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Abstract. The growing customer demand for small batch-size and customised products is putting pressure on manufacturers to adapt their current processes that were originally designed for large batch size orders. Smart manufacturing technology can be utilised to create new, effective, and sustainable processes. Many industries are still conservative when it comes to embracing smart manufacturing technologies including the textile industry. This paper demonstrates the implementation of smart technology to create a new "made to customisation" process in a textile factory. The case study involves upgrading a standard machine to a "smart" machine and utilising RFID technology to track and trace materials after they get prepared for a work order. The paper also presents a guide on how to effectively approach the implementation of smart technology in the manufacturing environment.

Keywords. Smart Manufacturing, Textiles, Continuous Improvement, RFID.

1. Introduction

Manufacturers are under continuing pressure to adapt to the growing customer demand for smaller batch-size and customised products [1]. To maintain competitiveness, companies must adapt their processes so that they can meet these demands, while also maintaining or improving their quality levels, cost margins and service levels [1]. This must be achieved while navigating a supply chain environment that has shown growing uncertainty, risk, and disruptive challenges [2]. Organisations must identify and implement continuous improvement initiatives within their manufacturing processes. Not investing in your products, processes, and people increases the risk of the company not being able to compete with the cost, quality, and reliability of the other products on the market [3].

A growing source of continuous improvement success is the implementation of smart manufacturing technology [4]. Advancements in this field have created the opportunity to implement processes that would not have been technically feasible or economically viable in the past [5]. Increases in variable costs such as raw materials, labour, storage, shipping, and energy have also driven business interest in implementing smart manufacturing technology [4]. Also, as the costs of mature technologies (RFID, smart sensors, industrial robotics, etc.) come down, the barrier of entry for businesses is reduced further [4].

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The textile industry has been conservative in deploying smart manufacturing technologies [6] and increasing customisation has become a new paradigm. For the factory represented in this paper's case study, the current process, which was designed for large batch size orders, cannot effectively cope with the frequent changeovers, leading to significant yarn waste and process inefficiencies that can be improved significantly. Instead of deploying the same process at the price of investing in more yarn preparation (YP) machines and operators, a more sustainable yet challenging solution is to create a new process to enable "made to customisation". This requires each bobbin to be uniquely prepared, identified and placed on the correct creel position. Given that each work order requires over 800 bobbins of yarn and up to 100,000 bobbins need to be handled every week, this will dramatically increase the complexity of the process, which is beyond the capability of today's manual approach and machine capabilities.

To overcome these challenges, a new 'smart' manufacturing process is proposed here, which will integrate an RFID track & trace system to enable the unique identification of each bobbin and an upgrade to the current yarn preparation machines' capabilities. Although these technologies have already demonstrated some success in achieving "made to customisation" applications [7], there are still significant challenges in deploying them on the shop floor, seamlessly integrating them with existing facilities and operating the entire new system in an optimised manner. Also, there is currently a skills gap in the factory in both implementing and using these technologies.

In this paper, an approach for effectively implementing smart technologies and smart processes into a textile factory is presented. This approach recommends that three key pillars act as the foundation for every project of this type: technological feasibility, business case validation, and factory fitness. The approach also recommends structuring the project implementation into stages, from proof of concept to factory sign-off. The approach is demonstrated and validated through an industrial case study. This case study demonstrates the implementation of RFID technology for material tracking, as well as an upgrade of a standard machine to a smart machine. The motivation behind this project was to achieve a more sustainable process for upstream material preparation that will lead to lower raw material waste and more efficient cycle times.

2. Methodology

As shown in Figure 1, the approach used in the case study is centred around the following three pillars:

- technological feasibility: proving the technical feasibility of the designed solution early,
- business case validation: constant updating and reviewing of the business case as information is gathered,
- factory fitness: engaging with the shopfloor personnel from the start to build a solution fit for daily use.

