

Supporting Tools for Transition towards Industry 4.0: A Pressurized Cylinder Manufacturing Case Study

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Abstract—The main purpose of this work is to report an implemented novel methodology to support Small and Medium Enterprises (SMEs) managers in better understanding the specific requirements for the implementation of Industry 4.0 solutions and the derived benefits within their firms. The methodology was implemented in a pressurized cylinder manufacturing company as a case study. The cylinder losing, inadequate scrap management, and bottlenecking in body welding were identified as three of the main problems that could be addressed through Industry 4.0. Potential solutions were considered and found suitable solutions for the problems. For example, Radio-Frequency Identification (RFID) tool was proposed to prevent the illegal cross-filling and illegal cylinder swapping problems and it will help for cylinder identification. A rough techno-economic feasibility analysis was also done for the proposed solutions, which will be helpful for SMEs manager to decide regarding when and how to migrate Industry 4.0.

Keywords— *industry 4.0, assessing tool, SME, pressurized cylinder manufacturing.*

I. INTRODUCTION

Industry 4.0, also called the fourth Industrial Revolution, is a flourishing research topic currently. It is the combination of several emerging tools and technologies, for example, 3D-printing, big data, cloud computing, smart sensors, machine learning (ML), radio-frequency identification (RFID), robotics, and Internet of Things (IoT), among others [1]. Implementing Industry 4.0 solutions has become familiar today in many process manufacturing organizations, as it has distinguished tools and technologies to solve critical problems. However, the novelty and diversity of tools making up this industrial revolution represent an obstacle for the transition towards Industry 4.0, above all for Small and Medium Enterprises (SMEs).

The novel methodology proposed by [2] will be applied to an LPG pressurized cylinders manufacturing and distributor company, as a case study. Some of the existing needs identified in the LPG company, are the existence of a bottleneck in the body welding operation, deficient scrap management, and a low rate of cylinder return for refilling. These problems could be solved by the implementation of Industry 4.0 solutions, for instance: cloud-based robotic arm, smart sensor based on real-time data acquisition coupled with machine learning algorithms, and RFID tags and GPS, respectively. By applying the proposed supporting tool, manager levels can identify the benefits of those potential solutions and the requirements for implementation.

The second section of this paper corresponds to a brief literature review on SMEs reality facing Industry 4.0, followed by a problem statement. In the next section, the proposed methodology is presented concisely and depicted through the case study. The paper closes with the limitations of the study, next work, and conclusions.

II. LITERATURE REVIEW

The literature review consists of two parts. The first is the reality of SMEs facing Industry 4.0, and the second is related to some applications of Industry 4.0.

A. Reality of SMEs facing Industry 4.0

In general, large enterprises are more advanced in integrating IT systems into their operations than medium-sized enterprises, and the latter are more advanced than small enterprises [3]. Kleindienst and Ramsauer [4] commented on the problems SMEs are facing in the Industry 4.0 context. These authors identified the lack of specialized IT personnel as the biggest of those problems since usually SMEs develop very easy spreadsheet-based tools (tailored solutions) with limited connectivity with other resources within the company or by

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interacting with other companies, making too difficult the implementation of Industry 4.0. Müller et al. [5] explored how SMEs approach implementation of Industry 4.0 and how they could innovate in their business to increment the derived benefits. Managers from 68 German SMEs were interviewed regarding the understanding of the term Industry 4.0, challenges for implementation, and Industry 4.0-enabled innovations across the business model.

B. Some applications of Industry 4.0

TABLE I. shows some examples of Industry 4.0 specific applications in SMEs. This kind of portfolio of projects could help SMEs managers to visualize how Industry 4.0 brings concrete benefits to their production processes.

