AN IMPROVEMENT OF PRODUCTIVITY BY REAL TIME MACHINE MONITORING SYSTEM: A case study of printing industry

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Abstract. Digital technologies and automation integration is one of the promising directions to increase productivity in the manufacturing. A consulting project to promoting the adoption of digital technology under the policy of the Department of Industrial Promotion, and Thailand 4.0 to help small and medium entrepreneurs (SMEs) to assess and gain readiness to the use of cyber-physical including digital technology. The real-time data gathering system for monitoring and displaying information is presented. For example, IoT based sensors is applied in digital counting of machine-made goods. This data can be used to analyze the root cause of a manufacturing process problem, for example, time lost due to discontinuity of work or setting up. Best practices are observed at a printing factory. The implementation shows the effective data acquisition even the running speed of a machine is high. The owner and manager gain real-time access to the dashboard through their mobile phone or personal computer. Therefore, they can manage their jobs instantly and remotely. Moreover, the stored data can be downloaded in Excel format. The data can be used in process waste analysis. The numerical results of using this system, overall equipment productivity and efficiency (OEE) were increased by 10% to 15%, approximately.

1. Introduction

The advancement in the internet of things (IoTs) technology has potential applications in various industry sectors. The technology enables manufacturers to gain access to precious and on-time production data via sensors and connected sensing nodes. This lays down the infrastructure as the starting point for the transition to Industry 4.0. In Thailand. The Department of Industrial Promotion (DIP) is one of the taskforces to accelerate the adoptions of technologies, especially for the small to medium enterprises (SMEs). Due to high competition and uncertainty in the current country’s and world’s economy amid the outbreak of the COVID-19, manufactures scramble to be self-reliant and adaptive seeking to improve efficiency in every aspect or the business. To improve productivity and competitiveness in the market, manufacturers must be making transition to for better adaptive, real-time and automated process and become more efficient and data-centric taking action and making decision as much as possible. However, moving toward industry 4.0 is not just a simple step, it requires dedication of resources and effort such as budget and human. In current situation where budget cuts and expense tightening is inevitable, investing in the 4.0 technology seems to be out of reach. SMEs are, therefore, behind and the investments are sometimes prohibitively beyond the return of investment point to consider whole factories adoption of such technology.
SMEs currently fall into between industry 2.0 – 3.0, aka., 2.5 where machine are operated separately and controlled manually by humans. The transition to from current industry evolutions requires innovative technologies and mass adoption in the eco-system [1]. Companies have been trying to improve the whole operation to digital based operations. From business to manufacturing, for example, utilizing software to handle business flow and resources (known as ERP system). Sub systems Material Resource Planning (MRP) and Manufacturing Execution System (MES) are also included. This system control flow of data through software. Gaining access to this software is also another challenge for companies. Production control and management of SMEs rely on paper based and individual employee skills. Without software and digital system, data gathering, which is a crucial step toward industrial 4.0 is still in paper based and pose delayed, unreliable of data and sometime those data will be not useful after a while and collecting those data for analysis or even to collecting them require labor intensive work when company wastes their resources on.

Thus, to accelerate industrial 4.0 adoption, this paper presents a case study how IoT sensing system is designed and implemented and integrating with printing machine to gather data and monitor production in real-time as well as integrating the data into company’s own production management system and knowledge transfer for further adoption of IoTs and digital technologies. One of the contribution of this work is how the promoting of industry 4.0 is done via advising and showcase with actual implementation. Challenges such as technical and management issues are also addressed.

This paper is organized as follows: The second section shows related work while section 3 provides company’s background, problem statement, challenge in apply machine monitoring system. Section 4 gives detail design implementation and data integration and usage. Section 5 provides the process improvement and the application of data analysis. Section 6 provides improvement and productivity results and discussion and further improvement. Finally, section 7 concludes this work.

