Mana Tohu Mātauranga o Aotearoa
New Zealand Qualifications Authority

Level 2 Technology 2024

91360 Demonstrate understanding of redundancy and reliability in technological systems

EXEMPLAR

Excellence

TOTAL 07

Subject Reference Generic Technology 2.7
Demonstrate understanding of redundancy and reliability in technological systems

Introduction:

For AS91360 I was required to demonstrate a comprehensive understanding of redundancy and reliability in technological systems, in this case, the Mars Curiosity rover.
The Curiosity rover is about 2.2m tall, 2.7m wide and spans 3m across, this cost NASA(The builders and engineers behind Curiosity) 116m to build, but ended up spending 2.42 billion to get the rover into space and Mars through developing spacecraft. It left the earth on the 27th of November, reaching Mars 8 days later on the 5th of August. NASA's mission with the Curiosity rover was to discover if Mars once had a habitable environment for small living organisms.

Reliability and Redundancy definitions:

Reliability:
The performance of a mechanism over an extended period, whilst maintaining its operating functions. A mechanism that can last over time and stay consistent whilst deteriorating at a slow pace is reliable.
Example| An example of reliability is a weight scale that produces a consistent value when given the same conditions over and over again.

Redundancy:
The addition of components gives the mechanism a backup system to ensure if one mechanism malfunctions, These components allow it to still function and ensure the system is still able to complete its task even when something malfunctions. These components are redundant till they are needed and when something malfunctions they undertake their functions to make the system still function.
Example| An example of redundancy is having a spare wheel in your car if one wheel were to fail there could be something to replace it.

Systems within the Curiosity Rover:

Wheel system:
The Curiosity rover has 6 individually controllable wheels that can help navigate the tricky terrain on Mars, each of the 6 wheels has its individual motor which can be adjusted to give variable speeds through each wheel allowing more adjustable movement. Complementing this advanced movement are the 4 individually controlled steering modules, 2 located in front and 2 in the rear, allowing the rover to complete very versatile manoeuvres to navigate the rocky terrain. To retain grip whilst driving the rover it has an aggressive tread pattern machined out of aluminium supported by titanium springs within the wheel helping the wheel stay in contact with the ground at all times. The titanium-supported wheels are accompanied by a rocker-bogie suspension that averages out the angle that the chassis of the rover is rolling over, helping equalise the load over all the motors for each wheel.

Redundancy and how that intros into reliability:
This wheel system possesses 6 wheels allowing the rover to continue to traverse over the rough extraterrestrial plane even with the loss of a wheel. The ability to continue and complete its mission whilst having an essential component of the system fail is the Mars rover's implementation of redundancy. When and if a wheel malfunctions the other wheels will be able to take over and continue their purpose of navigating the rover due to the fact that each wheel is individually driven. The loss of a wheel will decrease the overall output of the rover and most likely slow it down but the overall function of the rover will continue and allow the rover to complete its job. This Redundancy in the system allows the rover to persist for an extended duration because if, for example, the loss of a wheel did halt the operations of the rover then it would not be able to continue its job. With the ability to continue with the loss of a wheel, the rover can work for longer and is more likely to be able to complete its mission making the Mars rover more reliable. One essential part of the reliability of the wheels is the materials they are made from as this affects the wheel’s durability. The Curiosity rover wheels are made from high-grade aluminium for the tread because it is lightweight and durable. The wheel spokes are Titanium due to its special properties, which help with the wheel's durability. Reliability of the rover makes the system overall more dependable for something such as the rover which travels through space where there is no way to access the rover to fix it. The reliability of the rover is essential and is of utmost importance to the goal of the mission.

The Curiosity rover wheel system is the congregation of the learning from previous rovers' successes and failures on Mars. Past rovers such as Pathfinder’s, Spirit’s and Opportunity’s wheel system all consisted of a similar 6-wheeled rocker-bogie system to the system that the Curiosity rover has. This is because the design was so successful on the previous missions to Mars that the overall concept of the design was kept throughout its development. The subtle changes that were made to further improve the Curiosity rover design from past missions include the increase in wheel diameter that increased 2 fold, over spirit and opportunities wheels. This change was made to accommodate the much larger and heavier rover which weighed 900kg compared to the 180kg Spirit rover. By increasing the wheel size the weight of the rover was much less likely to get the rover stuck in any tricky situations, as the surface contact with the ground was larger, keeping the rover from digging into the sandy landscape of Mars. The increase in wheel diameter also allowed the rover to traverse larger obstacles and cover more ground in a quicker time, these benefits showed a significant improvement in the evolution of the rover over time. However, because of the implication of the rover's larger size, there are new challenges to face with the weight of the rover. This weight causes new stresses on the wheel system, affecting the lifetime of the wheel system as more forces are acting on the wheels causing them to wear more quickly.

