

A report on

Advanced Industry 4.0

ACPA 7001 Assignment 2

University of Wales Trinity Saint David  
(MADE Project)



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06/10/2023

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## **Introduction**

Quality failures will always happen in all aspect of life and more so in a manufacturing environment. During the Covid Pandemic Berry who was already a manufacturer of Non-woven filtration were struggling to supply the market with Materials for FFP3 masks. FFP3 masks are the top grade of Face masks and were highly sought after during Covid. As you can imagine suppling the machines to produce the fabric were also in high demand which unfortunately led to machine builders taking short cuts or using cheaper materials in production of the machines. In turn this led to quality failures of highly important and valuable filtration material and root causes could be traced back to multiple areas all impacting on the overall quality failure.

Non-woven filter materials of masks historically mainly used cotton gauze and polypropylene. Cotton gauze masks have high filtration efficiency but poor breath resistance and poor thermal and wet comfort performance. Meltblown fibres with static charge was invented and employed to reconcile the aerosol interception efficiency and air permeability thus becoming the favoured choice for most types of Face masks. Compared with cotton gauze masks, meltblown fibre masks exhibit higher aerosol interception efficiency with lower breath resistance due to the electrostatic adsorption effect in aerosol filtration process (Jiulang, 2020). The melt blowing process is one of the most versatile and cost effective processes commercially available to produce microfibers but is still relatively new with regards to age from invention with first European equipment manufacturing (Reifenhauser) not coming to fruition until 1989 (McCulloch, 1999). Manufacturers are still using original or older methods to produce the non-woven that does not include any Quality control instrumentation or smart sensors as part of the process, almost making it the norm

that customers accept high scrap levels on start up and change overs or when processing parameters change.

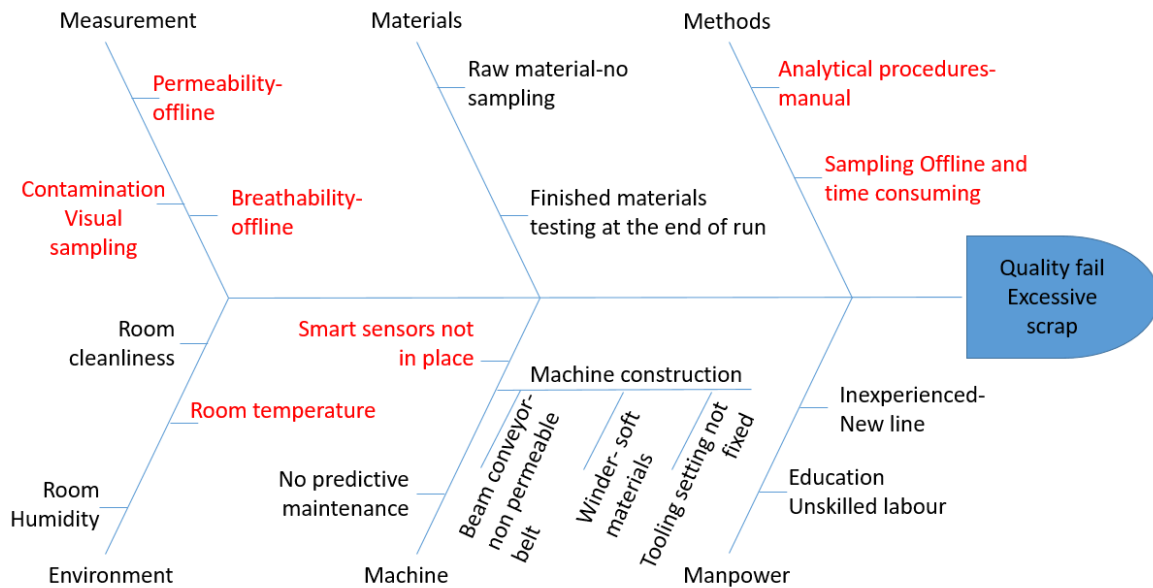
### **The process**

Meltblown material consists of layers of very small diameter (typically  $<3\mu\text{m}$ , 0.003mm) filaments of Polypropylene polymer laid randomly at various densities as required to achieve correct performance. There are multiple steps to the process from raw material addition to material processing and winding and conversion. Each step is very sensitive and critical whereby if any step fails or underperforms it can and will lead to quality failures with the product or machinery failure. Due to the nature of the machine process, efficient performance relies on consistency and product quality improved the longer the lines runs. Any stoppages can lead to the product falling out of specifications and creates a lot of scrap material. Key steps include:

- Polymer and additives transported up to top feed hoppers by vacuum then feed through gravimetric feeders for precise mix of polymer and additives. Polymer MFR is very high between 800 – 1200.
- Polymer and additive mix are fed into the Extruder throat. The Extruder auger screw transports the mix through the heated barrel causing the mix to homogenise through friction and external barrel heat. Typical external barrel heat between 240 - 260°C.
- Clean polymer passes through the filters to the Melt Pump. This is a mechanical pump, which dispenses a known amount of polymer per rotation. The extruder screw speed is set so it maintains polymer supply to the Melt Pump.

- Polymer is fed to the tool cassette where it's heated to optimise the polymer viscosity so it can be stretched successfully to achieve correct web properties.
- The polymer stretching starts as it is forced through small holes in the die tip. As the polymer exits the holes, hot air from each side of the tip stretches the polymer to the required diameter. The air from each side causes the polymer filament to move at right angles whilst stretching causing the filament to traverse across the web. The cassette also has a secondary air supply that maintains a constant ambient / quench temperature. The web is deposited onto a permeable conveyor, which has suction channels running underneath pulling the web onto the conveyor.
- Winding and conversion of the web is the last part of the process prior to the material undergoing rigorous laboratory testing for specification. Results of testing determine if the material being produced is within spec and contains no contaminants along with ensuring the filaments are laid correctly.

To critically appraise the Quality failure the first step is to ask what are the issue before Root causes are looked for. Although the quality failure highlighted is related to high scrap levels of valuable medical material the Root causes are likely to lead back to flaws in the original machine design. There is likely to be lots of separate root causes that when amalgamated into the one process could lead to a big process improvement and have a big impact on the quality fail. To analyse this a 5Y and Ishikawa diagram (fishbone) took place and my to highlight the factors that can be improved by an industry 4.0 way of thinking. The red areas in the Ishikawa are the main areas of focus being Measurement, environment and methods.



## Measurement

Measurement of nonwoven material that is carried out in a laboratory requires material sampling to be taken off the machine web and is tested for air permeability and breathability. Being that this test is not inline the information collected is logged and results take a long time to be processed thus creating material that may not be in spec whilst awaiting test results. Air permeability is important in masks to ensure the end user can breathe effectively whilst being fully protected. It's the volume of air that is able to pass through the mask. Breathability on the other hand is the masks ability to transmit moisture vapour back out through the material. Obtaining the correct ratio for a nonwoven to perform to the regulating bodies standards is surprisingly difficult even more so when results are only available in offline testing. A Critical question is can inline analysis take place where the obvious answer would be to look towards artificial intelligence (AI). Quality control in manufacturing may be missed by design engineers as the focus is on machine build as oppose to the process or future issues industrial engineers may see. Involving the

end users or engineers that will work on the machinery can help identify AI opportunities such as in this instance systems to inspect products for defects at high speeds. The journal of the textile industry document the finding of a textile department in a Turkish University where by the focus is on AI to predict air permeability. According to results, it was revealed that the air permeability and porosity properties of hydro entangled nonwovens can be predicted with high accuracy from their texture images (Gultekin, 2019). Developments in artificial intelligence methods, some soft computation applications were carried out to predict the performance properties. Image processing methods were applied to extract the texture features and models were built to predict the performance properties of the fabric samples. It was concluded that the accuracy of the model was higher for a real weight and tensile strength properties than the elongation at break. In order to obtain the cross section geometric properties of different samples, the cross-section slices were taken, assessed and the literature put forward. In this scope of the study a texture feature extraction algorithm on the base of image processing techniques and AI method were generated. (Gultekin, 2019) Results stated artificial intelligence system that has high potential for adaptation to the hydro entangled nonwoven production line for real-time application was proposed so at a site level we can look for integrators or manufacturers for such equipment to be fitted in line. Textest instruments provide a state of the art On- line Combiscan that provides test results in real-time, i.e., at a time when the production process can still be influenced (Textest, N/A). The data available from the AI embedded Combiscan is transferred to a big data collect cloud data base whilst also providing visual and graphical data that can feed back into the process or be manual analysed to make machine adjustments. If the machine supplier had been thinking along the lines of AI when designing the machine a portion of the quality issues highlighted in the Ishikawe diagram would not exist. New data on AI states:

Process deviations: In a similar way, AI allows for quality prediction relying on process parameters, which combined with real-time tuning of execution parameters, results in better quality outcomes, and scrap reduction, again, improving OEE (Martínez, 2020).

### **Environment**

During analysis, room temperature and humidity has been found to have a major impact on the quality of the material being produced and have a big impact on out of spec material. Of course changes in the environment will be seen once the material goes through sampling but there is lag in results with offline testing. Even small changes such as doors being left open allowing cold/ warm air to enter the machine has a detrimental impact. To gain more control of the environment, solutions can be found by looking at the internet of things (IOT). IOT refers to physical objects with sensors, processors, software and other technology that connects data with devices and systems. It has been said that the integration of sensors/actuators, radio frequency identification (RFID) tags, and communication technologies served as the foundation of IOT, and consequently industry 4.0 (MDopico, 2016). In the instance of non-woven manufacturing, smart controllers and controller positions will have a big impact on the quality of product. Something that has been missed in the design of the machine is the environment the machine sits within and how IOT can provide the process with valuable data to ensure grade one product is being produced. With an IOT enabled device, products can stream usage data back to engineers and machines. Imagine, for example a utility cabinet that transmits internal temperature readings (Martínez, 2020). A major improvement would be to allow the machine to have access to data regarding the temperature of the room so it can adjust the process to suit automatically in closed loop fashion. As little as a one degree temperature change can

change the fibre laydown of a non-woven with the impact being product failing Quality checks. During the design phase of the machine engineers could have highlighted this and designed in mechanical or process control fixes. The benefit of IOT in-particular smart sensors would be an ideal process control fix that would engineer out quality issues by design but would ultimately add additional cost during design which is a possible reason why it's not a standard offering. The other reason is integration with on site equipment is highly likely to be different for each end user. Although not a Pharmaceutical machine a filtration line sits within healthcare and works towards similar standards with the machine in a clean room environment. With this in mind similar defects where by temperature can define product quality are shared between sectors. When certain products are exposed to incorrect temperatures the product quality is no longer guaranteed. In the pharmaceutical, cosmeceutical and the food industry, this is even more important as consumers lives can be put at risk due to the temperature effects on the products (technologies, N/A).

Many Smart sensors are widely available in the market from large manufacturers such as Siemens, Rockwell and IFM to lesser known brands such as TT electronics. All options are available from hard wired smart sensors or battery powered sensors where most now offer wireless or cloud based access. Design on systems and the type of architecture used is vitally important so on the Filtration line designers would have had to place the positioning for the sensors in critical positions to maximise the effect on the process and reduce quality failures which is achievable with data to back findings up. A Similar study on the environment effect in a server room can be compared to the filtration line (minus the temperature and humidity variables that suit each process).

*The temperature and humidity of the server room will be taken by sensors installed on RaspberryPI which will process the data first. The data sent by RaspberryPI as a sensor will*

*be checked if the temperature is below 18 °C and above 27 °C then the paired Raspberry sensor will instruct Arduino as an actuator to reduce or raise the temperature of the Air Conditioner and provide notification to the Telegram. The sensor paired to Raspberry also gives notification to Telegram if the humidity is below 40% and above 55% (Utomo, 2019).*

Given the environment a machine sits has impacts across many sectors then why has it not been considered on the filtration line. Albert Einstein once said, “The best design is the simplest one that works.” But a simple design can be difficult and time-consuming to create. This is where Design for excellence (DFX) and lean six sigma methodology should have been taken into account. Design for excellence is an ever-evolving philosophy of a set of principles in design and manufacturing. It adopts a holistic and systematic approach to design, focusing on all aspects of a product – from concept generation to final delivery. It provides good practices and design guidelines to ensure we get the design and manufacturing methods right the first time. All this is done before the product even reaches the shop floor. Taking it a step further design for manufacturing and assembly and design for reliability would have had a high chance of identifying the identifying the environments impact on line reliability and grade 1 product.(Velling, 2021).

