A migration methodology for factories digital transformation

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Abstract. Over the last years, several technologies and control systems have been developed towards the decentralization of automation control architectures for cyber-physical production systems. Nevertheless, only few of these technologies are already in use. To support their adoption in brownfield production sites migration strategies and business case evaluations are necessary. This paper presents a migration approach and a business case evaluation methodology tailored to the migration of legacy automation systems towards the Industry 4.0 paradigm. The proposed approach aims to evaluate opportunities and mitigate the risks of migration from technical, operational, human and business perspectives. The methodology follows an iterative approach starting from the definition of the current situation of the factory and the identification of business goals aiming at evaluating a set of possible migration paths and selecting the optimal one according to a cost-benefit analysis. The paper concludes with an exemplary application of the methodology in a real industrial environment, developed within the FAR-EDGE European Project.

Keywords. Industry 4.0; Digital factories; Digital transformation; Migration strategy; Business case evaluation.

1 Introduction

"Flexible manufacturing" means manufacturing, which "allows changing individual operations, processes, parts routing and production schedules" [1]. Digital transformation represents one of the preconditions for production flexibility and to fast react to current changing conditions such as volatile market demands, increasing the frequency of new product introduction and new technological developments [2]. Digitalization represents one of the biggest challenges a company has to face nowadays [3]. In fact, it is not only a technical issue, but it requires also a cultural change that involves a slow modification of a deep and eradicated mindset in all the company structure and, therefore, requires an incremental change process. Companies not only need to be able to quickly reconfigure their production systems, allowing higher capacity-flexibility and smaller lot sizes. They, also, should finalize managerial capabilities, production management approaches, models and tools able to be compatible with rapid reconfigurations of the production system [4].

For these reasons, new automation architectures are required to enhance flexibility and scalability, enabling the integration of modern IT technologies and, consequently, increasing efficiency and production performance [5]. Nevertheless, reality today shows the dominance of production systems based on a traditional approach, characterized by a hierarchical and centralized control structure.

One of the main reasons is that manufacturers are traditionally conservative against the adoption of digital technologies. They need to make sure that any new technology is introduced with minimal disruption to their existing production operations. At the same time, they need to be confident that the new systems will improve production time, quality and cost. Manufacturers will never accept production systems that compromise the achievement of the above mentioned performances [6]. Indeed, the intent of this paper is to present a new business case evaluation methodology that gives support to strategy implementation for a smooth migration, considering a holistic vision from the technical, operational, human and business perspective.

The paper is structured as follows: section 2 describes a new migration methodology for factories digital transformation; section 3 describes a methodology application case for a durable goods company developed within the FAR-EDGE European Project context; section 4 draws some final conclusions.

2 A new migration methodology for factories digital transformation

To increase the adoption of future manufacturing paradigm, industries should be supported with migration strategies [7]. The term "migration" refers to the transformation of a system from its legacy condition to the desired one. In particular, this paper refers to migration as a progressive transformation, moving an existing production system towards digitalization. Migration strategies are essential to support the implementation of digital technologies in the manufacturing sector aiming at achieving a flexible manufacturing environment based on rapid and seamless processes as a response to new operational and business demands [5].

Fig. 1 shows the framework of the migration process and business case evaluation methodology proposed in this paper. It is a framework articulated in six steps. The procedure is described in the next sections, following a stepwise order.