The implementation journey is broken up into 5 stages: 1) proof of concept (POC), 2) prototype, 3) full-scale trials, 4) factory sign-off, and 5) continuous improvement. Each stage will have its own focus and a set of milestones that should be completed before moving to the next stage. For example, in the POC stage, the fundamental feasibility of the designed solution needs to be validated before moving to the prototype stage. This reduces the risk of time and capital being spent developing a solution that isn't technically feasible. This approach is recommended to any organisation that is implementing smart technologies into their facilities/processes for the first time. The approach focuses solely on the implementation stage and does not address the early stages such as ideation, planning or concept design.

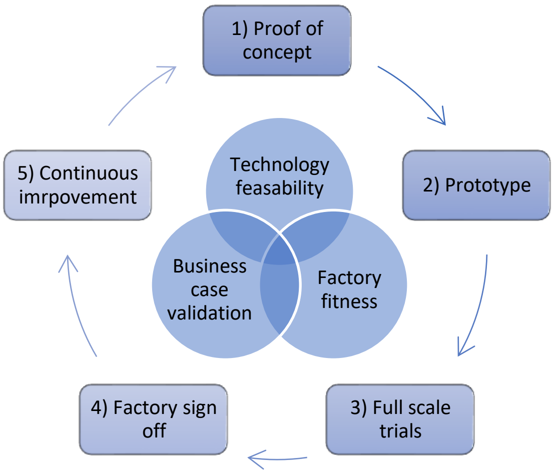

Figure 1. An approach to implementing smart technologies

2.1. Technology feasibility

Following on from the concept design stage of a project, the ability of the technology in the designed solution to do what is expected needs to be validated. The level of validation required depends on the complexity and novelty of the technology. It is encouraged that the fundamentals of the designed concept are researched early to understand from first principles if it is technically feasible. As the project moves to the POC and prototype stage, real-life validation can be done through experimentation to get a better understanding of how well the technology meets the project requirements. Validating the technology early and often during each stage reduces the risk of time, effort and capital being invested in the wrong technology or approach. It also reduces the risk of high levels of troubleshooting being left to be done at the full-scale trial stage or later.

2.2. Business case validation

In a business, it is critical that the effort, time, and capital required to implement a change is outweighed by the benefit that the change will bring to the organisation. The business case should be a living document that gets updated as new information is gained. It should include the scope, timescale, costs, benefits, the team involved, stakeholders, and risks associated with the project. As understanding grows throughout each stage of the project, the business case should be updated. The return-on-investment (ROI) calculation is a good metric to help business stakeholders decide if a project is worth pursuing. In the early stages, it can be difficult to calculate the ROI of a project, however, it is recommended that estimation is made to better understand the project's potential. This requires the current cost of the problem to be calculated, as well as the estimated cost of the solution and predicted savings. Although just an estimation, an early ROI calculation can highlight areas where the cost of the problem is not high enough to implement change, especially when the project requirements would involve a complex and costly solution. The maximum ROI considered acceptable will normally depend on the business and shareholders and project type. If at any stage during a project, the ROI increases past the maximum level, then the project should be re-evaluated.

2.3. Factory Fitness

To increase the chances of successful implementation and uptake for any project or process change, the solution needs to be designed with all stakeholder's needs in mind. The full-scale trials stage is too late to only start gathering feedback and engagement from the shopfloor personnel on the change. The end-users must give input at the POC and prototype stage as ultimately, they will be most impacted by the new technology and process. Incorporating their feedback early will increase the useability of the final solution and may uncover some poor decisions or design flaws. The end-users and shop floor personnel are often experts in the existing process as they live it day-to-day. Another benefit of this approach is that it leads to increased engagement from the shop floor personnel, and they will be more receptive to the process change whenever it is introduced. The work being carried out during each stage will also assist with creating the documentation and training material required at factory sign-off.

3. Case Study

3.1. Project scope

The company involved in this case study is a global carpet tile manufacturer. The case study focuses on the upstream process of preparing yarn for tufting, the first part of a carpet tile's manufacturing journey.