TABLE I. APPLICATION OF INDUSTRY 4.0 IN SMEs [2]

Application	Tools	References
Rescheduling	Real data processing/cloud computing	[6]
Debottlenecking	Augmented reality	[7]
Decreasing delivery time	Intelligent self-driving vehicles	[8]
Tracking items in the Supply Chain	RFID	[9]

III. PROBLEM STATEMENT

One of the reasons that delay the implementation of Industry 4.0 in SMEs is the challenge to understand the benefits in terms of productivity, competitiveness, and value creation that Industry 4.0 would bring to the firms. These beliefs are driven by the reality of SMEs that makes the transition towards Industry 4.0 look like a titanic endeavor. For an extended implementation of Industry 4.0 in SMEs, managers should count on guidelines for identification and assessment of value-creation opportunities tailored to the reality of their firm, supporting them in deciding to start the transition. However, the existing frameworks, roadmaps, and maturity models are more suitable for large MNEs that have already made the decision to move towards Industry 4.0 and even have dedicated resources and infrastructure.

In that sense, the objective of this research project is to propose a framework to help SMEs managers identifying specific opportunities and concrete projects that depict the benefits of the transition and ease the engagement with Industry 4.0. As a case study, the proposed framework will be implemented on an LPG operator that manufactures, supplies, and refills pressurized cylinders to its customers, and has not intended to migrate to Industry 4.0. The business itself is capital intensive, selling cylinder at a very lower price than manufacturing cost, where revenue generation depends on the refilling. Most of these types of businesses are prone to lose as there is no control over cylinder distribution and return for refilling. By applying the proposed framework, it is expected to visualize the benefits that the company would derive from Industry 4.0, such as adding value to the supply chain, minimization of cost, broaden business control, and increment of profitability.

IV. PROPOSED METHODOLOGY

Fig. 1 illustrates the proposed methodology by [2] for generating Industry 4.0-based solutions according to the current state of the company. The goal is to generate a set of proposals, or pilot projects, for the implementation of Industry 4.0 tools that respond to current needs and improvement opportunities previously identified. By doing this, SMEs managers would be able to apply existing maturity models to identify the areas of the company that should be improved to meet the requirements of specific projects. The proposed methodology is comprised of four gates and three processes to advance through the gates.

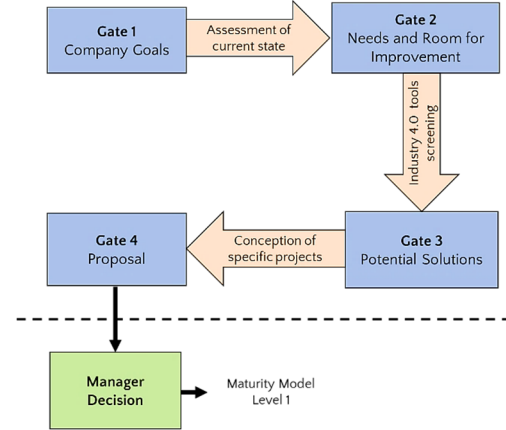


Fig. 1. Schematic of the proposed methodology [2]

V. CASE STUDY

A. Description

BM Energy BD Ltd (BME) is a joint venture between Netherlands and Bangladesh, currently continuing operation in Liquefied Petroleum Gas (LPG) in Bangladesh. BME commenced its operation in July 2015, up until now it has circulated more than 2,900,000 cylinders throughout the country roughly covering 26% of the LPG market.

BME imports pressurized or refrigerated LPG from the Middle East and capable of mooring 6000 MT ship thrice a month. BME is equipped fixed platform with conventional mooring buoy, 2.2 km subsea pipeline, and 12,000 MT pressurized storage and cylinder filling facility. BME owns its in-house cylinder manufacturing facility with a design capacity of 220 pcs per hour. The entire process flow of the company is depicted in Fig. 2, including the different flows involved in the operation. For purposes of this work, only the processes downstream pumping operation were considered.

B. Company goals, current state, needs and room for improvement

Company goals and data used for the assessment of the current state were obtained by personal communication with company personnel (e.g. process manager and project manager), as well as from public information available on the company website. The identified company goals are listed below without any priority order:

- To deliver the product to every corner of the country.
- To be customer-oriented.

- To emphasize on process and product safety.
- To be committed with efficient use of the resources.
- To address the root cause for business loss and waste.
- To secure the assets as a source of profit for the company.

