Increasing the efficiency and workers wellbeing in the European bakery industry: an Industry 4.0 case study

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Abstract. Industry 4.0 refers to a revolution where innovative digital instruments will be employed to improve the production process efficiency as well as the working conditions. However, this new approach is not the only way to achieve those critical objectives, and many companies implemented years ago quality management plans guaranteeing both, the production efficiency, and workers wellbeing. The nature of these solutions and their associated costs is totally different, and while Industry 4.0 schemes need important deployment costs, traditional management plans are supported by human resources. Companies should restructure, then. Thus, the Industry 4.0 adoption challenge is not necessarily technological but economical and strategic. And clear quantitative analyses showing the advantages (economical, societal, …) at short and long term are required to promote this revolution. In this paper we present a study case focused on the European bakery industry, where a sensing platform is employed to increase the global production process efficiency and the workers wellbeing. Variables such as temperature, humidity, power consumption and air quality are monitored through sensor nodes. A framework of performance and economic indicators is generated, and we analyze their changes and envisioned evolution after the Industry 4.0 paradigm adoption. Results show the advantages of these new solutions in an objective and clear way.

Keywords: Industry 4.0; DEMETER; bakery industry; efficiency; sensing platform

1 Introduction

Industry 4.0 [1] is the current industrial revolution, focused on the digitalization of all economical agents. The final purpose is the increase in the global efficiency, the waste reduction, the definition of innovative business models, the mitigation of the climate change and the improvement in the working conditions [2]. Many different technologies could be employed: from Cyber-Physical Systems [3] and sensing platforms [4] to Artificial Intelligence [5] and Blockchain [6]. And many innovative hybrid technological mechanisms are being reported [7] every day to support and promote this revolution.
However, digitalization is not the only methodology to achieve these global objectives. Since 1970, many quality management theories, methodologies and strategies have been developed [8]. Many companies, and other institutions, have now implemented these policies, [9] which are able to guarantee the production process efficiency and workers wellbeing in the same way Industry 4.0 schemes promise. Although Industry 4.0 solutions show some qualitative and well-known advantages, such as the process automation, the remote management, or the low maintenance cost [10]; there are many barriers that prevent the Industry 4.0 paradigm adoption. Basically, the required structure from the organization, and the associated costs to the new and the traditional quality assurance solutions are totally different. While Industry 4.0 solutions are characterized by high deployment costs (investment) and sporadic technical tasks, traditional quality management policies are supported by large human resources teams and continuous human intervention (but a negligible investment is needed) [11]. Thus, any company implementing Industry 4.0 paradigm is facing a restructuration process. This is a major challenge.

In order to promote companies to adopt Industry 4.0 paradigm, quantitative analyses are required. These studies should show a clear improvement in strategic, social, performance and economic indicators both at short and long term. Then, the profit-earning capacity of the required reorganization effort is strong enough to move companies towards the Industry 4.0 revolution.

Therefore, in this paper we present a case study focused on the European bakery industry and the Industry 4.0 paradigm adoption. The proposed study defines a framework of Key Performance Indicators (KPI), representing the production processes (efficiency), workers wellbeing, investment, and costs. These KPI are analyzed before the Industry 4.0 paradigm adoption, and their changes after the implantation and deployment are studied, together with their envisioned evolution at long-term. In this study case, we are using as Industry 4.0 solutions the DEMETER ecosystem. DEMETER ecosystem defines a set of tools to collect and publish data from different sources using semantic technologies. In this case, we are employing sensor nodes as data sources, including temperature, humidity, power consumption, and air quality sensors.

The rest of the paper is organized as follows: Section 2 describes the state of the art on Industry 4.0 study cases. Section 3 describes the main proposal including the KPI framework, DEMETER ecosystem and the deployment sensing platform. Section 4 includes the KPI analysis and their evolution study. Finally, Section 5 presents some conclusions.

2 State of the art: Industry 4.0 experiences

Different previous works have reported experiences and study cases about the performance and success of Industry 4.0 solutions.

A first group of works is focused on identifying the requirements [12] or technologies [13] that should be considered in real successful Industry 4.0 deployments. This approach is especially interesting regarding SME, whose budget is limited [20]. Some works are also analyzing the advantages and challenges of
Industry 4.0 solutions [14], from an economic and strategic perspective, but in a qualitative way. On the other hand, some papers have also described different use cases, but from a theoretical perspective [15][16], without proving information about how these proposals would perform in real scenarios. Proposals describing the integration of Industry 4.0 solutions into public bodies and institutions are also found [21].