### **Machine construction**

As with many Processes that rely on dies and tooling to manufacture a product the quality of build and ease of change over is critical. A Well-built tool heavily impacts product quality, machine reliability and overall equipment efficiency (OEE) but still has to be looked at holistically as part of a machine or process. A die or tool on its own is only a small part albeit

a critical part of a machine process. Issues analysed that impact the filtration line product quality have been split into 2 main categories;

- Proactive- Monitoring the performance of the tool and predicting failures
- Reactive- Removal and rebuilding of tool

Quality of the finished product is directly correlated to the condition and build of the tool.

From a proactive perspective having the ability to monitor the condition of the tool to determine when a tool is starting to block or become contaminated allows machine operatives to plan change overs and predicate failure before scrap product is produced.

Designs for reliability (DFR) would analyse the system's ability to perform over a period of time. IOT could also use smart sensors to analyse data trends on pressure differential either side of tooling or trending of motor currents increases to predict failures as a type of condition based monitoring. Main condition monitoring techniques include vibration and Motor Current Signature Analysis (MCSA) (Drakaki, 2021). MCSA uses multiple sensors to collect the current signal from each phase of the current. Signals from multiple sensors are correlated and disordered, therefore allowing an information fusion (IF) method to fuse information from multiple sensors and merge current features. Increase in currents against ordinary performance will highlight that a tool condition degrades as the motor has to work that much harder to achieve the same end goal of manufacturing.

When a prediction can be in place of when a tool is likely to be near the point of failure reactive topic of how do we replace and rebuild the tool can be taken in to account. In any design of Die/tooling a Poke yoke and SMED mind-set has to be considered as part of the design and Design for assembly (DFA). In design for assembly, designers implement qualities in a product that make it easy to assemble. Fewer, simpler components that can be easily assembled by simple operations are encouraged to eliminate the possibility of mistakes.

(Velling, 2021). Lean manufacturing tools such as Poke-Yoke and SMED fit into the portfolio of design for Six sigma (DfSS) which is a newly emerging process. DfSS involves a highly disciplined methodical approach to integrating the principles of Six Sigma as early as possible into the design and development process. It is a customer-driven business strategy that creates robust designs that have Six Sigma Quality “Designed In” to meet customer defined critical-to-quality (CTQ) requirements (Hendricks, 2011). Designers of tool when thinking in the mind-set of design for X could consider building a tool that has a single minute exchange of dies (SMED) approach, which is a system for dramatically reducing the time it takes to complete equipment changeovers. The essence of the SMED system is to convert as many changeover steps as possible to “external” (performed while the equipment is running), and to simplify and streamline the remaining steps (production, n/a). A prepared tool that is changed over and replaced easily impact downtime and the manufacturing line getting back to grade 1 product as soon as possible. Tooling designers may miss these steps as they are concerned with building a quality tool and not necessary concerned in the end user change over times.

Poke-yoke derives from Japanese manufacturing and loosely translated to mistake proofing or fool proofing. It is totally achievable when designing tools they are designed in a way where it's impossible to be put together wrong. Interference pins, shouldered bolt holes and limit switches for positioning are all methods of design poke yoke (Shimbun, 1987). When Poke yoke and SMED are considered in the design phase and implemented on a manufacturing line the impacts can be hugely beneficial for uptime, tooling life and product quality.

## **Conclusions**

Three key contributors to quality failure areas have been reflected upon and critiqued with each failure having impacts on quality that in their entirety result in a costly output in unwanted quality failures. All three contributors have root causes that if thought about in the context of industry 4.0 would reduce failures or have an impact on failures.

