UNIVERSITY OF WATERLOO
Faculty of Mechanical and Mechatronics Engineering

MTE 380

Milestone 1: Project Proposal and Conceptual Design

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Executive Summary

This report outlines the MTE 380 course project for Group 1. It also presents in detail the conceptual design phase that has been conducted.

To begin, a problem statement is formulated for the project. This problem statement stems from research into the hobby of extreme hiking. The problem is that hikers currently need to go off route to specific delivery spots for supplies. The needs analysis shows that a need for care package delivery to unique remote hiking location exists. Specifically, the project requirements impose a course with a wall in the middle that must be surmounted to deliver a package on the opposite side. The wall is wood, except for a section of it that is metal. There is also a ramp available to cross the wall.

There are five team members working on completing this project. As it is a mechatronics project, the main tasks are distributed amongst mechanical, electrical, and software design. These tasks are distributed in a Gantt chart to produce a timeline for the project. The expected date of completion of the project (fully functioning device built), is March 24th.

The budget for this project is also outlined in detail. The funded portion of the budget is $215, courtesy of the University of Waterloo. However, the project is expected to cost $390. The excess cost of $175 will be covered by the team members.

The conceptual design phase presents three main designs considered in detail:

1) A “crane” style robot that has a base portion which drives up to the wall. This base portion raises a platform which holds a mini robot chassis. Once the base is raised a above the wall the mini chassis is winched down the other side of the wall and continues driving to find the second base.
2) A “car” style robot that has a simple but robust drivetrain mechanism to drive up the ramp. The drivetrain is designed to drive at a steep angle and can keep itself aligned on the narrow ramp. Once on the other end of the ramp, the robot drives around to locate the second base.
3) A “stepper” style robot that has a split-chassis design. The split occurs in the middle of the robot, dividing it into two drivable sections. Each section can be raised and lowered to step over the wall. The robot also features a movable mass to shift its center of gravity and avoid tipping when one of the two chassis is raised.

Out of the three designs presented, the car robot best met the design criteria. The car design will be further developed in the coming months.

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1.0 Introduction

This section of the report describes the problem being solved including background information, a needs assessment, and a problem definition. The problem definition and key design problems further set the constraints and criteria for the problem.

1.1 Background Information

In the book "Wild", Cheryl Strayed introduces extreme hiking in which hikers traverse thousands of miles down rough terrain such as Pacific Crest, Trans Canada, and other trails [1]. While on long trails, hikers organize care packages which include food, clothing or gear replacements as it is impossible to carry sufficient supplies on your back through irregular terrain [1]. Cheryl describes the system that instructs hikers to organize food supplies for parts of the hiking trip and subdivide them into manageable portions [1]. The hikers mail the portioned packages to dedicated mail stops along the path of the trail. However, this system limits the hiker to specific pit stops and restricts which paths the hikers can take. Additionally, regular mail service is required to deliver these packages to the set destinations. These deliveries must happen by a specified time without delay in any weather condition. These constraints inconvenience hikers and are difficult for regular mail service to achieve.

1.2 Needs Assessment

The mail stops have to be accessible to an average mail delivery worker and not require hiking expertise to deliver. Therefore, hikers are limited to follow specific trail paths in order to receive their supplies at places such as general stores, lodges or hotels. Unwanted time and expense is usually added by these stops.

The hobby of extreme hiking has created a need for an organized and safe method of care package delivery to a hiker’s resupply location without interfering with the planned trail by adding a detour.

1.3 Problem Formulation

This section of the report refines the problem definition and outlines the details of the design requirements.

1.3.1 Problem Definition

Design and prototype a device to deliver hiking supplies to a specified location over rough terrain.

1.3.2 Desired Functions and Goals

The goal of the prototype is to deliver a package from base 1 to base 2 while remaining within the boundaries of the course. The device should be able to scale an obstacle in the center of the course, carry supplies, and navigate autonomously between bases. The device should complete these functions in a timely fashion, the amount of time required should be within an order of magnitude of what a human would take for the same task. Finally, the machine should be generally aesthetically pleasing.

1.3.3 Objectives and Constraints

This section contains lists of objectives and constraints for the design of the robot.

