Design Analysis Report

Team Wheelders

Rice Robotics Club | University Rover Challenge

TEAM MEMBERS

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PROJECT DETAILS

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Client: Rice Robotics Club

Project Summary

The Rice Robotics Club is participating in the University Rover Challenge (URC) for the first time. As part of this competition, our client has tasked us with designing a set of non-pressurized rover wheels to replace the team's current temporary, low-performance wheels. The objective is to provide wheels that can support a 50 kg four-wheel rocker-bogie suspension rover in completing the URC Delivery Mission, which involves navigating diverse Mars-like terrain, including soft sand, gravel, rocky and boulder fields, steep and loosely consolidated slopes, and vertical drops.

The rover must meet strict competition constraints, including a 50 kg total mass limit, non-pneumatic wheel requirements, tolerance for extreme environmental conditions, timely on-field replacement, and manufacturability with limited resources accepted by competition regulations. Current wheels do not provide sufficient traction, durability, or reliability, which hinders the rover's performance. A new design would address these limitations, enhance competitiveness, and potentially lead to greater recognition and engagement for the Rice Robotics Club.

Furthermore, the client also encouraged us to explore unconventional concepts alongside established and proven wheel designs. While the rover is still in development, we will have access to a similar test rover to evaluate prototypes. Our wheel design must also be flexible enough to accommodate the rover's evolving leg-to-wheel connection. The wheels are expected to be complete by early December in time for the qualifying event, and may be featured in the competition's System Acceptance Review video.

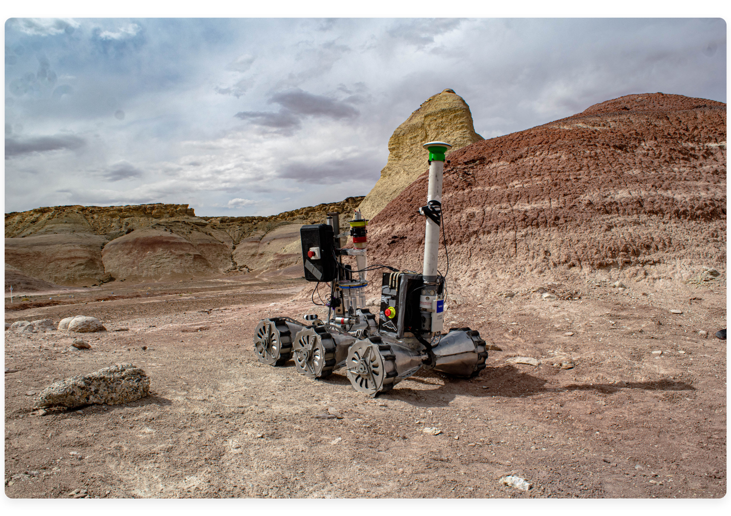

Figure 1: Image of URC Delivery Mission terrain

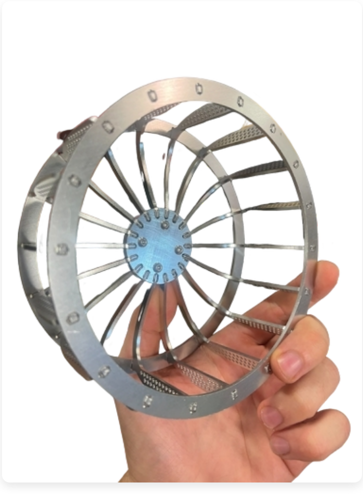

Figure 2: Current temporary wheels used by Rice Robotics

Problem and Vision Statement

The problem we are addressing is the need for a set of rover wheels that meet the competition's rules while outperforming the team's temporary wheels. We aim to design and build six wheels that can be constructed within a budget of around $500, while maintaining high maneuverability and traction, enduring extreme conditions, and allowing for quick and easy replacement.

By improving traction and durability, the wheels will directly improve the rover's performance on the URC Delivery Mission, where terrain is one of the most significant obstacles. Our solution has the chance to increase the rover's chances of completing the mission successfully and help Rice Robotics earn more points throughout the competition, thereby improving their standing. In the longer term, a successful rover design has the potential to bring the club greater recognition, participation, and support within the Rice community.

Background

The Rice Robotics Club is participating in the URC. Their 50kg rover requires wheels that enable it to complete tasks throughout the competition, including maneuvering through steep slopes, sand, and rocky fields. Within a 4-month timeframe, our team must design a rover that meets the URC's non-pneumatic wheel requirement, allows the rover to weigh less than 50 kg, withstands extreme desert operating conditions [9], and operates within a flexible $500 budget. Ultimately, the task at hand is to replace the wheels the team is currently using, which lack sufficient traction and durability, with new wheels that maximize traction on challenging terrain while adhering to the competition's strict rules.

From our research, we learned that traction is a key factor in rover mobility, relying on a balance between wheel-soil interaction and controlled slippage to prevent digging in or loss of motion[11]. In terms of material, we have learned that the most common method of increasing traction is using rubber in wheels, although some alternative options could include using grousers. This explains why the most successful teams in the URC are those that have used both rubber and metal. [1] Regarding wheel design, it is worth noting that some unconventional designs may be effective, such as the wheel design developed at the Missouri University of Science and Technology. However, most top teams adopt a standard wheel design approach.

