Team 23

Development of a Wheel Force/Torque Sensor for Autonomous Ground Vehicles

Operations Manual

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Abstract/Executive Summary

Continuing on work performed by last year's senior design team, this team is tasked with developing a system that allows the autonomous ground vehicle, GOLIATH, to better live up to its all-terrain designation. This is going to be achieved by adding a wheel force/torque sensor onto one of the wheels, and having it wirelessly communicate with the vehicle's computer control system. To date, several design concepts were created and reviewed by the team. Evaluating these designs objectively, the team has decided to implement a design given by one of the project's advisors. Pairing this design with an electrical circuit optimized by the team specifically for this setup presents the best option to move forward in the project. In the near future, the team will need perform more comprehensive calculations on the selected design in order to verify that it is capable of withstanding every obstacle that the GOLIATH will tackle. Simultaneously, prototyping and parts testing will occur once ordered parts arrive in the coming weeks.

1.0 Design for Manufacturing

1.1 Mounting

The assembly of the force/torque sensor onto the GOLIATH ATV is done using a socket and ratchet set, a vehicle jack, and a rubber mallet. These basic tools are currently the only prior tooling required. All nuts, screws, were purchased as part of the design portion of the project. The timeline for the assembly from the point of removing the ATV wheel to assembling the sensor is roughly 30 minutes granted that the proper tools are readily available. During the initial design phase, this time of assembly is very close to that which is allotted in application.

As it stands, there are 20 components to the force/torque sensor. This includes every component from the nuts and bolts to the electrical circuit. In the aspect of complexity of the design and as far as whether or not the design could have been done with more or less parts, there did turn out to be some problems that arose in regards to spacing available in order to fit in the battery and electrical components inside the sensor. It may be noted that a applicable work around was developed but in terms of security of possibly movable electrical parts (microcontroller, electrical circuit, battery) and better weight distribution for purposes of proper balancing, an additional component would be appropriate. An additional justification for a more complex assembly is the simplicity in regards to removal and mounting of the sensor. With a more secure means of housing for the movable parts, a more quantifiable set of data can be extrapolated in order to determine the effects of the conditions due to use.

The following is the procedure for mounting the assembly to the ATV:

1. Using a 17 mm socket with appropriate ratchet, loosen the four lug nuts on the ATV. **DO NOT REMOVE THE NUTS AT THIS TIME.**
2. Using a suitable lift point, preferably on the frame, place a jack underneath the ATV and lift it so that the wheel is off the ground. Support the ATV with a suitable jack stand. **DO NOT WORK ON OR UNDER ANY VEHICLE THAT IS SUPPORTED ONLY BY A JACK.**
3. Remove the lug nuts and the wheel.

4. (Figure 4) Place hub adapter on hub, and attach with provided short lug nuts. Torque lug nuts to 45-lb ft. with a 17 mm socket.

Figure 1. Hub Adapter

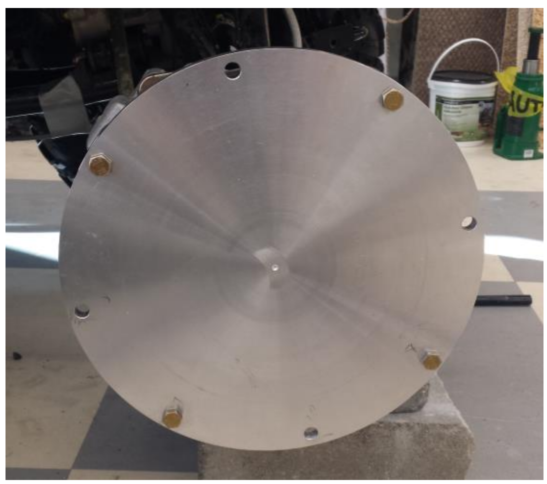

Figure 5 Inside plate

5. **Error! Reference source not found.**) Place inner plate on hub adapter and attach with M8x1.25 bolts. Tighten bolts to 25-lbf ft. with a 13 mm socket.