Cultural environment also affects the Industry 4.0 paradigm adoption, so some authors have studied the success of Industry 4.0 solutions in different countries, such as Germany [17], Italy [13] or Turkey [18]. Besides, some sectorial studies have been reported, like experiences in the LEGO factories [19]. In general, economies and companies more developed and a higher digitalization level show a higher success in Industry 4.0 adoption, contrary to more traditional sectors where more gaps and barriers are identified.

Very recently, study cases focused on the combination of Industry 4.0 and 5G technologies turned very popular, including hybrid architectures [23] and innovative network designs [24].

Finally, several evaluation frameworks to analyze the success of Industry 4.0 solutions and study cases have been proposed. From complex methodologies [24] to frameworks of indicators [25] may be found. Applications of these proposals to real Industry 4.0 deployments are still sparse [26]. This paper aims to fill this gap.

3 New Industry 4.0 solutions for the European bakery sector

Many different Industry 4.0 solutions may be designed and implemented, depending on the purpose and final objective we are trying to achieve. In this paper we are focusing on the European bakery sector, where the workers wellbeing (in terms of environmental working conditions) and production process efficiency (in terms of resource consumption) must be improved. To do that, Section 3.1 describes the KPI framework employed as reference and mechanism to design and evaluate the proposed solution. Section 3.2 introduces the DEMETER ecosystem, a European approach to support the digital economy in agri-food sector. And Section 3.3 describes the actual technological deployment.

3.1 Key Performance Indicators (KPI) framework

In the proposed case study, two main high-level global objectives want to be addressed: improving the production efficiency and the workers wellbeing. These objectives, however, are very abstract and need to be transformed into some quantitative measurable indicators. On the other hand, some indicators to evaluate the adaption costs are also required, so the final viability of the Industry 4.0 transition may be analyzed.

Table 1 presents the proposed KPI framework. Production efficiency is represented by three groups of KPI: resource consumption, waste management and production capacity assurance. Resources may be associated to production activities (supplies,
costs, etc.) or to quality operations (materials or human resources). Proposed KPI evaluates all these factors.

Table 1. KPI framework

<table>
<thead>
<tr>
<th>ID</th>
<th>KPI</th>
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<th>KPI</th>
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<tbody>
<tr>
<td>P1</td>
<td>Unitary power consumption</td>
<td>W1</td>
<td>Unitary annual number of thermal discomfort episodes</td>
<td>A1</td>
<td>Initial investment (total)</td>
</tr>
<tr>
<td>P2</td>
<td>Reaction time (malfunction in production line)</td>
<td>W2</td>
<td>Unitary annual number of lung infection</td>
<td>A2</td>
<td>Initial investment (relative to production capacity)</td>
</tr>
<tr>
<td>P3</td>
<td>Reaction time (malfunction in gas or power infrastructure)</td>
<td>W3</td>
<td>Unitary annual number of intoxications</td>
<td>A3</td>
<td>Annual maintenance costs (infrastructure)</td>
</tr>
<tr>
<td>P4</td>
<td>Percentage of discarded products (quality tests)</td>
<td>W4</td>
<td>Unitary annual number of general health problems</td>
<td>A4</td>
<td>Annual maintenance costs (information)</td>
</tr>
<tr>
<td>P5</td>
<td>Unitary quality monitoring costs (material)</td>
<td>A5</td>
<td>Unitary maintenance costs (infrastructure)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P6</td>
<td>Unitary quality monitoring costs (human resources)</td>
<td>A6</td>
<td>Unitary maintenance costs (information)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P7</td>
<td>Production infrastructure availability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P8</td>
<td>Production infrastructure maintenance costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P9</td>
<td>Production infrastructure resiliency</td>
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</table>

In the context of production efficiency, waste management is restricted to products that are discarded due to their low-quality characteristics (below quality standards). Finally, production capacity assurance is essential to avoid shortage in the food (bakery) value chain. Shortages may be caused by malfunction in infrastructure, supply infrastructures or non-operative periods. As can be seen the proposed KPI framework considers all these elements.

Regarding workers wellbeing, the basic indicator is the number of health problems workers suffer. In bakery industry, heatstroke, intoxication, or lung infection (caused by huge ovens) are the most typical. All these indicators are included.

Finally, adoption costs are mainly divided into two groups (initial investment and maintenance). Besides, information maintenance and infrastructure maintenance costs must be considered. The proposed KPI framework includes both aspects.

