



Research Methods

Error detection methods using industry 4.0 techniques.

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Lecturer: Graham Howe

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Nefyn Roberts

2009576

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Introduction

Since Frederick Taylor revolutionised industrial engineering by applying scientific management in order to seek out inefficiencies (Hounshell, 1988) and Henry Ford took things further after taking inspiration from the moving production lines of the meat processing industry and applied them to his automotive company (Science J Rank, 2022). The production line and related processes have been in constant review, upheaval and modification with gains in efficiency, cost and quality being key drivers for continuous improvement.

The development of the Toyota Production System (TPS) from the late 1940s onwards revolutionised how the industry assesses quality and waste (van Driel & Dolfma, 2009). Key components of the TPS such as Kaizen, Poka-Yoke, Andon and Just in Time, have created lasting paradigm shifts for how the automotive sector manages mass production of vehicles. TPS also acted as a precursor to Lean methodologies which was later combined with 6sigma analysis techniques.

In the 1980s the APQP process developed by GM, Ford and Chrysler created a framework of standardised procedures and processes within the industry (Mittal, et al., 2012), this was in order to improve both internal and Tier 1 standards to ensure consistency and on time delivery.

“In order to meet the customers’ high expectations, manufacturers have to increase product quality, reduce delivery time, and minimize the product cost or implement new production strategy.”
(Todorova, 2013)

The dawn of industry 4.0 now offers new opportunities of utilising technology to work harmoniously with production lines and operators in order to improve efficiency and quality further still (Dominik, et al., 2020). This enables smart factories to become a reality by integrating the Internet of Things (IoT) to Cyber Physical Systems (Mrugalska & Wyrwicka, 2017). With Moore’s Law (Ming-Yang, et al., 2019) enabling reductions in the costs of computers, sensors and cameras, it’s now easier than ever for manufacturers to apply technology to existing processes in order to improve data collection. Improved data collection can highlight key bottlenecks, areas for improvement or repeated errors. Using Pareto Analysis (Better Explained, 2018), companies can then identify the most frequent causes of inefficiency, error or waste within their processes and target these areas accordingly. Typically, in Pareto distribution 20% of problems will occur in 80% of the time. Therefore, focus should be placed on these most frequent instances of defect in order to most efficiently use resources to reduce or eliminate errors to continuously improve overall production.

This body of work will focus largely on the quality aspects of production, notably error detection methods and ways to implement new techniques to an existing production process by utilising industry 4.0 applicable technologies. Both technology and the processes will be evaluated in order to explore the area’s most applicable for change and development.

With reduced re-working and re-calls from improvements in quality, it’s also possible that efficiency and costs benefits can also be found. Policing output more efficiently can reduce manual checking of components and assemblies further reducing overall labour costs from a small initial outlay in technology investment.

Aims and Objectives

This piece of research aims to understand the scope of options available to Reflexallen in terms of error detection methods. In particular focusing on technological solutions that can be applied to what is currently a very manual process on the pipe/hose assembly lines.

Reflexallen produce plastic pipe and rubber hose assemblies for major OEMs, these assemblies often have many sub components (clamps, grommets, clips, end pieces/connectors, protective sleeves and labels) that must be applied in a particular order. The company deals with thousands of different top-level part numbers and sub components, so complexity can lead to errors and errors then lead to defects. Defects most commonly include missing parts/labels or incorrectly used components. These defects can then cause misidentification, leak paths or incompatibility at the customer end. To reduce incorrectly assembled parts being shipped to customers, at times 200% checks have been implemented, however this comes at a great expense in both time, resource and money and ultimately cuts into the profitability of the parts.

In this piece of research, different types of error detection tools will be evaluated and compared against each other. The pros and cons of each method will be assessed, looking at areas such as, application, ease of use/operation, cost and effectiveness. With the most appropriate solution(s) to be recommended for further analysis and implementation for the project proposal. In order to meet the objectives, this essay will aim to answer the following questions.

What you plan to accomplish?

This essay will aim to provide an overview of the different technological methods available for detecting assembly faults. This research can then be used as basis for further analysis and eventually implementation of these tools and techniques, in conjunction with industry 4.0, in order to reduce assembly errors and defective parts.

Why you want to do it?