Objectives

- Deliver the package in less than 2 minutes
- Perform reliably (deliver package 9/10 times)
- Be robust (no repairs or adjustments required for 20 consecutive runs)
- Remain within the boundaries of the 2.4m (8 feet) wide by 4.8m (16 feet) course
- Surmount the 0.9m (3 feet) high mountain range that bisects the course

Constraints

- Weight must not exceed 6kg
- Cost must be under $1000
- Must start operation within a volume of 60cm x 60cm x 60cm

1.3.4 Design Selection Criteria

Design selection criteria are defined for the design project based on the objectives and constraints. An important criterion is design time, which is estimated using a task breakdown chart. When it comes to technical design criteria, the project clearly defines a performance index. This index is determined by the formula:

$$PI = \frac{F_f}{mt^2}$$

Where F_f is a fudge factor, m is mass and t is time to complete. Based on this formula two initial technical design criteria can be defined: minimizing both weight and time to complete the course. Reliability of the design is a significant design selection criteria. Determining reliability is a more subjective process than evaluating other criteria and relies on the experience of the team for evaluation. Another design criterion is cost. In this case, less is better. The last design criterion is aesthetics. This criterion isn't vital to fulfilling any objectives and constraints but is a subjective criterion that is desired.

1.4 Key Design Problems

Due to the complexity of the project, it is likely design problems will be encountered. The following design problems have been identified:

Firstly, the quality of parts used may be overestimated and poor quality may not be taken into account in the design. This problem comes in the form of poor quality sensors and low robustness of mechanical parts. If sensors are placed in the design without a large margin for inaccuracy, or too few sensors are used, the resulting robot may not have the ability to find base 2 in a timely fashion. If the robustness of mechanical parts is not taken into account, parts might be designed too thin and degrade, negatively affect the robot's performance.

Secondly, the robot should be designed to avoid problems with assembly, repairs, and manufacturability. If parts are not designed with assembly in mind, they may not be able to be arranged as specified by the design without damage. If parts are not designed with potential repairs in mind, the cost of repairing or replacing a part after assembly may be very high. This adds unnecessary time and cost in the later stages of the project.

Finally, the search algorithm should be designed with the robot's physical qualities and sensor positions in mind. Due to the team's inexperience with pathfinding and search algorithms, there is a large chance that the software will need to be iterated on and possibly redesigned. Problems with the algorithm itself or a mismatch with the physical aspects of the robot can lead to lower performance and a large cost in design time. The design should take this into account and include some flexibility for sensor placement or have a surplus of sensors.

2.0 Project Planning

This section of the report outlines the schedule, budget, required tasks, and task leads for the project.

2.1 Team Members

In order to successfully complete the design, manufacturing and testing of the prototype, the team is composed of five individuals with various backgrounds.

Hugo has expertise in robotics with a specialization in software development. Through his work experience, he handled the development of robotics operating systems, as well as control systems for motor drivers and experimental development of neural nets. His knowledge of Python, C++ and Arduino code will allow for faster code iterations and better optimization of the searching algorithm.

Rishab has experience building robotics and all aspects of mechatronics systems. His experience began in high school, where he designed the mechanical, electrical, and software aspects of several competition robots. In university, this experience expanded to more analytical and detailed mechanical and electrical design through co-op and extensive student design team experience. This student design experience includes designing and iterating a full EV architecture, making him well suited to define the hardware architecture of the robot.

Mihai is competent in software development and system integration. His skills have been developed and honed through hackathons and lots of rapid prototyping experience in the software field. Through work in the industry, he has designed and built small systems to prototype applications, as well as more complex systems to be used in commercial products. This experience makes Mihai well suited to design the software system which will interact with the robot as well as contribute to general search algorithm development.

Max brings to the table 5 years of professional SolidWorks experience. Over his lifetime, Max has designed over 500 parts for everything from prototypes to mass production. He is a co-inventor on a pending patent for a mechanical alignment system. Max also owns two 3D printers which will be employed on the project to quickly and inexpensively produce parts.

Pavel is experienced in building robotics from all aspects, starting from high school, where he built robots to solve specific problems. However, in University, Pavel started developing more firmware and hardware expertise while still incorporating mechanical design, analytical, and manufacturing skills through co-op and student design experience. This experience makes Pavel versatile in terms of his abilities and well-suited to perform integration of hardware sensors with software requirements through firmware.

2.2 Work/Discipline Breakdown

Although every member has expertise in different technical fields, the work breakdown will be done in a way that ensures members get experience in all areas of the project. In other words, a member with mostly software experience might spend most of his time working on the software for the product, but he will also be asked to participate in mechanical design and electrical testing in order to expand his knowledge.