3.2 DEMETER ecosystem

DEMETER project aims to create an ecosystem of services to improve the efficiency of food productive sector (crops, dairy products, and meat) in Europe. Because of solutions must be customized according to every application scenario, different pilots have been defined to test all proposed services. Besides, several use
cases could be considered within every pilot, so more than one objective can be addressed. Finally, in the context of each use case, different experiments could and should be defined, to evaluate the performance and impact of all proposed services and solutions from different perspectives. The described case study in this paper belong to the “from the farm to the fork” pilot. This pilot considers three use cases, including the Industry 4.0 use case. Finally, within this Industry 4.0 use case, seven different experiments have been defined:

- **Experiment#1 [27]:** Evaluates if the Quality-of-Experience (QoE) of customers when buying bakery products increases if DEMETER mobile applications are employed to enhance the shopping experience.
- **Experiment#2:** Considers an Industry 4.0 scenario where we evaluate if the bakery industry efficiency increases while using a Blockchain-enabled marketplace to manage providers and raw materials.
- **Experiment#3:** Focuses on analyzing if the users’ satisfaction and QoE increases if customers are provided with trustworthy and transparent information about the bakery value chain, suppliers and products.
- **Experiment#4:** Provides an automatic solution to capture users’ recommendations and opinions about bakery products. The final purpose is to analyze if the industry adaptation improves according to Industry 4.0 principles.
- **Experiment#5:** Provides a decision-making system based on a dashboard, where managers may analyze their business from many different perspectives. The final objective is to improve the global efficiency of strategic management.
- **Experiment#6:** Deploys an information system monitoring and providing traceability data about raw materials, providers, production, etc. (for industry managers). This Industry 4.0 solution should avoid shortage caused by logistics, improve food security and promote food policies such as ecologic food.
- **Experiment#7:** Focuses on improving the production efficiency and workers wellbeing through an Industry 4.0 sensing platform. Continuous and automatic monitoring should help companies to reduce resource consumption, waste, and improve the wellbeing and working conditions. This paper is describing this seventh experiment.

Figure 1 shows the proposed service ecosystem for the DEMETER Industry 4.0 use case. As can be seen, every experiment is supported by a different set of tools. Basically, for each experiment a different interface is deployed (dashboard, mobile applications, sensors, etc.), and all these peripherals are connected to an Industry 4.0 digital platform where services are managed, and information stored. In previous works [27] we have addressed components such as the mobile applications or the bakery products database (experiment#1). While in this paper we are proposing a specific implementation solution for the sensing platform, sensing database and middleware, the semantic broker, and the sensing dashboard (experiment#7). Through the information displayed in this dashboard, bakery companies may make decisions to improve the indicators referred in the KPI framework. In future works, even this decision making and actuation processes could be automated.
3.3 Proposed Industry 4.0 sensing platform

Figure 2 shows the proposed implementation for the described Industry 4.0 platform.

Two different types of LoRa sensing nodes were deployed. Namely:

- The first node type was based on an ESP-32 architecture, provided with a LoRa WAN embedded communication module. To this module, it was connected an DTH-11 module to measure environmental temperature and humidity.
- The second node was also based on an ESP-32 architecture and a LoRa WAN embedded communication module. In this case, the module was provided with
an ACS712 current sensor. Through this sensor the power consumption was monitored.

![Diagram](image)

**Fig. 2.** Proposed solution for the Industry 4.0 sensing platform (experiment#7)

On the other hand, two different types of WiFi/Ethernet sensor nodes were deployed:

- The first group of nodes, based on an Arduino Mega architecture and an Ethernet W5100 shield, were provided with an DTH-11 module to measure environmental temperature and humidity; and a CCS811 module to monitor the air quality (equivalent CO2 -eCO2- and total volatile organic compounds - TVOC-).

- The second type of sensor node, also based on an Arduino Mega and 5100 Ethernet shield, was provided with a P100 (resistor) temperature sensor, to control de temperature in the ovens’ interior.

Ethernet sensors could send data directly to the adaptation middleware through a REST interface. However, LoRa WAN is a proprietary technology with specific protocols and messages. To connect LoRa sensors and the adaptation middleware, a LoRa gateway and ChirpStack server was required. Using a graphical interface, the ChirpStack server could be configured to communicate with the adaptation middleware using the HTTP protocol. The adaptation middleware harmonizes all messages (HTTP messages from the LoRa and Ethernet infrastructures might be...
different) and transforms received information according to the requirements of brokers. Orion broker (included in the European FIWARE project) receives data in a NGSIV2 format included in a HTTP POST message. On the other hand, semantic broker included in the DEMETER interoperability ecosystem receives data using the semantic JSON-LD format and compliant to the project’s data model. This semantic broker allows other use cases in the context of DEMETER project to reuse data generated by our Industry 4.0 platform.

Orion broker employs a MongoDB database to store data subscribers, and sends all received data samples to the QuantumLeap module (FIWARE project). QuantumLeap module manages a distributed database (CrateDB), which will be the sensing database where time series are stored. Finally, sensing dashboard (Grafana) displays information from distributed database in a dynamic manner (see Figure 3). Considering the information in this dashboard, manager can make decisions and improve the considered indicators.

