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Pearson BTEC Level 5 Higher Nationals in Engineering (RQF)

Unit 45: Industrial Systems

Unit Workbook 4

in a series of 4 for this unit

Learning Outcome 4

Performance Analytics

4.1 Performance Analysis Methods

Performance analysis methods are used to analyse the performance of a system. These methodologies are used to provide a starting point to eventually hone in on an issue's root cause. There is a range of methodologies that can be used, as no single one will be used to solve all problems for all cases, and some problems may need to apply more than one methodology to analyse the performance.

Performance analysis adds structure to what would be a guessing game of "what's wrong" and taking a blind approach to changing random factors and hoping that fixes the problem. The blind approach can be considered to be an "anti-method"; it is based entirely on luck, and those who are unlucky could cause huge delays in the process. There are two methods for performance analysis:

- Full load measurement
- Single transaction measurement

4.1.1 Full Load Measurement

Full load measurement is to run the system under a full production load, this is useful to gather all information that is measurable only under high-system loading. Full load measurement should always be done as there will be a rapid degradation in performance after a threshold is exceeded and the system reaches its ultimate load (the point at which the system will completely fail – much like ultimate tensile stresses in materials).

4.1.2 Single Transaction Measurement

Single transaction measurement is an isolation technique used to gather information about the individual components, and understanding how they would work. The system will need all the individual components to run at their optimum performance if the system is to do the same.

4.1.3 Full Load or Single Transaction: Which is Best?

Performance analysis should normally be planned around a full-load measurement test, but the performance constraints may vary at different times of the day, if you consider a number of factors (testing the acceleration of a car may depend on the windspeed, and can also affect fuel efficiency).

If the full load performance analysis does not show any serious problems, or if the system is not achieving the expected performance levels. Then the system needs to be isolated to examine each of the subsystems to ensure that they are running to their desired performance.

To ensure that these tests will succeed, the diagnostics team will need the appropriate data sets, but they will also need to ask the following:

- Is the performance fluctuating, or is it consistently below the expected level?
- Are performance issues related to a specific time or environmental factor?
- Has the system had a change recently and have these changes been fully documented?

4.1.4 Hybrid Example

Consider the example of a hybrid powertrain. The hybrid powertrain will be considered as a "series" system, meaning the output will be solely electrical, the power-flow of which can be seen in Fig.4.1 below, of course there will be much more monitored in the system, but this example will concern itself with the main components: the engine, generator, battery and output (in this case the motor).

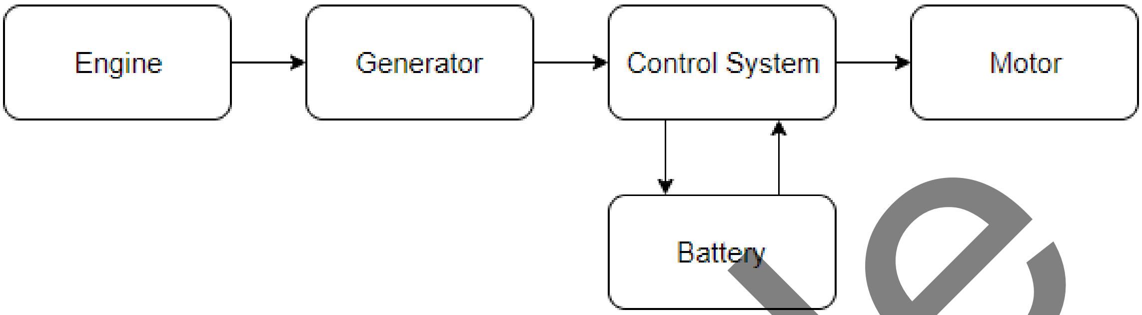

Fig.4.1: A series hybrid's main components

The performance of the system will typically be analysed by switching the system between its "power-modes", which will revolve around the following:

- Battery Discharging, Generator off
- Battery discharging, Generator on
- Battery charging, Generator on

These are not the only power modes, as there are several configurations a hybrid system designs that can be produced, each with their own advantages and disadvantages. The system is broken down into several components for isolated testing:

- The engine:
  - Engine temperature
  - Fuel intake
  - Air intake
  - Engine revolutions
  - Anti-knock sensors
  - Fuel tank
- The battery bank:
  - Temperature
  - Current drawn from each battery
  - Voltage of each battery
- The generator:
  - Generator Temperature
  - Electromagnetic torque produced
  - Rotational speed

  - Current drawn
  - Voltage produced
- The motor:
  - Motor temperature
  - Speed
  - Torque

Analysing isolated performance will help determine the part (or parts) that are not performing at the optimal level. However, it's important to consider certain factors that may alter performance, such as:

- The engine:
  - The quality of fuel used.
  - The quality of air (some lab tests will use oxygen rich air to compensate for laboratory conditions).
  - Has the engine had a cold or hot start up?
  - The quality of the oil, or the bearings
- The battery bank:
  - Battery performance is very dependent on their temperature, as they use chemical reactions.
  - Different battery chemistries will exhibit
- Generator and motor
  - Increased heat output in the system can weaken the magnets
  - The waste heat produced by the resistance in the wiring will increase losses further
  - Is there slip in the contacts between the engine and generator?
  - Is there slip in the contacts between the motor and the wheels?
  - The quality of the bearings.