Currently Reflexallen experiences frequent operator errors on the manual assembly lines leading to defects on finished products. The assembly processes require a degree of dexterity that does not allow them to be automated easily or cheaply. Therefore, operators are required to manually assemble thousands of different pipe and hoses per week. The variety of part numbers manufactured by the company presents the opportunity for errors and subsequent defects to occur. This can come in many forms such as;

- i. Wrong components/tube on the bench for the order/work instruction.
- ii. Manual operator error, processes steps missed or applied incorrectly.
- iii. Insufficient training.
- iv. Insufficient quality control/checks before parts are shipped.

How you are going to do it?

The different error detection methods will be evaluated for their suitability in adoption onto the Reflexallen production lines and processes. After analysing the defect occurrence data, the different error detection tools will also be compared against the other in order to conclude the most suitable methods to be implemented.

Literature Review

For the literature review, this essay will focus on the different types of sensors in order to fully evaluate the options available to Reflexallen. This will allow an objective decision to be made in the project on the best route forwards for the company in terms of updating the processes in line with industry 4.0. Ultimately the success of the project will be based on reducing errors and re-work/re-checking of parts.

As (Mirsa, et al., 2021) note “Traditional industrial processes are rapidly transforming towards Industry 4.0 standards by replacing processes consisting mostly of mundane and repetitive tasks into highly automated processes.”

In many respects some of the processes at Reflexallen are prime candidates for this type of transformation. Although the assembly of parts may not be suitable for automation, the checks required for approval can be. This literature review will explore what technological advances exist and which ones would best apply to the existing production process. As (Mirsa, et al., 2021) make clear, one of the first steps will be to digitise the work benches and processes. Connecting the production lines to The Cloud and the IoT will allow data to be shared, monitored and controlled live. In this respect, the planners will have an enhanced overview of the production rates from the lines.

As (Mirsa, et al., 2021) explain, most modern-day industries rely on a wide variety of sensors to keep processes under control and to automate tasks. They categorise sensors into six sections based on their underlying characteristics, they are; Thermal, Mechanical, Electrical, Chemical, Optical and Acoustic. This research will delve into each of these categories to better understand how they work, their pros and cons and how they could apply to the Reflexallen production lines/processes. Additionally, Magnetic Sensors and technologies such as smart screens, which can fit into a number of these categories, will also be explored independently of the (Mirsa, et al., 2021) list.

Thermal

Thermal sensors are designed to measure thermal energy in Joules (J) or temperature (°F °C or °K). thermal sensors themselves can be separated into three categories, these are; Resistive Temperature Detectors (RTDs), Thermistor and Thermocouple. (Mirsa, et al., 2021)

RTDs, are high precision temperature sensors. Using pure forms of conductive materials, e.g. gold, the changes in resistivity due to temperature are measured by passing a voltage through the metal. Whilst effective in measuring absolute temperature, RTDs are less effective at measuring temperature changes. (Mirsa, et al., 2021)

Thermistors, are sensors that detect changes in resistance of a voltage passing through a thermally sensitive resistor to measure changes in temperature. (Mirsa, et al., 2021)

Thermocouples, as Kenneth Williams describes in an archived BBC clip, work using the heat differences between two metallic atomic structures, this in turn can produce a measurable current. Semi-conductors can be used as an alternative to metals, like those used in wrist watches. (BBC, Kenneth Williams, 1981)

The benefits of thermal sensors are that they are relatively inexpensive and easy to implement. Thermistors and thermocouples are currently used at Reflexallen in the extrusion and oven processes. However, in relation to the manual assembly of the components onto the hoses, there are no obvious applicable uses for such thermal sensors at this point in time.

Mechanical

Mechanical sensors measure and quantify changes in their mechanical properties in order to describe rates of change in physical phenomena. Common types of mechanical sensor include; pressure sensor, barometer, altimeter, liquid flow sensor, gas flow sensor and accelerometer (Mirsa, et al., 2021).

Pressure Sensors, measure changes in fluids (liquids or gases). As (Mirsa, et al., 2021) describe, "Pressure sensors can be of various types such as piezoresistive, piezoelectric, capacitive, electromagnetic, strain gauge, resonant, and others."

Barometer, measures changes in atmospheric pressure.

Altimeter, measures changes in altitude of an object above a fixed level.

Liquid flow sensor, measures the flow rate of a liquid within a channel.

Gas flow sensor, measures gas velocity or flow rate within a channel.

Accelerometer, measure the acceleration of a body.

