, thanks to the large driving torque, this design had a high maximum speed achieving a speedy race time provided it reaches the finish line.
- Light, with the switch from four wheels to three, the overall weight of the vehicle dropped significantly.
- Lower centre of mass, due to moving most components to the top side of the plywood.
- Less friction, with only two guide rods as opposed to 4 there will be less contact friction between them and the track.

Cons:
- Risky, this design is calculated to be fast, but can only just make it up the 5 m track (5.2 m total travel distance) if everything goes perfectly according to our calculations. If there are any slight deviations in the manufacture or any unfactored energy losses, it may not cross the finish line.
- Awkward to manufacture, the front wheel would require a narrow cut in the centre of the plywood which could be difficult to make.
- Clearance issues at the front tip of the car, due to the smaller wheel at the front, the car's chassis is at an angle towards the track, therefore, if the front extends out too much this could leave the front wheel unable to contact the track.

Final Design

The final design finds a balance between Designs 1 and 2, though leans more towards the latter. Looking at the performance indicator, Design 2 is more in-line with the aim, however, the chance of failure is too high. Therefore, using Design 2 as a basis, several changes were made to address this risk factor:
- Three-wheel design with one smaller wheel at the front (ø60 mm W2) and two larger wheels at the rear (ø80 mm W4).
- Gear ratio of 2:1
- Two guide rods
- Medium pulley
- All components on the underside of the chassis

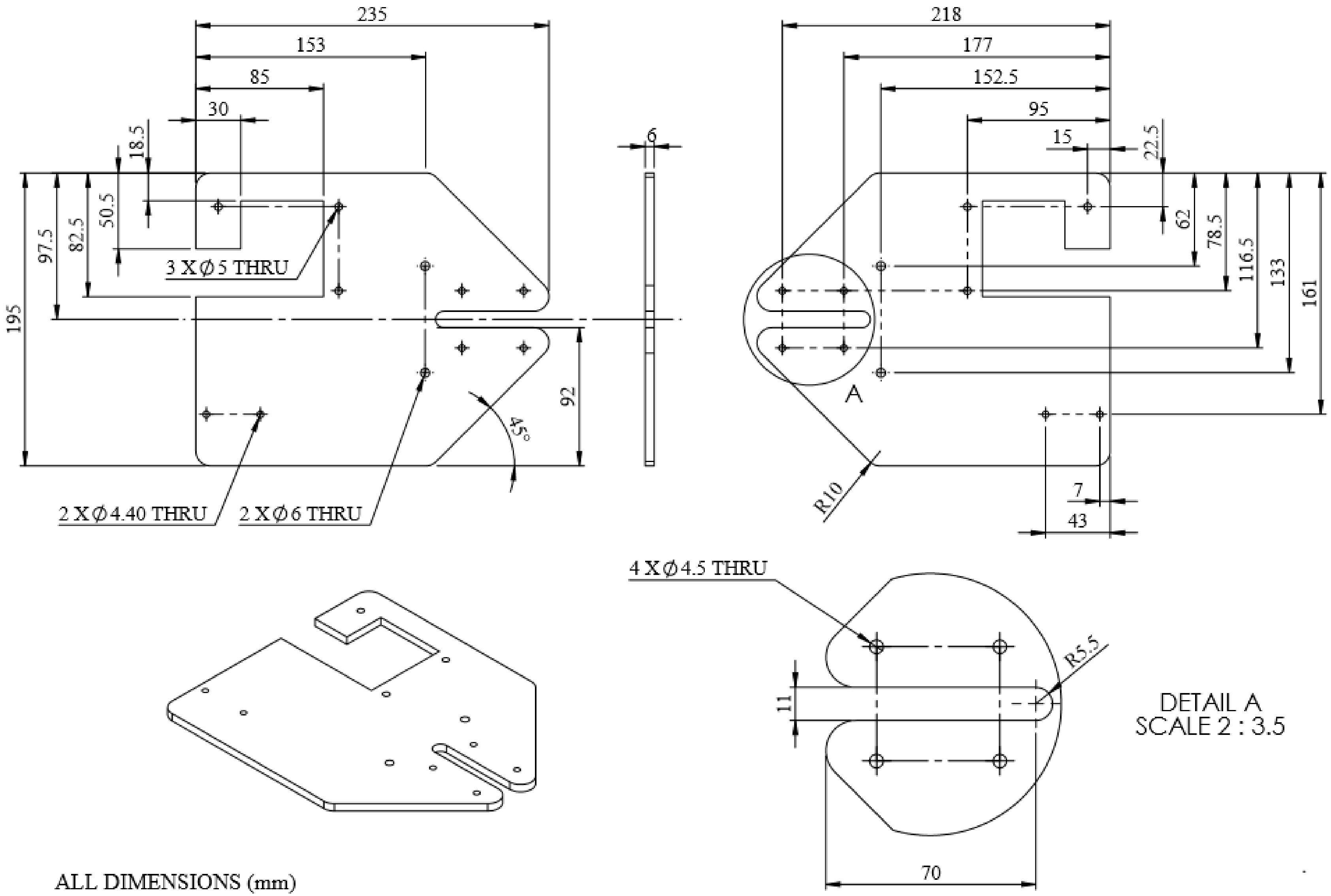
The chassis for this design is a cross between the previous two, a rectangular rear and triangular top gave the chassis enough material to keep its strength, without keeping any unnecessary weight. It has the same three-wheel set up as Design 2, with a smaller W2 at the front and two larger W4 at the back. The front wheel was moved to the very tip of the chassis, making it much simpler to make the cut and solving any possible clearance issues Design 2 may have had. The gear ratio stays at 2:1, but with a medium instead of a large pulley. While this does reduce the driving toque, it allows the car to travel further, therefore greatly increasing the chances of finishing the full track. This slows the car down, but it solves the main issue of Design 2, leaving no worries of a 60 second penalty. The other changes made were to improve the overall quality of the design; fillets were added each corner on the chassis for a nicer finish, the overall dimensions were tweaked to balance the load between the front and rear axle, and the guide rods were better oriented to minimize any friction or wobbling.