As shown in section 2.3, most of the hours spent by a team member will be on tasks he has the most expertise in. However, some of his time will be spent on tasks that he is unfamiliar with and can gain great experience from.

2.3 Task Breakdown and Responsibility Assignment

Table 1 breaks down the tasks required to complete the project and assigns a lead (marked "R" for responsible) to each task.

Table 1: Task Breakdown and Responsibility Chart

Task	**Description**	**Hours (R designates responsibility)**										**Total**
		Hugo		Max		Mihai		Pavel		Rishab		
1	**Administrative**											
1.01	Problem Definition	1		1		2	**R**	1		1		6
1.02	Schedule Outline	1		2	**R**	1		1		1		6
1.03	Budget Estimation	1		1		1		1		2	**R**	6
1.04	Conceptual Designs	5		10	**R**	5		5		5		30
1.05	Report 1	10		10		10		15	**R**	10		55
1.06	Report 2	10		10		10		15	**R**	10		55

1.07	Presentation	20	**R**	10		10		10		10		60
1.08	Competition	3	**R**	3	**R**	3	**R**	3	**R**	3	**R**	15
1.09	Report 3	10		10		10		15	**R**	10		55
2	**Mechanical**											
2.01	Mechanical Calculations	0		5	**R**	0		5		5		15
2.02	Component Sourcing	5		5		5		5		5	**R**	25
2.03	CAD Model	0		50	**R**	0		10		10		70
2.04	Construction Check 1	0		10	**R**	0		5		5		20
2.05	Construction Check 2	0		10	**R**	0		5		5		20
2.06	Component Manufacturing	0		10		10		10	**R**	10		30
2.07	Assembly	0		2		0		2		2	**R**	6
3	**Electrical**											
3.03	Electrical Calculations	0		5		5		5		5	**R**	20
3.01	Component Sourcing	5		5		5		5	**R**	5		25
3.02	Hardware Bring-up	0		0		0		5		15	**R**	20
3.03	Bench/Vehicle Testing	0		0		0		5		30	**R**	35
4	**Software**											
4.01	Hardware Driver Implementation	25	**R**	0		15		0		0		40
4.02	Basic Robot Control Functions (drive forward, turn)	25	**R**	0		15		0		0		40
4.03	Path Planning/ Base Locating	30		0		40	**R**	10		0		80
4.04	Software Testing	20		0		30	**R**	0		0		50
Total		171		159		177		148		149		**784**

2.4 Schedule - Gantt Chart

Figure 1 shows the project schedule. It is divided into administrative, mechanical, electrical, and software sections. The dates set on the chart are selected based on hard deadlines mandated by the course and the approximate time required to complete each task. The competition date is marked in red. Key deliverables for the project are coloured green.