Measurement, environment and Machine construction are parameters that when thought about in a design phase unwillingly lend themselves to industry 4.0 technology and with some analysis has led me to analyse AI, IOT and DFX solutions. Unfortunately in the design phase a manufacturing designer or enterprise may be hard pressed to understand how their day-to-day activities relate to social and economic factors. Social issues resulting from Industrial activity have not generally been approached with an engineering mind-set, which makes measurement and analysis challenging when holding feedback sessions with designers (Sutherland, 2016). All the key contributors can be improved but all will also have economic factors that perhaps designers would look at differently to end users, for example a cost increase in design may save thousands of pounds in quality concerns over the life time of that product. Manufacturers can also be mindful that if they rely on repairs and sales of dies/tooling and machine parts then longevity of part above and beyond expectation may result in lower sales over a longer period. If a designer or manufacturer rely on return customers to provide an income or revenue then parts at some point have to fail. If an industry 4.0 mind-set is with designers from the start the distance between design, manufacturing and usage tends to disappear thanks to the integration of product lifecycle management. (Fantini, 2020). Within some sectors it's still unclear how the industry 4.0 model will interact with the economic geo-political and social trends to shape future work and jobs.

Applying the correct amount of focus and money to implement industry 4.0 techniques can solve many problem but for machine designers who are pushed to work toward budgets and on proven designs there is still and may always be room for improvement and certainly room to hear the Voice of the customer when carrying out design. A subject matter expert, end user and innovative team collaborating on industry 4.0 ideas can make positive changes.

## **Bibliography**

- Drakaki, M., 2021. International Conference on Industry 4.0 and Smart Manufacturing. *Recent Developments Towards Industry 4.0 Oriented Predictive* .
- Fantini, P., 2020. Placing the operator at the centre of Industry 4.0 design: Modelling and assessing human activities within cyber-physical systems. *Computers and industrial engineering*.
- Gultekin, E., 2019. Predicting air permeability and porosity of nonwovens with image processing and artificial intelligence methods. *Journal of the textile industry*.
- Hendricks, 2011. *What is the definition of Design for Six Sigma?*. [Online]  
Available at: <https://www.isixsigma.com/methodology/what-is-the-definition-of-design-for-six-sigma/>
- Jiulang, i., 2020. Meltblown fabric vs nanofiber membrane. *Chinese Journal of Chemical Engineering*, p. 9.
- Martínez, L. R., 2020. *New Trends in the Use of Artificial Intelligence for the Industry 4.0*. London: Intechopen.
- McCulloch, J. G., 1999. The History of the Development of Melt. *International Non wovens Journal*.
- MDopico, 2016. A vision of industry 4.0 from an artificial intelligence point of view. *Proceedings on the International Conference on Artificial Intelligence (ICAI)*.
- production, L., n/a. *SMED (SINGLE-MINUTE EXCHANGE OF DIE)*. [Online]  
Available at: <https://www.leanproduction.com/smed/>
- Shimbun, N. K., 1987. *Poka-Yoke: Improving Product Quality by Preventing Defects*. Tokyo: s.n.
- Sutherland, J. W., 2016. *The role of manufacturing in affecting the social dimension of sustainability*. s.l.: C I R P Annals.
- technologies, P. s., N/A. *Temperature within the Pharma industry*. [Online]  
Available at: [https://www.processsensing.com/en-us/rms/applications/pharmaceutical-temperature-monitoring.htm?gclid=EAlaIQobChMI5fKRnJjYgQMV8opoCR17wQr9EAAYAAAEgIefvD\\_BwE](https://www.processsensing.com/en-us/rms/applications/pharmaceutical-temperature-monitoring.htm?gclid=EAlaIQobChMI5fKRnJjYgQMV8opoCR17wQr9EAAYAAAEgIefvD_BwE)
- Textest, N/A. *Textest Combiscan*. [Online]  
Available at: [https://textest.ch/wp-content/uploads/2022/02/FX3500CombiScan\\_E\\_web.pdf](https://textest.ch/wp-content/uploads/2022/02/FX3500CombiScan_E_web.pdf)
- Utomo, M. A. P., 2019. Server Room Temperature & Humidity Monitoring Based on IOT. *Journal of Physics: Conference Series*.
- Velling, A., 2021. *Design for X (DFX) Methods*. [Online]  
Available at: <https://fractory.com/design-for-x-dfx/>