In terms of production, we also discovered that for the delivery mission, having a larger radius wheel would be beneficial[10]. The tradeoffs of this approach are, of course, increased weight and production cost, but the larger radius improves speed and the ability to scale large objects, such as rocks and hills, during the delivery mission. We can start prototyping using low-cost 3D printing. Once the structure is proven to be strong and durable enough to support the rover's weight, we can proceed with producing the final design.

Finally, we also found that common field failures at URC include wheels detaching [7] and wheels made from weak or poorly chosen materials [8], which directly compromise performance. These findings underscore the importance of designing wheels that maximize grip on loose terrain while also being durable and securely attached, as failures in either area can prevent a rover from completing its mission. The successful combination of rubber and metal materials in wheels is a significant design trend among top teams, so we should follow this example in some regard. It has helped these teams improve durability, traction, and maneuverability performance in the complex delivery mission.

Design Criteria

Type	Criterion	Target Value (units)	Justification
Constraint	Regulations	Be eligible	Must follow regulations established by the URC rulebook[9]
Criteria	Replaceability	< 1 min per wheel	The wheels should be consistent in taking a minimal time to replace
	Durability	Handles 75 kg	Handles the maximum weight outlined in the regulations
	Size	~ 9.5 Inches	As requested from the Rice Robotics team
	Traction	> 62N per wheel	Minimum force for robot have the grip to be able to move under the 50kg rover weight + 10kg mission package on a steep incline (30 degrees)
	Weight	~ 6 pounds per wheel	As requested from the Rice Robotics team
	Coolness	Values from UDS	Wheel design should resemble rice and look menacing
	Replicability	Values from UDS	Amount of effort taken to assemble another wheel using the design

Table 1: Design Criteria table

Our Design Criteria Table has eight criteria that we identified as critical for the success of our project. These criteria, from most important to least important, are traction, durability, replicability, replaceability, weight, size, and coolness.

Traction is our most important factor(score: 6.0) because it is vital for the success of the wheels in maneuvering the terrain of the delivery mission. If the wheels don't have sufficient traction, then the rover will not be able to navigate the terrain in the given time, resulting in a damaging score towards the performance of the Rice rover team.

Second, we designated **durability** as important (score 5.0) but a bit below traction in terms of criticality. If the wheels are durable, they do not need to be replaced often, saving money and manufacturing time. Durability will also be necessary during the competition itself, as the wheels will need to survive the forces and wear applied to them during missions.

Following this, we have **replicability** and **replaceability** as medium to high importance criteria (scores: 3.0). The Rice Robotics club needs to be able to easily replicate and then replace the wheels on the rover so that the team can function self-sufficiently without requiring us to make the wheels and attach them for them. Also, in the field during competition, the wheels need to be easily replaceable in case something happens to them, so that the team doesn't get any penalties while spending time replacing wheels.

Following this, the **weight** (score: 2.0) and **size** (score: 0.5) of the wheels are both of lower priority because they are not directly regulated by the competition or Rice robotics. The weight would be better if it were on the lower end because the rover does have a maximum weight limit of 50kg, so the less we take of that, the better, but we don't want to sacrifice any performance in pursuit of this. Size (score: 0.5) is purely a trade-off criterion, as a bigger wheel will be faster but more expensive and heavier, and a smaller wheel is cheaper and lighter but slower.

Next is **coolness**, which we also designated as low priority (score: 0.5). We would like our wheel to be interesting and perhaps have something to make it stand out, but we aren't willing to sacrifice much, if anything, to do this.

Lastly, a criterion that we designated in our Design Criteria table but did not include in our Pairwise Comparison Chart is **regulations**. We did not include this since it is a constraint we must satisfy. If our wheels break the regulation rules, the robotics team will not be able to use them at all.

User-Defined Scales (UDS)

To quantitatively evaluate on User-Defined Scales, we designed two criteria: Coolness and Replicability. For **coolness**, a range from 1 to 5 was set up where one meant that people are not attracted to the design and decoration of the wheel, and five suggested that people would take photos of the wheel, discuss the design of the wheel, or even be a bit nervous to compete with our team due to the wheel design. Our target value is around 3.5, as we expect people to be attracted by the design. However, more effort should still be put into the wheel's structure instead of the decoration.

For **replicability**, the range of the criterion is also from 1 to 5, and the attribute was ranked from people feeling exhausted and giving up trying to replicate the wheel to the wheel being modular in structural design, the parts can be easily obtained locally, and the whole wheel is easy to assemble. Our target here is to aim for a level of 4.5 to 5 because modularity is relatively essential in assembling the wheel, and we hope that our design helps the robotics team succeed in the URC competition.

Conclusion

This design analysis report outlines the problem our team is solving, highlights its research and background, and establishes design criteria for our proposed solution. We have made four conclusions through our research in the Design Analysis Stage. First, we understand our clients' desire for the importance of wheel functionality and consistency. Secondly, we must always be aware of the trade-offs between our different design criteria, as improving one could compromise the ideal value of the other. Third, we would try our best to reach the target value in our user-defined scale. Finally, we emphasize the importance of further testing and prototyping to validate our assumptions and enhance any proposed solution.

Next, we will brainstorm ideas for initial design concepts using sketches for features and discuss different manufacturing methods, and prototype these solutions. Furthermore, we will test each prototype to assess how effectively it fulfills our design criteria. Finally, we can develop an effective wheel for Rice's URC team.