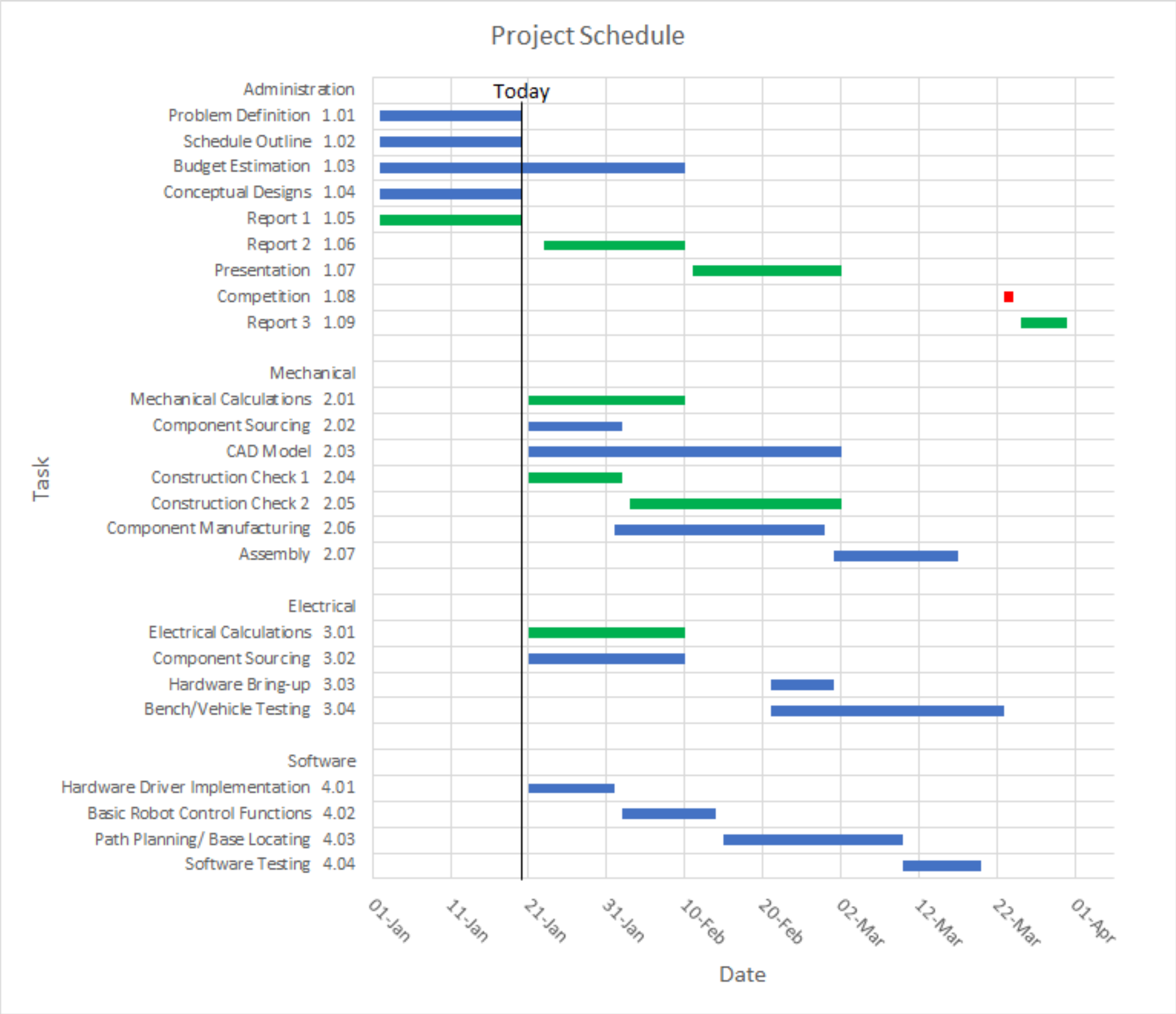

Figure 1: Project Schedule

2.5 Progress Monitoring and Deliverables

Throughout the execution of the project, weekly meetings will be held to report on the progress of tasks assigned to each team member. Each member will present a quick demonstration or update from the task they were assigned to.

On top of these weekly meetings, a list of tasks in order of priority will be regularly updated for all members to quickly gauge the overall progress of the project and synchronize the execution of dependent tasks. This will also allow for quick allocation of tasks, since the higher priority tasks will be at the top of the list.

2.6 Budget

The budget is expected to exceed the allowable reimbursable limit of $215. To handle the reimbursement, the first $215 will all be spent and reimbursed to Rishab, the team purchaser.

Any expenditures beyond $215 will be split evenly amongst. To facilitate easy splitting of costs, the team will be using an app called Splitwise. [3] Table 2 outlines the expected budget of the project.

Table 2: Budget

Item	Cost
Electronics	
• Spare Arduino	$60
• Motors/Actuators ○ Motors for drive, actuators for auxiliary functions ○ Motor controllers	$50
• Battery	$30
• Sensors/Electronics ○ Ultrasonic sensors, Arduino Shield, IMU, Encoders (if not included in motors) ○ Passives, Buttons, LEDs	$100
• Wiring/Connectors	$20
Mechanical	
• Chassis Components ○ Robot frame	$20
• Drivetrain Components ○ Tractive components (wheels/tracks) ○ Gears, axles, hubs	$30
• Actuated mechanisms ○ Arms, guides or lifting mechanisms	$50
• Fasteners	$30
Total (not incl. tax + shipping)	**$390**

2.7 Required Facilities and Equipment

The Student Machine Shop will be used for most of the mechanical manufacturing and assembly. Drill presses, bandsaws and other equipment will be used to measure, cut and shape each piece to its final dimensions. The MME lab in E3-3164 will be used for electrical purposes, with equipment such as oscilloscopes and DMMs to ensure the circuitry of the product is not faulty. A more detailed list of facilities and equipment can be found in Table 3.