Overall, this design took inspiration from both previous designs to balance speed and reliability. It takes into consideration each design objective while keeping the overall quality at a high standard.

Evaluation

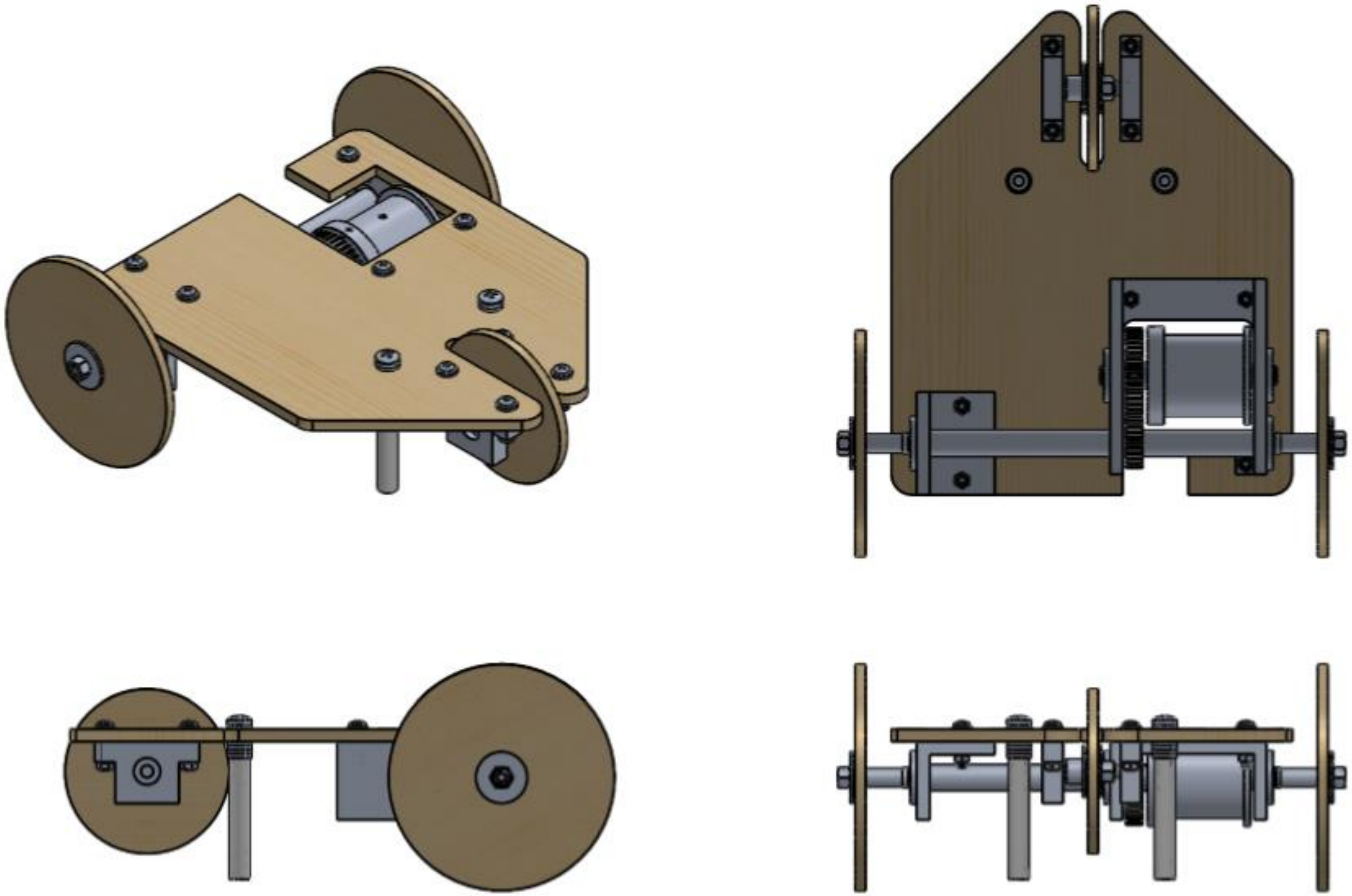
The manufacture of our car went very well, resulting in a high-quality final product. We managed to assemble our car to a high standard within the allotted 3 hours thanks to good preparation and the many manufacturing considerations made during the design process. One such preparation was the template we carefully made before the make session, this meant that we could simply draw around it to give us a perfect outline and mark our drill holes so that we could get straight to cutting. This also helped with the level of precision, as we were able to measure out our dimensions without worrying about any time limit. A plan was made before hand of how the chassis was going to be cut to make sure there was no breaks splinters, for as perfect of a finish possible. Finally, during the make session we drilled most holes slightly larger than they needed, leaving some room for adjustment to align each component, however, we were limited by the drill sizes provided.