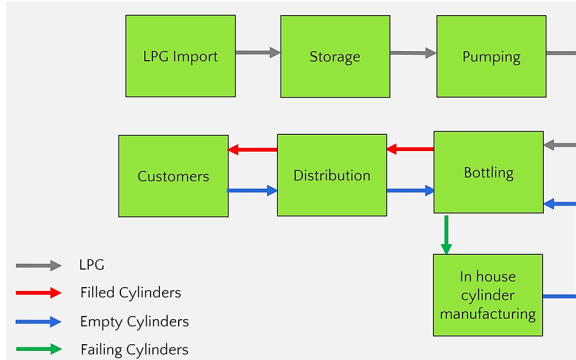


Fig. 2. Schematic of BM Energy process flow

The indicators considered in the current state assessment and that are relevant for this work are the following:

- About 2.9 million company cylinders are currently circulating in the market.
- The company holds 26% of the market share, covering most of the major cities but not in rural areas.
- The company relies on 220 distributors for delivering the product. No direct contact with the final customer.
- No data is collected regarding cylinder failure, once delivered to the distributors.
- Business solely dependent on cylinder refilling as each vessel is sold much less price than manufacturing cost. However, no actions are taken to protect cylinders from cross filling.
- Steel coils for cylinder manufacturing are provided by different suppliers, which introduces variation in properties and therefore in scrap produced per coil.

Steel coil represents 47% of the cylinder production cost. However, 7.8% of the total production cost can be recovered by selling the steel scrap. The breakdown of production cost is shown in Fig. 3.

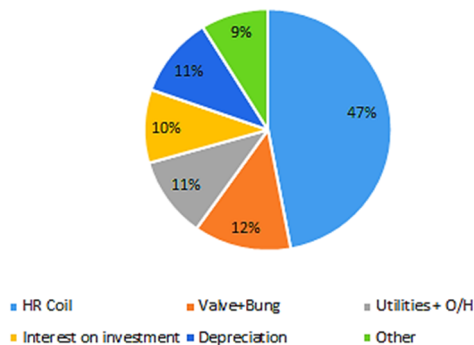


Fig. 3. Breakdown of cylinder manufacturing costs

According to the company goals and the current state, some of the identified needs and room for improvement were identified:

- No track of cylinder after it leaves the facility. Thus, unable to detect market growth.
- No data for cylinder failure, theft.
- No traditional steps are feasible against cylinder cross filling and illegal swapping.
- No direct connection with the final customers.
- No quantification of the amount of steel scrap generated during cylinder manufacturing.
- A bottleneck was identified in the welding process during cylinder manufacturing.

C. Industry 4.0 tools screening

From the literature, some Industry 4.0 tools were identified as potential means for the solution of the identified needs and room for improvement. TABLE II. summarize the findings.

Needs/Room for improvement	Industry 4.0 tools
Cylinder tracking	• RFID
	• GPS
	• OCR
Scrap management	• Ultra-wideband radar
	• Smart scale + cloud computing
Bottleneck	• Optical sensor + cloud computing
	• Advance robotics

The cylinder losing problem can be solved by radio-frequency identification (RFID), Global Positioning System (GPS), Optical Character Recognition (OCR), Ultra-wideband. Inadequate scrap management problem is solved by cloud computing. IoT-based Lean Manufacturing concept is used to solve the debottlenecking where three smart robots are used.

D. Potential solutions, specific projects, and proposal

Cylinder tracking: Cylinder tracking facility can incorporate revolutionary changes into the downstream supply chain. From screening asset tracking tools, it was found that RFID is the most suitable solution considering the company context and application. This decision is proposed based on the following:

- RFID requires no power to operate. So, no external power is required with a cylinder.
- Lower cost than other tools except for barcode.
- Barcode is rejected as a potential solution because of its limited data storage capacity and rewrite feature, speed of reading, and susceptibility to wear and damage.

Different types of RFID tags available for consideration. Most widely used are metal mounted, weldable, and RFID smart valve. Here only a smart valve is acknowledged to study. RFID attached valve will address supply chain and safety issues:

1. The RFID tag will store cylinder unique number cylinder manufacturing date, expiry date, distribution information, client information.
2. The smart valve RFID tag can only pair with smart nozzle, and cannot be filled with other filling head

3. A special lock pin under the valve will act as a safeguard against de-valving.
The specific project regarding this solution is depicted in the process flow diagram shown in Fig. 4.