Table 3: Facilities and Equipment

Facility	Equipment
Student Machine Shop	Drill Press
	Bandsaw
	Files
	Hammer
	Steel Cutter
	Welding Equipment
	Milling Machine
	Surface Grinder
Max Personal Shop	3D Printers
WATiMake Space	3D Printers
	Laser Cutter
	CNC Machining
MME Lab (E3-3164)	Oscilloscope
	Digital Multimeter

2.8 Risk Identification/Mitigation

Risks will be pre-emptively identified by the team during a failure method and effect analysis meeting. Pertinent risks will be heavily considered throughout the design process. Examples of the risks include component failure and sudden design changes. Two mitigations for these risks are purchasing backups of important components and following flexible 3D modelling design procedures.

2.9 Group Contract

First, each member is required to attend at least 80% of the meetings. By attending most of the meetings, each member shows commitment to the project, and information discussed during meetings will be more prevalent and will not need to be duplicated for the missing attendees. Also, during meetings any device not contributing will be turned off. This includes laptops that are not required, any smartphones, music or anything else that can disturb the meeting or distract the members.

Each member will be required to work at least 12 hours per week on average, with some busier weeks compensating for weeks with less work. This will sum up to 720 hours over a 12-week period for any required tasks. Members are also required to be available to work with a 1-day notice for important tasks such as final assembly or preliminary testing. Additionally, each member should focus on quality of their work versus quantity to avoid unwanted waste of time.

Each major change will need to be discussed between all team members before any decision is taken. These discussions can happen during the weekly meeting or any other time if deemed necessary. After the arguments are presented, a vote will be cast and 4 out of 5 members will be required to vote for the change in order for it to occur.

During any discussion between team members, whether it is during meetings, over messaging apps or informally, respect is needed to ensure that information is communicated in a professional manner. Issues need to be discussed before any unwanted consequences arise from them, and every member is to offer constructive criticism rather than put down comments or ideas.

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3 Conceptual Design

This section of the report goes through the conceptual design process, from concept generation to selection.

3.1 Morphological chart

Table 4 is a morphological chart outlining various design combinations that were considered. 3 designs were narrowed down from the chart and are presented in the following section.

Table 4: Morphological Chart

Category	**Considered Designs**				
Traction	3 Wheels	Treads	4 Wheels		
Chassis Construction	Sheet-metal	3D prints	Wooden	Acrylic	Machined Metal
Surmounting	Side of car guides	Crane	Under-ramp wheels	Large Wheels	Articulating wheels
Sensors	Ultrasonic	Camera	Encoders		
Motors	DC	Brushless	Stepper		

3.2 Concept generation

Collectively, over 30 different design and design ideas were considered. This report will highlight 3 of the most developed ideas for consideration: the crane design, the car design, and the stepper design.

3.2.1 Crane Design

This design is inspired by modern mobile cranes that are able to lift heavy loads to high elevations. Initially, the crane lift will start within the volumetric constraint of 60cm x 60cm x 60cm. The crane will drive up to the wall and extend the lift to lift a detachable vehicle to approximately a meter high across the 'mountain'. The crane then drives forward to move the car to the other side of the wall and then uses its winch to then lower and release the car to find the base. The car performs a search algorithm to find the second base. Key components of the design are shown in Figure 2.

The concept avoids the ramp entirely, making it feasible to meet the time objective of 2 minutes. Additionally, the design is mechanically simple, which increases the chance of repeatability and is predicted to be robust. Although the crane concept is big, it will easily stay within the boundaries as the base is will drive forward to the wall and release a vehicle much smaller in size and simpler to control. Additionally, given a mechanically simple design it should be easy to keep the materials relatively light weight thus making it feasible to stay within the 6 kg weight constraint and meet the budget.

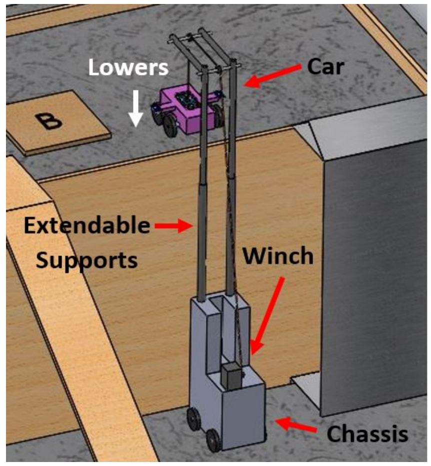

Figure 2: Crane Design Overview

3.2.2 Car Design

The car design drives up the ramp with the help of ultrasonic sensors. The ultrasonic sensors on the sides of the car identify the sides of the ramp, keeping the car driving straight. The front ultrasonic sensor assists in finding the ramp. The large wheels of the design elevate the chassis from the ramp, allowing the car to crest the top of the ramp without interference. Additionally, there is a cut-out in the bottom of the chassis to further prevent interference. The design is shown in Figure 3.