The amount of yarn required for each position depends on the pattern and in most cases, each bobbin requires a different amount of yarn. Due to the technical, practical, and economical challenges of preparing each bobbin of yarn to the exact specific length required and placing them in the exact creel position, all bobbins from the same colour group get prepared to the same length which is calculated by using the maximum bobbin length in the group. This results in the bobbins with length requirements less than the maximum length having excess yarn remaining at the end of the work order. Depending on the product, an average of 50% extra yarn can be required to be added to the bobbins due to the requirement of preparing each bobbin to the maximum length. With the growing customer trend toward small batch size work orders, the impact of preparing each bobbin to the maximum length has become more disruptive to manufacturing costs.

3.2. Developed solution

RFID technology and upgrades to the standard YP machine allowed for the challenges of preparing each bobbin to a unique length to be overcome. The upgrades include a new HMI and an industrial PC that is connected to the machine's PLC. The PC runs bespoke software that communicates the amount of yarn required to be prepared onto each bobbin. Other benefits from the upgrade include online connectivity that allows for real-time job supervision on how many bobbins have been completed. An RFID antenna is mounted above each of the YP Machine's multiple spindles and reads the RFID tag number of each bobbin that is processed. These antennas are connected to RFID readers that send the RFID tag information to the software's database. Whenever a bobbin is scanned by a wrist-mounted RFID reader, the database is accessed to find and display the corresponding information for that bobbin, such as the required creel position.

3.2.1. Proof of concept (POC)

At the start of a project, due to gaps in information, assumptions and estimations had to be made regarding the project's business case, technical feasibility, and achievability of a high "factory fitness". The aim of the POC stage is to help validate the assumptions and improve the estimations made before capital and further time is invested into the project and into the chosen solution. The insight and feedback gained when running tests to validate the assumptions will also guide the design of the solution and the technology selection. For the case study, the main assumptions that needed evaluated included:

1) The YP machine can be configured to prepare each bobbin to its unique length,
2) Assigning and identifying the creel positions of each unique bobbin can be done efficiently,
3) The amount of yarn waste reduced aligns with the calculated amount.

For assumption 1), old software from the original equipment manufacturer of the YP machine was used that allowed a file containing the length requirement for each bobbin to be sent from a laptop to the YP machine's PLC via serial communication. The software worked, but it was not user-friendly or secure enough to act as a final solution. For assumption 2), printed labels showing the creel position number were used to identify each bobbin and the operators were able to successfully read the label on each bobbin and place it on the correct creel position. The time taken to manually label each bobbin and sort them into the correct order for each spindle was not practicable and an alternative final solution was required.

Manually labelling each bobbin allowed for requirement 3) to also be tested as the uniquely wound bobbins could be put onto the creel and tufted in a trial work order. The decrease in remaining yarn waste after the work order was completed was weighed and it aligned with the expected savings. Variances were measured in the POC stage of the weight of the yarn wound onto each bobbin versus the expected weight, it was identified that this was due to the variability in the accuracy of the YP machine. It was concluded a safety percentage of yarn would need to be added to all bobbins to ensure that none ran short when on the tufting machine.

Having this inefficient, but simple, method of preparing each bobbin to its unique length was enough to validate the technical feasibility of the project. Measuring the new time taken to prepare all bobbins and to place all bobbins onto their unique positions on the creel and measuring the remaining yarn waste helped to shape the business case further. While in the POC stage, it was identified that RFID technology could be used to identify the creel position for each bobbin. Working with a technology provider, that has experience with RFID technology, the technical specifications of the system that would meet the project requirements were determined.

3.2.2. Prototype stage

The aim of the prototype stage is to develop a working solution. In this case study, the project team created a design brief that outlined the requirements of the YP machine's new software and the RFID system, these requirements were influenced by lessons learned in the POC stage. The technology supplier gave their expert recommendation on the type of RFID tags, antennas and mobile readers required that could meet our design brief. They also used our design brief to create the software application that was installed onto an industrial PC that was connected to the YP machine's PLC and to the RFID system. Once the technology was integrated, unit testing was completed to ensure that each component was working as required. Small-scale trials were conducted to test how well the system worked together. This involved putting dummy work orders through the system to evaluate the useability of the software, i.e., to check if the YP machine was preparing the bobbins to the correct requirements and if the RFID tags were being read and identified correctly. Unit testing is important, as there are costs and risks associated with running a full-scale trial, so it is important that as many errors are identified before moving to full-scale trials.