![Sensing dashboard (grafana)](image)

Fig. 3. Sensing dashboard (grafana)

4 Study case: methods, materials and results

Both sensing networks (LoRa and WiFi/Ethernet) were deployed in the CODAN factory in Arganda (Madrid, Spain). CODAN is one of the biggest companies in the Spanish bakery sector. It has one large production center, where more than sixty different bakery products are manufactured. Specifically, it has five production lines with three electrical ovens. Figure 4 shows the deployed platform.

All software components were deployed in a private cloud in the Universidad Politécnica de Madrid. The underlying server was a Linux architecture (Ubuntu 20.04 LTS) with the following hardware characteristics: Dell R540 Rack 2U, 96 GB RAM, two processors Intel Xeon Silver 4114 2.2GHz, HD 2TB SATA 7,2K rpm.

In order to analyze the evolution of all indicators in the KPI framework, the following methodology was designed and implemented.

In the first phase, internal monitoring procedures were modified to acquire information about all indicators in the KPI framework. In the second phase, and before
the sensing platform deployment, data were collected for six months and all indicators
where evaluated. In the third phase, the sensing platform deployed and was available
for CODAN managers to make decisions for six months.

![Deployment process: Industry 4.0 platform](image)

**Fig. 4.** Deployment process: Industry 4.0 platform

After the second data collection (third phase), measurements were introduced into
MATLAB 2019b suite to process and display the final results about the KPI evolution.
Besides, interpolation techniques were employed to explore how the proposed KPI
framework will evolve in future.

Figure 5 shows the evolution of all KPI at the end of the experimental period.

![KPI evolution (six months)](image)

**Fig. 5.** KPI evolution (six months)
As can be seen, production efficiency indicators are those where a higher change was produced. Power consumption was slightly reduced (around 5%), thanks to equalization policies (power peaks were detected using the Industry 4.0 platform, and production planning was modified to remove all these peaks). Although the reaction time against malfunctions in the production line was not improved (workers needed more time to learn about alarms in the Industry 4.0 platform), the reaction time against malfunction in supply infrastructure decreases near 90%. Thanks to devices such as the air quality sensor, gas leaks and similar problems can be detected in a very fast way, and much earlier than people in charge of monitoring this infrastructure in a manual and traditional manner. A more precise control in the production process extremely reduces the waste in quality control (almost 75%) and removes all costs related to quality control (materials and human resources). Besides, production infrastructure resiliency and availability are increased (around 15%), while maintenance costs are not increased. In conclusion, the production efficiency increases.
A smaller reduction is seen in workers’ wellbeing indicators. Although the number of thermic discomfort episodes reduces up to 15% (as environmental temperature sensors were deployed), the number of lung infection, general health problems or intoxications only reduced around 3%, as they were already very sparse. In general, however, we can conclude the workers’ wellbeing increases.

Finally, adaptation costs indicators do not show any relevant variation (below 1%), so the entire transformation presents a negligible impact on financial costs.

Figure 6 shows the expected evolution of the KPI framework in the future (4 years), according to the collected data and using interpolation techniques.

As can be seen, the highest change is associated to production infrastructure resiliency and availability. As more long-term policies are deployed it is expected both indicators to increase up to 30% (total) in four years. Reaction time to both malfunctions in production and supply infrastructures is also expected to be reduced up to 25% and 80%, respectively. At the same time, costs associated to production infrastructure maintenance are expected to be reduced up to 30% in four years.

While adoption costs do not suffer any increase in a four-year analysis, the workers’ wellbeing does increase as the number of health problems (including thermic discomfort episodes, lung infections, etc.) slightly reduces.

In conclusion, the workers’ wellbeing and production efficiency increase using the sensing Industry 4.0 platform.

5 Conclusions

Industry 4.0 refers to a revolution where innovative digital instruments will be employed to improve the production process efficiency as well as the working conditions. The nature of these solutions and their associated costs is totally different, and while Industry 4.0 schemes need important deployment costs, traditional management plans are supported by human resources. In this paper we present a study case focused on the European bakery industry, where a sensing platform is employed to increase the global production process efficiency and the workers wellbeing. Variables such as temperature, humidity, power consumption and air quality are monitored through sensor nodes. A framework of performance and economic indicators is generated, and we analyze their changes and envisioned evolution after the Industry 4.0 paradigm adoption.

Results show a clear increase in the production efficiency indicators, while adoption costs indicators do not change in any relevant manner, even in a four-year analysis. On the other hand, workers’ wellbeing also improves, as the number of heatstroke, lung infection and intoxication reduces in an important amount.

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References