The design maps well to the objectives and constraints. The concept is predicted to weigh less than 2.5 kg and will not exceed 6 kg as most of the chassis weight will be the wheels as the base can be made of light and durable materials such as aluminum, acrylic, and/or PLA. The power to weight ratio of the concept is relatively large due to the lightweight chassis, thus the objective of delivering the package within 2 minutes is feasible. Having a simple drive train should allow for easy vehicle control, therefore staying within the boundaries should not be an issue. Having a simple design and drivetrain also predicts low expenses and low volumetric footprint. This straightforward concept should increase the chance of successfully completing the task which corresponds well with reliability and robustness.

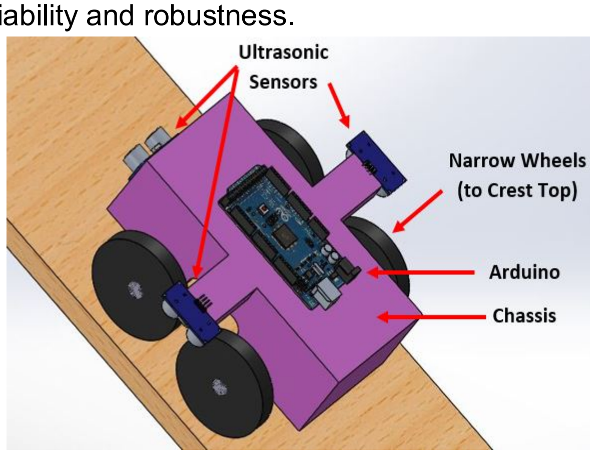

Figure 3: Car Design Overview

3.2.3 Stepper Design

The stepper design outlines a robot that is capable of lifting and lowering itself over the wall without using the ramp as shown in Figure 4. The robot is composed of two chassis, two sets of extendable supports and translating weight. The robot approaches the wall and lifts the front chassis over the wall by contracting its telescoping supports. Then, the front supports are extended back downwards so that the robot is straddling the wall. The translating weight is moved to the front of the robot, shifting the center of gravity of the stepper. Then, the rear chassis is lifted over the wall following the same procedure. The robot then drives to the second base.

Initially, the concept involves the robot to starts out confined to fit into a 60cm x 60cm x 60cm cube volume. The concept of stepping over the obstacle allows to keep the design as a single module that is able to navigate within the course boundaries and find the second base with the help of sensors. The symmetric design of the sub chassis in the concept allow to save cost for components and materials, which should meet the defined cost constraint. The design requires for the sub chassis to be lifted individually which requires them to be lightweight. This focus on lightweight design should allow for the design to remain under 6kg.

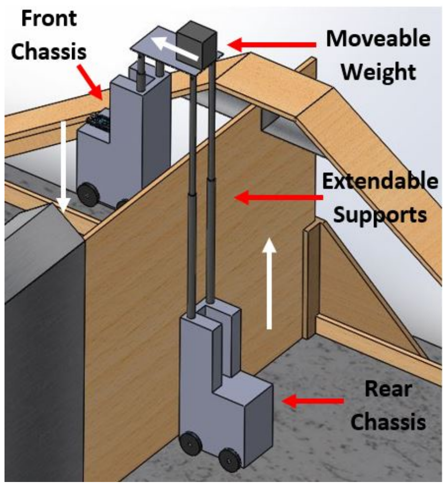

Figure 4: Stepper Design Overview

3.3 Proof of Concept

The crane design idea is taken after modern cranes existing in the industry, specifically the pick and carry crane [4] and the crawler crane [5] types. This design mimics existing cranes in lifting heavy loads to high elevations. The crane will have two wheels and one motor to drive the robot to the wall and stop once the sonar sensor detects the wall or a touch sensor is activated. The crane then uses another motor to retract the lift. Next, the third motor is used to lift the car attached either by wires with a detachable connector or a string that will be long enough for the car to go to any part of the course boundary on the other side. The car will have two motors and a ultrasonic sensor to sense the pole of base 2 or perform a simple sweep search algorithm without the use of any sensors.