2. Related Work
Promoting and assisting small to medium businesses to entering or at least considering of transforming to industry 4.0 is a challenging task. Companies executives usually have visions regarding how the ideal manufacturing should be or how the problems and issues should be handled or resolved. The obstacle, however, lies on the management and technological difficulties in addition to the investment and expenses priorities. Thus, realization effort is where SMEs seeks some assisting from government agencies and organizations. Acquiring manufacturing standard such as ISOs are often subsidised or trained/advises by experts and industrial specialists. The same approach applies to digital and automation technologies, energy, lean process, etc. Focusing on the general aspects of transforming to industry 4.0, one of the approaches is to form an institution advocating for promoting and transferring technologies. In [2], LeanLab is a platform that facilitate and provide evaluation and planning as well as testbed for industry to gain insight into transition to industry 4.0. The process consisting of 5 steps which include preparation, analysis, opportunity evaluation and implementation step. There are several areas where transition must be done, for example asset utilization, labor, quality, supply chain management, etc. One of the asset utilizations is machine utilization, which can be done in real-time via remote monitoring and control system [3]. This area is where machine monitoring system and IoTs can be applied and integrated to gain data and utilized in a timely manner.

IoTs-based machine monitoring is a mature technology, however, implementing, deploying and transitioning, as well as raising awareness of technologies are still new to SMEs. In [4], provides insight into how implementing IoTs in industrial environment is challenging from both managements down to day to day working operation due to limitations and constraints such as equipment communication and proprieters software, mixed of PLCs sub system. [4] demonstrate the application and adoption home-applicant based IoTs technologies to industrial environments. Home-applicants based IoTs are finished product with eco-system that satisfies user’s experience. The study aims to follow the approach by design easy to setup, easy to operate while maintain wide range of application. The main focus is to design their own IoTs edge devices and communication to be used with standard cloud based IoT
platform. In our work, however, we focus on integrating low-cost, low learning curve, ready-to-use, standard and open source platform that’s available with ease of transferring knowledge to the company with aim to educate as well as assisting them to rely on their available technical resources such as technician and retain with new IoT skill on the actual working environments. We aslso provide analysis an provide planning for their next steps investment. This allow the company to evaluate and know the gap between current situation and target environment. They may then estimate resource to archive that.

3. Company background and production process
We work with a printing company where machineries are outdated. The printing business maintain its customers pool via long-term relationship such as banks, utilities companies. Their products include receipts paper, invoices. The printing processes include preparing raw paper, ink then the printing plate preparation. As shown in Fig. 1, continuous paper is then fed to the machine, then folded. The machine counts number of pages per box then cut and pack the paper into the provided boxes.

In term of digital technology level in the current company. The company itself is consider active in developing and attempting to adapt and integrate digital and IoTs technology to its process. They have developed their own production control system software based on SQL database and Visual basic software platforms. It is interesting to observed that they also employ long-time IT employee who is a technician with basic software knowledge and has since became main developer who develop the in-house system that work seamlessly for the worker and provide reports to executives. Hence the company has successfully moved from paper based data collecting into computer based data gathering and printing process management. Customer invoice and orders are transformed into work order that will be planed into the system. Then workers at each printing station, each shift, get the information in advance and plan for the work, order the raw material, recording in the warehouse/inventory system as well as opening the job. After the actual work is done, date time, duration, break down, wastes, defects and

![Diagram of manufacturing process for printing.](image-url)
finish goods are recorded into the system. In this current system, the company and production that is with the software is consider ahead of other SMEs where flow of data is still on papers. This consider to be the advantageous and it is the key success to transferring to Industry 4.0.

Even though the machineries and equipment are not the main focus in transforming to the Industry 4.0 due to the business itself is old and hasn’t changed for decades, also the fact that new printing business model are unknown in the future, the company is still trying to stay competitive and to stay as efficient as possible. Hence their main focus is on the data gathering and data usage for business management, analysis, cost-control and forecasts. The system serves well with current day-to-day operation, however, it has some major drawbacks, worker at stations may not record data at the moment it happens, data may come as summary at the end of shifts which is sometime not very useful to be used as process improvement. The company needs real-time monitoring system where workers and business owner share the same data. More importantly the data that will be obtained are more accurate than hand-recorded, which is prone to errors. Thus the vision of this company is clear, the management prefer real-time machine monitoring system where they can take a quick capture of the current working state of the production line. The new IoTs based monitoring should show how the order has been produced and fulfilled. Fig. 2 show the printing stations.