Whilst mechanical sensors are varied the majority would not be applicable to Reflexallen in the assembly process for detect missing parts. That being said, liquid flow rate sensors are currently used on many of the assembly lines in order to leak test parts before approval, in this sense they are already used to detect defects in the form of leak paths. Pressure sensors, in relation to the checking fixtures, may also be applicable for detecting weight changes when components are added to or missing from assemblies.

Electrical

Electrical sensors quantify and measure the electrical properties of objects or their surroundings, the types of sensor include; Ohmmeter, Voltmeter, Galvanometer, Watt-hour meter (Mirsa, et al., 2021).

Ohmmeter, uses conductive materials to measure resistance or changes in resistance relative to the current flow through it.

Voltsmeter, used in an electrical circuit measures voltage or voltage drop across a material or a device.

Galvanometer, uses deflections in a coil surrounded by a magnetic field to measure current in a circuit. The current flowing through the circuit is directly proportional to the amount deflections of the coil.

Watt-hour meter, measures the amount of energy supplied to a device/machine/household in a fixed duration of time. Typically, this is found at the consumer side termination junction of electrical supplies.

Currently electrical sensors, as described above, would not be applicable to the processes or products made on the Reflexallen assembly lines. However, there may be future applications applicable for conductive materials/tubing or 'smart' products such as heater lines.

Chemical

Chemical sensors monitor an environment and detect the presence of and then estimate the amount of various chemical classes. These sensors use resistive, capacitive, chemical or biomaterial compounds to measure the rate of change of the substance being analysed. Chemical sensors are commonly used and can be found in devices such as smoke and alcohol detectors (Mirsa, et al., 2021).

Given the application of the parts made at Reflexallen, chemical sensors would not be applicable to the current processes and would not offer useful application in detecting process errors.

Optical

Optical sensors can detect the frequency of optical wavelengths or the intensity of light on a given area. They can be resistive or capacitive sensors that can characterise the optical properties of an environment or object. Common optical sensors include; Light sensors, photocells, infra-red sensors, ultraviolet sensors and colour sensors (Mirsa, et al., 2021).

Light sensors, detect the presence of light, they are also referred to as photodetectors.

Photocells, use a variable resistor to determine changes in light intensity through changes in resistance, they are also referred to as photoresistors.

Infra-red sensors, detect infra-red radiation frequencies in the electromagnetic spectrum beyond the red wavelength.

Ultraviolet sensors, detect ultraviolet radiation frequencies in the electromagnetic spectrum before the violet wavelength.

Colour sensors, detect the wave lengths and intensity of the optical wavelength bands (red, green, blue etc) in a given area of focus.

Optical sensors could offer a number of useful applications in the current Reflexallen process. One of the main errors repeated on lines are missing components. A camera system could be used to notify operators of missing or incorrectly positioned sub components in order to catch errors in real time and prevent re-work or defective parts being shipped. Simpler systems such as photocells or colour sensors could also be used to detect missing labels which is another common error.

Acoustic

Acoustic sensors convert changes in pressure due to sound wave vibrations into electrical signals/energy. Common examples of acoustic sensors, include the microphone, seismometers and ultrasonic sensors (Mirsa, et al., 2021).

Microphones, convert speech/sound into electrical signals by detecting changes in air pressure from the audio waves.

Seismometers measure seismic waves to detect earthquakes.

Ultrasonic sensors convert ultrasonic waves into electrical signals.

As the parts created at Reflexallen do not emit sound and the construction process does not use machining, of which resonance differences can be picked up by microphones to detect tool wear (Li, 2002), acoustic sensors would not be applicable to the processes used.

Magnetic

There are many types of magnetic sensor, of which the strength, function and design can vary significantly. This analysis will use the use a list collated by (AKM, 2022) to give an overview of these different types.

Coiled, these sensors can detect magnetic flux density by bringing a magnet closer to or farther away from a coil, that has a voltage passing through it, changes in current can be observed and measured.

Reed Switch, this type of sensor uses two pieces of metal (reed) overlapping but not touching in a glass tube. When a magnet (external from the tube) is moved toward the reeds they become magnetised, causing them to come into contact to then complete a circuit and turn on a switch.

Hall Elements, based on the phenomenon of the 'Hall' effect, are used to detect a magnetic field and are used in various applications such as non-contact switches and smartphones.

"It is based on the phenomenon that the electromotive force appears in the direction orthogonal to both the current and the magnetic field when applying a magnetic field perpendicular to the current to the object through which current is flowing" (AKM, 2022).