The car design is a solved problem, however for the purpose of this project the Clearpath Robotics Husky [7] unmanned ground vehicle (UGV) is used as an example of industry solution for the car design. The Husky also uses an electric drive train and sensory input to sense the surroundings. The UGV is made for rugged and all terrain with minimal moving parts. Mimicking this design idea will fit well with the design challenge. The car design will have to traverse a steep angled ramp and maintain a straight drive path. The vehicle has a simple two motor or four motor drive train to be able to turn. The car starts on base 1, and drives to find the ramp and traverse across the mountain. Next the search algorithm is performed to find base 2, and drive onto it.

The stepper idea is inspired by the construction of tall bridges. Tall bridges often consist of pillars that support a road deck. As the pillars are separated by long distances and the bridge can reach heights of over 200m, such as in the case of the Millau Viaduct, it is impossible to place the several ton sections of the deck directly on top. Instead, the deck slowly slides forward until it reaches the next anchor point, such as the next pillar. In order to do so, the center of mass of the machinery must at all times be on the side where the machinery is anchored, otherwise the whole system will tip over and fall to the ground. The same center of mass idea is applied to the stepper. In the first motion, the front part rises to prepare itself to go over the wall. It then moves forward so that it can slowly suspend the front part on the other side of the wall. At any time during each of the movements, the center of mass must be adjusted to avoid tipping over. Once the front part is passed the wall, the center of mass is moved from the back to the front portion, possibly through a mass or the extension of moment arms, and the whole process is repeated.

3.4 Concept Evaluation

Table 5 presents the weight and rating system of each design criterion.

Table 5: Criteria

Criteria	Weight	Weight Calculation Method
Mass	15%	The lightest design is assigned full points. Scores for the other designs are linearly interpolated based on their weight in comparison to the lightest design and the upper limit of 6kg. $m = mass \quad l = lightest\ design\ mass \qquad score = 15 - 15 * \frac{m-l}{6-l}$
Design Time/ Complexity	10%	The quickest design is assigned full points. Scores for the other designs are linearly interpolated based on their design time in comparison to the quickest design and the upper limit of 1000 hours. $h = design\ time\ q = quickest\ design\ time\ score = 10 - 10 * \frac{h-q}{1000-q}$
Course Completion Time	30%	The fastest completion is assigned full points. Scores for the other designs are linearly interpolated based on their completion time in comparison to the fastest design and the upper limit of 2.5 minutes (150 seconds).

		$t = completion\ time \quad f = fastest\ time \quad score = 30 - 30 * \frac{t-f}{150-f}$
Reliability	30%	The design which is rated to be most reliable will receive full points. Scores for the other designs are linearly interpolated based on their rated reliability in comparison to the most reliable design and a lower limit of 3. Any design under a reliability of 3 is not considered. $r = reliability\ rating \quad m = most\ reliable \quad score = 30 * \frac{r-3}{m-3}$
Cost	3%	The cheapest design is assigned full points. Scores for the other designs are linearly interpolated based on their cost in comparison to the cheapest design and the upper limit of $1000. $c = cost \quad l = lowest\ cost \quad score = 3 - 3 * \frac{c-l}{1000-l}$
Aesthetics	2%	The design which is rated to be most aesthetically appealing will receive full points. Scores for the other designs are linearly interpolated based on their rated aesthetic in comparison to the most appealing design. $a = aesthetic\ rating \quad b = most\ appealing \quad score = 2 * \frac{a}{b}$

Mass is assigned a weight of 15% to reflect its impact on the performance index. Masses are estimated from concept SolidWorks models by taking the square root of the mass of each design to correct for the fact that parts are conservatively modelled as large solid volumes.

Design time is given a weight of 10% because completion of the course is the project's primary goal and there is a limited amount of time before the competition. The design time of the car is estimated based on the responsibility chart (ignoring administration) is approximately 500 hours. Table 6 shows the factors used to estimate the design time. The factors are expressed in terms of design time required relative to the car design.