During the test race our car did not perform as we expected. This was largely due to a major fault in it’s manufacture, while setting up the drive pulley we did not use enough string, causing the car to stop part way up the track. This was an easy fix, as we simply need to use more string and our car should successfully reach the finish line. However, that wasn’t the only issue we spotted during the race; we also saw that our car had trouble accelerating. It had a high enough speed once it got going but took too long to get there. After analysis, the problem was found to be caused by a lack of torque due to the 2:1 gear ratio, this could be solved by either changing the gear ratio or using a larger drive pulley. We opted for the latter, as a lower gear ratio would slow the car down even further than it already was. The larger drive pulley will provide a larger driving torque, therefore providing a much smoother acceleration and could even further increase the maximum speed slightly. However, changing to a large pulley had many other implications, it meant that with the wheels we were using, the car might not have enough revolutions to make it all the way up the track. This meant enlarging each wheel by one size, with the front wheel increasing to W3 (ø80 mm) and the rear wheels to W5 (ø110 mm). This may impact the maximum speed but should be outweighed by the increase in driving torque from the larger drive pulley. The increased wheel size also meant that the guide rods no longer extended into the track, several washers had to be placed on the bolt to provide the extra length needed. Such drastic changes involved redoing each calculation and largely impacted our performance indicator, but we decided that compromising on weight and price was worth it for the extra few seconds on our race time. Considerable time and thought went into each modification, but we expect this to better achieve the aim we set at the start of this project.



ALL DIMENSIONS (mm)
ALL DIMENSIONS ± 1mm
ALL FILLET RADII 10 mm
MATERIAL: PLYWOOD

SCHOOL OF MECHANICAL, AEROSPACE & CIVIL ENGINEERING THE UNIVERSITY OF MANCHESTER OXFORD ROAD MANCHESTER M13 9PL	NAME	GROUP A11	TITLE	FINAL CHASSIS
	DATE	14/11/19	SCALE	1:3.5
	PROGRAMME	MECH	PROJECTION	FIRST ANGLE
	EMAIL	harry.byrne@student.manchester.ac.uk		



SCHOOL OF MECHANICAL, AEROSPACE & CIVIL ENGINEERING THE UNIVERSITY OF MANCHESTER OXFORD ROAD MANCHESTER M13 9PL	NAME	GROUP A11	TITLE	FINAL ASSEMBLY
	DATE	14/11/2019	SCALE	1:3
	PROGRAMME	MECH	PROJECTION	FIRST ANGLE
	EMAIL	harry.byrne@student.manchester.ac.uk		

FMEA

A FMEA (Failure Mode Effect Analysis) is used to identify and resolve any possible failures in design. It produces a numerical rating, Risk Priority Number (RPN), for how sound the design. The RPN is based on 3 factors; how often it occurs (O), the severity (S) and the difficulty of detection (D). Our initial designs had an RPN of **1008**, but with revisions this RPN dropped to **491**.