Drilling system:

To attain samples and complete other tasks the Curiosity rover uses a drill system that allows the rover to drill into different materials on the surface of Mars and take samples from the interior of the hole. This system was an essential part of the Curiosity rover by allowing a more in-depth knowledge of the substances that resided on Mars and led to the discovery of evidence that Mars used to possess water. The drill head which is similar to a Forstner bit cuts a wide diameter hole in which the surface material is fed through into a spiralling groove up the shaft of the drill covered by a sheath so the material is prevented from spilling. The material is then fed through a bearing seal and fed through an exit tube into a mechanism called the CHIMRA, which processes the sample by first sieving the sample to a size of 150 micrometres or about 0.15 millimetres, where it is then tested by many advanced subsystems to determine the chemical makeup of the sample.

Redundancy and how that intros into Reliability:
The Mars Curiosity Rover drill system is a substantial part of the rover's research and gains a large portion of use which can tire out and dull things like the drill bits. To overcome any expected wear and tear, as well as any unexpected breakages or faults the Curiosity rover has redundancy built in. Two spare bits are located in a box mounted on the front of the rover. The implementation of these bits allows the rover to continue obtaining the crucial samples from the Martian rock even in circumstances where the bit malfunctions. Spare bits make the system more redundant as the rover can continue consistent sample collection throughout the mission even through breakage or lengthy use. These bits are made from tungsten carbide, an alloy of tungsten and carbon that creates a durable base material that can withstand the excessive use it experiences on Mars. To ensure the bits remain sharp throughout use the bits are coated with a thin layer of titanium nitride that has a very high melting point that allows for the bit to not get deformed after prolonged use that causes high temperatures. The Durability of the bits in themselves combined with the redundancy of having multiple bits creates a very reliable system that is likely to continue functioning for a long period.
The Drilling system is run through two separate mechanisms, one for hammering and one for rotation, both aiding the collection of the samples. These two mechanisms are separately driven by individual motors allowing the system to potentially still complete its job if one of the systems were to fail making the system redundant. The dual-system design enhances the overall reliability of the sample collection system and ensures that the rover can continue gathering critical data in the event of a partial mechanical failure.

This drilling system represents a significant evolution from the previous rover's missions and their individual successes and failures. The Spirit and Opportunity rovers both do not use a conventional drilling system and instead use a Rock Abrasion Tool or RAT to essentially grind the rock with a diamond abrasive cutting wheel to gain access to the contents inside. This tool, while being very useful for examining Martian material, could not penetrate deep enough into the material to get samples from older layers of rock for NASA to determine things like evidence of water on Mars in the past. To overcome this limitation the Curiosity rover was implemented

with a percussive drilling system that is able to penetrate up to 5 cm deep into the Martian rock to retrieve samples of powdered rock from thousands of years ago. An issue experienced by both the twin Spirit and Opportunity rovers was the difficulty in penetrating the hard rock which required a significant amount of effort consuming a large portion of the rover's power and putting considerable mechanical strain on the RAT components. The new percussive drilling design uses not only conventional rotational drilling but also a hammering mechanism that aids in fragmenting the rock, allowing the Curiosity rover to collect samples from harder rock types that could not be accessed before.
The implication of these improvements impacted Curiosity's development into a further refined product that could deliver more towards the mission goal. The upgraded drill design habits further redundancy as there is now the option to swap drill bits so that if the cutting bit were to fail it could be replaced. The minimised stress on the mechanical components also allows for them to last much longer aiding the rover's reliability and its ability to complete the mission.

Power system:
The Curiosity rover utilises a form of nuclear power to generate the electricity for the rover to function, this power comes from the heat that radiates from the radioactive decay of plutonium particles, and this heat produced by the fission reaction is transferred into electricity using thermocouples that are extremely efficient. This form of energy generation overcomes the drawbacks of the Pathfinder rover which utilised solar energy through panels that would get covered in martian dust and lose their energy-generating ability. The nuclear power source charges the battery at a constant 100 or so watts, well enough to power the rover and for it to complete its various tasks. The plutonium source material should provide power to the rover for around 14 years, although the rover only planned to function for 2 years.