Table 6: Design Time Factors

Design	**Hours**	**Crane**	**Car**	**Stepper**
Mechanical Factor	200	2.5	1	2
Electrical Factor	100	1.5	1	1.5
Software Factor	200	1	1	1
Total		**850**	**500**	**750**

The crane has the greatest number of components and requires the development of both a releasable car and a chassis. Therefore, it received a mechanical factor of 2.5 and an electrical factor of 1.5. The crane is inherently more complex than the car, but it does not require a ramp identification and following algorithm so the software design time of the car and the crane were considered equal.

The stepper design has a large number of moving components and requires mechanical balancing to remain upright. Therefore, the mechanical development time is twice that of the car. The stepper has two chassis sections, each able to drive independently requiring approximately 1.5 times the electrical development time as the car. The software development time is similar to that of the car because there are more components to control in the stepper design but the stepper design does not require a ramp identification and following algorithm.

The course completion time is assigned a weight of 30% because it quadratically impacts the performance index. The course completion time is based on estimates by group members for each movement performed by each design.

Reliability is assigned a weight of 30% because the team only has one chance to have the robot perform properly. Reliability is scored based on the average rating out of 10 given by the members of the group. Each member took into account the complexity of each design, the variety of ways each design can fail and the likelihood of those failures.

Cost is given a weight of 3% because the team is willing to spend money as needed to complete the project. The cost of the car design is outlined in the budget. The crane design has the same base budget as the car plus the cost of a winch system, support extending system and an entire chassis. Therefore, it is estimated to be twice as expensive as the car. The stepper design requires the purchase of several motors to perform all of the necessary movements as well as more structural components than the car design. Therefore, the stepper was given a cost of 1.5 times the car.

Aesthetics are assigned a weight of 2% because they do not contribute to the objectives, constraints and criteria. The Aesthetics were evaluated by each group member out of 10 based on the appearance of the final design.

3.5 Design Selection Matrix

Table 7 shows the final scores that are assigned to each design.

Table 7: Design Selection Matrix

Criteria	**Crane**		**Car**		**Stepper**	
	Value	**Rating**	**Value**	**Rating**	**Value**	**Rating**
Mass	3.8kg	7.2	1.2kg	15.0	5.0kg	3.1
Design Time/ Complexity	850 hours	3.0	500 hours	10.0	750 hours	5.0
Course Completion Time	85 sec	30.0	96 sec	24.9	111 sec	18
Reliability	6.4	19.2	6.6	19.8	3.2	9.6
Cost	$800	1.0	$400	3.0	$600	2.0
Aesthetics	6.2	1.2	8.8	1.8	3.6	0.7
Total		**61.6**		**74.5**		**38.4**

From this table, it is clear that the winning design is the “car” style device.

4 Conclusions and Recommendations

The following conclusions and recommendations are drawn from the initial stages of the project.

4.1 Conclusions

Through setting up a clear problem statement and defining all design requirements, the conceptual design phase leads to a design that is most likely to result in a successful robot design. Out of the three robot designs suggested, the “car” style robot which traverses over the ramp in the course is the design selected. In order to achieve this design, a total of 720 hours of design work is expected to be completed. The expected completion date of the project is March 24th with an expected cost of $390.

Along with the design selection, the division of tasks amongst team members was also defined. Hugo and Mihai will be leading most of the software development work. Max will be leading most of the CAD of the robot while Pavel and Rishab will be leading the electronics portion of the robot.

4.2 Recommendations

It is recommended that mechanical and electrical components be sourced in a timely fashion to meet the project schedule. Furthermore, it is paramount that there is an accurate and editable 3D model of the design including all fasteners. The assembly procedure should also be considered during design to prevent unexpected interferences. All designs should be modular and adaptive to future design changes such as including additional sensors. Spare copies of critical components should be ordered pre-emptively in case of unexpected component failure.

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Appendix A – Course Completion Time Estimates

Crane Course Completion Time

Task	Time (seconds)
Raise boom	6
Drive up to the wall	10
Lower car	10
Drive around and locate base 2	60
TOTAL	**86**

Car Course Completion Time

Task	Time (seconds)
Find the ramp	15
Cross the ramp	30
Drive around and locate base 2	60
TOTAL	**95**

Stepper Course Completion Time

Task	Time (seconds)
Drive up to the wall	10
Raise front chassis	8
Move raised chassis over the wall	2
Lower front chassis	8
Shift balance	5
Raise read chassis	8
Move raised chassis over the wall	2
Lower rear chassis	8
Drive around and locate base 2	60
TOTAL	**111**