By considering these factors, it will be possible to discuss whether or not this change in performance is expected due to a certain factor, or if the component will need to be replaced.

4.2 Current Trends in Engineering

The world of engineering is constantly changing, with the goal to reduce the amount of human monitoring required. Another huge goal is to improve the sustainability and the longevity of the resources currently available to us, and also as a method of fighting climate change and preserving the current ecological system. This helps us analyse the performance, if we know what problems need to be solved in engineering, we can get better ideas of what it can do.

4.2.1 Reducing Human Monitoring

Humans, from an engineering point of view, are flawed compared to machines. Machines don't need breaks, they don't need to be fed, they don't need heating, or maybe even lighting, they are not prone to mistakes, they don't argue, and they don't need motivation. The current problem with machines is their decision making, machines are yet to fully understand learning and struggle to use information they have gathered to find a solution. In essence, humans have the creativity to solve a problem on the fly, but a machine will be able to work longer and produce more consistent results (when programmed properly).

Software engineers are also looking for a way to incorporate a brain into machines to give them the ability to learn, by creating artificial intelligence (AI) engineers will produce the creativity of the human brain, with the efficiency of the machine. Of course, there is a lot of debate surrounding AI, with a lot of science fiction based on an AI destroying humanity (some of the most famous examples are the Terminator franchise and books by Isaac Asimov). A lot of nations around the world are trying to restrict the allowable applications of AI, with regards to banning weaponry running without any human decisions.

But with all the fear mongering aside, there are advantages to having a computer that can think, it can take the emotion out of a situation; while a human can panic in the event of catastrophic failure, a computer is not affected by the imminent danger. Other positives can be considered such as the development of self-driving cars, building a brain that can monitor the roads, speed signs, other cars and pedestrians. It can also create companions for those who are confined and do not have much interaction, as well as provide assistance to the infirmed, relieving pressure on the care system.

"If our brains were simple enough for us to understand them, we would be so simple that we couldn't"

(I. Stewart)

The current problem is developing a digital version of the human brain when we don't even fully understand it. The brain is a hugely complicated organ and while neurobiologists are working tirelessly to study it, we have barely scratched the surface.

4.2.2 Sustainability

Earth is a replenishing system and does its best to stay in as stable state as possible, including replenishing soil, clean air, clean water and reducing carbon dioxide, among other natural resources. However, the human impact on the Earth cannot be ignored, and every year since 1986 we have calculated "Earth Overshoot Day", this is the day that the Earth can no longer keep up with the consumption. In the 1980s Earth Overshoot Day was in November, over the next decade, the day jumped to October, reaching September in the early 2000s and the date is currently about to break into July. This means that once Earth Overshoot day happens, humans are using resources that are not being replenished. This is due to deforestation, our water treatment facilities, air pollution, and our waste disposal facilities.

With an ever-increasing population, and wasteful behaviour, the date for Earth Overshoot Day will keep coming earlier, and there will be a need to restore the equilibrium, which means there will eventually be one of four predicted outcomes that will balance the Earth again:

1. Engineers can carve a more efficient pathway to reduce the amount of resources each human consumes while sustaining our comfort.
2. Humanity colonises other planets, such as Mars, for terraforming and reduce the resource demand on Earth.

The two others however, are the worst-case scenarios:

3. War for the scarce resources reduces the human population.
4. Famine or disease cause a mass extinction event for humans.

To get a better understanding on the lack of sustainability humans have in place, it would be worth researching the "garbage patches". Rubbish that has wound up in the ocean have been swept by the ocean's currents, gathered it and congregated into five large "garbage patches". It's hard to give a definite size to these patches, there are claims that the north pacific patch is almost twice the size as Texas, but these are largely exaggerated, the cost of figuring out the size of the patches is a huge task and requires significant labour and time to figure out.

The waste plastic is poisoning the wildlife as they breathe it in, or mistake it for food, and is causing huge problems, Fig.4.2 shows the effect of plastics in wildlife, and the cost of mistaking plastic for food. It is not just a case of mistaking plastic for food, sometimes animals will get caught in the waste, one of the most concerning cases is the plastic rings used to keep a pack of cans together; if an animal cannot remove the plastic rings from their body, then they will suffer deformations like peanut the turtle in Fig.4.3.