6. (**Error! Reference source not found.**) Attach hub adapter to inner plate with M10x1.25 x 60mm bolts through the back of the inner plate. Tighten bolts to 35-lbf ft. with a 13 mm socket. Be careful to not strike or crush electrical components when placing and securing section. Microcontroller, circuit boards and battery should fit within blank areas of section with ample room on all sides.

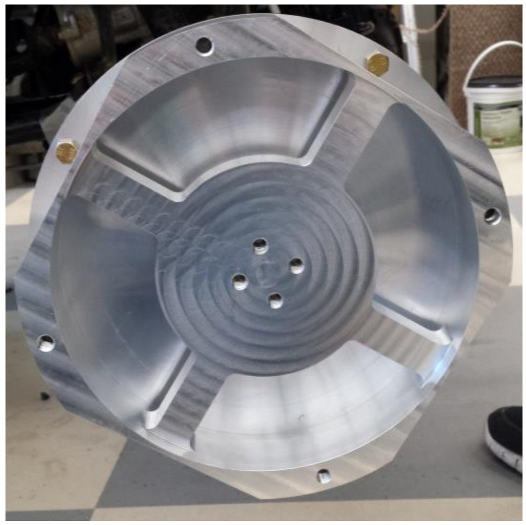

Figure 6 Cross Section

7. Connect strain gauges to circuits. Pay attention to what connections are made; connect plugs 1 and 1, 2 and 2, etc.
8. Turn on system.
9. (Figure 7)Place outer plate and attach with M10x1.25 x 70mm bolts. Torque bolts to 35 lbf ft with 17 mm socket.

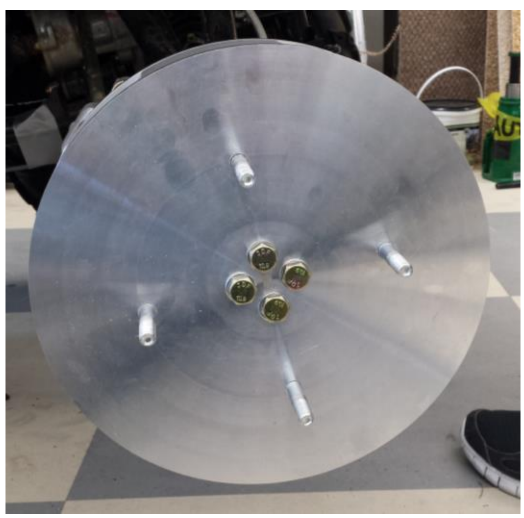

Figure 2 Outisde plate

10. (Figure 8) Place spacer on studs.

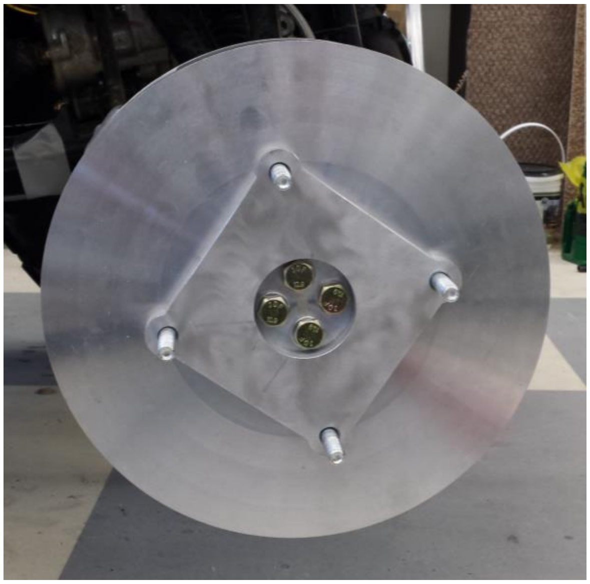

Figure 3 Spacer

11. Place wheel on studs and install supplied long lug nuts.
12. Lower ATV
13. Tighten lug nuts to 45-lbf ft. with 17 mm socket.
14. There are probably some more steps with the electronics, connecting with the ATV computer, etc.…

1.2 Exploded View

In this section, a visual of the exploded view is provided in figure 9 below. Each part is of the force/torque sensor is represented and highlighted using arrows for clarity. It should be noted that a representation of the hub of the ATV and the nuts and bolts are not shown. The scope was limited to the sensor assembly in order to provide an accurate status of the design and most up to date prototype.