Mode of failure	Cause of failure	Effect of failure	O	S	D	RPN	Required Action
Vehicle not moving straight	Axles/brackets not aligned properly, poorly built.	Vehicle will not move in a straight line causing more contact/friction between the guide rods and track.	6	6	3	108	Check and adjust the angle of axles before race.
Loose bolts/nuts	Bolts/Nuts not tightened properly due to poor construction.	Causes wobbling, or possible loss, of components resulting in unstable movement of the car.	3	5	7	105	Ensure all nuts are tightened with appropriate force before race.
Loose grub screws	Gears sliding over the axle.	Vehicle will not move as no power is transferred between pulley and rear axle.	5	10	6	300	Tighten all grub screws.
Tight bolts/nuts	Overtightening of nuts.	Plywood can splinter or possibly break, could shear the thread leading to complete failure of the fastening.	6	5	2	60	Take care when tightening not to use too much force.
Plywood breaking	Bad chassis design.	Deformation or possible break in chassis at any thinner/fragile areas while cutting.	4	9	2	72	Change shape/design of chassis to thicken any weaker areas.
Plywood splintering	Poor craftsmanship.	Ugly and sharp splinters on chassis surface/edges causing possible cuts or splinters.	5	2	1	10	Take care when cutting, file and sand down all edges.
Gear not meshing well	Gears not aligned properly.	Lower power transfer/jerky movement lowering overall speed.	5	7	3	105	Adjust alignment of gears to make sure there is full contact between each of the teeth.
Vehicle going in the wrong direction	String wound the wrong way around drive pulley.	Complete failure, vehicle will not finish the race	4	10	4	160	Make sure the string is wound the correct way, test direction of wheel rotation by pulling string.
Component assembly	Incorrect components used	Vehicle will not perform as expected, possibly causing complete failure	2	8	2	32	Check each component given at the start of the make session is correct.
Component assembly	Missing/misplaced small components; washers, clips, etc.	Bearings possibly falling off due to missing clips, bolts not being secure enough due to no washers to spread the force.	2	7	4	56	Check over each component with reference to design drawing and test cars function.
Total						1008	

Mode of failure	Cause of failure	Effect of failure	O	S	D	RPN	Required action
Vehicle not moving straight	Axles/brackets not aligned properly.	Vehicle will not move in a straight line causing more contact/friction between the guide rods and track.	2	6	3	36	Confirm alignment with multiple checks during assembly and again before the race.
Loose bolts/nuts (Not modified)	Bolts/Nuts not tightened properly due to poor construction.	Causes wobbling, or possible loss, of components resulting in unstable movement of the car.	3	5	7	105	Ensure all nuts are tightened with appropriate force before race.
Loose grub screws	Gears sliding over the axle.	Vehicle will not move as no power is transferred between pulley and rear axle.	1	10	6	60	Tighten all grub screws, then check by rotating the pulley to make sure the wheels also turn with equal speed.
Tight bolts/nuts	Overtightening of nuts.	Plywood can splinter or possibly break, could shear the thread leading to complete failure of the fastening.	2	5	2	20	Take care when tightening not to use too much force and use washers on all bolts in contact with the chassis.
Plywood breaking	Low quality material.	Deformation or possible break in chassis at any thinner/fragile areas while cutting.	2	9	2	36	Swap for a new piece of plywood or change material entirely.
Plywood splintering	Low quality material.	Ugly and sharp splinters on chassis surface/edges causing possible cuts or splinters.	2	2	1	4	Swap for a new piece of plywood or change material entirely.
Gear not meshing well	Gears not aligned properly.	Lower power transfer between rear axle and pulley resulting in lower overall speed.	2	7	3	42	Test the power transfer by comparing the rotation of wheels compared to pulley, adjust appropriately.
String slipping around drive pulley	String not properly wound around the pulley.	Will cause loss of rotations resulting in a lower total travel distance, leading to not finishing the race if too much distance is lost.	4	5	5	100	Make sure the string is properly tied and tightly wound around the pulley.
Component assembly (Not modified)	Incorrect components used	Vehicle will not perform as expected, possibly causing complete failure	2	8	2	32	Check each component given at the start of the make session is correct.
Component assembly (Not modified)	Missing/misplaced small components; washers, clips, etc.	Bearings possibly falling off due to missing clips, bolts not being secure enough due to no washers to spread the force.	2	7	4	56	Check over each component with reference to(Not modified) design drawing and test cars function.
Total						491	

Peer review of group members' contribution

This forms needs to be completed, signed by ALL group members and attached to the final report

Group number: A11	**Number of students in group: 4**	
Name of group member	What did this group member contribute to the project?	Mark [out of 100%]
Harry Byrne	Solidworks components, CAD drawings, document formatting/editing.	100%
Teppei Goto	Calculation check, FMEA	100%
Norbert Bacsko	All initial calculations, Solidworks check, evaluation.	100%
Haitham Al-Mahrouqi	Calculation check, Introduction, Presentation of designs	100%

H Byrne
....
Signature student 1

T Go
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Signature student 2

Norbert Bacsko
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Signature student 3

Haitham
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Signature student 4

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Signature student 5