Fig.4.2: The unaltered stomach contents of a dead albatross chick on Midway atoll National Wildlife Refuge in the Pacific.

Fig.4.3: Peanut the turtle, who suffered a deformation in her midriff after being caught in a plastic ring.

Unless action is taken to develop methods for retrieving the plastic out of the water, this will get progressively worse and will cause a huge ecological backlash. Not to mention that we are poisoning the food we eat with plastic, which will not benefit us either.

It's not just plastic poisoning the water, it's also sewage. Both domestic and industrial, water is treated before it is drunk, and it is only the past few decades where developed countries such as the UK have decided that the water needs to be treated after it is disposed of. Other countries however, do not have such systems in place, Fig.4.1 is the tourist hotspot in Rio de Janeiro, Copacabana Beach, with visible plumes of sewage pouring from the city as half of the houses in the Guanabara bay drainage basin are not connected to sewage treatment plants, Ipanema beach also has these problems. Problems like this are not just isolated in Rio, these are recurring issues visible across many less economically developed countries that do not have the money to pay for such infrastructure.

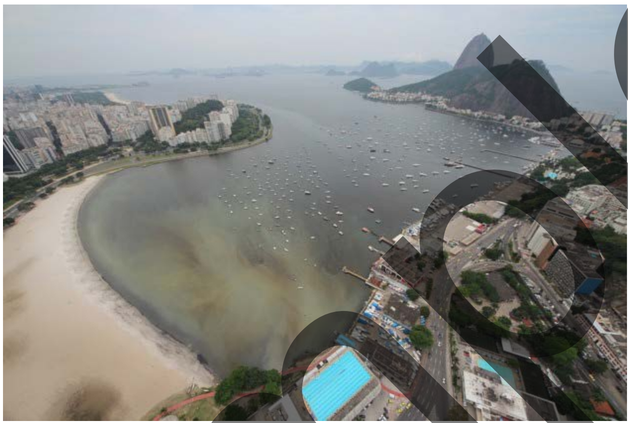

Fig.4.1: Visible sewage plumes in Guanabara bay, Rio de Janeiro

4.2.3 Climate Change

Climate change is causing huge problems with the global ecosystem, the global increase in temperature linked to the increase in greenhouse gases (Carbon Dioxide, Methane, Water vapour the most prominent) is having huge effects on both humans and animals. Rising sea temperatures is causing the polar ice caps to melt, which is taking away the Polar bear's hunting grounds, with images of starving Polar bears. There is also the damage that rising temperatures is causing to coral reefs, with the vibrant colours beginning to bleach white, as the high temperatures stress the algae.

There is also the impact to humans too, there has been a recorded increase in the intensity of the strongest hurricanes over the past few decades. The warmer sea surface temperatures can intensify the wind speeds in the storms, which cause more damage when they reach land. Scientists have begun to expect between $2 - 11\%$ increase in the maximum wind speed, on average. In some less economically developed countries, this can cause incredible damage, with the likes of some of the smaller islands in the Caribbean suffering huge damage. Puerto Rico had lost its infrastructure, and Barbuda had 90% of its buildings destroyed, with Prime Minister Gaston Browne saying the island was left "barely habitable" after Hurricane Irma. The rising sea levels are also making more coastal storms more damaging. In 2012, coastal flooding was a major factor in the $\$65$ billion of damage to New York, New Jersey and Connecticut that occurred during Hurricane Sandy.

4.3 What This Means for Industrial Systems

4.3.1 Reducing Human Monitoring

While computers may be getting smarter, the human body is still much more versatile than a machine. Humans are much more mobile and flexible and compact, since humans rely on muscles for movement, not actuators, motors and pistons. Machines do not have any real senses, with machines currently having to use barcodes to understand the role that they are required to do and having a barcode ready for everything in a constantly moving environment is going to be complicated. There is also the cost, replacing humans in industry for a machine that will be able to do the same task requires a huge capital cost, although long-terms savings are possible, since you do not have to keep the robots warm, they can work in the dark, and most importantly, they don't require a wage.

The URL below shows the current state of robotics, demonstrated by Boston Dynamic's latest generation of bipedal robot, Atlas, who has been developing in leaps and bounds. Or arguably the most famous robot, Honda's ASIMO, Honda have a long history with robotics, and ASIMO was one of the first robots capable of walking up and down stairs, it can and also run, engage in a conversation, and recognise faces. The development of ASIMO is also in developing mobility systems for people with weakened leg muscles. While both robots are impressive. It is still a long time before humans are completely replaced and obsolete in industry.

https://www.youtube.com/watch?v=fRj34o4hN4I (Atlas)

https://www.youtube.com/watch?v=1zlh9dHBEmo (ASIMO)

The best way to improve sustainability is to minimise the need for extraction from the Earth, whether this is metals, oils for plastics, glass, lumber for wood or paper, water, coal and gas for energy production.