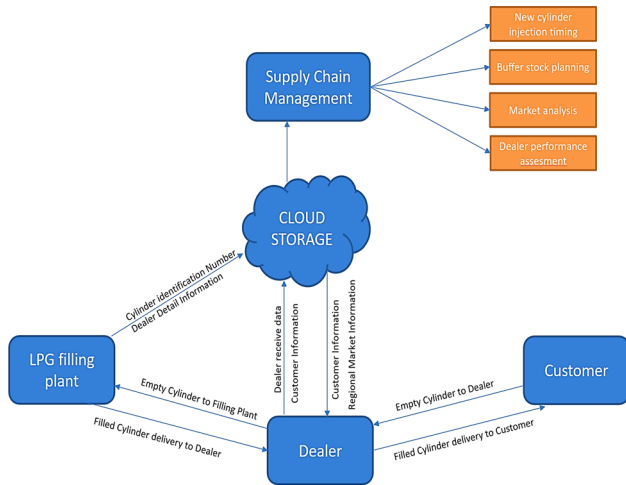


Fig. 4. Process flow of RFID project

The list of major requirements for the implementation of the RFID project are listed below:

- Smart filling head
- RFID valve
- RFID reader and writer
- Server PC
- Training of distributors and filling plant operators
- IT Service

To complete the conceptualization of the project, a rough techno-economic assessment was performed. First, it was calculated the company saving if the solution would have been implemented since starting of operations, and compared with the cost of the solution. BM Energy could secure at least 365 million dollars if the RFID system installed in the first place. Details are shown below.

Lost cylinders 2012-2019: 100,000 units
Revenue per refilled cylinder: \$365/year
Cylinder Avg. remaining lifetime: 10 years
Revenue lost throughout life cycle: \$365,000,000
Cylinder Filling Head = \$838/unit * 90 units
= (\$75400/3*10⁶) per unit [90 units carousel, 3 million cylinders]
= \$0.03/unit
RFID Valve = \$4.25/unit
Server & IT services = (\$10,000/3*10⁶) / unit = \$0.003/unit
Old Valve resale (50% off) = -\$1.00/unit
CAPEX = \$3.29/unit
OPEX = \$0.33/unit (10% of CAPEX)
Total Unit Cost = \$3.62
Total Cost = \$362,000

Also, the payback period of the solution was estimated, considering the annual rate of cylinder lost and the cost of installing the RFID system in each of the nearly three million cylinders existing in the market. This payback period is based on the present transition to the smart RFID supply chain system and the cost will yield within 2.1 years. Details are shown below.

Analogy POV 2:

Avg lost cylinder per year = (1000000/7) unit/year
= 14286 unit/year
Revenue lost per year = (14286* \$365) = \$ 5,214,286.00
Total project cost = (\$3.62*3*10⁶) = \$10,860,000.00
Payback period = \$10,860,000.00/\$ 5,214,286.00
= 2.1 years

This payback period is based on the present transition to the smart RFID supply chain system and the cost will yield within 2.1 years.

Scrap Management: Refer to Fig. 3, hot rolled steel takes up almost half of the costing portion. As a capital intensive organization, LPG operators sell cylinders much lower prices than manufacturing cost. So it is important to track how much assets are utilized in production, and how much scrap is generated and resold.

In a cylinder manufacturing facility, scrap is generally available after blanking (98%) and deep drawing, and in our case study, there is a big room for improvement in scrap management after blanking. It is almost impossible to figure out physically that which cylinder brings in how much scrap. On the other hand, steel metallurgy, and physical properties (i.e. thickness, density, coil ID/OD, length, and width) change with different mills and producers. Steel coil fed into a blanking machine to punch out circular disk as depicted in Fig. 5. The width and length of the coil is, on average, 1080mm and 1160mm per cutting portion. The red hatch area shows scrap for each cylinder production.