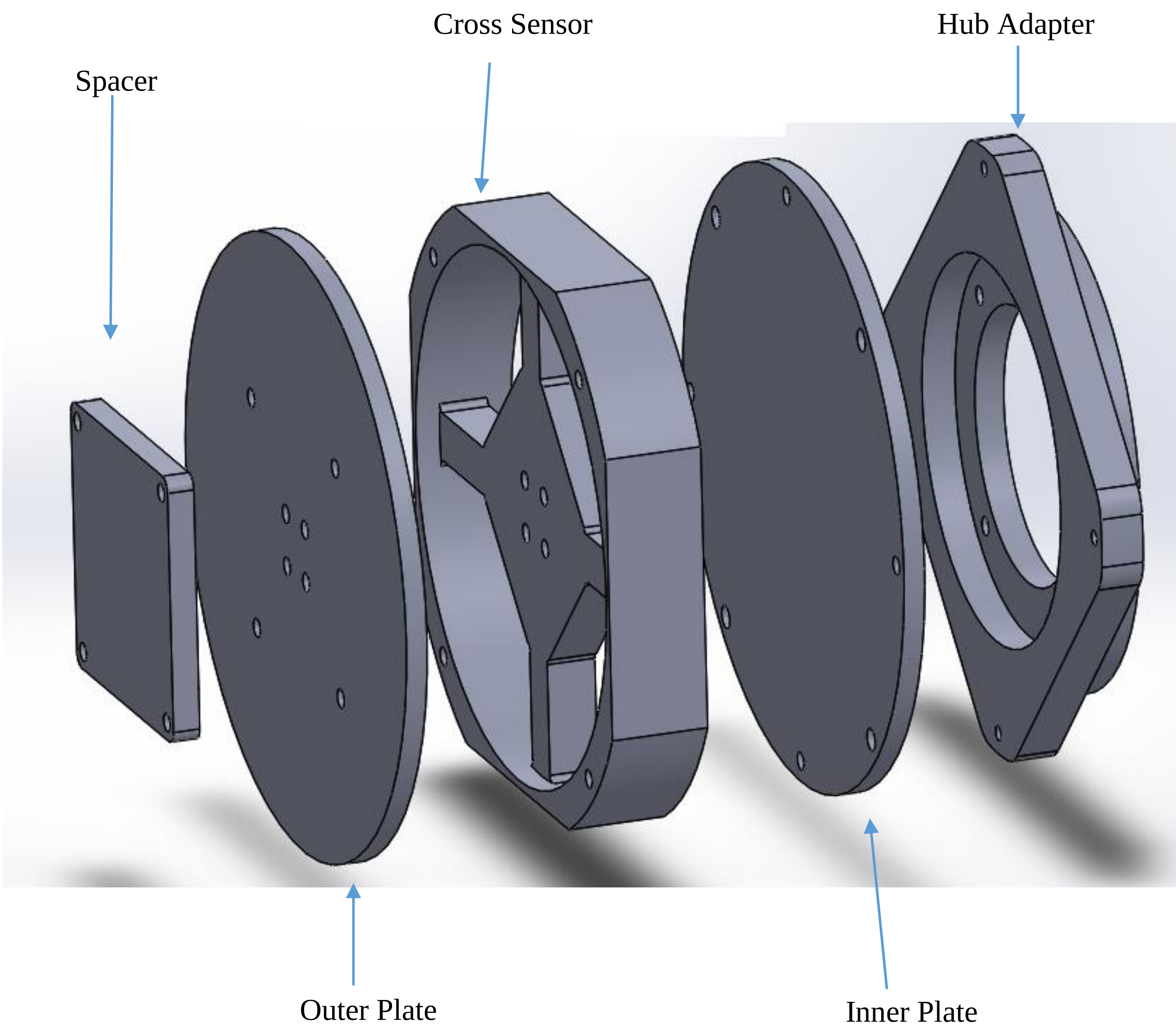

Figure 9 Sensor Assembly Exploded View

2.0 Design for Reliability

In the initial testing of the sensor assembly mounted on the GOLIATH ATV, the unit performed ideally. This means that the sensor did not hinder the capability and the performance of the ATV relatively speaking. Also, during testing the sensor was able to operate at the high velocities (approximately 14 m/s) that the ATV could travel. It is believed that the prototype will operate the same given that it were tested 100 times or even 10,000 times. The reason for this assumption is because of the material properties of the sensor. The mechanical components of the sensor assembly is made of aluminum 7075 which has a yield strength of 503 MPa and a hardness of 150HB which would be an order of magnitude higher that the ATV is capable of inducing to the sensor to cause deformation.