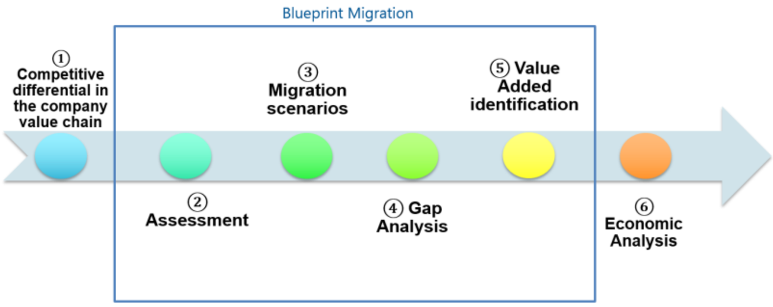

Fig. 1. Proposed migration process

2.1 Competitive differentials in the company value chain

The purpose of the first step is to assess from a business model perspective the opportunity for a factory to migrate towards digitalization by means of cloud and edge-based technologies. In this context, a SWOT analysis [8], [9] has been selected as one of the possible tools to carry out the identification of business changing factors. Due to its simplicity and well-known diffusion in the strategic context, the SWOT analysis can be applied to any project. The straightforward consequence of this analysis is the identification of the variables related to the migration. For this reason, a KPIs definition is a fundamental activity in order to clarify the desired impact of the project implementation, accordingly to the SWOT analysis outcome related to internal and external business changing factors. Then, Porter's value chain model is applied in the operations and management description [10], [11], in order to identify the relevant variable previously identified within the different business units of the enterprise.

2.2 Blueprint migration strategy

The blueprint migration strategy [6] is represented by steps 2-3-4-5 of the methodology. The term "blueprint" refers to an early plan that explains how something might be achieved. The strategy has been developed within the FAR-EDGE EU project. As described in [2], it aims at identifying the optimal migration path for a factory towards the decentralization of its current automation architecture by means of cloud- and edge-based technologies. The FAR-EDGE migration strategy implies the comparison of several features, such as risks, time, migration, costs and effort [7]. These steps are not usually performed by the company alone. In fact, through questionnaires and workshops with people involved in the manufacturing process, the methodology can support the company to define the migration goal and starting point, as well as the possible impact and the typical difficulties that the new digital solution can have.

The blueprint migration strategy starts with the "Technical, Operational and Human assessment" step. The main goal of this assessment is to obtain a clear picture of what should be changed in the company's business, by investigating the implications and preconditions of this change at technical, operational and human dimensions. To assess the various issues related to the three dimensions, a digital maturity model has been exploited [2], [5] .

The blueprint migration strategy continues with the “Migration Matrix and scenario definition” step. The migration strategy plays a crucial role in the target KPI values definition. There could be more than one way to reach the desired result and the TO-BE scenario could not be unique. In fact, different migration scenarios according to the possible technology options are investigated [7] in order to identify the migration alternatives to go from the identified AS-IS situation to the TO-BE one. To this end, a tool called Migration Matrix (Fig. 2) has been developed within the FAR-EDGE project [5] to identify all the necessary improvements in the direction of the Industry 4.0 vision of smart factory based on technical, operational and human dimensions and 5 levels scale of digital maturity. The matrix provides a representation of the current state of the company suggesting how the three dimensions can be combined in order to reach the final objective (envisioned by FAR-EDGE) in a smooth and stepwise migration process.

For this reason, a collaboration with OEMs and solution providers is required at this point in order to assess the feasibility of the scenarios and provide solutions able to improve the KPIs defined in the first step. The final result implies one Migration Matrix for each scenario where it is depicted only one AS-IS status and one of the different TO-BE status.

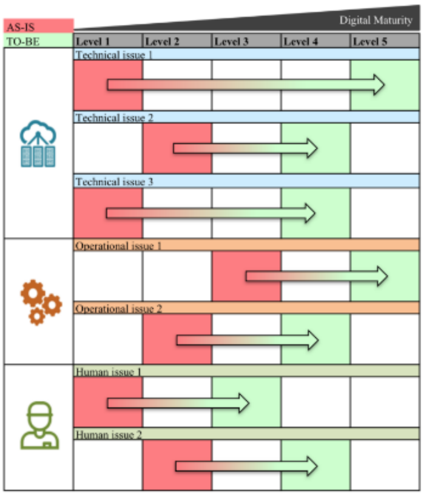

Fig. 2. Migration Matrix: AS-IS (in red) and TO-BE (in green) scenarios definition

Migration matrixes provide a clear map of the current and desired conditions of a factory, revealing different alternatives to achieve the first short-term goal in the direction of the long-term vision. These alternatives are then evaluated according to the business strategy, considering also strengths and weaknesses points outlined in the first step of the methodology.