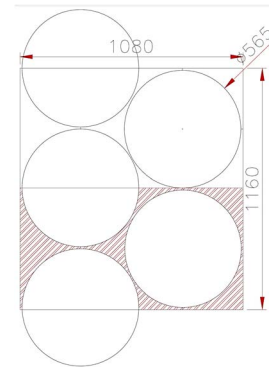


Fig. 5. Blanking process schematic

By implementing the proposed solution for scrap management will measure the exact amount of scrapper blanking and will give the company an accurate calculation of profit and pricing. Referring to Fig. 6, scrap after every blanking process will be weighted in Weight Scale 1, and the blank disc will be measured in Weight Scale 2. Both weights will be stored in the cloud which will give the exact data for the scrap.

Robotics: Bottlenecks in any manufacturing company is one of the major problems that hamper productivity. To overcome these problems in the LPG manufacturing company three robotic arms in blanking, deep drawing, and body welding have been proposed in the solutions. Substituting robotics with human resources can save money when the company is not in operation in the market saturation period but still has to pay the employees. Again, Replacing factory workers with industrial robots will save manufacturers costs over the long-term. Another benefit of

robotic systems is their ability to prevent employee injury and the resulting liabilities. Robots can complete tasks in extreme manufacturing environments without risking human health. A rough techno-economic analysis for robotic arms is presented below.

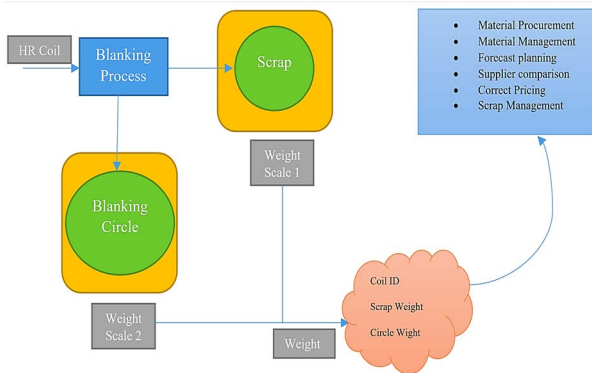


Fig. 6. Process flow of smart scale project

Currently, 12 workers are working on blanking, deep drawing, and body welding sections in the production process. Replacing 12 people with 3 robotic arms (CR-7iA 6 axis robot arm and industrial robot arm) [10] will minimize labor cost as well as it will help to debottlenecking. As a result, the company's productivity will be increased.

Labor Cost for 12 workers is \$20385 per year, whereas, capital cost and installation cost for three robotic arms are \$62,000. robotic arms also have operation and maintenance costs which are roughly \$10,000 per year.

$$\text{Annual benefit} = \$20,385 - \$10,000 = \$10,385$$

$$\text{SPP} = (\$62,000 / \$10,385) = 5.97 \text{ years} \approx 6 \text{ years}$$

The simple payback period is almost 6 years and the proposed solution is the best because the authors did not consider the increased profit for debottlenecking. The solution also increased safety and reduce liabilities.

VI. LIMITATIONS AND FUTURE WORK

The main limitations of the proposed methodology and the results obtained from the case study are:

- Adapting only existing industry 4.0 tools from the literature as proposed solutions, without developing new technologies.
- Due to some assumptions added to the price calculation, the authors concluded to a smoother result which may require further research and study when actual data is used in place of these assumptions. Only downstream of the supply chain is considered in this study, whereas, a supply chain consists of both up and downstream.

For improvement of this work the following steps could be implemented in the future:

- Further in-depth work on the tool for small and medium enterprises with more complex operations and logistics to improve their process and updating the company to Industry 4.0.

- Applying Industry 4.0 to cover all the components involved in the supply chain.
- Exploring more customer feedback-oriented solutions.
- Survey of manager perception regarding the transition to Industry 4.0 and pursuing management towards the transition with data of improved production rate and superior control over the process through tracking.
- A ranking model for prioritizing solutions could be added to the framework, so the manager could decide in regards to which solution would be considered in the first place.

VII. CONCLUSION

As a case study, the methodology [2] has been applied to an LPG operator that manufactures, supplies, and refills pressurized cylinders to its customers and this company had not considered migrating to Industry 4.0 before. Now, the manager level of the company count with concrete projects to be evaluated for further analysis and future implementation, This project showed remarkable development in the entire downstream supply chain of this industry and motivated the management in considering the option of implementing a complete Industry 4.0 system in their operation.

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