The data of the material properties of the sensor were inputted to a CAD model, which yielded what it would require in order to cause deformation in the unit. The data shows that given the conditions that the ATV expects to undergo, there will be no permanent, deformation caused. In figure 10 an element analysis is shown of testing done to simulate the effects of the sensor due to expected conditions that will be experienced by the ATV during operation with a factor of safety of 2. In figure 10, an FEA representation is shown to indicate the capability of the sensor to withstand a load close to fracture under assumed operating conditions. In figure 11, an element analysis displays the deflection caused to the sensor due to the expected operating conditions with a factor of safety 2.In figure 11, the area in red represents the points of greater stress with a load of 50kN-m applied to the entire sensor in torsion as well as 16kN in the radial direction. This applied caused a deflection of 0.249 mm in the radial direction.

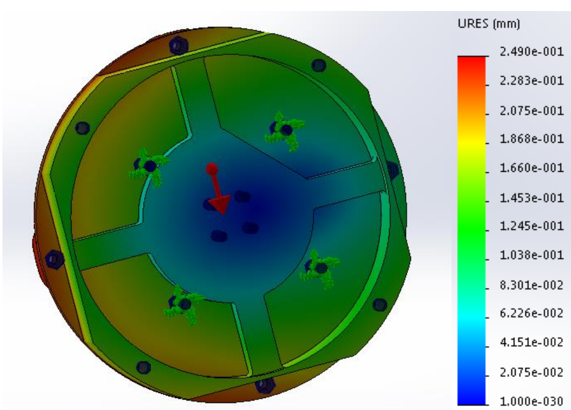

Figure 10 FEA of applied load in the radial direction

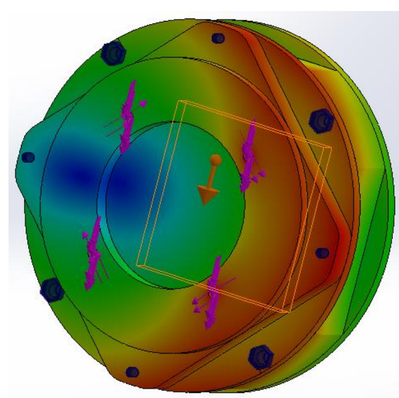

Figure 11 FEA during torsion

2.1 Failure Mode Effect Analysis

Table 1: FMEA

Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	RPN	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
What is the Process Step or Input?	In what ways can the Process Step or Input fail?	What is the impact on the Key Output Variables once it fails (customer or internal requirements)?	How **Severe** is the effect to the customer?	What causes the Key Input to go wrong?	How **often** does cause or FM **occur**?	What are the existing **controls** and procedures that prevent either the Cause or the Failure Mode?	How well can you **detect** the Cause or the Failure Mode?		What are the actions for reducing the occurrence of the cause, or improving detection?	Who is Responsible for the recommended action?	Note the actions taken. Include dates of completion.				
Hub mout	Fracture, Bolt Slip	ATV does not work, Injury, Death	7	Excessive Stress or fatigue	1	Large Factor of Safety	6	42	Visual Inspection before use	Opperator	N/A	7	1	3	21
Hub Plate	Fracture, Bolt Slip	ATV does not work, Injury, Death	7	Excessive Stress or fatigue	1	Large Factor of Safety	6	42	Visual Inspection before use	Opperator	N/A	7	1	3	21
Sensor Housing	Fracture, Bolt Slip	ATV does not work, Injury, Death	7	Excessive Stress or fatigue	1	Large Factor of Safety	6	42	Visual Inspection before use	Opperator	N/A	7	1	3	21
Wheel Plate	Fracture, Bolt Slip	ATV does not work, Injury, Death	7	Excessive Stress or fatigue	1	Large Factor of Safety	6	42	Visual Inspection before use	Opperator	N/A	7	1	3	21
Bolts	Fracture, Bolt Slip	ATV does not work, Injury, Death	7	Excessive Stress or fatigue	1	Large Factor of Safety	6	42	Visual Inspection before use	Opperator	N/A	7	1	3	21
Electronics	Shock, Failure, Bad Connections	Sensor does not work	2	Excessive Vibration/water, poor soldering	4	Rubber matts, field testing	4	32	Sealing unit in waterproof coating	Manufacturer	N/A	2	2	4	16
Wireless Router	Failure, Signal Disruption	Data is not Transmitted	2	Excessive Vibration/water	4	Rubber matts, field testing	4	32	Sealing unit in waterproof coating	Manufacturer	N/A	2	2	4	16
ATV	Failure, Explosion	ATV does not work, Injury, Death	8	Poor Operation, Component Failure	2	Polaris Control and Procedure Manual	4	64	Maintenance, Knowledgable Driver	Manufacturer, Opperator	N/A	8	1	2	16