The “Gap analysis” between the AS-IS and the TO-BE scenarios, derived by the Migration Matrix, has to be analyzed taking into account three main aspects: (i) required components, (ii) possible integrations and (iii) steps for application. Required components represent a detailed list of the additional components, operations, and new professional skills required for each scenario migration. Further possible extensions of the architecture, e.g. the integration of components, must be considered to enable system flexibility and easier future updates. Then, the steps required for the implementation of each scenario are defined. They consist in general instructions for the implementation of the technology starting from the AS-IS status. The gap analysis provides also a cost and time evaluation for the overall migration completion, which is very relevant for the economic analysis in the last step.

The “Value added identification” step aims to justify the efforts spent by the company on the use case implementation. The complete definition of the migration scenarios allows to evaluate the quantitative and qualitative improvement of the system. Value added has a double meaning:

1. KPI improvement: a quantitative and measurable increase of system performance with respect to the AS-IS situation.
2. Unmeasurable advantage: a benefit derived from the new system which has a positive impact on one of the three migration dimensions (technical, operational and human). The unmeasurable advantages of the scenario have to be coherent with the value added relative to the technological enablers selected in the scenario.

Every scenario can count on different features and peculiarities, hence the KPIs improvement and the unmeasurable advantages could differ from one another. For this reason, added value identification has to be performed for each scenario.

The “Economic analysis” step consists of a cost-benefit analysis to justify the investment in digital transformation is the last step of the methodology. This analysis is performed comparing the TO-BE situation with respect to the AS-IS situation and it deals with quantitative results. First, the KPIs improvement is translated into money and the results are addressed as Economic KPIs or Benefits. The Total Cost of Ownership (TCO) could be adopted for cost evaluation [12]. It is recognized as an industry-standard method for the economic analysis for IT and other enterprise issues due to its holistic view of costs across enterprise boundaries over time.

The investment is evaluated with a Discounted Cash Flow approach. The Net Present Value (NPV) is an economic index that measures the value acquired by the company associated with the investment. Moreover, the Profitability Index (PI) and Internal Rate of Return (IRR) are also considered in Step 6. The Discounted Payback Period (DPP) represents the number of years necessary to break even from undertaking the initial expenditure recognizing the time value of money. NPV, PI, IRR and DPP are indexes which defines the economic success of a project, and they are also a measure to compare different solutions, as in the case of multiple scenario evaluations. The final decision to implement or not one or more of the defined project is the arrival point of the assessment.

3 Methodology application: a durable goods company within the H2020 FAR-EDGE context

The application use case is provided by a world's top white appliances manufacturer company. The company needs to overcome the rigidity of the sorter that distribute the finished goods at the end of the assembly lines to different bays in order to be stocked in the warehouse. The static logic implemented by the sorter in the AS-IS situation does not allow the required flexibility in the use of the bay resources, and to adapt to the actual mix of goods produced.

Specifically, the FAR-EDGE based solution is composed of smart objects implementation that will be managed by an independent Edge Node, which is responsible to process the information from the field in order to modify the dispatching policy accordingly. All these elements communicate within a Distributed Ledger smart contract called Collaborative Sorting, which sets the sorting method depending upon the state of each bay. In fact, based on the operators' decision or based on the current workload each bay can be on-line, off-line, filled, empty or partially filled.

Furthermore, a smart object implementation is used for installing a circular smart conveyor that will be surrounded by many smart bays that, using a Distributed Ledger, can collaborate as peers towards the common goal of a new flexible streaming system.