3.2.3. Full-scale trials

Standard operating procedures (SOPs) were developed with the operators during the prototype stage and were used in this stage to ensure everyone knew how to complete the steps required when we began routing customer orders through this new process. This is the status of the project; several work orders have been completed using this new process and data and feedback are being collected after each trial. The technical feasibility of the solution was proven after the first full-scale trial was completed successfully, the remaining work to do now is to optimise some of the parameters such as the RFID antenna strength and the safety percentage added to each bobbin. After every trial, further feedback is gathered from the operators which helps improve the "factory fitness" of the solution. Also, the total people-hours required for the new process are being measured, as well as the reduction in yarn waste that will feed into the final business case.

3.2.4. Factory sign-off and continuous improvement

Once the full-scale trials have validated the solution has been integrated successfully it is important to appropriately close out the project. It is critical that all stakeholders have the correct information, resources, and training to be able to successfully continue with the developed solution. For this project, the factory sign-off stage will involve finalising all documentation such as the SOPs, final business plan and technical documentation. Discussions will be conducted with all stakeholders to ensure everyone is satisfied that the current solution is factory fit, technically sound and makes good business sense. Work orders will be processed through this new "made to customisation" process and the project team will continue to monitor the success of each work order and will continue to gather feedback from operators.

When fully implemented, opportunities to improve the solution will still be investigated. It is expected that as more work orders are completed, opportunities will be identified to optimise the process. The strong engagement from the shop floor personnel during the project will be maintained and they will be encouraged to suggest improvement ideas. If the project is implemented successfully, it is expected that further smart technology will be explored. During the concept ideation stage, other smart technologies were investigated such as a more efficient way to transport bobbins from the YP machine to the creel (portable creels, pick and place robots, smart conveyor systems etc.). To keep the scope of the project manageable, these technologies weren't explored further in the first phase of the project. It is hoped that at the end of this current phase, the approach will be repeated to implement other smart technologies into the process.

4. Discussion and Conclusions

In the case study, smart technology has been utilised to develop a new process for producing "made to customisation" orders. A standard machine has successfully been transformed into a user-friendly "smart" machine capable of preparing bobbins of yarn to individual lengths. RFID technology has successfully been utilised in the new process for tracking and tracing all prepared bobbins. The approach discussed in this paper has been used successfully to manage the installation of the smart technology into the factory. Implementing the change in stages allowed for an appropriate level of confidence and understanding to be gathered on the technology, business case and process design before key decisions were made. Also, evaluating all three pillars at each stage ensured that balanced decisions were made.
At this moment, we have completed five full-scale trials using the method. Current data from the trials completed have shown a reduction in cycle time at yarn preparation as less yarn is being prepared onto bobbins compared to the original method of preparing each bobbin to the maximum length. The yarn waste at the end of the work order has been reduced, the amount it has reduced varies depending on the product. The new requirement of scanning each bobbin to identify its creel position and placing it onto the correct creel position has led to an increase in cycle time at this stage. Also, it has been identified that preparing each bobbin to the exact calculated required yarn length is not sufficient due to variances in the YP machine's accuracy and the tufting machine's accuracy. This critical parameter, that is currently being evaluated, is the safety margin of extra yarn that must be added to each bobbin that will minimise the yarn remaining at the end of the work order while ensuring the work order achieves the metres required.

4.1. Limitations and future study

It is acknowledged that the approach described in this paper does cover all stages and areas that are important in a continuous improvement project, especially the ideation/concept design stage. The approach describes what aspects need to be evaluated and why they are important but does not give detailed overviews on how to best deal with these aspects. Future papers could involve a review of popular continuous improvement tools and techniques and how relevant they are when it comes to implementing smart manufacturing technology. In terms of the case study, it is acknowledged that the project is still in the full-scale trials stage and therefore still has stages to complete. However, the plans for the final two stages have been outlined in the paper. Future studies could include the implementation of further smart technology in the next phase of this project to address the current weaknesses such as the increased cycle time at creeling and the current variances of the YP machine.

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