4.3.2 Climate Change

With regards to climate change, industries are urged with government incentives to reduce the power consumption and use of "dirty fuels". There are several ways of doing this, such as:

- Improve the efficiency of the existing industry processes
- Reduce fuel consumption or use greener energy sources.

One method to do this is to move towards carbon free power production, such as renewable energy sources, or by using Nuclear. However, renewable energy sources such as wind, hydroelectric, solar etc. are very unstable systems. While fossil fuel and nuclear power plants can regulate their overall output, renewable energy are less reliable, and cannot be regulated which means the excess power can overload a system, or limited energy input can cause blackouts. As an example, a purely solar powered grid network will need to produce enough energy for 24 hours in the space of either 16 hours during the Summer solstice, or 8 hours during the Winter solstice, not even taking into account the cloud coverage during the day.

There are forms of energy storage, such as water pumps, but a more realistic system in the future would be based around balancing the load with a large battery bank, which is an idea that Nissan has put forward with their "vehicle to grid" project. Rather than produce one large battery bank, owners can plug their electric vehicles into the house and help stabilise the grid.

4.4 Digital Development

4.4.1 Moore's Law

With the development of the silicon transistor in the late 40s, computing power has improved dramatically. The transistor has been improved constantly over the past 70 years and they are still being improved on today. One of the co-founders of Intel, Gordon Moore has been a huge name in the industry since the company's foundation in 1968, and is most famously known for his prediction, known as "Moore's Law". Moore's law states that with the rate of improvement in semiconductors "the number of transistors and resistors on a chip doubles every 24 months". Fig.4.2 demonstrates the number of transistors on a system and the rate that it has increased, showing Moore's law in full effect.

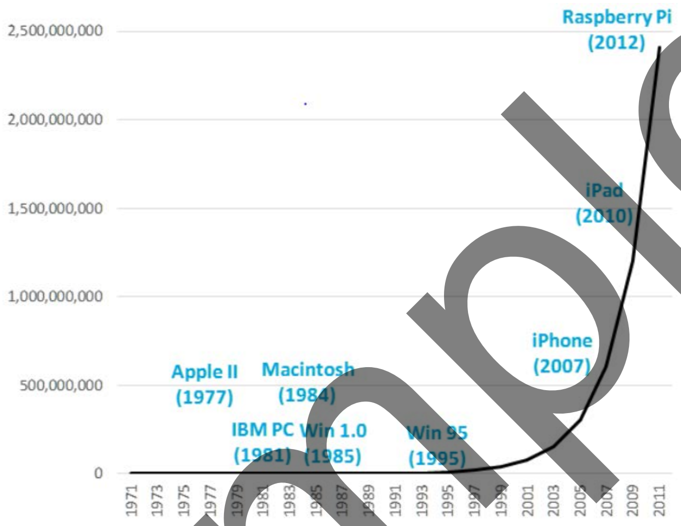

Fig.4.2: The number of transistors on certain computer products

At the current rate, it is believed that by 2023 computers will surpass a single human's brainpower, and by 2045 it is predicted that computers will surpass all human brainpower combined. Today's smartphones have more computing power than the systems used in the lunar missions. The advances in computing power have leaked to all different applications, the development of handheld equipment, improved calculation times for simulation software, advanced aerodynamics computation, 3D modelling, finite element analysis, heat transfer, and the list can go on and on.

The increase in power is not without drawbacks, there will always be heat dissipated from electronic circuitry, this is unavoidable without superconductors, special materials that have almost zero resistance, these currently require super-cooled metals (mercury becomes a superconductor at $-268.8°C$, or $4.35K$ above absolute zero) and so their applications are very limited, such as MRI scanners, particle colliders and the Magnetic Levitation (Maglev) trains in Shanghai which are capable of speeds of up to $600 km/h$ (shown in Fig.4.3). Therefore, as transistors get smaller and their density on a circuit board increases, the demand for improving the heat transfer away from the circuit to protect sensitive components will become a greater issue and could stall the trend of Moore's Law.

Fig.4.3: Maglev train in Shanghai

The ever-decreasing size of the transistors must also be considered, as it will eventually reach a point when electron behaviour will change as it reaches the level of quantum mechanics and standard laws of electronics will no longer apply.

4.4.2 Systems Communication

Most systems can communicate with one another, but this is short range communication and usually controlled by a centre console in the facility. Improving the transmission between systems by bypassing the centre console, and just have the two systems communicate directly with each other, will speed up the system and improve the "reaction" times of the system, which brings onto the idea of the "Internet of Things".