In this case, an algorithm is needed to provide indications to manage the physical flow of products flowing between the conveyor, the sorter and the bays, and the information flow, namely the different communications that the Edge nodes exchange with each other.

In this methodology application case, the TO-BE scenario is clearly defined by the innovative architecture proposed by the project. This way, pointed out the above described TO-BE scenario, a SWOT analysis has been applied in order to comprehend the strengths, weaknesses, opportunities and threats of the FAR-EDGE Architecture implementation within the company plant. The analysis underlined how the sorting system of the plant represents an issue which could be solved and improved by FAR-EDGE. The support activities involved are the firm infrastructure which should lead the change. In fact, the connectivity between the sorter and the bays will be implemented, installing information access points and instantiating security mechanisms in order to fully integrate the information exchange between production and logistic processes.

The technology development which should implement and maintain the new architecture enabling improved data management. Also, the human resource management will be impacted as it is responsible for employees training and hiring digital skilled people. From the operational perspective, a good ability for processes management will be requested, supported by a particular attention to utilize automation and analytics activities as enabling procedures to decrease not value-added activities and to gain more competitiveness. At this point, the KPIs were identified after to having get a clear idea about the potential application field of the project: (i) sorter OEE and (ii) sorter reconfigurability.

The gap analysis identifies two aspects of the FAR-EDGE functionalities could be instantiated for the TO-BE scenario realization: (i) Cyber Physical System, as all the smart objects are represented and configured on the Distributed Ledger; and (ii) Simulation Services needed to suggest an optimized sorting policy exploiting real-time data from the field.

The final consultation with the experts estimates a possible growth of the KPIs identified in the first step. The Sorter OEE will increase by 5% and the sorter reconfigurability will improve significantly, coherently also with the company lean strategy. Regarding unmeasurable advantages, it is possible to list: (i) a synchronization between field and simulation that could be further used for other purposes; (ii) an innovative machine autonomy which creates machine-to-machine collaboration in the operational dimension. For the human dimension, the number of stressful emergency breakdown situations are reduced and the reconfiguration of the system is not manual any more. On the other hand, the IT system becomes more complex and requires advanced widespread technical skills from the employees. The economic appraisal is then performed. First, the upfront costs and the recurring costs have to be computed. As a second phase, the improvement KPIs are transformed into economic benefits:

- An OEE improvement has a direct effect on the throughput of the system. It has been verified that an additional 5% of the sorter OEE implies an additional 5% of the system throughput.
- The improvement of the system reconfigurability has been considered exploiting a situation analysis: the flexibility acquired will impact on the Total Cost of Change (TCC) of the system in three different ways.

Finally, the Discounted Cash Flow appraisal is calculated. Alongside a consistent initial investment, the NPV is significantly positive after 10 year. The DPP occurs slightly after the third year. In the end, the IRR has been computed, with a value of 34,9%. Since IRR is greater than the discount rate has been utilized (10%), also this index confirms the profitability of the investment in the TO-BE scenario. The results cannot be evaluated without considering the FAR-EDGE context and all the specific hypothesis has been considered.

4 Conclusions

In spite of the benefits, the important impact of the potential technological and organizational changes has prevented many companies from investing in Industry 4.0 capabilities, especially for two relevant common barriers: (i) high investment costs due to a lack of Industry 4.0 suitability of the existing production infrastructure and (ii) missing transparency or quantification of benefits [13]. For these reasons, this paper presents a holistic methodology for business case evaluation related to digital transformation, that has been developed and applied to FAR-EDGE project use cases. Overall, the application case has confirmed the company's perception of the benefits that the adoption of the FAR-EDGE solution can bring for the use case. However, the advantage that the company has acknowledged is not only in the calculation of the economic indicators, but also in an increased awareness about the migration activities, with the associated efforts, costs, uncertainties and expected benefits.

In general, the revolution that the new automation paradigms are introducing involve as the first actor the employee and its way to adapt to this kind of changes in operations.

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