![Figure 2. The printing station and folding station](image)

4. System Architecture and Process Improvement

From the requirements gathered from managing team. It is clear that machine monitoring via IoTs technology will suit the needs from both managing and working force. Executive benefit on real-time and anywhere access to data via cloud-based monitoring system. Workers know there working efficiency and use the data to improve their working procedures. The process engineer can calculate the
overall equipment effectiveness (OEE) to understand and to improve for better resource utilization which will finally reflect the cost reduction and productivity improvement.

Even though the company has its own IT developer however, the IT does not have basic knowledge regarding IoTs platform and modern technologies. Meanwhile, they also have technician who operate and maintain the machine. These people are expert in PLC system and they can invent control mechanism based on PLC and digital I/O. The printing station has its own counter where counting paper piece and paper bulk are recorded on screen, however, this information cannot be linked to the database and production management platform.

We then form a team which consists of IT and technician to work together to come up with IoT-enable architecture. The first step is to transfer knowledge regarding IoTs and how modern IoT devices and sensor can be used. We then design a connection between PLC’s counting and a micro controller device which will be used as a communication device that collect data from the machine. The data consist of 1) counting piece of paper signal 2) bulk complete signal. The two information will allow users to know how many boxes of finish goods are produced. The real-time information is then mapped to the open work order job. Figure 3 shows the architecture below.

![Figure 3. The development of IoT edge communication device.](image)

![Figure 4. Raw data obtained from the system.](image)
The installation is done at printing station K11. The PLCs counting signal is tapped by the microcontroller which will transmit data through WIFI via low overhead UDP protocol to the SQL server that listen and insert counting data into its database. The increment counting method is used (e.g. car odometer), a few packages loss during transmission won’t affect the recorded data and the counting as number of paper is accumulated and transmitted the next interval time which is set to be every 10 second. The speed of the printing can be as fast as 300-500 pages per minute. The cloud server then processes and format the data into human readable showing information as graph as shown in figure 4. The microcontroller used as edge IoT device is a well-known nodemcu (esp8266), a system-on-chip unit, with WIFI available is connected to PLC pulse signal through optical isolator circuit which transmit information through light signal that separates 5-Volt MCU apart from 24-Volt PLC. The overall cost of making 1 unit is relatively low. The reliability of the unit is excellent in the current working environment where electromagnetic noise is quite low.

After this first implementation, the company has their know-how and is able to create, program install and integrate the system to other stations.

5. Process Improvement
After obtaining raw counting data from K11 machine, the data is then processed and displayed on dashboard as a graph in figure 4. Moreover, the data is also mapped back to the work order created during that time. The manager can now know the status of the current order. Sales persons can also get the real-time information of the their current in-progress work. The planning department can also benefit from the actual data so they can plan in case of break-down and get warning when machine stop for a certain period of time longer than a set threshold through line notification. The report is shown in figure 6. This is where managing team can monitor work-in-progress instantly. Any unusual event can be detected and notified right away as depicted in figure 7.

From figure 6, the data is obtained automatically via IoT device, it can be seen that for continuous working process, each box of printing paper requires 7-8 minutes to finish 1 batch. However, in the case of machine failures, interruptions or breaks can be seen as a record. Any setup time can be seen where the counting in 1 batch is low. For example, the current batch is 1000 pages per batch, if the user setup and spend a trial print for 100 pages, the worker will reset to start the actual batch. This setup information is also recorded separately as a row in the report.