Magnetoresistive Element (MR), this detects magnetic fields using a material that's resistance changes when magnet is applied. In all there are 3 types of MR, they are an anisotropic (AMR), giant (GMR) and tunnel (TMR). You can also get a semiconductor (SMR).

For parts using metallic components magnetic sensors may be applicable, however they would not catch all faults and defects.

Additional Techniques

Whilst the analysis above focuses on various types of sensors and tools, there are additional methods and techniques that can be applied to the current process to reduce errors in production.

For example, technology such as electronic touch screens/tablets use multiple sensors that can't be neatly fitted into the categories above. However, they can be added to the production lines and connected to the IoT to show live work instructions at the appropriate work cell and updated in real time once the order is fulfilled. When parts are scanned, as part of the process, the quantity of completed parts can be tracked live and alert the operator once the order has been completed. The screen could then update automatically to show the next products work instruction.

By connecting the work benches together through the IoT, when an order comes close to being completed an automated message could be sent to the stores team to prepare the next batch of sub components to be delivered to the work cell/bench in real time. This would allow the operator to stay at the work station and improve productivity by removing movement waste. As (Mrugalska & Wyrwicka, 2017) show, lean principles can be applied with industry 4.0 to combine the physical with the digital to maximise efficiencies.

Digital screens could also perform a dual function, as well as the points highlighted above, the screen could also alert the operator to any issues raised by sensors working in tandem, e.g. component missing or incorrectly orientated. Audio or visual alerts could also be used to aide operators in identifying defective parts before they are wrongly approved and sent to the customer. The result of these measures will enable TPS features such as the KANBAN to be more closely monitored in production and assembly areas (van Driel & Dolfsma, 2009).

Another recent innovation that could be utilised, thanks to reducing costs, are using a projector and camera system in tandem. This system can work by placing a projector and camera directly above a checking fixture, an image of the assembled product could be displayed on the work bench. As the operator assembles the part, it will become more visually apparent if there is an issue as there is a direct 1:1 comparison. Although some accuracy in the detail or the frame rate may need to be compromised in order to account for tolerances (Klein, et al., 2021). A red/green ANDON light approval system on the screen or through the projection can be used to enable clear instructions to operators on the work cell.

Methods

After evaluating the findings in the literature review, sensors in the Mechanical, Electrical, Thermal, Chemical and Acoustic categories can be eliminated for the remainder of this research proposal. Whilst useful in their own right, they will not be applicable to the current processes in the Reflexallen pipe and hose assembly processes.

This then leaves Optical and Magnetic sensors as viable avenues to explore further with 'off the shelf' technologies, as shown in additional techniques, are also applicable for implementation onto the work cells.

With Optical and Magnetic sensors being quite broad terms, its at this point that the specific sensors in these categories can also be singled out for further evaluation in the Final Project/Dissertation. However, with this Research Methods providing a broad overview, anecdotal factors such as ease of use, implementation and most importantly cost will be considered at this stage of research.

Optical

A relatively low-cost camera system can be applied to the work benches. Thanks to Moore's Law, the costs of digital cameras has greatly reduced whilst the quality has improved. As (Chalifoux, 2018) shows, applying a camera in tandem with a low-cost computer or processor and some relatively simple code/software can greatly benefit a manufacturing environment. A camera sensor can be split into two types, a Vision Sensor and a smart camera vision system (SCVS). The Vision Sensor provides limited functionality in a single view scanning for a feature such as a barcode or looking for a label position, whereas a SCVS can perform both functions (and more) at once (Chalifoux, 2018). Therefore, an SCVS would be most suitable for the Reflexallen work benches. Once the scan is performed signal to alert the operator can then be made to confirm 'OK/NOK'.

Magnetic

By adding magnetic proximity sensors onto checking fixtures for parts that use metal clips and clamps, another low-cost error detection system can be used. Once the applicable checking fixture is placed onto the work bench, it can either be plugged into a power source to power the sensors, alternatively they could be battery operated. If the part is placed for approval on the system and the built-in sensor does not detect the metal component then an alert can signal to the operator of the defect being present.

Other Technology

Screens can provide a very useful live data feed for the operators. The latest work instructions and works orders would no longer need to be printed, this can help save printing costs, paper waste and also prevent out of date information from being used. ANDON light systems could also be used in lieu of screens to highlight defect detection or assembly errors.

The aim and overall objective of this research is to find the solutions that can be easily and cost effectively applied to the current processes with a minimal amount of operator training required.