Redundancy and how that intros into reliability:
The Curiosity rover has one radioisotope generator onboard, this generator has multiple thermocouples that convert the heat from the plutonium going through a fission reaction into electricity by touching one end of the thermocouples to the heated area and another to a "cold junction" which creates a voltage disparity between the two sides and causes the flow of electrons creating electricity. The generator having multiple thermocouples allows for power

generation to still occur if only a few of them were functioning. Having this redundancy allows for the rover to continue its day-to-day operations with minimal disruption, ensuring that the rover can continue its mission while the essential systems are powered and the objectives can be completed.
The rover's excess energy that is produced by the generator is held in two separate lithium-ion batteries that support the rover when there is not enough power available from the generator. By using two batteries rather than one singular the rover has the ability to still store its excess power in the event one of the batteries gets damaged or malfunctions. This redundancy enhances the rover's overall reliability and protects against any interruptions caused by the failure of a battery which could be crucial to the completion of the mission. To help protect the generator and other components from the harsh conditions on Mars there is a cover made from “Aeroshell” which is composed of carbon fibre with a thermal layer that protects from the cold environment on Mars and prevents the rover from cold internal temperatures. This shell helps the rover withstand its environment and lasts for longer periods of time aiding the rover's reliability.

In previous missions on Mars, there have been significant issues with power generation in harsh conditions. With both the Spirit and Opportunity rovers utilising solar rays to generate their power through a configuration of solar panels, they faced issues through dust accumulating on the panel's surface and a lack of sunlight in the winter months. These issues caused the rovers to not generate sufficient power to operate reliably. To overcome these issues, the Curiosity Rover was introduced with a completely different way of generating its power, using a Radioisotope generator that converts the heat from decaying plutonium into electricity. The main issue of generating power from solar energy in the previous rovers was maintaining a consistent power level through the unpredictable environment on Mars where there are dust storms that could cover the solar panels at any time and reduce their power-generating abilities. The Radioisotope generator allows the Curiosity rover to operate reliably by losing the rover's dependency on sunlight and allowing continuous power generation through storms and different weather and seasonal events. The implication of this new design shows the development phases in which NASA improved the reliability of the rover as a whole. The new system also implemented redundancy through multiple thermocouples ensuring the rover will generate power even in a component failure extending its life. One added benefit of the new power generation was the ability to support more power-demanding instruments such as the new drill mechanism and more. All these improvements over the previous rover’s power generation aided the reliability and functionality of the Curiosity rover in its mission.

The importance of reliability and redundancy designed for the Mars rover:

The Mars Curiosity Rover was designed with high standards for reliability and redundancy, both key to success in such an uncompromising mission. The Rover must be completely self-supported and self-dependent given the distance from the earth or any assistance. The reliability of the rover is crucial as if it fails on Mars, there is no way to repair it, and the Billions of taxpayer dollars that have been put into this project and the rover would have gone to waste making the investors(taxpayers) unhappy. Because of these factors, the implementation or redundancy was paramount to the mission and ensured that every part of the rover had to incorporate these to guarantee reliability within the entire system. If the mission were to be successful many great things could be accomplished such as potential human habitation on Mars or the discovery of previous life on Mars, both being priceless objectives that are only possible when the rover can complete its job reliably. Moreover, this Mars rover has implications beyond the single mission. By proving that a human-made machine can withstand itself on Mars through unpredictable and extreme conditions, laying a foundation for future missions showing what is possible. The understanding that an autonomous mechanism can operate so far away from home proves the idea that a self-sustaining habitat, essential for human existence on Mars, could function reliably.

Reliability ensures that all parts of the Rover consistently perform throughout the extent of the mission. Without reliability, the mission could fail prematurely and compromise all the valuable scientific data that the rover could have collected.

Redundancy which ties in with reliability is the implementation of “backup” systems to allow contingencies for components and systems that fail. Redundancy systems and mechanisms ensure the rover continues its objective even through unexpected failures.

By building redundancy into the Curiosity rover the engineers who worked on the project can ensure the rover can adapt to unexpected failures, whilst maintaining its functionality and extending its operating lifetime. Reliability and Redundancy are fundamental to the performance of the mission and achieving the goal of exploring and studying Mars.

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Excellence

Subject: Technology

Standard: 91360

Total score: 07

Q	Grade score	Marker commentary
One	E7	The candidate explained the importance of redundancy & reliability (R&R) in the develop of a technological system. Comprehensive explanations were given for how R&R were addressed in a technological system. Previous versions of the technological system, and issues that arose, were used as a way of discussing how future R&R implications influenced the design and maintenance decisions when developing new technological systems. The candidate could have detailed how social / cultural and / or environmental factors impacted the technological system's reliability.