Hence, this allows us to compute the overall equipment effectiveness (OEE) which is a standard tool for measuring productivity and capacity of a machine and how effective the machine performs.

\[
OEE = \text{Availability} \times \text{Performance} \times \text{Quality} \tag{1}
\]

where

**Availability** means active time to total time when the machine is running and when the machine is idle or broken (planned/unplanned stop).
Performance is the speed or time the machine can produce compared to the maximum design speed. Older machine may have to run at lower than designed speed, otherwise it might affect the quality.

Quality measures good products against overall output produced by the machine. The 3 factors are weight as 100% or 1.0. The ultimate score is also 100% or 1.0 when the machine run perfectly non-stop.

According to the formula we are able to compute the OEE of sample from figure 6.

\[
OEE = \text{Availability} \times \text{Performance} \times \text{Quality} = (0.82) \times (0.87) \times (0.99) = 0.71
\]

The availability is obtained from overall runtime which is equal to 187 minutes. The active time is 153 minutes. Performance is when the machine run at the fastest speed at current period (although, the actual capacity can be used) which is 7 minutes per batch versus the average time of 8 minutes per batch. The quality when the paper is wasted during setup time.

\[
\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}
\]

Figure 6. An automatically generated report where work order and each processed box is record with date and time and duration.

Figure 7. Alert and notification through Line Application.
6. Results and discussion
As the managing people and workers are looking at the same numbers. As the data is accurately logged with actual time of the events. The supervisor and workers know exactly of when and what and then be able to record why and how to solve each incident on-time. The following measures and policies have been proposed to further utilize the real-time and historical data:

- Worker must try best effort to fix the problem and prevent the problem. Since the incident can be seen the worker must act on the timely manner. Also the manager will be notified and take action right away. The planning department can adjust the plan accordingly without having to wait till the end of the day.
- Historical data can be used at regular meeting to monitor and improve setup time.
- Root cause analysis can be used to find out the actual cause of the break down.

The direct and indirect outcome from this IoT implementation includes:

- There is no need to have a dedicated person to record and do quality control or record the data such as speed, quantity and wastes as the data can be obtained automatically. The person can help in other more important task such as improving availability and setup time.
- Manager, planner and worker can act on time.
- Historical data can be used to evaluate short-term and long-term performance and can be used to evaluate key performance index of workers and team.

Since speed and quality is a long-term improvement and will require better machine adjustment. The availability factor can be improved by better management of jobs scheduling and planning. Hence in this work we compare the availability before and after the improvement is imposed.

Table 1. Comparison between availability before and after the improvement.

|                  | Before (minutes) | After (minutes) |
|------------------|------------------|-----------------|
| Total Time       | 28800            | 28800           |
| Idle Time        | 7200             | 4200            |
| Availability     | 75%              | 86.85           |

The improvement is around 15% compared due the measures. Even though the IoTs monitoring system is not the direct cause of increase in the effectiveness, it is rather a tool that enables sharing and analyzing as well as automating the process of gathering data. This frees up resources and allows continuous improvement based on the real-time and actual data.

Finally, the overall success in this demonstration is due to a couple reasons stated below:

- Dedication and support from business owner and management team
- Strong in-house software system that is ready to accept IoTs plug-ins
- Long-term process improvement and long-term IT development who is able to learn new technology as well as technician team who support PLC connectivity

Each IoT unit costs under 1,000 baht, hence, the investment in the project is consider low compared to off-the-shelf IoT solutions and may not be readily suitable to the business flow and may need some customization. This however does not limit the company to integrate in such system in the future.

7. Conclusion
In this paper, we have shown a case study of a printing manufacturer who adopted IoT technology for machine monitoring. The technology transfers and training is also done on-site along with the actual
analysis and design while working as a team from the top down to bottom organization allows the adoption successful. The IoTs system is integrated into the main production management software. Usage of such data as a monitoring tool for process improvement resulted in 10-15% improvement of overall equipment effectiveness (OEE).

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Acknowledgments
Authors wishing to acknowledge assistance or encouragement from company, colleagues, special work by technical staff or financial support from TSE and DIP.