Overall; combining optical and magnetic sensors onto the work benches and implementing digital screens/Andon systems connected to The Cloud and IoT should yield beneficial results on the work benches. As these are relatively low-cost solutions, it can help in making the business case stronger to management when the proposals are presented.

As well as implementing new technology on the lines, there also needs to be a cultural shift in order to be better placed for detecting errors in assembly. The ANDON features of these solutions should make training easy and intuitive to operators.

Adequately training operators to use and understand the new technology and tools on the lines will also be vital. Role playing issues can teach operators quickly what to do in the event of an error detection occurrence. A key cornerstone of industry 4.0 is augmented reality (Hamilton Ortiz, 2020), as technologies progress it may also be possible to replicate production lines in Augmented/Virtual Reality (AR / VR). By scanning work benches the current process could be run virtually to identify areas for improvement. However; for now, training will be kept to the physical environment until this technology becomes more affordable. As a temporary measure it may be beneficial to implement a dedicated training bench that uses example parts that can cover the various defect scenarios for training purposes.

Lean 6 Sigma tools such as DMAIC should also be utilised moving forwards. Using this as a standard procedure, issues will be better identified using Pareto Analysis. Steps to then resolve the most frequently causes for defects and operator error can then be resolved in a more orderly fashion. On this note, it should also be recognised that although the new technology can improve the current process and reduce the most frequent defects, some errors may still occur albeit less frequently.

Results

To gauge the success of the implementation of these methods, first accurate data of the current processes will need to be measured. Statistical Process Control (SPC) on the lines will need to be implemented and monitored closely, as (Leseure, 2010) notes, training is vital for success in accurate data. By applying SPC to the lines, metrics such as throughput per bench/part number and faults per 1000 parts can be gathered. The success of the new technologies can then be measured against this baseline data. Based on the reduction of defect occurrences the positive cost impact of these new measures can also be predicted.

Therefore, before beginning the Final Project/Dissertation, it will be important to gather this baseline data first in order to measure and compare the results accurately. By applying Pareto Analysis to the baseline data, the most frequent types of defect can also be identified. Using this, the appropriate technologies can then be selected. For example, if a missing metal clamp is more common than a missing label, then a magnetic proximity sensor may be more appropriate than a visual ID/camera system. However, the frequency of metal clamps to paper labels used on parts may also need to be considered. Paper labels are used on almost all parts, whereas metal clamps are

used less frequently. Therefore, a consideration would need to be made on this basis using Pareto techniques in order to evaluate the cost benefit per technology usage.

The data gathered from the lines on defect types and frequency will be critical for building up the business case for the final project.

As (Dominik, et al., 2020) highlight in their chapter 'Smart SME 4.0 Implementation Toolkit', it is imperative that equipment infrastructure such as IT is working closely in tandem with production operations in order for the implementation of industry 4.0 to be successful. Only when the necessary technology is added to the work benches and the smart systems connected to the cloud can this project be considered industry 4.0 aligned.

Evaluation

The variety and complexity of the parts that Reflexallen produce and the frequency of faults and defects detected at the customer end mean that costly 200% checks are required for most products. This project aims to reduce defect occurrences significantly and for relatively low cost. The savings made from removing the additional check stations, the emergency freight costs of replacement parts and the reduction in scrap costs can significantly benefit the company and show the worth of this project.

A strong business case will still need to be made in order to gain approval to proceed. Therefore, it is imperative that the findings from this Research Proposal are presented succinctly and effectively in order to convince the stakeholders to proceed. The transformative impact of implementing industry 4.0 into the business and the positive effects it can have on production need to be made clear. Examples such as those shown by (De Propriis & Bailey, 2020) can be used to convince management to invest in these changes to the current process.

By implementing low cost error detection solutions into Reflexallen assembly lines, this project can be used as case study for ways in which productivity and quality can be improved on still largely manual assembly jobs. As (Kovacova, et al., 2020) point out, "Industry gradually advances towards digitally-enabled smart enterprises that harness the Internet of Things to carry out cutting-edge manufacturing notions". Therefore, it could be argued that by implementing these changes now, Reflexallen will be ahead of the technological curve that it will need to be implement in the near future anyway. The sooner the investment is made, the sooner the benefits can be felt.

The success of this project can also enable other production areas within Reflexallen to re-assess their processes and methods, with further opportunities for integrating i4.0 technologies into production to be explored.

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