3.0 Design for Economics

In this section, a breakdown of the products purchased for the prototype are represented and discussed. To begin, the allotted budget for the prototype is $5000 and the funds actually used for the project is just under $3400. This value includes funds used spare parts and parts that were found to be inadequate for what was desired. In figure 12, a pie chart is displayed in order to show a complete breakdown of how much was spent on each component directly relevant to the prototype as well as auxiliary components needed for calibration and assembly.

The significance of this prototype is although there are product in the same category of this prototype, is the fact that there are no plug and play units. This means that commercially, each of these units must be custom made for a specific application. Consequently, the force/torque sensors currently used commercially, usually run a minimum of $10,000 which is almost triple what was used to manufacture the prototype in discussion and are not designed for harsh terrain such as this design.

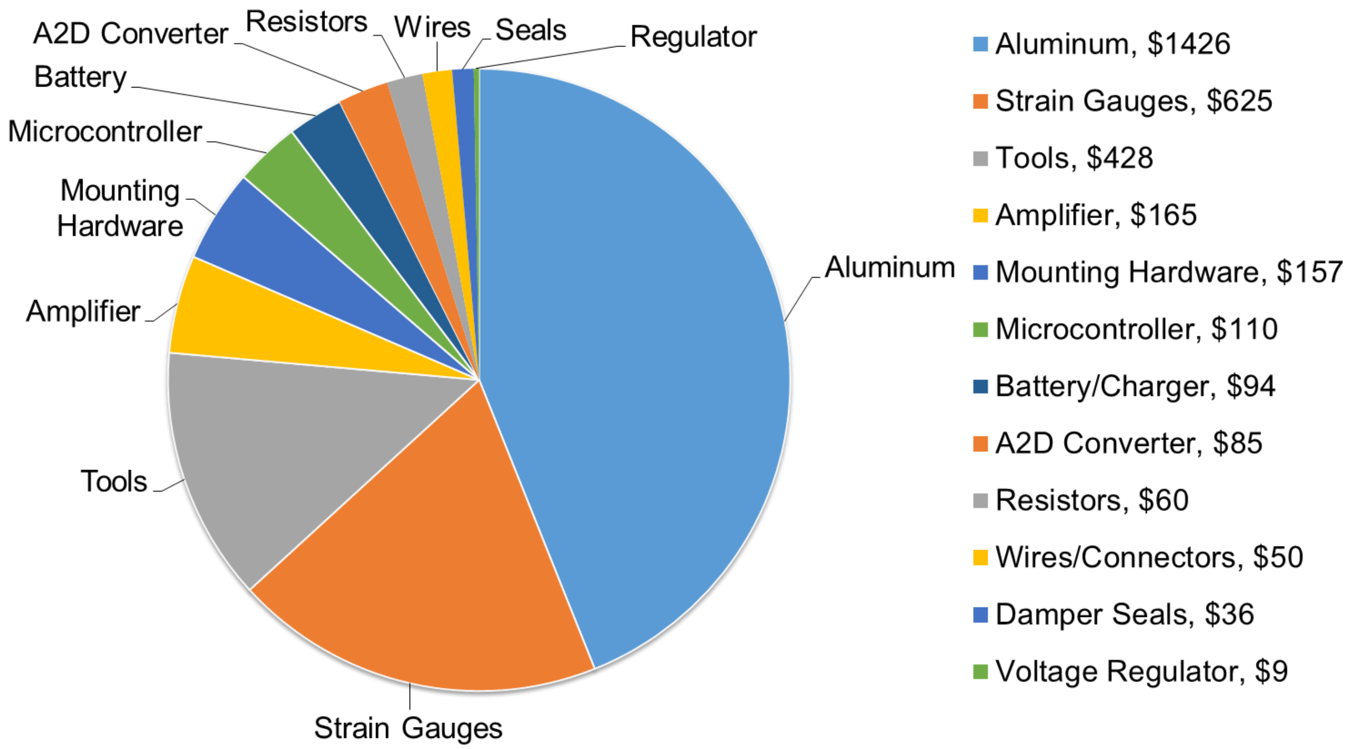

Figure 12 Budget used to manufacture force/torque sensor prototype

In figure 13, a visual representation is displayed in a clustered bar graph rating the force torque prototype in reference to the commercially available categories. The y-axis displays the cost that it would be to acquire one of the desired products and the x-axis represent s the products in discussion. In this aspect all three products in comparison are in the same category and are all used to find force/torque applied on the wheel of a vehicle relative to the surface acting on.

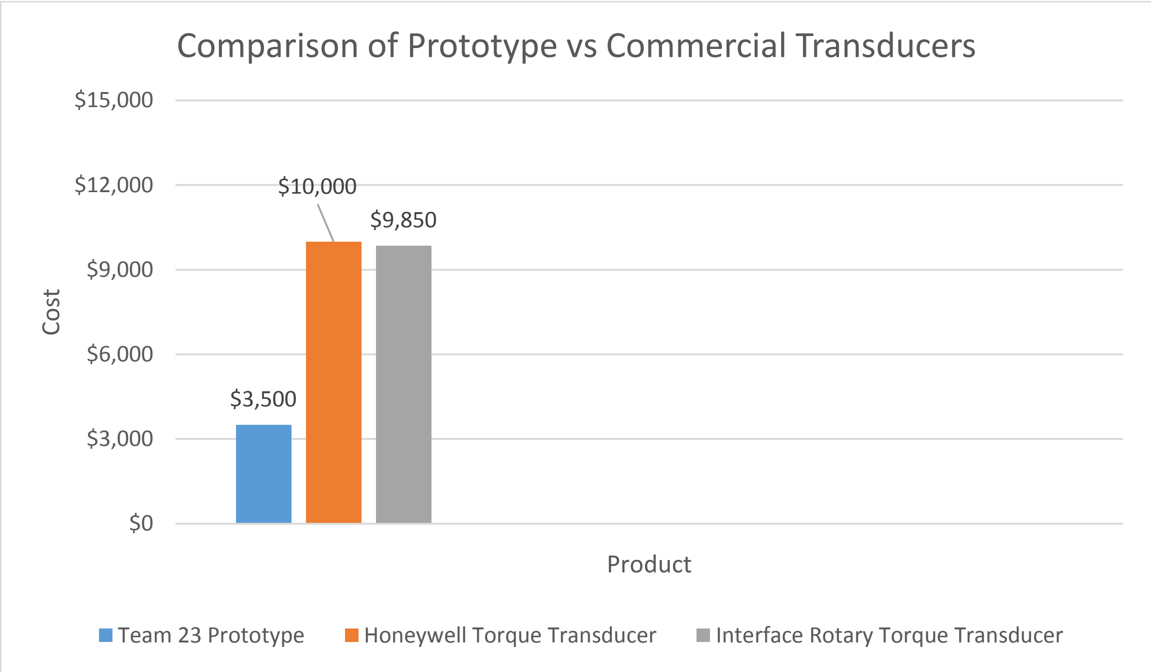

Figure 13 Prototype price versus commercially available products.

4.0 References

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5.0 Appendix

Table 1